CIMMYT 2008

Science Week

Program and Abstracts

Rodomiro Ortiz (editor)

El Batán, Texcoco, Mexico, 3-8 March 2008

CIMMYT
International Maize and Wheat Improvement Center

Seeding innovation... Nourishing hope. CIMMYT puts cutting-edge science at the service of developing country farmers, offering them better food security and livelihoods through nine flagship products encompassing maize, wheat, research tools, cropping systems, and capacity-building

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CIMMYT 2008 SCIENCE WEEK

Date: 3-8 March, 2008

Venue: CIMMYT Headquarters, El Batán, Texcoco, Mexico

Aim: A forum for exchanges among CIMMYT staff on progress, key issues and new opportunities related to CIMMYT's role in science and development for maize and wheat systems, for assessing progress in ongoing projects and the delivery of flagship products (first half of the week), and for adjusting the rolling Medium-Term Plan (second half of the week). The main outputs for the project meetings will be the draft updated project descriptions, 2008 work plans, and logframes with output targets for the 2009-2011 Medium-Term Plan.

Participants: All international recruited staff [see list in Annex 1], selected members of the nationally recruited staff-research cadre (as per nomination from Program/Unit Director), some members of Board of Trustees [Lene Lange, Salvador Fernandez Rivera], Director General designate [Thomas A. Lumpkin]. It is expected that all participants will attend all sessions.

Pre-plenary organization: Each Program and Unit Director will provide a 5 to 10-page summary of the respective projects for which they provide oversight, covering the following:

- Major achievements 2005-2007 (first half of business plan)
- Key changes in strategy and structure
- Strategic plan for 2008-2010 (second half of business plan)
- Critical issues for discussion

Science Forum speakers will also provide a brief summary (3-4 pages maximum plus supplementary tables or figures as needed, key references and recommended reading) covering the best available information for their assigned topic to allow participants to analyze the situation and comment. It is expected that nominated speakers will obtain inputs from other scientists associated with the topic or research, extending the list indicated in the program as appropriate. Refinements of the topics may be proposed in advance by the speaker. The write-ups by speakers should be submitted through Directors to Rodomiro Ortiz by 15 February 2008.

OVERVIEW OF SESSIONS

	OPENING PERSPECTIVES	Monday 10:30 a.m.
I	OVERVIEW: MAIZE and WHEAT FACTS and FUTURES	Monday AM
II	MTP PROJECT SYNOPSES	Monday PM – Tuesday AM
III	MAJOR INITIATIVES AND FLAGSHIP PRODUCTS	Tuesday AM – Wednesday AM
IV	EMERGING OPPORTUNITIES	Wednesday PM
V	MTP PROJECT INTERFACES	Thursday AM
VI	MTP PROJECT PLANS 2008 and 2009-11	Thursday PM – Friday AM
	CLOSING REFLECTIONS	Friday PM

Method for plenary interactions: The names of the proposed speaker(s) for each presentation are underlined in the program. Unless otherwise indicated, speakers will deliver their talks within two-thirds of the allotted time to leave one-third of the time free for discussion. Ideally, PowerPoint presentations should not exceed 2 slides per minute of presentation.

The session chairperson should encourage diverse interactions (by bringing a mixture of inputs from headquarters and regions, older and younger staff, as well as trustees and managers). Each participant will bring to the plenary their own expertise, experience, observation, and analysis of the written information provided in advance by respective speaker. This diversity of opinion from differing perspectives offers an opportunity for shared learning since CIMMYT advocates to be a knowledge-led center and colleagues should be ready for getting positive reinforcements and critical feedback on their research undertakings.

PROGRAM FOR CIMMYT 2008 SCIENCE WEEK

Monday 3 March 2008

08:00 a.m.	Free for non-headquarters staff to interact with their headquarter colleagues or follow-up pending issues with respective units or programs Guided tour to new Board of Trustees attending Science Week

OPENING PERSPECTIVES

Venue: Auditorium

9:30 a.m.	Welcome by Masa Iwanaga
9:50 a.m.	Remarks by Thomas Lumpkin
10:00 a.m.	Mixer with Mexico's snacks for Science Week participants in the Atrium

SESSION I: OVERVIEW: MAIZE and WHEAT FACTS and FUTURES

Venue: Auditorium

<suggested 45 minutes presentation for each, without discussion>

Chairperson: Masa Iwanaga

11:00 a.m.	Wheat Facts and Futures by Hans-Joachim Braun, Jonathan Crouch and John Dixon
11:45 a.m.	Maize Facts and Futures by Marianne Bänziger, Jonathan Crouch and John Dixon
12:30 p.m.	LUNCH BREAK

SESSION II: MTP PROJECT SYNOPSES

<discussion could be grouped by Project pairs where appropriate>

Chairperson: Erika Meng

2:00 p.m.	P11 – Knowledge, targeting, and strategic assessment of maize and wheat farming systems by Roberto La Rovere, Erika Meng, Dave Hodson, Jonathan Hellin and Petr Kosina
2:30 p.m.	P2 – Technology-assisted tools and methodologies for genetic improvement by Yunbi Xu, Susanne Dreisigacker and Graham McLaren
3:00 p.m.	P10 – Maize and wheat systems by Pat Wall, Ken Sayre, Olaf Erenstein, Mulugetta Mekuria, Paul Mapfumo, Christian Thierfelder and Bram Govaerts
3:30 p.m.	P1 – Conservation, characterization and utilization of maize and wheat genetic resources by Tom Payne, Suketoshi Taba, Graham McLaren and Marilyn Warburton
4:00 p.m.	COFFEE BREAK

4:30 p.m. General discussion of Projects 11, 2, 10, 1

5:00 p.m. Adjourn

6.30 p.m. Cocktail and dinner in Rincon Mexicano/Cafeteria

Tuesday 4 March 2008

SESSION II: MTP PROJECT SYNOPSES

Venue: Auditorium

Chairperson: Gary Atlin

8:00 a.m. P 3 – Stress tolerant maize by Stephen Mugo, Jose Araus, Gary Atlin, Marianne Bänziger, Fred Kanampiu, Augustine Langyintuo, John MacRobert, Cosmos Magorokosho, George Mahuku, Dan Makumbi, Luis Narro Guillermo Ortiz Ferrara, Peter Setimela and P.H. Zaidi

8:30 a.m. P 7 – Drought tolerant wheat with enhanced quality by Alex Morgounov, Julie Nicol, Murat Karavayev, Mahmood Osmanzai, Yann Manes, David Bedoshvill, Karim Ammar, Matthew Reynolds, Caroline Saint Pierre and Javier Pena

9:00 a.m. P 4 – Nutritional and specialty traits for maize by Kevin Pixley, Gary Atlin, Hugo De Groote, Alpha Diallo, Dennis Friesen, Natalia Palacios, S. Twumasi-Afriyie and Bindiganavile Vivek

9:30 a.m. P 8 – Disease resistant wheat with high productivity and quality by Karim Ammar, Ravi Singh, Etienne Duveiller, Alex Morgounov, Matthew Reynolds, Jiro Murakami, Zhonghu He, Javier Pena and Ivan Ortiz-Monasterio

10:00 a.m. General discussion of all Projects

10:30 a.m. COFFEE BREAK

SESSION III: MAJOR INITIATIVES AND FLAGSHIP PRODUCTS

Venue: Auditorium

Chairperson: Gary Atlin

11:00 a.m. International germplasm exchanges: safety issues regarding pests, pathogens, transgenes, intellectual property rights, and benefit sharing by Monica Mezzalama and Tom Payne

11:40 a.m. Biodiversity-based breeding: opportunities for integration by Marilyn Warburton, Yunbi Xu, Gary Atlin, Susanne Dreisigacker, Yann Manes and Jose Crossa

12:20 p.m. LUNCH BREAK

SESSION III: MAJOR INITIATIVES AND FLAGSHIP PRODUCTS

Venue: Auditorium

Chairperson: Monica Mezzalama

2:00 p.m. Drought tolerant maize for Africa by Wilfred Mwangi

2:40 p.m.	Global Rust and *Fusarium* Initiatives: essentials for functionality by Etienne Duveiller
3:20 p.m.	COFFEE BREAK
3:50 p.m.	Cereal systems intensification in Asia by Achim Dobermann
4:30 p.m.	Creating capacity and knowledge platforms for the devolution of research by Petr Kosina and John Dixon
5:10 p.m.	Adjourn

Wednesday 5 March 2008

SESSION III: MAJOR INITIATIVES AND FLAGSHIP PRODUCTS

Venue: Auditorium

Chairperson: Olaf Erenstein

8:00 a.m.	Intermediate products: concepts, reaching end users and measuring effectiveness by Jonathan Crouch, Erika Meng, Carmen de Vicente, Andy Hall and Rodomiro Ortiz
8:40 a.m.	Maize biofortification and new uses: where CIMMYT stands and new challenges by Natalia Palacios
9:20 a.m.	Analysis of the institutional bottlenecks affecting the deployment of maize seed in Eastern and Southern Africa by Augustine Langyintuo
10:00 a.m.	COFFEE BREAK
10:30 a.m.	The challenge of climate change: can wheat beat the heat and water stresses? by Matthew Reynolds
11:20 a.m.	Conservation agriculture on the ground: Reducing tillage, managing residues and diversifying cropping for higher productivity and sustainable soils by Ken Sayre and Bram Govaerts
12:00 p.m.	Needs and prospects for engaging NARS, private sector and NGOs in research for development (podium discussion) by John MacRobert, Julie Nicol, Ravi Singh, Bram Govaerts, Marilyn Warburton and P.M. Zaidi
12:30 p.m.	LUNCH BREAK

SESSION IV: EMERGING OPPORTUNITIES

Venue: Auditorium

Chairperson: Julie Nicol

2:00 p.m.	Challenge Programs: proposed, present and prospects for CIMMYT by Rodomiro Ortiz
2:45 p.m.	Advances in the Crop Research Informatics Laboratory by Thomas Metz, Graham McLaren, Guy Davenport and Jose Crossa
3:30 p.m.	COFFEE BREAK

4:00 p.m.	Bioenergy; any role for CIMMYT? by John Dixon, Ken Sayre, Marilyn Warburton, Jose Araus and Xiaoyun Li
4.45 p.m.	Corporate Services: finance, human resources and administration by Martin van Weerdenburg
5:30 p.m.	Adjourn

Thursday 6 March 2008

SESSION V: MTP PROJECT INTERFACES

<P1/P2 and P11 should find a time to specify priority linkages and joint research outside main meeting hours>

8:00 a.m.	Round 1
	Sasakawa Room: P1/P2 – P3/P4 by Jonathan Crouch and Marianne Bänziger
	Room B-115: P7/P8 – P10 by Hans Braun and John Dixon (45 mins)
	Room B-114: P7/P8 – P11 by Hans Braun and John Dixon (45 mins)
10:00 a.m.	COFFEE BREAK
10:30 a.m.	Round 2
	Sasakawa Room: P1/P2 – P7/P8 by Jonathan Crouch and Hans Braun
	Room B-115: P3/P4 – P10 by Marianne Bänziger and John Dixon (45 mins)
	Room B-114: P3/P4 – P11 by Marianne Bänziger and John Dixon (45 mins)
12:00 p.m.	LUNCH BREAK

SESSION VI: MTP PROJECT PLANS 2008 and 2009-2011

Venue: Meeting rooms to be indicated

2:00 p.m.	Concurrent Project meetings with 3:30 p.m. COFFEE BREAK
	Room B-115: P1 by Jonathan Crouch
	Sasakawa Room: P3 by Marianne Bänziger
	Room B-115: P7 by Hans Braun
	Room B-113: P11 by John Dixon
5:30 p.m.	Adjourn

Friday 7 March 2008

SESSION VI: MTP PROJECT PLANS 2008 and 2009-2011

<P10 will meet during 25-28 February to complete the draft MTP>

8:00 a.m. Concurrent Project meetings with 10:00 a.m. COFFEE BREAK

Room B-115: P2 by Jonathan Crouch

Room B-113: P4 by Kevin Pixley

Room B-114: P8 by Hans Braun

08:00 a.m. – 15:45 p.m. Concurrent Meeting at Sasakawa Room: South Asia Sustainable Cereals Intensification (SASCI) Project Formulation Task Group: Scope and foci of the SASCI proposal

12:30 p.m. LUNCH BREAK

2:00 p.m. Free for non-headquarters staff to interact with their headquarter colleagues or follow-up pending issues with respective units or programs

3:30 p.m. COFFEE BREAK

CLOSING REFLECTIONS

Venue: Auditorium

Reflections on the progress, issues and opportunities

Chairperson: Masa Iwanaga

4:00 p.m. New traits and technology-based tools by Jonathan Crouch

4:10 p.m. Maize germplasm products by Marianne Bänziger

4:20 p.m. Wheat germplasm products by Hans Braun

4:30 p.m. Systems management and impact assessment by John Dixon

4:40 p.m. Overarching issues for the future of CIMMYT and the CGIAR by Masa Iwanaga, Lene Lange and Ren Wang

5:15 p.m. ADJOURN

6.30 p.m. Farewell Dinner in Guest House’s gardens

EXTENDED ABSTRACTS

Wheat Facts and Futures

John Dixon, Hans-Joachim Braun and Jonathan H. Crouch

Introduction

For millennia wheat has provided daily sustenance for a large proportion of the world's population. It is produced in a wide range of climatic environments and geographic regions (Table 1). During 2004-2006, the global annual harvested area of "bread wheat" and “durum wheat” averaged 217 million ha, producing 621 million t of grain with a value of approximately US$ 150 billion. About 116 million ha of wheat was grown in developing countries, producing 308 million tons of grain (FAO 2007) with a value of approximately US $ 75 billion. Wheat serves a wide range of demands from different end-uses, including staple food for a large proportion of the world’s poor farmers and consumers. The similarity between average yields in developed and developing regions is deceptive: in developed countries around 90% of the wheat area is rainfed while in developing countries more than half of the wheat area is irrigated, especially in the large producers (India and China). In addition, there are large differences in productivity between countries within the two groups of countries, and even between countries deploying similar agronomic practices. For instance, among major rainfed producers (over one million ha) the average national yield ranges from about 0.9 t ha^{-1} in Kazakhstan to 2.6 t ha^{-1} in Canada, and up to 7.9 t ha^{-1} in the United Kingdom. Similarly contrasts are seen amongst irrigated producers, e.g. India with an average yield of 2.6 t ha^{-1} viz. a viz. 6.5 t ha^{-1} in Egypt. Thus, there is clearly considerable scope for increasing productivity in many countries.

The relative importance of wheat as a staple in selected countries is displayed in Figure 1. Wheat provides 500 kcal of food energy per capita per day in the two most populous countries in the world, China and India, and over 1400 kcal per capita per day in Iran and Turkey. Overall across in the developing world, 16% of total dietary calories come from wheat (cf. 26% in developed countries) second only to rice in importance. As the most traded food crop internationally, wheat is a single largest food import into developing countries and, also, a major portion of emergency food aid.

Wheat made a significant contribution to the increase in global food production during the past four decades as total production rose steadily through the use of higher yielding, water and fertilizer responsive and disease resistant cultivars supported by strengthened input delivery systems, tailored management practices and improved marketing (Braun et al. 1998; Dixon et al. 2006) The increased grain production attributable to improved germplasm alone has been valued at up to US$ 6 billion per year (Lantican et al. 2005). The increased production of wheat (and other staples) led to lower food prices (von Braun 2007) which contributed to the reduction in the proportion of poor in developing countries (Chen and Ravallion 2007). Looking to the future, global population is projected to steadily increase, albeit at a decreasing rate compared to the past century, to around 9 billion in 2050. The food and other needs of the growing population underpin the strong demand for cereals. The demand for wheat, based on production and stock changes, is expected to increase from 621 million tons during 2004-2006 to 760 million tons in 2020 (Rosegrant et al. 2001), around 813 million tons in 2030 and more than 900 million tons in 2050 (FAO 2006, 2007, Rosegrant et al. 2007) implying growth rates of 1.6% for 2005-2020, 1.2% for 2005-2030, and 0.9% for 2005-2050. As can be seen from Figure 2, projections suggest that the demand for maize will grow faster than for wheat, particularly because of the strong demand for feed maize as an animal and poultry feed, but also the increasing demand for biofuel maize; in turn the demand for wheat will grow faster than that for rice and follows very closely the growth in global population over this period.

Trends and organization of international wheat improvement

The steady increase in wheat production has been due to increases in both area and yield. Production area continuously expanded in all regions for many decades until 1980, then contracted in Latin America until 1995 (Figure 3). During 1995-2005 the growth in area was negligible in South Asia where land has become scarce, while growth has been slow in Central Asia and North Africa and Latin America in addition to the more favorable resource and input supply situations. Moreover, with slower productivity growth than some alternative crops and, until recently lower relative prices, wheat has been replaced by maize and high value crops in India, the USA and especially China, where the area of wheat has reduced from a maximum of 27 million ha to 23 million ha. Some of these trends maybe reversed in the near future in responses to changes in relative yields or prices (FAO 2007).

For many decades the global average yield of wheat has increased, supported by an effective International Wheat Improvement Network (IWIN), an alliance of National Agricultural Research Systems (NARS), CIMMYT, the International Center for Agricultural Research in Dry Areas (ICARDA) and Advanced Research Institutes (ARI). This alliance has deployed cutting-edge science alongside practical multi-disciplinary applications resulting in the development of germplasm which has made major contributions to improve food security and livelihoods of farmers in developing countries. For example, during the late 1950s and 1960s, researchers in Mexico under the leadership of Dr. Norman Borlaug, developed the improved spring wheat germplasm which launched the Green Revolution in India, Pakistan and Turkey.

Collaboration was broadened during the 1970s to include Brazil, China and other major developing country producers, and resulted in wheat cultivars with broader disease resistance, better adaptation to marginal environments and tolerance to acid soils. During the 1980s, an international collaborative partnership between Turkey, CIMMYT and ICARDA was established for winter wheat improvement in developing countries. The IWIN currently operates field evaluation trials in more than 250 locations in around 100 countries for testing improved lines of wheat in different environments.. With the growing research capacity of NARS in many major wheat producing countries, the number of wheat cultivars released annually by developing countries doubled to more than 100 cultivars by the early 1990s (Lantican et al. 2005). The early era of improved cultivars spread rapidly over the high potential production areas in most developing regions. As shown in Figure 3 widespread adoption occurred most rapidly in South Asia, especially in irrigated areas, followed by rainfed areas of Latin America; adoption has been slower in the Middle East and North Africa and sub-Saharan Africa because of drier riskier environments and weaker institutions (Evenson and Gollin 2003, Lantican et al. 2005). With such widespread adoption accompanied by yield increases, average annual rates of return for investments in wheat research averaged around 50% per year (Alston et al. 2000). In addition, the urban poor benefited substantially as production increases drove down wheat prices.

Prior to the Green Revolution, the global average wheat yield was increasing at about 1.5% per annum: around 2.2% per annum in developed countries but growing at less than 1% per annum in developing countries (Figure 5). The Green Revolution boosted the growth of average wheat yields to 3.6% per annum in developing countries during 1966 to 1979. However, yield growth in developing countries slipped to 2.8% per annum during the period 1980 to 1994, and then dropped to 1.1% per annum during 1995 to 2005 (Figure 5), once again falling below the population growth rate. Whilst poor productivity increases before the Green Revolution were compensated by expansion in production area, Figure 3 indicates that area growth during the 1995 to 2005 period was around 1% per annum in Latin America and close to zero in other developing country regions. It is noteworthy that a steady yield growth of the order of 1.7-1.8% per annum was maintained in developed countries until 1994 even though wheat production is mainly rainfed in these areas, but halved to around 0.7% per annum from 1995 to 2005.

In order to understand the causes for reduced performance after the mid-1990s, the production data was disaggregated to the national level for the top 20 wheat producers. Figure 6 shows, for each of these countries, average national yield growth during the period 1966 to 1994 compared with that of the period 1995 to 2005. A useful reference point is the 1.6% growth rate, the approximate yield growth rate required to meet the projected wheat production in 2020 (Rosegrant et al. 2001). Figure 6 shows that the initial 30-year period was a time of moderately rapid growth in wheat productivity in both developing and developed countries, although 14 of the 20 countries fell below the 1.6% growth and the USA and Canada performed especially poorly with only 1% growth although this also reflects the tendency for wheat to be increasingly cropped in less productive areas. Overall, the yield growth of the past decade (1995-2005) has been lower than the preceding 30-year period in 17 of the 20 countries: only Russia, Iran and Kazakhstan improved performance.

Only Pakistan and Iran have average growth in productivity above 2% for the entire 40 years from 1966 to 2005. Some of the countries with yield growth rates below 1% per annum are major wheat exporters, e.g. Australia, USA, Canada and France. Considering individual countries highlights a variety of reasons for lower recent performance, including the general decline in international wheat prices (affecting many countries), the collapse of agricultural services (e.g. Ukraine), adverse climatic conditions (e.g. Australia) and attractive diversification options (e.g. Australia, EU, USA, Canada, Egypt, India, Turkey, China). However, wheat remains part of the current cropping systems and productivity may increase as break crops (such as legumes and oilseeds) improve soils and in turn wheat yields in some countries. Weakening domestic demand has also contributed to the decline of wheat (e.g. China). Conversely, countries showing strong recent performance are characterized by effective domestic measures to enhance wheat production through a combination of utilizing better cultivars, improved agronomy and strong agricultural support policies (e.g. Iran and Egypt).

Whilst developing country wheat productivity growth exceeded that for all major crops during the 30 years up to 1994, productivity growth has slowed during the past decade to an average level amongst major crops. The growth rate of many crops has slowed during the past decade, and some of the explanations noted above for poor or good wheat performance would apply to other crops. In the group of 10 major crops during the 30-year period 1966 to 1994, only maize, wheat, soybeans and rapeseed exceeded 2% yield growth. These crops have benefited from strong public and private sector investments in breeding and crop management as well as good national policy support. During this period there was strong public support for food crops, prior to structural adjustment, and the private sector invested heavily in maize, soybean and rapeseed research in many developed countries and the spillovers to development countries were large (e.g. from the USA to the South America). Meanwhile, wheat benefited from the international alliance of public sector research which spanned developed and developing countries. However, during the 1995 to 2005 decade as annual growth in wheat yields slowed to 1.1%, seven other food crops performed better than wheat although only three crops exceeded the 2% threshold; i.e., rapeseed, groundnuts and cotton. Interestingly, the yield growth rate of rice was around 20% lower than wheat in both periods. It is noteworthy that rapeseed exceeded 2% yield growth in both periods, underpinned initially by strong public sector research, leading to a smooth transition to strong private sector investment in breeding, agronomy, processing and marketing; for similar reasons increases in soybean productivity have been robust. Also in less extensively bred crops the exploitation of genetic diversity often leads dramatic initial growth in productivity.

It would appear that factors associated with the declining rate of yield increase in wheat include relatively slow increase in private sector investments during the last decade, and lower applications of production inputs as oil prices drove up the cost of fertilizer and pumping irrigation water while until very recently the price of wheat gradually fell. In addition, a lack of attention to crop management and degradation of resources including soil fertility and quality of water for irrigation combined with increasing frequency of droughts.

Real wheat prices (adjusted for inflation) have declined substantially over past decades until 2007 (Figure 7). This decline halted abruptly in 2007, when wheat stocks fell to a 30-year low driving current market prices and wheat futures to strongly increase. This was partly due poor weather in major wheat producers including Australia, Canada and China, and the shift of acreage from wheat to maize and canola, particularly in the USA and Western Europe, prompted by the soaring demand for bioenergy crops. Historically, increases in oil prices have been one of the major contributing factors to spikes in wheat prices during the past four decades. However, there is now increasing uncertainty concerning medium term price forecasts for wheat and other grains, due to volatility in market demand and climatic unpredictability; one of the most recent forecasts suggests an increase of the real price of wheat of approximately 40% by 2050 (Rosegrant et al. 2007).

As the world food situation is being transformed by new driving forces (von Braun 2007), wheat farmers and researchers are confronted with major challenges but also emerging opportunities. It may be that the "easy gains" from wheat research have been exhausted. Clearly past impacts from wheat research have been greater in high input farming systems, where semi-dwarf cultivars responded well to increased use of fertilizers and irrigation. Later, spillovers accumulated as improved cultivars spread from irrigated to higher potential rainfed areas, and then progressively into lower potential rainfed areas (Dixon et al. 2006). Looking to the future, will changing consumer preferences and strengthening market value chains create adequate new markets for quality wheat that will justify increased attention to breeding for quality? Will molecular breeding improve the efficiency of field breeding and accelerate the release of dramatically more productive lines and cultivars? Does genetically modified (GM) wheat have significant potential benefits for the industry and consumers? Will the impact of global climate change require major shifts in wheat research and breeding objectives? Are there improved soil and crop management technologies which would enable farmers to obtain the full benefit of new wheat cultivars, while conserving the resource base for future generations of wheat farmers? Are there proven models of integrated "germplasm enhancement – improved crop management – more favorable policy environments" approaches that might be replicated in major wheat producing areas?

These are some of the issues that NARS managers and wheat researchers must now confront in order to select an optimal portfolio of strategic wheat research and breeding activities during the coming years which will have an impact on the ground during the coming decades. Until the dramatic expansion of demand for biofuels maize and the weather-induced supply problems in the past few years, the prospects for a reversal of the steady fall of the real prices of cereals including wheat appeared poor: now, as noted above, recent projections suggest a long-term increase in the real price of wheat (along with other cereals). There are a number of trends and predicted key factors on which to base decisions: for example, the growing world population needs more food and more energy, and more feed grain to supply an ever increasing global demand for animal products; decreasing water supplies for agriculture and the effects of climate change are increasing the levels of abiotic stress across major wheat production areas; the application of biotechnologies is likely to offer new opportunities to increase productivities providing the private sector is sufficiently engaged.

Drivers of future wheat research

The development of global and regional future scenarios for wheat production have been based on the "wheat drivers" discussed above combined with projections derived from economic modeling by IFPRI (Rosegrant et al. 2001, Rosegrant et al. 2007), FAO (Bruinsma 2002, FAO 2006) OECD-FAO (OECD-FAO 2007) and the University of Iowa (FAPRI 2007), supplemented by expert assessments from other sources (e.g. GRDC 2004). In the following discussion, those pressures which enhance wheat production are referred to as "facilitators" and those tend to hold back production increases are termed "dampeners".

The demand for wheat is projected to continue to grow, albeit at a declining rate. The wheat-2020 global production forecast is 760 million t (implying 1.6% annual growth), equivalent to 29% of total global cereal demand (slightly down from the current share of 30 percent), equivalent to 74.3 kg cap^{-1} yr^{-1}. Consumption in the developed world is expected to be 103.8 kg cap^{-1} yr^{-1}, compared with 67.7 kg cap^{-1} yr^{-1} in the developing world

(Rosegrant et al. 2001). The forecasts suggest that most wheat in developing countries will continue to be consumed as food, while in the developed countries a significant portion will be used as animal feed.

Great regional variation exists in per capita consumption of wheat, varying from virtually zero in some Africa countries to 200 kg cap^{-1} yr^{-1} in countries in North Africa, and Central and West Asia. Global average yields will need to increase to 3.5 t ha^{-1} (up from the present 2.9 t ha^{-1}) if the expected global wheat demand in 2020 will be met. Taking into consideration growing scarcity of land and water, increasing demand for high value products and climate change, it is likely that a greater proportion of wheat will be grown in extensive rainfed systems, such as currently predominate in the Southern Cone of South America and Central Asia.

Further development of institutions can be expected, with a stronger role for the private sector in seed systems across many regions. As a consequence of better seed systems and improved farm management, there will be faster turnover of cultivars. As labor costs rise, the average size of operational holdings (not necessarily ownership) will increase, which will foster a greater degree of mechanization and other economies of scale. With improved agronomic management, a growing proportion of wheat is likely to be produced under conservation agriculture systems. With improved cultivars better tailored to new crop management practices, increases in input use efficiency should be expected to facilitate a reduction in the level of input applications while at the same time maintaining for increasing yield (as compared to present rainfed conditions). This should then result in significant net profits for wheat producers. In addition, the development of markets for different end uses will require more segregation of wheat types.

Projections of the future of wheat production suffer from two main sources of variability (Rosegrant et al. 2001): global and macro-economic uncertainties plus specific ‘dampeners’ and ‘facilitators’ affecting wheat productivity which are summarized in Figure 8. The most probable set of forecasts indicate that wheat production (and consumption) will likely grow at approximately 1.6% per year, with the consequence that 760 million t will be produced in 2020 and approximately 813 million t in 2030. The required growth could be derived from a number of sources, some historical as described above, and some new, which are discussed below. The set of key facilitators which will tend to strengthen productivity (and production on the assumption that area would not increase) is identified; and the set of key dampeners which will tend to depress productivity and production is also identified. The facilitators include wheat “synthetics”, biofuels demand (although this might also increase competition for resources and dampen growth), better management of genetic-by-system interactions, increased breeding efficiency through marker-assisted selection, hybrid or GM-wheat increasing private sector investment, growing demand for health foods, and ultimately for special uses such as cosmetics and emerging industrial uses. On the other side, dampeners include shortage of fresh water for irrigation, soil degradation, emerging biotic stresses, high energy prices and failure to increase yield potential, shift of a substantial proportion of the wheat production area from intensive irrigated to extensive rainfed production, and climate change with respect to the negative effects of heat stress, insufficient irrigation water availability and increased pest and disease pressure (although climate change may also lead to the expansion of wheat into new rainfed production areas).

Table 1. Area and productivity of wheat in selected regions (2004-2006)

Region	Area (million ha)	Yield (t ha^{-1})	Production (million t)
European Union 27	26	5.3	137
East Asia	23	4.3	98
South Asia (including 2.2 million ha in Afghanistan)	38	2.5	97
North America	31	2.8	88
South America	9	2.4	22
Middle East and North Africa (including Turkey)	27	2.3	61
Eastern Europe and Russia	31	2.2	69
Central Asia and Caucasus	15	1.4	22
Australia and New Zealand	13	1.5	19
Other (including 3 million ha in sub-Saharan Africa)	4	2.3	9
World	217	2.9	621
Developing countries	116	2.7	308
Developed countries (incl. former-USSR)	101	3.1	313
Country contrasts			
…dominated by rainfed production			
Kazakhstan	12	0.9	12
Canada	10	2.6	27
United Kingdom	2	7.9	15
…dominated by irrigated production			
India	26	2.6	70
Egypt	1	6.5	8

Source: CIMMYT

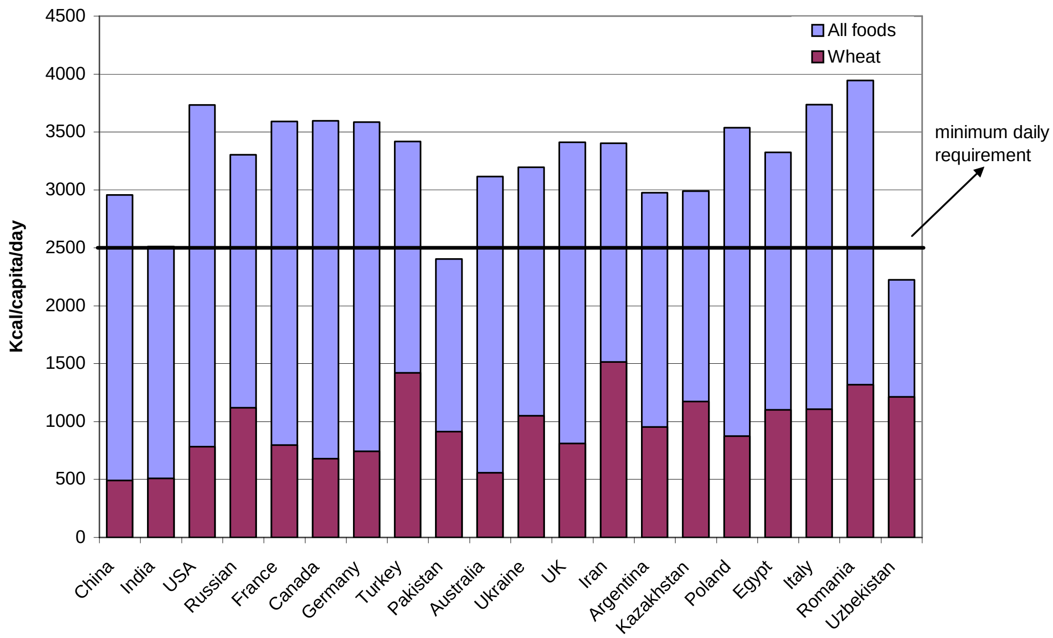

Fig. 1. Wheat share in food consumption in selected countries. Source: FAOSTAT (2007)

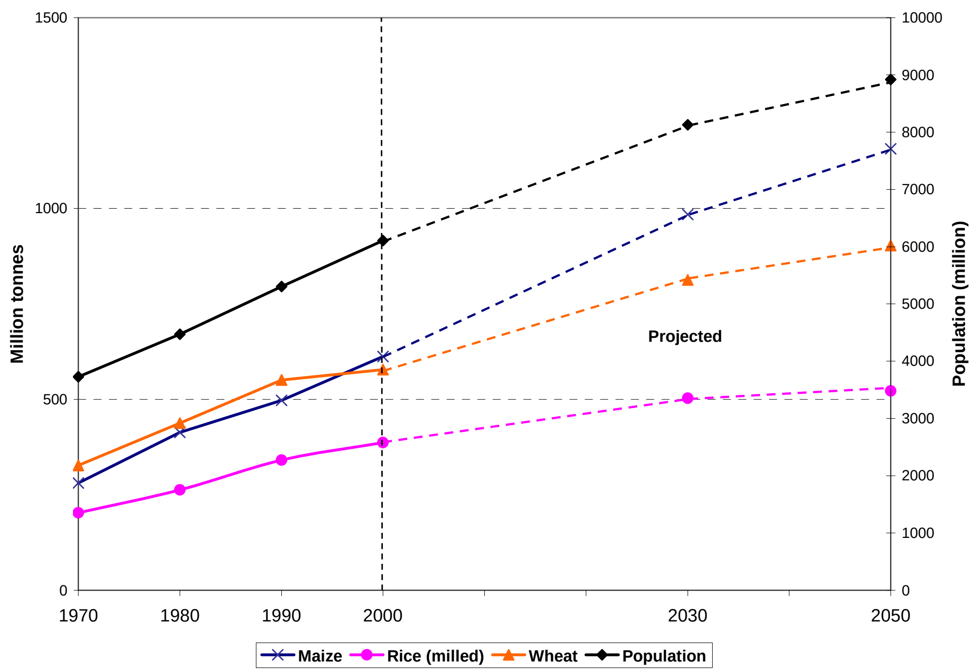

Fig. 2. World demand for wheat, maize and rice (1970 – 2050). Source: FAO (2006)

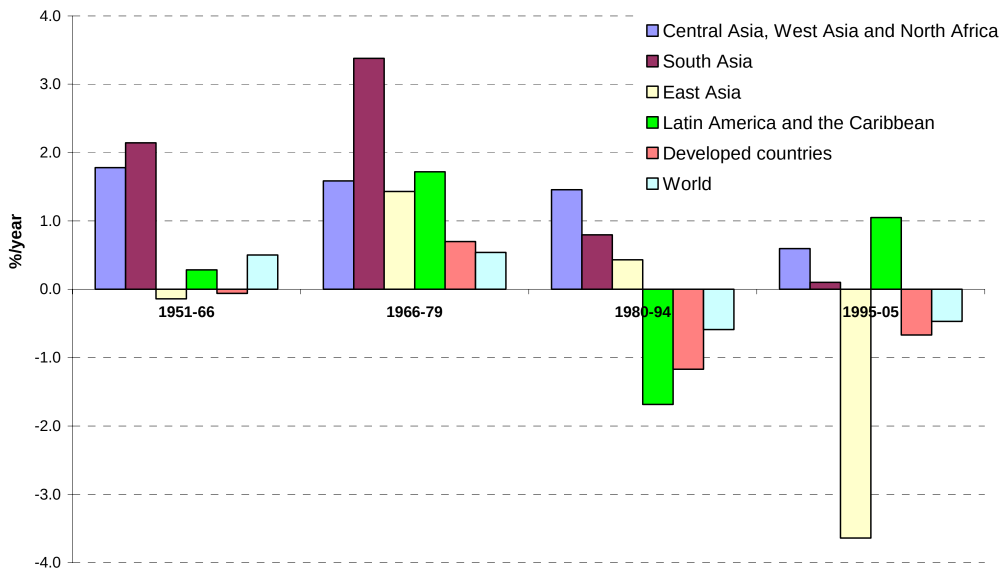

Fig. 3. Change in wheat area in selected regions (1951-2005). Source: FAOSTAT (2007)

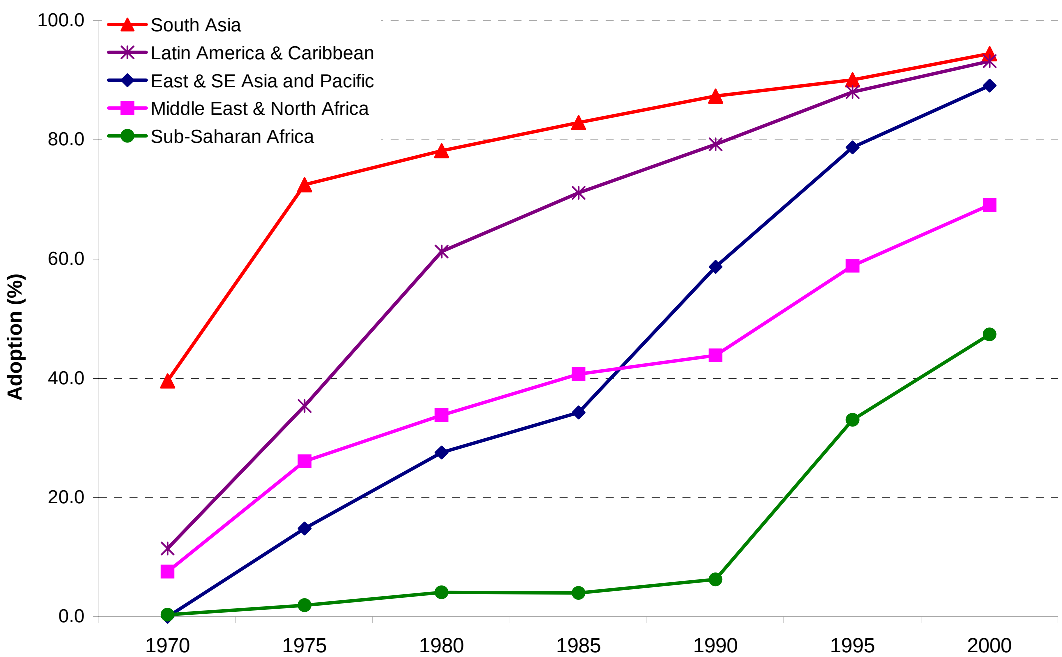

Fig.4. Adoption of modern wheat cultivars by region (1961-2000)
Source: Evenson and Gollin unpublished

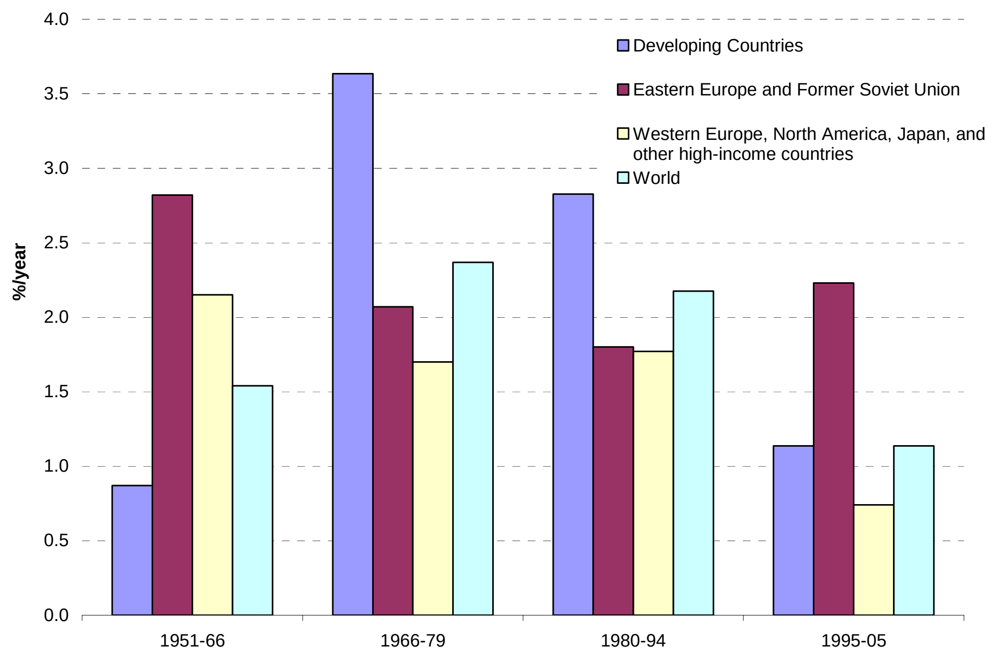

Fig. 5. Wheat yield growth rate (1951-2005). Source: FAOSTAT (2007)

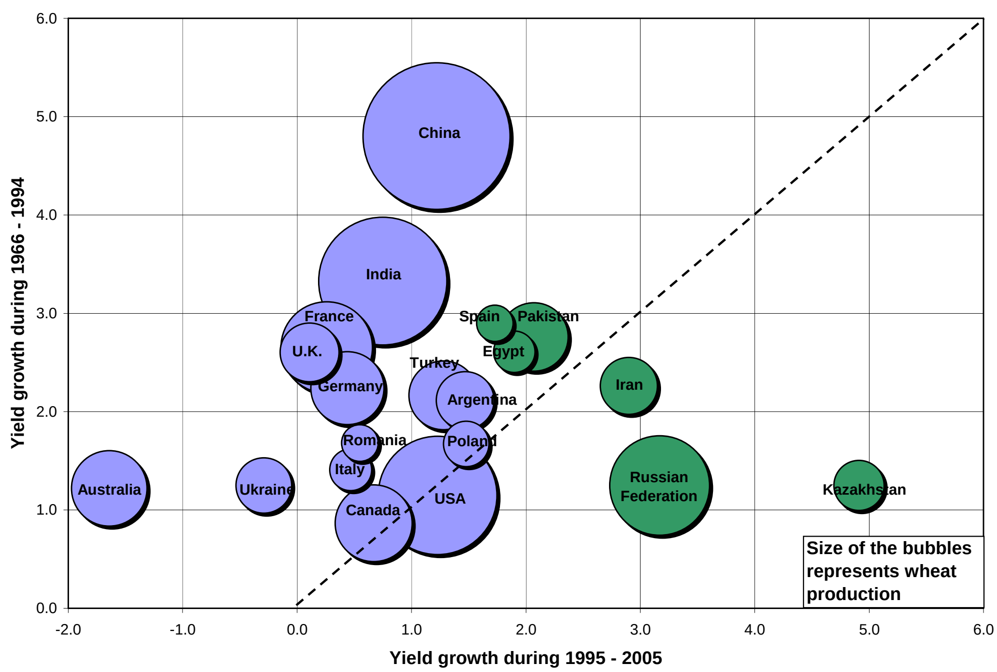

Fig. 6. Yield growth rate differentials by period (1966-94 cf. 1995-2005) for the top 20 wheat producers. Kazakhstan yield growth for 1966-1994 was taken from average of former Soviet Union. Source: FAOSTAT (2007)

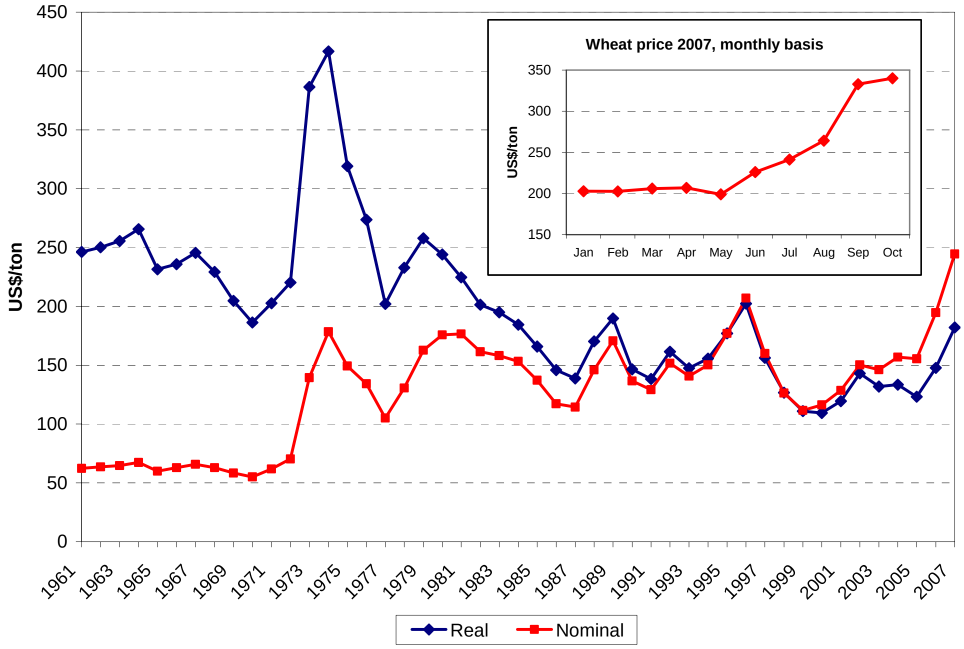

Fig. 7. - International price of wheat (real and nominal). Source: USDA Wheat Outlook

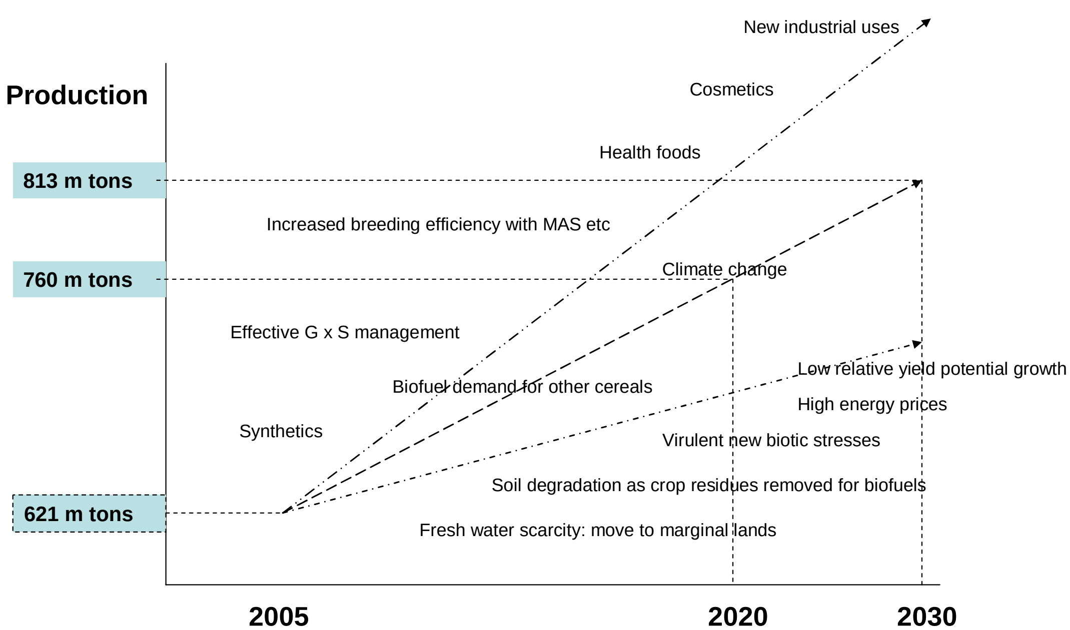

Fig.8. Wheat futures. Sources: FAO (2006), Rosegrant et al. (2001)

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Maize Facts and Futures

Marianne Bänziger, Jonathan H. Crouch and John Dixon

Introduction

Maize is grown in a wider range of environmental and socioeconomic conditions than other major crops. Not only is maize grown as the basic staple in central Zimbabwe on granite sands with less than 600 mm of rainfall, Filipino smallholders grow it in the high potential tropics as a cash crop for feed companies and Bangladeshi farmers produce winter maize under irrigation and high input levels for poultry feed. As well as staple food and feed, maize cobs are picked green to combat the "hungry" season in many countries – the value of green pick, baby corn and sweet corn alone makes maize one of the leading vegetables of the world. For many smallholders maize is an important source of green fodder, and the dry stover is a source of domestic energy as well as a means to prevent soil erosion and improve soil health and fertility. In reality maize is generally closely integrated with other crops and livestock in smallholder farming systems, and these linkages need to be taken into account when prioritizing maize research. Moreover, these systems are dynamic – witness the rate of change in Bangladesh or Bihar – and the rate of change is increasing with economic development in CIMMYT client countries.

The world's maize facts and future

Between 2004 and 2006, over 700 million t of maize were annually produced on 145 million ha; of which 380 million t on 100 million ha were in the developing world. By 2020 maize production in industrialized and developing countries will have surpassed that of wheat and rice and will have increased since 1997 by 45% at the global level and by 72% in developing countries (Rosegrant et al. 2001). Within the developing world, the demand for food maize will be the greatest in sub-Saharan Africa (40 million t), followed by Latin America (30 million t), and then South and Southeast Asia (25 million t).

Table 1. Maize demand in 1997 and 2020 (After Rosegrant et al. 2001)

	Demand (million MT)			Area (million ha)			Food		Feed		Other		Net trade
	1997	2020	Change	1997	2020	Change	Perc	million MT	Perc	million MT	Perc	million MT	million MT
Global	586	852	45%	138	158	14%	15%	128	69%		16%		
Industrial	291	344	18%	42	50	19%	5%	17	76%		19%		67
Developing	295	508	72%	96	108	13%	22%	112	64%		14%		-67
East Asia	136	252	85%	24	30	25%	4%	10	82%	207	14%	35	-43
Latin America	75	118	57%	28	32	14%	25%	30	60%	71	15%	18	5
Sub-Saharan Africa	29	52	79%	25	26	4%	76%	40	10%	5	14%	7	-6
South East Asia	23	39	70%	8	9	13%	32%	12	58%	23	10%	4	-8
WANA	18	28	56%	2	2	0%	28%	8	63%	18	9%	3	-14
South Asia	14	19	36%	8	9	13%	70%	13	13%	2	17%	3	-1

The drastic increases in demand for maize - driven by the livestock revolution, biofuels and crop substitution due to scarcity of water and land - will have implications for the poor.

Maize prices are predicted to increase by 23 to 41% (Rosegrant 2007) and, with accelerated demand for feed-stock based biofuel, maize could even become the food crop with the highest price increase (> 70%; von Braun et al. 2007). Even though higher maize prices may stimulate income and export opportunities for more commercial farmers, adverse impacts on food consumption (level and stability), childhood malnutrition and food import bills will likely prevail and call for renewed investments in accelerated agricultural productivity increases to maintain and improve food security and poverty reduction.

The rapid expansion of biofuels has had several major impacts on maize, including soaring prices and the associated increased malnutrition. The upward pressure on grain prices from the production of biofuels is expected to moderate as second generation biofuels come on stream during the next decade. However, the use of maize stover for ethanol production would threaten livestock production, through lack of fodder, and soil health, through lack of soil organic matter and soil cover.

While certain sub-regions still have scope for increased use of water and land for maize production, stagnation in irrigation investments and new demands on land and water (higher value use, increase in population) will by and large emphasize focus on technologies which improve crop productivity and water use efficiency (Rosegrant 2007). It will also imply crop substitution which may be driven by productivity (wheat, sorghum and millets to maize), water use (rice to maize) and wealth-related consumption patterns (maize to wheat and rice), and compel accelerated crop rotations in particular in Asia. As the demand for feed has increased rapidly in Asia, maize is spreading in upland and intensive rice systems which require new traits (e.g. water-logging during establishment, mid-season drought tolerance, early high-density types).

Climate change and the associated increase in production risk will further emphasize the need for maize with increased drought tolerance and water use efficiency (WUE), resilience to variable rainfall patterns (including surplus water situations) and heat tolerance, latter particularly in South and Southeast Asia. Without technology adaptation, maize production in developing countries will decrease by 3% (-7% to +2%) on average by 2030 with most pronounced impacts in the lowland tropics (including Brazil, South Asia with maize production changes varying between -13% to 2%) and dryland tropical environments (in particular Southern Africa with maize production changes varying between <- 50% to -15 %) (Lobell et al. 2008). Beyond the average decreases in maize production, Jones and Thornton (2003) emphasize the significance of large productivity variability across countries and years, and the greater occurrence of crop failure which of course has major implications for hunger and poverty.

Drawing on past experiences, it is well recognized that maize germplasm improvement and crop management have contributed equally to the increases of maize yield in the USA and especially in stressed environments. For example, the moisture conserving functions of conservation agriculture is a critical element of an integrated approach to maize development. Increased use of fertilizers is still an important avenue for enhancing maize productivity in particular in sub-Saharan Africa, Central America, parts of South America, plus Central, South and Southeast Asia, and the Caribbean. However, recent increases in demand for fertilizers, mostly driven by India, China and Brazil and increasing fuel costs, have made fertilizer prices climb approximately 50% more than fuel prices. As a result, fertilizer use for maize production is on the decline in certain regions and this is more likely to happen among the poor with low purchasing power and in rainfed maize production with lower and less reliable fertilizer use efficiencies. In addition to impacts on maize production, below optimal fertilizer use may further aggravate the substantial nutrient depletion which is on-going in large areas of Africa, the mid-altitude hills of Nepal, parts of northeastern India, Myanmar and northeastern Thailand, the Mesoamerican hillsides, the semi-arid Andean valleys, northeastern Brazil, and the Caribbean Basin lowlands (Scherr and Yadav 2007).

While environmental degradation is likely to have only a modest immediate effect on global food supplies, it could have dramatic effects in specific countries and sub-regions. Among maize growing areas in developing countries, soil erosion will create serious production problems in southeastern Nigeria, Haiti, southern China, Southeast Asia, and Central America whereas deforestation threatens critical habitats in the lowlands of Latin America and Southeast Asia (Scherr and Yadav 2007).

In summary, the maize future is dominated by (i) an accelerating demand for feed, biofuel and fertilizers by emerging and established economies, scarcity of irrigation water and land which will augment maize food prices, and (ii) the growing variability in local to sub-regional maize production due to climate change. Greater use of inputs is limited by availability (land, water) and alternative higher value uses (land and especially water), ineffective decentralized supply systems (fertilizers and irrigation in Africa), prices (fertilizers, water, fuel) and their cost effectiveness for use in maize production, orienting technology-based solutions mostly towards productivity-related research including both systems optimization and genetic solutions.

Based on such considerations, the World Bank's 2008 World Development Report (WDR) recently presented an output-oriented view of future international agricultural research priorities. It proposes an agenda focused on issues that address climate change, energy prices, the Asian demand, Africa's domestic production, the negative environmental foot-print of agriculture and malnutrition, and an overall emphasis on land/water/energy/labor/crop productivity increases (World Bank 2007). With the exception of biodiversity-related interests, the 2008 WDR provides a useful framework for priority setting amongst future agricultural research investments and relevant maize research-related topics.

The Consultative Group on International Agricultural Research (CGIAR) is seen as both an international public goods provider with little distinction between beneficiaries (e.g. conservation of genetic resources) and a "*mobilizer of science for the poor*" (CGIAR, 2008) but these two definitions are sometimes not synonymous. For example, biofuel may be a highly relevant maize research topic for the international community but it has a low impact potential for sub-Saharan Africa (von Braun et al. 2007) where the importance of maize and number of poor people is the most significant.[*] Indeed, if CIMMYT allocated its

[*] By 2010, the countries with the largest number of poor people and the greatest importance of maize will include China, Egypt, Ethiopia, India, Kenya, Malawi, Mozambique, Nepal, Tanzania and Zimbabwe

resources based on future trends in poverty (density and intensity), as well as the importance of maize and strength of alternative suppliers, our 2010 maize research investments would be allocated 70% for sub-Saharan Africa, 20% for Asia and 10% for Latin America and Central/West Asia and North Africa (CIMMYT Priority Setting Task Force 2003; average model). Such a resource allocation may also be justified by the much more significant contribution of agriculture to growth and poverty reduction in countries or provinces with a high proportion of rural poverty, most of them in sub-Saharan Africa (World Bank 2007).

Table 2 - Maize research areas and their relationship to priority areas for agricultural research identified by the 2008 WDR

Future issues (WDR 2008)	Relevant maize research areas
Africa domestic production	Drought tolerance, soil fertility, postharvest pests, *Striga*, crop productivity at large, input/output supply systems (seed – grain - fertilizer)
Asia demand	Systems intensification for irrigated areas (yield-maturity, water-use efficiency (WUE), nutrient-use efficiency (NUE), multipurpose and specialty maize, genetic vulnerability for emerging diseases) Drought tolerance in upland areas
Climate change/Water	Drought tolerance, WUE, water-logging, heat
Energy	Biofuel, NUE
Environmental foot-print	Nutrient and soil organic matter depletion, conservation agriculture, soil acidity
Malnutrition	Crop productivity, Vitamin A, Fe, Zn, protein

Maize technological facts and future

Over the past decade, huge advances have been made based on research in biotechnologies (transgenic and non-transgenic) and bioinformatics. This has traditionally been driven by the well funded, intellectual property rights (IPR)-protected maize seed and university sector of OECD countries but more recently increasingly also by the emerging economies such as China and India.

New non-transgenic technologies tend to accelerate breeding progress through more targeted, precise and cost-effective selection (phenotypic, molecular, environmental and pedigree related) or through more rapid generation advancement (doubled haploids, molecular based recurrent selection, but also accelerated cropping cycles). They are also rapidly evolving and their advancement capital- and knowledge intensive. These technologies generally only pay dividends when combined with competitive germplasm (i.e., elite trait combinations) and substantial field breeding programs. Molecular markers are only as good as the phenotyping capacity used to develop them. In addition, a

(“Top 10”) followed by Angola, Brazil, the Democratic Republic of Congo, Guatemala, Haiti, Indonesia, Mexico, Nigeria, Pakistan, Philippines, Somalia, South Africa, Uganda, Vietnam and Zambia (“TOP 25”) (CIMMYT Priority Setting Task Force 2003; average model).

comprehensive understanding of traits at the molecular basis is still the exception rather than the rule for many important agronomic traits in maize, mainly due to their polygenic nature. Many quantitative trait loci (QTL) identified to date are highly germplasm-dependant, and their effective use is highly correlated to the amount of information that can be accumulated across a breeding program. Finally, our ability to accelerate recombination at desirable locations (i.e., reassemble genes and alleles to create a desirable genotype) remains dependant on multiple breeding cycles, large progeny populations and appropriate breeding schemes. As a result, the relative use of unimproved or source germplasm *viz. a viz.* elite germplasm and of CIMMYT molecular *viz. a viz.* phenotypic information remains low at this stage. CIMMYT seems at a cross-road for further investing in the development of whole genome selection, simulation and modeling of breeding systems, molecular breeding decision-support tools - which would imply significant additional funding - or strengthen such access through institutional partnerships and alliances with the public and private sector.

The discovery and deployment of valuable transgenic traits in maize is increasing and, and other than for political reasons or a major mayhem, there is no indication that the trend of increasing research investments in transgenic over natural genetic variation will revert, even though only very few traits have been commercialized so far. Transgenic variation can be unique for its effects (e.g. *Bt* gene) but does not necessarily surpass (yet) the extent of natural trait variation (e.g. drought tolerance). In the current transition from protective (insect and herbicide resistance) to productivity-enhancing (drought tolerance, nutrient-use efficiency –NUE) traits, gene-by-genotype and gene-by-environment interactions have become much more important and, for CIMMYT target environments, they will need to be researched within relevant (tropical, elite) germplasm backgrounds and (resource-poor farmer) environments. Biosafety-related costs, complex IPR environments, and the vast number of potential events make transgenic technologies cost-intensive and there is no indication that, in the near future, CIMMYT will engage in any other approaches than licensing field-proven events for humanitarian purposes, and likely only those which have passed internationally acknowledged biosafety regulations in at least one country.

Institutional maize facts and future

Significant institutional changes have taken place for maize seed technology development and dissemination. The integrated institutional support required for the maize industry can be visualized in a U impact framework, starting with germplasm resources leading to farmers' fields and ultimately to consumers, either on farm or in urban areas. On the left bar of the U, national public and private maize breeding capacities have grown and will continue to grow in proportion to the economic development of a country and relative importance of maize. However, Asian and Latin American countries currently invest significantly more than sub-Saharan Africa in agricultural research and development, and human resource development (World Bank 2007). Hence, CIMMYT must give emphasis to research and breeding activities that will foster great private sector investment in product development targeting our primary beneficiaries.

The private maize breeding and seed sector has mostly expanded in emerging economies such as India, China, Brazil and Mexico, some of it driven by multi-nationals, others by medium-sized regional and national seed companies (e.g. Mahyco), some of which continue to be integrated into or associated with multi-national seed companies. Within low and medium income countries with less reliable markets and CIMMYT's most important target countries, market liberalizations has fostered an increasing number of private seed companies. However, many are either mere seed sellers or seed producers of varieties licensed from the public sector, challenging CIMMYT to develop new modes of partnership for effectively interacting with this important set of players in the delivery of our products to our primary beneficiaries.

In Eastern and Southern Africa, for example, the number of maize seed companies has increased four-fold over the past 10 years whereas the total amount of maize seed sold has not increased significantly (Hassan et al. 2001, Langyintuo et al. 2008). Even though these indigenous seed companies hold great promise for improved seed supply to farmers, none of them has been able to engage in breeding so far. Breeding investment by the private seed sector in this region has rather stagnated as average seed sales are at this stage too low to sustain many company-owned germplasm development programs. Indeed an average sized seed company in eastern and southern Africa would have to increase seed sales approximately five-fold to justify an own breeding program. Rate-limiting factors include access to elite varieties, maize seed business-related know-how (production, processing, marketing), capital, risk management systems, and policy changes (Langyintuo et al. 2008) some of which are embarked upon within new philanthropic investments in Africa.

Conscious of these changes, CIMMYT maize has reduced research investments targeted at emerging economies (with rapidly strengthening alternative national suppliers) to the benefit of lower income countries, and widened collaboration with private partners. Upstream, research alliances with advanced research institutes and the private sector are increasingly important for accessing rapidly evolving, capital- and knowledge-intensive technologies. We are engaged in open source code-based information systems development within ICIS, which includes a wide range of public and private contributors, and CIMMYT maize has most recently for the first time been able to gain access to state-of-the-art molecular breeding platforms within the public sector (Cornell University; through Generation Challenge Program and Drought Tolerant Maize for Africa –DTMA, projects) and, through another, soon-to-be-announced project, the private sector. Research collaboration with many NARS has been highly successful but always considering the national (not international) public goods character of their research outputs (including germplasm). Downstream, multi-stakeholder networks including public, private and non-governmental partners have become our most important vehicles for capacity building and research impacts among smallholder farmers in Africa, Asia and Latin America, though they are of variable strength.

Conclusions for CIMMYT's future

Based on international maize research trends and the changing environment of alternative research providers, CIMMYT needs to constantly reassess the elements associated with our obligations (tropical maize genetic resource conservation; agreement with the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture) and our competitive niche ("*Mobilize science for the poor*"; CGIAR 2008). These two factors have traditionally been well correlated but are increasingly becoming disassociated. By capturing a significant amount of genetic variation in CIMMYT improved maize germplasm, there are now only a few examples where the continued use of unimproved maize genetic resources has been relevant and effective in "*mobilizing science for the poor*" (postharvest pest resistance) or could potentially be important given current trait prioritization (banded leaf and sheath blight –BLSB, *Striga*, biofuel, specialty trait maize). For most other traits, genetic variation in CIMMYT improved maize germplasm has been found to surpass or be more relevant (time-lag; genetic drag; relationship to productivity) than those found in unimproved maize genetic resources.

CIMMYT maize researchers could engage in any of the agricultural research areas indicated in Table 2. However, much of our engagement remains driven by funding availability, the size of our institution, perceptions about the comparative role of CIMMYT *versus* alternative suppliers, our investment in a multi-disciplinary mix of staff, and the capabilities of our staff. We may conclude that:

- CIMMYT must target key roles that maize plays for poor households, as food, livestock feed and fodder, and as cash crop to produce feed, food additives, biofuels and industrial products; and target key types of farmers from among the diverse environments and socioeconomic situations in which maize is produced.
- The complex of drought-WUE- climate change is the undisputed most important maize research topic and breeding goal for CIMMYT but a single-minded focus on this topic can also not be the basis for our entire research agenda.
- Disciplinary-specific and trait-driven research cannot be dissociated from germplasm enhancement. It is the vehicle of delivery and an essential provider of end-user orientation and feedback. Virtually none of our clients are in a position to make use of new traits in non-elite backgrounds. CIMMYT's niche for introgressing novel or improved traits into elite agronomic backgrounds remains strong, and our access and use of unimproved genetic resources (where required) needs to be demand-driven and highly trait-focused.
- Our ability to "*mobilize science for the poor*" in a time-bound manner and with real impact depends on effective public and private partnerships for sourcing technologies and delivering intermediate products that will allow our clients to have significant impacts on improving the livelihoods of resource-poor farming families across the developing world. However, platforms and partnerships can provide important opportunities to achieve our mandate but if not planned and managed carefully they can become substantial liabilities to our future progress.
- Our maize research investment towards Africa-relevant issues will continue to be greater than that for Asia and Latin America due to donor interest in resolving hot spots of poverty intensity. In Asia and Latin America, our engagement will depend on our

ability to strengthen strategic alliances with national public and private partners in pursuit of international maize research priorities (as listed in Table 2) and access related funding opportunities. Progressing as a partner of choice will determine our future success and this much depends on staff quality.

- In addition to our mandate in maize genetic resource conservation, the international public goods character of value-enhanced germplasm, their traits and associated information remains the least disputed CIMMYT maize research output among stakeholders.

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P11 – Knowledge, targeting and strategic assessment of maize and wheat farming systems

John Dixon, Jonathan Hellin, David Hodson, Petr Kosina, Roberto La Rovere and Erika Meng

Introduction

Resource poor farmers and consumers in developing countries depend on risky and complex maize- and wheat-based farming systems for their survival. For crop research to sustainably reduce poverty, it must reflect the production, consumption and livelihood roles played by maize and wheat. P11 contributes to mission-effective maize and wheat improvement research by CIMMYT and partners.

Despite the diversity of maize and wheat systems, relatively homogenous mega-environments, farming systems and research domains can be defined to guide priority setting and targeting and supporting spatial knowledge bases assembled. The synthesis of ex post and ex ante impact assessments, conducted in the normal course of research, identifies key lessons for research targeting and operations. P11 develops key methodologies (e.g., socioeconomic and environmental characterization, impact pathway assessment, value chain mapping, knowledge sharing). Science knowledge sharing platforms are being developed under the IRRI-CIMMYT Alliance.

The Project produces international public goods in the following areas: spatial knowledge bases and strategic assessments to support priority setting, targeting, and scaling up for CIMMYT and partners, syntheses of ex post and ex ante impact assessments, better understanding of producer incentives and institutional drivers of maize and wheat diversity, analyses of maize and wheat value chains to improve marketing efficiency and producer and consumer benefits, and knowledge and associated knowledge sharing mechanisms for maize and wheat science that provide direct benefits and also support capacity building at CIMMYT. The principal users of Project products and services are research managers and scientists for the design and appraisal of agricultural research and development. The knowledge outputs of the Project are web products, reports, papers, and databases. Sometimes the knowledge flows through other CIMMYT Projects, sometimes directly to NARS partners. Ultimately, improved NARS understanding, research methods and targeting could lead to improved livelihoods and poverty reduction. By the publication *Wheat* and *Maize Facts and Futures* assembles, analyzes and interprets data assembled jointly with national agricultural research systems (NARS), including seed companies where appropriate, P11 provides maize and wheat status and scenario information to NARS.

The research of the P11 project is organized in three outputs or pillars:

1. Strategic information and data for impact assessment, targeting and priority setting
2. Functional understanding of value chains and innovations systems in selected regions
3. Strengthened partners involved in research and sustainable development for maize and wheat based cropping systems, in alliance with other CGIAR centers

PILLAR 1: STRATEGIC INFORMATION AND DATA FOR IMPACT ASSESSMENT, TARGETING AND PRIORITY SETTING

Characterization of drought. Drought is probably the major abiotic stress affecting cereal production worldwide (Byerlee and Moya 1993, Edmeades et al. 1992). Hence, it is a primary research theme for CIMMYT across both maize and wheat (CIMMYT 2007). Recurring droughts provide a continuous challenge to farming in many areas, but especially maize in sub-Saharan Africa. Drought is not simply low rainfall. The timing of drought relative to the crop stage and its intensity are key factors (Denmead and Shaw 1960). A good understanding of the target environment and the extent of genotype-by-environment interactions are essential elements of all cereal breeding programs.

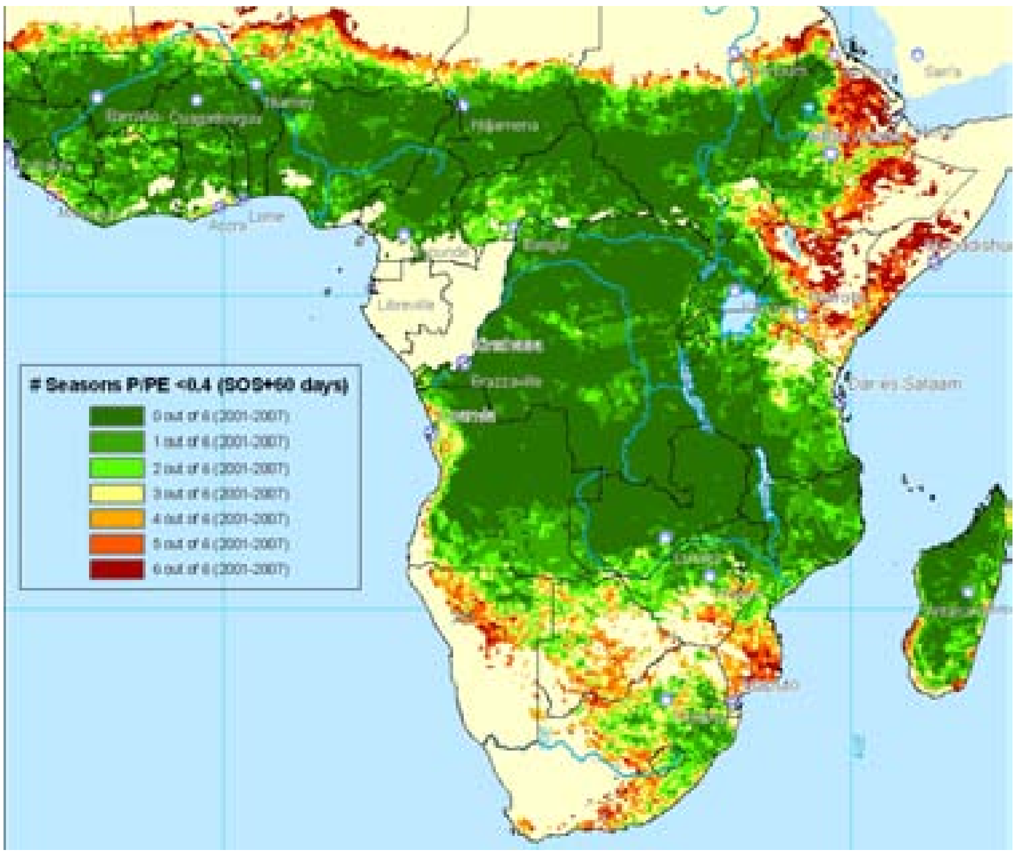

Fig. 1. Drought risks in sub-Saharan Africa

Through on-going research projects, such as the Drought Tolerant Maize for Africa (DTMA) project and the CONABIO Mexican landraces project, methods are being developed that will permit an improved understanding of the spatial and temporal aspects of drought in contrasting regions. Incorporation of the temporal aspects of drought has been a high priority. In sub-Saharan Africa, use of 10-day rainfall estimates on an 8x8 km grid allowed the development of models that permit the identification of water stress and rainfall variability at key crop growth stages (e.g., flowering) and the frequency of water stress over time for any given location (Fig 1.). This information will be a crucial element in the targeting and priority setting of germplasm products arising from the DTMA project.

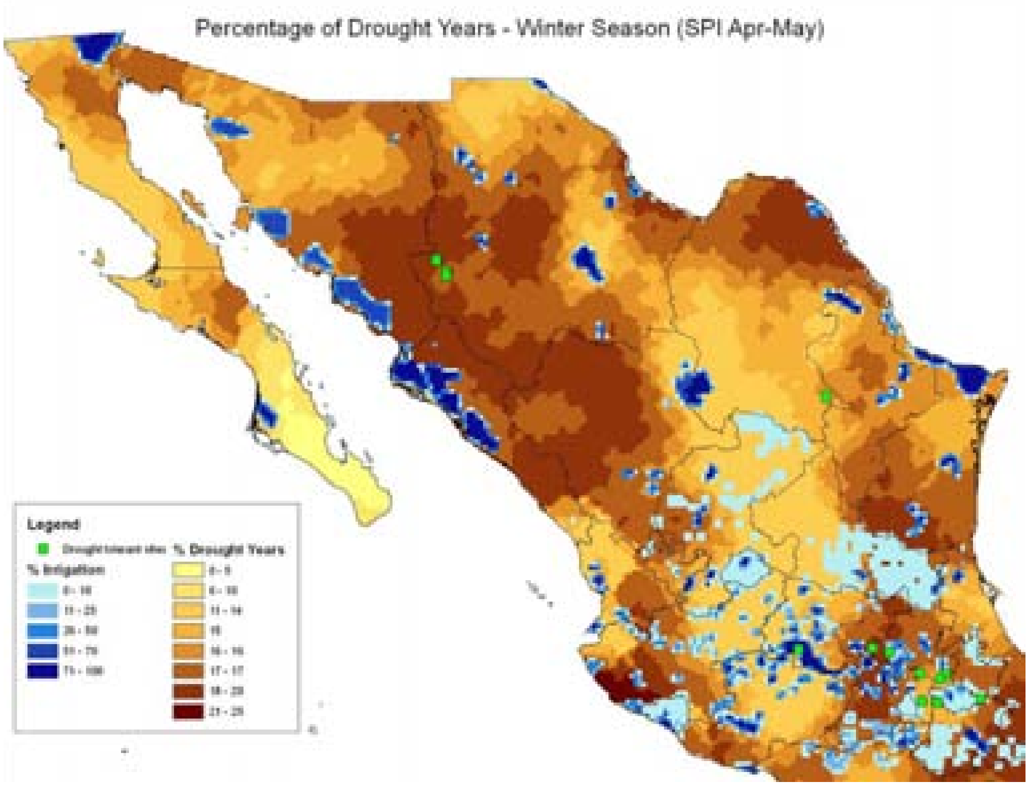

Fig. 2. Drought-prone areas in Mexico

Long-term (100 years) rainfall estimates have been used in Mexico to develop drought indices (Edwards and McKee 1997), which identify the intensity and frequency of drought events in relation to key stages of wheat development. These indices have been linked to performance of wheat landraces under managed drought stress, with indications of relationships between drought stress at collection sites and drought tolerance. These improved characterizations of drought are also being applied to other CIMMYT research areas, such as the targeting and priority setting for conservation agriculture technologies in Eastern and Southern Africa.

***Wheat stem rust – Ug99*: *Using GIS to track a threat to global wheat supply*.** Throughout recorded history, wheat stem rust has been the most feared of all plant diseases. A new race designated Ug99, after initial detection in Uganda in 1999 (Pretorius et al. 2000), is considered a major threat to global wheat supplies. An estimated 80% of current global wheat cultivars are regarded as susceptible to Ug99 (or derivatives). GIS is being used as a vital tool to track current status and likely movements of Ug99. This work is being undertaken as part of the Global Rust Initiative – an international consortium formed by CIMMYT and ICARDA together with NARS (e.g. Kenya and Ethiopia), FAO and USDA, among other partners. The chronological progression of known Ug99 sites is illustrated. There has been a gradual expansion throughout Eastern Africa and a subsequent crossing of the Red Sea into Yemen. These step-wise movements have been in line with prevailing winds. In addition, susceptibility of known cultivars (up to 2006) is mapped with symbols scaled according to planted areas – graphically illustrating the lack of resistance in current germplasm (Singh et al. 2006). A key component of the GIS work on Ug99 is the development of tracking systems and predictive models for likely movements and impact of Ug99. As the pathogen is wind-borne these models include the integration of wind and climatic data, in addition to wheat distribution data.

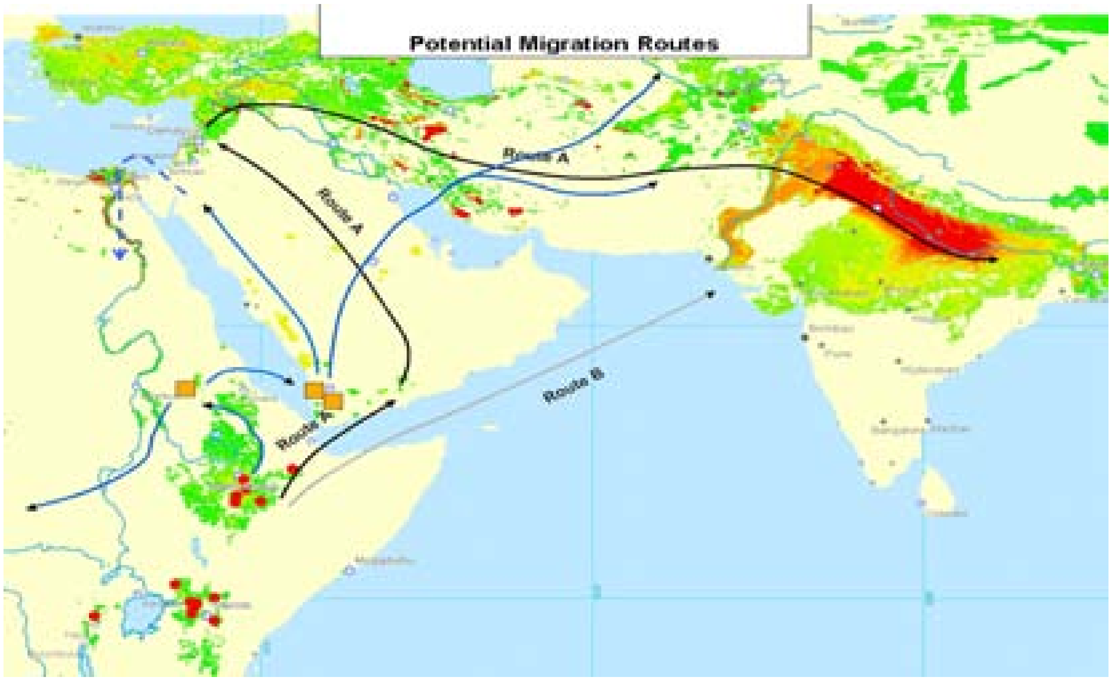

Fig. 3. Potential migration of Ug99 stem rust from East Africa

Potential migration pathways of Ug99 (routes “A” and “B”) were initially developed based on general regional wind flows, environmental data and historical evidence of yellow rust migration (Singh et al. 2006). Route “A” was considered to have higher probability, but both routes are still considered to remain valid options for onward movement of Ug99. Updated potential routes are based on results derived from the HYSPLIT air-borne trajectory model (Draxler and Rolph 2003). Use of this model is providing more detailed information on likely air flows, but it must be noted that the information from any air flow model can only be regarded as a potential indicator. Prediction of absolute movement has considerable uncertainty. Results indicate the critical importance of Yemen as a potential gateway for onward movement into the major wheat production areas of the Middle East and Asia (Singh et al. in press). Initial assessments of the wheat zone potentially at risk reveals ca. 20% of global wheat production and with ca. 1 billion people residing in the wheat areas (many of which are likely to be highly dependant on wheat for livelihoods and food security). In order to provide timely and accurate information to decision-makers, new tools such as RustMapper are being developed. Using Google Earth as base, RustMapper provides near real–time information (automatically updated) on Ug99 status and likely movements.

Selected GIS activities for 2008-2010 include: continuation of work on drought – with expansion of the spatial database in Africa, incorporation of socio-economic factors, seeds and markets, and key biotic stress distributions (e.g. *Striga*, Maize Streak Virus, gray leaf spot; climate change), particularly in terms of diversity and as a support for institutional priority setting. We will work on stem rust with a fully functional operational tracking and monitoring system (c.f. FAO locusts) –which we plan to set in place within a year. We also envisage a CIMMYT Wheat Atlas developed in this period.

Main achievements in impact assessment. Since 2005, and with the coming on board in the ITAU of a new research team, impact assessment (IA) has been changing in line with the new strategy, the launching of a learning platform and a series of workshops and other initiatives aimed at adjusting the focus and emphasis of impact assessment and priority setting (Fig. 4). We are moving towards a poverty and livelihoods, people centredness and systems approach. The main efforts have been in instilling an impact assessment culture and institutionalizing impact assessment through workshops and manuals (La Rovere and Dixon 2007b, Carrion and La Rovere 2007, and contributing to the CGIAR Standing Panel on IA strategic guidelines). We also carried out a series of targeted training courses on impact assessment (e.g. in Turkey during 2006) and initiated a series of Center Commissioned External Reviews (CCER): the first being for conservation agriculture, which will be synthesizing different experiences of CIMMYT –including the Rice-Wheat Consortium in the Indo-Gangetic Plains (Laxmi et al. 2007).

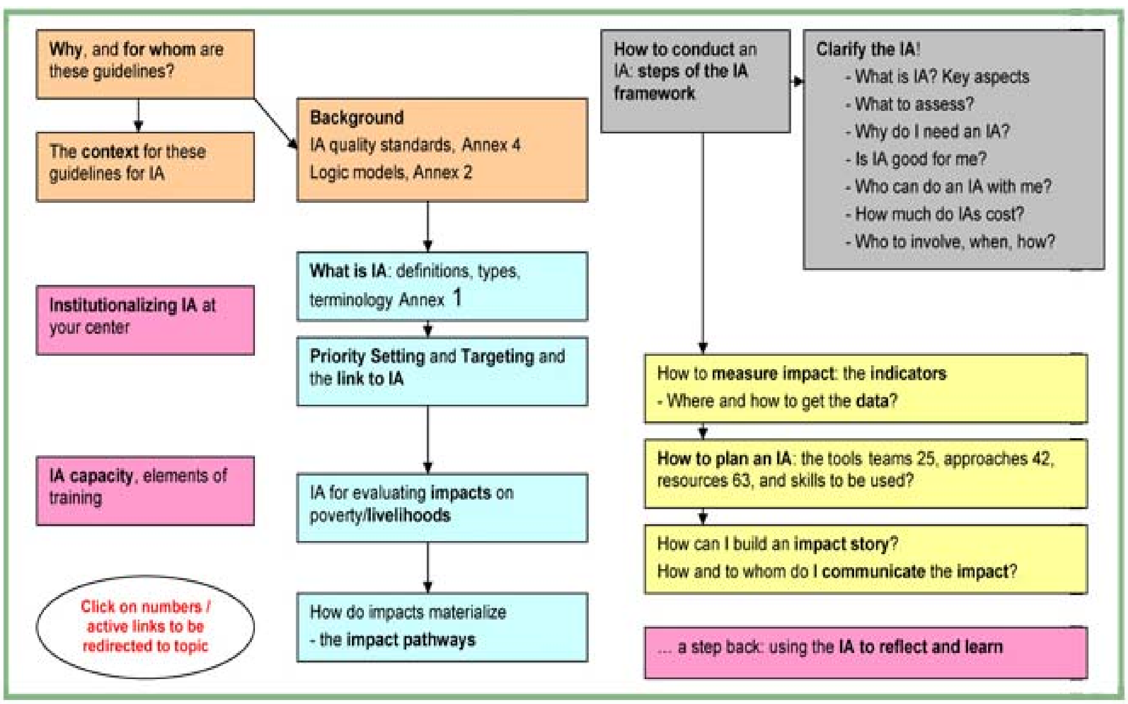

Fig. 4. Flow chart of impact assessment (IA) guidelines

The main internal assessments were on past participatory maize research projects in Oaxaca (La Rovere et al. 2007), which also served as a test case for impact assessement tools and methodology, in Nepal (Mathema and Kamala Gurung 2006), and in the DTMA project (all of an ex-post type). Ex-ante impact type was initiated recently for the DTMA project, which could guide future breeding investments (results are expected from 2009 onwards), *Fusarium* head blight or scab (through a scoping study), and stem rust (Hodson et al. 2005). Impact pathways' plotting was used for all medium-term plan (MTP) projects. We also looked at opportunities in the context of trade liberalization for wheat in Tunisia, and undertook, in the frame of HarvestPlus, an ex-ante assessment on malnutrition.

A trend towards more external assessments was also noted. The Impact, Targeting, Assessment Unit (ITAU) was successful by attracting impact assessment research such as the external assessment and monitoring system of 15-years of Sasakawa-Global 2000 (SG2000) interventions in Africa, or the external assessment of an eco-regional program (the African Highlands Initiative), which increases CIMMYT credibility in impact assessment, provides strategic data in key maize and wheat areas, and enriches the spatial meta-database to be used for priority setting, impact assessment, and targeting.

A strategy for building, strengthening, and sustaining impact assesment at CIMMYT

The IA strategy (La Rovere and Dixon 2007a) for the period 2008-2010 focuses on communicating IA and strengthening strategic human capacity on impact assessment, increasing the focus on ex-ante impact assessment and forward-looking studies on climate change impacts, stress impacts (drought), pathogens (e.g. rust), vulnerability (risk). They will be feeding in a new round of more explicitly forward-looking *Facts and Futures* series. The strategy also comprises the need for progressive decentralization of impact assessment, reliance on partners, and alliances on impact assessment with other key centers. This is in line with the new strategy of CIMMYT, and as the largest areas of expected impact on livelihoods is expected to be through research on drought, climate change, and pests as it will lead to key investment recommendations, breeding outputs and early warning systems of potential impacts. Areas of priority focus are therefore envisaged to be P2 and P7 among MTP projects; i.e., namely strategic assessment of value and impact of (intermediate) genetic resources and climate change.

In terms of balance between external and internal impact assessment, the strategy advocates a move to a 40:60 balance, where up to 40% of the work and resources is from external NARS partners (20%) and reputed professionals (20%), with CIMMYT retaining 60% of the work internally, to ensure credibility, maintain quality, and increase capacity.

The communication strategy for impact assessment results involves both the internal and external levels (e.g. spatial and socio-economic databases, internal reports, journal articles, web pages, briefs, list of ready-to-hand-out briefs and spotlights to understand key messages on impact assessment stories, videos or formal publications). This needs to be more frequent and systematic, also through decentralized (project based) ways, as in the DTMA and SG2000 projects.

PILLAR 2: FUNCTIONAL UNDERSTANDING OF VALUE CHAINS AND INNOVATIONS SYSTEMS

Research has continued in ITAU on the incentives for the conservation and utilization of genetic diversity at household and community levels. Research characterizing diversity outcomes and identifying significant determinants of diversity at household and community levels in Turkey and Mexico has expanded into research to characterize and understand changes over time in diversity levels, as well as livelihood impacts on farm households of cultivating diverse crop cultivars. Research has also focused on understanding the role of farmers' seed management practices on crop genetic structure.

Our understanding of determinants of household diversity outcomes has highlighted the important role of markets, input (e.g. seed) and output grain markets on crop diversity at household and community levels. Qualitative research has also demonstrated the importance of government policies, such as seed subsidies and rural poverty programs. A focus on the role of markets in crop diversity and a more in depth understanding of the impact of policies have thus been the focus of the most recent research. Value chain analysis has been an important component of the markets and diversity research. Since 2005 funding has been obtained for value chain research (e.g. FAO-funded project *Using Markets to Promote the Sustainable Utilization of Crop Genetic Resources*). Between 2005 and 2007, CIMMYT undertook a value chain analysis in Chiapas (Mexico) of the formal and informal maize seed supply chains and maize grain market: the chains through which grain produced by smallholder farmers reaches the final consumers.

The availability of two panel data sets, one in Turkey for wheat diversity and the other in Mexico for maize diversity, has also enabled quantitative analyses on changes in diversity over time. Research has also taken place at the aggregate level in China to test for a positive impact of wheat diversity on wheat productivity in China.

***Analyses of genes and genetic diversity*.** This area of research includes characterization of diversity outcomes and determinants for diversity at household and aggregate levels, impact of farmers' seed management practices on crop genetic structure, changes over time and drivers of change, productivity impacts of crop diversity, implications of on-farm diversity for household welfare and livelihoods, understanding of value chain mechanisms to support utilization and on-farm conservation of diverse crop varieties, and cost-effectiveness of utilization of diversity in breeding.

Diversity, value chains, and livelihoods: This research area considers household level changes over time of wheat diversity in Turkey (especially the impact of rust and drought incidence and agricultural policies), household and village changes over time of maize diversity in Chiapas (especially impact of seed subsidies and poverty programs), the relationship between household wheat diversity and deprivation in Turkey, the use and type of maize germplasm on rural poverty in Oaxaca and Chiapas, the value chain analysis of formal and informal maize seed supply chains and grain markets in Chiapas, and effects of wheat diversity in increasing wheat productivity in China.

***Role of quality and value chains*.** The opportunity for smallholders to raise their incomes from agricultural production, natural resource management, and related rural enterprises increasingly depends on their ability to participate successfully in marketplace exchanges. As a consequence, the focus of research and development issues has broadened from a concentration on building up farmers' production capabilities, via for example the use of improved germplasm, to include facilitating farmers' access to markets. CIMMYT Business Plan 2005-2010 and ensuing rolling medium term plans recognize the importance of market access for smallholder maize and wheat producers. For example, Project 4 is entitled *Nutritional and specialty trait maize*, while Project 11, *Knowledge, targeting and strategic assessment of maize and wheat farming systems* is developing key methodologies that include value chain mapping

The incorporation of a value chain analysis has also been a key component of research on quality characteristics for wheat and maize. There is growing interest within the CGIAR on the contribution of high value crops to poverty reduction. Ongoing and future research at CIMMYT explores the opportunities for increasing the value of maize through a three-pronged approach: firstly by identifying niche and differentiated markets for maize (e.g., exploring the extent to which commodity maize can be partly transformed into a differentiated high value agricultural product); secondly by exploring the opportunities for smallholder farmers to benefit from the growing high value markets for maize vegetables such as sweet corn, baby corn and corn-on-the-cob; and thirdly by exploring how existing value chains for commodity and differentiated maize and wheat can be made to work better for producers. The maize project, therefore, seeks to ensure that maize, a cereal crop of worldwide importance, makes a greater contribution to poverty reduction. Parallel research focusing on wheat value chains and wheat end use quality is also envisioned.

The changing consumption patterns occurring in many developing countries have resulted in a growing focus on the production of agricultural products that satisfy specific end use requirements. The possibility of price premium and other types of incentives to producers have been viewed as means to ensure the supply of maize and wheat with the desired quality characteristics. However, the appropriate institutions and infrastructure need to be in place to enable the transmission of information and incentives amongst actors (e.g., producers, traders, processing industry and consumers) in the value chain (Fig. 5). Issues of identification and traceability are an added complication for many end use characteristics, including nutritional traits.

An application on quality characteristics and value chains**.** This area includes diversity and markets, analysis of role of markets for seed input and grain output on maize and wheat diversity outcomes, analysis of value added and market potential for wheat and maize landraces, and more generally, to what extent is de-commodification through end use quality of wheat and maize possible?

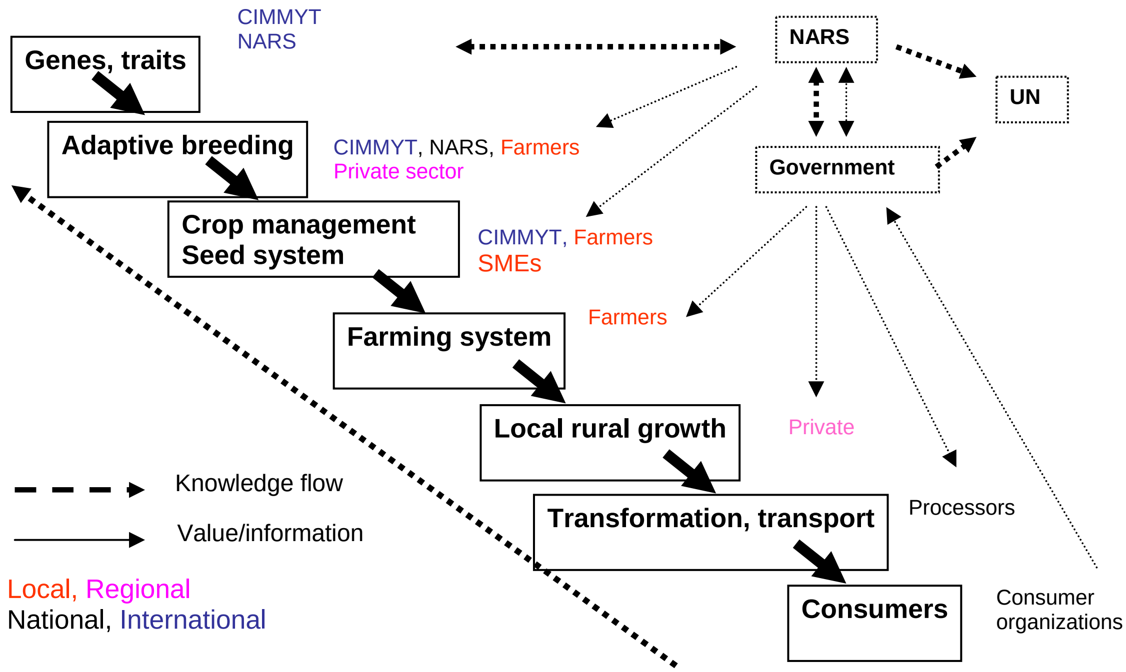

Fig. 5. Knowledge through the value chain

Ongoing and New Research 2008-2011 P11 MTP

Crop Diversity, Value Chains. This area could include continued application of value chain analysis to better understand demand for crop diversity and quality characteristics, assessment of impact of seed and grain value chains on diversity outcomes (Mexico, Turkey), documentation of value chains in marginal maize and rice-maize systems (Bangladesh, eastern India, Kenya), transmission of information and incentives for supply and demand of end use quality characteristics (e.g. demand for quality protein maize in Central America and synthesis role of markets and policies on diversity including wheat diversity in the Middle East and North Africa).

Sectoral Studies, Innovation Systems. This research undertaking could include assessment of macro- and meso-policies on the maize sector in Mexico, and synthesis of approaches and methods of innovation systems for conservation agriculture in maize and wheat farming systems

PILLAR 3 - STRENGTHENED PARTNERS INVOLVED IN RESEARCH AND SUSTAINABLE DEVELOPMENT FOR MAIZE AND WHEAT BASED CROPPING SYSTEMS, IN ALLIANCE WITH OTHER CGIAR CENTERS

In 2005, the IRRI-CIMMYT Alliance endorsed the integration of available maize and wheat information and knowledge into a suitable platform (Cereal Systems Knowledge Project – CSKP). CSKP advisory teams have been formed in each center. Content development began in 2006 from outcomes of special projects and is continuing.

Interactive diagnostic tools for identifying production problems have also been developed (*Maize* and *Wheat Doctor*). The CSKP teams of IRRI and CIMMYT reached an agreement on the format and content of extension materials for the core "knowledge bank" which, for the time being, is maintained on the IRRI server. The principles for broadening the Rice Knowledge Bank (RKB) into the Cereal Knowledge Bank (CKB) have been agreed upon and the CKB was launched in December 2007 (Fig. 6).

Fig. 6. The Cereal Knoweldge Bank portal at <u>www.knowledgebank.cimmyt.org</u>

In relation to the development of individual country knowledge banks and networks, priority was given to the digitalization and development of maize and wheat extension materials for Bangladesh (2007) and Nepal (2008). Further plans for CKB development include adopting a content management system (CMS), which will enable better content management; scaling out activities and extending the concept of country knowledge banks to Africa and South America; diversifying content formats (MP3, video, online user interaction); assisting partners with country knowledge bank management and applying content management systems; and extensive impact assessment. The demand for more intensive knowledge sharing and information management will be addressed through the design and implementation of a maize and wheat knowledge sharing platform for scientists.

The capacity building strategy of CIMMYT was approved in 2006 and has since been institutionalized and incorporated into the center's activities, through the geographical and thematic targeting of capacity building efforts, the adoption of monitoring and evaluation measures, and the development of self-paced distance learning materials. In addition to numerous other successful capacity building events, the International Plant Breeding Symposium was organized in Mexico City in 2006 and a 3-month interactive wheat improvement course was conducted in 2007. From 2008 onwards, important courses will be made available to partners through the development of video lectures (using a model adopted from Cornell University). Furthermore, an internal assessment of CIMMYT's capacity building efforts will be conducted in 2010.

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P2 – Technology-assisted Improved Tools and Methodologies for Genetic Improvement

Jonathan H. Crouch et al.

Flagship Products: Improved tools and methodologies for genetic improvement
Capacity-building in NARS and SME breeding programs

Contributing Scientists (2005-2007)

Genetic Resources Enhancement Unit (GREU): Yunbi Xu, Susanne Dreisigacker and Jonathan Crouch with Moises Cortes-Cruz, Jedidah Danson, Shibin Gao, Huixia Wu [Alessandro Pellegrineschi], [Jean-Marcel Ribaut], [Mark Sawkins], [Manilal William] and [Enrico Perotti]. **IRRI-CIMMYT Alliance Crop Research Informatics Laboratory (CRIL)**: Graham McLaren, Jose Crossa, Guy Davenport, Eduardo Hernandez, Thomas Metz, Trushar Shah, Rosemary Shrestha, Jiankang Wang and [Jens Riis]. CIMMYT collaborators include: **Global Maize Program (GMP)**: Hugo Cordova, Jose Luis Araus, Gary Atlin, Stephen Mugo, Alpha Diallo, BindiganavileVivek, Twumasi Afriyie, George Mahuku, Natalia Palacios, Kevin Pixley, [Dan Jeffers], [David Beck] and [David Bergvinson]. **Global Wheat Program (GWP)**: Karim Ammar, Hans-Joachim Braun, Etienne Duveiller, Yann Manes, Julie Nicol, Matthew Reynolds, Ravi Singh, [Janet Lewis], [Tomohiro Ban], [Richard Trethowan] and [Jacob Lage]. **Impacts, Targeting, Assessment Unit (ITAU)**: John Dixon, Erika Meng, Roberto La Rovere. (Staff departing during 2005-2007 shown in brackets […])

Introduction

Plant breeding is becoming increasingly dependent on tools and methodologies that can be used to facilitate breeding procedures to deliver breeding products more simply, quickly and cheaply. The tools and methodologies that are currently available and contributing to genetic improvement include: (1) molecular diversity analysis to help understand our germplasm at the molecular genetic level, (2) marker-trait association analysis to identify markers linked with traits of agronomic importance, (3) gene and allele discovery to exploit gene diversity for gene-based selection and genetic engineering, (4) marker-assisted selection to facilitate selection at any stage under any environment for any genes and gene combinations, (5) tissue culture and genetic transformation to help narrow the genetic distance between species, (6) computational systems to provide tools for management of all kinds of data and efficient extraction of information required for plant breeding, and (7) computer simulations and decision-support tools to minimize the size and number of progeny generations required to get the best combinations of genes and genotypes through optimized breeding procedures. P2 develops and validates new tools and methodologies in all these areas for more efficient and targeted manipulation of alleles and genes for traits prioritized by end-users in the maize and wheat improvement programs of CIMMYT, and, public and private sector NARS. In particular, this will involve applying quantitative knowledge-led phenotyping systems, analyzing environmental and genetic background effects, developing improved methodologies through retrospective analysis of current breeding data, and devising new selection systems based on holistic indices, on modeling and simulation, and on computational decision-support tools. Please see recent medium-term plans (MTP) for further details (available at http://intranet.cimmyt.org/programs/GeneticRes/Strategic%20Documents/strategic_documents.htm)

MTP 2005-2007 Outputs – Overview of Highlights

Development of biotechnology-based tools and transgenic resources Output 1

Increased knowledge of priority traits

Increased understanding of drought tolerance, pest and disease resistance, quality traits and agronomic adaptation based on in-house marker-assisted genetic dissection and/or collaborative functional profiling analysis. Many activities in this area are carried out in P3/P4 and P7/P8

- Evolution of genetic diversity in wheat breeding programs over the past 50 years
- Apomixis in model systems as related to maize and nitrogen use efficiency in wheat relatives [N.B. Our hands-on research in this area has been phased out]

Trait-specific markers

New micro-satellites (SSR) or single-nucleotide polymorphism (SNP) markers developed or validated through in-house efforts or acquired from outside sources associated with traits prioritized by end-users in national agricultural research systems (NARS), small-medium enterprises (SME), and CIMMYT breeding programs and background selection

- Consensus map of quantitative trait loci (QTL) influencing drought tolerance in maize
- Development of various wheat mapping populations for trait specific markers (*Septoria*, leaf rust, stem rust, drought)
- Candidate gene-based SNP markers for drought tolerance in maize
- Proof-of-concept for association mapping using historical data and development of diverse association mapping panels for future marker development and validation
- Development of SSR and SNP markers for four adaptive traits for development of Africa drought tolerance maize (grey leaf spot, maize steak virus, quality protein maize, and pro-vitamin A)
- Collection of a large number of maize genotypes with extreme phenotypes from worldwide sources for genetic mapping, marker development and validation via selective genotyping using 1536 SNP chips
- Collection of diverse drought tolerant maize germplasm for genetic mapping, marker development, and allele pyramiding

High throughput marker genotyping systems

High-throughput single-seed-based DNA extraction system, and high-throughput SSR, SNP, and gene-based marker detection systems

- ABC facilities and equipment updated and upgraded for DNA extraction and continuous cost reduction achieved through improved workflow efficiency
- Optimized 96-well DNA extraction system for maize and wheat

- Seed DNA-based genotyping system established, allowing marker-assisted selection (MAS) before planting to save 90% or more land and to be routinely used to replace leaf DNA for genotyping thousands of agarose gel-based SSR and millions of chip-based SNP markers
- DNA extraction facility established at Obregón, doubling wheat MAS throughput
- Acquisition of 96-capillary electrophoresis machines
- Protocol harmonization of more than 25 trait specific markers and routine application through annual screening of 20,000 data points for wheat molecular breeding

Rapid cycling technologies

Optimized large-scale doubled haploid (DH) systems for use as an integrated research and breeding tool to combine marker discovery, validation, and implementation within breeding populations

- DH service in wheat available for in-house and external contracts
- Inducer lines for maize DH obtained
- Simulation analysis of wheat DH breeding systems

Transgenics

Efficient *Agrobacterium*-mediated transformation protocols for wheat and maize integrated with large-scale MAS introgression systems for rapid transgene functional validation and effective molecular breeding product development systems.

- Contained field trials of *DREB*-wheat for evaluation of drought tolerance proved inconclusive
- Large-scale wheat transformation pipeline for disease resistance and drought tolerance with Molecular Plant Breeding Cooperative Research Center (Australia)
- *Agrobacterium*-mediated wheat and maize transformation protocols established in Mexico and Kenya, respectively
- A second generation of transgenic wheat lines using different combinations of genes and promoters being developed at Japan International Research Center for Agricultural Sciences (JIRCAS) and RIKEN labs and tested at CIMMYT
- Regeneration efficiency of tropical line CML395 improved by crossing to temperate inbred line A188 and the transformation efficiency of transformed A188XCML 395 evaluated
- Tropical maize lines (including 42 CML) evaluated for regenerability and transformability and a four good regenerable lines (CML 390, 442, 254 and 492) identified

Computational systems and molecular breeding methodologies Output 2

Informatics

Fully integrated, web-enabled data management and analysis system linking genetic resources, biotechnology, germplasm enhancement, variety development and GIS data sources for improved knowledge-led crop improvement.

- ICIS software (release of version 5.4), which includes improved breeders' applications for nursery generation, inventory control, and data management as well as new administrative tools for checking system and data integrity
- Software to synchronize the older system of IWIS, IWIS2, with the ICIS version, IWIS3 and a new version of IWIS3 released
- Genomics data management systems developed: GenoMedium prototypes available at http://www.genomedium.org and the Generation Challenge Program (GCP) Platform releases and prototypes available at http://maven.generationcp.org
- The freely available statistical analysis package, IRRISTAT, upgraded and re-packaged as CropStat version 6.1
- The CropFinder database and web interface developed as a data warehouse for ICIS DMS with a user friendly query interface, allowing users to systematically filter and search ICIS data across studies and traits
- Software developed to parse maize pedigrees from the consolidation report of Maize Fieldbook into IMIS GMS. Current and historical maize evaluation data has been added to a new release of MaizeFinder to accumulate all relevant evaluation data in a single database with 81,000 pedigrees being standardized and historical phenotypic data being curated
- The web page updated with new interactive map for Drought Tolerance Maize for Africa (DTMA) project

Precision phenotyping
More precise, higher-throughput phenotyping systems for dissecting complex traits, improving trait manipulation, and enhancing field selection. Many activities in this area are carried out in P3/P4 and P7/P8

- Physiological characterization methods for screening transgenic wheat lines with putative drought tolerance

Biometrics
New tools developed for improved the understanding and ability to manipulate genotype-by-environmental interaction effects through combining advances in informatics, genomics, phenotyping, and genetics with biometrics.

- Improved methods for genotype-by-environment analysis
- Composite interval mapping (ICIM) was developed by selection of cofactors prior to the interval mapping via stepwise regression analysis, eliminating the arbitrariness of conventional cofactor selection and improving the mapping power and precision. ICIM was also extended to mapping digenic epistasis
- New restrictive selection index method (RESIM) was developed by extending the eigen analysis selection index method (ESIM) to invalidate assumption concerning the coefficients of the index, showing improved selection response
- Adaptation of association mapping tools for use with breeding material
- An integrated methodology for clustering environments and genotypes with negligible COI was developed based on results obtained from fitting factor analysis to multi-environment trial data and supported by the results from two datasets

Molecular breeding
Efficient molecular breeding strategies and implementation systems developed and applied that effectively integrate multidisciplinary interventions for enhanced scope, cost efficiency, and impact on crop improvement gains.

- The genetics and breeding simulation tool of QuLine was extended to both inbred and hybrid breeding systems for various breeding programs, and to physiological models implemented through the linkage between QuLine and a crop growth model called APSIM
- The MAS case study aiming at combining 10 favorable genes for drought-suitable lines in wheat was simulated considering semi-dwarf plants, long coleoptiles, resistance to multiple diseases, good dough properties, and productive tillers, indicating that the enrichment of allelic frequencies in TCF_2 reduced the total number of lines screened from >3500 to <600. A genetic model containing long coleoptile and two reduced height genes (*Rht8* and *Rht-D1b*) and additional 14 QTL for coleoptile length was built
- A range of strategic reviews published in the area of development and application of molecular breeding

Capacity building and technical backstopping of implementation Output 3

Capacity Building – skills development:
NARS, SME, and CIMMYT staff trained in new technologies and methodologies, including genetic resources, biotechnology, computational systems, and germplasm enhancement.

- Diverse AMBIONET successes confirmed by external review
- Marker-assisted selection workshop
- Seed DNA-based genotyping training across ABC

Capacity Building – backstopping implementation:
Information, skills, and technological backstopping provided to assist NARS, SME, and CIMMYT breeding programs to make best use of new tools, methodologies, and genetic resources.

- Marker-assisted selection visiting scientists
- GCP and DTMA funded creation of a maize molecular breeding community of practice

Key Changes in Strategy and Structure

Refinement of P2 output structure during 2005-2007 reflects an increased commitment to the translation, validation, and facilitated application of strategic research outputs for the development of intermediate products with interdisciplinary added value with particular emphasis on more efficient and targeted manipulation of new alleles and genes for traits prioritized by end-users in maize and wheat improvement programs in CIMMYT, NARS, and SME. These have put GREU in a strong position to play a primary role in facilitating the development of a variety of biotechnology-based options for our client breeding programs in NARS, SME and CIMMYT by integrating multidisciplinary interventions into modern breeding systems.

The proposed structure for P2 in the next MTP is as follows:

- Technology-based tools for genetic enhancement [Output 1]
- Computational systems for crop improvement [Output 2]
- Backstopping implementation of technology-assisted breeding interventions [Output 3]

This embodies two minor changes: (i) shift of transgenics activities to new P1 Output 3 - Targeted development of or access to novel sources of genetic variation, and, (ii) shift of activities associated with precision phenotyping from P2 Output 2 to P2 Output 1 (although these activities may be just as well housed in P3/P4 and P7/P8).

Following the completion of the CIMMYT Business Plan, a number of attempts have been made to define the P2 portfolio to better reflect our emerging niche and priorities. For example, we have dropped: hands-on activities on maize functional genomics and maize apomixis molecular biology. Meanwhile, maize transformation activities have been centralized in Kenya and maize molecular breeding activities are being increasingly regionalized to Africa and subsequently to Asia. This process of focusing our research agenda and regionalizing our hands-on operations to be closer to target breeding programs will continue through the new MTP. Efforts to increase out-sourcing of technology-assisted implementations have not as yet been successful and this remains a significant challenge for the future (see 'Critical Issues for Discussion' section for further details).

Proposed Priority Activities for 2008-2010

Technology-based tools for genetic enhancement

<u>Increased knowledge of priority traits</u>**:** There is an increasing need to consolidate and enhance our emphasis of generating increased understanding of the underlying genetics of priority traits. This is very much in line with CIMMYT's future strategy and general efforts to improve breeding efficiencies.

<u>Precision phenotyping systems</u>: More precise higher throughput phenotyping systems for dissecting complex traits, improving trait manipulation and enhancing field selection. This is a primary bottleneck for all activities, not just genomics research, and is a primary niche growth area for CIMMYT.

<u>Trait-specific markers</u>: An immediate high priority in both maize and wheat, that needs to be increasingly delivered through 'map-as-you-go" approaches with genetic and breeding materials available from ongoing breeding programs. This is a natural extension of the successful 'proof-of-concept' of the Phenome Atlas approach.

<u>High throughput marker genotyping systems</u>: Based on acquisition of capillary genotyping technologies, this is no longer an immediate bottleneck but must be resolved for delivery within this next MTP where a logarithmic increase in throughput and decrease in unit costs should be expected.

Rapid cycling technologies: An immediate priority for wheat to resolve the in-house versus out-sourcing issue for wheat, while progress in tropical maize remains in the research domain for the immediate future.

Computational systems for crop improvement
Informatics: Following good progress in the integration of pedigree, breeding and phenotype data – now the immediate priority is to do similarly with genomics data plus breeding, international trial and GIS data.

Biometrics: Many new tools are in the pipeline – the immediate priority is now to have these refined through application in the breeding programs, and then integrated into a one-stop-shop computational tool.

Molecular breeding: Many proof-of-concept applications have been published during the last two years – now the immediate priority is to refine the tool through routine application in the breeding programs – plus to add economic models to the simulation tools.

Backstopping implementation of technology-assisted breeding interventions
Skills development and backstopping implementation: This remains a highly under-invested area that requires immediate concerted effort for fund raising. This is an increasing niche area of fundamental importance for implementing CIMMYT's future strategy and responding to the Science Council's call for devolving activities to strong NARS.

Strategic Vision for the Future: 2008-2010 and Beyond

Future gains in crop improvement will be increasingly dependent on the timely and appropriate implementation of *biotechnology-based tools and resources* are becoming a mainstay of all modern crop improvement programs. GREU has a primary role in facilitating the development of a variety of biotechnology-based options for client breeding programs in NARS, SME, and CIMMYT. The absence of *molecular breeding decision-support tools* has become the rate limiting factor for effectively integrating multidisciplinary interventions into modern breeding systems. CIMMYT has a comparative advantage in this area by virtue of the close interaction and comparative strength of its biotechnology, bioinformatics, and global maize and wheat improvement programs. *Capacity building and technical backstopping* is a fundamental priority for CIMMYT to ensure adequate uptake of outputs from Project 1 and 2, and to provide an iterative mechanism to empower end-users to orientate future efforts. Intermediate products from Project 2 ultimately enhance the crops' resilience against abiotic stresses, yield stability under biotic stresses, nutritional quality, agronomic adaptation, and profitability for resource-poor maize and wheat farming communities. Many of the activities in this Project are carried out in close collaboration with the Generation and HarvestPlus Challenge Programs.

Our future vision for P2 leads us to develop tools and methodologies more effective, efficient and applicable to genetic improvement, with a focus on whole genome level analysis and more complicate genetic systems considering more complex environmental factors, and thus better serving our breeding programs at both phenotypic and molecular levels. There are many areas of technology-assisted tools and methodologies research that are vital to future increases in breeding efficiency and impact. In addition, screening wild species or segregating early generation breeding material for complex traits is particularly fraught with problems. Thus, there must be an increasing emphasis on screening of physiological parameters associated with the trait of interest under highly controlled well designed experiments. CIMMYT has a strong niche in these research areas but still significant priority setting remains to be achieved, although in many cases this will be heavily influenced by donor interest.

More effective marker-assisted selection and molecular breeding methodologies

- Trait-specific SSR markers replaced by SNP markers and developed by association mapping in wheat
- Allele mining via genotyping or sequencing of candidate genes
- Detailed functional validation of alleles and haplotypes for qualitative and quantitative traits in diverse germplasm panels
- Continuous cost reduction through improved workflow efficiency
- Development of genic markers for all candidate genes and functional markers for MAS
- Integrated linkage mapping with genome-wide association mapping and into breeding programs
- Development and optimization of whole genome selection strategy for pyramiding minor genes and parental choice
- One-step selection for multiple traits

Fully functional tissue culture and genetic transformation system

- Re-introducing promising genes and promoters into different wheat backgrounds, involving donor cultivars Sokoll (drought and heat adapted), Berkut (drought tolerant, non re-synthesized derived), Vorobey (drought tolerant, re-synthesized derived) and Weebill (drought tolerant)
- Using drought and heat sensitive breeding line like SBS-II and drought sensitive line Finisi for validation of the function of foreign genes
- Integrated utilization of genes for drought and heat tolerance or promoters developed by JIRCAS and RIKEN and microarray system to understand which genes are up- or down-regulated after the introduction of new genes into the wheat background
- Improving transgenic wheat plant evaluation by combined pot evaluation at early stage with semi and real field condition under various appropriate drought stress profiles
- Improving transformation efficiency for disease resistance through further understanding the interaction between *Agrobacterium* cells and wheat immature embryos and by testing a collection of wheat varieties, susceptible varieties as well as resistant varieties to different types of wheat fungal, bacterium or virus diseases

Crop Informatics facilitating applications

- Developing a software MOSEL to aid MAS
- Widely use ICIS by CIMMYT scientists
- ICIS as breeding tool for NARS
- All CIMMYT breeding and research data available to query on line
- Bioinformatics and comparative cereal analysis starts to make impacts on MAS

Decision support tools meeting more requirements

- Development of the hybrid breeding simulation tool - QuHybrid
- Development of efficient QTL mapping method for various mapping populations
- Mapping QTL for drought and drought related traits in maize
- Designing efficient drought tolerance breeding strategies
- Strategic consideration of marker assisted recurrent selection (MARS)
- Extending ICIM to QTL mapping using F_2 populations
- Maintain and update of the QTL mapping software

INTEGRATING MARKER DEVELOPMENT AND APPLICATION: We expect to give substantial emphasis to establishing large-scale real-time “mapping-as-you-go” and “advanced backcross QTL” MAS development and application systems in maize and wheat breeding programs. This is the natural next step from the successful proof-of-concept of the Wheat Phenome Atlas concept, and, the successful proof-of-concept for large-scale marker-trait association and validation using collections of phenotypic extremes (selective genotyping and pooled DNA analysis) for various traits in maize. There is an urgent need to prioritize target traits, including where new traits for climate change fit into the overall rankings.

INTEGRATION OF GENOME DIVERSITY ACTIVITIES: The current challenge is to establish an intimate and iterative collaboration between molecular biologists and breeders such that the results of whole genome scanning and association genetics can be rationalized and deployed in breeding programs. These techniques have the potential to substantially improve parent selection for crossing, the rate of genetic gain and the time taken to develop new cultivars (Bresghello and Sorrells 2006). However, this will require substantial advances in facilitating computational systems although good progress has already been made (Crossa et al. 2007). In many case this will provide more robust and effective marker-trait associations than those developed through more conventional approaches. More importantly, it offers the opportunity for integrating the development and validation of new markers into breeding programs as opposed to genetic populations. This will be particularly important for MAS of complex traits such as drought tolerance and nutrient use efficiency, polygenic pest and disease resistance, and grain quality traits.

MOLECULAR BREEDING WITH TRANSGENIC LINES: Genetically modified (GM) crops, notably maize, soybean, cotton and canola, now account for about 143.7 million ha of commercial crop production across 23 countries in 2007, The estimated increase in farm income was calculated to be more than US$ 25 billion in the mid-2000s. Surprisingly this dramatic scale-up in production of transgenic crops is focused almost entirely on two traits; herbicide tolerance and *Bt*-based pest resistance, but there are now a wide range of transgenes under controlled contained field testing, including disease resistance, grain quality traits and abiotic stress tolerances. When the cultivar with the best agronomic type is not the most receptive to transformation, it is possible to transform a more receptive cultivar and then introgress the gene into the target background using diagnostic markers for the transgene. This type of MAS aided line conversion for a range of desired backgrounds is routinely practiced in the private sector for all crops where GM-cultivars have been commonplace. Thus, it is envisaged that this will also become an important tool for future maize and wheat breeding at CIMMYT. On this basis, it is then likely that intragenic GM approaches (using genes from the same species) to minimize GM-related issues and assist with the complexity of gene pyramiding will become increasingly common.

BREEDING WITH DOUBLE HAPLOID LINES: Double haploid lines have been used to improve the speed and precision of breeding many crops, particularly in the private sector. Double haploid systems allow rapid generation of homozygous lines which improves breeding efficiency by decreasing the amount of time required to develop fixed lines. Some breeding programs have completely converted to double haploid-based breeding systems. This has been most common where there is the greatest saving in time. In addition, the most technology-driven breeding programs have been the fastest to adopt double haploid breeding systems as they enable easy integration of MAS into breeding programs as well as facilitating mapping and genetic studies within breeding populations. However, double haploid breeding systems have substantial potential advantages beyond saving time and easing logistics. Double haploids allow the breeder to select among fixed lines at the maximum level of genetic variability, viz. at the first generation after crossing. In conventional breeding programs, early generation material must be selected within families of genotypes evaluated in relatively few replications and locations. Thus, at least for some traits, double haploid-based breeding systems should allow breeders to select elite genotypes that may have been missed during conventional breeding.

OPTIMIZING TECHNOLOGY-ASSISTED BREEDING SYSTEMS**:** CIMMYT is developing methodologies for assessing the contribution and cost-effectiveness of using re-synthesized lines to develop wheat cultivars for various target environments. This undertaking is part of ongoing efforts to assess impacts of intermediate products contributing to the development of new cultivars. Based on modeling of this data, it is then envisaged to generate simulations that can form the basis of breeding decision support tools that can help design the most efficient breeding system for any given target trait or cropping system. This approach will facilitate priority setting of investments in various breeding technologies or approaches. It is envisage that within 10 years wheat breeders will routinely use decision-support tools that allow optimization not only of genetic effects but also economic implications. This will bring a new level of design-led efficiency to breeding. However, this will require substantial advances in computational decision-support tools. Yet once available, these will help breeders select the best parental genotypes, optimize the breeding system and design the most appropriate selection methods. This will have a dramatic effect on the impact of MAS and in turn on the rates of adoption of MAS technologies.

Strengthening impact pathways – within and outside CIMMYT
The outputs of P2 are intermediate products such as new tools and methodologies, which have direct impacts on the scope, speed and precision of crop improvement programs. This is a primary niche area for CIMMYT researchers to improve the efficiency and impact of CIMMYT, NARS, and SME breeding programs. The extent to which the potential benefits of these intermediate products are realized relies heavily upon the extent of uptake and the skills of implementers. To ensure appropriate uptake and optimum impact, P2 researchers

will not only develop, validate, and refine tools and methodologies hand-in-hand with relevant breeding programs, but also assist implementation through intensive technical backstopping. CIMMYT will achieve this through proactive involvement in regional hubs, international shuttle breeding initiatives, and associated molecular breeding communities of practice. In this way, the Center will foster and synergize national programs' confidence to take a larger role in adaptive breeding. CIMMYT will increasingly emphasize its role as facilitator, enabler, and advocate in the overall value chain. Similarly, intimate and iterative linkages with advanced institutions are essential for proper orientation of their strategic research and early access to outputs relevant for germplasm enhancement.

Conclusions and Critical Issues for Discussion

To convert promising biotechnology-based publications into practical applications, particularly in the public sector and for crops with less commercial interest, requires the resolution of many logistical and genetical constraints that are rarely addressed in journal publications. These include challenges associated with making published markers work in different breeding materials, developing simple, quick, and cheap technical "protocols" for sampling, marker analysis, and data collection, establishing sample- and data- tracking and management systems, and designing the optimum breeding system and powerful decision-support tools to help the breeder make rapid but accurate selection decisions (Xu and Crouch 2008). All these issues substantially influence the cost effectiveness of MAS and as such its ultimate impact. The P2 targets developing and validating new tools and methodologies for more efficient and targeted manipulation of novel alleles and genes for traits prioritized by end-users in the maize and wheat improvement programs. The ultimate goal is to enhance resilience to abiotic stresses, yield stability under biotic stress, nutritional quality and the profitability for resource-poor maize and wheat farming communities, through targeted use of genetic resources. However, at the same time we must give much more emphasis to testing out-sourcing strategies for implementation of intermediate products from P2 biotechnology research (see below for further details). Finally, cost-benefit analysis and impact assessment of intermediate products from P2 remains an important gap in our activities – it is probably prudent to consider out-sourcing options for achieving rapid progress in this area – see Crouch et al. CIMMYT Science Week 2008 for further details.

Regionalizing technology-assisted breeding capacity

There has been good recent progress in this area that now needs to be translated into impacts on breeding efficiency. Fortunately the Bill & Melinda Gates Foundation is providing good levels of funding to drive this transition. In wheat recent staff changes have provided the opportunity to merge MAS application and genome diversity work which will be fundamentally important for establishing integrated genetic diversity analysis, gene mapping and MAS including effective 'map-as-you-go' approaches. Furthermore, the effective redesigning of breeding systems takes best advantage of MAS-pyramiding strategies, rapid cycling and phenotypic selection. Integrating transgenics into wheat germplasm enhancement and bring end-user focus to wide crosses is now a primary priority. In maize, strengthening maize biotechnology capacity first in Kenya then in India and China is on-going and a vital transition for increased impact through enhanced interdisciplinary integration. Building multi-sector communities of practice and recovering biotechnology networks in these regional locations is the next priority to support devolving of activities and increasing overall impact. The pros and cons of a similar regionalization strategy also need to be investigated for wheat, particularly as there are strong potential opportunities in both India and China.

Reducing the cost of molecular breeding

The large-scale use of markers in breeding is currently limited due to a lack of markers for complex traits and the absence of low cost, high throughput genotyping platforms appropriate to the needs of wheat molecular breeding. Marker detection through currently available capillary electrophoresis systems offers significant incremental advances in throughput and unit costs, but dramatic progress will have to await appropriate SNP-based systems.

NEW TECHNOLOGIES: SNP markers provide an important source of candidate gene-based markers for molecular breeding and allele mining. There are a number of potential high throughput platforms for large-scale, low cost simultaneous genotyping of less than one hundred SNP markers, which may be appropriate for the interim generation of molecular breeding applications scenarios during the next three to five years. However, it is envisaged that within the next 10 years, micro-array-based genotyping system will provide at least a 10-fold increase in throughput potential plus the all important magnitude reduction in unit costs.

OUTSOURCING: Outsourcing of high density whole genome fingerprinting of diverse germplasm has worked extremely well – SNP chip for maize and DArT analysis for wheat. In contrast, pilot out-sourcing trials for wheat MAS have not been successful, partly due to the short turn-around window currently required by the wheat breeding programs. Something that will be similar for maize and can only be resolved through innovative mutual compromise between molecular biologists and field breeders. For wheat, the acquisition of 96-capillary electrophoresis machines provides an excellent stop-gap until sufficient SNP markers are available in wheat to consider the next evolutionary phase on genotyping. Meanwhile, in maize the availability of SNP markers is not the rate limiting factor. Instead, the availability of a genotyping platform capable of simultaneously and cost effectively genotyping several hundred SNP markers in a short turn-around window appears to be a major constraining factor. The demands on a genotyping system for MAS are very different from those for fingerprinting.

Key Publications: CIMMYT

Development of biotechnology-based tools and transgenic resources

Ma, X,Q,, J.H. Tang, W.T. Teng, J.B. Yan, Y.J. Meng and S. Li . 2007. Epistatic interaction is an important genetic basis of grain yield and its components in maize. Molecular Breeding 20:41–51.

Primavesi, L., H. Wu, E. Mudd, A. Day and H.D. Jones. 2008. Visualisation of plastids in transgenic wheat expressing modified GFP fused to heterologous transit peptides from rice FtsZ and maize ferredoxin III. Transgenic Research. In Press.

Tang, J.H., W.T. Teng, J.B. Yan, X.Q. Ma, Y.J. Meng and J.S. Li. 2007. Genetic analysis of plant height using a set of recombinant inbred line populations in maize. Euphytica 155:117–124

William M., P. Langridge, R. Trethowan, S. Dreisigacker and J.H. Crouch. 2008. Genomics of wheat, the basis of our daily bread. In: Moore P. and R. Ming (eds.) Genomics of Tropical Crop Plants. Springer. pp. 511-544.

Wu H., A. Doherty, and H.D. Jones (2007) Efficient and rapid *Agrobacterium*-mediated genetic transformation of durum wheat (*Triticum turgidum L. var durum)* using helper plasmid with additional virulent genes. Transgenic Research. In press.

Xu Y. and J.H. Crouch. 2008. Genomics of tropical maize, a staple food and feed across the world. In: Moore P. and R. Ming (eds.) Genomics of Tropical Crop Plants. Springer. pp. 331-366.

Xu, Y. and J.H. Crouch 2008. Marker-assisted selection in plant breeding: from publications to practice. Crop Science. In press.

Please also see #28, #51, #89, #90, #137 and #139 in the CIMMYT 2007 Publication list.

Computational systems and molecular breeding methodologies

Bruskiewich et al. 2007. The Generation Challenge Programme (GCP) Platform: Semantic Standards and Workbench for Crop Science. International Journal for Plant Genomics. In Press.

Li, H, J.-M. Ribaut, Z. Li, and J. Wang. 2008. Inclusive composite interval mapping (ICIM) for digenic epistasis of quantitative traits in biparental populations. Theoretical and Applied Genetics. In press

Malosetti M., J-M Ribaut, M. Vargas, J. Crossa, M. Boer, and F.A. van Eeuwijk 2007. Multi-trait multi-environment QTL modeling for drought stress adaptation in maize. In: Spiertz, J.H.J., P.C. Struik and H.H. Van Laar (eds.) Scale and Complexity in Plant Systems Research, Gene-Plant-Crop Relations. Springer.

Trethowan R. and J. Crossa. 2007. Lessons learnt from forty years of international spring bread wheat trials Euphytica 157:385-390.

Please also see #10, #20, #68 and #128 in CIMMYT 2007 Publication list (Annex 2).

Key Publications: Non-CIMMYT

Breseghello, F. and M. Sorrels, 2006. Association analyses as a strategy for improvement of quantitative traits in plants. Crop Science, 46:1323-1330.

Kuchel H., R. Fox, J. Reinheimer, L. Mosionek, N. Willey, H. Bariana and S. Jefferies. 2007. The successful application of a marker-assisted wheat breeding strategy. Molecular Breeding 20:295-308.

Ishii, T. and K. Yonezawa. 2007 Optimization of the marker-based procedures for pyramiding genes from multiple donor lines: I. Schedule of crossing between the donor lines. Crop Science 47:537-546.

Christopher M., E. Mace , D. Jordan , D. Rodgers , P. McGowan, I. Delacy, P. Banks, J. Sheppard, D. Butler and D. Poulsen . 2007. Applications of pedigree-based genome mapping in wheat and barley breeding programs. Euphytica 154:307-316.

P10 – Maize and Wheat Systems

Patrick Wall, Ken Sayre, Olaf Erenstein, Mulugetta Mekuria, Paul Mapfumo, Christian Thierfelder, Bram Govaerts and John Dixon

Flagship Product: Resource-conserving technologies for maize and wheat cropping systems

Project 10 undertakes systems agronomy and resource-conserving technology research with the aim to spread the principles of conservation agriculture for the benefit of smallholder maize and wheat smallholder systems. In particular, the Project focuses on the continuing development of appropriate conservation agriculture technologies that reduce tillage, provide adequate surface retention of crop residues, and stress the importance of diversified crop rotations.

The Project works towards two principal outputs: Strategic systems knowledge of cereal-soil dynamics and management developed to exploit genotype-by-system interactions (G x S) and enhance resource and input-use efficiency for sustainable maize- and wheat-based cropping systems; and the development of coordinated innovation and learning platforms established in key farming systems to engage national agricultural research systems (NARS) technology developers and associated stakeholders (notably researchers, farmers, policy makers) and develop widely applicable technologies, identify policies to increase system productivity and sustainability, including improved efficiency of use of water, nutrients, and labor, and soil quality management.

The principles of conservation agriculture (CA) appear to have extremely wide applicability, but the particular combination of technologies and techniques to apply these principles may be very specific to climatic and soil conditions and farmer circumstances. This leads to the argument that the application of CA is site specific and therefore that project members do not produce international public goods. However, the goal of the project is not the development of locally adapted "packages" of practices, but rather of increasing awareness of the benefits and feasibility of CA, and empowering researchers and change agents to develop locally adapted systems. To achieve this it is necessary to develop, together with partners, examples of functional systems. Also particular component technologies, notably equipment, can be transferred across international boundaries, and knowledge of the conditions and circumstances under which these technological components are adapted adds to the utility of this public good.

It is unlikely that complex, multi-component technologies such as CA can be successfully scaled out through traditional linear models of research and extension, but that they require the development of innovation systems to underpin the development of locally adapted systems. Innovation systems need to be catalyzed, and this is an important facet of the *modus operandi* of P10. Again developing examples of functional innovation systems allows methodologies for their development and functioning to be evaluated and extended – another clear international public good.

Much of the science of agricultural soil physics and fertility is based on tilled systems, and the effects of applying CA practices on soil fertility and quality are certainly deficient, and often misunderstood. In order to be able to predict the effects of applying CA practices, and therefore the potential benefits from scaling out of the technology, in depth scientific studies of the effects of CA are required. Often this is beyond the physical capacity of the handful of staff in P10, but the establishment of “field laboratories” where CA systems are managed for a number of years under conditions representative of the major wheat and maize production systems allows partners from other organizations (who often do not have the capacity or capability to develop these field sites) to use them to conduct more basic research. Relatively often it is argued that CIMMYT needs disciplinary specialists in crop and soil management, but it is unlikely that we will have the funding to employ enough scientists to cover the range of disciplines necessary, or to compete with scientists in advanced research institutes (ARI) and even national programs where Ph.D. level specialist researchers are more common than generalist agronomists at the same level.

There is an ongoing debate on the level of commitment we should have to “other resource-conserving technologies” (RCT). Some argue that whatever resources are conserved, be they fuel, labor or cash, among others, the benefits implied are sufficient argument for CIMMYT to dedicate resources to researching and promoting the activity. On the other hand there is the argument that unless the resulting system exhibits clear indices of sustainability, resource-conservation alone is not sufficient argument to dedicate resources to the activity. With this background to the philosophy of Project 10 and some of the issues being discussed, the following paragraphs provide some examples of advances and highlights over the past few years.

The Indo-Gangetic Plains (IGP)
Farm household surveys in 2003-2004 confirmed significant adoption of zero-till (NT) wheat in the rice-wheat systems of the northwest IGP: 34.5% in Haryana (India) and 19% in Punjab (Pakistan) (Erenstein et al. 2007a). Experts estimate the total of no-tillage and reduced tillage (NT+RT) wheat area in the IGP to amount to some 2 million ha in 2004-2005 (www.rwc.cgiar.org).

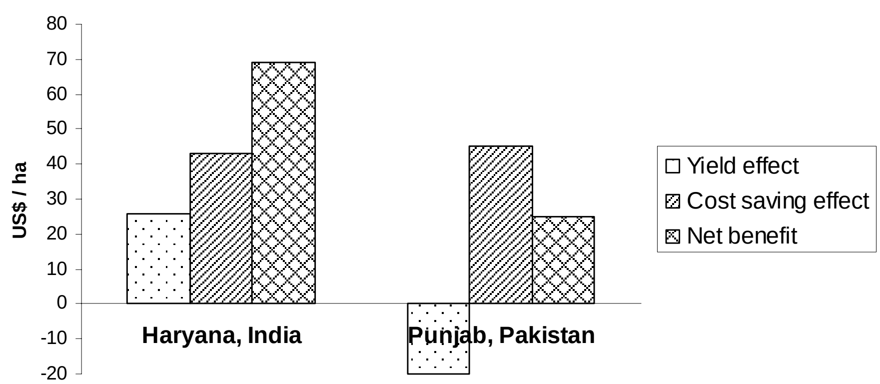

Fig. 1. Financial advantage of zero-till (NT) over conventional tillage for wheat in NT adopter farms in 2003-04 in Haryana, India and Punjab, Pakistan (farmer survey findings, adapted from Erenstein et al. 2007a)

The main driver behind the rapid spread of NT wheat is the significant, immediate and ongoing ‘cost saving effect’ that makes adoption profitable (Fig. 1, corresponding with a 15-16% saving on operational costs - Erenstein et al., 2007a). The cost saving effect primarily reflects the drastic reduction in tractor time and fuel for land preparation and wheat establishment. A significant yield effect can further boost the returns to NT (Haryana, India in Fig. 1, corresponding with a 4% yield increase - Erenstein et al. 2007a). The same survey results, however, show that the use of NT in wheat had limited spillovers for the productivity and management of the subsequent rice crop. For the rice crop in the IGP, intensive and wetland preparation followed by transplanting still predominates. Reduction of tillage in rice-wheat systems has thus been only partially successful, reflecting on the one hand the wide acceptance of NT for wheat, and on the other the remaining challenge of reducing tillage for the rice crop (Erenstein 2006).

The Rice Wheat Consortium (RWC) for the Indo-Gangetic Plains (www.rwc.cgiar.org, facilitated by CIMMYT until December 2007) played a catalytic role in promoting the public-private partnership, nurtured it through its formative stages and facilitated technology transfer from international and national sources (Seth et al. 2003). It has been estimated that the investments made by RWC and CIMMYT accelerated adoption of NT+RT by 5 years and yielded significant economic benefits (a net present value of US$ 94 million; a benefit-cost ratio of 39 and an internal rate of return of 57% - Laxmi et al. 2007).

In spite of the success of the RWC with NT practices in irrigated agriculture in the IGP, the full environmental benefits offered by CA have yet to be fully realized (Gupta and Sayre 2007, Laxmi et al. 2007). The vast majority of farmers in the IGP have adopted RCT like NT because they provide immediate, identifiable and demonstrable economic benefits such as reductions in production costs, savings in water, fuel and labor requirements and timely establishment of crops resulting in improved crop yields. But, in spite of the clear benefits and increasing adoption of RCT, most farmers, especially the small- and medium-scale farmers, have difficulties in following the basic tenets of CA, particularly residue retention and crop rotation. Most farmers do not retain crop residues on the soil surface as they use crop residues for other purposes, particularly to feed livestock (Erenstein et al. 2007b). Therefore, building on the success of NT+RT wheat, research and de still faces the challenge of adapting and developing sound, economic CA practices that farmers will adopt year round and across crops in the system.

Evidence of longer-term productivity, intensification and sustainability benefits of permanent raised beds with crop residue management are now emerging in Bangladesh. Results are available from a 4-year Wheat Research Centre (WRC)-Cornell Univ.-CIMMYT study conducted at the Wheat Research Centre, Nashipur, Dinajpur. The combination of permanent beds and straw retention produced the maximum grain yields of 11 to 21 t ha^{-1} per year compared with 7 to 15 t ha^{-1} for conventional tillage without straw retention. Straw retention was confirmed as an important component of soil restorative management, helping reduce soil moisture depletion and weed pressure and increasing N uptake.

Mexico

CIMMYT manages a series of long-term trials located in Mexico. One such rainfed trial was established in 1991 at El Batán to investigate the long-term effects of different tillage, crop residue management practices and crop rotations, based on CA tenets, as compared with the most common farmer, tillage-based practices for wheat and maize production in the surrounding rainfed region.

Results from a rainfed long-term trial at El Batán confirm the benefits of CA for farmers – including small-scale farmers – in the rainfed highlands of Mexico (Govaerts et al. 2005, 2006a, 2006b, 2007a, 2007b) – similar in climate to the high plateau of Ethiopia and parts of the Andean region. Grain yields for wheat and maize over a 10-year period (1996 to 2006) are shown in Fig. 2, which illustrates that the best CA practice (no-tillage, retention of crop residues and rotation of maize and wheat; i.e., CA) provided continuously higher and more stable yields for both wheat and maize compared to the farmer tillage/residue removal practice, even though optimum inputs and cultivars were used in all cases.

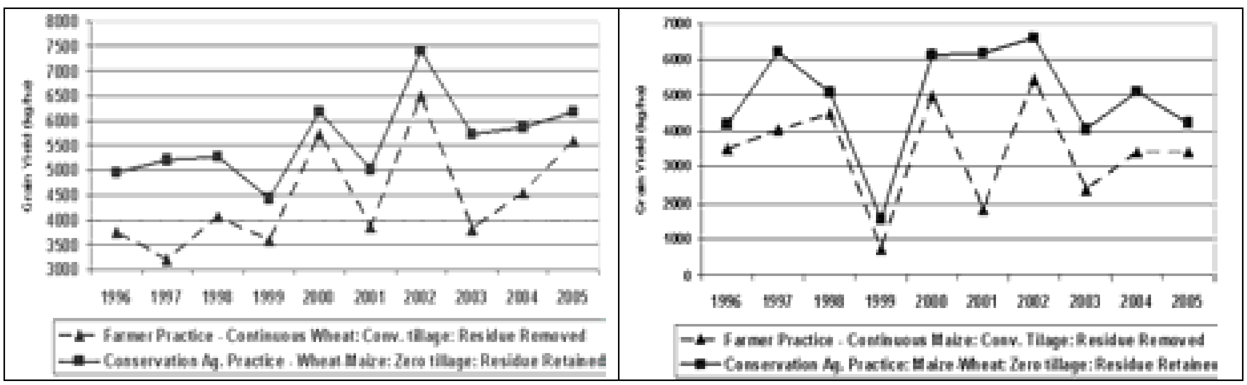

Fig. 2. Comparison of rainfed yields for wheat (left pane) and maize (right pane) for the most common farmer practice versus the best CA practice at El Batán, Mexico from 1996 to 2005 (CIMMYT conservation agriculture trials in Mexico, unpublished data)

Under the irrigated conditions in the Yaqui Valley no major wheat yield differences were observed between the various contrasting tillage/residue management practices for the first 5 years – 10 crops including the soybean or maize crops planted each summer in rotation with wheat (Fig. 3). However, wheat yield declined radically from the 1998 crop onwards on the permanent raised bed treatment where all crop residues from both summer and winter crops were burned. Wheat yields using this practice have dramatically and continually lagged below those for the other management practices studied.

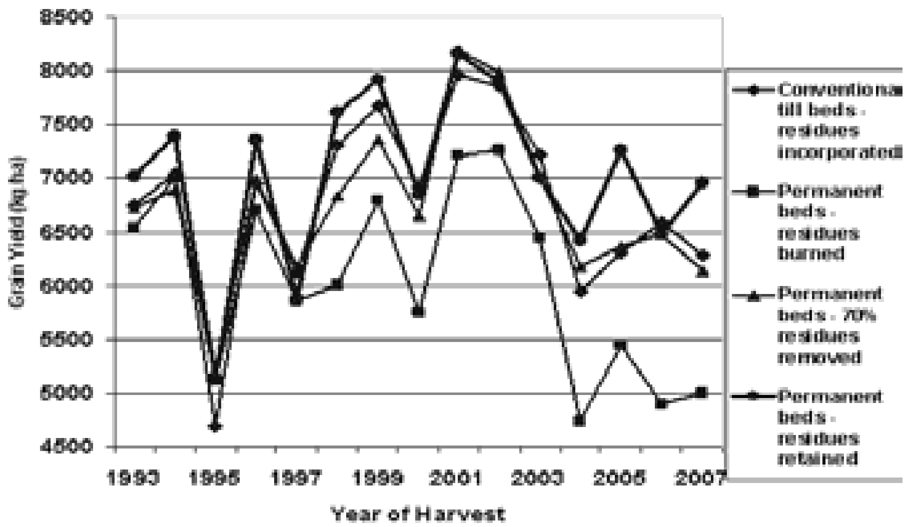

Fig. 3. Effect of tillage and residue management with optimum management on wheat grain yields over 15 years in the Yaqui Valley, Sonora, Mexico (CIMMYT conservation agriculture trials in Mexico, unpublished data)

Water savings are increasingly important in irrigated areas where water tables are commonly declining and where agriculture has to compete (often poorly) with other uses for the scarce water. The use of permanent raised beds (a CA system) has been shown to give 30% or more savings in water over a number of environments, including northwest Mexico, China and India, while at the same time giving higher and more stable yields. The combination of these factors results in large benefits in water productivity – more "crop per drop".

Southern Africa

Drawing on experiences with NT and CA elsewhere, CIMMYT began a concerted effort in 2004 to demonstrate that the principles of CA are applicable to the circumstances of smallholder farmers in Southern Africa, with a project in Malawi, Tanzania, Zambia, Zimbabwe and, more recently, Mozambique. CA systems have been developed and used on large-scale commercial farms in South Africa and Zimbabwe, but until recently there has been little emphasis on extending these practices to smallholders, and indeed many (most) believe that it is not possible, especially given the use of crop residues for animal feed. Fig, 4 shows the effects of two CA systems compared to the common tillage practice under the harsh conditions of the Zimuto Communal Area (average annual rainfall 650 mm and soils with over 90% sand throughout the profile).

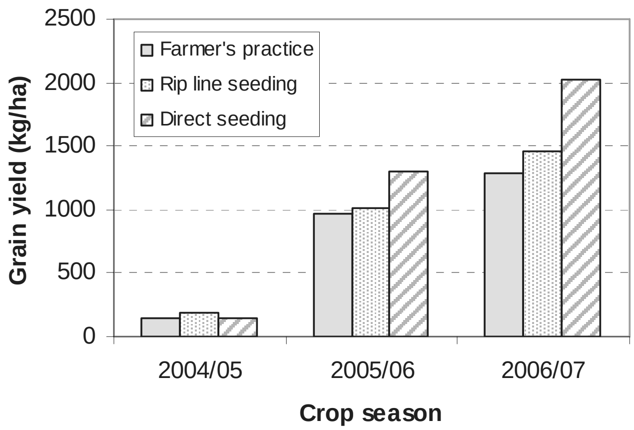

Fig. 4. Mean grain yield of maize on seven smallholder farms under conventional agriculture and two CA practices, near Masvingo, central Zimbabwe (CIMMYT conservation agriculture project in Southern Africa, unpublished data)

However, social issues also present challenges: communal stubble grazing after harvest is the norm in many rainfed smallholder mixed crop/livestock systems, including those in Eastern, Southern and Northern Africa, West Asia, Mexico, and in Central and South America. After the harvest period is over, grazing animals are free to roam and individual farmers are unable to protect residues from grazing. Community participation is thus a prerequisite: it is important that the whole community realizes the benefits of CA and acts cohesively to reverse the long-term deleterious effects of soil organic matter decline. Two very positive examples, one involving community decision and the other policy-maker definition, have shown that once the benefits of CA have been demonstrated there are options to maintain crop residues on the land.

Other areas

CIMMYT has collaborative activities on CA and related RCT in other areas, notably in China (both in rainfed and irrigated wheat areas), in Central Asia in both the cotton-wheat system and the extensive wheat systems of the steppes. The IRRI-CIMMYT Alliance Intensive Production Systems in Asia Project was launched, several projects formulated, and a major resource mobilization exercise planned for cereal systems based poverty reduction in South Asia (for further details see Doberman et al. CIMMYT Science Week 2008).

Key changes to structure and strategy

In January 2007 the current P10 was established through the expansion of conservation agriculture for maize and wheat cropping systems Project, adding a research group who were working in Southern Africa on maize systems management – thus providing a CIMMYT-wide research platform for RCT and CA research on both mandate crops. During 2005-2006 the Project leadership lay with the Directors of the Intensive Agro-Ecosystems Program (2005) and Global Wheat Program (2006). From January 2007 project leadership was assigned to the Director of Impacts, Targeting, Assessment, who during 2005-2006 was the focal point for a global conservation agriculture initiative (At the end of 2007, the Global Forum for Agricultural Research asked CIMMYT to facilitate their Global Partnership Program in the subject). Current P10 researchers include agronomists, soil scientists and agricultural economists working with maize and wheat systems, providing multidisciplinary support to the strategic science platform and the regional innovation and learning hubs. Research is planned and conducted in consultation with maize and wheat breeders.

Climate change mitigation and climate change risk adaptation will be key elements. Both reduced tillage and crop residues retention are central to CA. For many poor cereal producers, residues have value as livestock fodder and domestic fuel, but protect the soil against erosion, reduce water losses through surface runoff (on the short-term) and contribute to the build-up/restoration of soil organic matter, soil structure and soil fertility (on the medium term) if left in the field. In the near future crop residues may have additional value as a feedstock for second generation bioethanol production. Since crop residue retention impacts directly on the crop/soil water balance it reduces risk, especially in rainfed environments, but increasingly also in irrigated systems where the availability of irrigation water is declining. Balancing the short- and longer-term benefits of residue management will be a key issue.

The research will deliver international public goods which can be grouped as follows: adapted technologies for CA systems; knowledge of the effects of CA systems on soil quality, water and nutrient dynamics, returns to land and labor, and farm household incomes and livelihoods; and strengthened capacity of partners (NGOs, NARS, farmer groups, public and private sector entities, and policy-makers) in farmer-focused CA innovation systems and the scaling out and up of CA systems.

In order to address the above themes, both short and medium term investigations are required to capture the dynamics of soil-plant responses. The research is organized through inter-related components, as follows: decentralized learning hubs for different farming systems and agro-ecological zones; and a strategic research platform for dynamic, medium term scientific research.

The strategic science platform also generates knowledge which guides the design of research in the regional CA innovation and learning hubs. The strategic science platform comprises the mid-altitude rainfed trials at El Batán and the lowland irrigated trials at Obregón which provide the basic understanding and data to support modeling and the research and learning processes in the decentralized hubs (see diagram below), contrasting conventional farming and CA systems with different levels of residue management. Like crop improvement, some research on water and nutrient cycling and the effects of CA systems is necessarily medium to long term. The principal reasons for such medium-long term research are: lagged interactions between crop systems and resource degradation; as one trial in a coordinated network; construction of models to extrapolate results; and the creation of a long term research platform to support efficient short term research[ϒ] (an example would be the innovative soil carbon measurement using experimental laser and mid infrared measurement). With the growing concern and funding for climate change and other long cycle researchable issues, new long term trials have been established in many parts of the world during the past 15 years: however, few systematically investigate CA

[ϒ] GRDC/LWRRDC report "Assessment of Long-term agronomic experiments in Australia" systems, or maize-wheat rotations. The extensive research domains and geographic relevance of the strategic science platform are shown in Fig 5.

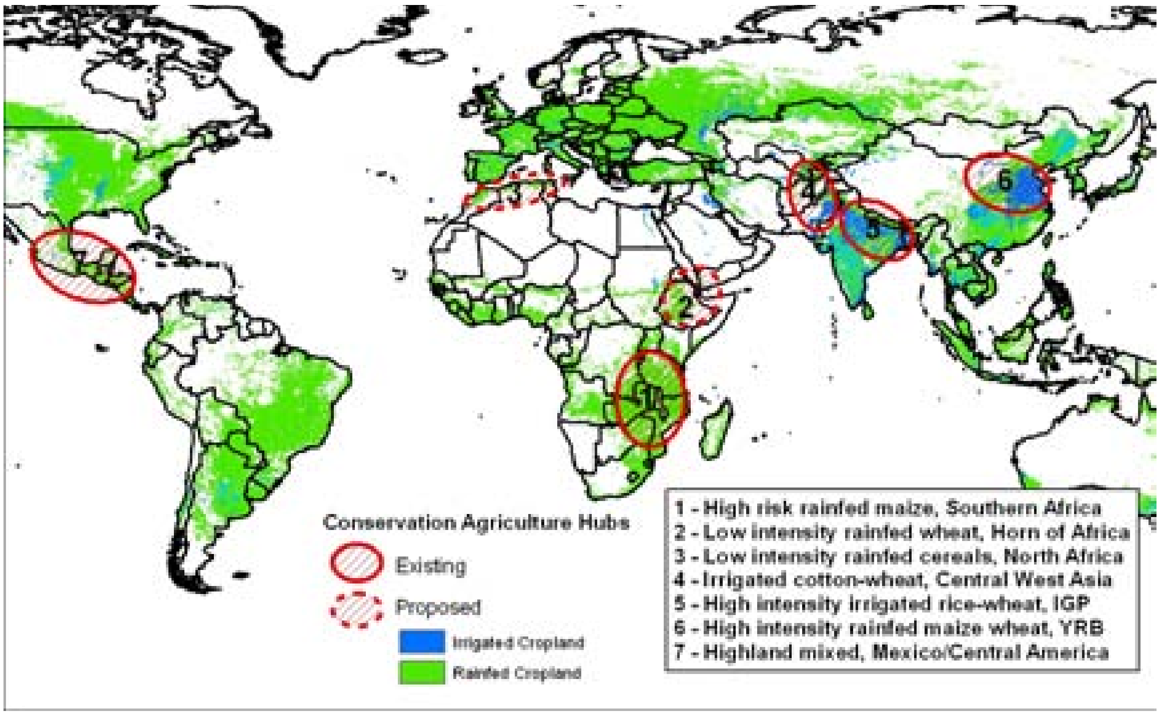

Fig. 5. Current and possible innovation and learning hubs for conservation agriculture partnership research

Each hub will comprise a mix of on-station and on-farm research operated as joint CIMMYT-NARS research on the themes listed above; and will link with the strategic science platform in Mexico to synthesize a global understanding of CA, and its application and adaptability to different environments, cropping systems and farmer circumstances. Research in the hub will also serve as a platform for "hands-on", practical in-service training of young professionals in the region on the principles and practice of CA. At the same time, technological options developed in other hubs can be verified. Some hubs are already operational in China, India, Uzbekistan and Southern Africa; others are proposed in Ethiopia/Yemen, Morocco and Mexico.

<u>The high risk rainfed maize system of Southern Africa</u> is located in a semi-arid mono-modal rainfed region facing substantial climatic variability, especially of precipitation amount and distribution. These systems are characterized by poor market access, pervasive land degradation, and mixed crop-livestock systems. They support a large proportion of poor and vulnerable households. The variability of climate and importance of producer risk places a premium on yield stabilization. Similarly, the <u>low intensity rainfed wheat system hub of the "Horn of Africa"</u> (proposed) of northern Ethiopia is characterized by a semi-arid climate, low wheat yields, prevalence of livestock and grazing of the straw, and significant levels of production risk. The <u>low intensity rainfed cereals system hub of North Africa</u> (possible) is a rainfed, wheat-based system in North Africa, with research themes on

rainfall use efficiency, residue management including crop/livestock interactions, crop rotation and diversification, labour dynamics, farmer learning, and farm household risk management.

The irrigated cotton-wheat system of Central West Asia has common problems in Uzbekistan and Pakistan. The high intensity irrigated rice-wheat system of the IGP in South Asia is a high yielding systems with intensive use of inputs and substantial food production for the market. These systems underpin global and national food security but many are suffering from over-extraction of water, competition for water with alternate users, soil degradation, loss of diversity and rapidly changing market forces. The high intensity rainfed maize-wheat system of the Yellow River Basin in China, has small farm size, relatively good market access and a fairly wide range of crop choices characterize the rice-wheat area; whereas the cotton-wheat systems generally have larger farms, more mechanization, weaker market institutions and fewer crop choices. Key research themes in this system include water use efficiency (including germplasm-tillage interactions), residue management especially the management of excess residues, development and understanding of functional and sustainable crop rotations, heat-tolerant germplasm and optimizing production systems to reduce household and system vulnerability. Finally, the highland mixed system of Meso-America (i.e., Mexico and Central America) is characterized by sub-humid conditions, poor soils, some mechanization, medium-large farm sizes, crop-livestock interaction and moderate system risk, and contribute to food security and farm income growth. The medium-intensity maize and wheat systems located in highland Mexico have similarities to the highlands of Ethiopia and also the Andean Region of South America, which share a similar climate, similar cropping systems and constraints and smallholder farming. Poverty is moderately to extensively prevalent. The major problems for successful CA systems in these regions are low fertility, degraded soils, undulating topography, erratic rainfall and competition for crop residues for animal feed.

The research in the strategic science research platform in Mexico and the decentralized hubs will systematically contrasting conventional farming and CA systems. The principal questions to be addressed focus on the C and N cycles under different germplasm and system management regimes, as well as on water balance dynamics, while also addressing climate change mitigation and adaptation issues, residue management and soil fertility regeneration under sustainable management systems. The research data will be used to build and validate models and decision support tools for global application. Given the existence of 15 years trial data on the strategic science platform in Mexico and 3 to 5 years trial data in several hubs, the following four hypotheses can be tested in each site and a synthesized across all hubs in the next three years.

Water use efficiency: CA systems improve water use efficiency and productivity of drought tolerant maize and wheat under rainfed conditions and of high yielding lines under irrigated conditions

We aim to enhance water use efficiency by improving infiltration (both rain and irrigation water) and reducing evaporation through the development of appropriate CA technologies based on dramatic tillage reductions and surface retention of adequate crop residues. This includes opportunities for the inclusion of more drought resistant varieties selected under CA and new, economically viable crops into the rotation that use water more efficiently than current crops. In irrigated systems, it includes development of more efficient water production systems. Modeling of water dynamics in rain-fed and irrigation systems, based on realistic data collected under different tillage, residue management and rotations, will be used to test the implications of different crop management (including irrigation) scenarios and up- and out-scaling of the results.

Input use efficiency: CA systems improve input use efficiency and productivity of high yielding maize and wheat

We aim to develop appropriate RCT and CA technologies that will provide opportunities to improve fertilizer (especially N) use efficiency, thereby decreasing losses via runoff, leaching or greenhouse gases (GHG) emissions (N_2O), and reduce production costs for farmers (N fertilizer being one of the major cost items for farmers in intensive systems. By implementing suitable crop rotations and appropriate levels of residue retention we aim to minimize the use of herbicides for weed control. By improving soil health through CA together with the implementation of suitable crop rotations and selection of resistant varieties under CA we aim to reduce inputs of agrochemicals for disease and pest control.

Crop residue management which balances food/feed-fodder/fuel/soil fertility trade-offs: An optimal level of residue retention can be determined for each farming system and economic environment, leading to the creation of a residue retention advisory tool

We aim to develop systems that address problems of low soil fertility, physical soil degradation as well as low overall farm profitability by adapting CA systems to the conditions of, especially resource poor, small scale, farmers who often combine crop production with livestock production. Thereby special emphasis is laid on the development of alternative management practices that take into account the fact that crop residues often have an additional economic value, e.g. as fodder or biofuel. Options being investigated are partial residue retention and inclusion of alternative, high quality fodder crops. One objective is the creation of a residue retention advisory tool (RRAT), which allows determination of the optimal level of residue retention depending on soil, farming system and economic environment. In addition, especially for the small scale farmers, we aim at the development of systems that ensure neutral or positive effects on farm income on the short-run.

Climate change mitigation and adaptation: CA systems reduce green house gas emissions from cereal farming systems

We aim to mitigate climate change through the development of CA systems, which lead to a reduction of overall GHG emissions. This will result from reduced fuel inputs, eliminating the need to burn crop residues, increased soil C sequestration (especially in rain-fed systems), and, in case of flooded rice fields, a reduction of methane and N_2O emissions by developing new rice production methods to reduce or eliminate puddling and flooding of rice fields. Regarding the adaptation to climate change, we aim to modulate soil temperature and rainfall and drought extremes by surface retention of crop residues. Moreover, we will develop and include in those systems more heat and drought resistant varieties selected under CA. Modeling of C and N dynamics in rain-fed and irrigation systems, based on realistic data collected under different tillage, residue management and rotations, will be used to test the implications of different crop management (including irrigation) scenarios and up- and out-scaling of the results.

Beyond research, the strategic science platform and regional learning hubs have great additional value as venues for capacity building of scientists and policy makers.

Strategic Plan 2008-2010

P10 research tackles four main thrusts in relation to resource conserving technologies and conservation agriculture: water use efficiency; input use efficiency; restoration of soil fertility; and climate change and climate risk. As described in the Medium Term Plan 2008-2010, CIMMYT CA research focuses on two outputs during the coming three years: the strategic science platform and the innovation and learning hubs.

Output 1. Strategic science platform

CIMMYT conducts strategic research on CA and other RCT in Mexico and in regional programs. Historically, however, the focus of the strategic research has been on research stations in Mexico, especially El Batán for rainfed trials and Obregón for irrigated trials. The focal point of these efforts has been the development and establishment of a strategic research "platform" as well as technology component trials in the main stations in Mexico. The advanced strategic research is mainly conducted through partnerships, where CIMMYT's comparative advantage is that of linking the basic and strategic research to an active cropping systems research program whose goal is improved livelihoods of smallholder farmers. ARI and universities scientists use CIMMYT trials as laboratories (e.g. carbon sequestration, trace gas emissions, WUE, NUE, among others). Examples of advanced research centers which have partnered with P10-Mexico include K.U.Leuven (Belgium), Wageningen University (Netherlands), Univ. of California-Davis (USA) and CINVESTAV (Mexico).

Output 2. Innovation and learning hubs

As mentioned earlier, CIMMYT sees the development and maintenance of a series of CA "hubs" in key agro-ecosystems as the core to its efforts on CA and the provision of international public goods. These hubs provide benchmark sites for research on the impacts of CA on crops and the environment in the prevalent cropping systems of these regions, and importantly provide the focal point for regional (agro-ecological) capacity-building and scaling out of research and innovation systems. Through the research and training, regional CA networks are established which facilitate and foment research and extension of CA innovation systems and technologies. Importantly research at the hubs also provides an example of the functionality of CA systems. Through systematic location of the hubs, synthesis of research results both within and across the hubs, e.g. on nutrient use efficiency or water use efficiency, can be achieved.

At the moment CIMMYT has CA hubs in Mexico for both irrigated wheat-based systems and irrigated and dryland, highland maize and wheat-based systems; in the Indo-Gangetic Plains for the rice-wheat system under the Rice-Wheat Consortium; in Southern Africa in the risk-prone rainfed maize systems; and dryland wheat systems in the Yellow River Basin of China. Efforts to expand the number of hubs have been constrained by funding opportunities, but CIMMYT is working to develop priority hubs in the following regions:

- West Asia and North Africa: dryland cereal/sheep systems including a transect across rainfall zones.
- South and Central Asian cotton-wheat systems.
- East African highland maize and wheat systems.

Beyond the research outputs documented in the MTP, the P10 team supports capacity building in Mexico and the regions, which disseminates knowledge acquired from the strategic science platform, creates an informal global network of CA scientists and fosters CA champions in developing countries. The Mexico team also provides support to Obregón, Toluca and El Batán station management in order to maintain soil resources for cost effective breeding efforts. Moreover, inter-Center collaboration is encouraged notably with IRRI through IPSA and with ICARDA in Central Asia.

Issues for discussion

- The complementarity of germplasm improvement and crop management is recognized. However, the magnitude and extent of G x S interactions are not well understood.
- Crop residue retention is a critical element of CA yet the value of residue in alternative uses; e.g. livestock fodder, domestic energy, is increasing. Furthermore, second generation biofuels production may increase the demand.
- CA potentially contributes to climate change mitigation; e.g. reduction of GHG, C sequestration, and climate change adaptation (i.e., yield stabilization in the face of increasing climate risk). Further discussion on the specific research priorities of climate change related research in maize and crop system management would be valuable.
- The adoption of CA is accelerated by effective innovation systems, but further research is needed on factors determining the effectiveness of innovation platforms and the speed of adoption of CA.

Finally, the debate on upstream versus downstream research and the provision of international public goods, brought into sharp relief by the advice of the CGIAR Science Council and with the endorsement of some CGIAR members versus the funding priorities of some donors or development investors, requires clarification.

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P1 –The conservation, characterization, and utilization of maize and wheat genetic resources

Jonathan H. Crouch et al.

Flagship Product: New alleles and genes from global crop biodiversity for priority trait improvement

Contributing Scientists (2005-2007)

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Introduction

Crop-related biodiversity is the founding asset of the CGIAR and continues to be the basic raw material for the breeding programs of CIMMYT and its partners. The emerging strategy of the CGIAR in the new millennium builds on this foundation, with emphasis on technology-assisted methodologies and intermediate products created from the efficient identification of value-added traits and their rapid introgression into agronomically elite widely adapted breeding material. Structured and well-characterized germplasm subsets (of diverse germplasm, advanced breeding lines or cultivars), trait-specific genetic stocks (near-isogenic, introgression and substitution lines), double haploid lines, synthetic polyploidy genotypes, genetic mapping populations and enhanced gene pools are becoming increasingly critical assets for the global plant research and breeding community. Targeted development, intensive characterization, and extensive evaluation under diverse field conditions of this germplasm is increasingly seen as the rate-limiting factor for translation of outputs from the genomics and information technology revolutions into tangible products for developing country farmers. Much of the above depends in turn upon effective data management. Thus, one of the major new strategic focuses in Project 1 is the creation of a fully-integrated, web-based support system for CIMMYT and partners involved in the conservation, utilization, evaluation, and enhancement of genetic resources, whereby all types of data can be integrated, compared, and collectively analyzed and queried by anyone anywhere. A fundamental task of P1 is also to search for genetic diversity that is not readily accessible through conventional screening approaches, using novel tools and methodologies to identify crop-related genetic diversity beneficial for improvement of specific priority traits. Please see recent rolling medium term-plans (MTP) for further details (available at http://intranet.cimmyt.org/programs/GeneticRes/Strategic%20Documents/strategic_documents.htm)

MTP 2005-2007 Outputs – Overview of Highlights

Output 1. Genetic resources conservation, characterization, distribution and informatics

Conservation and characterization of genetic resources
Germplasm accessions from global sources (including related wild species, genetic stocks and improved breeding lines) available from the genebank

- Confirmation of wheat collection integrity, new collections of maize landraces and putative wild relatives
- Molecular characterization of Generation Challenge Program (GCP) maize and wheat global composite collections
- Maize and wheat global genetic resources strategic plans

Informatics systems for global biodiversity
Fully integrated, public accessible, multidisciplinary germplasm information resources with powerful query and analysis tools

- Agreement to shift to ICIS-based informatics systems through founding agreement of CRIL
- CRISCO and CRIL maize and wheat data curation activities
- Development of ICIS modules to accommodate DNA marker data
- Implementation of genebank management system initiated

Distribution of improved germplasm
Globally recognized and accredited guidelines for the maintenance, regeneration, purification, distribution and documentation of germplasm regarding pests, pathogens and transgenes

- Reduction in operational cost
- International Treaty of Plant Genetic Resources for Food and Agriculture's standard material transfer agreement (SMTA) implementation for germplasm distribution, and ISO accreditation of Seed Health Lab (SHL)

Output 2. Targeted access to useful genetic variation

Sequence-based allele mining
New allele mining methodologies (and outputs thereof) to create and use gene-based PCR markers to identify beneficial genetic variation for well studied target traits in maize and wheat improvement

- Successful 'proof-of-concept' for allele mining in maize for beta carotene trait
- Allele-specific SNP marker development from candidate genes for marker-assisted selection (MAS)

Dynamic germplasm subsets
Improved interdisciplinary methodologies (and resultant web-enabled resources) for the development of end-user defined maize and wheat germplasm subsets, maximizing genetic variation for priority traits

- Maize core collection of landraces defined
- New models for improved germplasm sampling methods
- GCP-funded maize and wheat drought tolerant focused germplasm subsets now available for distribution
- Preliminary germplasm subset selector software developed

Association mapping-based gene discovery:
New added-value alleles and genes identified from germplasm subsets through marker-trait association analysis of precision multilocation phenotyping and genome-wide genotyping data

- Preliminary association mapping of drought tolerance
- Association mapping of carotenoids
- Successful proof-of-concept of Phenome Atlas using historical wheat international nurseries

Output 3. Trait-based germplasm enhancement

Wheat germplasm enhancement
Beneficial genetic variation introgressed into elite wheat breeding lines focusing on client breeding program priorities in abiotic and biotic resistance, quality, and agronomic adaptation traits

- Reached landmark 50% of rainfed wheat program based on synthetic-derivatives
- Screening of genebank material for resistance to Ug99 and germplasm enhancement thereof

Maize germplasm enhancement
Trait-based enhancement of maize genetic resources for end-user priorities in abiotic and biotic resistance, quality and agronomic adaptation traits, within geographically assigned heterotic patterns

- Landrace introgressions into tropical gene pools from which breeding lines extracted
- Development of highland sub-tropical gene pool
- Synthesis of 25 years of work on gene pools and uptake by breeding programs

Capacity building and backstopping implementation
Information, skills development and assistance provided to NARS, SME, and CIMMYT breeders to enable their best use of maize and wheat-related biodiversity

- Many genetic characterization training workshops and visiting scientists
- Maize genetic resources NARS cooperator workshop
- Several ICIS training workshops

MTP 2005-2007 Outputs – Selected Highlights in Detail

***New collections of maize genetic resources* [Output 1].** During 2006 and 2007 CIMMYT together with INIFAP, the State University of Hidalgo, and Cornell University focused on the preservation of populations of teosinte, a wild relative of maize. Monitoring of the 12 *Tripsacum* spp. has been carried out in several states across Mexico as has been previously carried out in Guatemala. A collecting mission in Mexico, led by INIFAP, has found a new teosinte population (perhaps *Zea luxurians*) that seems to have been grown since the 1930s in river beds under very wet conditions. Further research will be conducted to see whether the teosinte carries a flood adaptation trait that could be useful in the rice-maize cropping systems in Asia or in other regions of the world. In addition, CIMMYT and partners from ICTA-Guatemala and Cornell University, USA, undertook an in-situ monitoring mission for *Tripsacum* in Guatemala. The team found *T. lanceolatum, T. pilosum, T. jalapense or T. dactyloides* ssp. *hispidum, T. latifolium* or *T. maizar intermediate*, and *T. laxum*. DNA samples as well as herbarium samples will be used for further taxonomic research. Due to the threat of extinction of these species, future work will aim at rescuing the plants and transplanting them to ICTA field stations. Seed samples will later be harvested for preservation in genebanks.

***Allele mining proof-of-concept* [Output 2].** Combined analysis of the two genes in the pro-vitamin A synthesis pathway, indicated that 43% and 56% of the phenotypic variation for β -carotene content and the ratio of β-carotene over total carotenoids respectively are accounted for. The frequencies of the beneficial alleles of the two genes are very different in temperate and tropical lines, indicating that major advances in β -carotene improvement are likely if these two germplasm sources are combined. To facilitate this task, we have created PCR-based markers and present the allelic composition of global maize germplasm that should be very useful for producing high level pro-vitamin A maize in the future, especially in developing countries. See Warburton et al. CIMMYT Science Week 2008 for further details.

***Extensive use of re-synthesized wheat in breeding programs* [Output 3].** Tetraploid (durum) wheat and hexaploid (bread) wheat can be re-synthesized from their progenitor species. This allows artificial crosses to capture the full taxonomic diversity rather than the few rare chance events that occurred during evolutionary time. Creating re-synthesized wheat lines is much easier than conventional interspecific hybridization and the resultant germplasm is much more readily used in mainstream breeding programs, although still requires several backcrosses to remove undesirable agronomic traits such as glume tenacity, shattering, seed dormancy, tall stature and late maturity. The use of re-synthesized wheat lines in CIMMYT's rainfed wheat breeding undertaking has facilitated a dramatic increase in drought tolerance. It is expected that this type of material will have similar impacts on other abiotic stress tolerances as well as pest and disease resistances during the next decade. In China a new cultivar has already been released based on disease resistance acquired from a CIMMYT re-synthesized wheat line. In addition, field tests have confirmed that re-synthesized lines may be good sources for improvement of photosynthetic rate, salt tolerance, elevated grain micronutrient content, resistance to Karnal bunt, *Helminthosporium* leaf blight and kernel high weight. Thus, a large proportion of crosses in CIMMYT's wheat breeding projects now include a re-synthesized wheat line or derivative thereof. Molecular genetic diversity analysis of current and past CIMMYT breeding lines has shown a dramatic increase in general diversity associated with the increased use of re-synthesized wheat derivative parental lines.

Key Changes in Strategy and Structure

Refinements in the name and output structure of Project 1 during 2005-2007 reflect an increased commitment to developing and applying new tools and methodologies for accessing beneficial genetic variation for germplasm enhancement in a trait-targeted way. For historical reasons, germplasm enhancement activities are somewhat arbitrarily split between P1 and P3/P4 or P7/P8. Thus, in order to maximize synergy between disciplines, the Management Committee (MC) decided in its October 2007 review, to consolidate all activities in the area of 'germplasm enhancement' within each respective commodity project. In this context, 'germplasm enhancement' covers all activities that might otherwise be referred to as genetic resources enhancement, pre-breeding or germplasm enhancement etc. These reassignments will be articulated in the next MTP. P1 will then focus on the identification or creation plus characterization and evaluation of beneficial genetic variation. However, to ensure appropriate targeting and feedback associated with the identification and flow of new sources of genetic variation from P1 to P3/P4 and P7/P8 we are in the process of recruiting geneticist/genetic resources enhancer positions for each commodity who will split their time equally between P1 and P3/P4 or P7/P8. This is analogous to the maize and wheat molecular breeder positions housed in the GREU that facilitate parallel interactions between P2 and P3/P4 or P7/P8.

The proposed structure for P1 in the next MTP is as follows:

- Genetic resources conservation, characterization, informatics and distribution [Output 1]
- Targeted access to useful genetic variation from maize and wheat global biodiversity [Output 2]
- Targeted development of or access to novel sources of useful genetic variation [Output 3]

This embodies two major changes: (i) shift of transgenics activities to a new P1 Output 3 – Targeted development of or access to novel sources of useful genetic variation, where there will also be a major focus on integration into on-going germplasm enhancement program strategies, and, increased emphasis on legal negotiations for access to proprietary genes, and, as discussed above, (ii) Trait-based germplasm enhancement will be shifted to P3/P4 or P7/P8, this will also result in the need to drop 'utilization' from the title of P1.

Following the completion of the CIMMYT Business Plan 2005-2010, a number of attempts have been made to refine the P1 portfolio to better reflect our emerging niche and priorities. For example, we are phasing out hands-on activities in gene isolation (including for apomixis) and generic evaluation of genetic resources (in favor of trait-targeted activities). Similarly, we have been pursuing opportunities for outsourcing such that now a large proportion of data generation for genome diversity analysis is out-sourced through Cornell University (USA) for maize and through DArT (Australia) for wheat. This has allowed us to invest more human resources in the development of appropriate computational systems and the application of analytical approaches necessary for rapid developments in this research area. This process of focusing our research agenda and consolidating our hands-on operations through increased out-sourcing will continue through the new MTP.

Proposed Priority Activities for 2008-2010

Genetic resources conservation, characterization, informatics and distribution

New collections. Continuing collecting of new maize germplasm (landraces, teosinte, Tripsacum) in Mexico needs to be expanded in the first instance to the rest of Latin America and then subsequently to Africa and Asia as funds become available. However, activities in this are need to become increasingly trait-driven. Completion of the global wheat genetic resource registry (a catalogue of wheat plant genetic resources across major global collections), allowing gap and redundancy identification, and rationalized global wheat genetic resource conservation.

Informatics. Based on the successful ‘proof-of-concept’ for association mapping using Wheat International Nurseries Network data, we now expect to rapidly scale-up activities in this area and achieve ‘proof-of-concept’ application in on-going breeding programs (whereupon this becomes a P2 activity).

Distribution. Duplication of collections in the Global Seed Vault at Svalbard (Norway). Implement rationalized system for cost recovery. Explore options for automation of seed packeting within Mexico.

Targeted access to useful genetic variation from maize and wheat global biodiversity
Allele mining. Based on the successful ‘proof-of-concept’ allele mining with the beta carotene trait, we now expect to attempt the same for more complex traits based on trait priorities to be established with GMP: good candidates from the genomics knowledge perspective would be other nutritional traits such as iron and zinc, forage digestibility and bioethanol traits, plus metabolite and physiological component traits of drought tolerance.

Association mapping. Based on good success with establishing the SNP platform at Cornell University for GCP and Drought Tolerant Maize for Africa (DTMA) germplasm fingerprinting activities, we now expect to carry out 1536 SNP analysis of the GCP maize mini-composite – including where possible doubled-haploids of landraces. At the same time we need to develop a protocol for SNP analysis of heterogeneous/heterozygous samples. Based on our success with DArT fingerprinting of diverse germplasm, we now expect to carry out DArT analysis of the GCP wheat mini-composite. In both cases, this will require new funds for extensive multi-location evaluation. In maize, this association mapping approach can feed into sequencing of newly identified genes and subsequent allele mining in the global collection.

Dynamic germplasm subsets. Defining the wheat core collection for overall understanding of the entire collection. Ability for individual users, anywhere in the world, to define their own germplasm subsets using all available data and their own criteria. In addition to growing a range of pre-defined subsets based around high priority primary selection criteria such as drought tolerance, rust and *Fusarium* resistance, productivity under resource conservation technology cropping systems. The dynamic core selector would run in real time to take advantage of routine additions to the dataset.

Targeted development of or access to novel sources of useful genetic variation

Development of new transgenics. Development of GM-wheat lines with putative drought tolerance and disease resistance continues as a major activity through our involvement in the Molecular Plant Breeding-Cooperative Research Center. In addition, we will test second generation DREB and other regulatory genes through a Japan Min. Agriculture, Forestry and Fisheries-funded project with Japan International Research Center for Agricultural Sciences (JIRCAS) and RIKEN. Finally, we continue to investigate the opportunities for GM-quality protein maize through a Rockefeller Foundation-funded project.

Access to proven proprietary transgenics. A range of negotiations will be initiated to gain access to proprietary transgenic products, with a particular focus on drought tolerance and pest resistance. In many cases this will require the formation of novel public-private sector partnerships, particularly to deal with product development and deployment.

Strategic Vision for the Future: 2008-2010 and Beyond

Structured sets of germplasm are becoming an increasingly critical asset for the global plant research and breeding community. Characterization and distribution of this germplasm is a major niche for CIMMYT, as is the coordination of associated web-enabled informatics resources. *New technology-assisted methodologies* are facilitating targeted access to new beneficial alleles, genes and traits. However, intensive characterization and precise evaluation (under diverse field conditions) is now the rate-limiting factor for effective utilization of outputs from the genomics and information technology revolutions. CIMMYT has a major role to play in this area and in subsequent interdisciplinary integration of resultant outputs. *Germplasm enhancement* provides the mechanism for incorporating new added-value traits (such as pest and disease resistance), meta-traits (such as drought tolerance), and pyramided traits (such as resistance to root health complexes and multiple sources of resistance to the same disease) into acceptable genetic backgrounds that can be readily adopted by the pre-breeding programs.

The above listed on-going activities broadly cover the spectrum of our incremental strategic plan. However, these will need careful scrutiny at critical milestone timelines to confirm justification for continuation. Conversely, several newly emerging opportunities and potential speculative areas of research will need to be evaluated including:

The role of wild species in adapting cropping systems to climate change**.** A third of the world's nitrogen fertilizer is applied to wheat crops whose efficiency of use is only about 33%. The resulting nitrification of soils causes annual losses in the order of US$ 6 billion in over-use of fertilizers, as well as untold costs in environmental pollution. Artificial and biological control of nitrification can improve nitrogen recovery and nitrogen-use efficiency (NUE), and synthetic nitrification inhibitors have been used in wheat to boost NUE and reduce environmental load. However, the potential to improve the release of biological nitrification inhibitors (BNI) in wheat root exudates or to apply such a trait is unknown. Partnership research with JIRCAS shows that *Leymus racemosus,* a distant relative of wheat, has a high capacity for producing effective BNI, and this trait has been introduced to cultivated wheat via inter-specific crosses. Preliminary results are encouraging: using recombinant luminescent *Nitrosomonas europaea* to quantify BNI released in plant-soil systems, the research team has found that *L. racemosus* releases about 20 times more BNI than wheat in an NH_4^+ enriched environment. By introducing the high-BNI release capacity of *L. racemosus* into cultivated wheat, breeders could develop cultivars whose genetic capacity to inhibit nitrification would allow more sustainable, ecologically-friendly farming in intensive cereal cropping systems, with significant economic and ecological benefits, including reduced emission of nitrous oxide which is a highly potent greenhouse gas.

The importance of new traits for encouraging private sector investment in the development and deployment of products for our target beneficiaries. There is no doubt that the private sector offers a highly effective route for delivering improved germplasm to developing country farmers. However, in many cases our target beneficiaries represent niche markets that are currently difficult for seed companies to justify focusing on. It is, therefore, important for CIMMYT to prioritize activities on traits that will encourage the private sector to see these target markets more favorably. Previous efforts on some of these traits have not been successful in the past. However, the justification for solutions in these areas remains strong. Thus, we must assess the reasons for past failures, evaluate the probability of success of recent advances and investigate alternatives.

[1] <u>Drought and heat tolerance</u>: Rapid advances are being made in transgenic technologies for heat and drought tolerance, particularly in the private sector, suggesting that this approach can be successful in both maize and wheat. The combination of drought and heat stress occurs in large areas of production and has a substantial impact on yield. Thus, substantial developments in this area will have significant impact on improving productivity in semi-arid and rainfed production systems across the developing world.

[2] <u>Hybrid wheat technologies</u>: Half a century of research on hybrid wheat has yet to provide a compelling case for hybrid wheat, partly due to the relatively low yield advantage observed with hybrid varieties. Nevertheless, an effective hybrid technology is likely to stimulate private sector investment in wheat due to the biological protection that this technology provides in the market place. Hybrid wheat has been commercialized in a small number of countries (France, Australia, USA, South Africa, China and India). Meanwhile, there is considerable on-going research in model systems that could lead to GM-cytoplasmic male sterility-based systems.

[3] <u>Development of novel quality traits in maize and wheat</u>: Surveys suggest that consumers are more likely to accept GM-maize and -wheat if the improved traits significantly enhanced product quality, e.g., increased nutrient concentration, pharmaceutical and health benefits. It would be important to engage the food industry in supporting GM-maize and -wheat as the social acceptance issues have caused the

processing industry to adopt a highly conservative approach on this issue. However, it is highly probable that major emerging economies in need of high national yields to offset increasingly expensive imports will commercialize GM-maize and -wheat for food production

Strengthening impact pathways – within and outside CIMMYT

The intermediate products from P1 are likely to have an impact on the productivity, stability, and resilience of new, experimental maize and wheat cultivars. Resultant impacts of new cultivars on livelihoods are envisaged and, in most cases, direct impacts will first reach the CIMMYT breeding programs through P3/P4 and P7/P8, then through national agricultural research systems (NARS) intimately involved with CIMMYT through globally decentralized shuttle breeding initiatives, and then to other NARS and small-medium enterprises (SME) breeding programs in target countries.

The outputs of P1 are intermediate products such as tools, methodologies, and genetic resources associated with more targeted, efficient, and rapid access to and use of the most desirable genetic variation for maize and wheat breeding programs. The primary users of these intermediate products (who will also participate in their further development), includes breeders and other researchers from CIMMYT, NARS, SME, and andvanced research institutes (ARI). Facilitating a better collation of genetic variation across national and international genebanks is a critical role for CIMMYT. Similarly, intimate and iterative linkages with advanced institutions are essential for proper orientation of their strategic research and early access to resultant outputs relevant to germplasm enhancement for stakeholders. Thus, P1 has a major role to play in coordinating information networks to help ARI, NARS, and SME focus on the most important needs of resource-poor clients. Many of the activities in this Project are carried out in close collaboration with the CGIAR System-wide Genetic Resources Program (SGRP) as well as the Generation and HarvestPlus Challenge Programs.

Genetic resources information sharing and databases are helpful in facilitating the efficient access of ARI, NARS, and SME to useful germplasm. CIMMYT has a comparative advantage in facilitating this, coordinating networks to share knowledge and skills focused around the generation of enhanced germplasm products. P1 has a role in creating and then maintaining new networks, since many existing networks established in national chains exist for different purposes. Achieving regular constructive feedback from primary end-users is fundamentally important. Conversely, information from the farmers and ultimate beneficiaries is generally indirect, and interpreted by the other projects. However, the connection between P1 and the other projects is important to strengthen these networks and make sure the right questions are being asked about end-users' needs. Particularly in terms of the priority traits, issue include the nature of the most desirable genetic backgrounds for introgression of those traits and the range of tools required for effective utilization of the traits in mainstream breeding programs. It seems clear that we still have a long way to go in terms of creating a truly effective system in this area.

Conclusions and Critical Issues for Discussion

Since the formulation of the Business Plan, P1 research area has been sequentially focused and re-orientated towards more targeted identification of beneficial genetic variation. Meanwhile, the MC has agreed to firewall the necessary unrestricted funds to support our basic germplasm conservation responsibilities. On this basis we wish to now focus down our germplasm enhancement activities in a trait-based end-user driven manner. We are proposing to consolidate germplasm enhancement activities in the commodity program-led projects in order to maximize synergy and minimize overlap in this process. In addition, we believe there should be a renewed focus on strategic traits that will enhance investment by the private sector in our commodities that will serve our target stakeholders/end-users. Finally, cost-benefit analysis and impact assessment of intermediate products from P1 remains an important gap in our activities – it is probably prudent to consider out-sourcing options for achieving rapid progress in this area – see Crouch et al. CIMMYT Science Week 2008 for further details.

The Science Council and others are often encouraging the CGIAR to devolve more activities to our NARS partners. To effectively achieve this, at least during the transition phase, we need to take a more proactive role in coordinating the overall value chains in which we operate in order to ensure impact of our increasingly upstream outputs. To move ahead in this area we must initiate some proof-of-concept devolution initiatives. In many cases, the first essential step in this process will be to form strong effective collaborator networks in genetic resources conservation and evaluation, germplasm enhancement and molecular breeding. For example, the implementation of the recently concluded global maize and wheat *in situ* conservation strategies will contribute to the sharing and devolution of responsibilities in the area of genetic resources. Shifts in this direction should also force a more rapid interdisciplinary multi-sector regionalization of CIMMYT's operational structure across programs, units, disciplines and projects – perhaps most immediately in the area of biotechnology. This will clearly require a substantial increase in the range and depth of collaborations with public and private sector NARS on priority setting, skills development, backstopping implementation and fostering delivery of resultant products. We propose the creation of communities of practice based on mutually dependent activities to achieve this. Clearly, this process will be highly reliant on an enhanced integration between GREU, ITAU, GMP and GWP.

Key Publications: CIMMYT

Genetic resources conservation, characterization, distribution and informatics

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Ortiz, R., R. Sevilla, G. Alvarado and J. Crossa. 2008. Numerical classification of related Peruvian highland maize races using internal ear traits. Genetic Resources and Crop Evolution. DOI 10.1007/s10722-008-9312-3

Ortiz R., R. Sevilla and J. Crossa. 2008. Minimum resources for phenotyping morphological traits of maize (*Zea mays* L.) genetic resources. Plant Genetic Resources Characterization and Utilization. In press.

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Please also see the #20 and #79 in the CIMMYT 2007 Publication list (Annex 2)

Targeted access to useful genetic variation

Harjes C.E, T.R. Rocheford, L. Bai, T.P. Brutnell, C.B. Kandianis, S.G. Sowinski, A.E. Stapleton, R. Vallabhaneni, M. Williams, E.T. Wurtzel, J. Yan and E. S. Buckler. Natural genetic variation in lycopene epsilon cyclase can enhance provitamin a biofortification of maize. Science 319:330-333.
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Trait-based germplasm enhancement

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Dreisigacker S., M. Kishii, J. Lage, and M. Warburton. Use of synthetic hexaploid wheat to increase diversity for CIMMYT bread wheat improvement. 2008. Australian Journal of Agricultural Research. In press.

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Ortiz, R. and M. Smale. 2007. Transgenic crops: pro-poor or pro-rich? Chronica Horticulturae 47 (4):9-12.

Targeted access to useful genetic variation

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Trait-based germplasm enhancement

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P3 – Stress Tolerant Maize

S. Mugo, M. Bänziger, J. Araus, G. Atlin, A. Diallo, F. Kanampiu A. Langyintuo, J. MacRobert, C. Magorokosho, G. Mahuku, D. Makumbi, L. Narro, G. Ortiz-Ferrera and P. Zaidi

Flagship Product: Stress-tolerant maize

Introduction

Most resource-poor farmers in low-income countries grow maize under highly variable, stress-prone conditions. Key abiotic stresses include drought, low soil N, acid soils, water-logging and heat. Biotic stresses include fungal, bacterial and viral diseases and insect pests which may cause pre- and post-harvest damage, as well as the parasitic weed, *Striga*. P3 researches, develops and disseminates elite maize germplasm with tolerance or resistance to the most intractable and important stress factors. It also researches and employs partnerships to effectively deliver stress tolerant varieties to target farmers. Most of P3's investment is on drought with significant though changing (mostly special project investment driven) emphasis on acidic and water-logged soils, pre- and postharvest insect pests, *Striga*, and mycotoxins.

MTP OUTPUTS: PROGRESS, HIGHLIGHTS AND CRITICAL ISSUES

1. Drought tolerant maize to enhance food and income security, reduce use of scarce irrigation water and adjust to climate change

Summary of progress toward achieving the MTP promised outputs

The destabilizing impacts of drought, climate change and increasing scarcity of irrigation water make drought and water use efficiency to P3 research topic number one. Farmers are affected by lack or variable rainfall in rainfed systems, and shortage or cost of irrigation water in intensive systems.

Breeding for drought tolerance was initiated in CIMMYT in the 1980s, resulted in distinct drought breeding protocols in the mid 1990s (Bänziger et al. 2000) and is being globally applied and researched at molecular level since the mid/late 1990s. Exposing natural genetic variation to selection under carefully managed drought conditions has resulted in breeding gains of more than 100 kg ha^{-1} more grain under drought with every year of investment. They are currently larger but likely complementary to transgenic sources of drought tolerance (Bänziger and Araus 2007).

Significant research investment has been directed at secondary traits, molecular markers, statistical design and analysis, use of genetic resources, and genotype-by-environment analysis. Research efforts are enhanced for greater coverage by working with national agricultural research system (NARS) partners during variety development, and backstopping NARS and local seed companies in variety testing, variety release, and in seed production. Through this process, the number of hybrids and open pollinated cultivars

(OPV) tested in regional and local trials annually has expanded to more than 3,000 entries, most prominently in Eastern and Southern Africa, and to a smaller extent in Asia, and significant quantities of seed have reached farmers' fields.

Drought research has received support by SDC, RF, BMZ, IFAD, GCP and ADB. With the addition of Drought Tolerant Maize in Africa (DTMA) and several other "in-design" projects, new tools, protocols and platforms are being explored and accessed to increase the efficiency of developing drought tolerant elite maize germplasm, in particular phenotypic and molecular markers and covariates, high-throughput systems for capturing and processing molecular and phenotypic data (SNP platform, mechanization, automated data collection), more uniform field screening sites, improved use of germplasm information and accelerated breeding cycles (double haploids, MAS recurrent selection schemes). Important upstream research partners include: Cornell University, the Generation Challenge Program (GCP), the International Institute of Tropical Agriculture (IITA), the International Rice Research Institute (IRRI), the University of Hohenheim, and multi-national seed companies.

New screening techniques for plant drought adaptation include: reduced leaf senescence using spectro-radiometry, photosynthetic efficiency through chlorophyll fluorescence, and transpiration efficiency or water status using infrared thermometry, porometry, mineral content, and stable ^{18}O content. Initial tests conducted indicated that combination of at least two traits explains a substantial part of genotypic variability in grain yield, and that traits chosen change with growing conditions but some positive trends were evident.

P3 aims at an annual provision of more than 10 elite drought germplasm for use by breeders in NARS and private seed companies, leading to a continued increase of drought tolerance in maize varieties made available to farmers and reduced maize yield losses. Most recently, 20 OPV and hybrids were released by NARS in Eastern and Southern Africa, and 15 hybrids taken up by seed companies in 2007 alone. A further diversification of hybrids and OPV adapted to various agro-ecologies is achieved by backstopping NARS maize breeding projects in Angola, Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe (Africa) and China (Yunnan), Indonesia, the Philippines, Thailand, Vietnam (Asia), and regional and multinational private seed companies' use of CIMMYT germplasm in breeding and variety registration.

Critical Issues for (possible) discussion – including key changes in strategy/structure

- Even though drought and water-use efficiency (WUE) is a global issue, funding has been mostly forthcoming for Africa. With initiation of projects such as the new BMZ project for Asia and the recent appointment of a stress physiologist/breeder, we need to ensure that projects capitalize and interchange knowledge, germplasm and capacities across continents.
- Several teams have evolved around conventional and marker-assisted drought breeding projects; we need to further define breeding schemes and team members' responsibilities to ensure we make best use of various disciplines, best germplasm and state-of-the-art output-oriented breeding schemes, and are accountable for breeding progress.

- In Asia, water-logging and excess soil moisture has come on as a new research topic (Zaidi et al. 2004).

2. Maize germplasm tolerant to acidic and low fertility soils to enhance productivity increases among resource-constrained farmers, and reduce encroachment of maize production into more fragile environments

Summary of progress toward achieving the MTP promised outputs (Table 1)

Acidic soils are important mostly in the high rainfall lowland tropics of Latin America and parts of Asia and Africa, in the highlands of Eastern Africa and on some particular soil types (granitic sands) in Southern Africa. Soil acidity makes farmers in Latin America encroaching into fragile ecosystems. In Africa, few farmers are able to pay for or transport lime.

Recurrent selection and more recently pedigree breeding projects have developed high yielding germplasm sources that are productive on acidic soils (Pandey et al. 2007). In many instances low pH is associated with P deficiency and recent research by CIMMYT in Colombia has focused on revealing the inheritance of P-efficiency, low pH tolerance and studying rapid screening techniques for acid soil tolerance (in particular callose content), involving a significant number of graduate students (Arcos et al. 2007, Pérez-Velasquez et al. 2007). Important collaborators include the University of Sao Paulo in Brazil, the University of Hanover, CIAT, CORPOICA and FENALCE.

These studies found P-acquisition and P-use efficiency to be multi-genic traits and their inheritance explained mostly by additive effects. Narrow-sense heritability for P-acquisition varied from 10.3 to 29.7% and for P-use efficiency from 16.3 to 38.9%, depending upon the target population.

Several acid soil tolerant hybrids and OPV have been released (most recently the white three way cross hybrid CML247/CML254//CLA127) and CIMMYT Maize Lines (CMLs) as important sources for acid soil tolerance have been identified.

Critical Issues for (possible) discussion – including key changes in strategy/structure, if any

- Next to drought and low N, soil acidity is an important factor accounting for genotype-by-environment interactions (Setimela et al. 2005). Impressive breeding progress for acid soil tolerance has been made over the past two decades and valuable germplasm made available to a wide range of public and private partners in particular in South America and to lesser extent in Asia. Brazil is an important alternative provider of know-how although not an international public goods provider for germplasm.
- The use of acid key screening sites remains likely important for the success of CIMMYT germplasm in the lowland tropics and eastern African highlands and we need to assess to what extent acid soil tolerant sources from the CIMMYT research team in Colombia have enriched germplasm in other CIMMYT breeding teams.

3. *Striga* resistant maize to restore maize production in affected areas in sub-Saharan Africa

Summary of progress toward achieving the MTP promised outputs

Striga, a parasitic weed, affects maize production and poor farmers' livelihoods on 3 to 6 million hectares in sub-Saharan Africa. *Striga* is highly phytotoxic (30-100% yield reduction), prolific (20,000-50,000 seeds per plant), its seed may survive in the soil for over 20 years, and it is difficult to control. Its occurrence is associated with poor soil fertility and hence it is prevalent among the poorest of farmers.

The Imazidalinone resistant (IR) maize technology utilizes herbicide resistant maize seed coated with the herbicide imazapyr. IR-maize has proven to be effective, inexpensive, compatible with traditional farming systems, and gives up to four-fold maize yield increase under farmers' conditions (DeGroote and Kanampiu 2007). A partnership among CIMMYT, NARS, BASF, AATF, local seed companies, NGOs and farmers has resulted in more than 15,000 demonstrations, five cultivars registered for commercialization, with certified seeds of one of the hybrids being marketed since 2007. Farmers say "*It is the most effective Striga control measure available*".

At this stage, private seed companies and their ability to invest in capital (equipment, seed stocks) and absorb risks are rate-limiting for large-scale impact. The technology is new. It requires different seed coating techniques/processing lines and quality assurance strategies. New markets are being explored, indeed those among the poorest farmers with the least purchasing power. Based on seed-companies feed-back, they are willing to increase seed volumes annually by no more than 25% - because they explore new and not established markets - which makes scaling-out rather slow.

Farmers around the Victoria Lake Zone in Eastern Africa (Kenya, Tanzania, Uganda), parts of Ethiopia, Malawi and several countries in West Africa prioritize *Striga* as a major pest. In Kenya, IR-maize increased yields in farmers field by 500 kg ha^{-1} (US$100 ha^{-1}). The benefit from the improved (stress tolerant) germplasm was estimated at 370 kg ha^{-1} or US$ 74 ha^{-1}, while the benefit due to the herbicide and reduced *Striga* was estimated at 130 kg ha^{-1} (dependent on *Striga* infestation: 49 kg ha^{-1} of *Striga* m^{-2}), and the overall marginal rate of return (MRR) at 2.4 (good) with 1.9 (respectable) for germplasm, and 5.6 (very good) for IR maize (DeGroote et al. 2007).

Critical Issues for (possible) discussion – including key changes in strategy/structure

- There is need to discuss our IR germplasm improvement strategy given the absorption potential of the seed market.
- A recently initiated PhD project aims at identifying and characterizing new sources of resistance to Striga through: 1) mapping of the new Mutator-induced sources of *Striga* resistance and 2) search among white endosperm gene bank accessions.

4. Disease and insect resistant maize to reduce pre-and postharvest losses

Summary of progress toward achieving the MTP promised outputs

P3 entertains internationally one of the few research and improvement programs for conventional pre- (*Busseola fusca*, *Chilo partellis*, *Diabrotica* spp., *Diatraea* spp., *Ostrinia furnicalis*) and post-harvest insect (*Prostephanus truncatus*, *Sitophilus* spp.) resistance in maize, and past project reviews have been in strong support of this approach. Sources of resistance were identified among germplasm bank accessions and transferred, over a decade and with variable funding support, to agronomically acceptable types and then to elite germplasm (Mugo et al. 2007). Research in the underlying resistance mechanisms revealed a complex set of biochemical traits, most prominently those contributing to cell wall components (Garcia-Lara et al. 2004, Mugo et al. 2001).

Over recent years, three stem borer insect resistant OPV and six hybrids were released in Kenya, and collaborative breeding projects with Asian and African NARS are being implemented to share insect resistance traits and develop germplasm adapted to various ecologies. In Africa, this involved sharing S_2 bulks among several breeding programs in different ecologies with collaborating breeders developing their own inbred lines adapted to those ecologies.

As a special 2007 highlight, the first elite maize hybrids with superior grain yield and usable resistance to the larger grain borer (LGB) (*Prostephanus truncatus*) and the common maize weevil (*Sitophilus zea mais*) were developed and nominated to the Kenya NPT for 2008 (KARI and CIMMYT 2008). This germplasm has more than 30% resistance compared to the best commercial checks and - given the enormous losses to post-harvest pests in Africa - has attracted significant interest by NARS and private sector breeders. More research is needed to identify best elite lines and their genetic background.

In collaboration with KARI, the Syngenta Foundation for Sustainable Agriculture and the Rockefeller Foundation, the University of Ottawa and more recently private sector providers, CIMMYT has been engaged in *Bt*-maize research since 1999. In 2007, testing of a new *Bt*-maize event with transgenic resistance against *Busseola fusca* was initiated in biosafety greenhouse and field facilities in collaboration with the trait provider and KARI. The application to test the new *Bt*-maize event was approved, biosafety facilities inspected and approved, and a refresher course on biosafety conducted. Given commercial interests, options for market segmenting between humanitarian and commercial use of transgenic *Bt*-maize seed are being investigated.

Even though CIMMYT focuses on the more intractable among the biotic stresses and where genetic variation is rare, breeders routinely ensure that our elite germplasm which is improved for priority traits such as drought also possesses a basic level of resistance against most prevalent diseases as otherwise the germplasm will not be acceptable to national and private sector breeders (Langyintuo et al. 2008). Recent searches for more intractable disease resistance traits addressed the corn stunt complex, Rio Mal de Cuarto virus, *Fusarium* and aflatoxin resistance (see below). With the appointment of a new maize pathologist, P3 invests in better characterizing and making available these sources for NARS breeding projects.

Critical Issues for (possible) discussion – including key changes in strategy/structure

- Insect resistance research has essentially been transferred from Mexico to Kenya with strong focus on post-harvest pests and its breeding strategy linked to DTMA. Funding commitments are available from the Syngenta Foundation for Sustainable Agriculture.
- CIMMYT's role and engagement in *Bt*-research has transitioned from public trait provider to licenser for humanitarian purposes.
- Use of molecular markers for important biotic stresses: Maize Streak Virus (MSV), gray leaf spot (GLS).

5. Mycotoxin resistant maize for increased food safety

Summary of progress toward achieving the MTP promised outputs

Mycotoxins are among the more complex biotic constraints affecting human health and trade. Their importance in developing countries is likely undervalued even though sampling of maize grain routinely shows concentrations, which grossly exceed international trade limits. In high concentration, mycotoxins can cause death. Chronic exposure may result in cancer, abortion, immune deficiency and retarded growth.

Fusarium spp. are prevalent in most growing ecologies; high aflatoxin expression is frequent under pre-harvest drought. Mycotoxin causing ear rots are opportunistic diseases which are fostered by maize cultivation under subsistence conditions, end-of-season drought; mechanical damage to kernels; poor harvesting and storage methods. Given lack of awareness and monitoring facilities in most low income countries, regulations may not exist or cannot be implemented as monitoring is costly and maize is mainly consumed by the producers themselves. Host plant resistance hence seems among the more effective avenues for reducing exposure.

CIMMYT developed first sources for *Fusarium* and *Diplodia* resistance during the early 1990s and engaged in aflatoxin research in the late 1990s, all at very low levels of funding. Most recent work includes collaboration with Texas A&M Univ., the University of Georgia and USDA which identified several promising lines for aflatoxin resistance, including CML247 and CML495 with consistent performance across locations (Mississippi, Georgia and Mexico) and years.

The CIMMYT biotic stress unit provides basic biotic stress services (inoculums production, diagnostic, etc) to breeders and partners for research on mycotoxins. Most relevant applications include combination of best sources with drought-tolerant and insect resistant germplasm (*Aspergillus*), or highland germplasm (*Fusarium*). Funding for mycotoxin research pursued with proposals submitted or under preparation targeting CGIAR-Canada linkage fund, Bill & Melinda Gates Foundation (BMGF), CGIAR System-wide Program on Integrated Pest Management (SP-IPM) and the European Union (EU). Unfortunately, the proposal for a Food Safety Challenge Program did not progress beyond the concept note stage.

Critical Issues for (possible) discussion – including key changes in strategy/structure

- Update on sources of resistance and focusing of future work and fundraising

6. Strengthened impact pathways for stress tolerant maize

Summary of progress toward achieving the MTP promised outputs

P3 has a major engagement in the capacity building of NARS and private sector breeders in applied stress breeding approaches and also engages in more effective impact pathways for drought tolerant maize. In 2007:

- 11 PhD, 22 MSc and 4 BSc students were engaged in P3-related research topics and 10 visiting scientists exposed to aspects of stress breeding
- A drought tolerance workshop was organized in Zimbabwe and attended by 45 breeders and technicians from the Southern African Region
- Three in-country training workshops were conducted for 110 technicians in Zimbabwe, Tanzania and Nigeria to support more rapid variety release. A DVD-& web-based record of training sessions was developed in collaboration with Cornell University
- Breeding projects of NARS backstopped in Africa and Asia, and emerging seed companies supported through training and supply of breeders' seed. In East Africa, there was a shift of focus on support from community based seed production (CBSP) to small seed companies with support to CBSP only when formally linked to a seed company
- In the frame of DTMA, the African maize seed sector was surveyed to assess factors affecting the uptake of improved seed and identifying the bottlenecks for deploying seed to more stress-prone environments (Langyintuo et al. 2008)
- The New Seed Initiative for Maize in Africa (NSIMA) provided technical input to the regionalization of seed policies in the Southern African Development Community (SADC) that covers regional variety release, harmonised certification standards, and a revised pest quarantine list and was adopted by the SADC Ministers of Agriculture
- The Hill Maize Research Project (HMRP) in Nepal facilitated the release and dissemination of three new maize cultivars through community seed multiplication programs, informal research and development (IRD), FAT (farmer acceptance test), and mother-baby trials. HMRP encourages linkages between seed traders and seed producer groups to facilitate seed marketing (Ortiz-Ferrara et al. 2007). Efforts are made to motivate private sector entities to engage in seed marketing and to develop seed marketing channels to remote areas. Through its multi-sector and multi-cultural research and dissemination partners, HMRP works directly with more than 5,000 farmers every year, covering more than 20,000 households in 32 hill districts. As a result seed production through farmers groups has steadily going up with 480 t produced by 90 farmers groups in 2007.

Critical Issues for (possible) discussion – including key changes in strategy/structure

- Insights gained from the African maize seed sector survey – implications for research, most relevant impact pathways and focus of our capacity building efforts.
- Possible cross-linkages in seed sector training between Africa, Nepal and AgroSalud.
- Strategies for pyramiding stress traits, especially quantitative traits for biotic and abiotic stresses.

Conclusion

P3 includes a highly relevant set of CIMMYT flagship products oriented towards increasing food and income security of resource-farmers in stress-prone environments. Our strategic focus is on globally most relevant intractable research topics (drought/WUE, post-harvest pest resistance/mycotoxins) while not missing on opportunities for medium priority research areas (water-logging, heat, acid soils, NUE, *Striga*) as they arise. P3 has strong and wide-ranging research partnerships with NARS, NGOs, the private seed sector, ARIs including other IARCs (most prominently IITA) and this has ensured farm-level impacts.

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P4 – Nutritious and Specialty Traits for Maize

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Flagship Products: Biofortified maize for improved nutrition and health
Opportunities for income generation from special trait maize

Introduction

P4 has an exciting mix of mature, frontier and unexplored research areas. The focus of our quality protein maize (QPM) work has been to maximize impact by assisting partners to release and promote competitive cultivars, while enhancing the viability of QPM by developing technologies and building partners' capacity to succeed with QPM. Our pro-vitamins A, Zn and Fe biofortification research is largely in unchartered scientific fields and involves trial and error, and the occasional exciting success. Specialty maize types are potential income generating, livelihood enhancing products for small-holder farmers, but success relies on meeting complex market demands, which requires socio-economic priority-setting research, and highlighting often novel traits, which may require cereal quality, food technology or nutritional research. As we will describe in this report, most of P4's investment is currently in biofortified maize research and development, whereas our efforts on specialty maize are modest or exploratory.

MTP OUTPUTS: PROGRESS, HIGHLIGHTS AND CRITICAL ISSUES

7. Micronutrient enriched maize for improved nutrition, health and agricultural productivity

Summary of progress toward achieving the MTP promised outputs (Table 1)

Highlights

Quite a few new pedigree breeding populations are achieving values of 5-6 ug/g, whereas we have one or two exceeding 10 ug/g of provitamins A. This compares with starting values (4 years ago) of 0-2 ug/g, and target values of 8 (intermediate) and 15 ug/g (long-term). We are now confident that the intermediate target values are achievable, and are focusing increasing effort on developing and testing experimental cultivars that will be agronomically competitive.

We have completed 3 cycles of intra-population S_1 recurrent selection to increase pro-vitamins A concentrations in 3 African open pollinated cultivars (OPV). We are forming the full set of materials (3 OPV x 4 cycles) and will evaluate progress from selection in trials during 2008 and 2009. More than 20 elite African (white) inbred lines and 15 OPV are in the process of pro-vitamins A enhancement. The best new lines are in yield trials evaluated in Mexico, Zimbabwe, Zambia, India, China, and under drought and low-N stress conditions.

Evidence on the costs and potential benefits of biofortification for a large number of countries in Africa, Asia and Latin America was calculated using a modification of the disability adjusted life years (DALY) framework (Meenakshi et al. 2007). This work concluded that the biofortification can make a significant impact on the burden of micronutrient deficiencies in the developing world, and can do so in a highly cost-effective manner.

We are investigating the potential to breed for enhanced bioavailability for Fe (and to a lesser extent for Zn and pro-vitamins A) as an alternative strategy to breeding for enhanced concentration per se (see Palacios CIMMYT Science Week 2008). This is particularly important for Fe, given that very little natural variation has been found for this micronutrient in maize.

Exciting work and efforts toward implementing rapid laboratory screening methods, and marker assisted selection in this work will be reported by Palacios (CIMMYT Science Week 2008).

Critical Issues for (possible) discussion – including key changes in strategy/structure

- This is a scientifically exciting project. Little research has been conducted, so almost everything we do can contribute to the literature on biofortification of maize.
- Acceptance of orange/yellow maize by many of the intended beneficiaries is far from certain. De Groote and Kimenju (2008) have conducted experimental auctions in Kenya and found that white maize is much preferred over yellow, and there is little willingness to pay for fortified products. Additional “acceptance work” is ongoing in Kenya and elsewhere.
- This is a high risk project
    - The breeding goals will be challenging to achieve.
    - The product will likely be mostly supply rather than demand driven.
    - The product will be invisible and difficult/costly to monitor.
- This is expensive, long-term work.

8. Quality protein maize (QPM) for improved agricultural productivity and health

Summary of progress toward achieving the MTP promised outputs (Table 1)

Highlights

New, faster, cheaper, more robust laboratory analysis methods were developed for measuring tryptophan and protein for QPM grain (Nurit et al. in preparation). These methods, and particularly the tryptophan method, which is based on replacing acetic acid with glyoxilic acid, will aid QPM breeding efforts at CIMMYT and by partners.

CIMMYT’s QPM breeding efforts are ongoing in Zimbabwe, Kenya, Ethiopia, India, Colombia and Mexico. There is a dual focus: 1) Make agronomically competitive QPM cultivars available to farmers, and expand the germplasm base for QPM. New QPM cultivars have been or will in 2008 be released in Bangladesh, Bolivia, Colombia, El Salvador, Ethiopia, Haiti, Kenya, Panama, Peru, Tanzania and Zimbabwe. Extensive on farm QPM validation and demonstration programs are also ongoing in Latin America and Africa, with CIMMYT leadership. 2) Expand the germplasm base for QPM: This includes projects to develop QPM with resistance to drought, low soil N, Maize Streak Virus, *Striga*, and acid soils, as well as combining QPM with increased pro-vitamins A or Zn concentrations.

A recent QPM review article (Krivanek et al. 2007) summarizes the history and current status of QPM breeding, including examples of the shrinking yield gap between normal and QPM cultivars, and information about extent and distribution of QPM cultivation in Africa. This article also provides a good review of published literature on the nutritional value of QPM, both for animals and humans.

A 2007 statistics PhD dissertation (Gunaratna 2007) conducted a meta-analysis of available QPM human nutrition studies and found 8 and 9% average height and weight advantage of children fed QPM versus conventional maize. She also conducted some simulations of the likely impact of QPM substitution of conventional maize, and described scenarios in which it would lead to decreased risk of lysine deficiency and associated health problems. Unfortunately, the final conclusion of her dissertation was: “It is hoped that the positive results presented here encourage greater attention and investment in evaluating the nutritional impact of QPM in sound scientific studies.”

Ongoing QPM impact assessment work in four East African countries will report in 2008 on the likelihood that QPM “can make a difference” across a range of agro-ecological zones.

Critical Issues for (possible) discussion – including key changes in strategy/structure, if any

- Should we focus on white grained QPM, which is mainly for human food; on yellow QPM, which is mainly for feed; or should we invest in both? Should we maintain parallel breeding programs for QPM and non-QPM; merge them; or focus exclusively on QPM?
- At present, QPM is mainly “supply-” rather than “demand-driven.” How should we stimulate important demand for QPM from farmers, seed sector, and industry, so that the impact of QPM will achieve the potential we envision?
- The debate about the nutritional value of QPM continues, and the results of the meta-analysis do not completely put this to rest.

9. Dual purpose or specialty maize for improved livelihoods and income generation

Summary of progress toward achieving the MTP promised outputs (Table 1)

Highlights

Through collaborative research with ILRI, we found significant variation for stover quality among maize hybrids at CIMMYT, India (Srivastava et al. 2006). Cultivar dependent variations that will have measurable implications for livestock productivity were observed for in vitro digestibility and metabolizable energy content. For example, differences of 3 to 5% in digestibility were associated with 17 to 24% differences in animal performance.

However higher stover quality might come at some costs for grain yield since stover quality and grain yield were inversely associated. Yet this relationship was not very strong

Improvement of blue maize is proceeding in Mexico via two strategies: 1) Intra-population improvement in a popular blue maize population, and 2) conversion of CIMMYT Maize Lines (CML) to blue.

The USDA-SAGARPA project initiated in mid-2007, and it is funding ex-ante impact assessment work in the State of Mexico, as well as some laboratory methods development for measuring various quality parameters.

Critical Issues for (possible) discussion – including key changes in strategy/structure

- Specialty maize market opportunities tend to have high reward potential, but high risk. What precautions can we take to ensure our work on specialty maize benefits poor farmers?
- How can we attract funding to better characterize our maize germplasm for quality traits of current and potential value?
- Requests from partners for specialty maizes are often for help in highly competitive markets, e.g. baby or sweet corn, for which CIMMYT has no competitive advantage
- Biofuel will be discussed separately and is not currently part of this project

10. Strengthened impact pathways for nutritional and specialty trait maize

Summary of progress toward achieving the MTP promised outputs (Table 1)

Highlights

During 2007 a consultant visited partners' labs in Nigeria, Ghana, Ethiopia, Uganda, Zimbabwe and Mozambique to assist them to implement the new tryptophan analysis method mentioned above.

At least 10 MSc and 6 PhD students (12 from Africa) completed in 2007 or are currently still working toward their degrees on topics within P4 and (co-)supervised by P4 staff.

Critical Issues for (possible) discussion – including key changes in strategy/structure

Network building and nurturing, for example to enhance impacts of agricultural research on farmers, has traditionally been an important part of CIMMYT's agenda: How much of our effort should we dedicate to this?

Conclusion

P4 explores new options for poverty alleviation through maize research and germplasm development. The novelty is that: 1) biofortified products improve nutrition – and quality of life - without compromising crop productivity, whereas 2) specialty maize types offer income generating opportunities that may be scale neutral or actually favor small-scale producers. P4 scientists work closely with colleagues from P1, P2, P3 and P11 to set and achieve our objectives.

Table 1. Summary of status toward timely achievement of CIMMYT's P4 MTP outputs

Out-put*	Output Type	Year when due	Status
1	Micronutrient Enriched Maize		
1.1	Germplasm	2008, 2009, 2010	On-track
1.2	Knowledge/genetics	2009	Excellent
1.3	Knowledge/germplasm	2008	Doubtful due to staff departure
1.4	Knowledge/methods	2008	On-track
1.5	Knowledge/priority setting	2009	On-track
1.6	Knowledge & germplasm	2009	On-track
1.7	Knowledge/methods	2009	On-track
1.8	Germplasm	2010	Too soon to assess
2	Quality Protein Maize		
2.1	Germplasm	2008, 2009, 2010	On-track
2.2	Germplasm	2008	On-track
2.3	Knowledge/capacity bldg	2008	Excellent
2.4	Knowledge/priority setting	2008	On-track
2.5	Knowledge/capacity bldg	2009	Likely only partial success
2.6	Knowledge/germplasm	2010	On-track if we modify slightly
3	Dual-Purpose or Specialty Maize		
3.1	Knowledge/priority setting	2008	On-track
3.2	Knowledge/germplasm	2008	On-track
3.3	Knowledge/priority setting	2009	At least 50% on-track
3.4	Knowledge/methods	2009	On-track
3.5	Germplasm/fund raising	2010	Too soon to assess
4	Strengthened Impact Pathways		
4.1	Networking/capacity building	2008, 2009, 2010	On-track
4.2	Capacity building	2008, 2009, 2010	Excellent

* For detailed description of these outputs, which are listed here in the same order as in the MTP document, please refer to CIMMYT (2007)

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P7 – Drought Tolerant Wheat with Enhanced Quality

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Flagship Product: Wheat with enhanced water productivity and appropriate quality profiles

P8 – Disease Resistant Wheat with High productivity and Quality

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Flagship Product: Rust resistant wheat

Introduction

During 2005–2007, the Rainfed Wheat Systems Program and the Intensive Agro-ecosystems Program were merged to form the Global Wheat Program (GWP). The GWP was asked to provide oversight to four projects:

P7: Drought tolerant wheat with enhanced quality;
P8: Disease resistant wheat with high productivity and quality;
P9 Wheat grain enriched for health and profitability, and;
P10: Conservation agriculture for maize and wheat cropping systems.

In 2006, P9 was merged with P8, and P10 oversight was transferred to the Impacts, Targeting, Assessment Unit. This report focuses only on achievements of P7 and P8+P9.

P7 – Drought tolerant wheat with enhanced quality

Nearly half of the 110 million ha of wheat cultivated in developing countries is grown under resource-poor, rainfed conditions that receive less than 500 mm of precipitation annually. Some of the poorest and most disadvantaged wheat farmers live in rainfed areas that receive less than 350 mm annual rainfall and their livelihoods often depend solely on food and income from wheat production with wheat straw or fodder often contributing significantly to farm animal sustenance. In these areas, wheat is a staple food providing up to half the daily caloric requirement. In rainfed areas, water availability is limited and unpredictable. Climate changes may result in more extreme variability temperatures and precipitation. Tolerance to higher temperatures (both diurnal and nocturnal) will become an important breeding objective, in a crop that is generally more suited for cooler production environments. The growing scarcity of water in irrigated areas will increase the need to develop more water use efficient wheat germplasm. Soil borne diseases are major constraints for wheat production in drought stressed environments, and will likely become more important. Tying resource efficient germplasm with ever more effective conservation agriculture practices – and germplasm that performs better under these new agronomic systems – is our challenge.

P8 – Disease resistant wheat with high productivity and quality

Contrary to developed countries, where nearly 90% of wheat produced is under rainfed conditions, in developing countries nearly 50% of the total area devoted to wheat is produced in full or supplementary irrigated systems. Agriculture is a major user of water (72% globally) and therefore the water productivity of wheat is becoming increasingly important. These more optimal production environments also favor disease development Rust diseases, historically as today, pose one of the most significant and ever-present threats to wheat production worldwide. Ug 99, a new stem rust race first identified in Uganda, is highly virulent on most currently grown varieties worldwide. Losses in global wheat grain production of only a few percent points due to disease and climate irregularities would spike grain prices and affect availability harming the world's poorest wheat producers and consumers disproportionately. Increases in the wheat grain production needed to meet the projected demand of 760 m tons by 2025 will likely need to come from higher sustainable intensification of irrigated wheat production systems. Food safety, nutrition and market oriented quality are also important requirements for wheat produced in the value chains where P8 is targeting.

Spring Bread Wheat Breeding (P7): Major achievements 2005 – 2007

The main objective of the Rainfed Bread Wheat Improvement project for the period 2005-2007, was to develop wheat germplasm adapted to drought stressed environments with good disease resistance including resistance to Ug99 and improved end-use quality. Genetically diversity is emphasized by using hexaploid-derived lines from resynthesized wheat and landraces as parents. Parental characterization data from the Wheat Physiology Group contributes to information used to plan crosses. Marker assisted selection (MAS) is routinely used to enhance resistance to soil-borne diseases. The main achievements of this project have been:

- Analysis of the 3rd to 13th Semi Arid Wheat Yield Trial (SAWYT) data showing a yield increase of 1.1% $year^{-1}$ in environments with trial means below 3t ha^{-1} and 1.5% $year^{-1}$ in environments with trials means from 3 – 8t ha^{-1}
- Nearly 50% of advanced lines are at least moderately resistant to stem rust race Ug99
- Shuttle breeding by planting two consecutive segregating generations (F_3 and F_4 or F_4 and F_5) for stem rust resistance in Njoro, Kenya
- Yield of derived lines from resythesized wheat in SAWYT, under severe stress, are as good as most drought tolerant non-synthetic lines
- New elite lines derived from crosses with landraces show excellent expression of drought-adaptive traits and increased genetic diversity for those traits
- High yielding, leaf rust resistant lines well adapted to high latitudes in Kazakhstan have been developed.

- Drip irrigation allows to simulate controlled drought stress resulting in more uniform yield trials with average yields of <1.5t ha^{-1}. Such low yields could not be obtained in the past with gravity irrigation. Lines are visually and statistically well discriminated. Yield data from drought stressed drip trials are well correlated with SAWYT data.
- MAS data routinely used to characterize crossing block parents, and select within F_1 Top and F_3 populations and elite lines; priority traits selected by MAS include soil stresses (Boron tolerance, cereal cyst nematode (CCN)), rust resistance (*Lr34*, *Sr25*) and 1A1R wheat:rye translocations. Annually about 20,000 samples and 35,000 data points are analyzed
- DNA extraction is now fully operational in Ciudad Obregón with INIFAP
- Quality: Significant progress for gluten strength has been achieved; 1B/1R has been largely removed from rainfed CIMMYT wheat germplasm. Greater emphasis is now placed on improving dough extensibility, a key trait to for end-use quality, with approximately 20% of rainfed lines exhibiting good extensibility
- Under conservation agriculture, mean yield of the 14th and 15th SAWYT were 9% higher under severe drought and 8% higher with reduced irrigation compared to conventional tillage treatments, while no difference was observed in full irrigation. Zero-tillage retains limited soil moisture much better

Key changes in strategy and structure

- To investigate the impact of genotype x tillage interactions under various stress regimes (drought and heat), on yield and end-user quality. The objective is to get a conclusive understanding on whether selecting under conservation agriculture practices will result in as high or higher yielding lines with acceptable quality
- To increase gene frequency for key traits (CCN, *Bo1*) in SAWYT and SAWSN germplasm using MAS
- Focus on QTL discovery and marker development for crown rot and yield in drought and heat stressed environments

Spring Bread Wheat Breeding (P8) Major Achievements, 2005-2007

The main objective of the Irrigated Bread Wheat Improvement during 2005-2007 was to develop wheat germplasm adapted to both irrigated and high potential environments with increased grain yield potential in combination with potential for durable rust resistance (including resistance to Ug99), end-use quality characteristics and water use efficiency. The main achievements were:

- Global Rust Initiative was launched in 2005 to combat the threat posed by Ug99 race of stem rust pathogen
- Diverse Ug99 resistant wheat lines with 10 to 15% higher yields than currently grown cultivars identified in multisite trials established in Afghanistan, Egypt, India, Iran, Pakistan, Nepal, and Sudan during 2006-2007
- Replicated yield trials consisting 26 new Ug99-resistant, high yielding lines established at 50 sites during 2007-2008 crop season in various countries in the Ug99 projected migration path
- Migration of Ug99 beyond East Africa monitored. Two new variants with virulence for resistance genes *Sr24* and *Sr36* detected in Kenya in 2006 and 2007 respectively

- Field screening facilities in Njoro, Kenya enhanced to have two cycles per year. About 10,000+ wheat lines from various countries screened during each of 2006 and 2007. Shuttle breeding between Mexico and Njoro established in 2007
- 1st and 2nd Stem Rust Resistance Screening Nurseries (SRRSN) containing diverse race-specific and durable, adult plant resistance sources distributed during 2006 and 2007 to about 120 cooperators. About 7 or 8 race-specific resistance genes were/will be distributed through these nurseries and the frequency of wheat lines with adult-plant resistance increasing to >50% in the 3rdSRRSN
- Frequency of high yielding lines resistant to Ug99 has increased to 36.5% (26.3% based on APR) in 29thESWYT and 41stIBWSN (to be distributed worldwide during 2008) and is expected to increase to about half (35-40% based on APR) in 30thESWYT and 42ndIBWSN are finalized in 2008
- Early maturing wheat lines identified with above 15% higher yields than currently grown cultivars in on-station and on-farm participatory variety selection trials in Eastern Gangetic Plains, India
- Thousand kernel weight (TKW). Lines retained for international distribution have TKW above 40 g in Obregón and around 40% have a TKW of 50 g or higher
- About 15% new wheat lines have excellent to good industrial pan-bread making quality while another 25% have acceptable chapatti and other types of flat bread making characteristics
- Diagnostic molecular marker was developed for durable pleiotropic resistance genes *Lr34/Yr18/Pm38* conferring partial resistance to leaf rust, yellow rust and powdery mildew (CIMMYT-CSIRO-PBIC, Australia collaborative project)
- Genomic regions conferring slow mildewing identified in Avocet/Saar population and pleiotropic nature of partial resistance genes *Lr46/Yr29/Pm39* established (CIMMYT-Norwegian Univ. of Life Sciences collaboration)
- Five leaf rust resistance genes effective to the new durum race BBG/BN identified and four of them mapped in durum wheat. Two of these were confirmed to be previously known genes *Lr3* and *Lr14a*, known to be present in bread wheat. One gene was linked to *Lr3* in repulsion and another was found to be located in chromosome 6BS and was designated as *Lr61*. Durum wheat germplasm with slow rusting resistance to leaf rust identified and genetic basis determined. (CIMMYT-SLU, Sweden collaboration)
- High yielding wheat lines with diverse sources of resistance to *Septoria tritici* blotch, including resistance derived from synthetic wheats, identified in Toluca (some also resistant to Ug99)

Key changes in the strategy and structure 2005-2007

- Breeding for irrigated environments and rust research merged in one group
- Emphasis to breed high yielding lines with durable, adult plant resistance to all three rusts (leaf, stem and stripe)
- Segregating populations selected at Toluca under zero-tillage and maize stubble mulch -high incidence of *Septoria* and *Fusarium*
- Emphasis to select for water use efficiency and lodging tolerance. 2nd year testing of advanced breeding lines expanded to three environments in Obregón (raised bed- 5

irrigation cycles, raised bed - 2 irrigation cycles, and flat plots-2 irrigation cycles) Testing further expanded in 2007-2008 season to test for drought and heat tolerance

- Testing of advanced lines during off-season (December-April) in Njoro, Kenya while 1st year yield trials being conducted at Cd. Obregón
- Shuttle breeding by planting two consecutive segregating generations (F_3 and F_4 or F_4 and F_5) for stem rust resistance in Njoro, Kenya
- More emphasis to improve end-use quality characteristics
- International nurseries ESWYT and IBWSN will consist only of white grained seed
- Responding to the Ug99 threat by multiplying seed at El Batán and distributing special yield trials consisting of Ug99 resistant, high yielding materials

Strategic Plan for 2008-2010

- Increased emphasis in identifying and mapping genes involved in durable resistance to stem rust and breeding high yielding wheats with near-immune levels of triple rust resistance in conjunction with other necessary traits
- Implement breeding for heat tolerance

Critical issue for implementation

- Need to strengthen regional activity in South Asia, especially to strengthen breeding for heat tolerance
- Need to strengthen collaborative work on spring wheat improvement in China

Durum Wheat Breeding Major Achievements 2005 – 2007 [P 7 and P8]

- Since breakdown of leaf rust resistance in 2001, widened genetic basis for leaf rust resistance and recovered high yield potential combined with improvement in industrial quality attributes, especially yellow color
- Identification of 40 slow-rusting lines with low yield losses under heavy epidemics and initiation of inter-crossing to obtain high resistance levels based on accumulated minor genes
- Started to effectively address *Septoria* through productive partnership with Tunisian NARS, which allowed the identification of a few sources of resistance, which gave us access to their resistance germplasm and prompted the initiation of parallel selection stream between Tunisia and Mexico
- Started to effectively address the Hessian fly problem through partnership with Moroccan NARS, which gave us access to their resistance germplasm and allowed the exchange of segregating materials between Morocco and Mexico
- Identification of several CIMMYT derived sources of resistance to Ug99 in Kenya and to the Ethiopian durum races of stem rust (different from Ug99) which form the basis for an effective program to breed for resistance to this rust
- Developed, through marker-assisted selection, durum wheat lines stably harboring markers linked to tolerance to boron toxicity (*Bo 1*), cereal cyst nematode (*Cre 1* and *Cre 5*) and root lesion nematode (*Rln 1*)
- Phenotyped a world collection of durum wheat and a mapping population under various conditions in Obregón, producing more than 60,000 phenotypic data points for

morphological, agronomical, physiological and quality traits as part of an association mapping project with PSB-DISTA-Italy to identify related QTL to yield potential, drought tolerance, nitrogen use efficiency, and industrial quality

Key changes in strategy and structure

- More emphasis on breeding for water use efficiency and drought tolerance in the new high yielding, high quality, rust resistant germplasm
- Substantially greater use in crossing program of non-CIMMYT germplasm as sources for industrial quality, disease resistance genes, and generic genetic variability
- Adoption of "fixed" shuttle breeding sequence of generation to allow spreading of generation over the two breeding cycles
- Use of larger population sizes during the selection process
- More systematic analysis of quality attributes of fixed advanced lines
- Adoption of selection under zero-till conditions for most segregating materials
- Implementation of drought testing earlier in the yield testing phase of the breeding process
- Allocation of a significant part of the resources to collaborative research projects

Strategic plan 2008-2010

- Continue widening the genetic variability for leaf rust focusing on the use of minor gene based resistance and pre-screening of candidates in hot spots prior to distribution
- Increased frequency of germplasm combining high yield potential under favorable conditions and outstanding performance under drought
- Increased frequency of wheat lines with durable resistance to stem rust
- Expand shuttle with Tunisia to improve *Septoria* resistance
- Expand shuttle with Morocco to improve leaf rust resistance
- Expand use of MAS improve tolerance to nematodes and, as marker linked genes become available, for tolerance to crown rot
- Continue enhancing CIMMYT's contribution to special research project studies to elucidate the physiological and molecular basis of important traits related to yield potential, drought tolerance, nitrogen use efficiency, industrial quality and disease resistance in durum wheat
- More focus on India, the most important spring durum wheat producer in the developing world

Critical Issues for discussion

- A postdoctoral fellow or associate scientist needed to enable the durum wheat breeder to have stronger interactions with NARS,
- Sustainable support for shuttle breeding with NARS in North Africa

Wheat Physiology [P7 and P8]

Major Achievements [P7]

The Wheat Physiology Project interacts strongly with P7 and P8 breeding activities and achievements are arranged by P.

- Genetic variation in wheat for rate of tissue expansion and its interaction with moisture stress was demonstrated for the first time. The trait was best associated with leaf water potential
- Importance of water extraction in the 60-90cm depth profile for drought adaptation and confirmed its association with canopy temperature;
- Identified stress adaptive traits between drought and high temperature environments in wheat and common QTL related to heat and drought adaptive traits
- Detected QTL by environment effects in heat and drought environments for canopy temperature in wheat
- Resynthesized wheat-derived material showed a greater capacity for water uptake especially at intermediate root depths increasing total water uptake by 11% compared to recurrent parents. The resynthesized wheat-derived lines appear to be more adaptive in their ability to redistribute roots biomass enabling them to take better advantage of water available throughout the soil profile
- Quantification of the potential value of physiological trait expression in genetic resources: Results suggested that improved water use efficiency was the trait most likely to be improved by crossing with exotic germplasm, while increased ability to access water deep in the soil as well as elevated levels of stored stem carbohydrates also showed promise

Major Achievements [P8]

- Yield Potential Symposium organized with 160 participants and 33 papers (in physiology, agronomy and social science) published in *Euphytica* and *Journal of Agricultural Science* (Cambridge)
- Characterized crossing block lines for irrigated program. Biomass at anthesis is a key trait in determining yield, along with canopy temperature (CT). Therefore, biomass was estimated radiometrically and CT measured after heading on two dates of BW crossing block, ESWYT, and SAWYT (irrigated). Significant variation in both traits was found and lines suggested for crossing as genetic sources of yield potential.

Strategic plan 2008 - 2010

CIMMYT's wheat physiology program is very strong in precision phenotyping for drought adaptive traits, a prerequisite for marker development. Therefore great interest by research groups around the world to cooperate with CIMMYT on drought and heat research.

P7 and P8

- Extend implementation of trait based crossing breeding programs to develop germplasm with optimal combinations of stress-adaptive and yield potential traits.
- Estimating genetic gains associated with rapid physiological screening tools applied directly within breeding programs.

P7

Targeting and prioritizing physiological traits to distinct heat and drought environments.

- Continue to discover QTL associated with drought adaptation in different wheat populations.
- Develop new generations of wheat mapping populations that are not confounded by phenology.

- Quantify the potential to increase productivity under heat and drought stressed environments through strategic use of genetic resources.
- Physiological characterization of primary resynthesized wheats to identify superior genotypes for back-crossing.
- Determine main and pleiotropic effects of transgenes (from JIRCAS) in wheat in controlled environments and field.
- Develop major proposal on remediation of degraded agro-ecosystems with NARS.

P8

Discover QTL associated with spike fertility in different wheat populations

- Pinpoint underlying physiological and genetic basis of grain set and grain-abortion to develop plants with a less conservative strategy better adapted to modern agronomy.
- Develop major proposal for raising yield potential with UK and NARS collaborators.
- Lodging screening experiments with Agronomy to develop a fast and efficient screening protocol for lodging using small plots at an early yield trial stage such as PYT.

HarvestPlus (H+), Nitrogen Use Efficiency and research on Yield Gaps Major Achievements [P8]

- Identification of the best parents with high levels of iron (Fe) and zinc (Zn) in the grain, which are currently being used at CIMMYT and by our NARS collaborators for the development of biofortified wheat.
- Milling studies and effect on Fe and Zn concentration and bioavailability in the grain. Milling reduces Fe and Zn levels in the flour but hydrate is reduced even more resulting in a more favorable Zn/hydrate ratio, which is highly correlated with bioavailability. A flour extraction rate of 80% is best to optimize function of increasing bioavailability vs. decreasing content with decreasing flour extraction.
- Developed in collaboration with Oklahoma State University a sensor based nitrogen management in irrigated wheat and transferred to farmers. The average savings compared to conventional N management were about US$ 75 ha^{-1}, mainly from fertilizer savings. Validation started in Mexico. Around 19% of all N worldwide is applied to wheat (viz. a viz. 16% for maize and 16% for rice).
- Collaboration with Stanford University developed methodology to estimate reasons for yield gaps by using remote sensing. Identified and quantified in Yaqui Valley losses from inappropriate planting date, weeds, and timing of irrigations. Method could be very useful to identify reasons for yield gaps between farmers' fields in research stations in other wheat growing regions in the developing world.

Strategic plan for 2008 – 2010 N-Use efficiency and yield gap

- Establish if crop algorithms to be used with sensor base nitrogen management in irrigated wheat are site specific or can be used across large regions. Continue to expand the adoption of sensor based nitrogen management in irrigated wheat and maize in other countries around the world; China and India use together 41% of all N applied to wheat worldwide.

- Establish critical time for the application of the first post plant irrigation in the Yaqui Valley, Sonora, with implications to other wheat irrigated areas around the world. In general how to improve water use efficiency in irrigated wheat.

Strategic Plan for 2008 - 2010 H+

- Breeding for high Zn / Fe grain content has proven to be more difficult than initially expected; the GxE is very high. To meet future milestones in cultivar development with high Fe/Zn grain content, three scenarios are considered to achieve the targets of H+ of a 10 ppm higher Zn and Fe grain content compared to currently grown cultivars in a given environment; this means the target is not a fixed value, e.g. 50 ppm Zn but varies with environment.
  - Optimal Scenario: High yielding, disease resistant elite lines with + 10 ppm Zn compared to the main varieties in northwest India and Pakistan identified by 2010 and released around 2012
  - Likely Scenario: advanced lines with + 10 ppm Zn, with *Yr 27* genee and Ug 99 resistance and competitive yield identified by 2012, and released around 2015.
  - Pessimistic Scenario: a significant and high genotype-by-environment interaction (GEI) for Zn grain content, wheat biofortification requires transgenics, and cultivars released after 2015.
- Employ H+-breeder. More than 200 crosses made with new sources (many poor agronomic types) for high Zn and Fe. Crosses with wild types require huge segregating populations to identify plants with acceptable agronomic type
- Establish selection sites with low soil heterogeneity for Zn, since GEI extremely high. This is compulsory for future field based selection work.
- Evaluate importance of agronomy versus breeding to achieve high Fe/Zn grain content. Target regions (Punjab of India and Pakistan) have Zn deficient soils which complicates the production of high Fe/Zn wheat, which may require and agronomic component to complement the breeding effort.
- Breeding lines with high Fe/Zn content became even more challenging, as potential lines for the target region need to be resistant to Ug 99, leaf and yellow rust.

Global Fusarium Initiative (GFI) Major Achievements [P8]

[For background information on GFI see Duveiller – Global Rust and Fusarium Initiatives in CIMMYT Science Week 2008 Book of Abstracts]

- Moved *Fusarium* head blight (FHB) screening operations from Toluca to El Batán.
- Automated mist irrigation with precision CO_2 sprayers for liquid inoculum application established.
- 9,000 bread wheat accessions screened for resistance to FHS.
- New non-Chinese derived sources of resistance to FHS identified with resistance similar to Sumai 3.
- Identified white grained lines with moderate to good levels of resistance (non-Chinese source).

- Seedling bioassay for Fusarium pathogenicity developed, which allows discarding most susceptible lines to FHB. Lesion size of area infected with conidial suspension is correlated with susceptibility to FHS.
- Molecular identification for *Fusarium* species and chemotype established .
- Major QTL for field resistance to FHS identified on 3BS, 5A and 6BS.
- 17 QTLs for toxin low accumulation detected.
- Other Pathology: Re-organization and new emphasis of wheat pathology besides rusts at headquarters: a) Strengthening wheat lab, b) Addressing better wheat diseases such as Septoria, tan spot, wheat blast (on limited scale) through new funding and work on Karnal Bunt.

Key issues in coming years

- Attracting scientists from advanced universities making them keen to work and stay at CIMMYT for more than just a short term contract. Long term scientific commitment required to delivered products (i.e., germplasm versus knowledge).
- Improving research capacity through upgrading lab.
- Increasing capacity to address wheat foliar disease though staffing and funding.
- Strengthening molecular pathology and use of molecular tools in wheat pathology.

Strategy 2008 – 2010

- Emphasis is shifting from screening to breeding. Combine genes form sources of resistance other than Sumai 3 in elite material.
- Combine minor genes for FHS resistance. An approach similar to breeding for durable rust resistance is needed. This requires fine tuning of the inoculation methods. At present the infection is pressure is so strong, that quantitative differences are difficult to detect.
- Apply molecular screening techniques to discard most susceptible accessions to FHS prior to field screening.
- If Japan funds Phase II of the FHS project, breeding for low mycotoxin content will be emphasized.

Quality and Cereal Chemistry Lab: Achievements 2005 – 2007 [P7 and P8]

- The Quality and Cereal Chemistry Lab analyses annually close to 20,000 bread and durum wheat lines, including samples from the winter wheat breeding in Turkey and NARS programs. Establishing a small quality lab in Ciudad Obregón has greatly enhanced the capacity for quality analysis.
- Determined main end-uses and grain quality requirements in targeted wheat–producing areas and developed a classification of quality traits based on grain quality attributes associated with major wheat end-uses in target areas. Main wheat grain traits are: hardness, protein quality, starch properties, which influence bread quality (flat, leavened), noodle quality, cookie quality, pasta quality.
- Characterized wheat germplasm with molecular markers for grain hardness, gluten protein quality, starch pasting properties, yellow pigment, and flour polyphenol oxidize.
- Compared MAS with conventional tools (NIRS, electrophoresis, dough rheology) for characterization of genetically-controlled grain quality traits.

- NIRS in El Batán and Obregón used to analyze for grain hardness, protein quantity and quality (based on the sedimentation test), straw-N, and water-soluble carbohydrates.
- Low-cost assay for toxin analysis based on commercial fluorimetric kit protocol (Fluoroquant) implemented for determination of deoxynivalenol (DON) concentration, a Fusarium-related mycotoxins. Method is in the validation stage using diverse germplasm tested in several different locations (Mexico, Uruguay and Paraguay).
- Unified nomenclature of Glu-1 and Glu-3 glutenins developed in collaboration with researchers from Japan, France, China and Argentina.

Key issues for work in the period 2008-2010

- Determine what molecular markers should be used to characterize progenitors and to enhance selection pressure for key quality traits.
- Apply more efficient quality testing tools (NIRS dough viscoelasticity, starch pasting properties, bread making) in advanced lines to enhance the proportion of lines with improved quality in international nurseries.
- Examine factors influencing quality stability across environments.

Winter Wheat Breeding – Turkey [P7 and P8]

The International Winter Wheat Improvement Program (IWWIP) is a partnership between Turkey, CIMMYT and ICARDA. The breeding program operates at 6-7 sites and builds on the infrastructure of Turkish research institutes. Crossing and screening is also done at ICARDA’s headquarters near Aleppo in Syria.

Major achievements for 2005-2007

- 39 winter wheat cultivars originating from IWWIP have been released since the program started. Nine cultivars were released in 2005-2007. They are characterized by higher yield potential under irrigated conditions and better disease resistance compared to currently grown cultivars. Total area under these cultivars is about 1 million ha.
- Genotype-by-environment analysis showed good correspondence of germplasm performance in Turkey with target regional environments. Breeding lines and cultivars with broad adaptation have been identified.
- International nurseries are distributed from Turkey to more than 100 cooperators in 50 countries.

Key changes in strategy and structure

- The breeding program reorients its priorities more towards semi-arid, dry environments, thus reducing the work for irrigated environments where it is strong.
- The structure of the program remains largely unchanged. Activities carried out at ICARDA-Syria will be reviewed to avoid duplication with the activities in Turkey.
- The system of international nurseries have been re-designed to better suit needs of cooperators: two observation nurseries for irrigated and semi-arid environments are distributed globally and two replicated yield trials with elite lines for semi-arid and irrigated environments target mainly at Central/West Asia and North Africa (CWANA).

Strategic plan for 2008-2010

- Increased emphasis on development of stem rust (Ug 99) resistant germplasm and study the genetic make up of resistance to yellow rust and if needed diversify the resistance.
- Introgress resistance to soil-borne diseases from resistance sources identified in the SBD program.
- Improve reliability for drought screening in environments with 1.5 to 2.5 t ha^{-1} and identify lines with proven performance under drought conditions.
- Emphasis on improving the grain quality.
- Establishment efficient MAS and double haploid systems for priority traits.
- Promote new superior cultivars in the target region.

Critical issues for implementation

- The implementation of IWWIP depends on local institutions whose capacity and commitment is variable.
- Establishment of efficient routine MAS and double haploid system at ICARDA.
- Infrastructure, equipment, facilities and human resources of the Turkish partners need to be enhanced for efficient modern wheat breeding program.
- Capacity of national programs to promote new cultivars limited.

Soil Borne Diseases (SBD) Major Achievements [P7]

- Established network on SBD research and showed that soil borne diseases are a problem in major wheat producing countries including India, China, Iran, Tunisia and Morocco.
- CCN is widespread in China – now identified in 10 provinces. Several of these (Henan, Hebei and Shandong) are in the key wheat bowl of China. CCN is also found in the drier provinces of Gansu and Inner Mongolia.
- Pathogenicity of CCN populations in China different from Turkey, but Cre 1 effective.
- CCN populations in China reported per gram or root are much higher than those in other areas where CCN has been reported to be economically important, although in almost all cases outside China, these are rainfed or supplementary irrigation systems with below 3 t ha^{-1}, whereas yields in China are much higher.
- In India, all nine known published sources for resistance to CCN were ineffective; however resistance sources derived from re-synthesized wheat were found resistant, suggesting that this is a new source.
- Identification of multiple root disease resistant wheat germplasm.
- Yield losses due to *F. culmorum* among 60 promising source of potential resistance again yield ranged from 6 to 43% in Turkey.
- Based on data from long term trial in Central Anatolia, fallow is an effective method to reduce root lesion nematodes but not cyst nematodes. Safflower is the best crop to reduce nematode populations. Barley should be avoided when CCN is a problem and lentil where lesion nematode populations are high.
- Started to establish a global nematode collection. Turkey agreed to have isolates from around the world in a quarantine facility in Turkey .
- Sources of resistance to root rots identified in Turkey and Australia hold throughout the CWANA region.

Key changes in strategy and structure

- Focus shifted from screening to breeding.

Strategic Plan for 2008-2010

- Expand collaboration with China and India in area of SBD.
- Further characterization of the importance of soil-borne pathogens (SBP) in the developing world.
- Incorporation of resistance of SBP into winter and spring wheat germplasm with an inter-disciplinary integrated approach.
- Application of MAS for SBD in winter wheat.
- Understanding of the importance of cropping systems and control of SBP in a holistic context of soil health, sustainability and economics.

Critical issues for the implementation

- Establish growth room to ensure reliability and throughput of germplasm resistance screening for SBP.
- Better integration of breeders, pathologists and molecular biologists to ensure molecular tools (e.g. MAS) are utilized in the most cost effective and efficient manner for the germplasm improvement.
- Continued support to capacity building activities in the region and alliances with key ARIs, and financial support through special projects (especially through the CGIAR System-wide Program on Integrated Pest Management as a vehicle to obtain funds for research on SBP affecting rainfed wheat productions systems worldwide.

Wheat Improvement in China – Major Achievements [P8]

The team in China has developed very strong skills in marker development for mainly quality and some disease traits and is MAS application in quality analysis among the leading groups in this area worldwide. In 2007, CIMMYT lines were sent to China for characterization for various traits using MAS.

- Developed and validated five functional (diagnostic) markers for polyphenol oxydase (PPO) –which causes browning of wheat products, yellow pigment and sprouting tolerance. More than 30 markers for quality, plant height, vernalization, photoperiod, and disease resistance were used to characterize Chinese and CIMMYT wheats.
- Characterized a *phytoene synthase 1* gene (*Psy1*), a critical enzyme in the carotenoid biosynthetic pathway related to yellow pigment, on 7A and development of a functional marker.
- QTL mapped for flour color components, yellow pigment content and polyphenol oxidase activity in common wheat.
- Isolated and expressed novel *Viviparous-1* genes in common wheat and developed and validated STS marker for pre-harvest sprouting tolerance.
- Characterized ca. 300 CIMMYT bread wheats for high- and low-molecular-weight glutenin subunits and other quality-related genes with SDS-PAGE, RP-HPLC and molecular markers.

- Developed two multiplex PCR assays targeted at improvement of bread-making and noodle qualities in common wheat.
- Characterized 300 Chinese cultivars for Allelic variation at the vernalization genes *Vrn-A1, Vrn-B1, Vrn-D1* and *Vrn-B3* their association with growth habit.
- Development of a STS marker specific to *Yr26* conferring resistance to wheat stripe rust using the resistance gene-analog polymorphism (RGAP) technique.
- Screened 1000 lines from China and Mexico with markers for *Yr 18/Lr 34* and *Yr 26*
- Identified optimal method for noodle quality testing (60% flour yield, 35% of water, and 1% salt).
- Released two cultivars.
- Received for work on wheat quality testing system and study on molecular aspects of processing quality, first class award, Chinese Academy of Agricultural Science and Beijing Municipal Government (highest award presented by Beijing Municipality).
- Wheat Quality Teams from Shandong AAS and CAAS received CGIAR Regional Award for Outstanding Agricultural Technology in Asia and Pacific Region.

Key changes in strategy and structure

- Make MAS a routine part of wheat breeding programs in China.
- Apply more emphasis on MAS for disease resistance and yield potential.
- Develop closer linkages with provincial program and advanced institutes.
- Facilitate greater data return and analysis on CIMMYT international nurseries grown through China.

Strategic plan for 2008-2010

- Greatly expand screening of Chinese cultivars in Njoro/Kenya for resistance to Ug99.
- Implementation of MAS in several leading wheat programs in China.
- Expand the collaboration with CIMMYT staff at headquarters on characterizing CIMMYT lines using MAS.
- Expand collaboration with CIMMYT staff at headquarters for developing germplasm with durable resistance to yellow rust.

Wheat Improvement in Kazakhstan – Main Achievements 2005-2007 [P7]

- Area under conservation agriculture expanded to more than 600,000 ha in 2007 and expansion continues rapidly. CIMMYT played major role that conservation agriculture became a state policy for crop production in Kazakhstan.
- Established KASIB - 50 best bread and durum wheat lines from 14 breeding programs in Kazakhstan and Russia tested over a large geographical area.
- Shuttle Mexico – Kazakhstan fully functioning: four lines jointly developed by CIMMYT and NARS are submitted for registration trials.

Strategic plan for for 2008-2010

- Identify winter wheats for Northern Kazakhstan. Due to global climate change, winters will become milder and this opens option to grow winter wheat, which has higher yield potential than spring sown spring wheat.

- Activities on conservation agriculture will focus on weed control, crop rotations and fertilization approaches.

Global Wheat Program Issues

- Master plan prepared to modernize the field operation of the wheat program; implementation started.
- Search for alternative locations to replace Toluca stations initiated.
- Development of a Global Wheat Atlas & Almanac.

Conclusion

Wheat germplasm developed by P7 and P8 is targeted at more than 70 million ha in the developing world. The occurrence of Ug99 represents a major threat to global wheat production and consequently global food security. Developing Ug99 resistant wheat cultivars is of highest priority for P7 and P8 for the coming years. As of today around 50% of all advanced lines have acceptable levels of resistance. Breeding wheat lines with enhanced water productivity is key trait for P7 and becomes increasingly important for P8 (water-use efficiency in irrigated systems). Global climate change affects wheat yields in P7 and P8 target regions and breeding for tolerance to high temperature became a priority trait. Developing wheat lines with enhanced end-use quality and industrial processing characteristics is paramount in major wheat markets, including breeding for increased micro-nutrient content (Fe and Zn) and reduced toxin content (*Fusarium*). MAS is routinely used in segregating populations and MAS and precision phenotyping to characterize parental lines. P7 and P8 scientists interact with their colleagues in P1, P2, P10 and P11.

Publications

In 2007, 21 GWP scientists published 24 (P7 = 9, P8 = 15) papers as senior author and 84 publications as co-author in refereed journals [see details in Annex 2].

International Germplasm Exchanges: Safety Issues regarding Pests, Pathogens, Transgenes, Intellectual Property Rights and Benefit Sharing

Monica Mezzalama

"Centers cannot distribute samples that do not meet health or quarantine standards, or whose transfer could pose the danger of a spread of pests or disease. In distributing samples, the Centers will comply with all relevant international and national legislation and regulations regarding phytosanitary, biosafety and other relevant standards and procedures."

"The Provider makes no warranties as to the safety of or title to the Material ………The phytosanitary condition of the Material is warranted only as described in any attached phytosanitary certificate. The Recipient assumes full responsibility for complying with the recipient nation's quarantine and biosafety regulations and rules as to import or release of genetic material."

Seed Health Laboratory

The above quoted statements determine the conditions under which germplasm exchange can be carried out safely preventing the distribution of seed carrying quarantined seed-borne pathogens and non quarantine seed-borne pathogens, that may reduce the quality of the seed or represent a potential threaten if introduced in a certain environment and that may induce the raise of new quarantine measures. There are at least 3 different levels of control to guarantee that the conditions stated above are met:

- At an international level the International Phytosanitary Certificate, a mandatory document that must accompany every shipment, and which adoption was ratified and accepted by all countries adhering to International Plant Protection Convention (FAO 1997, https://www.ippc.int/IPP/En/default.jsp) warrants that an official recognition on the condition of the germplasm is carried out under specific national regulations. The enforcement of the national phytosanitary regulations may not be homogeneous across different countries; therefore the recipient of the material is responsible for complying with its national phytosanitary regulation for importation.
- The CGIAR level guidelines for the safe movement of germplasm were established at the end of the 1990s (CGIAR 1999). Currently, these guidelines are under revision in the frame of the Collective Action for the Rehabilitation of Global Public Goods in the CGIAR Genetic Resources System: Phase 2, of the CGIAR System-wide Genetic Resources Programme, where CIMMYT participates as coordinator of two important activities regarding the preparation of seed health and unintentional transgenes detection guidelines.
- CIMMYT has policies and practices and its Seed Health Laboratory (SHL) controls and ensures the accomplishment of the international and national phytosanitary regulations of the material that is distributed every year. These guidelines respond to the need of the center to be in tune with the national phytosanitary regulations. CIMMYT SHL operates since 1998 under the approval of the Mexico's Ministry of Agriculture (SAGARPA) (*Norma Oficial Mexicana* 036-FITO-1995), and since April 2007with the accreditation under norm ISO/IEC NMX-EC-17025-IMNC-2005 *General*

Requirements for the Competence of Testing and Calibration Laboratories. These essential legal recognitions guarantee to the Mexican phytosanitary authorities that CIMMYT seed exchange activities do not jeopardize Mexican internal and international phytosanitary rules. Likewise, they provide re-assurances to our collaborators that CIMMYT procedures are standardized, internationally recognized and controlled constantly through internal and external audit processes.

Monitoring Transgenes

Following a report on the unintended presence of transgenic maize in the state of Oaxaca (Quist and Chapela 2001), CIMMYT was involved in the preparation and implementation of guidelines and practices to ensure that the maize bank accessions and the breeding materials are maintained free from the unintentional presence of transgenes. Moreover, to date 16 countries require a genetically modified organism (GMO)-free declaration for receiving wheat or maize germplasm from CIMMYT. CIMMYT drafted in 2003 the guidelines *Towards a CIMMYT strategy for screening germplasm and gene bank accessions for genetically engineered traits*. CIMMYT in collaboration with the International Rice Research Institute (IRRI, Philippines) and the International Potato Center (CIP, Peru), within the framework of the Collective Action for the Rehabilitation of Global Public Goods in the CGIAR Genetic Resources System: Phase 2, of the CGIAR System-wide Genetic Resources Programme, updated in 2007 this draft into a new document entitled *Develop Crop-specific Guidelines to Maintain Germplasm Free from Transgenes*.

Since 2004 maize seed introductions from countries were transgenic maize is grown in the open field were tested with the Enzyme Linked Immuno Sorbent Assay (ELISA), a protein detection method, for the presence of the most common events (insect and RoundUp-Ready® resistance). The practice of planting “maize sentinel rows” on station was adopted in 2006 and 2007 cycles by the genebank manager, and seed produced in sentinel rows was sent to the SHL for ELISA testing as well.

The principal functions of CIMMYT SHL are to:

- Certify the viability and health of maize and small grain cereals seed for international shipments.
- Control the safety of seed arriving to CIMMYT and application of the Mexican quarantine regulations .
- Detect the unintentional presence of transgenes on maize introductions from risky countries.
- Maintain the relationship with, and act as spokesman with Mexican phytosanitary authorities .
- Supervise the seed treating procedures.
- Inspect field multiplication and introduction plots.
- Ensure that chemical prophylaxes against quarantine disease are applied in the multiplication plots, in storehouses and in seed preparation areas (ex. against Karnal bunt of wheat).

Safe Movement of Germplasm

The SHL represents the point of entry and exit of all seed shipments to and from CIMMYT headquarters. Seed samples are delivered by programs for analyses, and upon completion of the testing process the seed is "released' and ready to be shipped. In 2007, the Crop Research Informatics Laboratory (CRIL) started the development of software supported by the International Crop Information System (ICIS) for a centralized registration of the shipment or of the introduction including pedigrees and seed testing results.

When the interception of a quarantine pathogen occur both on outgoing or incoming material, the SHL has the obligation to inform the Mexican phytosanitary authorities, who will indicate the measures needed to prevent the spread of the pathogen. In 2007 Karnal bunt (*Tilletia indica*) –a pathogen quarantined in Mexico by NOM 017-FITO-1995, was detected on wheat seed proceeding from Pakistan and the material was incinerated.

The International Treaty of Plant Genetic Resources for Food and Agriculture

Starting 1 January 2007, the CGIAR Centers had to use for all shipments the Standard Material Transfer Agreement (SMTA), which was adopted in the 1st Session of the Governing Body of the International Treaty on Plant Genetic Resources. It was agreed upon through the *Statement of the CGIAR Centers regarding Implementation of the Agreements between the Centers and the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture*. CIMMYT started using the Standard Material Transfer Agreement as of January 14, 2007, but did not distribute any material prior to that date. The implementation implied the printing of the SMTA in the six official languages of the United Nations (Arabic, Chinese, English French, Russian, and Spanish), the printing of the sticky labels (in the six official languages) that must seal the box containing the seed and that must be torn open when the seed shipment is opened (shrink-wrap option), and preparation of the website for the click-wrap option. A report of the result of the first year of implementation of the SMTA and related concerns regarding its use can be found in the document *International Treaty on Plant Genetic Resources for Food and Agriculture – Experience of the Centers of the CGIAR with the implementation of the agreements with the Governing Body, with particular reference to the SMTA*, which was submitted to the 2nd Session of the Governing Body" (Rome, Italy, 29 October – 2 November 2007).

Seed Inspection and Distribution Unit

Table 1 provides a summary of the number of seed shipments made during 2007 from CIMMYT headquarters. This table includes small grain cereals (SGC, bread and durum wheat, triticale and barley) international nurseries, maize international trials, and maize and SGC miscellaneous shipments. The seed is washed (in the case of SGC), treated, dried and packed by four permanent staff plus an adequate number of temporary workers, hired during peak times, in the preparation area of the Seed Inspection and Distribution Unit (SIDU). Two permanent SIDU staff organize the shipments, starting from the registration of seed requests to the preparation of the shipping documentation. The greatest part of maize germplasm distributed from CIMMYT headquarters goes to North and South America whereas wheat germplasm goes to Asia and Middle East. Both maize and SGC germplasm is distributed mainly to governmental research institutions and national programs. In 2007 the shipping costs for delivering the material listed in this table were US$ 105,000, of which 54.3% was charged to SIDU for sending international nurseries and trials and some genebank shipments, and the remaining was charged to programs and units sending miscellaneous shipments.

Table 1. Seed shipments from CIMMYT headquarters in 2007

	MAIZE													
Sector	EDUCATIONAL				GOVERNMENTAL				PRIVATE				TOTAL by REGION	
Region	No.	%	Kg	%	No.	%	Kg	%	No.	%	Kg	%	No.	Kg
Africa	4.00	*8.89*	50.59	*0.09*	38.00	*84.44*	466.11	*85.73*	3.00	*6.67*	27.00	*4.97*	45.00	543.70
Asia	9.00	*25.71*	61.54	*0.18*	23.00	*65.71*	267.86	*80.52*	3.00	*8.57*	3.25	*0.98*	35.00	332.65
Central America					8.00	*88.89*	70.20	*87.59*	1.00	*11.11*	9.95	*12.41*	9.00	80.15
Europe	6.00	*33.33*	3.50	*0.17*	9.00	*50.00*	10.40	*51.23*	3.00	*16.67*	6.40	*31.53*	18.00	20.30
Middle East					3.00	*100.00*	4.30	*100.00*	0.00	*0.00*	0.00	*0.00*	3.00	4.30
North America	40.00	*33.06*	214.63	*0.20*	34.00	*28.10*	592.60	*55.11*	47.00	*38.84*	268.16	*24.94*	121.00	1075.39
Oceania	3.00	*100.00*	53.40	*1.00*									3.00	53.40
Pacific Islands					1.00	*100.00*	3.30	*100.00*					1.00	3.30
South America	6.00	*12.00*	49.90	*0.08*	30.00	*60.00*	435.28	*68.46*	14.00	*28.00*	150.68	*23.70*	50.00	635.86
Total by crop	68.00	*23.86*	390.06	*0.14*	145.00	*50.88*	1645.20	*59.85*	71.00	*24.91*	465.44	*16.93*	285.00	2749.04

	SMALL GRAIN CEREALS													
Sector	EDUCATIONAL				GOVERNMENTAL				PRIVATE				TOTAL by REGION	
Region	No.	%	Kg	%	No.	%	Kg	%	No.	%	Kg	%	No.	Kg
Africa	6.00	*11.76*	492.67	*0.21*	39.00	*76.47*	1707.9	*73.10*	6.00	*11.76*	135.80	*5.81*	51.00	2336.31
Asia	20.00	*29.41*	300.82	*0.16*	46.00	*67.65*	1559.1	*82.66*	2.00	*2.94*	26.17	*1.39*	68.00	1886.13
Central America					1.00	*100.00*	8.60	*100.0*					1.00	8.60
Caribbean					1.00	*100.00*	0.70	*100.0*					1.00	0.70
Europe	8.00	*14.54*	24.06	*0.03*	35.00	*63.64*	564.25	*70.52*	12.00	*21.82*	211.77	*26.47*	55.00	800.08
Middle East	3.00	*16.66*	64.60	*0.05*	14.00	*77.78*	1177.8	*94.65*	1.00	*5.56*	2.00	*0.16*	18.00	1244.40
North America	20.00	*50.00*	175.83	*0.22*	17.00	*42.50*	535.57	*67.91*	3.00	*7.50*	77.20	*9.79*	40.00	788.60
Oceania	6.00	*60.00*	46.32	*0.61*	4.00	*40.00*	29.40	*38.83*					10.00	75.72
South America	9.00	*23.07*	113.87	*0.12*	24.00	*61.54*	659.31	*71.15*	6.00	*15.38*	153.50	*16.56*	39.00	926.68
Total by crop	72.00	*25.4417*	1218.2	*0.15*	180.00	*63.60*	5680.41	*70.41*	30.00	*10.60*	606.44	*7.52*	283.00	8067.20

References

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Biodiversity-based Breeding: Opportunities for Integration

Marilyn Warburton et al.

New methodology for identifying the diversity available to CIMMYT breeders

Methods to find new candidate genes/traits

- Extensive DNA sequence information is available: databases include DNA sequences of all species (EMBL, GenBank, TIGR/Venter Inst. DDBJ), maize (MAGI, and the entire sequence soon to be available), rice (RiceBlast, INE and Monsanto), *Arabidopsis* (TAIR), and wheat (ESTs at ITEC, GrainGenes, and HarvEST), which will soon be tied to a physical map. All sequencing will be very cheap in the near future, including re-sequencing techniques tied to the initial sequence reported for a gene or genome.

- Tilling/Eco-tilling: A method for reverse genetics called Targeting Induced Local Lesions IN Genomes (TILLING) has been developed as a method for inducing and identifying novel genetic variation, and has been demonstrated in the model plant *Arabidopsis thaliana*. Recently, TILLING has been extended to the improvement of crop plants and shows great promise as a general method for both functional genomics and modulation of key traits in diverse crops. However, maize may not be the best candidate for TILLING due to high levels of natural variation.

- Comparative genomics: has been suggested to find useful genes in any species following the identification and sequencing of a homolog in any species, including model plants such as *Arabidopsis* and rice. The same genes are not always present in all species, and microsynteny (gene order in short regions of the chromosome) is rarely as conserved across species as we would like, but comparative genomics has been very useful to find candidate genes for use in association analyses, and in some occasions, fine mapping or even map based cloning of genes in one species based on map position in another.

- Quantitative Trait Loci (QTL) mapping: Lest we forget the old tools in the rush to try new ones, QTL mapping is still a valid and valuable option for localizing genes and finding linked markers for marker assisted selection. In addition, with the advent of association mapping, both become even more valuable, since linkages found by either method that can be validated by the other method are ready to apply to the breeding program without fear of spurious results, and linkages specific to only one or a few genetic backgrounds.

- Core collections: the selection of representative subsets of germplasm allows a more in-depth analysis (genetically and phenotypically) but with a high probability of retaining much of the variation present in the entire collection.

- Interspecific crosses, to tap diversity from other species, have been extremely successful at CIMMYT. Genetic transformation remains an option, but is not always economically feasible or socially acceptable.

Methods to validate marker/gene associations

- New SNP and DArT markers (and the possibility to outsource analyses economically): SNPs in particular are getting better coverage of genomes, including 500,000 publicly available in humans, 250,000 in rice, and soon (within 3 years) 100,000 in maize. In wheat, we now have some SNPs ready to use, and 2500 polymorphic DArT markers.

- Association analysis: Seeks to find statistical associations between a change in a specific piece of DNA and a change in the phenotype of the plant. If the actual causal mutation is not being tested, a linked polymorphism can be associated if it is within the distance that linkage disequilibrium has not yet broken down for the germplasm under analysis. This can be done using the candidate gene approach for species or populations with low levels of linkage disequilibrium (usually out-crossing), or whole genome scanning, for species or populations with high levels of linkage disequilibrium (usually inbreeding). False positives due to population structure must be ruled out.

- Allele mining: Seeks to find new sequence diversity for known genes of interest and associate the new haplotypes with phenotypic differences. In addition, the effect of each haplotype in different genetic backgrounds, or in combinations with alleles from other genes, can be studied. Allele mining can be done on the level of the phenotype, protein/metabolite expression, gene expression, or DNA sequence. New sequencing methods make this technique very cheap and fast, but the question of what gene, and what region within the gene, is to be sequenced must be resolved. Some genes can be very long, and thus will be more expensive to sequence entirely; parts (especially expressed exons) may be sufficient. Correlating the changes in the DNA sequence (new haplotypes) with differences in phenotypes is done with the same statistical analyses as are used for association analysis.

- *In silico* mapping: For candidate genes in maize with no mapped position, it is now possible to map without a genetic mapping experiment. Once a single copy maize sequence is identified that you want mapped, you do a BLAST search against DNA sequences from BAC clones. BLAST (Basic Local Alignment Search Tool) is a set of programs designed to perform similarity searches on all available sequence data. BACs are Bacterial Artificial Chromosomes, which is a way to keep very long sequences of DNA in the lab. These BACs have been sequenced and physically mapped (put into the proper order per chromosome). A maize sequence BLASTed against the BAC sequence will identify where your gene is in the maize genome; this will be even more efficient when the entire sequence of the maize genome is publicly available.

- Precision phenotyping: more precise measurements or breaking down of complex traits into components with higher heritability (for breeding, mapping, and best linear unbiased predictor [BLUP] analyses of breeding value). Development of more precise higher throughput phenotyping systems for dissecting complex abiotic stresses including drought tolerance makes it more likely to find DNA sequences associated with the traits. What will be phenotyped should be carefully considered, as even in the best case it may take a few seasons, or a few years, to get populations ready (choose materials, intercross if necessary, line inbreeding if necessary, and seed increase and hybrid formation).

CIMMYT pilot studies for finding useful new sequence diversity via genomics tools

- Maize: allele mining of carotenoid content. This trait was chosen as an ideal pilot study for the search for new functional variation at the DNA level for several reasons. It is an important trait. Approximately 4.4 million pre-school aged children globally have developed visible eye damage due to VAD. It is a well studied trait, as the carotenoid pathway is known, and all genes and intermediate compounds have been worked out in other species. And a fortuitous union of projects and funding opportunities has allowed CIMMYT and US scientists to work on this trait in a very efficient manner. We found a gene underlying a quantitative trait locus, β *-hydroxylase* (*hydb1*), that is associated with the pro-vitamin A content in maize kernels. Three independent association mapping panels, three independent linkage mapping populations, qRT-PCR expression analysis and *E.coli* functional assays were used to confirm these results. Natural variation was identified within *hydb1* that explains 23% and 37% of the phenotypic variation for β -carotene content and the ratio of β -carotene over total carotenoids, respectively. Strong epistatic interactions were found between *hydb1* and *lcyopene epsilon cyclase* gene (*lcyE*), another recently identified major gene controlling provitamin A content in maize. Combined analysis of the two genes indicate that 43% and 56% of the phenotypic variation for β -carotene content and the ratio of β-carotene over total carotenoids respectively are accounted for. The frequencies of the beneficial alleles of the two genes are very different in temperate and tropical lines, indicating that major advances in β -carotene improvement are likely if these two germplasm sources are combined. To facilitate this task, we have created PCR-based markers and present the allelic composition of global maize germplasm that should be very useful for producing high level provitamin A maize in the future, especially in developing countries.

- Maize: association mapping of drought tolerance. Details of this project can be found in the appendix 1 *Development of informative DNA markers through association mapping in maize to improve drought tolerance in cereals*.

- Wheat: association mapping of disease resistance, maturity, and yield. Details of this project can be found among the suggested readings of Appendix 2 (Crossa et al. 2007.)

Overview of current maize and wheat genetic resources enhancements activities – some examples

- In wheat, for example, more targeted synthetics development and *Ph1* manipulation breeding schemes for making better use of translocation lines.

- More than 15,000 maize accessions have been phenotypically characterized for the selection of core subsets. In addition, dynamic core subset selectors have been created that can create cores based on phenotypes, crossing data (also being collected) passport/origin/pedigree data, genotypic data, or all three, for both maize and wheat.

- About 50 newly created primary re-synthesized hexaploid populations have been developed in wheat, and 30 enhanced maize pools refined with introgressed Latin American landrace germplasm. All have been developed as international public goods.

- Exotic parents are being used to increase allelic diversity in bread wheat breeding through crossing with landrace accessions, originating in abiotically stressed environments that have become isolated from mainstream gene pools. Evaluation of the inherent genetic diversity encompassed by drought adapted landraces compared with checks using DNA fingerprinting confirmed that some landraces were not only distant from checks but also showed significant diversity among each other. The best Mexican landraces showed superior ability in terms of water extraction from soil depth, as well as increased concentration of soluble carbohydrates in the stem shortly after anthesis.

Problems and prospects (what to do with the information gained)

- Development of markers for MAS in pro-vitamin A breeding: PCR markers have been developed for two key genes in the carotenoid pathway and key CIMMYT lines are now being screened to see which haplotype they carry. This information will be used to decide which hybrids could be made; to see if CIMMYT lines lack the best haplotype at either gene (a good possibility in the case of HydB1); and to quickly introgress this haplotype into key breeding lines at CIMMYT.

- Some of the DArT markers associated in the study of Crossa et al. 2007 are being converted to PCR or SNP markers for testing marker-assisted selection (MAS) in wheat in the wheat molecular breeding lab. Modeling is suggested to see how many can/should be used in the breeding program for maximum gain and minimum cost, and which markers would be the best to use. Family sizes will have to be very large in order to find individuals with favorable alleles at all those markers, or work over successive generations done with markers. Total selection gain could increase and number of generations of selection could be reduced. If modeling tests successful, any other bottlenecks to adoption by the wheat program will have to be identified and removed.

- One possibility combing many of the above mentioned techniques is the use of markers and pedigrees for predicting breeding value in maize and wheat, using all available data on markers, pedigrees, and phenotypes to calculate the BLUP of breeding value (or any specific trait). This can then be used for *in silico* QTL mapping or whole genome selection. Pilot studies at CIMMYT have been initiated with Cornell Univ. (Ithaca, N.Y, USA). Many questions still exist for this very new methodology (in crops), but would work well for alleles already present (and not rare) in breeding lines. How to find new alleles from other sources not already in CIMMYT breeding programs using this technology is not so apparent.

Steps forward: overcoming bottlenecks

- Cost: New markers are highly cost efficient when many markers are run on the same line but not when one or few are run, but hopefully costs for fewer assays will come down. Older marker types may be more cost efficient per marker for the short term when only a few markers are run on each line, but not when running many.

- Turn around time of analyses: we have been unsuccessful finding a company who we can outsource marker work for MAS because they cannot return the data fast enough. We are scaling up marker work in CIMMYT ABC by working to convert markers to what can be run on the sequencer in highly multiplexed runs, but our equipment is getting out of date. It is, however, an advance over old systems of agarose gel electrophoresis, which could only be scaled up linearly, and only up to a limit.

- Appropriate use of the biotech data in each step of the breeding program: Many questions must still be worked out in practice: When is it most efficient to use MAS? What weight to give the marker data vs. field data? Would modeling help?

- Validation of markers/techniques in each breeding program, for each trait: we have more markers than are currently being used, because of questions of utility in each genetic background for each trait. How much validation must be done before it is used? How much validation can be done as it is being used? We are exploring at CIMMYT some of these questions with traits such as maize's grey leaf spot (GLP), maize streak virus (MSV), and quality protein maize (QPM). How can we scale up to more quantitative traits in maize breeding?

- Finding and then integrating markers associated with more complex traits: this activity will have to be done with a combination of phenotypic plus genotypic selection. Modeling may help find the most efficient combination and timing of each.

- User friendly tools for data handling pipeline and selection modeling to integrate the information from markers: Do these tools already exist? Do we have to re-write them for our own species and programs? This research has been started at CIMMYT, but how can we speed up the process, and ensure the end products are acceptable and used by the breeders? It would be best if end users are involved from the very beginning of writing and implementation, but they are usually quite busy already. This engagement must start from the very beginning, and now data on accessions in the genebank, in the international trials, and increasingly, from breeder's programs are now becoming available to everyone electronically in a common platform.

Appendix 1.

Project update report

Date Report Submitted: **15 Oct 2007**

Identification

GCP Project Number:
Number 13

Project Name:
Development of informative DNA markers through association mapping in maize to improve drought tolerance in cereals

Principle Investigator
Marilyn Warburton

Collaborators (name, affiliation):

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Total project budget
$899,052

Grant Period
January 2005 – December 2007 (no-cost extension until July, 2008).

Reporting period
May 2007 - October 2007

Report

Executive Summary

Drought and low soil fertility are the major limiting factors for cereal-crop production in developing countries. The objective of this project is to use the natural variation inherent in the maize genome for the dissection of drought tolerance and for the identification of superior alleles. While maize grows in a wide range of environments and is the most diverse crop in the world, we do not know the genes that are responsible for these adaptations. For phenotypic selection, although allowing genetic progress, crops need to be fully evaluated in every environment, which is costly and time consuming. Association studies, proposed in this project, are based on correlation between a gene sequence and plant performance for target traits, and represent a powerful approach to evaluate candidate genes regulating plant phenotype. This project will focus on evaluating the genes in two major pathways that are involved in drought tolerance. We will build upon previous mapping approaches that have identified genomic regions containing a few hundred genes, and use high resolution approaches that can evaluate individual genes. This high resolution mapping will require combining rapid molecular approaches with careful evaluation of diverse germplasm for drought tolerance and physiological response. Additionally, by screening several hundred diverse lines this project maximizes its potential to identify the best alleles in the maize gene pool. The discovery of superior alleles at the gene level will permit the development of molecular markers that can facilitate breeding drought tolerance in a wide range of germplasm. One important benefit of working with the natural variation, it is that any discovery can be rapidly converted to improved breeding materials without the societal and regulatory obstacles of transgenics materials. Because of the genetic and physiological commonalities among cereal crops, this knowledge gathered in maize can be applied to all other cereal crops.

Introduction/Background

Drought strongly affects the production of cereals, and poses a serious threat to the food security of households, countries, and even entire subcontinents. In the future, the destructive impact of drought may grow, as the specter climate change becomes a reality. Plant breeding through phenotypic selection has resulted in major progress. To generate new information to complement plant breeding programs, association studies in maize have been proposed. These have great potential for resolving which individual genes may be responsible for the expression of a target trait and have the power to evaluate and characterize a wide range of alleles. In maize, only polymorphisms with extremely tight linkage to a locus that causes the phenotypic effect are likely to be significantly associated with the trait in a randomly mating population, thus providing a much finer resolution than genetic mapping. Therefore, association studies based on linkage disequilibrium (LD) may allow identification of the actual genes that are underlying QTL. Informative polymorphism identified in gene haplotypes and associated with a contrasting phenotype can then be converted into DNA markers for use in MAS experiments. Since the association approaches work with a wide range of germplasm, the MAS is more to likely work in diverse backgrounds.

Genes to study for association will be chosen from previous data produced at CIMMYT and from a study of the literature. The regulations of carbohydrate and ABA have been identified as two pathways of high interest. Other pathways with high probabilities for being involved in drought stress from studies in maize and other species will be included as well. Once target pathways have been identified, the selection of the most suitable candidate genes for association studies, i.e. those that have an impact on plant phenotype, is a key issue for consideration. The concentration of a given metabolite (e.g. sucrose or ABA) at a given time point is an informative property, but one that needs to be interpreted with care. To be most valuable as a straight-forward tool for phenotyping genetic material in an association mapping program, a trait should provide a time-integrated measure of pathway function. Such a measure is possible by assaying a succession of key anabolites and catabolites in target pathways. So, in this project, candidate genes will be identified by taking into account the following criteria: 1) genes encoding components of metabolic or signaling pathways that have established roles in carbohydrate and ABA sub-systems, 2) genes whose expression in previous transcript profiling experiments responded differently to drought in contrasting genotypes and 3) genes whose map positions are known and which co-localize with QTL previously detected under drought. All the information generated from the QTL and functional genomic approaches by the different partners of the project, and in related cereal species will be carefully considered to select the candidate genes to be studied here.

Phenotyping of drought tolerance of hybrids of the 350 lines chosen for this study will be done at the level of the field in 5 locations over two years, and at the level of metabolites from leaf, silk, and ear tissue harvested from lines and hybrids. Phenotyping will occur under well watered and water limiting conditions. Thus, the association of the genes chosen above to the phenotypes will be possible under the most rigorous conditions possible. Genes found to be associated to drought tolerance will be converted to simple-to-use markers for MAS in maize improvement.

Scientific Activities

I. Pre-phenotyping Trials conducted at CIMMYT, Tlaltizapán Station, Mexico

Dec 2005: Based on the flowering data collected from the previous evaluation we reassigned genotypes into different precocity groups. These groups were planted in two trials (well watered and stress) in replication (three replicates). Leaf samples, silks and ear tips were harvested at mild and severe stress stages for metabolite analysis.

The number of accessions was reduced from 460 to 400 (for genotyping issues). Reduction in numbers was achieved by looking at adaptability in Mexico (flowering and seed set) and extremes of flowering (MFLW under stress). Reclassifications was made to facilitate the field design (maintenance of different flowering times), with number of accessions in group 1 (n=110), group 2 (n=170) and group 3 (n=120). Numbers were further reduced to 350 when some testcrosses failed or failed to grow well in the first year's phenotyping of the hybrids.

Field treatment has been as follows:
Water stress at flowering time (first planting date)
Well-watered conditions (second planting date)

Field design: Alpha lattice, 2 Reps, for each individual group
2.5 meter row/plot 2 seeds per hole

Measurement: Harvest in methanol target tissue at 0 and 7D at flowering

About 4800 samples were harvested from field under stress in March and April 2006.

Three tissues – ear tips, silks and leaves
Two time points – 0 days and 7 days
Two stress replicates
Samples were placed in 80% methanol in the field and stored for 1 month in cold storage for exodiffusion.

Phenotyping: MFLW, plant size, chlorophyll content, SEN and root conductivity were collected for all inbred line entries.

Seed distribution: Testcrossed seeds (to CML312) were prepared for distribution to collaborators in four countries (May 2006); repeated for distribution in May 2007.

II. Metabolite analysis

Samples of leaves, silk and ear tip were stored at -20 for 4 weeks to let the metabolites from the tissues diffuse into the medium. Samples were processed and dry aliquots of the methanol were sent (96 well plates) to Cornell for analysis in early June 2006.

Metabolite analysis will be done at Cornell for sucrose, glucose, ABA, and ABA glucose ester (ABA-GE).

III. DNA extraction

DNA has been extracted from the 460 genotypes (which was then reduced to 350, the final drought association mapping panel size) and is ready to be used to determine the population structure using SNP markers.

IV. Identification of candidate genes

A first list of 20 candidate genes were developed following the meeting in Kenya based on: relevance of the gene pathway, 2) potential regulatory role of the candidate genes on the metabolites quantified in this study. A new list of 346 potential candidate genes was then generated by Tim Setter and Marilyn Warburton based on knowledge of the ABA and carbohydrate synthesis pathways and drought tolerance in maize and other plant species. This list was reduced to 150 when genes with no sequence similarities (or conversely, genes with too many homologs; i.e., gene families) in maize were removed; and genes with a lower probability of success were removed. Primers were developed for one or two contigs per candidate gene and were tested for amplification; successful primers were used to sequence a panel of 10 – 12 diverse inbred maize lines for SNP discovery. This was completed in September, 2006 for about 120 genes (others failed). The entire set of candidate genes were submitted to the Illumina company, and a panel of 1536 SNPs were developed from 102 candidate genes, which is considerably higher than what was

originally proposed, and greatly increases the probability of finding genes that significantly affect the performance of maize plants under drought conditions. Each gene is represented by 1 – 3 amplicons per gene, and 2 – 3 SNPs per amplicon have been found and submitted to the Illumina company. These SNPs, and 530 other SNPs from genes of interest to this project and to others, will be developed into a chip that will be used to screen the 350 inbred lines in this study.
An Illumina BeadStation format array was used for the 1536 SNPs. Information on the SNPs can be found at:

http://www.panzea.org/lit/data_sets.html

The DNA of the 350 inbred lines has been sent to the Cornell Core Facility for genotyping with the 1536 array (data still pending…)

V. Phenotyping of the hybrids
It was noted that we have phenotypic data for metabolites on inbred lines, and we will have field measured phenotypes on hybrids of those inbreds with a tester, but no overlapping data sets to correlate directly metabolite measurements with field measurements. Both can be associated with the candidate genes, which will be assayed for SNPs in the inbreds only (which will work fine assuming fixed effects of the tester alleles on all lines). It was debated if we should phenotype the inbreds, but it was pointed out that it wouldn't be in the same field trial as the tissues for the metabolites were taken from, so if there are high GxE or GxY, it wouldn't mean much. It was debated whether measuring metabolites for all hybrids would be worthwhile or feasible, but we concluded that the cost and sampling would be too much. Therefore, we decided to obtain field phenotypic data (but not metabolites) from the 2006-2007 growing season on the hybrids in all 5 field locations, and in the 2007-2008 season sample field phenotypic data on all the hybrids and sample metabolites on hybrids representing the best and worst hybrids (tails of the distribution, 50 each) based on important traits (yield, ASI, ears per plant) as determined in our trials in the 2006-2007 hybrid trials. The hybrids for metabolite analysis will be sampled in 2007-2008 under drought stressed conditions for one time period (either 0 or 7 days after anthesis, not both) and for the most significant tissues (to be determined from the 2005-2006 year's data and past experience) in order to correlate field performance and metabolite concentrations in the hybrids (in the tails, at least). These would be collected and sent to Cornell from 2 field locations (to test GxE for the metabolite work, too).

The following field analysis plan had been put forward to all partners and completed in the 2006-2007 planting season (and planned to repeat in 2007-2008):

Field treatment will be as follows:

Field design: Alpha lattice, 2 Reps, for each individual group
2.5 meter row/plot 2 seeds per hole
Water stress at flowering

Phenotyping will include:

Ear number per plant (ENO)
Grain yield (GY)
Hundred kernel weight (HKW)
Kernel number (KNO).
Drought tolerance index (DTI)
DTI = (GY-WS/GY-WW)*100
Ear height (EHT, first ear)
Plant height (PHT, base of the tassel)
Relative ear position (EPO)
Female flowering, days after sowing (FFLW)
Male flowering, days after sowing (MFLW)
Anthesis-silking interval (ASI)
Senescence (SEN) Score on a scale from 0 to 10 scored 20 and 30 days after female flowering (Kenya will not score this, as instructions arrived too late for their trial)
In addition, in Mexico and Thailand, the following will be measured (in the drought cycle only):
Chlorophyll content (CH) at the beginning and the end of the stress using a a portable chlorophyll meter (SPAD)
Root conductance (RCT), measured using an electrical capacitance meter, evaluated at the end of the stress (possibly! There is some doubt as to the utility of this measurement, see footnote*)

Phenotypic data from the 2006-2007 field season were turned in by all partners before July 2007. Preliminary analysis was conducted to ensure the data would be useable for association mapping. A correlation was calculated between the two reps within each location and treatment in order to access how good the data are (repeatability, confidence we have in the data); and the difference in the yield between the well watered and the drought stressed materials was calculated to ensure that the stressed plants are seeing a harsher environment. Unfortunately, the data from one field site (Zimbabwe) had very low repeatability between reps and many suspicious outliers, as well as low precision (not measured within units required) and cannot be used. Other field sites showed either lower than wanted correlation or low difference between the stressed and non-stressed fields. Only one field site (Thailand) showed excellent data for both criteria, but we feel that the data for all sites except Zimbabwe can be used.

VI. Association Analysis

A meeting was held on February 15, 2006 at Cornell University to discuss the project. In attendance were Tim Setter, Jean Marcel Ribaut, Marilyn Warburton, Ed Buckler, Mike Gore and Jonathan Crouch. A phone meeting with Alain Charcosset the previous day had brought his concerns to the table as well. Aspects of the project were discussed, in particular: genotyping/SNP discovery and staffing.

A postdoctoral researcher was hired to work on the data in 2006. He has spent part of that time based at Cornell’s IGD and part at CIMMYT, Mexico. A no cost extension was granted, as the postdoc was hired later than anticipated. He will complete all association mapping studies after harvest of the second year's phenotyping data (hopefully by July, 2008, the end of the project after the no-cost extension). All data will be turned in (and the final report) before the end, and manuscripts for publications should follow shortly after.

Deviations from the work plan
There are two main issues that need to be dealt with here. First the population genotyping. Initially we were going to contract out a company called Genaissance to undertake the SNP genotyping. This company is no longer able to do this work and therefore we are trying to find an alternative genotyping company that can do this work. We are now working with Ed. Bucker at Cornell to develop a complete set of SNP markers and Illumina platform has been chosen for genotyping.

Concerns raised in the November 2006 report on the progress of the SNP discovery work have been addressed and this area now progresses very smoothly.

Conclusions
Work is progressing well on this project. Major outputs have already exceeded expectations (the development of the SNP array containing 102 genes, not the originally planned 20, for example). The importance of good phenotyping data is coming into even clearer understanding, and the efforts on next year's phenotyping will be redoubled. Drought is a difficult trait to work on, but we have high hopes for this project. The entire list of candidate genes has already proven helpful to other projects on drought as well (the ADOT project of the GCP for example.)

Appendix A. Activities, Quantifiable Outputs, and Key Products

Project Title: Development of informative DNA markers through association mapping in maize to improve drought tolerance in cereals	
Principal Investigator/Institute: Marilyn Warburton	
Objective 1: Select a diverse set of maize inbred lines	
Activities	Quantifiable Outputs
1. Choose 350 lines from a larger set of over 600 based on field performance and ability to make testers with a common tester	1. Set of 350 diverse inbred lines that form the core of the Drought Association Mapping Panel 2. Testcrossed seed of all 350 lines to a common tester (CML312)
Objective 2: Select the candidate genes to be considered for the association tests	
Activities	Quantifiable Outputs
1. Select a set of candidate genes based on previous mapping studies, literature reviews, comparative genetics, etc, and narrow down to a list of ~100 based on availability of sequence data in maize and non-repetitive gene families.	3. List of ~300 candidate genes that may be important in drought tolerance in maize 4. List of ~200 candidate genes that have been sequenced in maize and are not part of repetitive gene families.
2. design primers and amplify in a diverse set of inbred lines; find SNPs within the successfully amplifying fragments	5. Successful amplification tests on amplicons from ~150 genes 6. SNPs found within all successfully amplified fragments
3. design a SNP array using 3 – 5 SNPs in each gene and many highly-informative SNPs from other genes for association mapping	7. Illumina format SNP array containing 1536 SNPs (half from the 101 successfully assayed drought candidate genes, half high information genes).
Objective 3: Characterize the plant material both at morphological and physiological levels	
Activities	Quantifiable Outputs
1. Metabolites assayed in inbred lines	8. 350 inbred lines characterized for sucrose, ABA, and starch over two years, two treatments (well watered and drought stressed) from three tissues.
2. Phenotypes measured in the field for identified traits in 5 locations, two treatments, two reps over two years	9. Phenotypic data collected for the first year 10. phenotypic data collected for the second year
Objective 4: Run association tests at selected candidate genes for the different target traits considered in this study	
Activities	Quantifiable Outputs
1. Population structure data collected on all inbreds in the study	11. Matrix of genetic distances between all pairs of lines in the study calculated based on neutral markers
2. Enter SNP data, population structure data, and phenotypic data into Tassel for analysis	12. Association data for candidate genes linked to each morphological and physiological traits.
Objective 5: Develop a set of suitable informative DNA markers for MAS	
Activities	Quantifiable Outputs
1. Design simple to assay markers from each SNP found to be positively associated with drought tolerance in maize	13. Molecular markers for Marker Assisted Selection of drought tolerance in maize
Objective 6: Disseminate results and strategies to NARS and other Generation Challenge Program (GCP) scientists	
Activities	Quantifiable Outputs
1. Place data into GCP central repository	14. Data available to all interested parties from the GCP central repository
2. Report results in GCP quarterly reports and at GCP annual research meetings	15. Data sent to GCP HQ and shown to GCP scientists
3. Publish in peer reviewed scientific journals	16. One or more journal articles explaining all results.

Key Products Developed by the Project (those that you think have the biggest potential impact – please limit to 5)

1. Testcrossed seed of all 350 lines to a common tester (CML312)
2. Illumina format SNP array containing 1536 SNPs (half from the 101 successfully assayed drought candidate genes, half high information genes)
3. Genetic, metabolic and phenotypic data sets for the 350 lines
4. Association data for candidate genes linked to each morphological and physiological traits
5. Molecular markers for Marker Assisted Selection of drought tolerance in maize

Appendix 2. Suggested Reading – Examples of the methodology listed in Part 1

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Drought Tolerant Maize for Africa (DTMA)

Wilfred Mwangi

Background and Rationale: "*Maize is life*"

Maize is the most important cereal food crop in sub-Saharan Africa (SSA), where over 650 million people consume on average 43 kg of maize per year (a 35% increase since 1960), reaching 85 to 140 kg in Kenya, Lesotho, Malawi, South Africa, Zambia, and Zimbabwe (FAOSTAT 2006, 2003-2005 average). Among different income groups, maize is a relatively more important source of both calories and protein for the poorer proportion of consumers, including HIV/AIDS-affected families, who cannot afford more expensive foods such as bread, milk or meat. For a smallholder farm family to harvest sufficient maize despite drought is core to family food and income security. With more than 50% of all SSA countries assigning over 50% of their cereal area to maize, maize production has strategic importance for food security and the socio-economic stability of countries and sub-regions.

Impact of drought and the role of drought tolerant crop varieties

Recurring droughts provide a continuous challenge to farming in Africa. In Southern Africa, the drought of 2002/2003 resulted in a food deficit of 3.3 million t, with an estimated 14 million people at risk of starvation. In 2005/2006, severe droughts affected maize farmers in Eastern Africa. Annual investments for food aid for SSA now range typically above US$ 500 million to over US$ 1 billion, which is an unsustainable burden on donors and recipients alike, not withstanding its destructive impact on local markets. Predictions of climate change suggest increased variability of rainfall, which will significantly affect maize grain outputs. Many farmers living in drought-prone areas are highly vulnerable and would benefit from crop cultivars that are high-yielding in good and bad years, and produce sufficient food in a much greater number of drought years. Stabilizing and increasing productivity in the face of recurring droughts also has significant importance for crop diversification, soil fertility and income generation, as farmers respond to the recurring threat of drought typically by planting more maize than needed in an average year. Drought tolerant maize cultivars provide them with food security on a smaller land area, freeing up land and labor for soil fertility-enhancing legumes and cash crops.

Vision of success for this project

The project has a 10-year vision to:

- Generate maize germplasm with 1 t ha^{-1} yield increase under drought stress conditions
- Increase average maize productivity under smallholder farmer conditions by 20 to 30% on adopting farms
- Reach 30 to 40 million people in SSA
- Potentially adding an annual average of US$ 160 to 200 million of grain in drought-affected areas

This project will reduce farmers' vulnerability, increase their food security and improve their livelihoods in drought years. It would also help them avoid resorting to damaging coping strategies such as reducing food consumption, selling meager assets, livestock and land, or taking children out of school.

Project Design and Implementation Plan

Target countries: The major maize producing countries of SSA - Angola, Benin, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Zambia, and Zimbabwe.

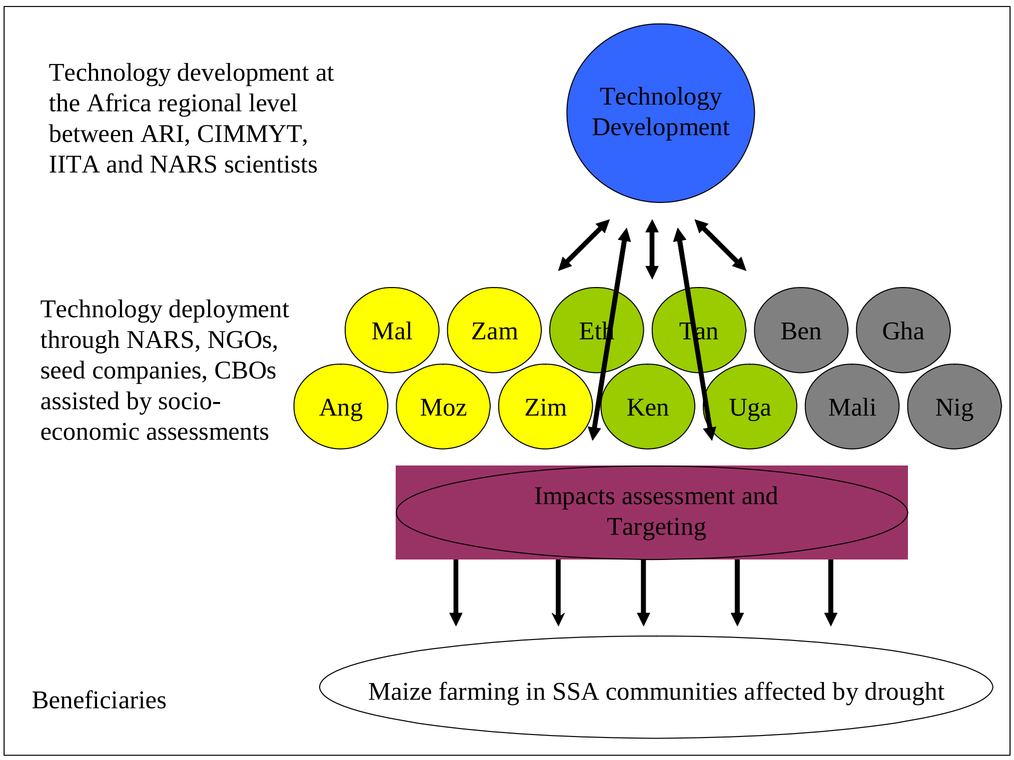

Fig 1. Overview of project design.

[Although schematically represented as a pipeline, the project will in fact be implemented in a value web context where all stakeholders from across the respective value chain are represented in planning and review of all components. Respective sub-region of each country indicated by different colors: Eastern (green), Southern (yellow) and West Africa (grey)]

Project design: This project consists of an Africa region-scoped technology development component and a nationally-scoped technology deployment component, as shown in Fig. 1. The project engages the collaboration of the International Institute of Tropical Agriculture (IITA), advanced research institutions (Cornell University for SNP platform, University of Hohenheim for doubled haploid technology), and partners from national agricultural research systems (NARS), seed companies, NGOs, and CBOs.

Project Objectives and First Year Achievements

The DTMA Project has nine objectives. 2007 included the following highlights:

Objective 1: Optimized pipeline for identifying new sources of drought tolerance (DT) - Identify new DT sources and develop molecular markers for DT genes of major effect

- A set of 350 inbred lines from CIMMYT and IITA breeding programs were chosen for association mapping after evaluating a set of 850 under two different water regimes at Tlaltizapán, Mexico.
- DNA was extracted from the 350 inbred lines and is of sufficient quality and quantity for SNP analysis, and will be used in association mapping for drought tolerance.
- An agreement was reached with a major seed company to introgress germplasm from most elite drought tolerant temperate inbreds into CIMMYT inbred lines.
- Elite temperate inbred lines whose plant variety protection expired were acquired from the USA for identification of drought tolerance effects that may not be available within tropical maize.

Objective 2: New tools and methodologies for drought tolerance breeding - Develop and invest in technology-assisted tools and improved breeding methodologies that greatly enhance the speed, cost effectiveness and precision of breeding progress for drought and complementary traits for smallholder conditions.

- On-the-ground activities on expansion and upgrading of managed drought screening and phenotyping facilities in Kenya, Mexico and Nigeria began in the second part of 2007.
- Two memoranda of understanding with NARS on hosting phenotyping sites were developed in Kenya and Zimbabwe.
- A major seed company assisted in analyzing mechanization options, which are in support of increasing breeding gains and first equipment investments in accelerating seed preparation and trial harvest/processing we made at all phenotyping locations.
- Strategies for selective genotyping and mapping using extreme phenotypes have been developed. Also, a seed-based DNA extraction and genotyping method was developed. A scientific paper on each was accepted for publication.
- Two software packages (Fieldbook and MaizeFinder) were upgraded to better manage increased volumes of phenotypic data and a large volume of historical data entered for making more appropriate selection decisions. Twenty-five DTMA scientists and technicians were trained in how to use these tools during August 2007 in Nairobi, Kenya. The updated version of Fieldbook (V8.4.5) has been available for downloading from the Internet via ftp://ftp.cgiar.org/cimmyt/FIELDBOOK/FIELDBOOK increasing its accessibility to the public.
- To accelerate tropical inbred development, inducer lines for doubled-haploid production were acquired from the University of Hohenheim, development of tropically adapted inducer lines initiated, and the first doubled-haploid plants produced during the Tlaltizapán summer season.

Objective 3: Focused and effective product development - Generate DT hybrids and open-pollinated cultivars (OPVs) adapted to the main drought-affected agro-ecologies and small farmer production conditions in SSA, in particular the mid-altitude and lowland ecologies

- 16 OPVs and 20 hybrids have been chosen for improvement based on farmers' and seed companies' feedback on deficiencies in Kenya, Zimbabwe and Nigeria and their targeted improvement for drought tolerance and distinct adaptive traits (e.g. resistance to Maize Streak Virus, (MSV)) initiated.
- A large number of new breeding crosses were initiated at all locations involving highly drought tolerant germplasm from Mexico and well adapted germplasm with medium to high levels of drought tolerance from Kenya, Nigeria and Zimbabwe, significantly expanding drought-breeding efforts from CIMMYT and IITA .
- Marker-assisted selection projects were initiated between 10 highly DT lines from the physiology research team in Mexico and moderately drought tolerant donors of multiple disease resistance (CML 395 and CML312) for rapid introgression of adaptive traits into DT background.
- In addition the formation of new recombinant inbred line (RIL) populations to pyramid and map DT alleles from various genetic backgrounds have been initiated. This activity will likely lead to germplasm with highest expression of drought tolerance (but varying levels of adaptation).

Objective 4: Involvement and capacity building of breeders from NARS and seed companies - Enhance the success of public NARS; particularly those supported by the Bill & Melinda Gates Foundation through PASS and private sector breeders for developing their own DT maize varieties with good performance and acceptance under smallholder farmers' conditions.

- 16 NARS breeders and economists from 10 project countries participated in the January 2007 project inception meeting in Naivasha, Kenya, while 22 took part in the annual planning meeting in September 2007 in Addis Ababa, Ethiopia.
- Four visiting scientists, one of whom was funded by DTMA, were attached to the CIMMYT-Kenya breeding program for six months.
- 30 NARS and private sector staff visited drought screening activities at the CIMMYT-Zimbabwe phenotyping location in Chiredzi in August 2007.
- A traveling workshop to visit breeding and dissemination activities in Ethiopia, Kenya, Tanzania and Uganda involved 10 NARS and 5 CIMMYT scientists.
- A minimum of 5 PhD students, 13 MSc students and 4 BSc students were supervised by DTMA project staff.
- A procedures' document detailing the process of submitting new maize cultivars to CIMMYT and IITA for entering into regional trials was distributed to collaborators.
- DTMA initiated the annual Best Maize Breeding and Technology Dissemination Team Award. In Eastern Africa, the 2007 award for the best maize breeding team was won by the Ethiopian Institute of Agricultural Research – Melkassa.

Objective 5: Variety testing and release - Improve and accelerate the variety testing and release process for new DT cultivars through NARS, seed companies and regulatory agencies.

- Multi-location and on-farm variety trials were distributed to partners in Eastern, Southern and West Africa. In West Africa, 70 multi-location trials were conducted in Benin and Nigeria while about 127 on-farm trials were carried out. In Eastern Africa, 156 multi-location trials were conducted in Ethiopia, Kenya, Tanzania and Uganda. In Southern Africa, 164 multi-location trials were conducted in Angola, Malawi, Mozambique, Zambia and Zimbabwe.
- Three training workshops on various aspects of effective maize variety testing and variety release considering drought conditions were held in 2007 in Harare, Zimbabwe (March); Arusha, Tanzania (June) and Ibadan, Nigeria (July) for 80 participants from NARS, private seed companies and national seed regulatory authorities.
- DVD- and web-based records of training sessions are in development in collaboration with Cornell University .
- Reports on regional trials managed in Eastern, Southern and West Africa were disseminated in February, October and March 2007, respectively and print copies were shared with NARS and private sector collaborators.
- The DTMA Best Maize Breeding and Technology Dissemination Team Award in Eastern Africa was won by Tanzania for the best dissemination team, led by the Selian Agricultural Research Institute.

Objective 6: Scale up seed production - Increase the capacity of seed companies to disseminate DT maize cultivars to a greater number of farmers in SSA.

- Breeder seed production is ongoing in Ibadan, Nigeria, Kiboko, Kenya and Harare, Zimbabwe.
- A simple spreadsheet for planning the seed production of OPVs and hybrids has been developed and disseminated to seed companies. Modules and applied curriculum. relevant to SSA-based seed companies have been prepared for a 2008 training course.
- Discussions were held with seed companies in Kenya, Malawi, Tanzania, Zambia and Zimbabwe to discuss production plans and business ideas for scaling up DT cultivars. National maize programs of Nigeria and Benin have been funded to produce adequate quantities of breeder seed for community-based seed production schemes.

Objectives 7: Advocacy and promotion - Assess and draw lessons from past impacts. Inform policy makers and farmer support groups about new DT cultivars and supporting interventions, which increase smallholder farmers' access and use of appropriate DT maize cultivars.

- A survey of the seed sector was conducted in the 11 project countries in SSA. All interviews and data management were completed at the end of October 2007.
- A total of 126 seed providers (80 seed companies and 46 NARS and NGOs) were interviewed in Angola (5), Ethiopia (13), Benin (4), Kenya (13), Malawi (10), Mozambique (16), Nigeria (15), Tanzania (15), Uganda (8), Zambia (11) and Zimbabwe (16). Also 10 seed companies were interviewed in South Africa. South Africa has a mature seed industry and the information will be used to compare with the situation of the seed industry in the 11 project countries.

- The Project Leader attended several regional meetings and in-country meetings, where he interacted with policy makers, NARS leaders, NGOs, private seed. companies, and other stakeholders about DTMA project objectives and activities
- The DT cultivars currently available have been posted on the DTMA website - http://www.cimmyt.org/dtmp/availabSeed.htm . An updated list of all available cultivars is under preparation and when completed will be disseminated through the web, NGOs, government agencies and farmer support groups.

Objective 8: Impact assessment and targeting – Inform investors of the most effective DT maize research and distribution strategies for greatest impact on poverty reduction of smallholder farmers in drought zones of Africa.

- Using internet map services, based on ArcIMS technology from ESRI an interactive map viewer was developed for the DTMA project. It gives access to layers of useful information on DTMA - target countries, seed survey data, maize mega-environments as well as on other agro-ecological and demographic information. It is accessible at http://www.cimmyt.org/gis/dtma/ Six CIMMYT maize mega-environments (ME) were identified and two specific ME were selected for DTMA: dry mid-altitude and dry lowland.
- Household survey interviewing was completed in Ethiopia, Kenya, Mozambique, Nigeria and Zambia. Data entry and cleaning is well under way.

Objectives 9: Project management and communication - Effectively implement and review project objectives with appropriate stakeholder representation, while keeping stakeholders, the public and policymakers in both the south and north informed about project progress.

- The DTMA project inception meeting was held in Naivasha, Kenya, in January 2007, brought together 46 participants from 10 of the 11 project countries.
- Both the Project Manager and the Project Administrator were appointed. The Executive Steering Committee of the project, consisting of four CIMMYT Program Directors and an IITA Deputy Director General is in place. A monitoring and evaluation (M&E) system was developed, is operational and under frequent review.
- Six Advisory Board members were identified and appointed based on their expertise to provide advice to the scientific, organizational, and institutional components of the project. They are Andy Greenland (Biotechnology, UK), Aline Funk (Commercial seed production and sales, USA), Jeff Luhanga (Seed systems, Malawi), Derek Byerlee (socio-economics, Australia), Peter Freymark (Genetics and plant breeding, USA), (David Bergvinson, BMGF, Canada) and Joe DeVries (AGRA/PASS, USA).
- The annual project meeting was held in September 2007 in Addis Ababa, Ethiopia and was attended by 61 participants, who included members of the newly inaugurated Advisory Board. Progress was reviewed and work plans for 2008 were developed.
- Three Regional Steering Committee meetings were held in Nairobi, Kenya, Ibadan, Nigeria and in Harare, Zimbabwe to review and approve annual in-country work plans.
- The Project's semi-annual progress report was prepared and presented at the end of July 2007.
- The DTMA website was developed and launched in July, as a means of increasing the public's access to information on the Project and is accessible at

http://www.cimmyt.org/dtmp/. The DTMA newsletter was also launched and is available on the DTMA website.

- Country-specific working group meetings were held in all partner countries. The working groups bring together representatives from all national stakeholders in the maize seed value chain (seed companies, NGOs, NARS, national regulatory authorities and CIMMYT) to increase impact of new technologies at the national level. The working groups developed and reviewed concept notes and proposals for DT maize development and dissemination based on national priorities for approval by regional Steering Committees and project executing agencies (CIMMYT, IITA).

6. Projected Five Year Achievements

Over the five years (2007 -2011), the project will have:

- Identified and characterized new and diverse germplasm with high levels of drought tolerance from among global genetic resources and made them widely available. Over a 10-year frame, these sources will form the foundation for generating a minimum of 20 elite, inbred lines with > 1 t ha^{-1} superior drought tolerance and diverse genetic basis.
- Identified molecular markers for drought tolerance genes in selected, high-value inbred lines and confirmed drought tolerance chromosomal regions in the maize genome likely to give the highest frequency of new DT alleles in future searches of maize genetic resources.
- Enhanced drought phenotyping sites in Kenya, Mexico, Nigeria and Zimbabwe to establish large-scale precision drought screening and research by CIMMYT, IITA, and NARS scientists that can be linked to drought research in other crops.
- Developed new tools that enhance breeding progress, e.g. reducing time and increasing efficiency of the development of inbred lines by above 25%.
- Developed a SNP-based marker genotyping platform for handling high-throughput gene-based marker-assisted selection (MAS) systems for DT maize development, and used both SNP and SSR-based approaches for combined field- and marker-based selection.
- Generated improved versions of current DT open-pollinated and hybrid cultivars and expanded the drought tolerance breeding efforts targeted for SSA by 100% to develop, over a 10-year time-frame, new cultivars with 20 to 30% increased productivity under smallholder farmers' conditions.
- Developed more effective field-based, molecular and bioinformatics approaches, substantially increasing genetic gain and breeding efficiency for drought tolerance.
- Backstopped 20 to 25 NARS maize breeding and graduate research projects, built the capacity of over 400 maize staff from NARS and seed services, and greatly increased their know-how, for more rapid development and release of new cultivars with improved drought tolerance.
- Trained and backstopped 20 to 40 small and emerging seed companies, focusing on maize-specific know-how relevant to SSA, and assisted them in building up a producer base and defining seed markets.
- Provided elite DT germplasm to NARS and the private seed sector at large, and information to farmer support groups (NGOs, community-based organizations, extension agencies, private seed sector) to increase farmer demand and access to seed

of DT maize cultivars, thereby extending the benefits of the project to 30 to 40 million farmers by Year 10.

- Supported in-country multi-stakeholder workgroups for promoting and integrating DT maize optimally with other value adding services, disseminating information and training for effective local scaling up strategies.
- Assessed past and potential future impacts of DT maize on maize grain production, rate of return to research and development investments as well as identified best investment portfolios and effective delivery pathways for DT maize.
- Developed policy briefs which describe hot-spots of vulnerability, priority zones for scaling up DT maize technology, and interventions that will increase smallholder farmers' access and use of appropriate DT maize cultivars and informed decision makers through two policy workshops and other non-project-specific venues.

Additional information

Project Annual Highlights on DTMA web site: http://www.cimmyt.org/dtmp/

Global Rust and *Fusarium* Initiatives: Essentials for Functionality

Etienne Duveiller

CIMMYT has been involved in two major initiatives to control wheat diseases in the past few years: the Global Rust Initiative (GRI) since mid-2005 and the Global *Fusarium* initiative (GFI) since March 2006.

The origins of GRI and GFI

The GRI was triggered by the new threat on food security caused by the potential spread of *Puccinia graminis* f.sp. *tritici* race Ug99 also known as TTKS in the USA, and discovered in Eastern Africa (Uganda) in 1999. Stem rust can cause major grain yield losses if resistant cultivars are not grown. This disease was a primary reason for the establishment of the Rockefeller Foundation sponsored Oficina de Estudios Especiales in Mexico, the predecessor of CIMMYT. The semi-dwarf, stem rust resistant, widely adapted spring wheat germplasm generated by this program led to the Green Revolution. Much of the materials possessed the historically durable "*Sr2* complex" from Hope and other well-known stem rust resistance genes. Later, as indicated by Dr. Norman Borlaug, "*the widespread use of the 1BL.1RS translocation with Sr31 and its continuing stem rust protection on a worldwide basis has led to complacency throughout the wheat community*". Very few scientists worked directly on stem rust in the world since the disease was pretty much under control. But the new race combines virulence for several resistance genes in the widespread and broadly adapted CIMMYT wheats, including *Sr31* and *Sr38*. As pointed by Borlaug, "*The discovery of race Ug99, was a reminder of the pathogen's ability to respond" and yet "little happened in breeding programs between the emergence of new concerns following the continued incidence and spread of race Ug99 in Eastern Africa*" until the race was found in Kenya in 2001, and then in Ethiopia in 2003. The degree of vulnerability of wheat production appeared more obvious with the confirmation in 2007 that Ug99 has spread from Eastern Africa across the Arabian Peninsula, and was infecting wheat in Yemen and Sudan. As of 2008, there are indications, pending confirmation by local authorities, that it has reached Iran, which corroborates the fears of wheat breeders and rust specialists. Given that spores of the fungus can travel great distances on the wind, the concern is that the new race could spread to the vast wheat-growing areas of the Middle East, Pakistan, India, Southeast Asia and beyond, where it has the potential to cause major crop losses. Wheat grown in other continents is also at great risk from Ug99, as studies have shown that many of the wheat cultivars grown are very susceptible to this new race.

The spread of UG99 to Kenya and Ethiopia prompted scientists from CIMMYT, ICARDA, EARO, KARI, Cornell and University of Sydney to form a panel of experts, who sound the alarm on a global stem rust pandemic as early as 2005. This collective reaction raised significant attention in the press, the scientific community and among important decision makers. It formerly launched a truly Global Rust Initiative with the aim to tackle a stem rust pandemic on time. Also this initiative offered prospects of positive spill-over effects for research on two other wheat rusts: yellow and brown rusts.

Fusarium Head Blight (FHB) or scab is a disease that reduces kernel weight, yield, and flour extraction rates in many important wheat growing areas in North and South America, China and Europe. In contrast with rusts, it is endemic to several regions, does not move through airborne spores over long distance and is not characterized by 'bust and burst' cycles that typify large acreages grown to a same variety when a new race defeats major genes of resistance. It is caused by several *Fusarium* species. Several *Fusarium* species associated with scab produce mycotoxins that contaminate the grain. Several of these compounds have been shown to be harmful to human and animal health. Thus, more stringent authorized mycotoxin contents have been imposed by various countries on producers depending on the type of wheat product. The most common mycotoxin in wheat affected by scab is deoxynivalenol (DON) produced by *F. graminearum* and *F. culmorum*. Yield losses due to scab are variable and depend on rainfall patterns and varieties. Combined losses to all steps in the food system are difficult to estimate, but the bill at the farm-gate alone in the USA is estimated to have exceded US$ 3 billion for the period 1990-2002. Yet, factors triggering epidemics are multiple and difficult to assess. Genetic resistance to the scab is much less clearly understood and managed than for wheat rusts and relies essentially on a Chinese source (Sumai#3) although some Brazilian and CIMMYT materials are promising.

Scab is considered as a major threat to food safety and wheat production in particular since the resurgence of FHB and huge losses found in North America in the mid 1990's which led to the USA to launch the USWBSI (US Wheat & Barley Scab Initiative) with a multi-million dollar investment annually in many research areas through this initiative. In Europe where the resurgence of FHB was also recognized, an European Fusarium Seminar was established in 1987 and met every 2 or 3 years to cover resistance breeding, pathology, molecular genetics, toxicology, pathogenicity and other areas as in the USWBSI. The main issue in the European Union is now the concern on food safety and production that is highly affected by *Fusarium* mycotoxin(s) and partly motivated the funding of actions such as the "Myco-Globe: *Research for Food Safety in Global System*". In the meantime, CIMMYT actively participated to two major symposiums to defeat FHB in Suzhou (China) in 2000, and in Orlando (USA) in 2004, which allowed involving more directly partners from Asia and developing countries. In this context, the call for a Global Fusarium Initiative by CIMMYT in March 2006 with support from the JIRCAS-CIMMYT project funded by the Govt. of Japan received attention of major stakeholders from the existing FHB research network with participation of scientists from USWBSI, Canada, Europe, Japan, China, South America and Australia. However, defining exactly the specific type of new actions needed for a collective action against FHB was probably more challenging considering the degree of investment already committed worldwide in advanced research on wheat scab. In summary, whereas the rust and FHB are recognized global threat on wheat production, the perception of emergency and effects differ. Whereas it seems possible to react quickly to defeat a rust epidemic and have impact on food security with the appropriate funding, mitigating FHB and improving food safety require more complex research needs to be addressed to effectively control scab based on the present knowledge.

Essentials for Functionality

Global initiatives to tackle rust and FHB due to the complexity and dimension of the problems are not a small endeavor and require full commitment in staff and resources. The chances of success depend on the following:

- Recognized leadership on the subject
- Prospects of impact.
- Defining CIMMYT's specific role and partnerships.
- Advocacy and awareness.
- Resources, staff stability and management capacity of collective actions.

We revise briefly CIMMYT's comparative advantage and weaknesses in the above aspects toward contributing to both initiatives and solving problems.

Recognized leadership on the subject

- Dr. Norman E. Borlaug came to Mexico in 1944 to solve stem rust problem and succeeded in doing so through the high-yielding, rust resistant cultivars. Stem rust resistance was behind the success story that led to the Green Revolution. CIMMYT is the recognized global leader in building effective durable resistance against other rusts. Resistant cultivars of CIMMYT origin with leaf and yellow rust are released worldwide. Numerous first rank publications on rusts are authored by CIMMYT.
- CIMMYT is a recognized international partner for FHB research since the early 1980s and made adapted germplasm with resistance to FHB more accessible to breeding programs worldwide through shuttle breeding with China and collaboration with Brazil. The impact has been however less visible. Compared to the current investment in FHB research in particular in USA, Europe, Canada and Japan, CIMMYT's research on FHB remains small despite the significant investment of the Govt. Japan in recent years. Likewise, CIMMYT's current expertise in *Fusarium* mycotoxin(s) is small.

Prospects of impact

- Unsurprisingly, the prospect of impact differs depending on disease, the sense of emergency, the dimension of potential consequences if not acting timely, e.g. food security may be at risk in the developing world at a time that staple food prices are already high, or losses of market shares and hidden food safety issues due to mycotoxin contamination.
- Impact means delivering a product/cultivar in the field in relatively short time and concrete actions such as a new shuttle breeding program between CIMMYT-Mexico and Eastern Africa, screening cultivars from around the world in a record time at a hot spot site, and not the least, training…
- Strong collaboration with advanced research partners specialized on the subject and keen interest taken by them as well as by the NARS partners.
- Outcome of investment. Despite huge investments in scab research in USA and Europe in the last decade, no breakthrough is observed in the field and the world relies essentially on the same Chinese source of resistance as well as use of chemicals.

- Prospects of spill-over effects: Action against stem rust will have collateral advantages to tackle yellow rust and leaf rust. Synergies between FHB and crown rot research are less obvious.
- Credibility. Actions must be tangible and the initiative should offer a platform to develop what could not be done otherwise than in joining efforts.

Defining CIMMYT's role and partnerships

- Why is CIMMYT needed in a Global Initiative? What can we offer to clients on rusts; what can we offer on FHB?
- CIMMYT has a global mandate for wheat improvement in less developed countries. Germplasm is paramount for networking with NARS partners, who are equally necessary and unique for developing and delivering research products, e.g. EARO in Ethiopia and KARI in Kenya for Ug99 rust, or JAAS, CAAS and PROCISUR for FHB.
- CIMMYT wheat germplasm is adapted to most wheat growing environments in the developing world and traits of interest can be most efficiently be made available to cooperators in elite background.
- No success without strong partnerships with ARIs involved in impact-oriented and applied research.
- In FHB, a great deal of research is on-going in well established and funded networks in Europe in USA and China. A GFI cannot work independently from such key players.

Advocacy and awareness of the public and donors

- Key role of an organized lobbying, e.g. Dr. Norman Borlaug bringing the global threat of Ug99 to the attention of the international community. Having a champion like Dr. Borlaug as supporter allowed placing news in key weekly journals such as Nature and Science.
- High-profile press releases, contacting US congress, FAO or influential political leaders was needed to develop with a sense of urgency awareness about Ug99.
- Alliance between centers (CIMMYT–ICARDA), ARIs (Cornell Univ., Univ. of Sydney, USDA-ARS, Ag-Canada) and key NARS was a strong selling point for GRI.
- Perception of the likely impact on the lives of resource poor. Stem rust epidemic is likely to hurt poor people in Africa, the Middle East and Asia.
- Web sites are excellent but provided they are not static and we have a real website administrator position in house to make the site dynamic and necessary to the global community.

Resources, staff stability and management capacity of collective actions

- Specific resource allocation is needed for long-term undertakings.
- Leading a global initiative requires commitment for communication, funding and staff time, as well as resources for establishing and routinely updating the web site.
- Steering committee must be established or an endorsed panel of experts from different horizons should be in place.
- Resources for regular stakeholders and research partners meetings.
- Staff stability is essential, e.g. the key staff involved at CIMMYT in organizing the GFI meeting in March 2006 left the institution. Resolutions from the meeting were not formally endorsed and publicized neither was the steering committee established.

Cereal Systems Intensification in Asia

Achim Doberman et al.

Management Issues

IRRI and CIMMYT staff involved in the Intensive Production Systems in Asia (IPSA) Project have further strengthened their communication mechanisms, including joint development of project concept notes and proposals, sharing of a wide range of information, and discussion of specific project details. Roland Buresh was interim IPSA leader until Achim Dobermann became the IRRI Program 2 and IPSA leader effective 1st September 2007. He also joined IRRI as a consultant to begin working with various IRRI and CIMMYT staff on IPSA issues, including three stays at IRRI, an initial visit to CIMMYT, and discussions with international private sector representatives. Likewise, Jagadish Timsina was hired as consultant to lead the currently ongoing initial strategic assessment of rice-maize systems in Asia. He has worked at both IRRI and CIMMYT, interacting with a wide range of staff. As per today the core IPSA team includes

- IRRI: Roland Buresh, Achim Dobermann, and Jagadish Timsina.
- CIMMYT: John Dixon, Stephen Waddington, Gary Atlin, David Hodson, and Erika Meng.

Other support is provided by a wider range of scientists at both institutes.

Technical Progress

IRRI and CIMMYT scientists organized a special symposium on *Emerging Rice-Maize Systems in Asia*, held at the annual ASA-SSSA-CSSA meeting in November 2007. A regional IPSA planning workshop with National Agricultural Research and Extension Systems (NARES) was held during 4-8 December 2006 at IRRI to develop the general framework for IPSA activities, with initial emphasis on rice-maize systems. It was agreed that IPSA will concentrate on irrigated and favourable rainfed lowland areas in Asia with rice-based cropping systems in which rice and maize are grown in sequence in the same field. Five research outputs were identified as shown in Fig. 1.

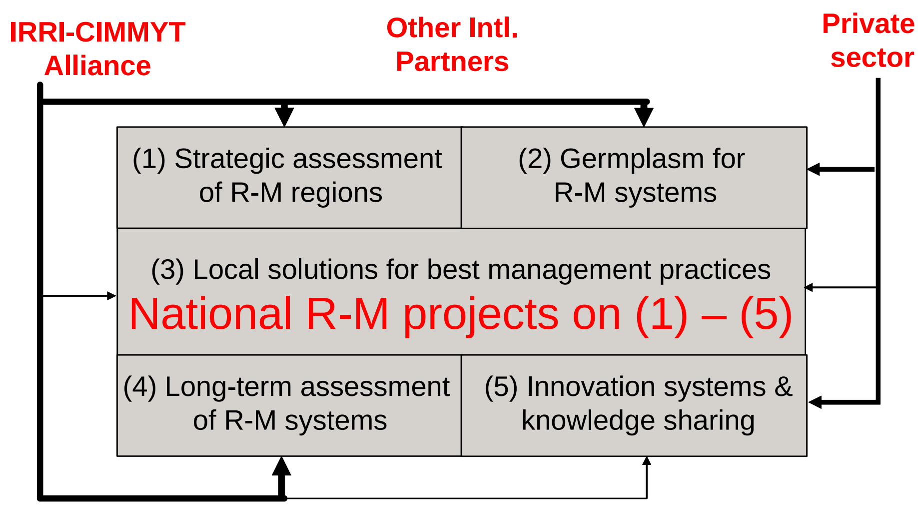

Fig. 1. Proposed framework for IPSA activities on rice-maize (RM) system

During the first six months of 2007, scientists of the two centers and their NARES partners have communicated further to consolidate their views on current and future rice-maize agroecosystems (Table 1) and what immediate priorities to address. Several specific research proposals have been developed and specific research activities were started with available core funds and NARES contributions for national activities.

The regional biophysical and socioeconomic assessment of the current and future potential for rice-maize systems in Asia was started. A first phase focuses on yield potential simulations and identifying major cropping system scenarios in 27 potential or existing rice-maize system domains in the Philippines, Indonesia, Vietnam, Thailand, China, India, Bangladesh, and Nepal (Table 2). Contacts to NARES scientists in these regions were established. The ORYZA2000, Hybrid-Maize, and CROPGRO (for soybean in Vietnam) models were used in combination with a new set of NASA climate data. Results show substantial potential for rice-maize systems and in many areas, including large existing yields gaps, particularly for maize.

The second phase is currently concentrating on integrating biophysical and socioeconomic characterization and GIS analysis. A two-stage approach is followed, including collection of baseline information for the initial strategic assessment in 2007 at regional scale (key sites, Table 2) and more detailed socioeconomic assessment at national level, as part of country-level strategic assessment and planning activities in 2008. The baseline survey was designed and is currently being conducted. Results will be summarized and published by February 2008. In addition to the regional effort, more detailed strategic assessments were initialized for two countries, Bangladesh and the Philippines, and are being conducted by national staff in collaboration with IPSA scientists. Work on Bangladesh was carried out by Dr. Yusuf Ali during a visit to CIMMYT in collaboration with CIMMYT and IRRI staff and is near completion.

At CIMMYT, work commenced on breeding for water-logging tolerance in maize. Screening methods are being developed at CIMMYT headquarters for anaerobic seed germination tolerance. Initial efforts to conduct field screening for vegetative-stage tolerance at the CIMMYT lowland tropical station at Agua Fría indicate that this facility is not likely to be suitable for this purpose without substantial investments in land leveling and development of bunded fields. It is therefore suggested that field screening for vegetative-stage water-logging tolerance be conducted at IRRI.

Approaches for site-specific nutrient management in rice were further developed and fine-tuned for local conditions. A revised pocket guide for nutrient management in rice was published. National and location-specific guidelines continued to be refined in collaboration with NARES groups in Indonesia, the Philippines and Vietnam. In collaboration with the maize project of the Southeast Asia Program of IPNI and IPI, a first version of SSNM in tropical maize was developed and a pocket guide similar to the rice one will be drafted in the upcoming months. Outputs of activities on site-specific nutrient management for rice have been incorporated in the Rice Knowledge Bank (RKB) and the output for rice and maize will be incorporated in the Cereal Knowledge Bank.

A new rice-maize experiment was initiated at IRRI in response to findings in the 14-year-old rice-maize experiment at IRRI of reduced soil carbon and reduced soil nitrogen-supplying capacity following conversion of continuous rice to rice-maize with full tillage for maize. In the new experiment, maize was established following rice into rice stubble with zero and minimum tillage. With best management practices for irrigation and fertilization, comparable maize yield of 8 t ha^{-1} was obtained with zero-tillage and full-tillage. Based on these encouraging results, we plan to expand evaluation into farmers' fields in Laguna Province in late 2007 in partnership with Univ. of Philippines at Los Baños (UPLB). In addition, a staff member of UPLB will begin her PhD research in late 2007 on the assessment of carbon and nitrogen dynamics and sustainability of rice-maize systems with alternative tillage practices.

Several concept notes or full research proposals were submitted during the year:

- Concept note on *Strategic assessment and sustainable management of rice-maize systems in India*
- Phase 0 proposal on *Sustainable Intensification of Emerging High Productivity Maize-Rice Systems in Bangladesh through the Combination of Water Efficient Maize Germplasm and Conservation Agriculture Interventions*
- Phase 0 proposal on *Optimizing the management of rice-maize production systems for sustainable profit in response to water supply and landscape position*
- Proposal on *Integrated rice-maize production system in selected areas in Luzon Island, Philippines*
- Proposal on *Detection, mapping, and deployment of alleles conferring anaerobic germination and seedling water-logging tolerance in maize for Asian tropical lowlands*
- Proposal on *Abiotic stress tolerant maize for increasing income and food security among the poor in eastern India and Bangladesh*

At the national level, we have encouraged and supported NARES-led activities in selected countries. In the Philippines, the lead partner is UPLB. Activities were planned and submitted for support by DA-BAR. Despite the absence of support from DA-BAR, activities with other sources of funds will proceed in the second half of 2007 on the strategic assessment of rice-maize systems at selected locations in the Philippines and on the assessment of reduced tillage maize arising from 2007 field research at IRRI. A rice-maize working group was officially formed in Vietnam, led by the Director of the Food Crops Research Institute. First discussions were also held with ICFORD leaders in Indonesia to gradually move into rice-maize work in 2008 through an emerging national Indonesian Rice Research Consortium.

Preliminary discussions were held with leaders of the International Fertilizer Industry Association (IFA), the International Plant Nutrition Institute (IPNI) and the International Potash Institute (IPI) to jointly fund a new initiative on *Ecological Intensification and Diversification of Rice Systems*. We will continue developing this in late 2007 - early 2008, including holding a small brainstorming workshop at IRRI. In 2008, we will begin working more closely with the Irrigated Rice Research Consortium (IRRC) and the Rice-Wheat Consortium (RWC). A high priority will be to jointly develop a large umbrella proposal on improving intensive cereal systems in South Asia, targeting the Bill and Melinda Gates Foundation for funding.

IPSA in IRRI and CIMMYT Medium Term Plans

IPSA activities are integrated into the Medium-Term Plans of both IRRI and CIMMYT. At IRRI, IPSA activities fall into Output 2 (Integrated resource management options and germplasm to address threats to sustainability related to trends of increasing intensification and diversification and decreasing freshwater resources) of Program 2 (Sustaining productivity in intensive rice-based systems: rice and the environment. At CIMMYT, IPSA activities falls into MTP Project 10: Maize and Wheat Systems Management, which addresses systems aspects of conservation agriculture including crop-soil management principles and methods (related to soil water and carbon) and best practices related to system management (nutrient and water use efficiency, measurements of system productivity, residue management, and innovation and learning systems). IPSA activities also relate to CIMMYT MTP Project 3: Stress Tolerant Maize and MTP Project 4: Nutritious and Specialty Maize.

Table 1. Preliminary classification of rice (R)-maize (M) agroecosystems in Asia

Key features	Current systems	Emerging systems	Examples
1. Tropical, warm, humid and subhumid, no winter			
Tropical, high rainfall; mostly in a dry season – wet season pattern; both rice and maize not limited by low temperatures and can be grown all year round	R – R, R – Fallow	R – M, M – R	Laguna, Central Luzon, Philippines; West Java, Central Java, North Sumatra, South Sulawesi, Indonesia; Central & lower north Plain, Thailand
	R – R – R R – R – M	R – M – R R – R – M	Mekong Delta, Vietnam; East Java, Central Lampung, Indonesia
	R – M – M	R – M - M	
2. Tropical, warm, semiarid, no winter			
Tropical monsoon with longer dry season; both rice and maize not limited by low temperatures and can be grown all year round	R – R – pulses (WS – DS)	R – M (maize in dry season to save water)	Cauvery Delta, Tamil Nadu, India; Karnataka, India; Hyderabad, India
3. Sub-tropical, subhumid, warm summer, mild cool winter			
Sub-tropical monsoon with cool winter and summer rainfall; rice but not maize maybe limited by low temperatures	R – W R – Boro rice	R – M (maize on residual moisture), R – R – M	Central, western Bangladesh; Eastern Terai, Nepal; West Bengal, eastern Bihar, India
4. Sub-tropical to warm temperate, subhumid, warm summer, mild to severe cold winter			
4.1. Sub-tropical monsoon with cold winter and summer rainfall; both rice and maize limited by low temperatures and can't be grown for some time in winter	R – W (kharif – rabi)	R – M (maize in winter or rabi)	Northern India; Northwest Bangladesh; Central & western Terai & hills, Nepal; Red River Delta, Vietnam
4.2. Sub-tropical to warm temperate, with severe cold winter; both rice and maize limited by low temperatures and can't be grown for some time in winter	R – R R – Fallow	M – R R – M	South Central China (Hunan, Hubei), Southeast China (Jiangsu, Zhejiang)

Table 2. Locations for the strategic assessment of lowland rice (R)-maize (M) systems in Asia

Country	Location	Climate	Soils	Current systems	Emerging systems
Philippines	Pila, Lagna	Humid, tropical monsoonal	Heavy clay	Rice-rice (R-R), rice-fallow (R-F), rice-vegetables (R-V), rice-watermelons (R-WM)	Rice-maize (R-M), maize-rice (M-R)
	Munoz, Nueva Ecija	Humid, tropical monsoonal	Heavy clay	R-R, R-F, R-V, Rice-maize (R-M)	R-M, M-R
Indonesia	Sukamandi, West Java	Humid, semi hot, equatorial	Clay	R-R, rice-secondary crops (R-SC)	R-M, R-R-M
	Kediri, East Java	Humid, semi hot, equatorial	Clay	Rice-rice-vegetables (R-R-V), rice-maize-maize (R-M-M), rice-rice-maize (R-R-M)	R-R-M, R-M-M
	Medan, North Sumatra	Humid, semi hot, equatorial	Clay	R-R, R-M, rice-rice-mungbean (R-R-MB), R-R-M, rice-rice-soybean (R-R-SB)	R-M, R-R-M
	Central Lampung	Humid, semi hot, equatorial	Clay	R-R, R-M, R-R-MB, R-R-M, R-R-SB	R-M, R-R-M
	Maros, South Sulawesi	Humid, semi hot, equatorial	Clay	R-R, R-F, rice-mungbean (R-MB)	R-M
Vietnam	An Giang, South Vietnam	Tropical, monsoonal	Sandy loam	R-R-R	
	Thanh Hoa, Central-north Vietnam	Sub-tropical, cold winter, hot and humid summer	Sandy loam	R-R	R-R-M
	Vinh Phuc, North Vietnam	Sub-tropical, cold winter, hot and humid summer	Clay loam (degraded)	R-R, R-R-M, R-R-SB, R-R-V, rice-rice-sweet potato (R-R-SP)	R-R-M
China	Changsha, Hunan	Sub-tropical, cold winter	Clay loam to silty clay	Early rice- late rice (ER-LR), Late rice- fallow (LR-F)	R-M
	Wuhan, Hubei	Sub-tropical, cold winter	Clay loam to silty clay	ER-LR, LR-F	R-M
	Yangzhou, Jiangsu	Sub-tropical to warm temperate, severe cold winter	Clay loam to silty clay	ER-LR, late rice-winter crops (LR-WC)	R-M, M-R
	Jinhua, Zhejiang	Sub-tropical to warm temperate, severe cold winter	Clay loam to silty clay	ER-LR, LR-WC, late rice-wheat (LR-W), LR-F, late rice-vegetables (LR-V)	R-M
Thailand	Phitsanulok, Muang Dist.	Tropical	Loamy clay to clay	R-R	R-M
	Suphan Buri, Central Plain	Tropical, warm and humid	Clayey	R-R, R-R-R	R-M, R-R-M
	Chiang Rai, North	Tropical	Loamy clay to clay	R-R	R-M

Country	Location	Climate	Soils	Current systems	Emerging systems
India	Aduthurai & Thanjavur, Tamil Nadu	Humid tropical, northeast monsoon	Ad: Clay loam to clay, Th: sandy loam to clay loam	R-R, rice-rice-pulses (R-R-Pu), rice-rice-sesame (R-R-S), rice-rice-cotton (R-R-C)	R-M, R-R-M
	Hyderabad, A.P.	Tropical, semi-arid, southwest monsoon	Clay	R-R, R-M, rice-pulses (R-Pu), rice-mustard (R-Mu)	R-M
	Bangalore, Karnataka	Tropical, semi-arid, monsoon	Clay	R-R, R-M, R-Pu, R-V	R-M
	Patna, Bihar	Sub-tropical, monsoonal, cold winter	Clay	Rice-wheat (R-W), rice-Boro rice, R-Pu, R-F	R-M
	Ludhiana, Punjab	Sub-tropical monsoonal, cold winter	Sandy loam, loamy sand	R-W	M-W, R-M
Bangladesh	Bogra, Central	Tropical, warm/cool winter	Sandy loam, silty loam	T. aman rice- Boro rice (TR-BR), T. aman rice-wheat (TR-W), Maize-T. aman rice (M-TR), Potato-maize-T. aman (P-M-TR), Maize-Jute- T. aman (M-J-TR)	TR-M, M-TR, P-M-TR, M-J-TR
	Jessore, Central west	Tropical, warm/cool winter	Sandy loam, silty loam	TR-BR, TR-W, M-TR, P-M-TR, M-J-TR	TR-M, M-TR, P-M-TR, M-J-TR
	Dinajpur, North west	Sub-tropical, cool winter	Sandy loam	TR-BR, TR-W, M-TR, P-M-TR, M-J-TR	TR-M, M-TR, P-M-TR, M-J-TR
Nepal	Chitwan, Central south	Sub-tropical, cold winter	Sandy loam, silty loam	R-W, rice-wheat-maize (R-W-M), rice-potato-maize (R-P-M), rice-mustard-maize (R-Mu-M)	R-M, R-M-M
	Dhankuta, eastern hills	Sub-tropical to warm temperate, cold winter, cooler nights all year round	Sandy clay loam, silty clay loam	R-W-M, R-P-M, R-Mu-M	R-W-M, R-P-M, R-Mu-M

Creating Capacity and Knowledge Platforms for the Devolution of Research

Petr Kosina and John Dixon

"Give a man a fish, he'll eat for a day; teach a man to fish and he'll eat for a lifetime"
Chinese proverb

The international public mandate of the CGIAR requires that the outputs of its research – public goods in the form of data, information, knowledge, and genetic resources – are preserved for posterity. However, delivering impacts today and tomorrow also requires that data, information and knowledge produced by, or held by CGIAR centers are made available, accessible and applicable in forms that meet the needs of its partners and other actors in rural development. To achieve this objective, the CGIAR centers need to adopt policies and tools that will make the information and knowledge goods produced by such research truly both international and public (Ballantyne, unpublished).

CIMMYT aspires to recognition as the maize and wheat knowledge center and there is no doubt that over the 42 years of its existence an immeasurable amount of data, information and knowledge[∇] has been generated. However, can it be clearly demonstrated how this knowledge finds its way into use? Is the process a spontaneous and uncontrolled one-way flow or is it well mapped and managed, targeted and actively supported? Do we know the knowledge impact pathways? Does CIMMYT have any comparative advantage over other players in the field of maize and wheat science in the improvement of information management (IM) and knowledge sharing (KS)? What is the relation between knowledge and capacity building? While recognizing that a lot has been done, undoubtedly the process of IM/KS from CIMMYT could be done much more efficiently. This paper presents some important issues to be considered when formulating an information management and knowledge sharing strategy and actions in CIMMYT.

Information management and knowledge sharing - Why?

Information and knowledge that is not shared has no value for intended users. It is a common presumption that once generated, the information will be picked up and will find its way into use, but bookshelves are full of technologies and information in the form of reports and scientific articles waiting for 'rediscovery'. It is unfortunate that there is a large gap between the information and knowledge generating processes and their transformation "into use" by scientists and policy makers. Users can also include participants in training and other capacity building activities of CIMMYT who would benefit from updating on recent research results. In a world of business and open markets, any new product must either respond directly to customer demands or be intensively marketed to create awareness of its existence and usefulness and to support the customers' willingness to buy. Information and knowledge are products with value and behave similarly. Therefore, there is often a need to establish a suitable environment and provide incentives for active

[∇] For this abstract we understand knowledge as tacit and information as explicit knowledge acquisition and use for intended users. A great deal must still be done in the area of effective science advising on 'boundary work' carried out at the interface between communities of experts and communities of decision makers. This area of work is not conventionally associated with research, leading many scientists to see their participation in knowledge systems as at best uncomfortable and at worst inconsistent with real scholarship (Cash et al. 2003).

It is also important to mention use of the IM and KS within the institution generating the knowledge itself. Dynamic modern institutions have well designed and managed processes ensuring proactive knowledge mapping, capturing, storage and mobilization. These practices ensure a perpetual intra-institutional learning process and contribute to institutional business continuity.

IM/KS for whom?

From the demand point of view, it is important to recognize the need of differentiation of our main clients - NARS - in terms of dependency on donors and international assistance, as well as the growing importance of the private sector in some segments of agricultural research and input supply. This shift logically implies the need for CIMMYT to better target its activities, including information management and knowledge sharing, not only in terms of geography, but also in relation to the intended final users. While knowledge is an abstract concept and it may be difficult to define, it is necessary to distinguish the method of knowledge packaging based on the targeted audience - knowledge will be targeted differently for scientists (and students), extension specialists, farmers, and policy makers. In order to determine efficiency, it is also crucial to determine the pathway from knowledge to impact and to analyze how the return of investment into efficient knowledge systems and its effect on poverty alleviation can be measured.

IM/KS - when and where?

Information and knowledge is needed, used and also generated during all stages of research cycle (Fig. 1). Hence, it is essential to design a system for the effective integration (operationalization) of IM/KS into project planning, implementation and evaluation. IM and KS activities must be recognized as a key process rather than an add-on to ongoing activities.

Such a process must be linked to key priority areas and must be fast and functional, otherwise the users and contributors will resist the process. Finally, it is important to recognize the existing knowledge of farmers and other actors, which, though it is often not based on scientific evidence, is nonetheless an important resource and worth being shared as well.

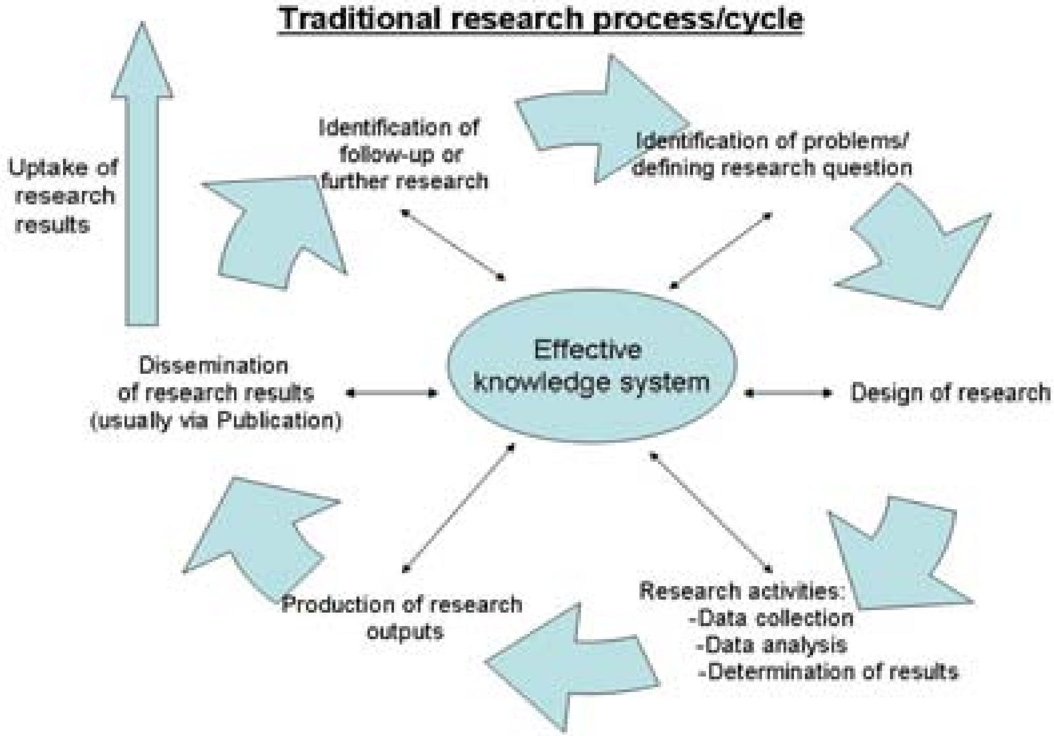

Fig 1. Information and knowledge during the research cycle

KM/KS - How?

Criteria for success of knowledge systems may be simplified into the triple A concept (Ballantyne, unpublished). In order to make the most of the generated information and knowledge, it must be:

- Available (existing, shared)
- Accessible (in format accessible for clients)
- Applicable (in the form useful for clients)

In the broader view, in order to strengthen adoption of knowledge (and technology) the knowledge has to be salient, credible and legitimate for the intended user (Cash et al. 2003). The integrated knowledge system shall promote communication and translation across multiple actors and be a tool for active, iterative, and inclusive communication. The effective knowledge systems must also serve as venue for negotiation and mediation.

It is clear that the availability of knowledge on its own does not necessarily result directly in its learning, adoption and application. In this sense, capacity building efforts in the CIMMYT context shall be seen as a tool for enhancing knowledge sharing and ensuring its targeted impact. A transition from simple knowledge sharing to the 'development of competences for bringing knowledge into use' is therefore a logical next step.

Towards capacity building of partners: proposed actions in CIMMYT

In order to bring CIMMYT up to the level of institutions with well managed processes of information management and knowledge sharing, it is essential to develop a detailed long term strategy, including the identification of necessary resources. This strategy shall be adopted and strongly endorsed by CIMMYT management. In order to ensure sustainability of the process, the IM/KS shall become an integral component of all CIMMYT projects and processes. It is also important to clearly define responsibility over the management of individual IM/KS platforms listed below.

Internal information management and knowledge sharing platforms at CIMMYT

Intranet
The main purposes of an intranet are to share part of an organization's information or operations with its employees and foster communication among the employees. The current arrangement in CIMMYT is a rather one-way flow of information, centrally controlled and often with accessibility problems in several regions. In order to make the intranet a vibrant communication platform, CIMMYT needs to adopt a content management system (CMS) that will enable:

- Accessibility (for reading and contributing) for all CIMMYT offices
- The delegation of responsibility over different sections to various programs, units, and communities of practice within CIMMYT
- Compatibility with other IM/KS tools listed below (institutional document repository, image repository and collaborative tools)
- Compatibility with various CIMMYT databases (corporate communications database, training database or distribution lists)

Institutional document repository. With the exception of major high profile research results, information produced from CIMMYT research is often difficult to locate. Internally, CIMMYT needs to identify and adopt a software platform/repository for digital objects (e.g. project documents and reports, power point presentations, concept notes, meeting reports or trip reports, among others). This platform must be compatible with library databases and other IM/KS platforms in order to prevent doubling of efforts. (One such option may be Dspace, which is currently under testing by CRIL and has already been adopted by IRRI). Identified staff (administrative assistants) must receive adequate training on metadata filing in order to make the repository well organized and useful. Use of this repository shall be required by management as it is in the interest of our institution (institutional memory and business continuity). Part of the institutional document repository shall become repository of pictures – the recently adopted Gallery software (http://cril.cimmyt.org/gallery) seems to be fulfilling the requirements well.

Wiki
A variety of information software tools are available to increase knowledge productivity. In this connection, a wiki is software that allows users to collaboratively create and edit content (e.g. project proposals, reports, articles, etc.). It is a powerful tool to assist teams distributed geographically. However, it becomes useless and only adds more work if it is

not adopted by all members of the team. CIMMYT is currently using the Confluence wiki (http://wiki.cimmyt.org), installed and managed by CRIL.

External information and knowledge sharing platforms at CIMMYT

NARS, the major client group for CIMMYT, can be classified into according to their science strength and budget expenditure: a common classification is well-resourced, e.g., China, medium, e.g., Kenya, and poorly resourced, e.g., Malawi. Based on such distinctions between CIMMYT's client and partner groups, knowledge impact pathways can be designed for each of the groups and platforms can be identified that will provide direct and easy-to-navigate access to the most relevant cereal systems information and knowledge coming from CIMMYT and its partners. An essential step is to adopt mechanisms for keeping IM/KS platforms active; i.e., actualized, dynamic, and used. The extraction and packaging of information and knowledge (e.g. from project reports, training courses, seminars, internal repositories) in different formats for different users or media shall become part of work flow of all projects. It is important to point out that this process needs input from an instructional design specialist. To ensure commitment, sustainability and continuation, staff contributions shall be evaluated annually. For example, with approximately 80 international scientists at CIMMYT, if each scientist prepares one brief or synthesis from conducted research each year with clear outputs for final users, this would mean two products each working week in the year, keeping the platforms continuously updated.. Platforms for external IM/KS

CIMMYT Webpage
This platform is a resource of information presenting CIMMYT to the general public, donors, and policy makers, among others. It is and shall remain centrally controlled, visually attractive, but simple, with mainly static content. Of primary importance is fast access (bandwidth) and indexing of content. The website can be also seen as a gateway to all other web platforms of the institution – internal IM/KS platforms (with access limited to CIMMYT employees), project web pages, and the externally targeted IM/KS platforms listed below. Adopting a content management system will be helpful.

Extranet (portal for scientific community)
An extranet can be viewed as part of a company's intranet that is extends communication to users outside the organization or immediate partners. This platform will enable controlled access to CIMMYT's databases and resources for targeted users and partners. While part of the content may be entirely public (e.g. access to CIMMYT's publications, e-courses and learning materials), access to some content (such as working documents or project reports) will be limited to registered users. Selected users and partners shall be enabled to contribute directly to the content.

Knowledge bank (downstream part of knowledge sharing for extension services)
One of the three IRRI-CIMMYT Alliance projects is the Cereal Knowledge Bank (CKB) – http://www.knowledgebank.cimmyt.org. The CKB is a global digital extension service for those who provide information and support for farmers (such as extension specialists and NGOs) and also a comprehensive, digital rice/maize/wheat-production library of information in the form of fact sheets, field practices and diagnosis tools, e-courses, and training materials.

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Cereal Knowledge Bank (CKB) – http://www.knowledgebank.irri.org or http://www.knowledgebank.cimmyt.org

Intermediate Products: Concepts, Reaching End Users and Measuring Effectiveness

Jonathan H. Crouch, Carmen de Vicente (Generation Challenge Program, Mexico)**,**
Erika Meng, Andy Hall (UNUTECH, India) **and Rodomiro Ortiz**

"*The key role of the CGIAR in providing food security through continued increased production of the major staples must be sustained, but with an increasing emphasis as a provider of novel genes for adaptation and yield enhancement. Specific attention should be paid to drought tolerance and biofortification of relevance to the poor. Genetic enhancement activities, usually in collaborative arrangements, should also extend to some high-value crops, livestock, and fish.*

Focus will be imparted by more closely tailoring the CGIAR program to NARS needs. In general, the CGIAR will move its efforts upstream to provide technologies, genes and enhanced breeder lines rather than finished varieties. The CGIAR should seek to combine forces with strong NARS to provide international public goods to serve partners with less capacity. Although the CGIAR is expected to be involved with more plant and animal species, all new initiatives will incorporate clear time-bound strategies to aid financial and resource planning."

CGIAR 2005 (p.25)

Introduction

In the broadest sense, the term 'intermediate products' may be applied to virtually all of CIMMYT's research outputs. However, there is a substantial body of literature in this area related to improved germplasm and the ultimate impact of this type of product on farming systems and the livelihoods of resource-poor farming families. In fact, CGIAR socio-economic units have extensive experience in this domain from the value of conserving global biodiversity to the impact of elite breeding lines. Thus, in the context of this paper, we will focus on the much less well studied (in the public sector) area of estimating the value of more upstream (in the value chain context) intermediate products regarding their impact on the efficiency and effectiveness of CGIAR and NARS breeding programs. So our focus here will be on intermediate products such as individual germplasm accessions, biotechnology-based tools and methodologies plus computational systems and ultimately training in the use of these products.

The Generation Challenge Program intermediate product development and deployment framework

The GCP policy on products provides an excellent framework for understanding the concepts in this area. For the purpose of its own operations, the GCP has defined a "product" as "*any output from any research* [activity that has been] *designed to meet the demands of an identified set of users* [and measures have been put in place to ensure that the product will] *be put into use by that set of users*." The use of 'product' by the GCP is broadly analogous with the use of 'intermediate product' in this paper – explicitly including germplasm, validated molecular markers, new protocols, genomics resources and training materials. The GCP goes on to state in its delivery strategy, that "*Those users in turn will* *use the product they received to produce another product, which is designed for another set of users, all the way through the value chain to* [end products reaching] *farmers and consumers.*" This is a tremendously powerful framework for how the GCP aspires to operate within the 'Research-for-Development' continuum – a vast value web within which it can only provide inputs into just a few areas but by careful planning and broad consultation throughout its product development and project review phases, can hope to influence many of the linkages between its own activities/outputs and the ultimate desired impact on the livelihoods of the target resource poor across the developing world. The GCP has shown exemplary boldness by acknowledging in its delivery plan the axiomatic flaw of the traditional 'Research-for-Development paradigm, viz. "*the effectiveness of every link in the value chain to deliver useful outputs to other links will affect the overall success of GCP research* [to achieve its ultimate goal of improving the livelihoods of the poor]".

Most importantly for those working at the bench and in the field, the GCP approach provides a strong demand-driven framework where every researcher is required to meet the demands of a set of real users. This is, of course, a highly time consuming commitment which will necessarily force researchers to prioritize which users they can target. However, this is a significant step forward from the all too familiar designation of an amorphous set of undefined users whose activities will be revolutionized by the outputs of the proposed research. On this basis, the GCP requires every proposed new project to define its product development and delivery pathway and to ensure that users are involved in the design, review and uptake of those products during the life of the project. This includes the necessary capacity building and training required to ensure that users are capable of implementing the product in a way that maximizes the probability of impact. This is a significant issue, as targeted training and capacity building are an essential component for minimizing the probability of broken links in the end product development and delivery chain. Moreover, the GCP management team defines in their delivery strategy that they will "*play an oversight role by ensuring that its products are inserted into existing delivery systems*". The degree to which this type of framework can be successfully implemented is directly related to the monitoring and evaluation systems that are designed to reinforce its ideals. The GCP have developed a delivery strategy implementation document that begins this process. However, it is clear that there is a great deal of hard earned experience from the private sector that can help further optimize this pivot point for success in the agricultural research-for-development continuum.

Background from the Private Sector

The impact of technology investments in the private sector has been carefully analyzed for many decades contributing to a significant body of literature on the subject. These analyses have used a range of measures of performance at the economy, industry, company and activity levels. These methods have then been used to gain insight into the impact of technology investments on "production efficiency"[♣], "product quality"[♦] and

[♣] High *efficiency* means minimizing inputs for a given level of output

[♦] *Quality* improvements are realized when a technology investment leads to the creation of a new product or new features for existing products which are more desirable in the target market "productivity"[♠].This type of analysis is somewhat simplified in the private sector due to the closed-loop feedback effect provided by measures of success such as gain in market share and increasing profit margins. However, this should not stop us from seeking to develop analogous models to assist our own priority setting during activity planning and review. Most critically to enable us to make important trade-off decisions regarding whether to invest in a new area of research, whether to continue investments in pre-existing areas of research, and, whether to invest in the application of specific research outputs in our breeding programs.

Synthesizing the literature on the impacts of technology investments on intermediate and activity-based measures of performance in the private sector, it is clear that even in this domain there are often complex interactions between efficiency, quality and productivity. For example, a negative correlation has sometimes been reported between software investments and labor productivity. While a significant positive relationship is usually reported between investments in data processing systems and activity-based performance. Similarly, investments in bar-coding systems and decision-support software are usually associated with higher revenues and better quality products. However, the general conclusion from these reports is that the impact of efficiency-enhancing investments on other performance measures depends upon the technology being implemented and thus decisions in this area must be based on detailed comparative economic analysis. Using the outputs from this type of analysis has clearly provided important frameworks for management decisions. For example, too heavy a focus on reducing production costs and improving productivity can often lead to under-investment in product quality. Furthermore, investments in new technologies rarely occur in isolation but instead tend to influence many other operational areas. In a research organization we can all intuitively agree with these conclusions but the power of the analysis is to identify the most effective compromise point.

Thus, there is a need for us to identify performance indicators that aid the planning and control of our institutional activities. This is clearly easier for finished products irrespective of sector. However, with respect to intermediate products, one solution in the private sector is the ex-ante estimation and ex-post analysis of so-called 'quasi profits' from outputs of introducing a new intermediate product or technology. This appears to provide a measure that satisfies both ex-ante planning requirements as well as ex-post control requirements. Thus, this approach is being used in the private sector to directly determine whether, for example, it is desirable to introduce a cost reducing technology. Although the calculation for determining the desirability of introducing an intermediate product that enhances the quality of a subsequent product will be more complex. Nevertheless, this model appears to be highly analogous across sectors for assessing and comparing the cost : benefit ratio associated with the implementation of intermediate products such as new technological practices. Interestingly, it is noted in the literature on this subject that even upon establishing optimum performance measures and incentive systems, the organizational structure still plays an important role in the success of implementing this type of approach.

[♠] Enhancing productivity may have both efficiency and quality elements.

Recent Advances in the Public Sector Literature

There is very little public sector literature on this type of issue. However, one consistent exception to this is the wheat breeder turned economist, Paul Brennan, working at the Wagga Wagga Agricultural Institute, New South Wales Department of Primary Industries. For nearly two decades, Brennan has been carrying out economic assessments of the value of a wide range of components of the wheat breeding pipeline, including physiological selection systems, molecular markers, and training in disease scoring techniques (for specific details see http://intranet.cimmyt.org/programs/GeneticRes/ Recommended%20Reading/ recommended_reading_index.htm for some of his recent papers). As Brennan highlights, there are a wide range of new technologies that may potentially enhance the efficiency [and impact] of genetic gain in plant breeding programs, including: gene and allele discovery, transformation, marker-assisted selection, physiological selection, double haploids and improved statistical analyses. However, it will not be economic for all breeding programs to invest in all new technologies. Thus, there is a need for a holistic analytical tool to assist each breeding program to assess the added-value impacts of new technologies for their specific circumstances.

Thus, we are currently establishing a collaboration project to effectively combine our modeling and simulation work for genetic, genomic and physiological parameters with costing modules in order to provide breeders with a holistic decision-support system for determining whether investments in a new technology-assisted tool or methodology is warranted. In addition, the same tools will facilitate monitoring of the actual value-added effects of applying intermediate products in order to generate unbiased assessment data to help others in similar situations – not least our NARS partners.

Nevertheless, it remains a substantial task to define the optimal parameters for assessing the added value of implementing new intermediate products in our maize and wheat breeding programs. This will require significant input from end-users both within and outside CIMMYT together with translation of lessons learnt in analogous private sector situations.

Conclusions and Issues for Discussion

CIMMYT has established an eight project structure feeding into the following nine flagship products:

- Stress tolerant maize for enhanced food security and crop diversification.
- Wheat with enhanced water productivity and appropriate quality profiles.
- Rust resistant wheat.
- Bio-fortified maize for improved nutrition and health.
- New or improved traits through gene discovery and allele mining.
- Improved tools and methodologies for genetic improvement.
- Capacity-building in NARS and SME breeding programs.
- Resource-conserving technologies for maize and wheat cropping systems.
- Opportunities for income generation from special trait maize.

These are now our nine reasons to exist and we must ensure that the majority of our efforts are focusing on maximizing our productivity towards these nine products. However, our institutional culture still has some way to evolve to fully internalize this project-based product-driven framework. Regular unbiased quantitative analysis of our progress towards these products will be critical to keep us on track and identify where critical links are dragging down the rest of the pipeline.

The topics discussed in this paper do not operate in isolation and there are many other issues of equal or greater importance that require attention, including:

- Reinforcing an end-user framework on intermediate product development through priority setting, planning, review and uptake processes (Ortiz and Crouch 2007)
- Opportunities for bringing power to our monitoring and evaluation systems at the individual, team and product level
- The pros and cons of our current organizational structure at the individual, team and product level
- Ensuring synergy across disciplines within and between institutions – internalizing fully the project-based product-driven concept
- Galvanizing partners around the projects – creating systemically integrated pipelines
- Coping with the transition to devolution scenarios
- The role and impacts of the private sector
    - Public-Private sector partnerships in intermediate product development.
    - Public investments in intermediate products to stimulate private sector interest.
    - Implications for CIMMYT niche and priority setting.
    - The future of intellectual property management at CIMMYT.
    - Models for private sector interaction around intermediate product uptake and development of finished products.

Further Reading

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Maize Biofortification and New Uses: Where CIMMYT Stands and New Challenges

Natalia Palacios

Biofortification efforts at CIMMYT primarily involve research and development of wheat with enhanced Fe and Zn contents, and maize with enhanced lysine and tryptophan (quality protein maize -QPM), pro-vitamin A and Zinc contents.

CIMMYT work in QPM dates back to the early 1970s and is a great example of breeding efforts supported by laboratory methodologies to manipulate and combine the three distinct genetic systems needed for QPM (Krivanek et al. 2007). QPM germplasm development is ongoing in Africa, Asia and Latin America (Pixley et al. CIMMYT Science Week 2008). To boost QPM development work in different countries and reduce the cost of laboratory assays, we developed an alternative colorimetric method for tryptophan analysis (Nurit et al. unpublished). This method overcomes an important reliability problem of the previous procedure and allows high-throughput analysis in laboratories with the appropriate conditions (96-well format Elisa readers). The method will also increase the ease and efficiency of monitoring QPM quality.

QPM is an important example for other biofortification efforts, and many lessons can be derived from the achievements, challenges and constraints in impact and dissemination of this type of biofortified maize.

Our research on pro-vitamin A, iron and zinc began only recently, and the first steps involved the identification of the genetic variation for those compounds within CIMMYT germplasm (Ortiz-Monasterio et al. 2007). In the case of maize at CIMMYT, the Fe variation found was insufficient for use in conventional breeding to increase the basal levels. However, screening by colleagues at the International Institute of Tropical Agriculture (IITA, Ibadan, Nigeria) has found promising material with which they are working and which we are now evaluating in tropical and subtropical conditions in Mexico. The scenario is much more promising for zinc and pro-vitamin A, and most of our work on maize biofortification is on these two micronutrients.

It is well recognized that maize plays an important role not only as a staple food in many countries, but also as part of the culture of different communities. Maize is also important as feed, silage, and as raw material for industrial starch, oil and bio-ethanol production (Ortiz et al. 2007). Given the genetic diversity, cultural uses and potential novel uses of maize, specialty maize types can be income-generating and livelihood-enhancing products for farmers of some communities. The role of CIMMYT in research and development of specialty maize has been limited and it requires case by case impact assessment and socio-economic studies.

This presentation describes research and developments regarding breeding strategies, biochemical and molecular support tools for faster breeding progress and challenges and opportunities for Fe, Zn and pro-vitamin A maize biofortification given the knowledge and experience gained until now. Additionally, a description of the current activities on specialty maize will be given as well as perspectives on areas where CIMMYT could engage given the current situation of maize in the world, the genetic diversity and the mission of the Center.

Biofortification for pro-vitamin A

This is a new area of research and the HarvestPlus Challenge Program involves interdisciplinary work to develop products and implement strategies to achieve appropriate impacts.

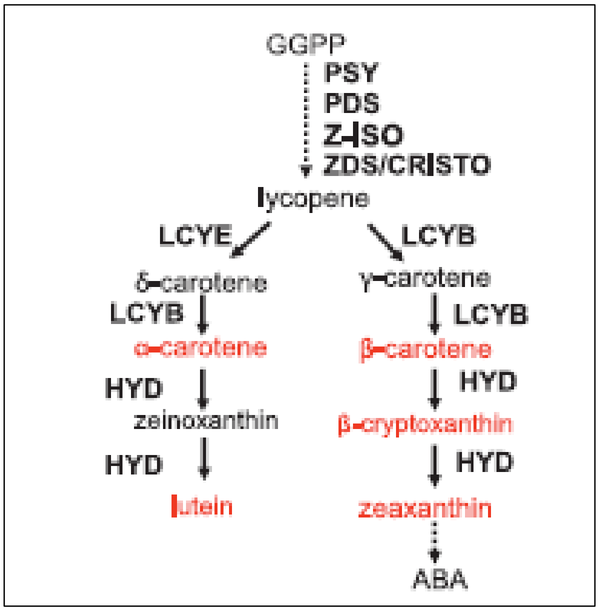

Fig. 1. Simplified carotenoid biosynthetic pathway
GGPP:geranylgeranyl diphosphate, ABA:absicic acid
Enzymes: PSY: phytoene synthase, PDS: phytoene desaturase, Z-ISO: 15-cis zetacoretene isomerase, ZDS: zetacrotene desaturase, CRTISO: carotene isomerase, HYD:carotene hydroxylase enzymes, which include epsilon and beta-ring hydroxylases

All yellow maize contains carotenoids, but the fraction with pro-vitamin A activity (beta-cryptoxanthin, alpha and beta-carotene, which can be converted to vitamin A) is typically very small (Fig. 1). Breeding strategies for biofortification of pro-vitamin A in maize include:

a) intra-population recurrent selection where we also aim to compare the effectiveness of full-sib vs. S_1 recurrent selection for improving pro-vitamin A,
b) conversion of white lines and open pollinated cultivars (OPV) to "enhanced pro-vitamin A content",
c) pedigree breeding

In addition to monitoring pro-vitamin A content, the agronomic performance and combining ability in early and advanced generations is evaluated at several locations in Mexico, Zimbabwe and Zambia, as well as drought and low-nitrogen conditions. At the same time we are assessing the importance of genotype-by-environment interaction on pro-vitamin A concentration.

General combining ability effects, or additive gene action, accounts for most of the variation for pro-vitamin A (Egesel et al. 2003). However, non-additive gene action is important and gives the possibility of exploiting heterosis in breeding biofortified pro-vitamin A maize (Fig. 2).

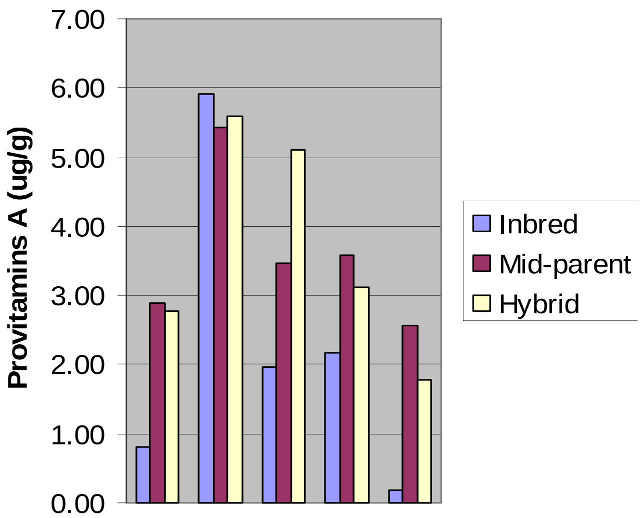

Fig. 2. Mid-parent heterosis for pro-vitamin A content

Biochemical and molecular techniques

Visual selection of yellow/orange ears in the field is the first approach we followed, although we know the correlation between color and pro-vitamin A content is weak. Nevertheless, this preliminary screening needs to be confirmed by HPLC (high performance liquid chromatography) in the laboratory. Because the HPLC methodology is expensive and time consuming, we are attempting to develop calibration curves to measure important carotenoids using near-infrared reflectance (NIR) in collaboration with the Centro Internacional de la Papa (CIP, Lima, Perú). This has proven difficult due to the low levels of the pro-vitamins that we are attempting to measure, and we are now increasing the numbers and variation of lines included in the calibration models to refine them.

Recent exciting results from association mapping projects using temperate (Harjes et al. 2008) and tropical germplasm (CIMMYT carotenoid association mapping and China association mapping) (Warburton et al. CIMMYT Science Week 2008) have led to the development of polymerase chain reaction (PCR) markers for two critical genes along the carotenoid biosynthesis pathway: LYCE and HYDB1 (Fig. 1). We are currently assessing which alleles are present for these two genes in our best parental lines with enhanced pro-vitamin A content. In a preliminary screening of about 200 CIMMYT tropical lines, a high frequency for the most favorable allele of LYCE was found; however, none of the lines had the most favorable allele for HYDB1. Fortunately, the best HYDB1 allele has been identified in several temperate pro-vitamin A sources that we work with and we will begin pyramiding the LYCE and HYDB1 genes in the near future.

Biofortification for zinc and iron

Moderate variation for zinc concentration in grain (mostly within 15-35 ppm) has been identified in material evaluated at CIMMYT (Ortiz-Monasterio et al. 2007). A large environmental effect on zinc concentration in grain has been found, and we are currently assessing whether the putative high Zn lines are consistent across environments. Although the scope for breeding seems limited, we are working with the most promising material we have identified and adapted to highland environments. Enhanced Zn hybrids have been evaluated in locations at Ethiopia and Mexico, and under low-nitrogen and drought stresses. Currently, three-way hybrids are being formed and they will be evaluated in different locations during 2008. We are also initiating within-heterotic group bi-parental populations (high pro-vitamin A x high Zn), where we will select for both pro-vitamin A and Zn contents.

In addition to the challenges of large environmental effect and limited genetic variation, the analytical evaluation of zinc (ICP- Inductively coupled plasma) requires stringent lab conditions to avoid sample contamination. We are currently establishing the laboratory capacity to evaluate Zn and Fe for wheat and maize at CIMMYT.

As mentioned above, the genetic variation we have found for Fe in CIMMYT material is insufficient to allow conventional breeding for this trait. As an alternative strategy, we are evaluating variability for bioavailability of Fe. Bioavailability is the amount of a nutrient that is potentially available for absorption from a meal and, once absorbed, is utilizable for metabolic processing in the body (Welch and Graham 2004). Many factors influence Fe bioavailability including phytate, insoluble fibers and phenolic compounds knows as inhibitors. Inulin, by contrast, protects Fe and Zn against sequestering action of inhibitors. It is possible to study the bioavailability of Fe in vitro using the caco-2 cell model. In collaboration with USDA/ARS and Cornell University (Ithaca, New York, USA), we are assessing the genetic variation and the effect of genotype-by-environment interaction (GEI) for Fe bioavailability in diverse maize hybrids. Preliminary analysis for two hybrid trials grown at 2 or 3 locations showed significant location and genotype differences for Fe, Zn and ferritin (indicator of Fe bioavailability). No significant GEI for Fe bioavailability were observed in these materials. However, in the case biovailability can be use as an alternative to breed for biofortified maize for Fe-deficient populations, the challenge will be the development of fast, cheap and reliable methods to monitor the progress in bioavilability breeding. This will be a new area for research.

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Analysis of the Institutional Bottlenecks Affecting the Deployment of Maize Seed in Eastern and Southern Africa

Augustine Langyintuo

Introduction

Enhancing the productivity of maize through the use of improved, high yielding cultivars has the potential of improving the livelihoods of farm households in rural Africa because the crop plays a dominant role in their farming systems. Recent data suggest a proliferation of seed providers in the region marketing various types of improved maize seed yet more than half of the maize area (about 6.7 million ha) is still under traditional, unimproved low yielding cultivars. This is of great concern to policy makers, donors and researchers working to better the livelihoods of the rural poor. To provide a better understanding of the factors limiting the production and deployment of improved maize seed in Africa, this study was undertaken in 2007 under the auspices of the drought tolerant maize for Africa (DTMA). The objectives of the study were to:

- Identify and characterize maize seed production organizations in Africa.
- Document maize cultivars marketed by seed providers in each country.
- Identify factors preventing the efficient deployment of seeds.
- Make recommendations for addressing critical bottlenecks and contribute to the efficiency of cultivar release, seed production and seed dissemination for new drought tolerant (DT) maize cultivars in Eastern and southern Africa.

Data collection

A total of 116 representatives of seed providers made up of 73 seed companies (or 92% of all registered maize seed companies) and 35 National Agricultural Research Systems (NARS) and non-governmental organizations (NGOs) promoting community-based seed production schemes were interviewed in Angola, Ethiopia, Kenya, Malawi, Mozambique, South Africa, Tanzania, Uganda, Zambia and Zimbabwe by CIMMYT and NARS scientists using structured questionnaires.

1. Maize seed supply in Eastern and Southern Africa

During the 2006/2007 crop season, an estimated 103,600 t of improved maize seeds (80% hybrids) were marketed in the region. Registered maize seed companies accounted for 100% and 91% of all hybrids and open pollinated cultivars (OPV), respectively. Table 1 lists that the quantities of seed sold, which were sufficient to cover 35% of the total maize area compared with 26% observed in 1997. Estimated adoption rates ranged from 5% in Angola to 80% in Zimbabwe. The unmet demand is often fulfilled through recycling from the previous harvest at the risk of yield decline at a rate associated with the type of seed (whether hybrid or OPV). According to Pixley and Bänziger (2004), the average yield loss of recycled OPV seed is 5% compared with 32% for hybrids and 16% for top-crosses. Assuming that farmers recycle similar quantities of improved OPV maize seed purchased for at least two seasons, one would expect that during the 2006/2007 crop season, seeds purchased in 2004/2005 will be in their second year of recycling and those purchased in 2005/06 in their first. Based on the 2004/2005 – 2006/2007 OPV sales figures (Table 1, columns 4 - 6), adoption rates are adjusted upwards by 4 and 14% higher in Eastern and Southern Africa and by 9% in the whole region (Table 1, column 9).

In each country the volumes produced and marketed varied tremendously between companies but averages ranged from about 230 t in Mozambique, where the majority of seed companies are emerging, to about 3,000 t in Zimbabwe with well established seed companies. The low productivity rates are partly attributed to institutional bottlenecks affecting the seed value chain. At current productivity levels, about 140 additional seed companies, ranging from 2 in Zambia and Zimbabwe to 115 in Mozambique will be needed to meet the shortfall in supply over demand.

2. Institutional bottlenecks hampering seed production and deployment

The impacts of these bottlenecks on the maize seed value chain seem to differ by country. Broadly speaking, however, at the regional level respondents consider production and processing related constraints as the most challenging (36%) followed by those related to seed policy (19%), organizational establishment (18%) demand side constraints (16%) and seed marketing and distribution (13%). The specific bottlenecks are identified and discussed below.

Bottlenecks affecting the establishment of a seed production unit
In Eastern and Southern Africa, governments are encouraging the establishment of seed companies by facilitating their licensing. Nevertheless 10% of seed companies mainly in Mozambique and Zimbabwe observe non-transparency and lengthy licensing processes. Beyond registration, challenges known to hinder the smooth establishment and running of maize seed businesses include (i) high initial investment costs necessary to set up and run an office, recruit and retain qualified personnel, procure and operate production and processing units and finance storage costs; (ii) lack of qualified manpower especially breeders and agronomists (due to staff attrition and death) to develop, maintain and test cultivars and lines for ecological adaptability; and (iii) lack of access to operational credit. While high investment capital is ranked first in Southern Africa, it is ranked second to lack of qualified manpower in eastern Africa.

Seed production bottlenecks
Seed production and processing are carried out by established and emerging seed companies, NARS and community-based seed production groups. Due to lack of adequate land and limited access to other production resources to meet projected supply volumes, seed companies contract between 15 and 50 farmers annually to produce and deliver seeds to them for processing.

The major bottlenecks during seed production are (i) lack of access to suitable germplasm; (ii) technical constraints [mainly lack of production infrastructure (45%), unfavorable land policies (34%), unfavorable climate (18%) and pests and diseases (3%)]; and (iii) lack of production credit especially for emerging seed companies. About 40% and 64% of seed companies in Eastern and Southern Africa, respectively, together with all the NGOs do not have their own research facilities and therefore find it difficult to access suitable germplasm. While accessing germplasm from CIMMYT and the International Institute of Tropical Agriculture (IITA, Ibadan, Nigeria) is very easy, partners see non-exclusivity of inbred lines as a potential source of conflict if same materials are given to different partners.

Seed marketing and distribution bottlenecks

The current seed deployment pattern suggests that only a quarter of all improved maize seed sold by seed companies goes to farmers in the low potential areas to compliment the limited sales by the community-based seed production units. To reduce marketing costs, most seed companies rely on third-party agents such as agro-dealers, large retail stores, NGOs and the government to retail a bulk of the seeds they produce. Poor marketing infrastructure (such as bad roads and storage facilities) commonly observed in the region heavily constrain seed distribution.

Companies that retail seeds through third-party agents observe lack of credibility, adulteration of seeds and poor storage facilities as the challenges limiting their levels of operation. Most agro-dealers in particular lack adequate operational capital to purchase seed and retail and hence receive seed on consignment basis thereby compelling companies to retrieve unsold seed at costs. Additionally, agro-dealers often lack adequate knowledge on the characteristics of the cultivars they retail to be able to educate farmers so that they purchase cultivars suitable for their (farmers') ecologies.

Constraints limiting seed demand at the farm level

According to seed providers, the three most important factors limiting seed demand at the farm level include (i) low adoption rates (32%) [due primarily to lack of awareness and economic value of available cultivars, high relative price of seed, uncompetitive grain prices, farmers' reluctance to change from their old practices, and lack of access to credit to buy seed or complimentary inputs such as fertilizer]; (ii) poor extension coverage due to limited financial and human resources (25%); and (iii) difficulty in estimating seed demand to inform production planning decisions (22%). It is also believed that lack of insurance against drought risk discourage farmers from investing in new cultivars. In addition, deployment of non-adapted cultivars is also thought to harm the confidence of farmers preventing them from subsequent purchases of new seed.

Policy related bottlenecks affecting seed production and deployment

The maize seed industry in Africa often receives special attention from policy makers given the importance of seed as a key technology component (Tripp 1998). Varietal registration and seed certification laws instituted ostensibly to control the genetic and physical purity of commercial seed sold on the market have tendered to serve as bottlenecks impeding the development of the seed sector. In particular, unfavorable seed policies (such as taxation, import and export restrictions), lengthy cultivar release processes, and controlled seed markets (such as price fixing) are the most damaging. Cultivar registration procedures are very lengthy (at least three years of testing) and cumbersome especially in countries such as Kenya.

3. Policy implications

The bottlenecks identified have differential impacts on the seed value chain depending on the country in question and the distribution of types (or operational levels) of seed providers (whether community-based seed production units, emerging or established national, regional and multinational seed companies) as manifested in the quantities of seed produced and marketed. Based on the results of the survey, the following policy interventions are proposed to help address the critical bottlenecks so as to smoothen the production and deployment of improved, high yielding DT maize cultivars in Eastern and Southern Africa.

Facilitating the establishment and operation of seed production units

At the current productivity levels of existing seed companies more than 100 additional seed companies will be required to meet the shortfall in demand over supply but that seems untenable given the high investment costs, limited qualified manpower, and lack of access to operational credit observed in the region. To enhance the operations of seed companies, therefore, two complementary strategies may be proposed. Firstly, improving productivity levels of existing seed companies, which can be done through for instance (a) use of appropriate and adapted DT maize germplasm, (b) investment in irrigation facilities to further minimize drought risk, (c) better education and training of contract growers in improved crop management, and (d) increased access to production inputs at affordable prices. Secondly, supporting seed companies to run their seed production businesses efficiently, which can be achieved through training and backstopping to circumvent the limited manpower problems observed.

Clearly, governments, development investors, centers of the Consultative Group on International Agricultural Research (CGIAR), and the universities have strategic roles to play here. In the long run, seed companies should work towards appropriate remuneration and recognition of recruited staff to limit attrition. Efforts should be made by the relevant stakeholders to encourage the traditional financial institutions to review their lending portfolios to include lending to seed companies at very reasonable interest rates.

Maintaining efficient seed production and processing programs

The following interventions are critical in ensuring the efficient production and processing of improved high yielding maize cultivars for farmers in the region:

- Access to suitable germplasm by seed producers. CIMMYT, IITA and their NARS collaborators should continue to develop pest and disease resistant and adapted DT maize cultivars and make them readily available to needy seed providers to broaden their varietal portfolios. Granting limited exclusivity for public germplasm will facilitate branding of such materials to promote seed sales. Where applicable, foundation seed production should be decentralized to optimize the benefits from improved germplasm
- Loan financing from the government, development investors and private financial institutions can relax credit constraints allowing seed providers to acquire relevant plant and machinery for seed production and processing.

Improving seed marketing and distribution
As long as seed companies are reluctant to invest in retail networks, seed sales can only be boosted in the rural areas if agro-dealers (who market a large proportion of all seeds) are supported with targeted loans from the government and development investors (in the short-run) that allow them to buy and sell seeds (rather than relying on consignment seeds from seed companies) as well as maintain good storage facilities. In the long-run, traditional and non-traditional lending institutions should be identified and encouraged to play a positive role in providing targeted loans to agro-dealers. For efficiency of operations, agro-dealers should also benefit from regular training in maize varietal characterization, good seed handling practices, and business management skills.

Given that the volume of seeds marketed in a given area is positively related to demand, it is imperative to improve farmers' adoption rates through: (i) enhanced extension message delivery by seed companies, governments and NGO agents through field demonstrations, and research bulletins, as well as voice and print media; (ii) improved retail networks; (iii) improved access to credit; and (iv) improved and competitive grain prices. Where it is not possible to ensure fair grain prices, farmers should be granted targeted seed (and fertilizer) subsidies.

Reforming seed policies and regulations
Strengthening internal seed laws and regulations to police fake seeds, a complete liberalization of seed trade and avoiding undue delays in the release of cultivars will benefit the seed industry tremendously. Where applicable, carrying out the distinctiveness, uniformity and stability (DUS) tests alongside the national performance trials (NPT) can quicken the time it takes for a bred cultivar to reach farmers. For rapid spillovers of cultivars released in one country to similar agro-ecologies in different countries, regional harmonization of seed laws and regulations initiated by the sub-regional organizations, CGIAR centers, development investors, and other relevant stakeholders should be expedited.

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Table 1. Estimated maize seed demand and supply in selected countries in Eastern and Southern Africa

Region/country	Maize area (million ha)	Estimated seed demand (1000 t) [1]	Improved OPV maize seed sales (x 1000 MT)			Hybrid maize seed sales in 2006/07 (1000 t)	Adoption rate 2006/2007 (as % of maize area) [2]	Adjusted adoption rate in 2006/2007 (as % of maize area)
			2004/ 2005	2005/ 2006	2006/ 2007			
Eastern Africa	*6.6*	*161.8*	*4.0*	*3.5*	*11.1*	*42.0*	*33 (23)*	*37*
Ethiopia	1.7	42.4	0.4	0.4	2.0	6.2	19 (8)	21
Kenya	1.6	38.9	0.6	0.1	1.7	26.3	72 (71)	74
Tanzania	2.6	64.0	0.6	2.0	3.9	7.3	18 (4)	22
Uganda	0.7	16.5	2.3	1.0	3.5	2.2	35 (9)	54
Southern Africa	*5.4*	*133.4*	*9.3*	*9.8*	*12.0*	*38.5*	*38 (28)*	*52*
Angola	0.8	19.3	0.8	0.1	0.8	0.2	5 (12)	10
Malawi	1.4	35.3	5.2	4.5	5.4	2.5	22 (14)	50
Mozambique	1.2	30.3	1.2	2.2	3.1	0.2	11 (9)	22
Zambia	0.6	14.1	0.3	1.0	0.5	9.7	73 (23)	81
Zimbabwe	1.4	34.4	1.8	2.1	2.2	25.9	80 (82)	93
Total	*12.0*	*295.1*	*13.3*	*13.3*	*23.1*	*80.5*		
Average							*35 (26)*	*44*

[1]Estimate based on area and planting rate of 25 kg/ha
[2]In parentheses are figures observed in 1997. Only seed sales in 2006/2007 were used in the estimation

The Challenge of Climate Change: Can Wheat Beat the Heat and Water Stresses?

Matthew Reynolds

Introduction

The Intergovernmental Panel on Climate Change (IPCC 2001) predicts that mean temperatures around the planet may rise by between 2° to 5°C by 2050. Analysis of climate risks for crops in 12 food-insecure regions based on weather projections through to 2030 (i.e. the timeframe for impact of agricultural research conducted during the next decade) indicated that South Asia and Southern Africa would be especially vulnerable to negative effects on wheat productivity if measures are not taken to improve crop adaptation (Lobell et al. 2008). Understandably, crop scientists from all major wheat growing regions continue to identify heat stress as a major priority for investment (Reynolds et al. 2008a). Although the immediate aim is to maintain productivity of rural economies and thereby help ensure food security at a broader level, investments in mitigating effects of climate change may have far wider implications. A recent analysis of high resolution paleo-climatic data showed that in both Europe and China long-term weather patterns were strongly linked to the frequency of wars between 1400-1900 AD (Zhang et al. 2007). In fact, use of climate change to predict incidence of war constitutes the most reliable model documented.

It is inevitable that climate change will also be associated with increased drought stress in many regions due to changes in rainfall distribution and because increased temperatures (at least in low relative humidity regions) will results in greater evaporative demand thereby reducing water use efficiency. Considering these likely effects of climate change scenarios, wheat, which is grown on 200 million ha worldwide –about 15% of total cropping area– and accounts for over 20% of the consumed calories is an obvious target for investment to maintain food security. A number of complementary approaches will be outlined, currently in use or under development, which can be adopted relatively easily by CIMMYT and her partners in mitigating effects of climate change. Most were recently endorsed in extensive consultations with wheat researchers worldwide (Kosina et al. 2007, Reynolds et al. 2008a).

Conventional mega-environment breeding

Heat stress for wheat has been defined as where mean average temperature of the coolest month is greater than 17.5°C (Fischer and Byerlee 1991). The heat prone mega-environment (ME) –classified as ME5 by CIMMYT (Braun et al. 1992) currently covers approximately 10 million ha in Asia, Africa and South America and has been a breeding target for international wheat improvement since the mid-1970s, with major objectives of improving resistance to the leaf disease *Heminthosporium sativa* in high relative humidity (RH) environments and grain size under terminal heat stress in low RH environments (Kohli, et al. 1991, Fischer and Byerlee 1991). Although ME5 encompasses a highly diverse range of heat profiles considering sites in different countries (Reynolds and Trethowan 2007a) analysis of genotype-by-environment interaction (GEI) for the High Temperature Wheat Yield Trial (HTWYT) confirmed previous conclusions that relative humidity is a significant factor determining adaptation of genotypes internationally, most likely associated with increased disease spectra and pressure in high RH versus low RH environments (Lillemo et al. 2005). In addition to *H. sativa*, other heat-specific diseases of wheat include wheat blast disease -caused by *Magnaporthe grisea*-, and to a more limited extent the soil borne *Sclerotium rolsii*. The HTWYT analysis also indicated that of the approximately 500 genotypes distributed to over 100 international sites, a significant number displayed good performance in both heat stressed and temperate locations.

Currently about 30 million ha of wheat is cultivated under moisture stress in the developing world (Morris et al. 1991), defined by CIMMMYT as ME4 (Braun et al. 1992). Achieving genetic progress under abiotic stress and especially drought is still one of the most difficult challenges in agriculture due to the many adaptive traits expressed in crops (Fig. 1) and their complex interaction with a highly variable environment (Table 1). As a result, accumulation of genes conferring superior access to water or water use efficiency does not guarantee better performance if genome interaction with these 'confounding' factors is not considered; highlighting the practical difficulty of breeding for drought-prone regions. While ICARDA adopted a highly targeted strategy for drought prone environments in terms of selection of parents and performance evaluation (Shakhatreh et al. 2001), CIMMYT focused initially on delivering broadly adapted germplasm that performed relatively well in dry years but also retained good yield potential in above-average rainfall years (Rajaram and van Ginkel 2001). Subsequently, broader genetic bases were used in breeding including wild wheat ancestors through interspecific crossing techniques, generating re-synthesized hexaploid wheats (Trethowan and Mujeeb-Kazi 2008).

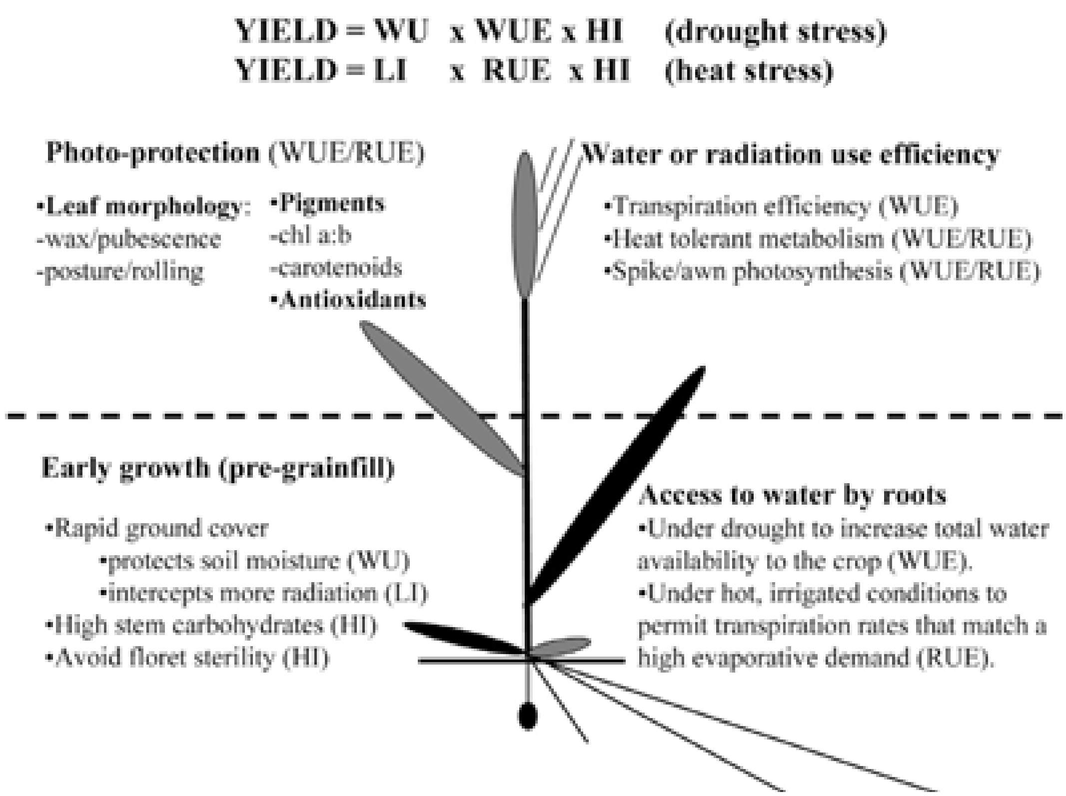

Fig 1. Adaptive traits expressed in crops

Table 1. Factors affecting crop productivity under abiotic stress

GENETIC
- Traits presented in Fig. 1 (heat and drought stress)
- Crop phenology and stress escape
- Ability of plants to sense and respond to environmental cues (e.g. through root signaling)
- Balance between conservative mechanisms which favor evolutionary survival vs. those which favor economic productivity
- Epistasis

ENVIRONMENT
a) Seasonal water distribution and temperature profiles
b) Other meteorological factors affecting plant temperature and water-relations (radiation, humidity, wind)
c) Soil physical properties that influence root growth, access to water, and water storage capacity
d) Soil chemical properties that influence the utility of soil resources (e.g. toxic levels of Bo and Na or deficiencies in microelements such as Zn)
e) Presence of diseases that exacerbate stress
f) Crop management practices that impact on water and nutrient availability
g) Latitude and sowing date that affect photoperiod response

GENOTYPE × ENVIRONMENT (and management) INTERACTION
- Trait interaction with site- or region-specific environmental factors a) to g)
- Trait interaction with seasonal variation in environmental factors, especially a) and b)
- Trait interaction with field-scale spatial variation in environmental factors, especially c), d), e), and f)
- Three-way interaction of crop phenology, trait expression, and environmental factors, especially g)
- Economic imperative to combine stress-adaptation with yield-responsiveness in favorable years
- [QTL × environment interactions are implicit in the above]

Economic analysis has shown that CIMMYT's conventional wheat breeding approaches have resulted in substantial annual yield gains in marginal –heat and drought affected– environments (Lantican et al. 2003). Furthermore, analysis of CIMMYT international yield trial data for germplasm distributed between 1979 and 1998 show significant yield improvement in dry environments as well as under irrigation. Trethowan et al. (2002) compared two nurseries: the Elite Spring Wheat Yield Trial (ESWYT) targeted for irrigated regions and the Semiarid Wheat Yield Trial (SAWYT) targeted for rainfed regions. Respective genetic gains were higher in the drier regions for genotypes of the SAWYT and vice versa, clearly indicating that internationally coordinated breeding targeted to mega-environments is effective in realizing genetic gains even for the highly complex drought-prone environments. In conclusion, results from both drought and heat affected environments support the notion that the mega-environment approach is a powerful tool that, with strategic redeployment of resources among MEs, could be fine-tuned to address the issues of climate change.

Strategic research in crop management

There are a number of reasons why strategic research in conservation and precision agricultures has important implication with respect to mitigating effects of global warming. Soils in many of the world's largest agro-ecosystems are heavily degraded due to millennia of cultivation as well as recent agricultural intensification in irrigated regions (Lal et al. 2004). These regions include South Asia where global warming is predicted to have major negative consequences (DEFRA 2005) and the CWANA region where water resources are already scarce and can be expected to diminish further (Ryan et al. 2006). If new cultivars are grown on degraded soils, potential genetic gains associated with current and future investment in genetic improvement are not likely to be realized. In addition, conservation agriculture (CA) and precision application of nutrients can help to reduce greenhouse gas emissions as a result of increasing input use efficiency in hundreds of millions of hectares of farmers' fields.

CA practises can increase the amount of water available to crops, an important factor in mitigating heat and drought stress, as well increasing water and radiation use efficiency by reducing stresses associated with degraded soils (Hobbs 2007). Strategic research (Table 2) can facilitate adoption of CA by small-scale farmers worldwide. In addition to work on residue retention (Govaerts et al. 2007), other areas of strategic research include bio-fumigation that permits control of root diseases through rotation with crops leaving biocidal residues (Matthiessen and Kirkegaard 2006); exploitation of subsoil water through 'biological drilling' by rotation with deep rooting perennial pastures (McCallum et al. 2004), exploitation of mycorrhizal fungi to increase water uptake, improve crop nutrition, and control pathogens (Plenchette et al. 2005); use of rhizobacteria which promote growth under stress (van Loon amd Glick 2004); and technologies directed at providing specific crop needs -i.e. precision agriculture- (Sadler et al. 2005). An example of the latter is represented by work showing that zinc deficiency exacerbates drought stress leading to recommendations for foliar applications affecting 4 million ha of wheat in Turkey (Bagci et al. 2007).

CIMMYT agronomists have also taken the lead in developing more efficient protocols for fertilizing crops, including delayed and precision N application, both of which substantially increases NUE at the field level (therefore reducing levels of greenhouse gas emission). The latter has involved development of portable and simple to use spectral radiometers in collaboration with soil scientists and agricultural engineers at Oklahoma State University. The technique uses near infra-red reflectance to detect relative greenness of the crop and thereby acts as an integrative bioassay for available nitrogen in the soil, providing a cheap and practical alternative to more soil analyses. The technology has been tested in collaboration with small scale farmers in Ecuador and larger scale farmers in Mexico and is now being disseminated (Ortiz Monasterio, personal communication).

In conclusion, the long-term work and trials that CIMMYT wheat agronomists have developed over the last two decades in collaboration with NARS (Hobbs 2007; Govaerts et al. 2007) provide an excellent platform for both strategic and adaptive research in crop management. With the right investments, outputs from these research platforms have the potential to be applied in farmers' fields worldwide thereby buffering or mitigating many detrimental effects associated with climate change (Ortiz et al. 2008). Healthier soils also provide an improved environmental baseline from which to realize returns on investments in molecular and conventional breeding by permitting new cultivars to express their true genetic potential.

Table 2. Factors associated with reversing soil degradation and improving water harvest through conservation agriculture (adapted from Reynolds and Tuberosa 2008)

MAJOR BENEFITS OF CONSERVATION AGRICULTURE (CA) PRACTICES (Hobbs 2007)

- Reduced water evaporation from soil surface
- Increased infiltration of rain water into the soil profile
- Improved soil structure and organic matter content increasing:
    - Water-holding capacity
    - Cation exchange capacity
- More stable soil structure that is less prone to wind and water erosion

STRATEGIC RESEARCH ISSUES FACILITATING ADOPTION OF CA

- Genomic studies to develop marker-assisted selection for CA adaptive traits
- Biological control of pests and diseases in CA systems
- Bio-fumigation of soils for root disease control
- Managing arbuscular mycorrhizae in cropping systems
- Biological drilling to increase root penetration to deep water
- Exploiting growth promoting rhizobacteria
- Quantification of impacts of CA on natural resources
    - System-level water productivity
    - Carbon cycle and C sequestration
    - N cycle, soil microbiology, and greenhouse gas emissions
    - Interaction of physical fluxes at soil surface (i.e. water, gases, heat, dust particles) with tillage and crop residues

Exploration of genetic resources

While conventional plant breeding has achieved significant progress in stress breeding as outlined, three main approaches can be employed to widen gene pools, namely (i) introgression of traits from genetic resources with compatible genomes such as landraces, (ii) wide crosses involving inter-specific or inter-generic hybridization, and (iii) genetic transformation.

Genetic resources showing enhanced expression of stress-adaptive traits have been used in wheat breeding programs to a limited extent but the majority of accessions in germplasm collections remain uncharacterized in terms of their potential to improve yield under abiotc stress. Current challenges are to identify elite sources of traits among genetic resources, estimate potential yield gains associated with trait expression in good agronomic backgrounds, and define potentially complementary traits that if introgressed into a common genetic background are likely to result in cumulative gene action for yield. In experiments conducted in northwest Mexico, 25 elite genetic resources (including Mexican landraces) were characterized for agronomic and physiological trait expression in drought and heat stressed environments in order to calculate theoretical yield gains based on extrapolating the best trait expression to the highest yielding backgrounds. Under drought, the best expression of canopy temperature and carbon isotope discrimination suggested potential yield gains of approximately 10% and 9% above the best yielding cultivars, respectively. Under heat stress, canopy temperature and remobilization of stem carbohydrates suggested potential yield gains of approximately 7% and 9%, respectively (Reynolds et al. 2008b). Other physiological trait expression was associated with potential yield gains to varying degrees and principal component analysis indicated that many of the physiological traits that were associated with yield and biomass were not strongly associated with each other, suggesting potential cumulative gene action for yield if traits were combined. When comparing trait expression across drought and hot environments, several physiological traits -including canopy temperature and spectral indices- showed closer association with each other than did performance traits, supporting the idea that such stress-adaptive traits have generic value across stresses.

Inter-specific and inter-generic hybridization has been used to introgress genes into wheat and other crops for biotic stress (Dwivedi et al. 2008), however, relatively few wild crop relatives have been exploited for abiotic stress (Hajjar and Hodgkin 2007). Nonetheless, wheat has been an excellent model for alien introgressions and has resulted in substantial genetic gains for yield under drought (Trethowan and Mujeeb-Kazi 2008). For example, comparison of lines derived from re-synthesized wheat (AB +wild D genomes) with their recurrent parents showed increased water uptake associated with a root system that is more responsive to moisture stress than conventional cultivars, changing its relative depth profile according to moisture availability (Reynolds et al. 2007b). A vast reserve of genetic potential in closely related species of wheat has yet to be evaluated. For example in collaboration with Japan International Research Center for Agricultural Sciences (JIRCAS), CIMMYT is addressing use of *Leymus racemosus* to introgress genes for root exudation of nitrification inhibitors (Subbarao et al. 2006). The potential impact on reducing potent greenhouse gas emissions is enormous.

Transgenic technology effectively removes taxanomic barriers altogether but although much data has been collected under controlled environments for candidate genes that improve survival of both model and crop species under abiotic stress (Umezawa et al. 2006) more candidate genes need to be tested in a range of relevant field environments (Nelson et al. 2007) if impacts are to be achieved. Candidate genes, such as those associated with functional proteins and especially upstream regulation, could affect any of the drivers of yield under stress (Fig. 1) depending on at what stage of development and in which tissue they are expressed. Therefore, it is important to design experiments to test these effects, for example distinguishing between water uptake and water use efficiency when drought tolerance is reported so that genes can be more effectively targeted in breeding for different environmental constraints and effective gene combinations identified. Such approaches are being applied in a collaborative project involving JIRCAS, IRRI, CIAT and CIMMYT where *DREB* and other candidate genes are being tested with different promoters. Another candidate gene relevant to climate change is soluble starch synthase (SSS) from rice that may overcome the heat susceptibility of the enzyme in wheat.

Trait based approaches to breeding

Physiological trait based approaches to breeding have merit over breeding for yield *per se* by increasing the probability of crosses resulting in cumulative gene action as well as the efficiency of enriching for stress-adaptive alleles in early generation progeny selection. For example, parents can be chosen to combine traits from different drivers of yield (Fig. 1) that will theoretically show complementary gene action (Reynolds and Trethowan 2007, Reynolds et al. 2008). Collaborative work between CIMMYT and NARS focusing on hot, irrigated environments in the 1990s led to development of remote sensing of canopy temperature as an efficient high throughput screening tool which has found application in ME4 and ME5 (Trethowan and Reynolds 2007, Reynolds and Trethowan 2007). A number of lines developed using this approach –many incorporating crosses to 'elite' landraces screened under intense drought and heat stress– have shown excellent drought adaptation in yield trials and are candidates for the SAWYN international nursery (Trethowan and Reynolds 2007).

Molecular breeding

While marker-assisted selection (MAS) is routinely applied by CIMMYT for genetically simple traits indirectly related to drought tolerance like disease resistance (William et al. 2007) few quantitative trait loci (QTL) of large effect have been documented for performance related traits under abiotic stress. This is partly to do with the complexity of the phenomenon, however, many mapping populations to date have been developed using the concept of crossing highly contrasting parents to maximize genetic polymorphisms in the progeny. This has the inherent drawback that performance QTL identified in random lines are likely to be associated with traits that have already been optimized by breeding. Furthermore, no systematic effort is made to fix genes of major agronomic effect (e.g. *Ppd, Rht*) in experimental populations, making the task of identifying genes of minor effect statistically more challenging. This is exacerbated by the extreme sensitivity of reproductive growth to environment; consequently, in experimental populations with variable phenology, recombinant inbred lines (RIL) reaching critical growth stages on different days may trigger different signal transduction pathways. Accordingly, QTL studies frequently identify major loci related to flowering time as those most strongly associated with drought adaptation (Forster el al. 2004) which is essentially an artifact of not controlling phenology in experimental populations.

Gene discovery will be accelerated using populations with more uniform phenology. Populations are already under development at CIMMYT that through phenotypic and genotypic characterization of parents are expected to show narrow range of phenological response. In addition, lines are being selected using similar criteria from international yield trials for association genetics studies. In the mean time, the Wheat Physiology research team has developed (or has access to) 5 doubled haploid and 2 RIL populations to expedite gene discovery using appropriate statistical procedures to minimize confounding effects of agronomic type. These are being characterized using large scale phenotyping protocols including (i) spectral reflectance for growth analysis (Babar et al. 2006); (ii) infra-red thermometry for canopy temperature measurement –a trait which has a strong association with yield in both hot and dry environments (Olivares et al. 2007), and (iii) near infra-red reflectance analysis to estimate stem carbohydrate (that are re-translocated during grain-filling).

Understanding GEI

Characterization of large mapping populations in stressed environments will provide unprecedented opportunities for analysis of genotype by environment interaction for stress adaptive traits at a global level. With access to comprehensive environmental data sets facilitated by the latest GIS techniques, sophisticated statistical approaches such as partial least squares analysis can pinpoint the most vulnerable phenological stages of crop development to specific abiotic stress factors (Vargas et al. 1998; Lillemo et al. 2005). Future studies with larger and more comprehensive data sets are expected to indicate clear targets for genetic enhancement and basic research into stress-adaptive mechanisms.

Conclusion

In addition to the promise from new technologies much crop research conducted to date (www.plantstress.com) has the potential to mitigate negative effects of climate change if combined in a multidisciplinary, problem-oriented focus. *Ex-ante* analysis should consider which approaches are most likely to be cost-effective, balancing research on crop genome and crop management strategies.

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Conservation Agriculture on the Ground: Reducing Tillage, Managing Residues and Diversifying Cropping for Higher Productivity and Sustainable Soils

Ken Sayre and Bram Govaerts

Farmers in both developed and developing countries are confronting new challenges related to the global economy, climate change and accelerating production costs. At the same time, conventional farming practices that involve tillage for land preparation and weed control, removal or burning of crop residues, and mono-cropping are clearly associated with soil loss by erosion and the congruent degradation of soil physical, chemical and organic parameters needed for efficient water productivity and sustainable crop production. Over the past 30 years, realization by farmers and other stakeholders that a new approach to farm management is needed that addresses these issues and which relies on reduced tillage, proper crop residue retention and use of more diversified crop rotations, all applied in an economical manner. This approach is now referred to as conservation agriculture. Since this approach requires major mind-set changes in conventional production, farmer participation in the development and adaptation of new conservation agriculture technologies, both on station and on farmer fields is crucial to successful extension and farmer adoption.

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Challenge Programs:
Proposed, Present and Prospects for CIMMYT

Rodomiro Ortiz

The concept and process

A Challenge Program (CP) of the Consultative Group on International Agricultural Research (CGIAR) is a time-bound, independently-governed program of high-impact research, which targets the CGIAR goals in relation to complex issues of overwhelming global or regional significance, and requires partnerships among a wide range of institutions in order to deliver its products. A five-phase process is used for the development and implementation of all CP:

1. Idea Generation
2. Development of Pre-proposals
3. Development of Full Proposals
4. Program Implementation
5. Program Evaluation

The ongoing 1st Cycle CP

The first CP, namely, Water and Food, HarvestPlus, and Generation , were launched on a pilot basis in 2003 following a CGIAR-approved process and guidelines for developing and implementing CP. A fourth CP, the Sub-Saharan Africa Challenge Program (SSA CP), was approved by the CGIAR, conditional on successful implementation of an inception phase that ended in 2007. CIMMYT may be the only CGIAR center participating actively in the four CP and implementing projects with their funding: for adaptative natural resource management research-for-development with Water and Food and SSA CP, and strategic genetic resources enhancement with HarvestPlus and Generation. CIMMYT takes the lead, among CGIAR sister centers, for biofortification of maize and wheat in the former, and hosts the latter. CIMMYT also facilitates 3-year project for conservation agriculture research in the dry lands of the Yellow River Basin (under the Water and Food CP), and on soil fertility in the Zimbabwe-Malawi-Mozambique pilot learning site of the SSA CP. Some partial reports given during this CIMMYT 2008 Science Week ensued from CP investments in the Centers' projects, particularly in P2, P4, P7 and P10. For further information about each CP and links to their web sites browse http://www.cgiar.org/impact/challenge/index.html

The 2nd Call for CP

At the end of December 2006 the CGIAR Secretariat issued the 2nd Call for CP. More than 40 concept notes were submitted (about ¼ by the Alliance of CGIAR Centers) and the Science Council selected five of them for further pre-proposal development. However, the CGIAR Executive Council (ExCo) only endorsed the following: Climate Change, High Value Fruits and Vegetables, and Combating desertification/Dry land degradation[†].

[†] "Mycotoxins" and "Linking Markets to Farmers" CP idea notes were also initially recommended by the Science Council for moving into CP pre-proposals but did not find a strong support among ExCo members. It was initially agreed

Following this ExCo decision, the CGIAR issued a call for pre-proposals on the three selected subjects. There were 14 pre-proposals for Climate Change, 10 for High Value Fruits and Vegetables, 4 for Combating desertification/Dry land degradation, and 11 on other subjects out of the call. The Science Council after appraising the 35 pre-proposals found that none of those submitted was of sufficiently good quality to move to the full-proposal stage. The Science Council recommended to ExCo that pre-proposal development stage be extended for the following pre-proposals:

1. Climate Change, Agriculture and Food Security (submitted by the Environmental Change Institute [Oxford, UK] in partnership with the Alliance of CGIAR Centers and others in the Earth System Science Partnership or ESSP hereafter)
2. Oasis –focusing on desertification (submitted by the Alliance of CGIAR Centers et al.)
3. High-Value Crops - Fruit and Vegetables (submitted by the World Vegetable Center on behalf of the Alliance of CGIAR Centers together with other partners)

ExCo also expressed disappointment with the low quality of the pre-proposals but recognized these are important research areas and the CGIAR should signal a willingness to move forward. In this regard, ExCo asked the proponents of the pre-proposal on climate change (hereafter CCCP) to incorporate lessons learned from the first cycle of CP, comments from the Science Council (http://www.cgiar.org/exco/exco13/exco13_sc_commentary_cp_pre-proposals.pdf), and information on gaps identified by the stock taking, and develop a more focused full proposal for submission to the Science Council by 29th February 2008, for assessment by the Science Council in its first 2008 meeting, and further discussion and recommendation at ExCo 14 (May 2008). With respect to the pre-proposals on Oasis and High-value Crops, ExCo decided the following:

1. The proponents of the pre-proposals on Oasis and High-value Crops should incorporate lessons learned from the first cycle of CP, and guided by inputs from the Science Council on the pre-proposals, develop full proposals for Science Council review.
2. Oasis should be submitted by end of March 2008 for assessment by Science Council and discussion and recommendation at ExCo 14.
3. High-value Crops should be submitted at the latest by July 31, 2008, if not earlier for assessment by the Science Council and discussion and recommendation at ExCo 15 (October 2008).
4. After submission of the full proposals, if ExCo does not believe the full proposals are of sufficient quality, they would be withdrawn from further consideration.

Since CGIAR AGM07 (Beijing, Dec. 2007) the Alliance of CGIAR Centers called on the Alliance Deputy Executive (ADE) for a stronger strategic input into guiding development of the full proposals for the second cycle CP to ensure that they would be of acceptable

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that some ideas included in the "Bio-energy" CP concept note to be an input into the Climate Change pre-proposal. They may be also taken into the content of the "Alliance Bio-energy Platform" launched in Dec. 2007. Similarly some of the elements included in the concept note for Mycotoxins CP were included in a proposal under perusal by the EU 7th Framework and may be taken into account by a IFPRI-led proposal to Bill & Melinda Gates Foundation (BMGF) focusing on West Africa. Elements of the CP idea note on "Intensifying and Diversifying Cropping Systems" may be considered for the IRRI-CIMMYT-IFPRI proposal to BMGF for South Asia quality as CP, It also decided that small writing groups will lead the proposal development and through consultations with all partners involved. The selected organizations for the small writing groups are for CCCP: Four ESSP partners and CIAT [natural resources], IFPRI [policy], ILRI [livestock] and IRRI [crops]; for Oasis: ICARDA, ICRISAT as Oasis co-conveners and involving a few non-CGIAR co-proponents; and for High Value Fruits and Vegetables: The World Vegetable Center together with Bioversity International and ICARDA on behalf of the Alliance. ADE asked their members participating in the small writing groups (IFPRI for CCCP, Bioversity for High Value Fruits and Vegetables, and ICARDA for Oasis) to ensure the quality of the proposals as per the guidelines given by the Science Council. The ADE chair and the Chief Alliance Officer are closely following the proposal development for each CP. In January 2008, the CGIAR Secretariat agreed to host a meeting in Washington DC between the Science Council and the small writing groups to assist the proposal proponents to adjust their drafts to the feedback provided taking into account that the Science Council was clear in their last appraisal of pre-proposals: "*a CP must add value to the on-going agenda, and not be the on-going agenda.*"

Status of CP proposal development and CIMMYT "niche" therein

CCCP

The proposal by CGIAR chairwoman on launching a CGIAR Initiative on Climate Change (endorsed initially by ExCo13, approved by the membership at AGM07) put CCCP in other perspective. As per the press release during the High Level Meeting at Bali (Dec. 2008), the CGIAR invests annually nearly US $ 70 million (or 15% of its total budget) on research related to climate change. This "ongoing research" includes paying attention to the vulnerability of agriculture, assessing the impacts of climate change, adapting agriculture and natural resource management to global warming, mitigating greenhouse emissions through better land management, and developing appropriate policy. In short, all the ongoing CGIAR research regarding climate change was included under the adaptation theme of this "virtual" CGIAR Initiative on Climate Change. Hence, CCCP proposal should show as "adding value" to, rather than being this Initiative. Considering such views, CCCP proponents already drafted the proposal following a meeting between the small writing group and non-proponent stakeholders (held in Addis Ababa in Jan. 2008) and the recent meeting with the CGIAR Science Council and Secretariat in Washington DC. This draft includes as goal "*to increase food security, enhance livelihoods and improve environmental management in the context of climate variability and climate change*". The CCCP main objectives are:

1. To overcome critical gaps in knowledge of how to enhance – and manage the tradeoffs between – food security, livelihood and environmental goals in the face of a changing climate. *[CP outputs-orientated]*
2. To develop and evaluate climate adaptation and mitigation options to inform agricultural development, food security policy and donor investment strategies. *[CP outcomes-orientated]*
3. To empower key stakeholders to continually monitor, assess and adjust their actions in response to a changing climate. *[CP impacts-orientated]*

The CCCP research questions are still being refined and the suggested five Science themes are (1) **diagnosing vulnerability** of agriculture and food security to climate variability and climate change, **and analyzing opportunities** for adaptation and mitigation and their impacts on poverty, food security and the environment; (2) **developing adaptation pathways** for agricultural and food systems to reduce vulnerability to climate variability and change, and analysis of tradeoffs between improving livelihoods, food security and environmental benefits (3) **identifying emerging mitigation options** that simultaneously directly or indirectly increase food security, enhance livelihoods, and better manage environmental services, (4) **enhancing researcher–stakeholder interactions** for improved communication that facilitates responses to climate variability and change in a sustainable manner, and (5) **understanding the role of macro-level policies** in adaptation and mitigation options for developing-country agricultural growth, food security, and environmental sustainability.

Geo-domains: The Intergovernmental Panel on Climate Change identified South Asia and Africa as regions vulnerable to climate change and deserving of priority attention. Hence, CCCP proposal writing team, after consulting with main stakeholders, decided three regions would be a realistic starting point, with others to be identified and added in as soon as funding allows. The initial six candidate regions were South-East Asia, the Indo-Gangetic Plains, Northern Africa, Western Africa, Eastern Africa, and Southern Africa. In the view of the writing group "*two of the six regions – South-East Asia and Southern Africa – are making progress towards the food security MDG, while the other four are not. South-East Asia has relatively low water stress, while Southern Africa has relatively good management of water stress. The other four regions are all exposed to water stress and are failing to manage its impacts, although Northern Africa has limited geographical area with unique characteristics, which reduce transferability of results.*" The three selected regions for initial studies are therefore the Indo-Gangetic Plains (IGP), Eastern Africa and Western Africa. In the available CCCP draft, for Western Africa, research with national partners will be facilitated by a coordination group involving AGHRYMET, the West and Central Africa Council for Agricultural Research and Development (CORAF/WECARD), and the regional Alliance Collective Action Network, whereas for Eastern Africa, research with national partners will be facilitated by a coordination group involving The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), IGAD (Inter-Governmental Authority on Development) Climate Prediction and Applications Centre (ICPAC), and the regional Alliance Collective Action Network. Likewise, for IGP, research with national partners will be facilitated by a coordination group involving the Rice–Wheat Consortium (which will bring links to agricultural research institutions in each country), and a leading climate change institute from each country.

CCCP implementation: Research in each region will be conducted across a number of 'benchmark sites' representing biophysical and socioeconomic gradients. Close liaison with World Food Program, Food and Agriculture Organization of the United Nations and other major international organizations will build links with policy processes at the highest levels both regionally (e.g. with the African Union) and nationally. In Western and Eastern Africa these will be selected by the regional coordinating group, in consultation with national agencies. In the IGP it is suggested to adopt the set of five sites (districts) where collaborative CGIAR–ESSP research is already underway within the project of the Global

Environmental Change and Food Systems (GECAFS). A variety of research funding mechanisms is envisaged, including commissioned studies (main method), international networking and synthesis activities, and competitive open calls when deemed necessary.

CIMMYT niche: As per above developments, CIMMYT research may find a "niche" in research themes such as **developing adaptation pathways, identifying emerging mitigation options** and perhaps on **diagnosing vulnerability and analyzing opportunities**, and team up on the research to be undertaken in both Eastern Africa and the IGP. During 2007, CIMMYT started positioning on the above by showing its involvement in climate change research through institutional publications (e.g. last annual report, brochure, overview in forthcoming medium-term plan), journal articles ("Can wheat beat the heat?"), and CGIAR press releases. In this way, the Center can be seen as contributing towards the CCCP evolving research-for-development agenda, especially in breeding crops for adapting and mitigating climate change that fits especially into P3 and P7.

Oasis

The Oasis Writing Group's held deliberations in its first meeting at Bonn in mid-January 2008. This meeting focused mainly on the science questions and briefly on the geographic targets thought to be most relevant to those questions. Prior to this meeting, the proposal conveners proposed a reduction of "Knowledge Streams" (or KStreams for short) to three as a first step in meeting the Science Council's instructions to more sharply focus Oasis. This reduction needs to be further focused and sharpened by the writing group into "new science" directions that build on and extend, rather than duplicate or re-package the existing agenda of the CGIAR Centers and partners. The basic outlines of the three KStreams are as follows:

1. KStream 1. Understanding the drivers of dryland degradation from a sustainable development perspective. Remote sensing tied to land surface indicators and human or social development analysis, and linkages between dryland degradation and climate change [with the World Agroforestry –from the Alliance Centers, facilitating this KStream proposal development]
2. KStream 2. Landscape-scale natural resource trends and solutions. Landscape-scale natural resource pools and flows in the drylands. Resilience and buffering strategies, interdependencies between agricultural and non-agricultural dryland ecosystems, valuation methodologies for ecosystem goods and services [with ICARDA facilitating this KStream]
3. KStream 3. Livelihood and policy interactions for dryland degradation and rehabilitation. Multi-agent analysis, bio-economic modeling, typologies, GIS-linked models to understand how policies, institutions, markets and others influence dryland livelihoods in ways that save lands [with IFPRI facilitating this KStream]

The "soul-search" of Oasis was an important item in the Bonn meeting. As a result of this meeting, the revised core question that of this CP proposal was re-defined as "*Can, and if so, how can better land care and livelihoods be realized?*" The challenge (or main goal) for Oasis is therefore "*to develop the understanding that answers the above core question for major dry land areas in the developing world, and to develop the analytical tools and protocols needed by development partners to achieve win-win outcomes for people and land*". The small writing group did brainstorming on some subjects such as conceptual and implementation frameworks, including novel approaches to land health[‡] and on the target locations. The discussion continues on refining both frameworks and some agreement was reached on five priority regions for initial research undertakings (though specific locations within each region still need to be agreed upon): West Africa, East Africa, Southern Africa, South Asia, and Central Asia and the Caucasus. Further work for the proposal development includes identifying strategic partners, potential impacts, funding sources, and governance.

CIMMYT niche. CIMMYT P10 research on conservation agriculture can contribute to **KStream 2**, especially in the selected priority regions, where CIMMYT has ongoing partnership research, namely Eastern and Southern Africa, South Asia, and Central Asia and the Caucasus

High Value Fruits and Vegetables
As pointed out by the Science council, the pre-proposal had four specific objectives which span the research very broadly over issues of productivity (including breeding), market chain development, food quality and safety, and capacity building. The Science Council concluded that the majority of the pre-proposal objectives and outputs did not show clear international public good attributes, and that the added value to the CGIAR agenda was not clear, except "possibly" for the research proposed on food safety. For example, the first objective on improving the productivity and sustainability of fruit and vegetable production systems included very broad outputs, including improved cultivars and management practices, dissemination of cultivars, and identification of market opportunities for underutilized fruit and vegetables, which in the view of the Science Council, "encapsulates" much of what the World Vegetable Center currently does. Above and many other points brought to the attention of the proponents by the Science Council need to be addressed in the full proposal for this CP since in their view "*the elements of this pre-proposal in part represent business as usual by one proponent, and other parts seem to be more appropriately done by NARS and private sector institutions.*" In short the research agenda for this full proposal to be successful and obtain the endorsement from the Science Council before ExCo approval should show how this CP "*contributes and adds value to, rather than recapitulates, global initiatives.*"

CIMMYT niche: **Vegetable maize** research as recently suggested by 2007 CIMMYT publications (brochure and review article), which fits into P4. For this purpose CIMMYT needs to continue showing the ranking of vegetable maize among the top vegetable crops, and its importance in sub-Saharan Africa and Latin America (though this 2nd region may not be a priority area for this CP), and its potential in South Asia.

[‡] The advantages of the "land health approach" to dry land degradation, as seen by the writing group are: *(1) it takes a scientific approach to the assessment and diagnosis of land degradation, using objective measurements and sampling techniques rather than guesswork or assumptions or subjective judgments; (2) it allows identifying and understanding "syndromes", or combinations of certain factors that may help recognize similar patterns and associations of symptoms in different locations and settings, leading to quicker and more effective prescriptions for solving the problem; and (3) it requires to follow up by monitoring the "patient" to see how the "prescriptions" are performing, and to make adjustments on that basis; something which is often overlooked in conventional approaches to combating dryland degradation. This follow-up or adjustment approach neatly accommodates the "development pathways" concept, which recognizes that solutions may require multiple steps and gradual progress, with midcourse corrections along the way*

Advances in IRRI-CIMMYT Crop Research Informatics Laboratory (CRIL)

Graham McLaren et al.

A. Institutional Progress 2007

Institutional Organization and Infrastructure

Institutional organization of CRIL within IRRI and CIMMYT continues to evolve. At IRRI the head of CRIL reports directly to the Deputy-Director General of Research (DDGR) and this facilitates working relationships across all units and programs. At CIMMYT CRIL is organizationally placed within the Genetic Resources Enhancement Unit (GREU). This masks the institute-wide mandate of CRIL and could lead to management issues since there is no reporting line through the GREU program leader. For now this is a workable arrangement but it should be reviewed in the future. The masking of institute-wide mandate could be addressed by the establishment of a CIMMYT Research Informatics Steering Committee with representation from each program. This was planned by the previous DDGR but never instituted – he was to chair that committee. It would be a good idea to form this committee as soon as possible. In the absence of CRIL head, Jose Crossa will act as head at CIMMYT and Thomas Metz will act as head at IRRI.

Staffing

The senior staff compliment of CRIL during 2007 is as follows:

Head of CRIL and Biometrician	Graham McLaren	IRRI-CIMMYT
Principal Scientist and Biometrician	Jose Crossa	CIMMYT
Bioinformatics Specialist	Richard Bruskiewich	IRRI
Computational Biology Specialist	Guy Davenport	CIMMYT
Research Information Specialist	Thomas Metz	IRRI
Quantitative Geneticist and Modeler	Jiankang Wang	CIMMYT
Information Specialist	Eduardo Hernandez	CIMMYT
GCP Bioinformatics Post Doc.	Ramil Mauleon	IRRI
GCP/C4 Bioinformatics Post Doc.	Samart Wanchana	IRRI
GCP Bioinformatics Post Doc.	Trushar Shah	CIMMYT

In addition the following senior positions are being recruited:

Bioinformatics Post Doc. (Ontology)	CIMMYT
Quantitative Geneticist and Modeler	IRRI
Software Engineering Project Manager	IRRI

CRIL Support staff now number 42 of which 13 are nationally recruited staff (NRS) positions, 25 are project or contract positions and 4 are students. New NRS positions have been created to support Thomas Metz at IRRI and Guy Davenport at CIMMYT (replacing a current contract position). Recruitment of programmer/informatics support staff at IRRI was slow and difficult due to market competition. This has affected delivery on several Generation Challenge Program (GCP) projects.

Progress on medium-term plan institutional outputs on data management and crop information management are severely constrained due to lack of staff at CIMMYT planned for those tasks. Output targets for Institutional Research Data Management and Crop Information Systems must be revised downward in the absence of NRS support for data management and an IRIS position for Crop Information Systems at CIMMYT.

Budget

Table 1. Total CRIL budget (US$) for 2007 by category and institute

Budget Category	IRRI	CIMMYT	TOTAL
A. Staff			
Senior staff – Unrestricted	298,841	258,052	556,893
Senior staff – Restricted	22,900	150,000	172,900
Support staff – Unrestricted	112,785	100,000	212,785
Support staff – Restricted + Consultants	161,703	150,000	311,703
Totals	588,229	658,052	1,246,281
B Operational			
Unrestricted	173,482	215,132	388,614
Restricted	297,438	142,827	440,265
Totals	470,920	357,959	828,879
Totals	1,059,149	1,016,011	2,0751,60

Medium Term Plans (MTP)

CRIL activities for 2007 are integrated into the MTP of both IRRI and CIMMYT. Most CRIL activities fall into Program 5 - Conservation and discovery of rice genetic diversity: enhancing the ability to meet the genetic resources needs for sustainable development and Program 6 – Information and communication: convening a global rice research community at IRRI; and into Projects 1 – Conservation, characterization and utilization of maize and wheat genetic resources and Project 2 – Technology-assisted tools and methodologies for genetic improvement at CIMMYT.

B. Technical Progress 2007

Research support and quality assurance

Consultation

Consultation on design and analysis of experiments and surveys continues as well as consultation on information management and bioinformatics.

Training

A list of completed or planned training courses on research informatics is in Table 1.

Table 2. List of Courses and Workshops offered or supported by CRIL in 2007

Courses/Workshops	Date	No. of Participants
Genotyping Data Quality Workshop (GCP)- IRRI	19-23 February	11
Experimental Designs and Data Analysis for Plant Breeders, CRRI, Cuttack, India	6-9 March	19
Workshop on Quantitative genetics and Statistical Methodology in Support of Germplasm Conservation and Crop Improvement - IRRI	14-16 March	29
Workshop on GE interaction and Breeding Simulation – Beijing	19-22 March 2007	38
Basic Experimental Designs and Data Analysis Using CropStat – IRRI	26-30 March	24
Experimental designs, CropStat and the analysis of multi-environment trails for Wheat Research Training Course – CIMMYT, El Batán	April – May 2007	10
Agricultural Research: Design and Management for Bangladesh - IRRI	30 April – 11 May	8
Use of CropStat for the Analysis of GxE interaction-Tamilnadu Agricultural University, Coimbatore, India	8-10 May	24
Analysis of Experimental Data Using the SAS System - IRRI	28 May-1 June	16
2007 Rice Breeding Course IRIS, EDDA, and Combined Analysis	August 20-31	23
2007 Rice Breeding Course IRIS, EDDA, and Combined Analysis	October 1-12	27
Basic Experimental Designs and Data Analysis Using CropStat – Myanmar	November 8-12	22
FieldBook training for Maize breeders, Nairobi, Kenya	August 21-31	25
Use of ICIS applications for managing breeding programs, ICARDA, Syria	September 2-6	25
Analyses of Mixed Models and Categorical Data - IRRI	November 20-22	17
Analysis and curation of Microarray data – South Africa	11 September	20

IRRI is also leading a GCCP Subprogram 5 commissioned research activity to develop an online introductory course for bioinformatics, which will be published by the end of the year at the web site: http://mcclintock.generationcp.org

Collaboration Tools

Collaborative platforms for software engineering (http://cropforge.org) and content development (http://cropwiki.irri.org) continue to be maintained by CRIL and are used by several global communities (e.g. GCP, ICIS, CropStat). The JIRA issue tracking system (http://cril.cimmyt.org/jira) is used for some projects, including the GCP Templates GenoMedium projects. CRIL also provides support for the confluence wiki at CIMMYT (cril.cimmyt.org/confluence). The installation and maintenance of these systems is primarily funded through a GCP project:

Task 2005-34 – Generation CP Software Engineering and Collaboration Platform
The CropForge system is in continuous use by software developers and has become the core collaboration and communication platform to facilitate software development and support (http://cropforge.org). Several manuals were produced to facilitate working with CropForge (http://cropforge.org/projects/cforgeinfo/).The CropWiki system hosts a number of Wiki sites for different communities (http://cropwiki.irri.org).

Data Quality
CRIL leads a GCP project on research data quality improvement and assurance:
Task 2006-17 – Generation CP Data Quality Improvement and Assurance
This project has conducted several workshops related to data quality:

- Genotyping data quality – 19-23 February 2007 at IRRI
- Passport data quality – 3-5 July 2007 at Bioversity
- LIMS developers' workshop – 24-31 August at ICRISAT
- Quality Management and Performance Measurement System design workshop - 16-19 October hosted by CGN.

Reports of these workshops are available on the GCP Wiki at: (http://cropwiki.irri.org/gcp/index.php/DataQuality2006).

Institutional research data management

Presentations of the proposed framework for Research Data, Information and Knowledge Management were given to the Crop and Environmental Sciences Division (CESD) and ITS at IRRI, and in the form of two seminars during a visit at CIMMYT. At IRRI, file management and structured data management support in the form of individual training and data conversion has been given to several groups in CESD. Data management support was also provided to the Analytical Services Laboratory at IRRI for the production of quality control charts.

At CIMMYT, the conversion of many separate sets of agronomy data (Ken Sayre) into a single database was further tested. A set of 382 experiments, comprising about 2.4 million data points was converted into a single database, and a meta-data catalogue was created. Further work on the datasets and the curation of the meta-data is required.
A new NRS position, Officer - Institutional Information Systems Management was recruited at IRRI and started work in May. At CIMMYT, an equivalent position is still under consideration.

A support site for research data management in the form of a Wiki was established at IRRI (http://cropwiki.irri.org/everest). The site has been populated with best practices, data management recipes, and guidelines. Short video clips of complex procedures or useful tools are being integrated.

At IRRI, initial installation, configuration, and testing of OU file repositories was carried out in cooperation with ITS, and the possible structure of such a repository was discussed with the head of CESD. Three research groups of CESD and several users in SSD are currently using these OU repositories. The institutional repository software system DSpace was installed at IRRI (http://dspace.irri.org:8080/dspace/) and made available for testing to CPS and Library staff. About 200 digital knowledge objects were uploaded, a simplified version of the Rice Thesaurus was integrated, and full text indexing locally and through the Google search engine was achieved. A final evaluation report and recommendation for institutional adoption will be prepared by January 2008.

ICT-KM – Good Practices for Managing Research Data
This project was accepted for funding in June 2007. The objectives are to develop, collect, record, and apply good practices in research data management at IRRI and CIMMYT and to initiate and support communities of practice of research data managers at IRRI and CIMMYT. The outputs will contribute to the IRRI/CIMMYT Wiki support site for research data management.

<u>Task 2005-25 – Creation and maintenance of templates for Generation CP data storage in repositories (CIMMYT led task)</u>

Work on the new versions of the GCP templates is nearly completed using input from the GCP Genotyping Data Quality Workshop held at IRRI, 19-23 February (http://cropwiki.irri.org/gcp/index.php/Genotyping_Data_Quality_Workshop) and from the data already available in the Central Registry. Development of templates for SNP and DArT genotyping has also been started.

In collaboration with the GCP Central Registry we did a review of the data in the Central Registry to see if they conformed to the GCP templates. The results of this review are reported in the Central Registry report. The providers of data not conforming to the GCP templates will be approached and given help to reformat or complete their datasets. As part of a no-cost extension to the 2006 project the web interface for GCP is expect to be finished by early next year. Improvements to the template dataset editor and validator plug-ins for GenoMedium have been started and the improvements GenoMedium will be available on the GenoMedium website by the end of the year

Crop information systems for rice, wheat and maize

International Crop Information System
The 2007 ICIS Developers' Workshop was hosted by Agriculture and Agri-Food Canada at SPARC Swift Current, Canada, 4-8 June 2007 (<u>http://cropwiki.irri.org/icis/index.php/ICIS_Workshop_2007</u>). A new release of ICIS software (version 5.4) was delivered to the ICIS community at that workshop. This release has improved breeders' applications for nursery generation, inventory control, and data management as well as new administrative tools for checking system and data integrity. The GRIMS module for managing genetic resources information is complete for rice but will probably need some modification for other crops. The gene management system, GEMS, has been completely designed and is being deployed for rice, wheat and maize.

Facilities for managing high throughput Diversity Array Technology (DArT) genotyping data have been tested. Queries for genotyping data are being developed. ICIS adaptation as a data source for the GCP platform is continuing and a web interface to ICIS will be available through the generalized GCP platform data integration and query builder, Koios. The CropFinder database and web interface has been developed as a data warehouse for ICIS DMS. It has a user friendly query interface which allows users to systematically filter and search ICIS data. Development of a CropFinder API has started in order to provide a more flexible system that will allow different database systems and user interfaces to use the CropFinder software, including both standalone and web based software. ICIS 5.4 software is available from the CropForge collaboration site (http://cropforge.org/projects/iciscomm/) under the GNU General Public License for collaborative development of deployment for different crops.

International Rice Information System (IRIS)
New releases of the IRIS central database have been made throughout the year. These are available from the ICIS FTP site which can be reached via the ICIS web page (www.icis.cgiar.org). Facilities were added to IRIS to implement the Multi-lateral System (MLS) of germplasm exchange through the Standard Material Transfer Agreement (MTA) brought into effect by the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture. These facilities implement complete tracking of germplasm in and out of IRRI, identification of MLS ancestors in germplasm for export, allocation of MTA status to all exports and imports (MLS, Under Development, or other special cases), publication of exported germplasm with identification of MLS ancestors, pedigrees, passport and evaluation data on the Web (www.iris.irri.org/smta).

International Wheat Information System (IWIS3)
Software to synchronize the older system of IWIS, IWIS2, with the ICIS version, IWIS3, has been completed and a new version of IWIS3 released at the ICIS workshop in June. This synchronization allows existing IWIS applications (such as large-scale field-book generation) to continue uninterrupted while programs and projects adopt ICIS applications to improve efficiency or handle new situations. Wheat genotyping data for diversity studies, marker assisted selection and genome-wide scanning (DArT data) are being stored in IWIS3 DMS.

A prototype CropFinder web interface to wheat genetic resources data has been developed and is awaiting feedback for improvement and further development (http://sas.cimmyt.org/cfiwis).

International Maize Information System (IMIS)
Software has been developed to parse maize pedigrees from the consolidation report of Maize Fieldbook into IMIS GMS. This will be deployed in as many breeding projects as possible as well as on data from the maize genebank to develop a central IMIS GMS which can form the basis of an ICIS implementation for maize. Current and historical maize evaluation data has been added to a new release of MaizeFinder in an on-going effort to accumulate all relevant evaluation data in a single database. Work is underway to standardize 81,000 pedigrees and to curate historical phenotypic data. A prototype CropFinder web interface to maize genetic resources data has been developed and is

awaiting feedback for improvement and further development (http://sas.cimmyt.org/cropfinderimis).

Bioinformatics, computational biology and comparative genomics

GCP funded CRIL postdoctoral scientists continue work on a number of fronts supportive of the goal of comparative genomics across rice, maize and wheat. These efforts include the continued development of a comparative stress gene catalog and of an integrated analysis pipeline and database for microarray and quantitative trait locus data, the latter a formal part of the GCP Subprogram 2 data analysis task led by Guy Davenport with IRRI-CRIL co-PI, Richard Bruskiewich, plus two postdoctoral scientists, Ramil Mauleon (IRRI) and Trushar Shah (CIMMYT). CRIL is continuing its leading role on GCP domain model and ontology development, and on GCP platform use case development for GCP subprogrammes 2 and 3.

Task 2005-31 – GCP comparative stress gene ortholog database and visualization tools (IRRI-led task)

CRIL is continuing its leading role on GCP comparative stress gene ortholog database and visualization tools. The database and web interface (http://dayhoff.generationcp.org) were significantly enhanced in 2007 in time for presentation at the annual review meeting of the GCP. In addition, an article was submitted and accepted in the Nucleic Acids Research database issue (Wanchana et al. 2008).

Task 2006-16 – GCP platform development (IRRI-led task)

Development of the stand-alone interface (GenoMedium) was continued with new functionality such as ICIS data sources and integration with the GCP Templates data editor. Tools to support molecular breeding will be developed next year for GCP Subprogram 3. A breeder's decision making tool based on GCP platform technology is being designed in consultation with several public communities including local IRRI and CIMMYT scientists, ICIS community scientists and other experts.

For Subprogram 2, work continues on the adaptation of the MAXD microarray database (http://www.bioinf.manchester.ac.uk/microarray/maxd/) and the GMOD (www.gmod.org) Chado database to host GCP functional genomic data using domain model and application programming interface standards of the GCP platform middleware (http://pantheon.generationcp.org). This work is including the integration of several publicly available 3rd party analysis tools like the TIGR Multiple Experiment Viewer (TMeV; http://www.tm4.org/mev.html), Cytoscape (http://www.cytoscape.org/), Apollo (http://www.fruitfly.org/annot/apollo/), ATV (http://phylosoft.org/atv/) and CMTV (http://www.ncgr.org/cmtv). Concurrently, work is progressing on both standalone (http://www.genomedium.org) and web-based GCP domain model-based search engine applications.

At IRRI, significant bioinformatics effort is focusing on the analysis of the 20 rice cultivar genome-wide polymorphism detection experiment with Perlegen Life Sciences, which has yielded a data set of over 160,000 high quality polymorphic loci (mostly bi-allelic SNPs). The first full production release of the data to the international community was made in October, and is accessible on the new OrzyaSNP portion of a new Joomla! web site deployed as the public portal of the International Rice Functional Genomics Consortium (http://irfgc.irri.org).

In addition to GCP project activities, both IRRI and CIMMYT are embarking on longer term comparative biology efforts focusing on comparative genomics for plant disease (namely, the CIMMYT rice-wheat comparisons to shed light on wheat rust pathology) and in photosynthesis (C4 rice development through rice-maize genomic comparisons). An invited scientific manuscript about the GCP platform was submitted to a special bioinformatics issue of the International Journal of Plant Genomics.

Task 2006-08 - Data analysis support for existing projects in SP2 with emphasis on integrating results from microarray and mapping experiments (CIMMYT-led task)

Two general activities were carried out in microarray data analysis at IRRI. The first major activity was customizing the microarray expression database (maxd-GCP) to load GCP-specific data. Data for two array platforms (Agilent 22k rice oligoarray platform – catalog no. G4138A, and University of Arizona maize oligoarray chip) were coded as XML scripts loadable into maxd-GCP. These are available at the cropforge site http://cropforge.org/projects/gcpmicroarray/. The second major activity was the development of data analysis software for microarray analysis. Two sub-activities were done: (1) Implementation of published analysis algorithms as R and Perl scripts, for pipeline analysis, and (2) Reconfiguration of pre-existing open-source or freeware programs. This was initially done for the rice array system.

Determination of a common genetic basis for tissue growth rate under water-limited conditions across plant organs and genomes

CRIL has taken the lead at CIMMYT on this GCP commissioned project, which was recently extended until the end of 2008. The project in CRIL involves determining the affect of water deficit on growth maintenance in Maize through analysis of gene expression. The approach is primarily a computational one in which genes with differential expression between well watered and water deficit samples are aligned on physical and genetic maps and associated with known drought quantitative trait loci (QTL), putative metabolic pathways and genotypes with known drought responses. CRIL will also compare these results with similar efforts in rice and wheat to hypothesis on a common mechanism for growth rate.

GCP Subprogram 5 – Online Bioinformatics Course

As mentioned in the training section, IRRI is leading a GCP Subprogram 5 commissioned activity to develop an online introductory course for bioinformatics. The course is available at: (http://mcclintock.generationcp.org).

Decision support tools for crop improvement

Statistical methodology to support crop improvement

Statistical models for analysis of multi-environment trials

Genotype-by-environment interaction can be due to crossover interaction (COI) or to non-COI. Statistical methods for detecting and quantifying COI, and for forming subsets of environments or genotypes with negligible COI have previously been based on fixed effect linear-bilinear models. Linear mixed models with factor analytic (FA) variance-covariance structures offer a more realistic and effective approach for quantifying COI and forming subsets of environments and genotypes without COI.

We have done research that developed an integrated methodology for clustering environments and genotypes with negligible COI based on results obtained from fitting FA models to multi-environment trial data and for detecting COI using predictable functions based on the linear mixed model with FA covariance and Best Linear Unbiased Prediction (BLUP) of genotype effects. Results show that the proposed method formed subsets of environments and/or genotypes with negligible COI. The main advantage of the integrated approach is that one unique linear mixed model, the FA model, can be used for: (1) modelling the association among environments; (2) forming subsets of environments without COI; (3) grouping genotypes into non-COI subsets; and (4) detecting COI using the appropriate predictable function.

Statistical methodology for association mapping

Significant advances in association mapping using historical CIMMYT wheat multi-environment trials have been achieved by means of linear mixed models. This association of markers and traits is based on linkage disequilibrium (LD) between loci determined by their physical distance across chromosomes. However, covariance between markers and traits due to factors other than physical distance can arise. False associations can also arise when alleles occur at very low frequencies in the initial population. These factors create LD in loci that are not physically linked and cause a high rate of false positives when relating polymorphic markers to phenotypic trait variability. Thus, separation of LD due to physical linkage from LD due to population structure is of importance in association analyses.

In the present research, we investigate the association of DArT markers with stem rust, leaf rust, stripe rust, powdery mildew, and grain yield in five historical CIMMYT Elite Spring Wheat Yield Trials (ESWYT) conducted from 1979 to 2004 in a large number of international environments. Two linear mixed models were used to assess marker-trait associations incorporating information on population structure and additive genetic variation. Several DArT associated to reported leaf rust, stem rust, yellow rust, powdery mildew and grain yield genes have been found and work is in progress to compile, interpret, and write all the vast information generated by these analyses (Crossa et al. 2007).

Important new developments on association mapping using Bayesian methodology are underway. The problem is similar to the association mapping outlined above but here the statistical approach uses Bayesian inference. Since we use the Gibb sampler for obtaining information from the conditional posterior distribution a great deal of computer time is required to obtain the samples. Unfortunately CRIL-CIMMYT computer power is limited and this is a constraint to rapid progress in this area.

Selection indices based on eigen analysis

Traditional phenotypic and molecular marker selection indices use economic weights to combine traits. Selection indices based on eigen analysis (ESIM or eigen analysis selection index) do not require these subjective weights. Preliminary results from computer simulations using QUGENE and QULINE show greater selection response using ESIM as compared with other selection indices including molecular markers.

Development of a novel QTL mapping method for bi-parental populations

Composite interval mapping (CIM) is the most commonly used method for mapping QTL with populations derived from bi-parental crosses. However, the algorithm implemented in the popular QTL Cartographer software may not completely ensure all its advantageous properties. In addition, different background marker selection methods may give very different mapping results, and the nature of the preferred method is not clear. A modified algorithm called inclusive composite interval mapping (abbreviated as ICIM) has been proposed. In ICIM, marker selection is conducted only once through stepwise regression by considering all marker information simultaneously, and the phenotypic values are then adjusted by all markers retained in the regression equation except the two markers flanking the current mapping interval. The adjusted phenotypic values are finally used in interval mapping. The modified algorithm has a simpler form than that used in CIM, but a faster convergence speed. ICIM retains all advantages of CIM over interval mapping (IM), and avoids the possible increase of sampling variance and the complicated background marker selection process in CIM. Extensive simulations using two genomes and various genetic models indicated that ICIM has increased detection power, reduced false detection rate and given less biased estimates of QTL effects than traditional CIM (Li et al. 2007, 2008).

Development of the user-friendly software of Windows QTL IciMapping

User-friendly software is essential to apply ICIM to practical mapping populations. A prototype of computer software called IciMapping to implement ICIM has been developed (available from website www.isbreeding.net). More features have been added among which are ICIM for epistasis, an interface for choosing mapping parameters, graphical representation of linkage groups, and integration of the identified QTL on the linkage map, etc. By adding such new features, IciMapping will provide the Windows version implementing ICIM for mapping individual QTL and QTL networks in standard experimental populations such as backcross, doubled haploids, and recombinant inbred lines. Windows QTL IciMapping will not only complete a conventional QTL mapping study, but also conduct a QTL detection power analysis for a set of predefined QTL. The mapping populations generated from a power simulation study can be re-analyzed in Windows QTL IciMapping and Windows QTL Cartographer (developed by the Department of Statistics, North Carolina State University).

CropStat Statistical Analysis Software

The freely available statistical analysis package, IRRISTAT, has been upgraded to the latest versions of Delphi and Intel Visual FORTRAN and re-packaged as CropStat version 6.1. This version has new facilities for analysis of generalized linear models such as logistic regression and log-linear models. New functionality of REML analysis allowing complex covariance structures to be used for field evaluation data and facilities for cluster analysis are currently being tested for the next release of CropStat.

Routine Computation and Visualization of Coefficient of Parentage Matrices

The BROWSE application of ICIS has been developed to allow rapid computation of large COP matrices. Spectral decomposition of COP matrices can be used to visualize additive genetic relationships in a set of germplasm and the COP matrices may be used with mixed linear models to improve precision of breeding evaluation data.

Simulation modeling

Design breeding using chromosome segment substitution lines in rice

A permanent mapping population of rice consisting of 65 non-idealized chromosome segment substitution lines (denoted as CSSL1 to CSSL65) and 82 donor parent chromosome segments (denoted as M1 to M82) was used to identify QTL with additive effects for two rice quality traits: area of chalky endosperm (ACE) and amylose content (AC), by a likelihood ratio test based on stepwise regression. Subsequently, the genetics and breeding simulation tool QuLine was employed to investigate the application of the identified QTL in rice quality improvement. Different target genotypes containing positive QTL were identified and different crossing strategies were compared with respect to their efficiency in producing the target genotypes. These results can be used for parent identification, choice of crossing system and selection strategy to increase the target genotype frequency without significantly increasing the total cost of breeding operations (Wang et al. 2007).

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Bioenergy: Any role for CIMMYT?

John Dixon

Introduction

Biofuels are used mainly for transportation which expands rapidly with economic growth – the demand for gasoline in the transportation sector is projected to grow from 280 million tons oil equivalent in 2005 to 400 million tons oil equivalent in 2030. Ethanol, which represents 90% of total biofuels, is currently produced from starch or sugar crops (and 90% of ethanol is produced from maize or sugarcane) and is primarily used to blend with (or substitute for) gasoline. Biodiesel is primarily used to blend with (or substitute for) fossil-based diesel, and is mostly from oil crops or fruits. Global production of ethanol in 2005 was about 36.5 billion L, dominated by USA, Brazil and China; and of biodiesel about 3.5 billion L, dominated by Germany and France – both represent a tiny fraction of the energy needs of the transport industry and farming. .

Many countries have set targets or introduced regulations for blending ethanol with gasoline or biodiesel with diesel, e.g. India's mandatory E10 blend from mid-2007. Even to substitute 10 % of fossil fuel consumption in the transportation industries would require a substantial proportion of crop land – about 70 % in the EU but much lower in Africa. The substantial planned investments in ethanol production could have far reaching long term impacts on maize and perhaps wheat prices, stocks, consumption and production. Consequently, there are opportunities and risks for food security and livelihoods of poor producers and consumers, and also for the environment which are not well understood. Therefore, CIMMYT and IFPRI are conducting a joint assessment of the likely effects on food stocks and trade, on national and household food security and farm household livelihoods.

Sky-high oil prices (around the US $ 90–100 per barrel) have stimulated renewed attention to alternative energy sources, including the use of grain or stover of cereal crops as well as sugarcane, beets and cassava for the production of ethanol for blending with gasoline. Conversely, cereal prices were declining steadily until the interest in ethanol drove up maize prices. Whilst Brazil and the USA have been producing ethanol in quantity for decades, China and India are entering the field on a major scale and many other countries are considering whether and how to invest. The current technology for conversion uses starch or sugar crops as feedstock and therefore on the surface appears to compete with food (in practice the use for fuel may compete directly with feed rather than food, and only indirectly with food crops through the use of land, water, labour and capital resources). The second generation technology uses lingo-cellulose feedstocks (for example, agro-industrial waste, forest products and crop residues and perennial grasses) and has far higher energetic efficiency than the first generation technology.

Impacts – present and potential

In terms of global impacts, a collaborative preliminary assessment by CIMMYT and IFPRI ascertained that, with large scale production of ethanol using first generation conversion technologies, food prices and child malnutrition would increase significantly, especially in sub-Saharan Africa and South Asia. The phasing in of second generation technology reduces, but does not eliminate, the negative impacts. Specialization is some energy crops, e.g., could have much larger negative impacts. Distributional effects across countries, farming systems, and producers and consumers, need to be looked at more closely.

Ethanol production impacts on livelihoods through different channels. Producers of energy crops gain from increased crop prices even without expanding or intensifying production; in so far as producers are poor, poverty would reduce. As well as reducing crop production and household domestic costs (heating, lighting, cooking, –which has strong gender implications) and contributing to local energy security, the ethanol industry generally stimulates additional employment. On the negative side, the increased food prices mean that poor people will not be able to purchase as much food and so hunger and malnutrition will increase. Lower energy prices would reduce production costs for farmers; but expanded ethanol production could have indirect factor market effects though increased demand for good land, irrigation water, capital and labour – to the disadvantage of other sectors. Moreover, a major concern arises with second generation technology which would increase the demand for and price of crop residues and would very likely cause farmers to remove even more straw from the field and thus threaten soil fertility.

The diverse impacts on local food security and livelihoods are illustrated by a number of case studies of the possible expansion of ethanol production in the Pearl River Basin (China), Ganges Basin (India), and Tanzania. These cases point to a number of determinants of the impacts on livelihoods. The relative abundance of land as well as other natural resources is a partial determinant of the relative intensification and extensification of ethanol feedstock crops. The three cases show that the degree of overlap of feedstock crops with food and feed crops is important in determining the impacts. The potential success of some areas, e.g., Tanzania, hinges more crucially on the possibility of second-generation technologies than others. The relative ratio of large/small producers, and landed to landless is an important determinant of potential socio-economic (as well as distributional) impacts. The quality of infrastructure and functioning of markets is also important.

The ex ante impacts differ by agro-ecosystem. In irrigated agro-ecosystems market and technology considerations are generally satisfied. Economic feasibility depends on market prices (for feedstock and ethanol), location and field-plant transport costs. In many tropical and sub-tropical areas sugarcane is a preferred feedstock –about half of current output is produced from sugarcane– but under irrigation is a heavy user of increasingly scarce water and under rainfed conditions will not be able to expand sufficiently to satisfy demands for medium or high blending levels, e.g. E30. Sweet sorghum has potential on saline land, but it is little used currently as a feedstock and is unlikely to produce a large proportion of global Ethanol in the near future. Maize grain is an alternate feedstock – about half of current output is produced from maize grain– especially in sub-tropical and temperate zones. There is a preoccupation about the effect of displacement of food crops in irrigated environments which are the breadbasket of the world. Documented evidence suggests some benefits to producers through increased crop income and rural communities through increased employment. In moist rainfed agro-ecosystems (more than 120 growing days), market and technological considerations are satisfied under some conditions and crops (e.g. for rainfed sugarcane and maize with "industrial" yield levels). Sorghum and cassava are alternate feedstocks. There are substantial knowledge gaps about optimal crops, varieties and management and livelihood impacts, especially for biodiesel feedstocks like *Jatropha*. In the dry agro-ecosystem (less than 120 growing days), production (and perhaps processing) considerations are often not yet satisfied. Market opportunities are fewer, and the lack of infrastructure may be a binding constraint –but for this reason local production would have more impact on livelihoods. Other crops more appropriate than maize or wheat, such as sorghum and cassava – and biodiesel– would have to be considered. The knowledge gaps are considerable. The conflict or competition with livestock activities is more intense than in moister area. The options for this agro-ecosystem need to be explored more fully in an integrated fashion. Biodiesel production, although accounting for only 10% of total biofuels, is seen as a potentially viable enterprise in remote and marginal areas – and while soybean and canola are important feedstocks in the USA and EU, in developing countries there is much interest in *Jatropha*, *Pongamia* or castor bean, in marginal areas –but very little knowledge about genetic variation, agronomy of farming system fit.

There are significant environmental considerations associated with first and second generation conversion. Ethanol generates less greenhouse gases (GHG) than gasoline (biodiesel produces only half the GHG). There is synergy, complementarity and competition between ethanol and livestock which needs to be managed. Whilst ethanol production from starch, sugar or cellulose competes with livestock feed and fodder, feed supplements are also produced which could launch or support milk or meat production. The linkages to health were also stressed.

Implications for CIMMYT research

Production technologies, and specifically crop cultivars, underpin efficient biofuel development. Breeding for ethanol cultivars is underway for sugarcane, maize and sorghum. Maize and sugarcane ethanol cultivars have been already released. There is some knowledge of genetic variation for starch quality in maize and cassava, but less on the variation for cell wall, cellulose and lignin composition. New diversification crops might have potential for ethanol, e.g. triticale. The possibility of developing perennial maize, incorporating traits from teosinte, for ethanol production might be considered. There is likely to be a wide range of useful traits in the CIMMYT managed maize and wheat genebank, which would be of value to breeding programs –for consideration by the Genetic Resources Enhancement Unit should external funds become available for such work. There is a general consensus in the Global Wheat Program that selection for ethanol traits should not be undertaken by CIMMYT. Similarly, it is not yet clear how many smallholder maize producers might benefit from improved ethanol maize, which anyway are being developed by the private sector.

Crop management determines productivity and the environmental outcomes, particularly in relation to water and soil. Key practices related to sustainability intensification include water, nutrient and residue management –which corresponds to the research foci of P10. However, the greatest preoccupation lies with the removal of crop residues as feedstock for second generation conversion technologies – already a second generation pilot ethanol facility based on wheat straw is operational in Canada and another is being constructed in Idaho (USA), while severe degradation affects many agricultural soils from the Ganges to the Atlas Mountains, and from the Limpopo to the Yellow River Basin. The return of sufficient straw or stover to cover the soil is an essential first step –a precondition– for their maintenance or ideally restoration. Unfortunately there are few data available to guide decisions on the required level of residue retention in each farming system that would maintain soil and crop productivity –but long term trials of CIMMYT in El Batán show an approximate halving of cereals yield after only seven years of residue removal. While the high biomass production in irrigated systems may permit the removal of a proportion of the straw whilst maintaining soil health, biomass production in dry rainfed systems is so low that most or perhaps all straw would be needed to cover the soil. A research program to ascertain the long term effects of crop residue management on soil health and productivity in different farming systems is urgently needed –and P10 scientists would have a comparative advantage in leading such research in the innovation and learning hubs. In order to understand farmers' incentives for different residue management options, an assessment of the value of straw or stover for the different uses in each farming systems is urgently needed: such an assessment has been initiated in P10 and preliminary results are available from the rice wheat farming system in South Asia.

While a considerable amount of knowledge exists, there are not mechanisms for consolidating and sharing the knowledge among scientists and policy makers, and especially among businesses and farmers. A holistic, full life cycle, value chain approach is needed to understand and assess biofuels. Trade, policies, subsidies and regulations are crucial determinants of the incentives for production and choice of technology. This might be considered for the IRRI-CIMMYT Alliance project on Cereal Systems Knowledge. There would be opportunities and advantages in collaborating with FAO and other biomass and renewable energy networks.

Finally, CIMMYT impact assessment scientists could play a key role in ex ante impact assessment for maize and wheat based systems. The development of participatory multi-stakeholder assessment tools adapted to bioenergy is needed to develop more detailed scenarios and strategic assessments and to appraise options. Such tools need to bridge several levels of aggregation including village and national, take into account the supply and demand for energy, production and conversion technologies, and risk management especially in dry areas.

ANNEX 1. STAFF AND GUESTS IN CIMMYT 2008 SCIENCE WEEK[†]

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* Only for Friday 7th March 2008

ANNEX 2. CIMMYT RESEARCH IN 2007 JOURNAL ARTICLES BY CURRENT OR FORMER STAFF (*)

1. 2007 AQUINO Pedro Aquino Mercado*, Federico Carrion Perea*, Alejandro de la Rosa Zamora, Lucila Cruz Alonso, Mario A Martinez Sevilla, Israel Almazan Jauregui. La productividad y competitividad del cultivo de maíz en el Estado de México. ***Estudios Agrarios: Revista de la Procuraduría Agraria*** **35** 125-141 With Universidad Autonoma de Chapingo UACh, Chapingo (Mexico) MX; Procuraduria Agraria, Mexico (DF) MX

2. 2007 ARCOS Alba Lucia Arcos*, Luis Alberto Narro*, Fredy Salazar*, Creuci Caetano. Efectos genéticos de la formación de calosa en ápices radicales de líneas de maíz resistentes y susceptibles a suelos ácidos. ***Acta Agronómica (Palmira)*** **56** (4) 157-164 . With Universidad Nacional de Colombia, Palmira CO

3. 2007 AYALA-NAVARRETE L Ayala-Navarrete, H S Bariana, R P Singh*, J M Gibson, A A Mechanicos, P J Larkin. Trigenomic chromosomes by recombination of *Thinopyrum intermedium* and *Th. ponticum* translocations in wheat. ***Theoretical and Applied Genetics*** **116** (1) 63-75. With CSIRO Plant Industry, Canberra (ACT) AU; University of Sydney, Cobbity (New South Wales) AU

4. 2007 BABAR M A Babar, M van Ginkel, M P Reynolds*, B Prasad, A R Klatt. Heritability, correlated response, and indirect selection involving spectral reflectance indices and grain yield in wheat ***Australian Journal of Agricultural Research*** **58** (5) 432-442. With Oklahoma State University, Stillwater (Oklahoma) USA

5. 2007 BADSTUE. Lone B Badstue*, Mauricio R Bellon*, Julien Berthaud*, Alejandro Ramírez*, Dagoberto Flores*, Xóchitl Juárez. The dynamics of farmers' maize seed supply practices in the central valleys of Oaxaca, Mexico. ***World Development*** **35** (9) 1579-1593. With Universidad Autónoma de Chapingo UACh, Chapingo (México) MX

6. 2007 BHUSHAN. Lav Bhushan, Jagdish K Ladha, Raj K Gupta*, S Singh*, A Tirol-Padre, Y S Saharawat, M Gathala, H Pathak. Saving of water and labor in a rice–wheat system with no-tillage and direct seeding technologies. ***Agronomy Journal*** **99** (5) 1288-1296. With International Rice Research Institute IRRI, Manila PH New Delhi IN; Cornell University, Ithaca (New York) USA

7. 2007 BORLAUG. Norman E Borlaug. Sixty-two years of fighting hunger: personal recollections. ***Euphytica*** **157** (3) 287-297

8. 2007 BRENNAN J P Brennan, A G Condon, M Van Ginkel, M P Reynolds*. An economic assessment of the use of physiological selection for stomatal aperture-related traits in the CIMMYT wheat breeding programme ***Journal of Agricultural Science (Cambridge)*** **145** (3) 187-194. With Wagga Agricultural Institute, Wagga Wagga (New South Wales) AU; CSIRO Plant Industry, Canberra (ACT) AU.

9. 2007 BRUSSAARD Lijbert Brussaard, Mirjam M Pulleman*, Elisee Ouedraogo, Abdoulaye Mando, Johan Six. Soil fauna and soil function in the fabric of the food web ***Pedobiologia*** **60** (6) 447-462. With Wageningen University, Wageningen NL; Centre Ecologique Albert Schweitzer, Ouagadougou BF; International Center for Soil Fertility and Agricultural Development IFDC, Lome TG.

10. 2007 BURGUENO Juan Burgueno*, Jose Crossa*, Paul L Cornelius, Richard Trethowan, Graham McLaren, Anitha Krishnamachari. Modeling additive x environment and additive x additive x environment using genetic covariances of relatives of wheat genotypes ***Crop Science*** **47** (1) 311-320 . With University of Kentucky, Lexington (Kentucky) USA; International Rice Research Institute IRRI, Los Banos PH.

11. 2007 CARRIZALES Norberto Carrizales Mejia, Hugo Cordova Orellana*, Jose de Jesus Sanchez Gonzalez, Salvador Mena Munguia, Fidel Marquez Sanchez, Florencio Recendiz Hurtado, Mario Abel Garcia Vazquez, Juan Francisco Casa Salas. Estabilidad en genotipos de maíz tropical del patrón heterótico -Tuxpeño x Eto -. ***Scientia - CUCBA*** **9** (1) 47-56 . With Universidad de Guadalajara, Zapopan (Jalisco) MX; Universidad Autonoma de Chapingo UACh, Guadalajara (Jalisco) MX

12. 2007 CERVANTES-ORTIZ Francisco Cervantes-Ortiz, Gabino Garcia-De los Santos, Aquiles Carballo-Carballo, David Bergvinson*, J Luis Crossa*, Mariano Mendoza-Elos, Ernesto Moreno-Martinez. Herencia del vigor de plántula y su relación con caracteres de planta adulta en líneas endogámicas de maíz tropical [with English translation] ***Agrociencia*** **41** (4) 425-433 . With Colegio de Postgraduados, Montecillo (Mexico) MX; Instituto Tecnologico Agropecuario No. 33, Celaya (Guanajuanto) MX; Universidad Nacional Autonoma de Mexico UNAM, Pabellon (Aguascalientes) MX

13. 2007 CHAPMAN. S C Chapman, K L Mathews, R M Trethowan, R P Singh*. Relationships between height and yield in near-isogenic spring wheats that contrast for major reduced height genes. ***Euphytica*** **157** (3) 391-397 . With CSIRO Plant Industry, St. Lucia (Queensland) AU.

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16. 2007 CHEN-2 Feng Chen, Zhonghu He*, Dongsheng Chen, Chunli Zhang, Yan Zhang, Xianchun Xia. Influence of puroindoline alleles on milling performance and qualities of Chinese noodles, steamed bread and pan bread in spring wheats ***Journal of Cereal Science*** **45** (1) 59-66 . With Chinese Academy of Agricultural Sciences CAAS, Beijing CN; Ningxia Academy of Agricultural and Forestry Sciences, Yongning (Ningxia) CN; Heilongjiang Academy of Agricultural Sciences, Harbin (Heilongjiang) CN.

17. 2007 CHEN-F-3 Chen Feng, Xia Xianchun, He Zhonghu* Rapid determination of Arabinoxylans in bread wheat and its genetic analysis [in Chinese, English abstract]. ***Journal of Chinese Cereals and Oils Association*** **22** (5) 142-146 . With Chinese Academy of Agricultural Sciences CAAS, Beijing CN

18. 2007 CHEN-4 Chen Feng, He Zhong-hu*, Chen Dong-sheng, Zhang Chun-li, Xia Xian-chun. Allelic variation of puroindoline genes in Chinese spring wheats [in Chinese, English abstract] ***Scientia Agricultural Sinica*** **40** (2) 217-224. With Chinese Academy of Agricultural Sciences CAAS, Beijing CN; Ningxia Academy of Agricultural and Forestry Sciences, Yongning (Ningxia) CN

19. 2007 CHEN-J Chen Jing, Zhang Xiao-ke*, He Zhong-hu*, Sun Wen-yu, Wu Ling, Li Li-rong, Yu Mao-qun. Distribution of genes associated with noodle qualities in Sichuan wheat cultivars [in Chinese, English abstract]. ***Journal Triticeae Crops*** **27** (6) 1010-1015. With Chinese Academy of Sciences, Chengdu (Sichuan) CN; Chinese Academy of Agricultural Sciences CAAS, Beijing CN; Northwest Science and Technology University of Agriculture and Forestry, Yangling (Shaanxi) CN; Sichuan Academy of Agricultural Sciences, Chengdu (Sichuan) CN

20. 2007 CROSSA Jose Crossa*, Juan Burgueno*, Susanne Dreisigacker*, Mateo Vargas*, Sybil A Herrera-Foessel*, Morten Lillemo, Ravi P Singh*, Richard Trethowan, Marilyn Warburton*, Jorge Franco, Matthew Reynolds*, Jonathan H Crouch, Rodomiro Ortiz* Association analysis of historical bread wheat germplasm using additive genetic covariance of relatives and population structure. ***Genetics*** **177** (3) 1889-1913
With Universidad de la Republica de Uruguay, Montevideo UY

21. 2007 DAS M K Das, G-H Bai, A Mujeeb-Kazi* Genetic diversity in conventional and synthetic wheats with drought and salinity tolerance based on AFLP. ***Canadian Journal of Plant Science*** **87** (4) 691-702. With Oklahoma State University, Stillwater (Ohio) USA; Plant Science and Entomology Research Unit USDA, Manhattan (Kansas) USA

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