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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 CO_2 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

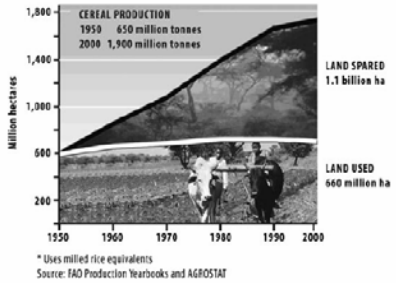
Outline

- 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, CO_2 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

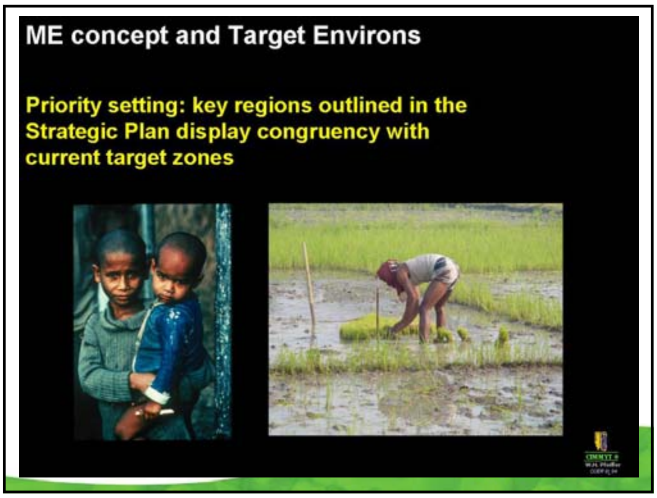


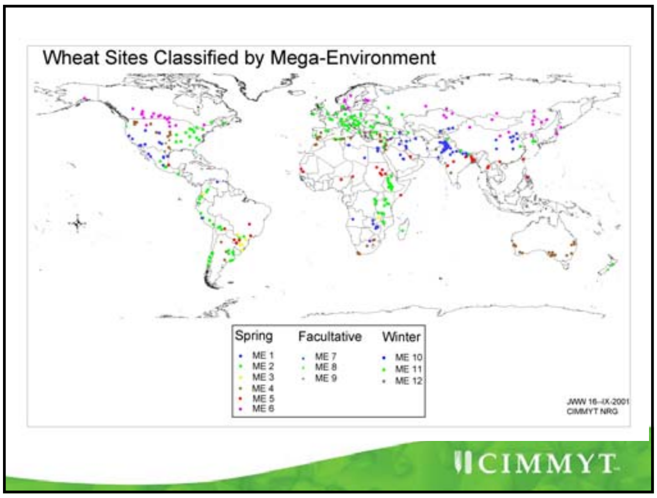
Global food security

- 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.


ME concept and Target Environs
Priority setting: key regions outlined in the Strategic Plan display congruency with current target zones


Wheat Sites Classified by Mega-Environment
Spring
ME 1
ME 2
ME 3
ME 4
ME 5
ME 6
Facultative
ME 7
ME 8
ME 9
Winter
ME 10
ME 11
ME 12
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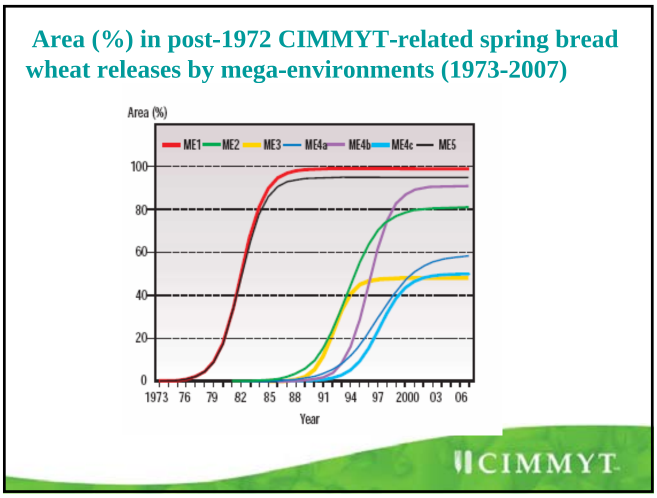
Area (%) in post-1972 CIMMYT-related spring bread wheat releases by mega-environments (1973-2007)
Area (%)
ME1
ME2
ME3
ME4a
ME4b
ME4c
ME5
100
80
60
40
20
0
1973 76 79 82 85 88 91 94 97 2000 03 06
Year
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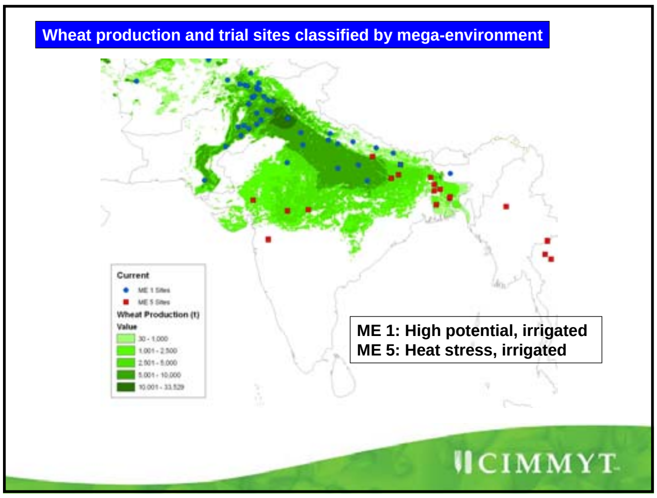
Wheat production and trial sites classified by mega-environment
Current
ME 1 Sites
ME 5 Sites
Wheat Production (t)
Value
ME 1: High potential, irrigated
ME 5: Heat stress, irrigated
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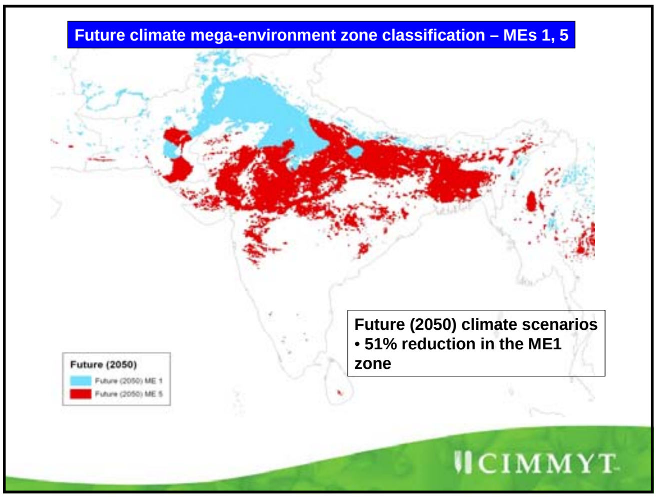
Future climate mega-environment zone classification – MEs 1, 5
Future (2050)
Future (2050) ME 1
Future (2050) ME 5
Future (2050) climate scenarios
• 51% reduction in the ME1 zone
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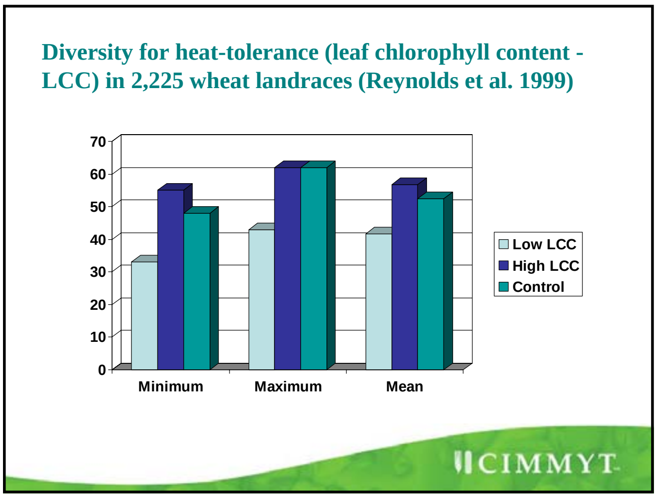
Diversity for heat-tolerance (leaf chlorophyll content - LCC) in 2,225 wheat landraces (Reynolds et al. 1999)
70
60
50
40
30
20
10
0
Minimum
Maximum
Mean
Low LCC
High LCC
Control
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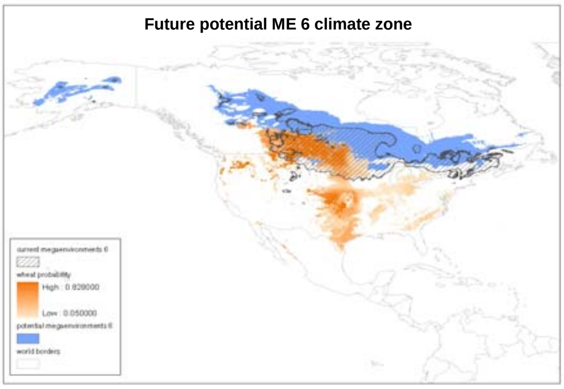
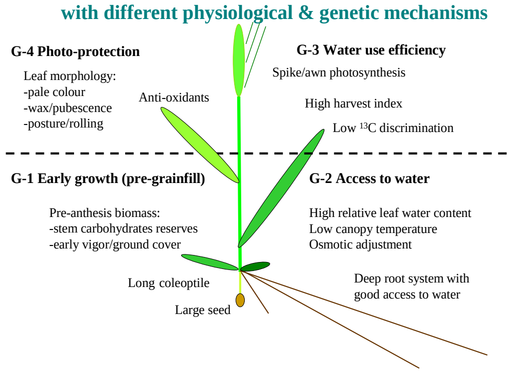
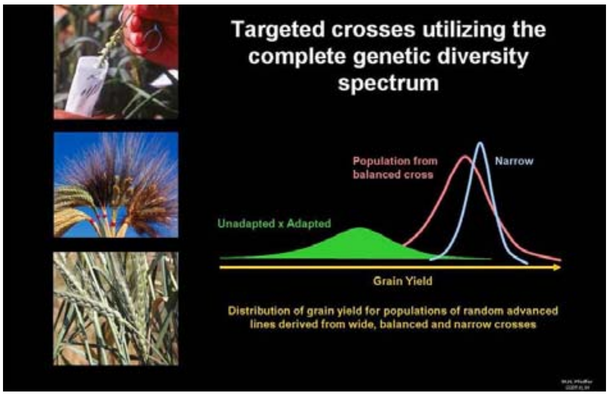


Genetic Enhancement by Design

- Guided- crop physiology H_0 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"

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





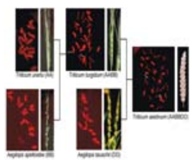
Breeding wheat for water-use efficiency

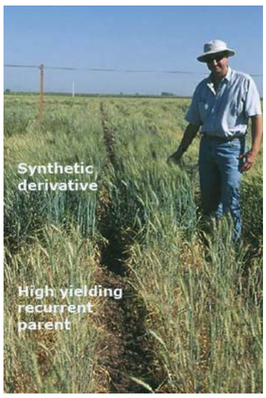
The challenge:

- 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

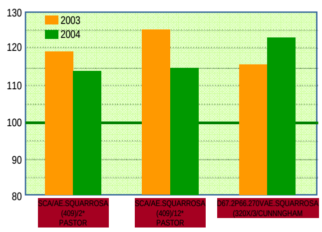
Sources of drought tolerance:

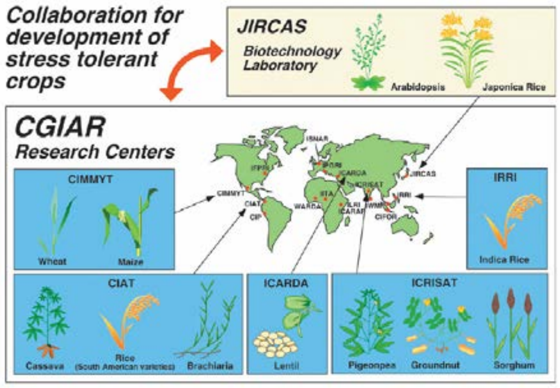
- Durum x wild grass crosses
- Traditional landraces
- Genetic engineering (DREB)





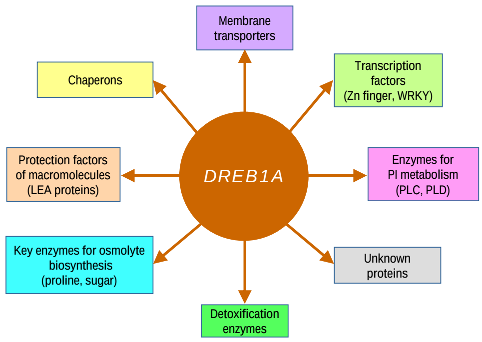
Yield of re-synthesized wheat derivatives expressed as % of the recurrent parent over two year under drought stress





Source: Nakashima and Yamagushi-Shinozaki 2005

Function of the target genes of DREB1A



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

Engineering of better adaptation to drought

Drought responsive element transcriptional factor and stress inducible promoter (partnership with JIRCAS, Japan)

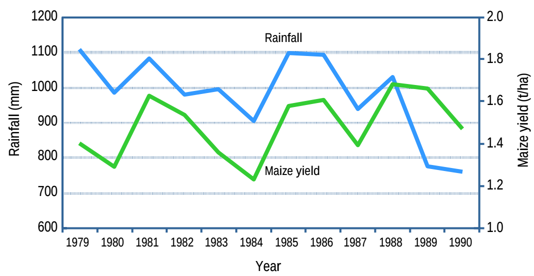
Photosynthetic performance of GM-Bobwhite with DREB gene (with extreme water stress)

	Evapo-transpiration (mm/m2/s)	Conductance (mm/m2/s)	Assimilation rate (umol CO2 m-2 s-1)	Sub-stomatal CO2 (ppm)	Chlorophyll spad
% Difference	29%	35%	90%	-8%	-4%

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

- Source: P.G. Jones (CIAT) & P.K. Thornton (ILRI) – Global Environmental Change 13 (2003): 51-59
- 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

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Maize drought stress at grain filling

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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

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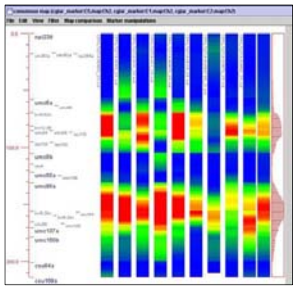
MAS for drought in maize

- **BC-MAS by introgressing five target QTLs into an elite line**
- **QTLs are germplasm-specific**
- **Back-crossing is not a very effective breeding approach**
- **Costs too high compared to progress from conventional breeding**

=> Challenge: conduct MAS in broad genetic background

=> Use MAS in more effective (pedigree) breeding approaches



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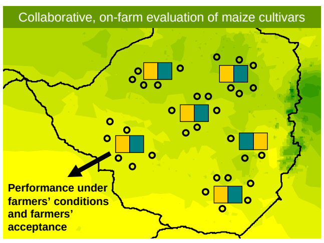
Participatory maize breeding in Africa

- 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

The Mother / Baby trial design



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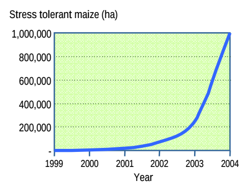
Genetic enhancement of maize for Africa

- **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



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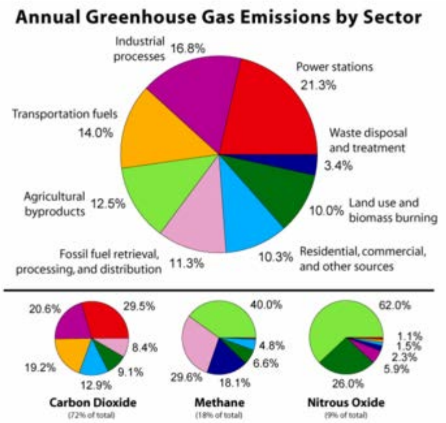

Reducing emissions of nitrous oxide

- 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 (NVDI)

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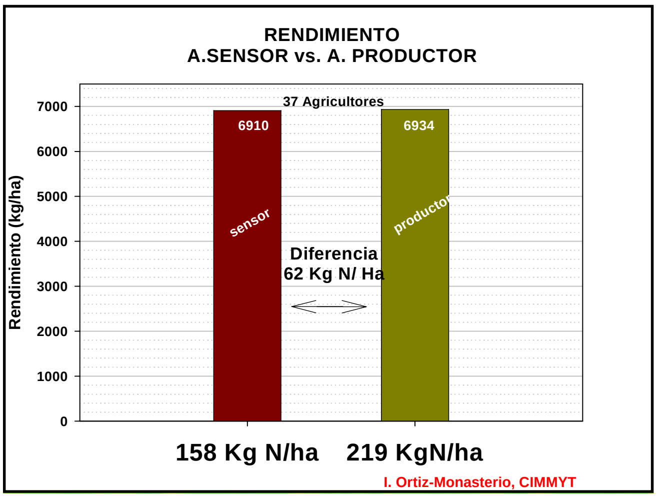

Crop genetic enhancement to address nitrification

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A DALr#n wheat field may release 87,500,000 ATU of BNI activity ha^{-1} day^{-1} = 52.5 g of the synthetic nitrification inhibitor

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EDITORS' CHOICE

CROP SCIENCE

A Boost from Wild Wheat

Nitrification, a microbial process that generates nitrate in the rhizosphere through the biological oxidation of ammonia with oxygen, deleteriously affects the availability of soil nitrogen to plants and is a major agricultural concern, as approximately one-third of fertilizer nitrogen is lost in this manner. Subbarao *et al.* report a potentially powerful strategy to reduce nitrification in cultivated wheat. A wild relative of wheat, *Leymus racemosus*, releases biological nitrification inhibitors that dramatically reduce nitrification in the root rhizosphere in comparison to domesticated wheat. When a *Leymus* chromosome containing the relevant gene(s) was introduced into wheat, biological nitrification inhibitors were also produced, and productivity increased. New strains of wheat can now be bred to transfer this trait stably into the domesticated wheat genome. — LMZ

Plant Soil 10.1007/s11104-007-9360-z (2007).

Or only 19 days for a BNI-enabled wheat crop to produce the inhibitory power of a standard commercial application of 1 kg ha^{-1}

Downloaded from www.sciencemag.org on October 11, 2007

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Conservation agriculture: No-till direct seeding

- Emphasis to increase farm revenues through production - higher yield

← *Mechanization - Integrating Factors*

- 50% of traction force required
- 85% less distance to walk to seed 1ha

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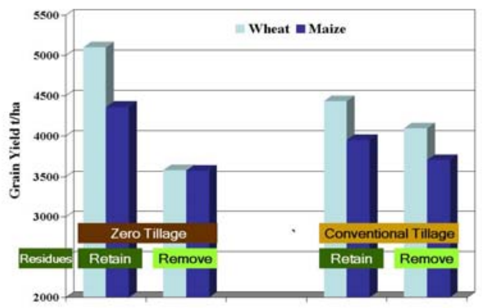

Effect of crop rotation and crop residue management on maize and wheat yields under rainfed conditions (El Batán, average 1996-2000)

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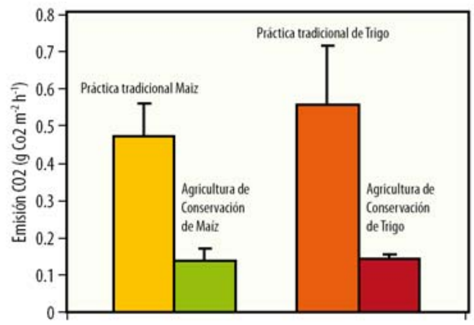
CO_2 emissions under traditional practices and conservation agriculture in maize and wheat



Ken Sayre – Bram Govaerts, CIMMYT

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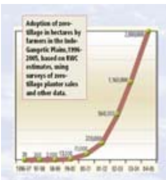
Rice-Wheat Consortium impacts in the Indo-Gangetic Plains



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 CO_2 emissions**

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Science and partnerships to reduce poverty and hunger

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