CLIMATE CHANGE AND CIMMYT

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ABSTRACT
Climate change—including higher average temperatures, heightened extremes in weather, and increased atmospheric carbon dioxide levels—is expected to impact most severely upon agriculture in the developing world. Research on major maize and wheat production areas in key parts of the developing world suggest that changes in temperature, growing season length, and rainfall patterns will significantly reduce crop yields, challenging farmers’ ability to make a living and affecting regional food security and livelihoods. Expected changes may also include reduced grain quality, intensified nitrogen leaching and soil erosion, and shrinking land and water resources for farming. CIMMYT is working with partners worldwide to mitigate these and other effects of climate change on the poor in developing countries. The efforts will help maize and wheat farmers to increase productivity using tomorrow’s limited land and water resources and to deal with environmental and market instabilities.

Stress tolerant crop cultivars. Improved maize cultivars that tolerate drought, heat, and low soil fertility will help maize farmers in stress-prone areas to obtain better harvests under dry conditions and higher temperatures. In Southern Africa alone, enough seed of new, stress tolerant cultivars has been produced to sow two million hectares. The work has received added impetus recently and is being extended to Asia and Latin America. The Center has also developed wheat lines that are better at using available water to produce grain. Experimental cultivars derived from crosses between wheat and goat grass, one of wheat’s wild relatives, produced up to 30% more grain than their wheat parents, in tests over two years under tough dryland conditions. In more recent experiments, this type of wheat out yielded its pure wheat parents by 18% under irrigation and drought, due in part to an increased ability to take up water from greater depths, superior water use efficiency, and, possibly, improved early vigor that increases ground cover and thereby conserves soil moisture. These wheat cultivars can help farmers in irrigated areas, where water is growing scarce, as well as resource poor farmers who grow the crop under rainfed conditions for food, income, and livestock fodder. They are being used in breeding programs worldwide, and their derivatives are being released to farmers in China and highland Ecuador. CIMMYT scientists are also seeking and testing new sources of drought tolerance from gene bank collections and other wheat or grass species, including wheat landraces brought to Mexico by Spanish colonizers and grown for centuries under dry conditions. Likewise, CIMMYT breeders have worked for nearly two decades to develop heat tolerant wheat. They have identified key physiological traits associated with higher yields in heatstressed environments, including low canopy temperatures and high leaf chlorophyll content during grain filling. Partly as a result of the development and release of improved, stress tolerant cultivars by CIMMYT and partners, wheat yields improved 2 to 3% per year in dry and heat stressed environments in developing countries from 1979 to 1995.

Saving soil, water, money. Fundamental changes in farming practices will be central to getting maximum benefits from improved maize and wheat and to addressing and mitigating climate change. CIMMYT has studied and fostered testing and adoption by farmers of various resource-conserving practices—including conservation tillage and keeping a crop residue cover on the soil—to save food production costs and resources, and maintain or improve soil quality. The Rice-Wheat Consortium (RWC) for the Indo-Gangetic Plains, an award-winning national agricultural research systems-led eco-regional partnership, has fostered the adoption of conservation tillage to sow wheat after rice by farmers on nearly 2 million hectares in South Asia. The practice results in a net savings of 50 liters or more of diesel per hectare, greatly reduced water use, and lower CO₂ emissions. These and other practices being tested by farmers (for example, sowing on permanent, raised beds) provide a better soil cover, moderate soil temperatures, and reduce the evaporation of irrigation water. Fertilizer is another resource whose efficient use can improve crop productivity and
reduce greenhouse gas emissions and other damage to the environment. With the Center’s help, wheat farmers in irrigated zones of Latin America and South Asia are testing use of infrared sensors to fine-tune fertilizer amounts, timing, and application methods. This saves money for farmers and cuts emissions of nitrous oxide, a gas with some 300 times the greenhouse effects of carbon dioxide. Research to date also supports the hope of using wheat’s grassy relatives as a source of genes to inhibit soil nitrification and the associated release of nitrous oxide.

**Socioeconomic research, knowledge-sharing.** Resource efficient crop cultivars and knowledge-intensive, conservation agriculture farming practices must be properly tested by scientists and with farmers. Participatory and socioeconomic research by CIMMYT supports such efforts, as in the case of the RWC or work on stress tolerant maize for sub-Saharan Africa. It also elucidates economic and policy issues relating to climate change and developing world agriculture. For example, a recently-completed series of studies on maize production in marginal areas of seven Asian nations is serving as a baseline against which to gauge changes and devise interventions. Addressing new climate conditions will require complex policies and adjustments at many levels in developing country agriculture. Many players in maize and wheat market chains could benefit from reliable information on the economic opportunities and risks associated with biofuel expansion. Socioeconomics knowledge will help guide the use of Center resources best to catalyze relevant change among a wide range of stakeholders and partners. CIMMYT can develop and share information dissemination products/systems about climate change for farmers, policy makers, and others in agricultural market chains. This will be crucial, given that farmers will need to apply knowledge-intensive practices such as increased cropping diversification, use of rotations to manage pests and pathogens, and generally more robust systems that provide insurance against risks and shocks from climate extremes.

**Information technology and monitoring systems.** Building on linkages within the center’s global maize and wheat nursery systems and geographic information system capacity and partnerships, it will be possible to form networks that allow researchers to follow and anticipate the movement of pathogens, pests, and invasive species and share the information with relevant stakeholders. For example, CIMMYT characterizations of heat-stressed wheat environments are being refined using spatial analysis and climatic factors identified through multi-location trials in those environments.

**No security without food security.** It is already clear that the security and quality of life of affluent nations are closely tied to conditions and events in the developing world. A 2007 report by the German Advisory Council on Climate Change, states that “…without resolute counteraction, climate change… could result in destabilization and violence, jeopardizing national and international security to a new degree.” Falling agricultural yields would block development and heighten poverty, thereby increasing the risk of conflicts. Decades prior to that report, CIMMYT wheat breeder and 1970 Nobel Peace Laureate, Norman Borlaug, said roughly the same thing in these terms: “If you desire peace, cultivate justice, but at the same time cultivate the fields to produce more bread; otherwise there will be no peace.” Now and in the future, CIMMYT contributes to global security and peace by improving the food security and livelihoods of those who depend on maize and wheat farming in developing countries.

**KEYWORDS**
Conservation agriculture, drought, heat, plant breeding
Climate change and CIMMYT

Rodomiro Ortiz on behalf of CIMMYT researchers and R4D partners

Outline

- Forecasting climate change effects in mega-environments
- Breeding wheat for drought-prone and warm environments
- Maize improvement under drought
- Reducing agric. N-led pollution through genetic enhancement and resources management
- Conservation agriculture, CO₂ pollution and crop residues

The Green Revolution and Norman E. Borlaug (Nobel Peace Prize 1970)

“For more than half a century I have worked with the production of more and better wheat for feeding the hungry people, but wheat is merely a catalyst, a part of the picture. I am interested in the total development of human beings. Only by attacking the whole problem can we raise the standard of living for all people in all communities, so they will be able to live decent lives. This is something we want for all people on this planet.”

Cereal yield gains and agric. land savings

Global food security

- World cereal production must double within the next 50 years
- 80% of the increased demand must come from lands already in cultivation

Importance of maize and wheat

- Together with rice, the 3 most important food crops to achieve MDG 1.
- Maize and wheat account for 40% of food and 25% of calorie intake in developing world.
- Both crops are grown in 200 million ha (or 44% developing country agricultural land).
- Growing demand cannot be satisfied by imports alone.
Area (%) in post-1972 CIMMYT-related spring bread wheat releases by mega-environments (1973-2007)

Future climate mega-environment zone classification – MEs 1, 5

Diversity for heat-tolerance (leaf chlorophyll content – LCC) in 2,225 wheat landraces (Reynolds et al. 1999)
Genetic Enhancement by Design

• Guided-crop physiology H₃ testing (leading to defining ideotypes for crop breeding)
  1. Temperature component fine-tuning in crop models
  2. Instrumentation from remote sensing to trait recording in the experimental fields or greenhouses
• Molecular trait analysis – reverse genetics
• Allele discovery, comparative biology (synteny)
• Cross-breeding targeting “hot spots”

**MAIN OUTPUT:** Genetically-enhanced seed-embedded technology (GESET) to “beat the heat”

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Drought-adaptive traits groups associated with different physiological & genetic mechanisms

- **G-4 Photo-protection**
  - Leaf morphology: pale color, wax/puberulence, post-troffiling
- **G-3 Water use efficiency**
  - Spike/tissue photosynthesis
  - High harvest index
  - Low ¹³C discrimination
- **G-2 Access to water**
  - High relative leaf water content
  - Low canopy temperature
  - Osmotic adjustment
  - Deep root system with good access to water
- **G-1 Early growth (pre-grainfill)**
  - Pre-synthetic biomass: very carbohydrate reserve, early vigor, ground cover
  - Long coleoptile
  - Large seed

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Breeding wheat for water-use efficiency

**The challenge:**
- Drought strikes > 50% of developing world wheat area
- In Central and West Asia and North Africa, the poor depend on wheat but grow it on only 350 mm rainfall

**Sources of drought tolerance:**
- Durum x wild grass crosses
- Traditional landraces
- Genetic engineering (DREB)

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Yield of re-synthesized wheat derivatives expressed as % of the recurrent parent over two year under drought stress
Function of the target genes of DREB1A

DREB constructs kindly provide to CIMMYT by Dr. Kazuko Yamaguchi-Shinozaki (JIRCAS)

Transcription factors
Zn finger, WRKY

Chaperons

Protection factors of macromolecules (LEA proteins)

Key enzymes for osmolyte biosynthesis (proline, sugar)

Detoxification enzymes

Unknown proteins

Membrane transporters

Key enzymes for osmolyte biosynthesis

Enzymes for PI metabolism (PLC, PLD)

Engineering of better adaptation to drought

Photosynthetic performance of GM-Bobwhite with DREB gene (with extreme water stress)

Potential impact of climate change in maize production in Africa and Latin America

- High resolution methods to generate daily weather data for driving a detailed simulation model of the crop
- Overall reduction of 10% in maize production to 2055, equivalent to losses of US $ 2 billion per year

Rainfall and maize yields in Eastern and Southern Africa
Maize drought stress: Leaf senescence at flowering time

Maize drought stress at grain filling

Genetic dissection of drought tolerance at CIMMYT (1994 - 2003)
- 10 segregating populations
- F2/3, F3/4 and RIL families / hybrids
- Mexico, Zimbabwe, Kenya
- 30 stress environments
- About 350 morphological traits
- About 70 physiological parameters
- About 3,000 QTL data points

MAS for drought in maize
- BC-MAS by introgressing five target QTLs into an elite line
- QTLs are germplasm-specific
- Back-crossing is not a very effective breeding approach
- Cost too high compared to progress from conventional breeding
- => Challenge: conduct MAS in broad genetic background
- => Use MAS in more effective (pedigree) breeding approaches

Participatory maize breeding in Africa
- Prioritize most important stresses under farmers' conditions
- Manage trials on experiment station and evaluate large numbers of cultivars,
- Select the best, and …
- Involve farmers
  - Mother trials in center of farming community grown under best-bet input conditions
  - Farmer-representative input conditions
  - Farmer-managed baby trials
- Partnership with extension, NGOs, rural schools, and farmer associations
- Now used in 13 countries

Genetic enhancement of maize for Africa
- Geographic frame: environmental and socio-economic characterization of drought zones
- Informal participatory survey of maize communities, survey of maize seed suppliers, household interview survey and data analysis show impacts
- CGIAR King Baudouin Award 2006
Reducing emissions of nitrous oxide

- $N_2O$ a potent greenhouse gas generated through use of manure or $N$ fertilizer
- Reduced emissions (50% less) possible in intensive irrigated wheat systems by proper amounts and timing of $N$ applications.
- Use of infrared sensor to measure yield potential as plants grow.
- Normalized Differential Vegetative Index (NDVI)

Crop genetic enhancement to address nitrification

Crop genetic enhancement to address nitrification

Conservation agriculture: No-till direct seeding

- Emphasis to increase farm revenues through production - higher yield
- 50% of traction force required
- 85% less distance to walk to seed 1ha
Effect of crop rotation and crop residue management on maize and wheat yields under rainfed conditions (El Batán, average 1996-2000)

CO₂ emissions under traditional practices and conservation agriculture in maize and wheat

Rice-Wheat Consortium impacts in the Indo-Gangetic Plains

OUTCOMES: 1.2 million ha under zero-tillage in Indo-Gangetic plains with net benefits of US$150 million in 2004; savings of 50 liters of diesel per hectare; less labor and machinery wear; reduced CO₂ emissions

Science and partnerships to reduce poverty and hunger