# Agrobiodiversity management for food security

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**Tropentag 2012:**

**“Resilience of agricultural systems against crises”**

**19-21 September 2012, Göttingen - Kassel/Witzenhause**

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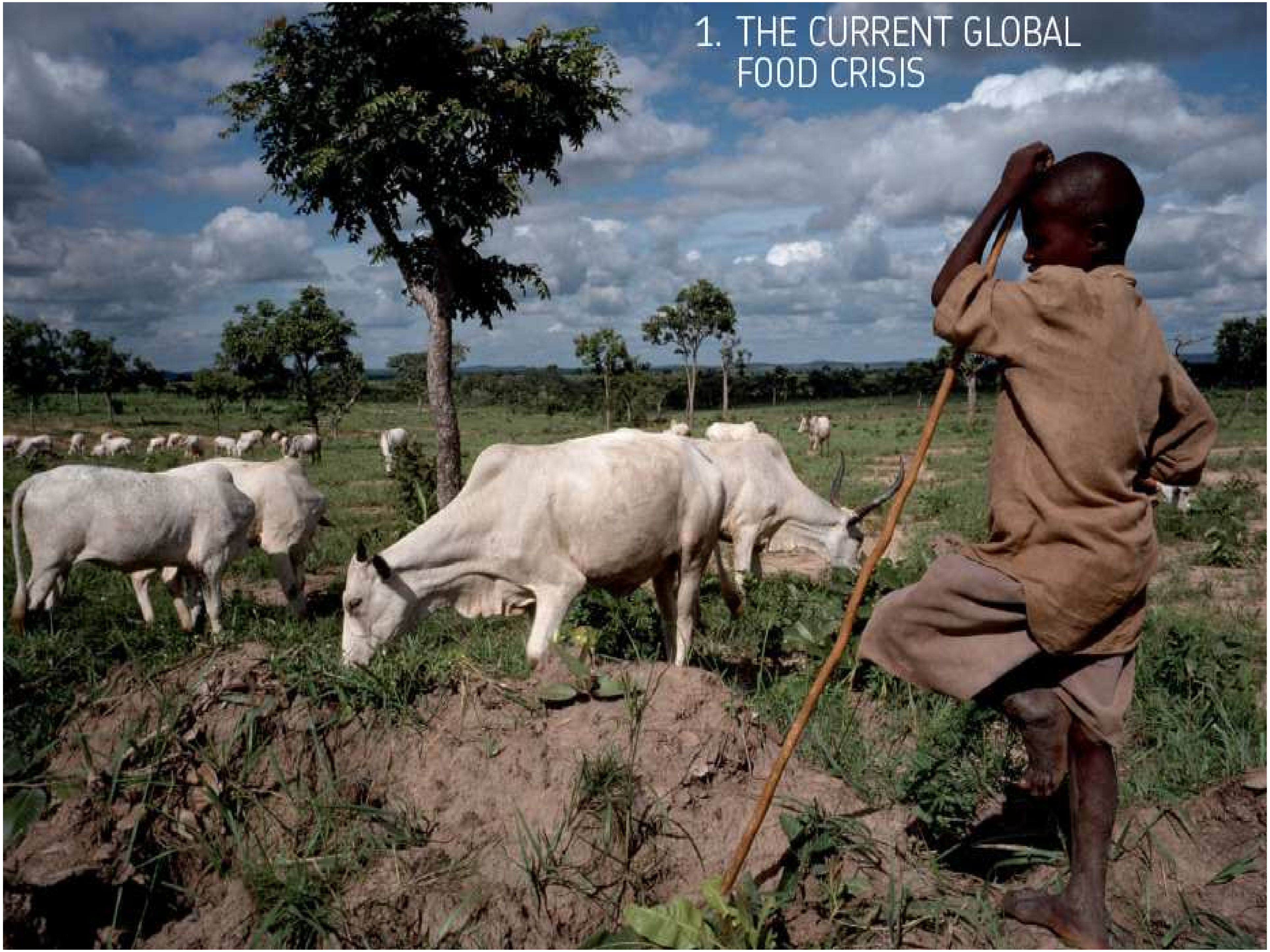
# Outline

- World´s food
- Agrobiodiversity
- Green Revolution
- Climate change
- Biotechnology tools

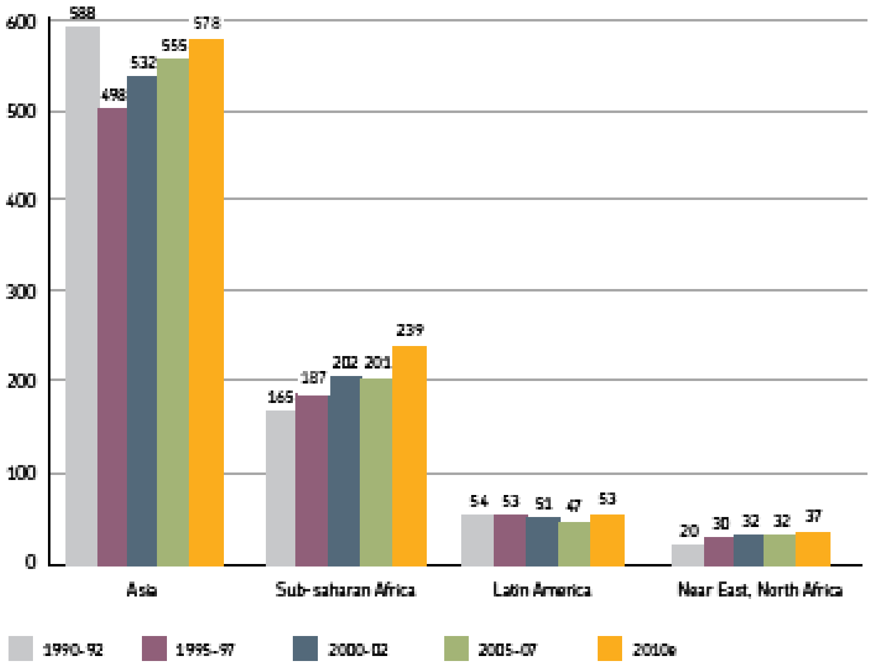
# 1. THE CURRENT GLOBAL FOOD CRISIS

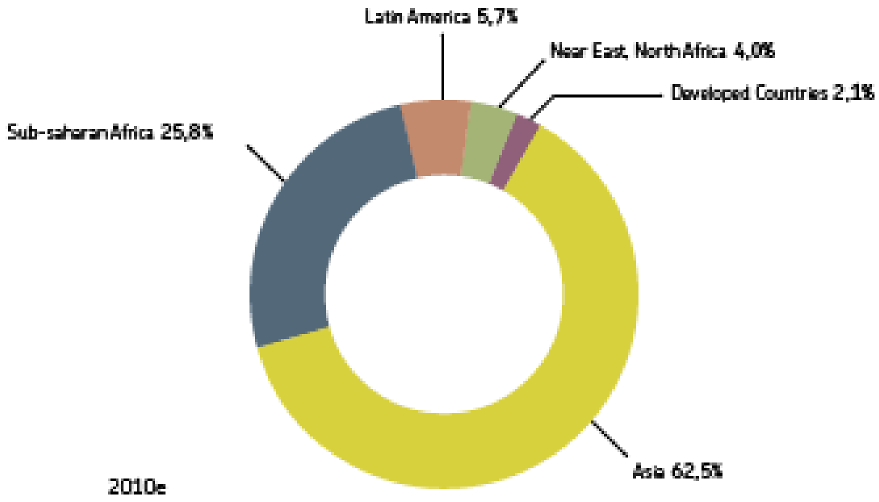


# Planet Earth Home of 7 billion people

- The **world population keeps increasing** (about 78 million annually)
- About **1 billion human beings suffer from hunger**
- **3 billion malnourished people** live with less than US$ 2 daily
- Anthropogenic **climate change continues affecting food output and quality**

# Number of starving people in some regions of the world (millions of people)




Source: FAO, 2011[3] (the data reported for 2010 are estimates).


Barilla Center FOR FOOD & NUTRITION
Photo by: NATIONAL GEOGRAPHIC ITALIA

# Food availability paradoxes

1.5 billion people suffering obesity worldwide while about 1 billion (14%) are undernourished

Can we halve food waste?

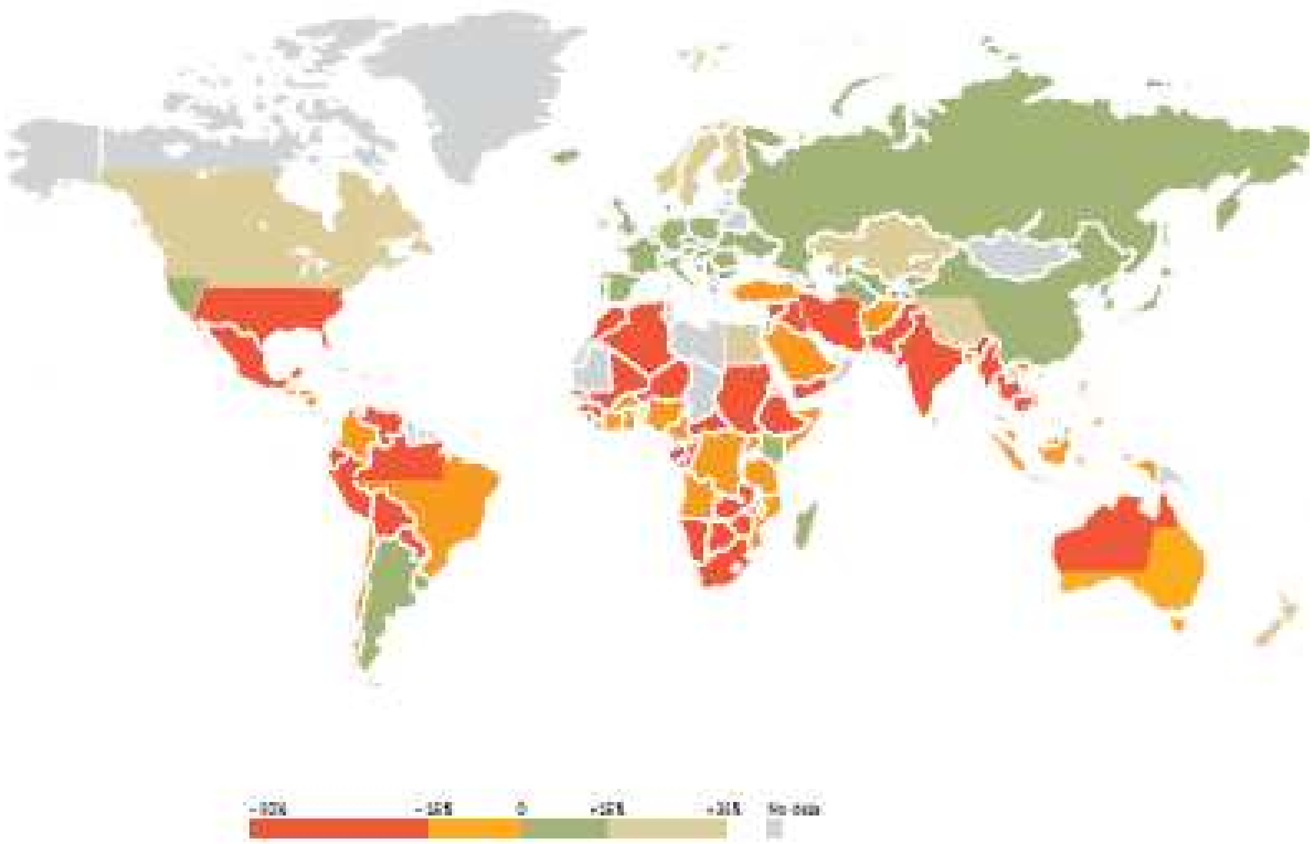
30% of all food crops worldwide are wasted

http://blog.friendseat.com/more-obese-people-than-starving-in-world

# Today´s Challenge

- The world continues facing **an increasing demand for nutritious and quality food, feed, fiber and fuel**
- There will be **1.7 billion more people to feed by 2030**, but with a **declining ratio of arable land between 40 and 55%**
- Many people living in environments affected by **water scarcity, land erosion, drought intensity, stalled progress on crop productivity, declining ground water aquifers, overgrazing of pastures, tropical deforestation, species extinction, overfishing, and anthropogenic climate change**

# Projected losses of food caused by the adverse effects of climate change (2080)



Source: Cline, 2007; FAO. The Environmental Food Crisis. 2009.

# Agriculture needs eco-efficient and resilient systems to meet end-user demands

- Provide **enough and safe food**
- Enhance **human health through better nutrition** for the poor **and well-balanced diets** for the rich
- **Diminish use of fossil fuels**
- **Adapt to** extreme weather and water **stresses**
- **Reduce environmental degradation and decline in the quality of soil, water, air and land resources** in an increasingly urbanized world
- Bio-energy and **bio-based economy**

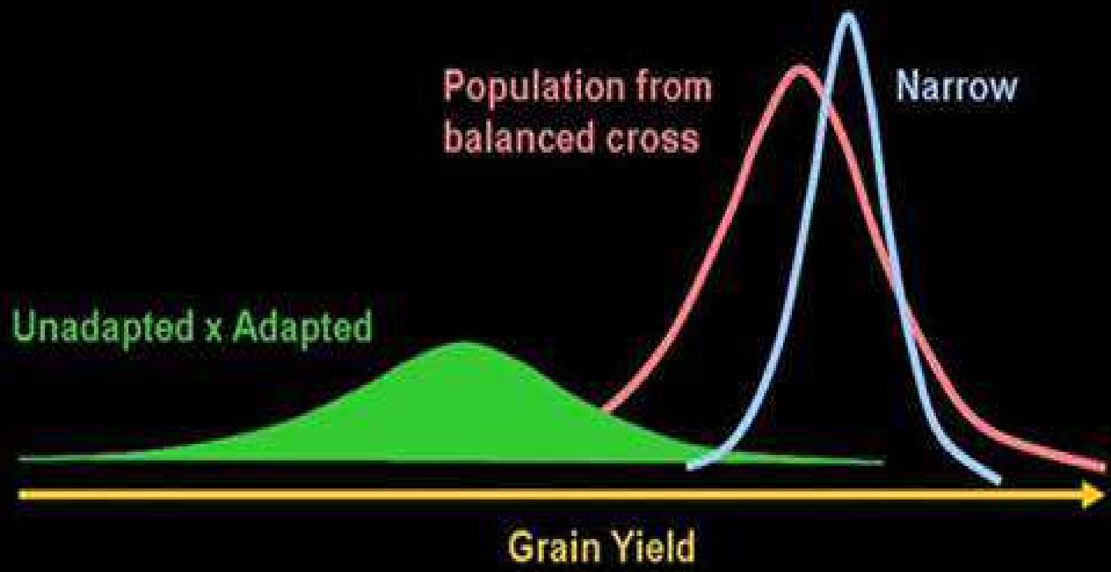
# Agrobiodiversity matters

- Agro-biodiversity components act similarly in agro-ecosystems than biodiversity in other ecosystems
  - **Genetic diversity** or the genetic variation within the species
  - **Species diversity**; i.e., the variation existing for species in a specific region
  - **Ecosystem diversity**, which comprises the variation between agro-ecosystems within a region

# Genetic enhancement and crop breeding

- **Germplasm enhacement: transfer or introgression of genes and gene combinations from non-adapted sources into breeding materials**
- **General paradigm of plant breeding: facts of evolution (descent with modification) plus selection as chief agent of change**
- **Two phases: collection and generation of variation and reproductive potential followed by selection of most productive surviving genotypes**

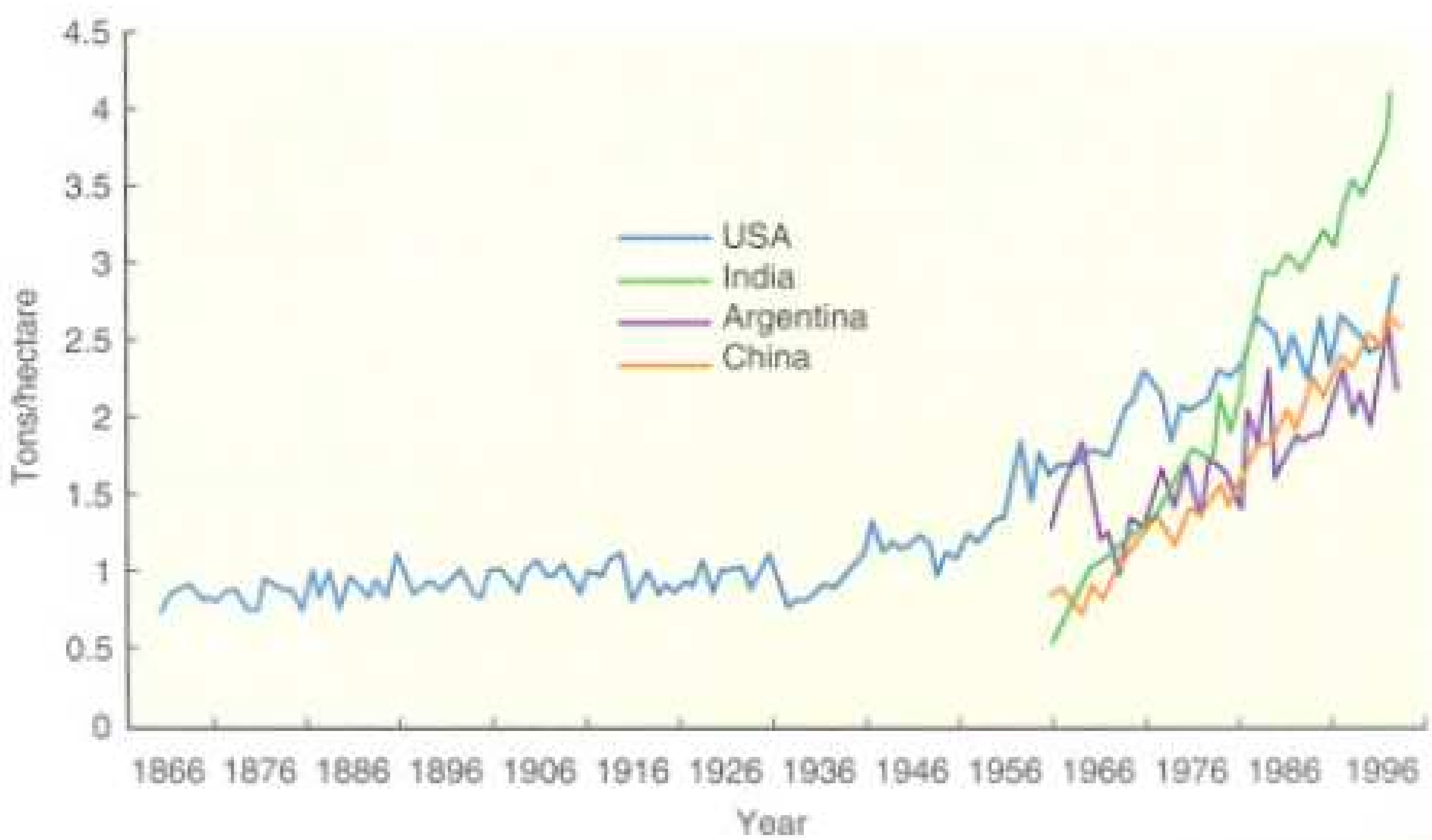
# Targeted crosses utilizing the complete genetic diversity spectrum




Distribution of grain yield for populations of random advanced lines derived from wide, balanced and narrow crosses

## Dramatic increases of crop yields since the 1950s made food cheaper and more affordable

## Long-run trend in wheat yields





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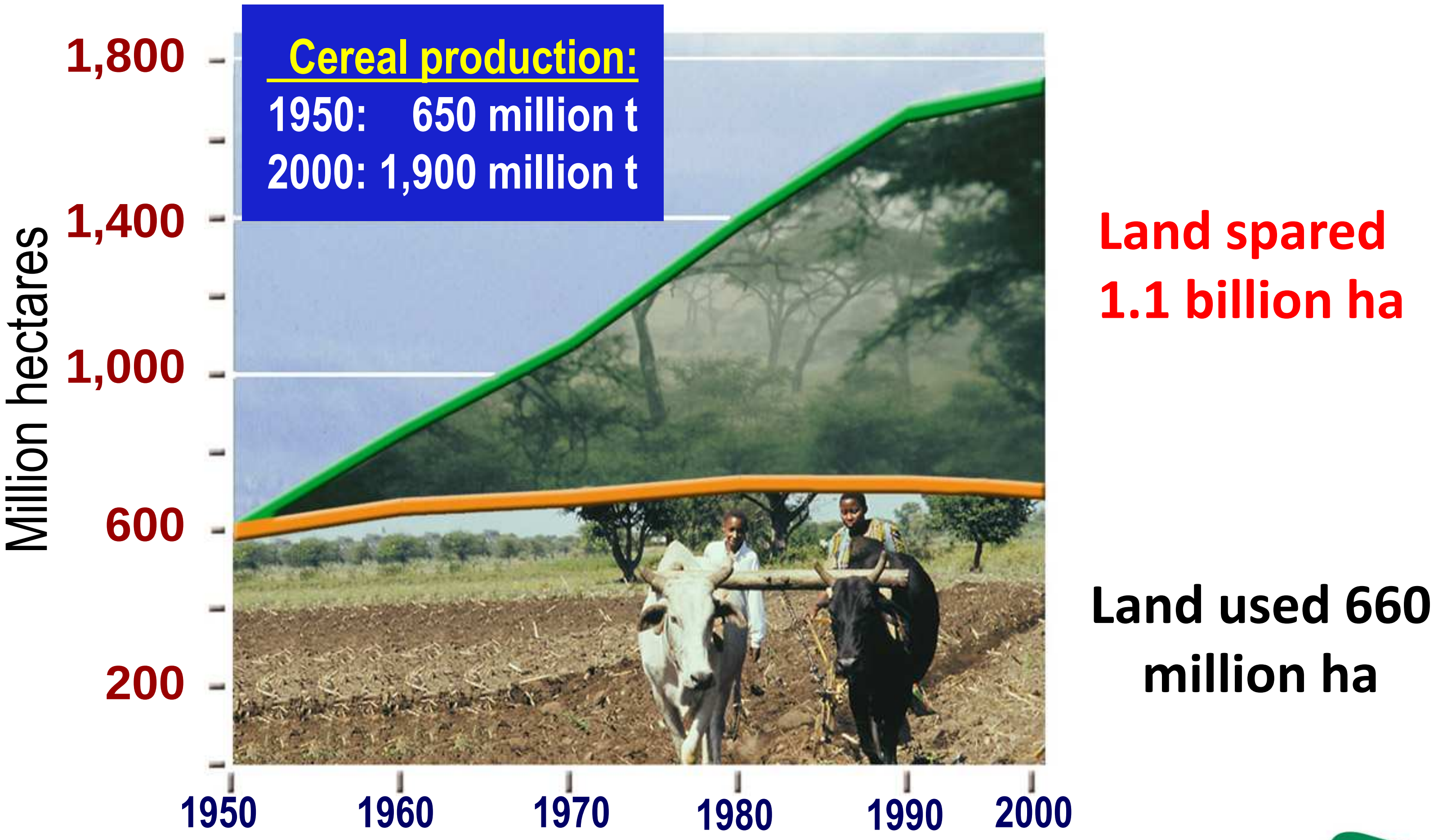
# The Green Revolution

- The **research, development, and technology transfer that happened between 1943 and the late 1970s** – known collectively as the Green Revolution – increased production in agriculture in many nations of Asia and Latin America
- **Crop yields in the developing world** would have **been at least 20% less and food prices about 19% higher than they were in 2000** without the innovations brought by the Green Revolution
- **Calorie consumption would have dropped by about 5% and the number of malnourished children increasing by at least 2%**; i.e., the Green Revolution helped improve the health status of 32 to 42 million pre-school children
- Net effect of high yields due to the Green Revolution **avoided emissions of up to 161 gigatons of carbon (GtC) (590 $GtCO_2e$)** since 1961

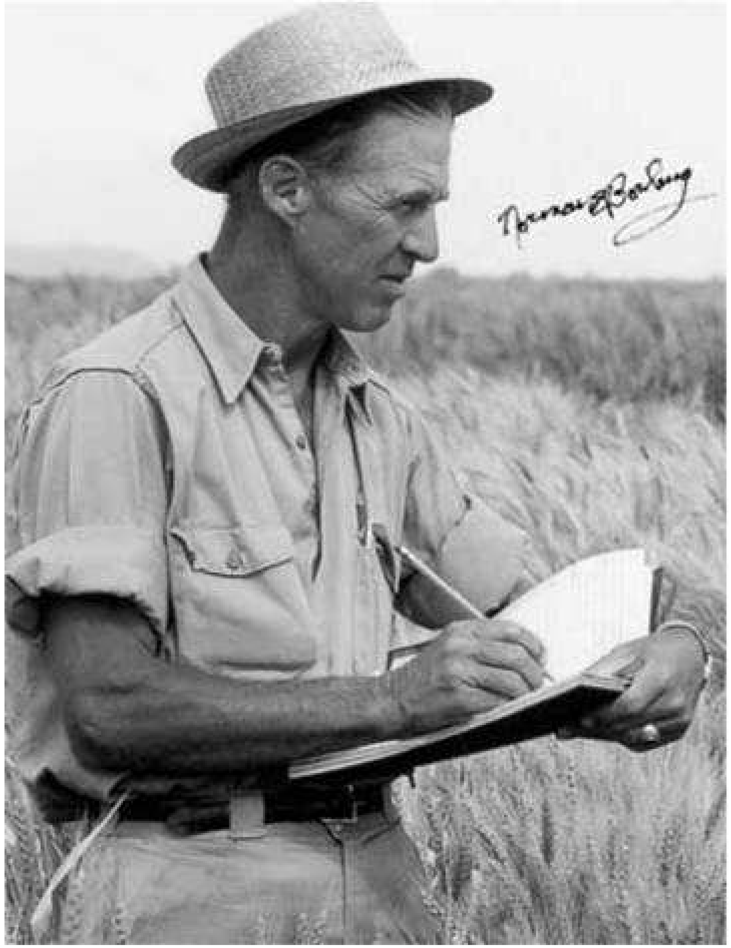
# World cereal* production: areas saved through improved technology (1950-2000)




* Uses milled rice equivalents

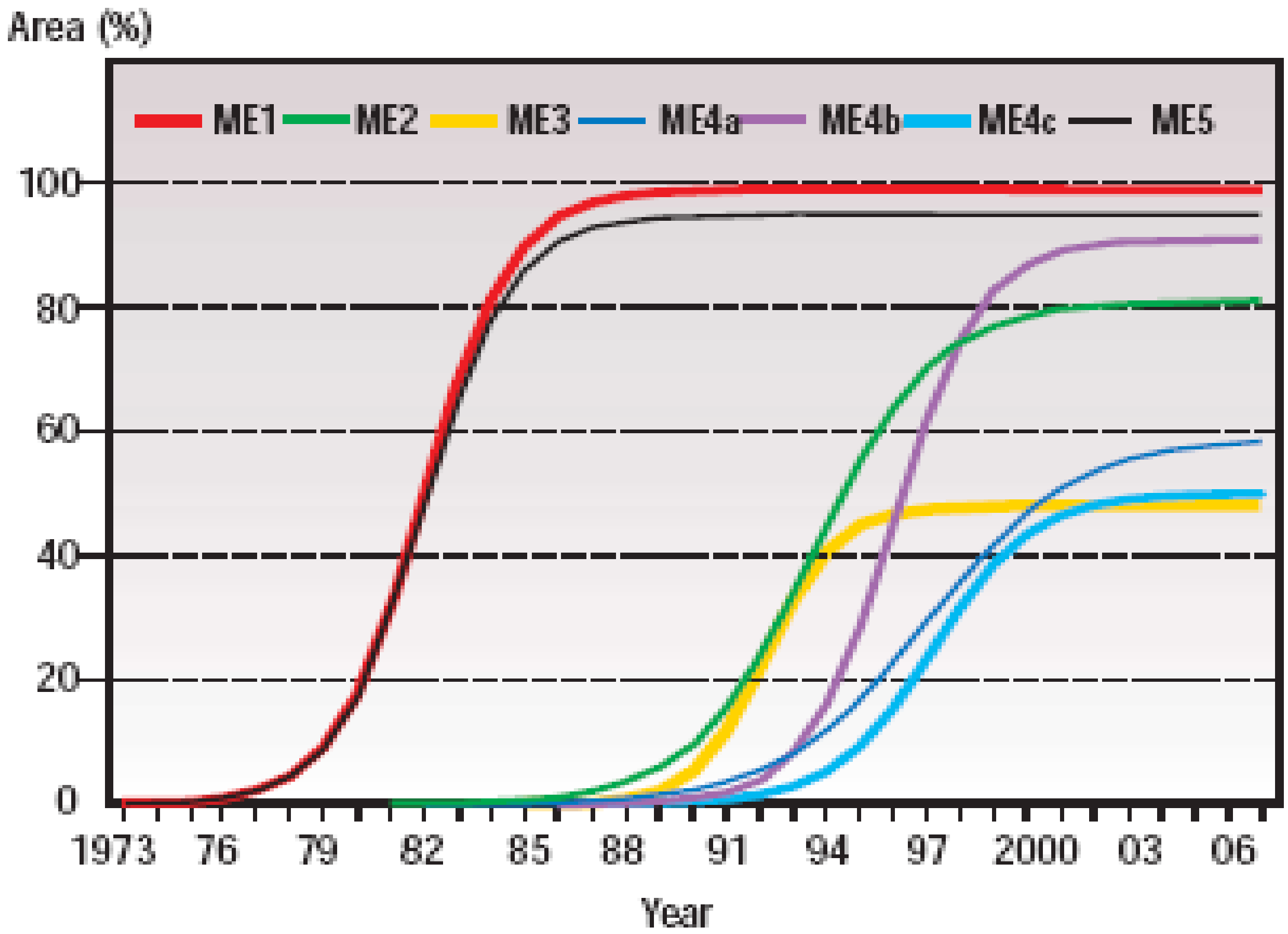
Source: FAO Production Yearbooks and AGROSTAT

# Borlaug's legacy to plant breeding



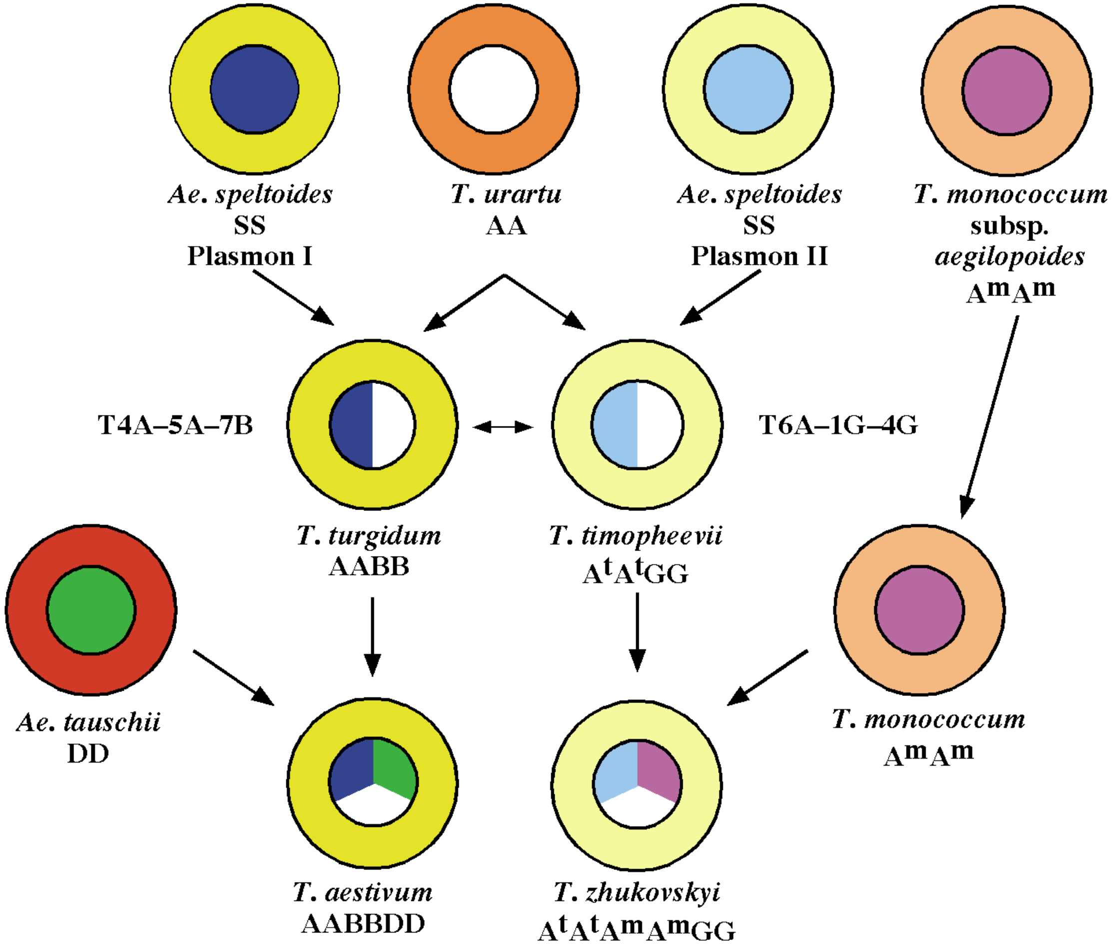

- Shuttle breeding + Wide adaptation + Durable rust resistance + International testing = **Improved wheat yield stability**
- Appropriate use of genetic variation = **Enhanced yield gains of subsequently produced genotypes**

# Area (%) in post-1972 CIMMYT-related spring bread wheat releases by mega-environments (1973-2007)



# Wheat Evolution

## *Scope for Capturing New Diversity in Re-synthesis*

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*Wheat Genetics Resource Center, KSU*

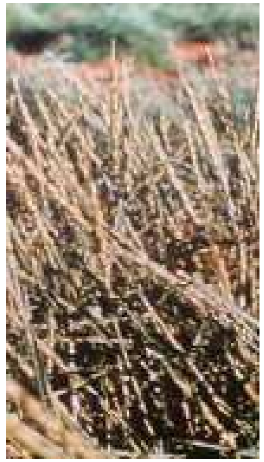
# Continued expansion of the genetic based of wheat

- Development of re-synthesized hexaploid wheat based on **wild tetraploids**

- Continued exploitation of **re-synthesized hexaploid wheat** lines

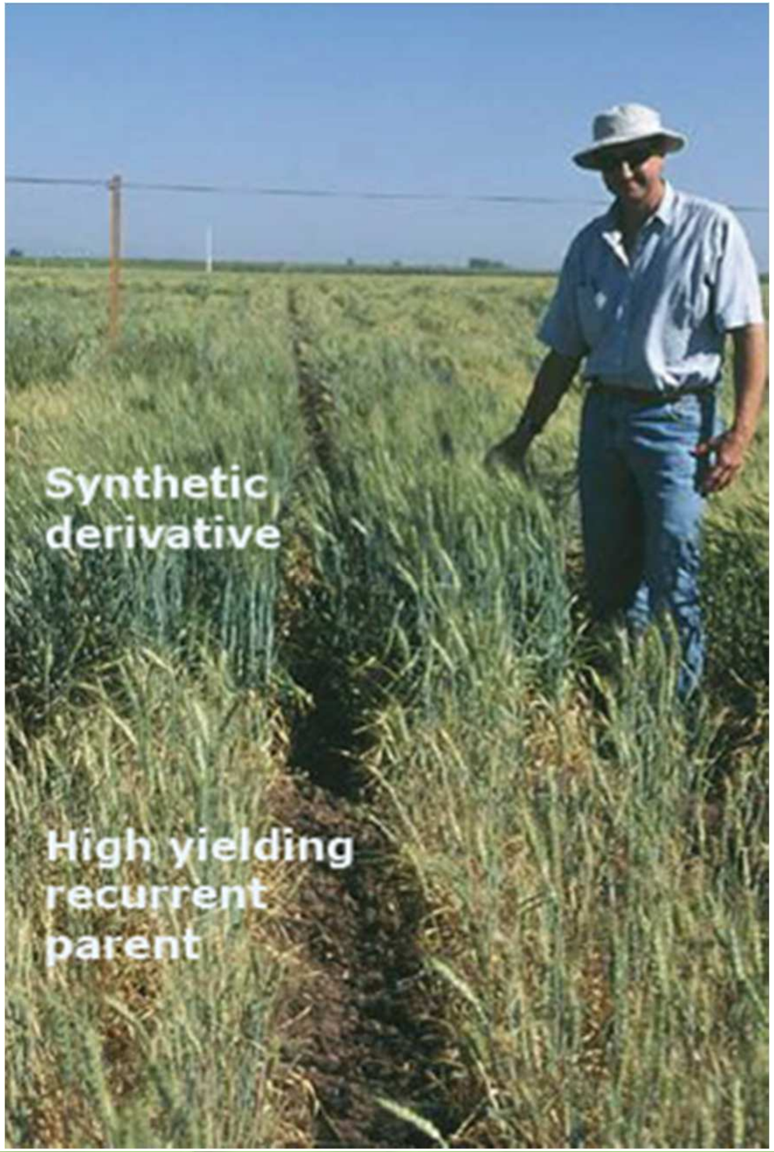
***AB***
***T. durum***

+

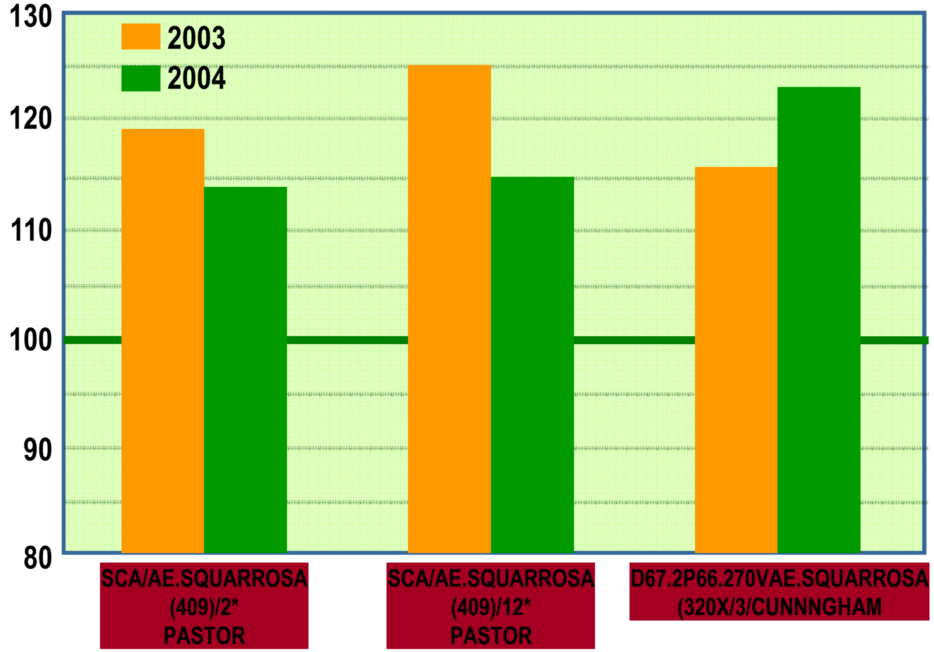


***D***
***T. tauschii***

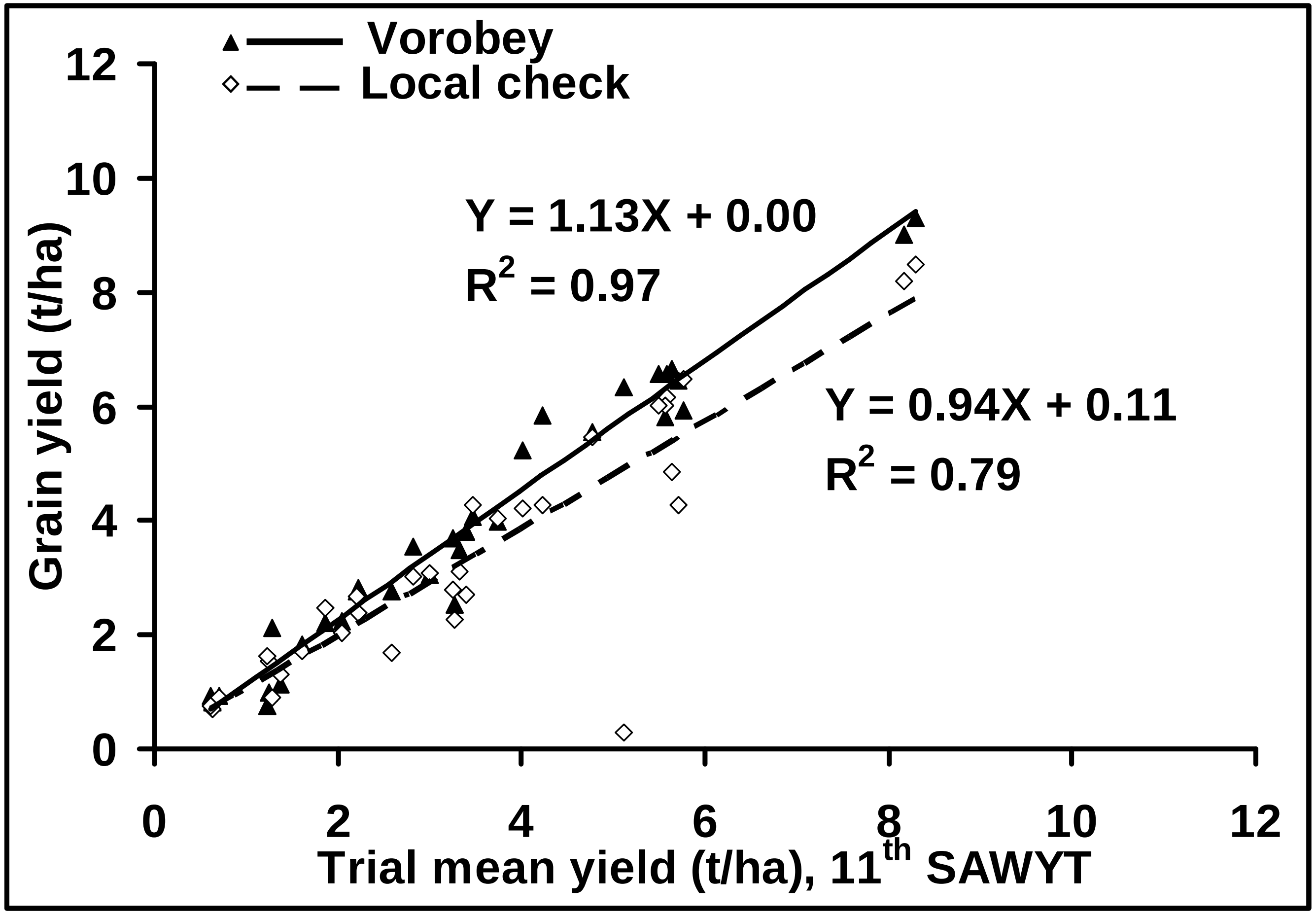
**ABD**



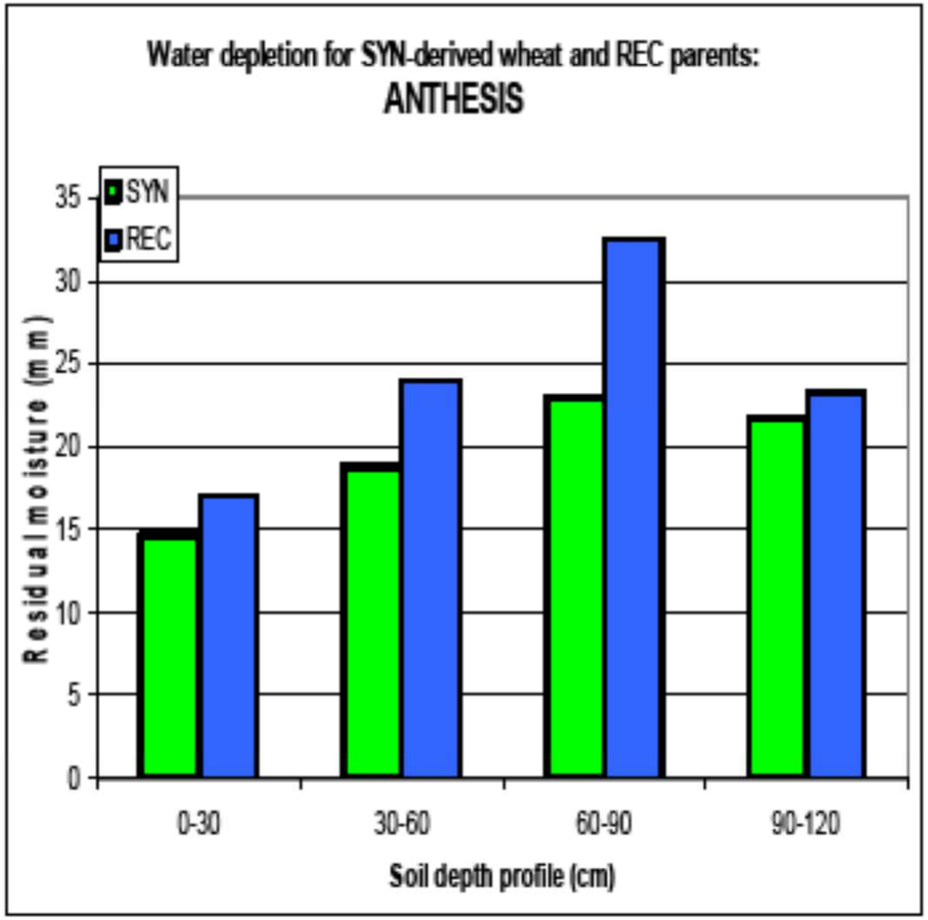

# Yield of re-synthesized wheat derivatives expressed as % of the recurrent parent over two year under drought stress

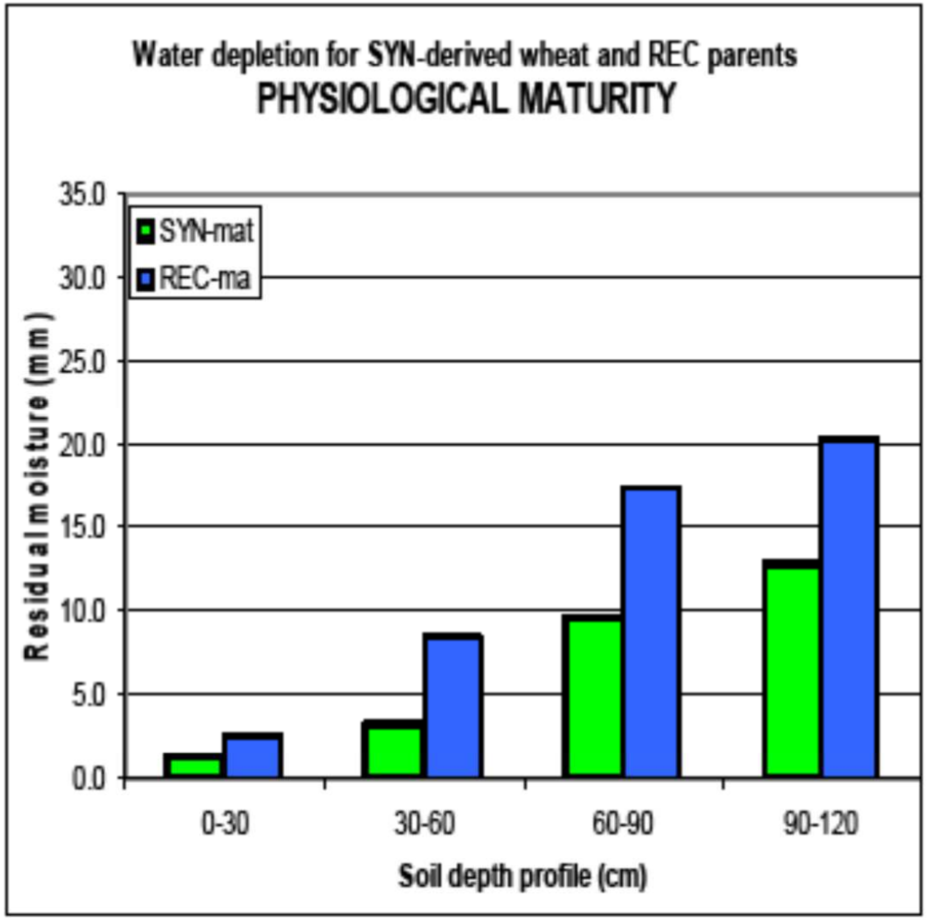


# Best re-synthesized wheat derivative versus local check across locations in multi-environment trial



# SYN-derived lines extract more water from deeper in soil profile

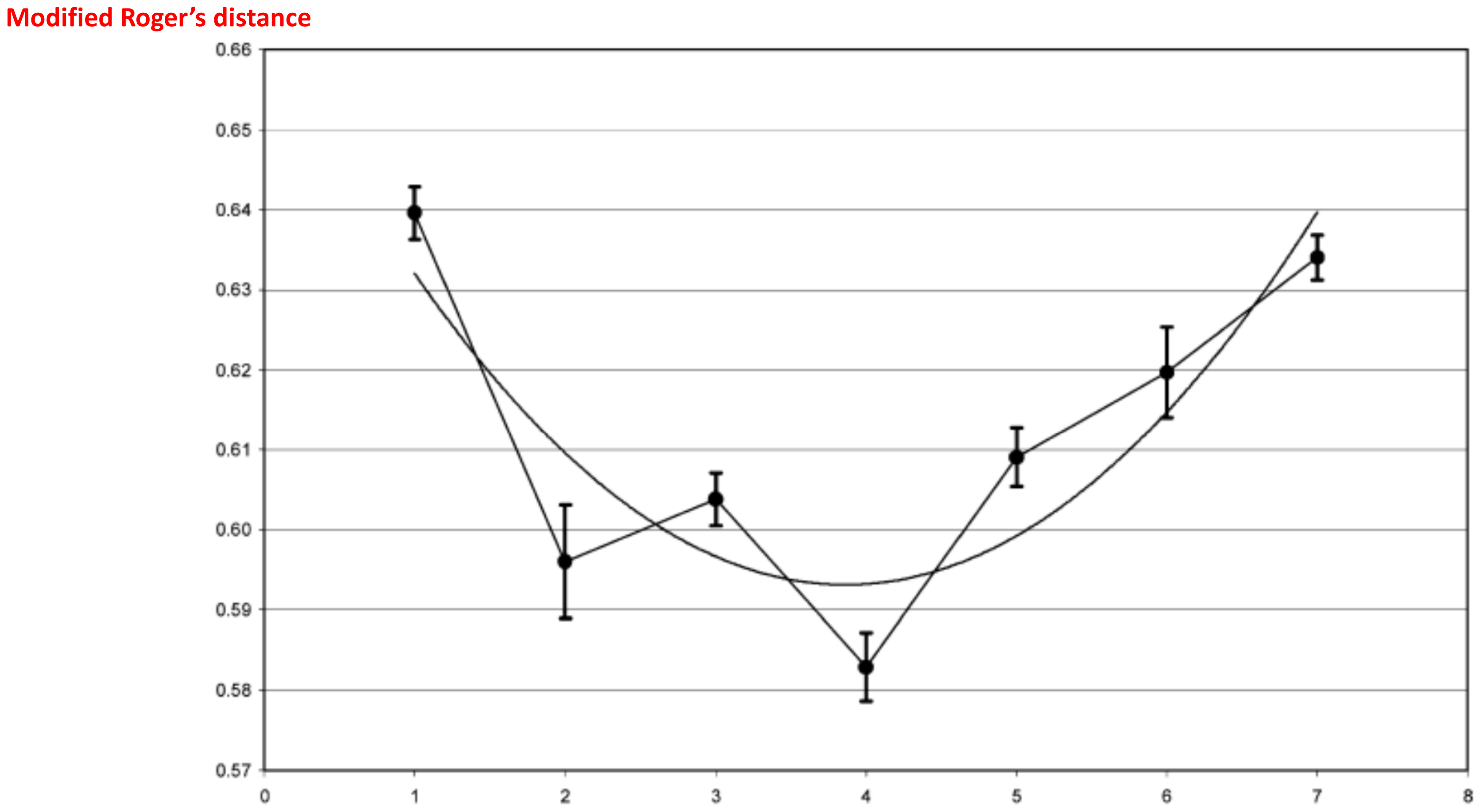


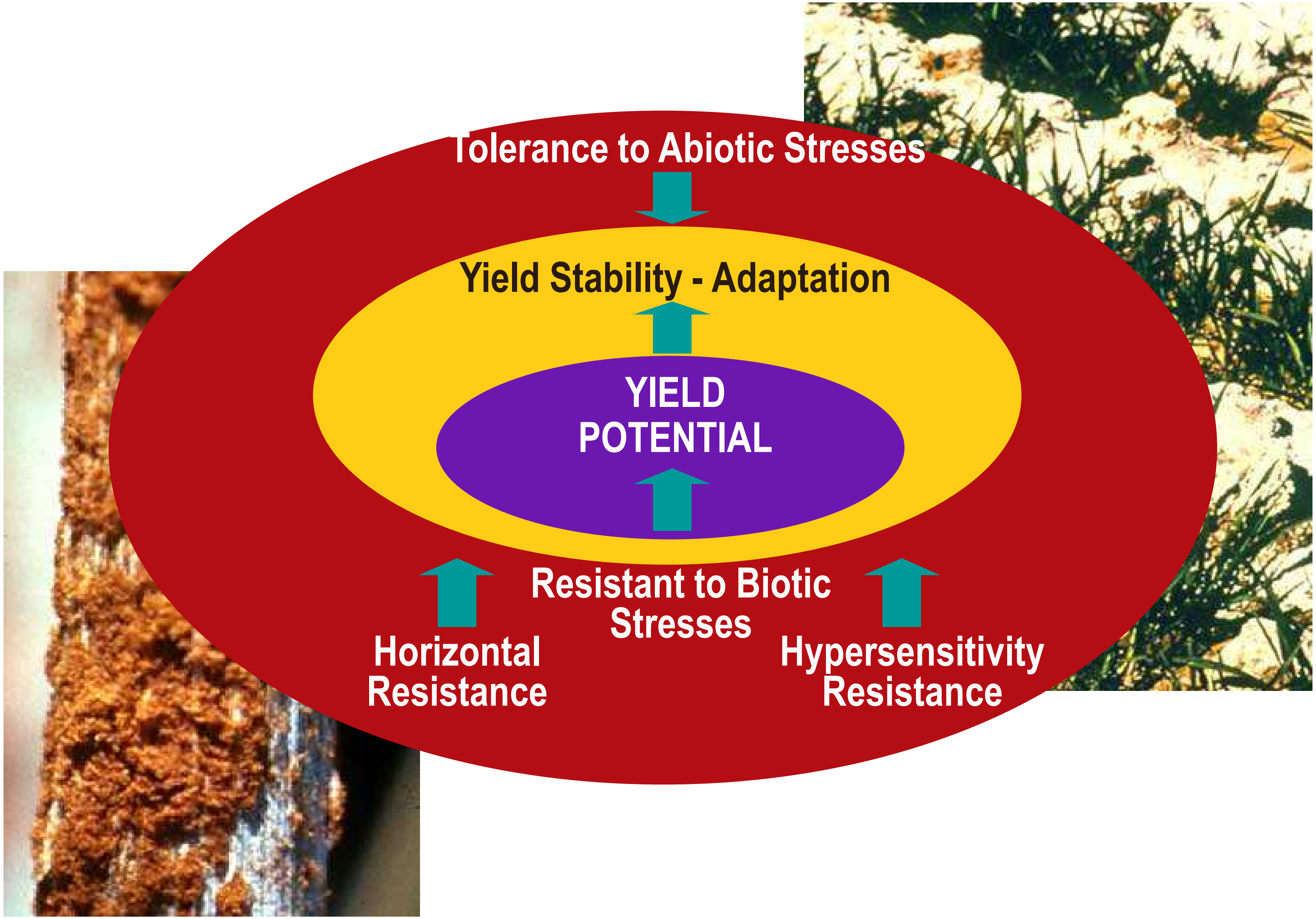

CIMMYT
International Maize and Wheat Improvement Center

*Seeding innovation... Nourishing hope*

# Bringing wild relatives back into the family: recovering genetic diversity in CIMMYT improved wheat germplasm




**1 = landraces, 2 = 1950-1966 cultivars (cvs), 3 = 1967-1974 cvs, 4 = 1975-1982 cvs,**
**5 = 1982-1989 cvs, 6 = 1990-1997 cvs, 7 = 2002-2003 promising re-synthesized wheat-derived lines**
**Source: Warburton et al. (2006) *Euphytica* 149: 289-301**


Tolerance to Abiotic Stresses
Yield Stability - Adaptation
YIELD
POTENTIAL
Resistant to Biotic
Stresses
Horizontal
Resistance
Hypersensitivity
Resistance

# Enhancing potato cultigens with wild species and landrace gene pools

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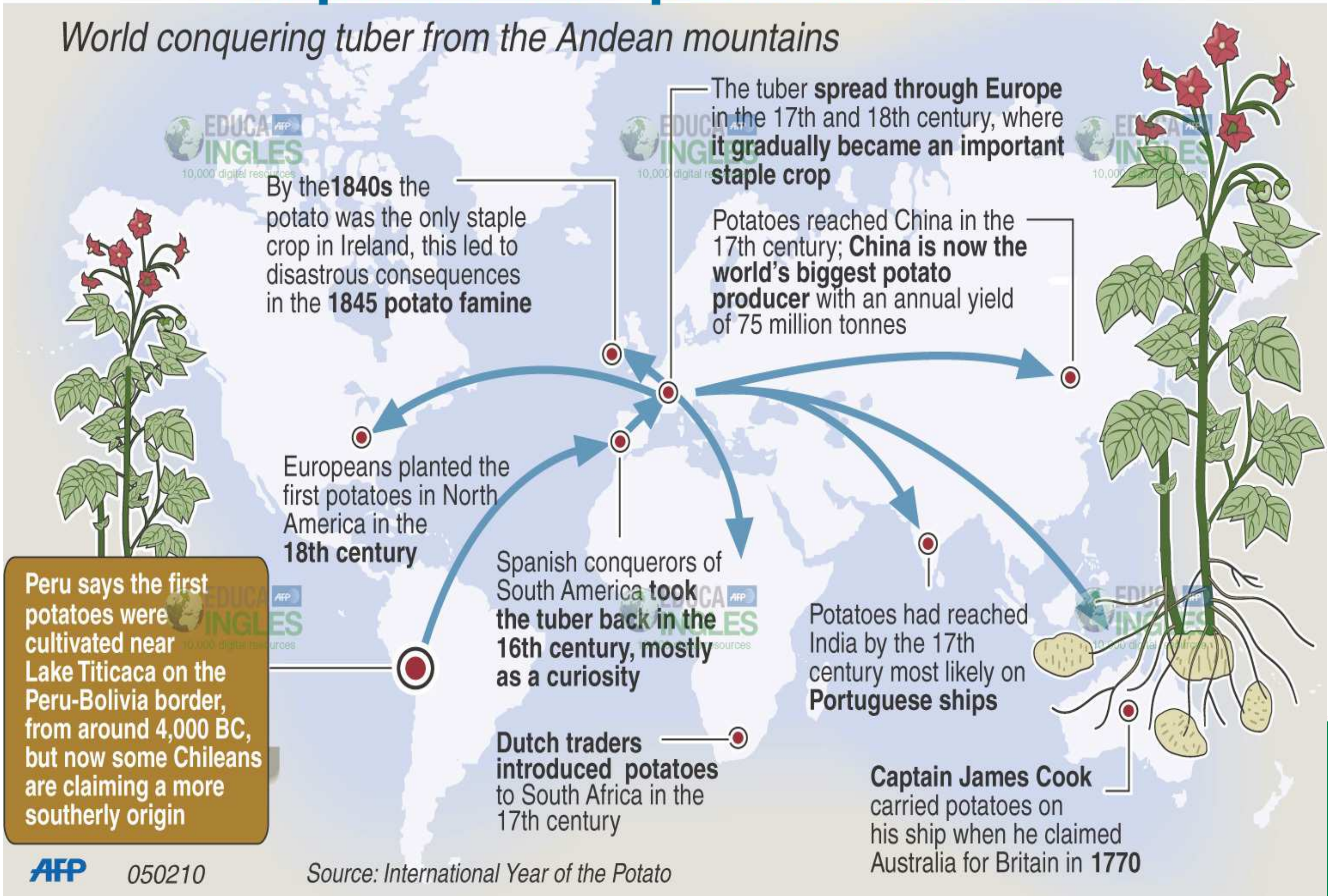
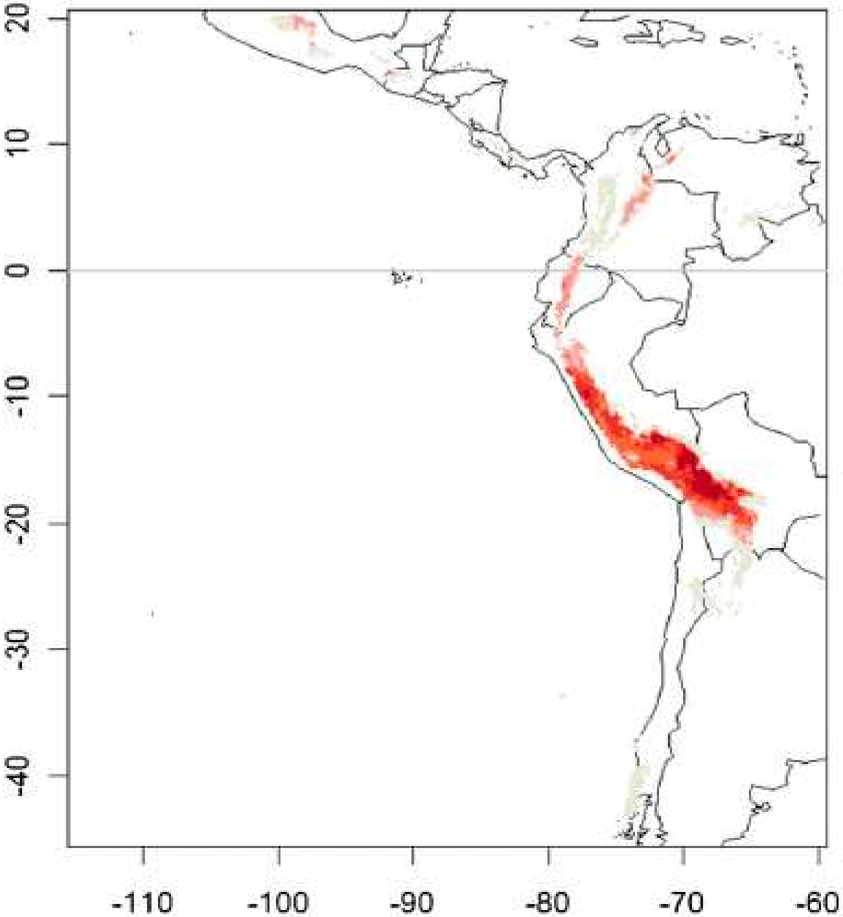
# The potato conquest of the world



# Richness map of the cultivated potato

Prof. Carlos Ochoa
(1920-2008)



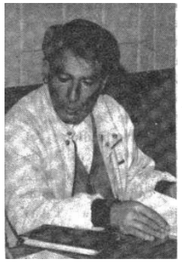

**The darker the shades of red the higher the total probability of cultivated potatoes summed over seven taxonomic and ploidy classes**

**Erwin Baur collection assembled in Germany with wild material collected in Mexico (1930s)**

US cultivars Earlaine and Saranac released by USDA in 1930s-1940s

Huinkul MAG (Earlaine x Saranac) released in 1948 in Argentina

**Crosses between S. acaule, S. demissum, S. stoloniferum and local cultivars made at Max Plank Institute (MPI, Germany) in the 1950s**



**Américo O. Mendiburu**
**1938-1991**
**INTA**

MPI 61.375/23 sent by MPI to Argentina in 1967

MPI 61.375/23 and B25.65 (derived from Huinkul MAG) are crossed in Argentina in 1971

**Selection B-71240.2 from such cross sent to CIP (Perú) in 1976**

**B-71240-2** sent by CIP to Inst. Plant Industry (Burnley, Australia) for “cleaning”

**B-71240** sent from Australia to China as **CIP-24** in 1978

Cultivar testing of **CIP-24** in Inner Mongolia in 1980s

**CIP- 24** released as new cultivar by China in 1984

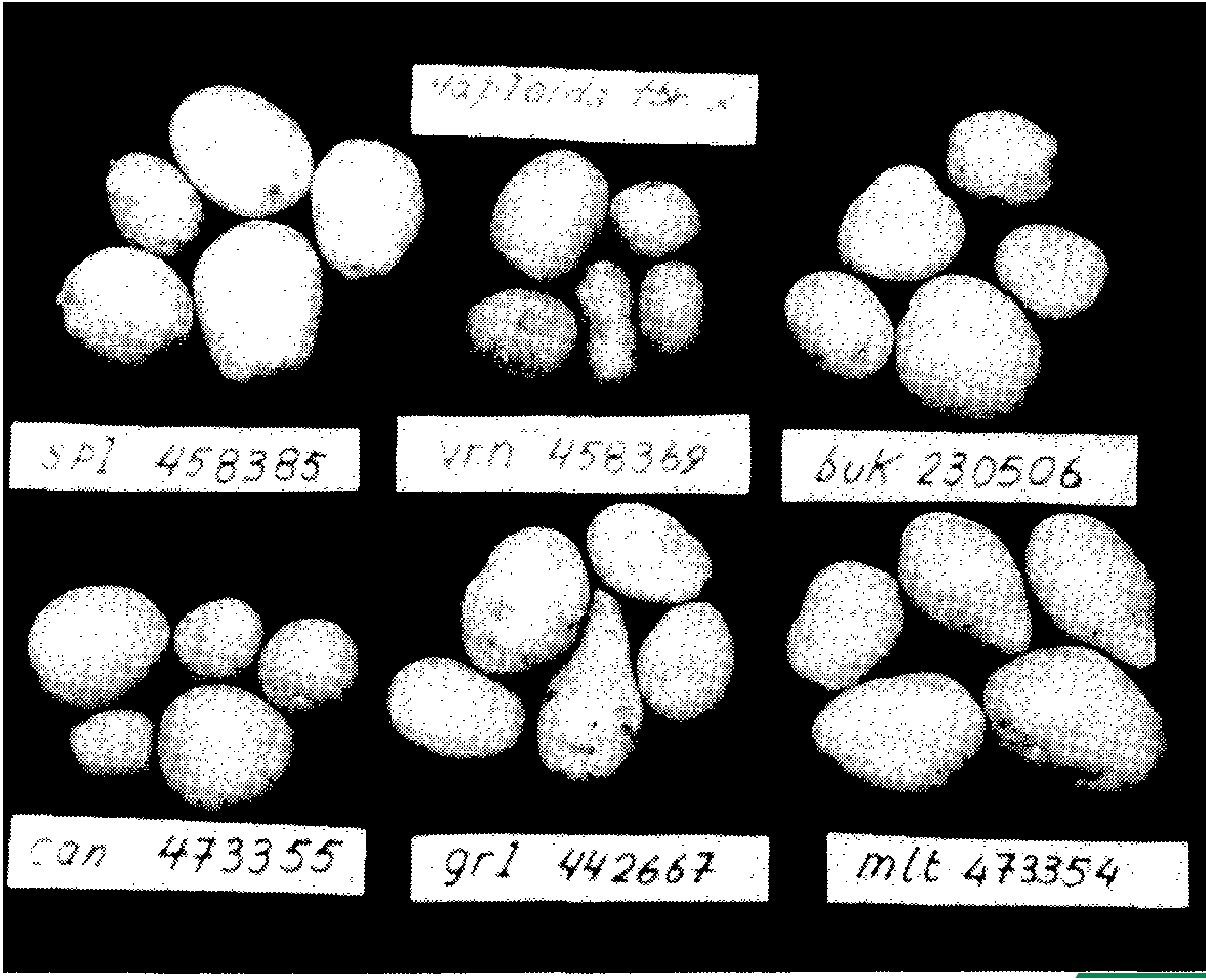
**CIP-24** grown in 250,000 ha in the 1990s in China

**B-71240.2** released as **Achirana-INTA** in 1986

# Ploidy manipulations in tuber-bearing Solanums

4x cultivar or advanced selection
↓ ***haploid extraction*** *(partenogenetic development of eggs)*
haploid (2x) × 2x species
↓
2x haploid-species hybrid
↓ ***selection for:*** *pest resistance, FDR* 2n *pollen production*
*& tuber appearance*
FDR 2x clone × 4x cultivar
***2n* pollen (=2x)** ↓ **n eggs (=2x)**
4x-2x family → **Yield trials**
↓ ***selection*** ↓
*(for pest resistance & tuber appearance)* combining ability of 2x & 4x parents
↓ and selection of true seed progeny (TPS)
Tetraploid-diploid (TD) × 4x or 2x
↓ ***testing*** *over years and locations* ↓ ***combining ability***
*of TD &* ***selection***
improved 4x cultivar TD parent in clonal breeding program
(specific resistance, high yield)

**Emeritus Campbell-Bascom Prof. Stanley J. Peloquin (1921-2008)**



spl 458385
vrn 458369
buk 230506
can 473355
grl 442667
mlt 473354

# Potato: the model crop species for genetic enhancement of polysomic polyploids

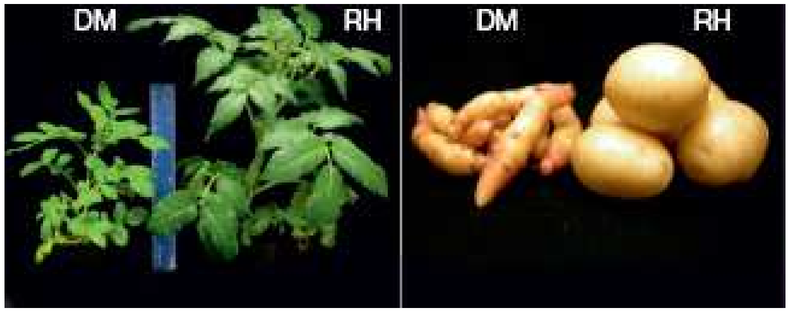
- **Wild species** and **diploid landraces** are the **source of genetic diversity**
- **Haploids** (or sporophytes with the gametic chromosome number)derived from adapted tetraploid cultivars are able to **'capture' this genetic diversity** in crosses with the diploid germplasm
- Haploid–species hybrids **transmit this genetic diversity** to the adapted tetraploid breeding pool via **2*n* gametes** (or gametes with the sporophytic chromosome number)
- **Endosperm balance number** (EBN): an endosperm dosage system, common to other angiosperm genera, requires a correct proportion of **2:1 maternal to paternal contributions for proper seed development**

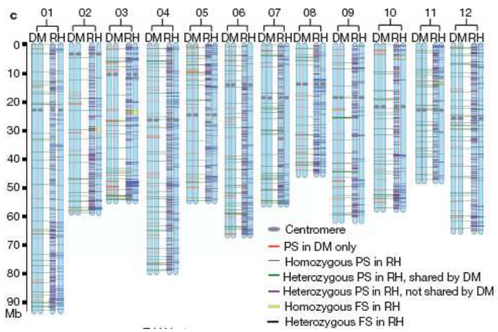
 doi:10.1038/nature10158

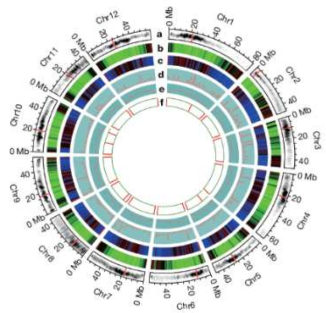
# Genome sequence and analysis of the tuber crop potato

The Potato Genome Sequencing Consortium*

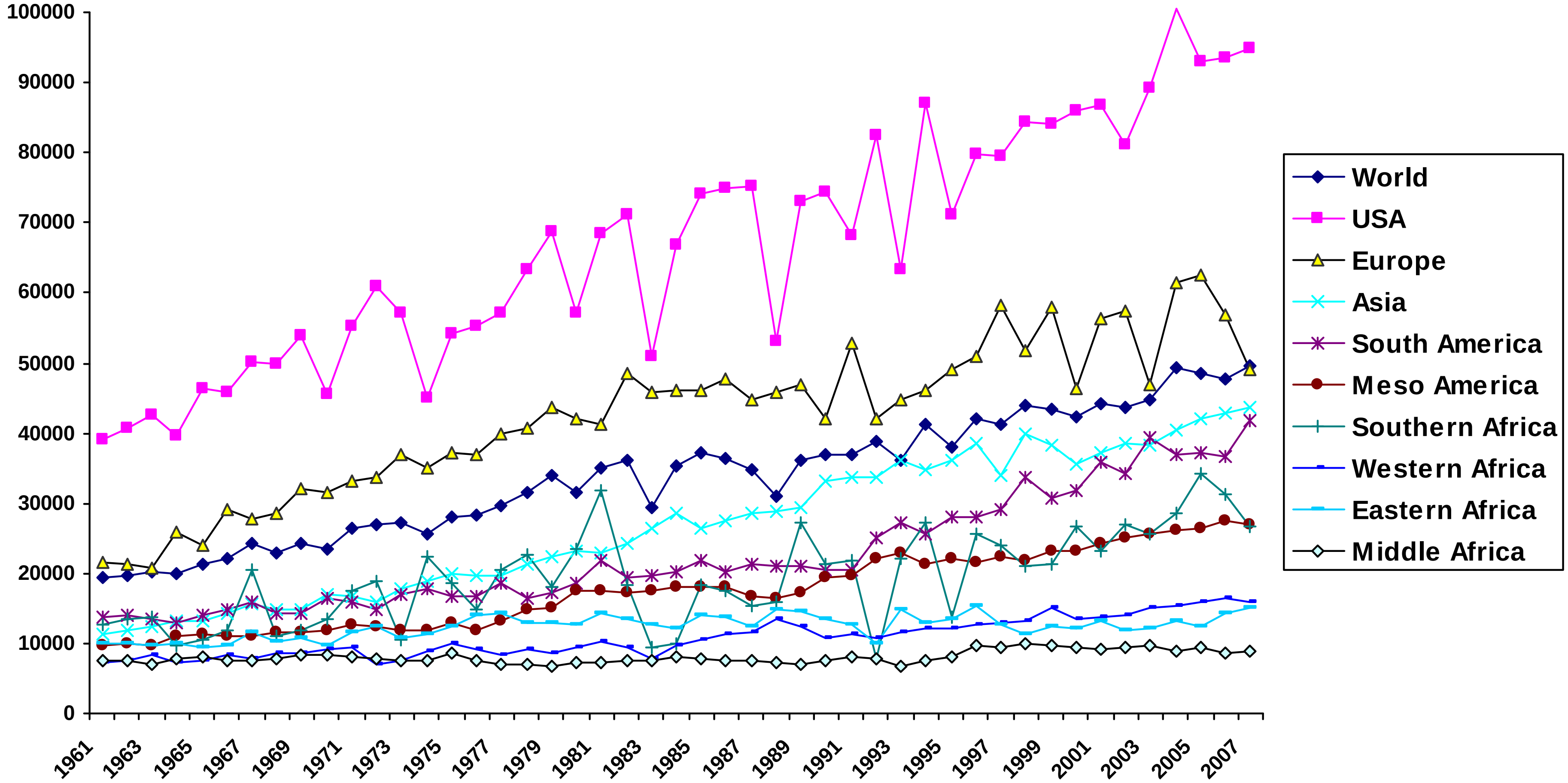
Potato (*Solanum tuberosum* L.) is the world's most important non-grain food crop and is central to global food security. It is clonally propagated, highly heterozygous, autotetraploid, and suffers acute inbreeding depression. Here we use a homozygous doubled-monoploid potato clone to sequence and assemble 86% of the 844-megabase genome. We predict 39,031 protein-coding genes and present evidence for at least two genome duplication events indicative of a palaeopolyploid origin. As the first genome sequence of an asterid, the potato genome reveals 2,642 genes specific to this large angiosperm clade. We also sequenced a heterozygous diploid clone and show that gene presence/absence variants and other potentially deleterious mutations occur frequently and are a likely cause of inbreeding depression. Gene family expansion, tissue-specific expression and recruitment of genes to new pathways contributed to the evolution of tuber development. The potato genome sequence provides a platform for genetic improvement of this vital crop.



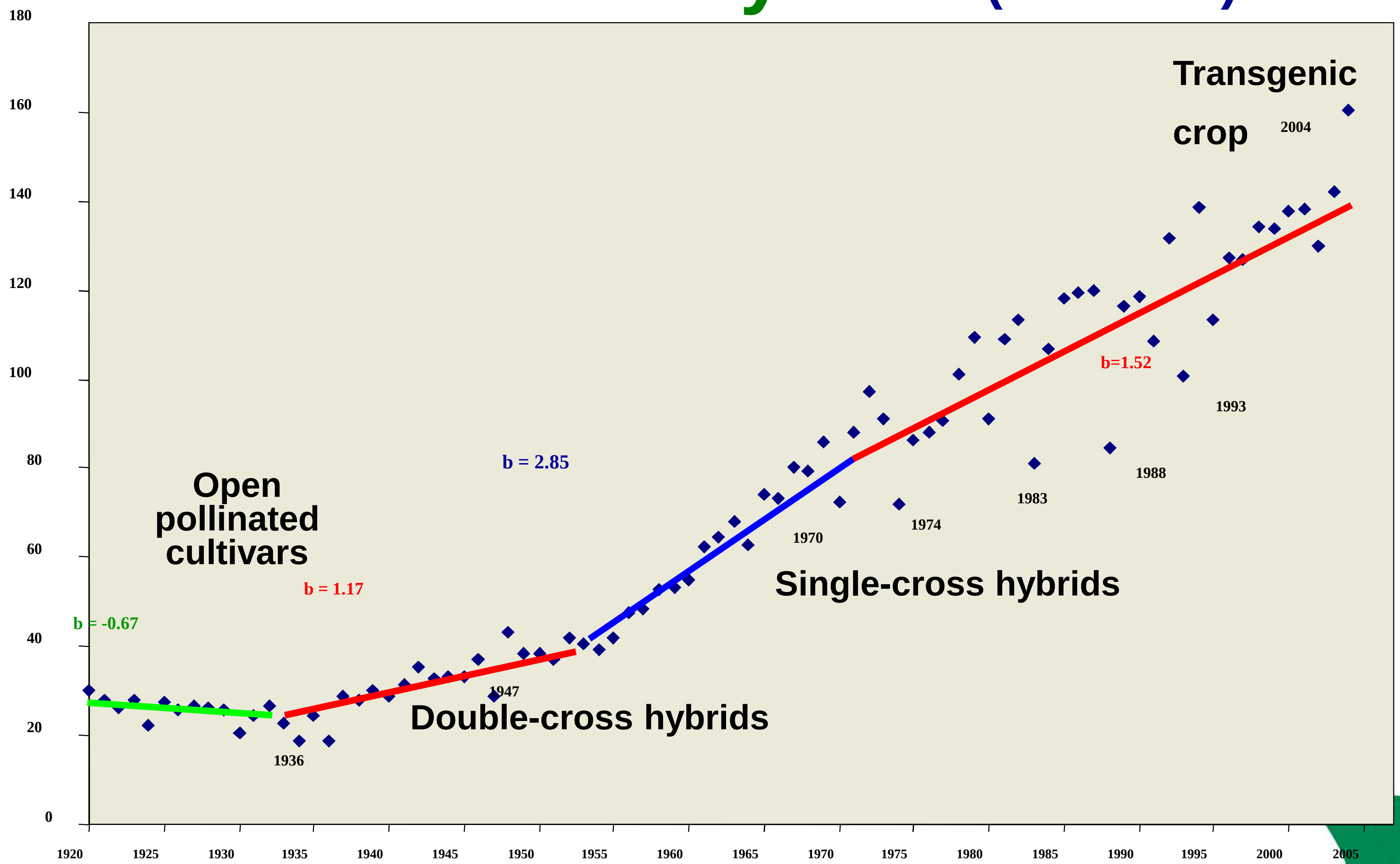



# Maize global yields (1961-2008)



# Seed technology evolution and US national maize yields (bu acre$^{-1}$)

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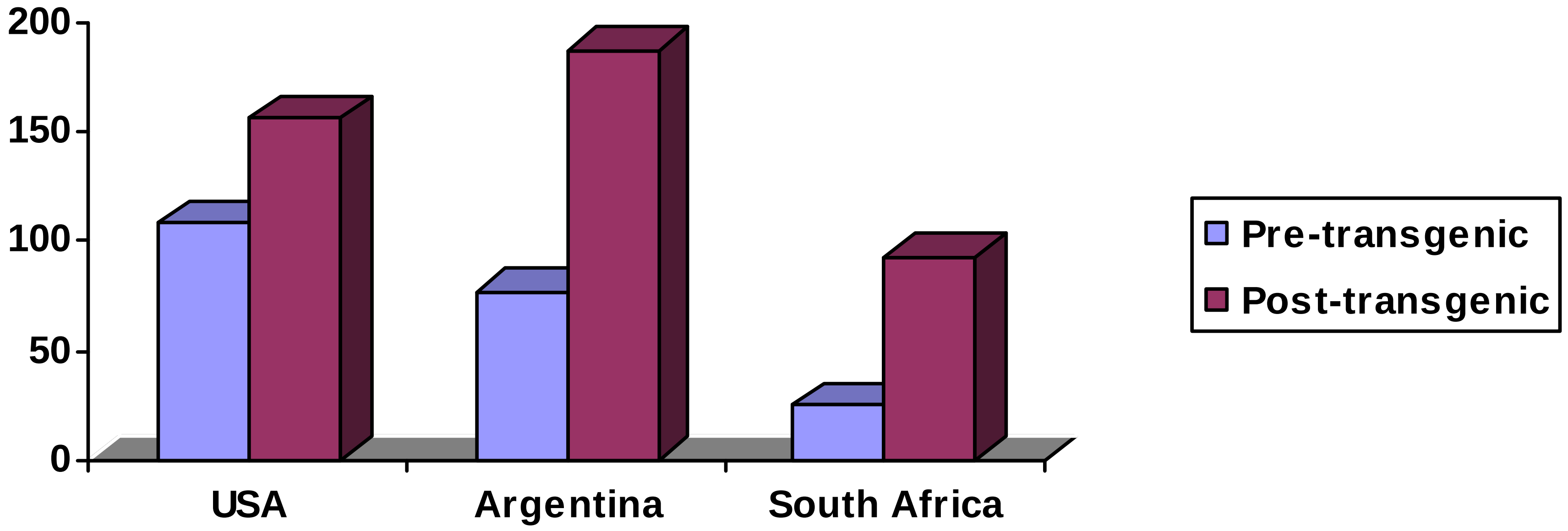
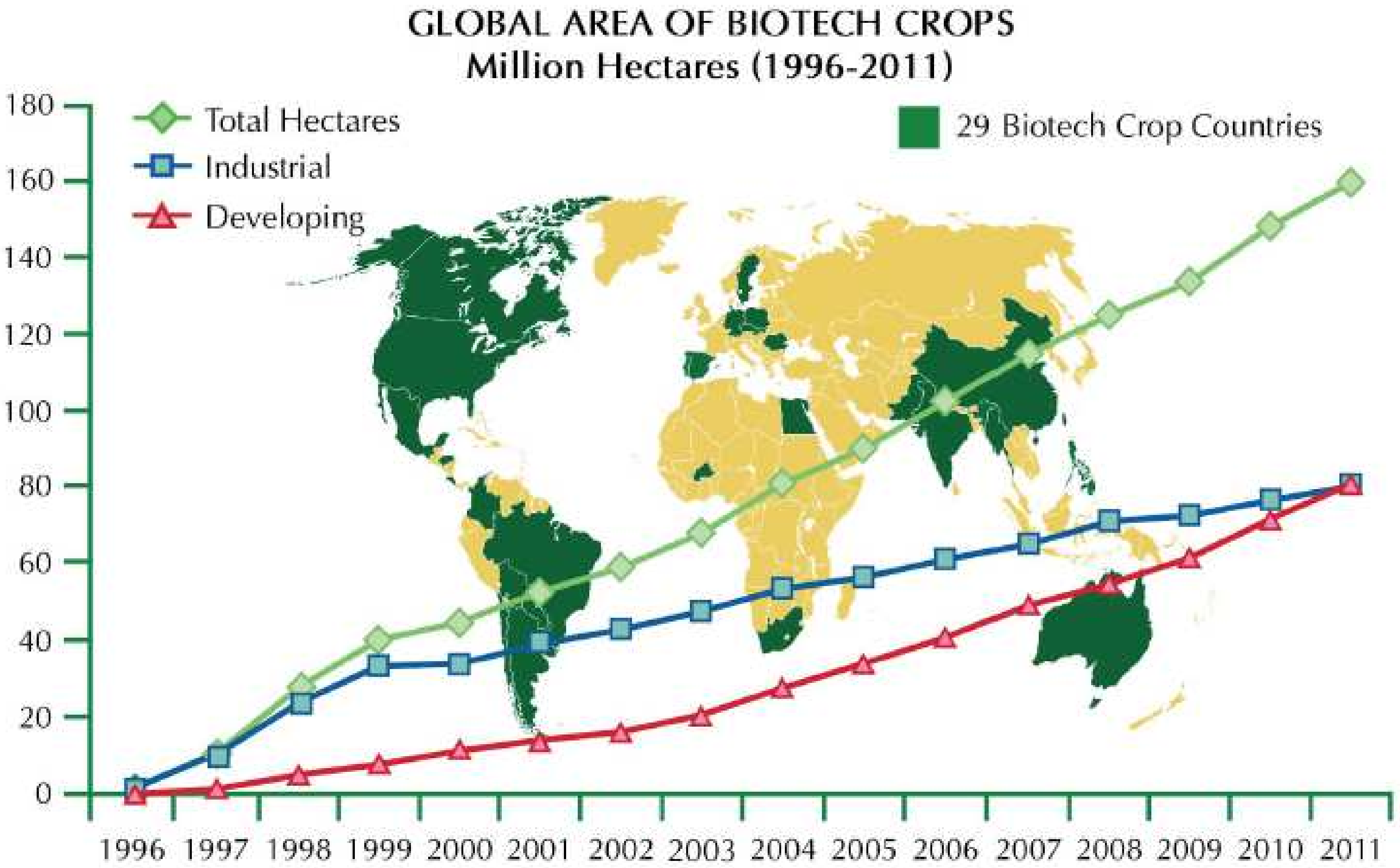
# Annual growth rates of maize grain yield
## (kg ha$^{-1}$)




**Source: Mezzalama et al. 2010**

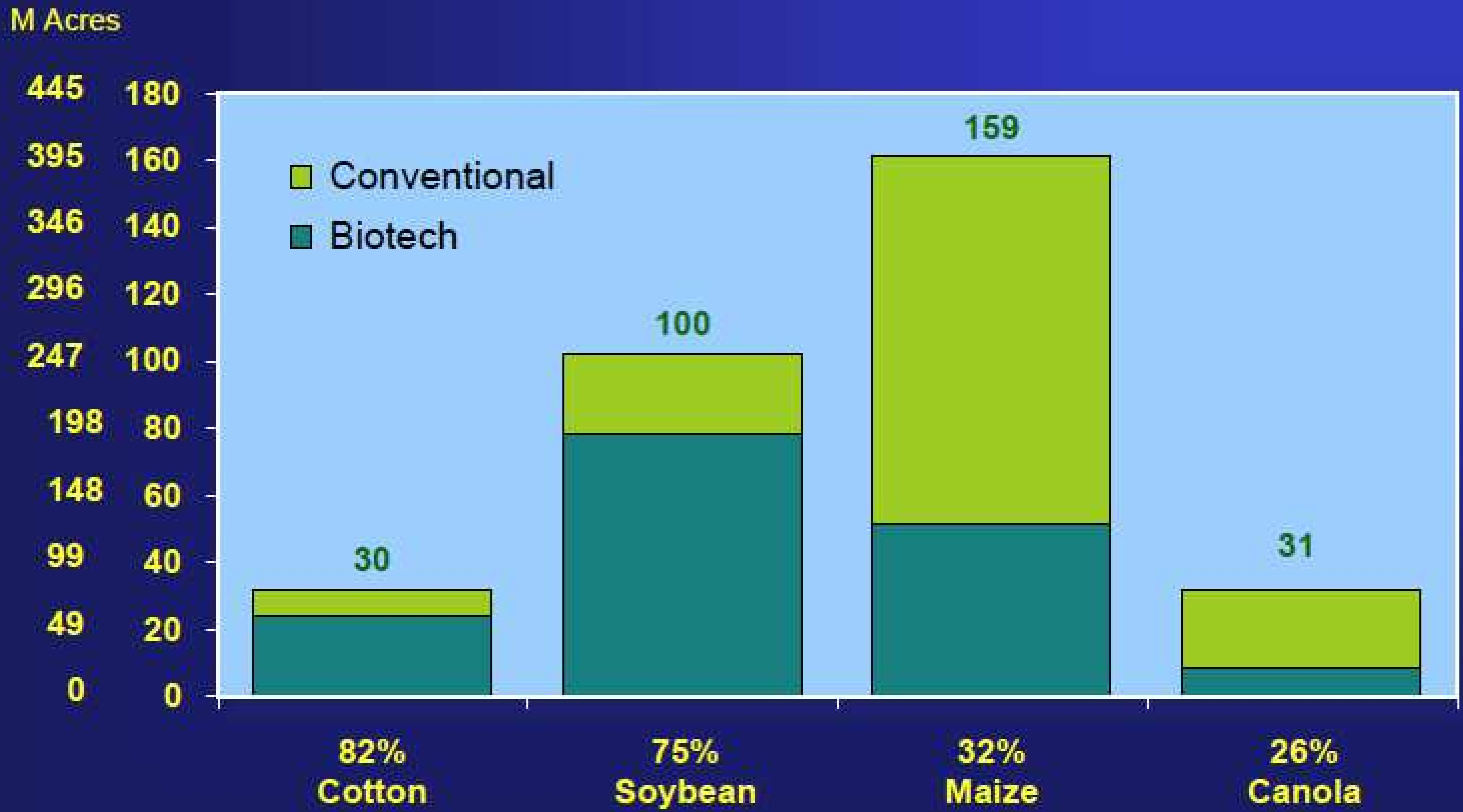



*A record 16.7 million farmers, in 29 countries, planted 160 million hectares (395 million acres) in 2011, a sustained increase of 8% or 12 million hectares (30 million acres) over 2010.*

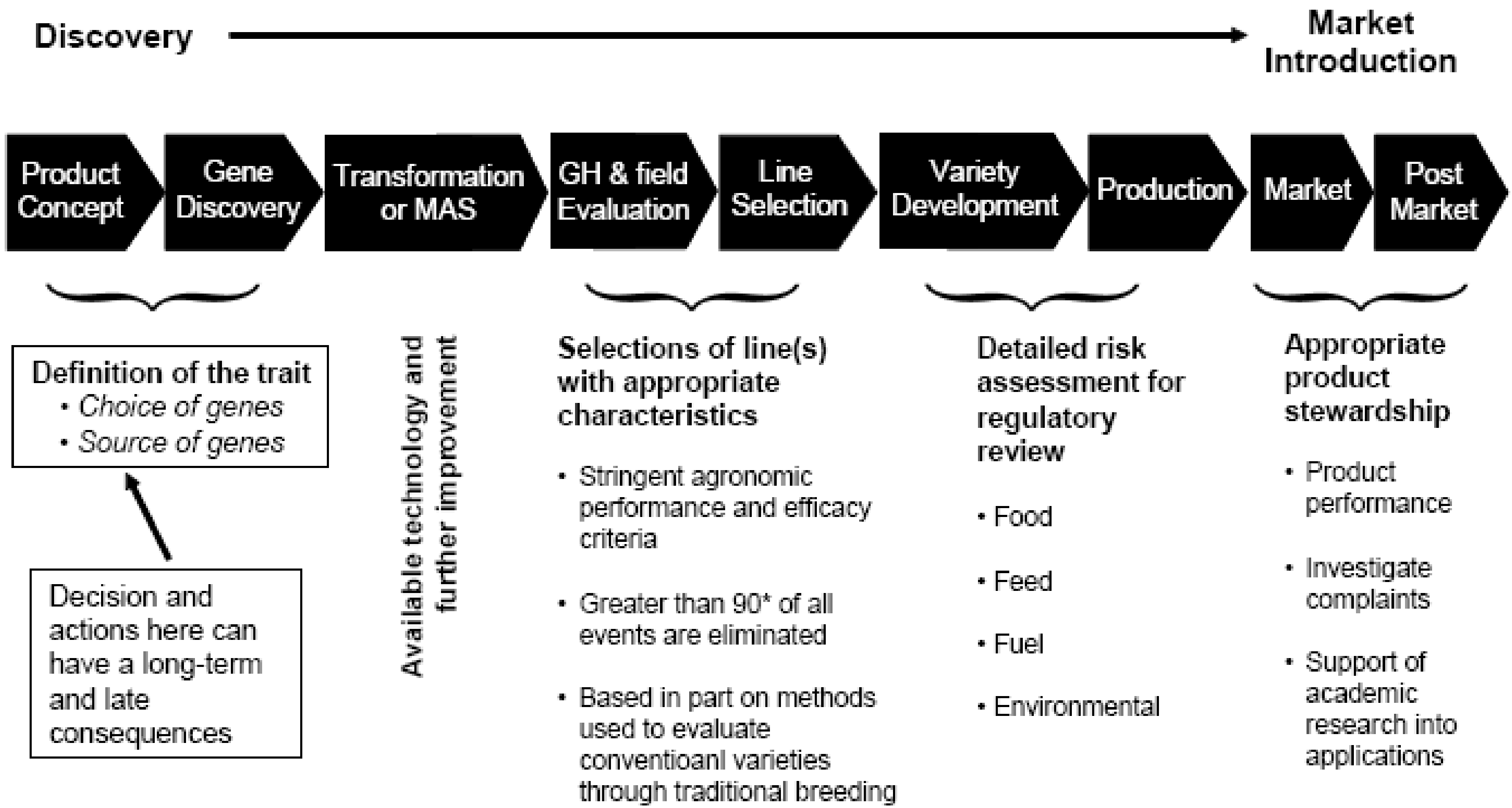
Source: Clive James, 2011.

# Global Adoption Rates (%) for Principal Biotech Crops (Million Hectares, Million Acres), 2011

ISAAA

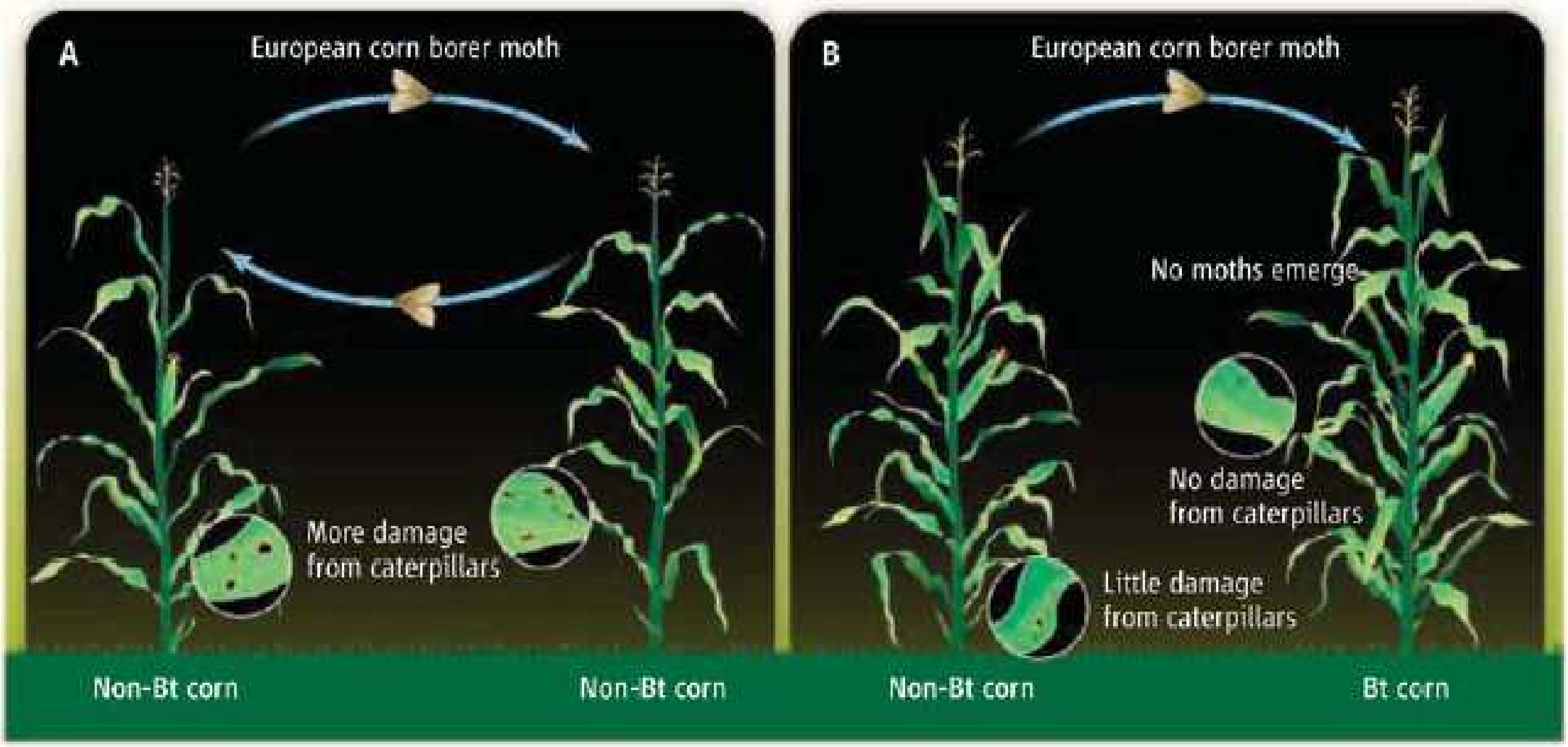



Source: Clive James, 2012




**Biotechnology product development process with projected time: 7-12 years**

# Communal benefits of transgenic maize




**Areawide Suppression of European Corn Borer with Bt Maize Reaps Savings to Non-Bt Maize Growers**

222 8 OCTOBER 2010 VOL 330 SCIENCE www.sciencemag.org

LETTER

doi:10.1038/nature11153

# Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services

Yanhui Lu[1], Kongming Wu[1], Yuying Jiang[2], Yuyuan Guo[1] & Nicolas Desneux[3]

- **Marked increase in abundance of three types of generalist arthropod predators** (ladybirds, lacewings and spiders)
- **Decreased abundance of aphid pests** and reduced insecticide sprays in this crop
- **Predators might provide additional biocontrol services spilling** over from *Bt* cotton fields **onto neighbouring crops**
- (maize, groundnut and soybean)

(**Data**: 1990 to 2010 at 36 sites in six provinces of northern China)

# Economic impacts and impact dynamics of Bt (*Bacillus thuringiensis*) cotton in India

Jonas Kathage[1] and Matin Qaim[1]

www.pnas.org/cgi/doi/10.1073/pnas.1203647109

- *Bt* has caused a **24% increase in cotton yield per acre** through reduced pest damage and a 50% gain in cotton profit among smallholders
- **Benefits are stable**; there are even indications that they have **increased over time**
- Bt cotton adoption has **raised consumption expenditures**, a common measure of household living standard**, by 18%** during the 2006–2008 period

(**Data**: collected between 2002 and 2008, and controlling for nonrandom selection bias in technology adoption)

# Transgenes for enhancing maize adaptation to drought-prone environments

| Transgene | Reference |
|---|---|
| Oat arginine decarboxylase cDNA (→polyamines) | Bassie et al. 2008 |
| *Escherichia coli*'s glutamate dehydrogenase (*gdhA*) gene | Lightfoot et al. 2007 |
| Cold shock proteins (CSPs) from bacteria | Castiglioni et al. 2008 |
| Phosphatidylinositol-specific phospholipase C (PI-PLC) | Zhai et al. 2005<br>Wang et al. 2008 |
| Orthologous maize transcription factor (ZmNF-YB2) | Nelson et al. 2007 |

Annals of Arid Zone 47(3&4): 1-12, 2008

Crop Genetic Engineering Under Global Climate Change

Rodomiro Ortiz

# Field trial of GM-maize showing enhance grain yield under drought

In collaboration with


| Discovery | Phase 1 | Phase 2 | Phase 3 | Fase 4 | Release |
|---|---|---|---|---|---|
| | Proof of concept | Initial develpment | Advanced development | Pre-release | |

# 21st Century Crops

**Host plant resistance to pathogens and pests**

**Herbicide tolerance for conservation agriculture**

**Nutritional quality of healthy food**

**Adaptation to abiotic stresses**

**Genetic yield potential**

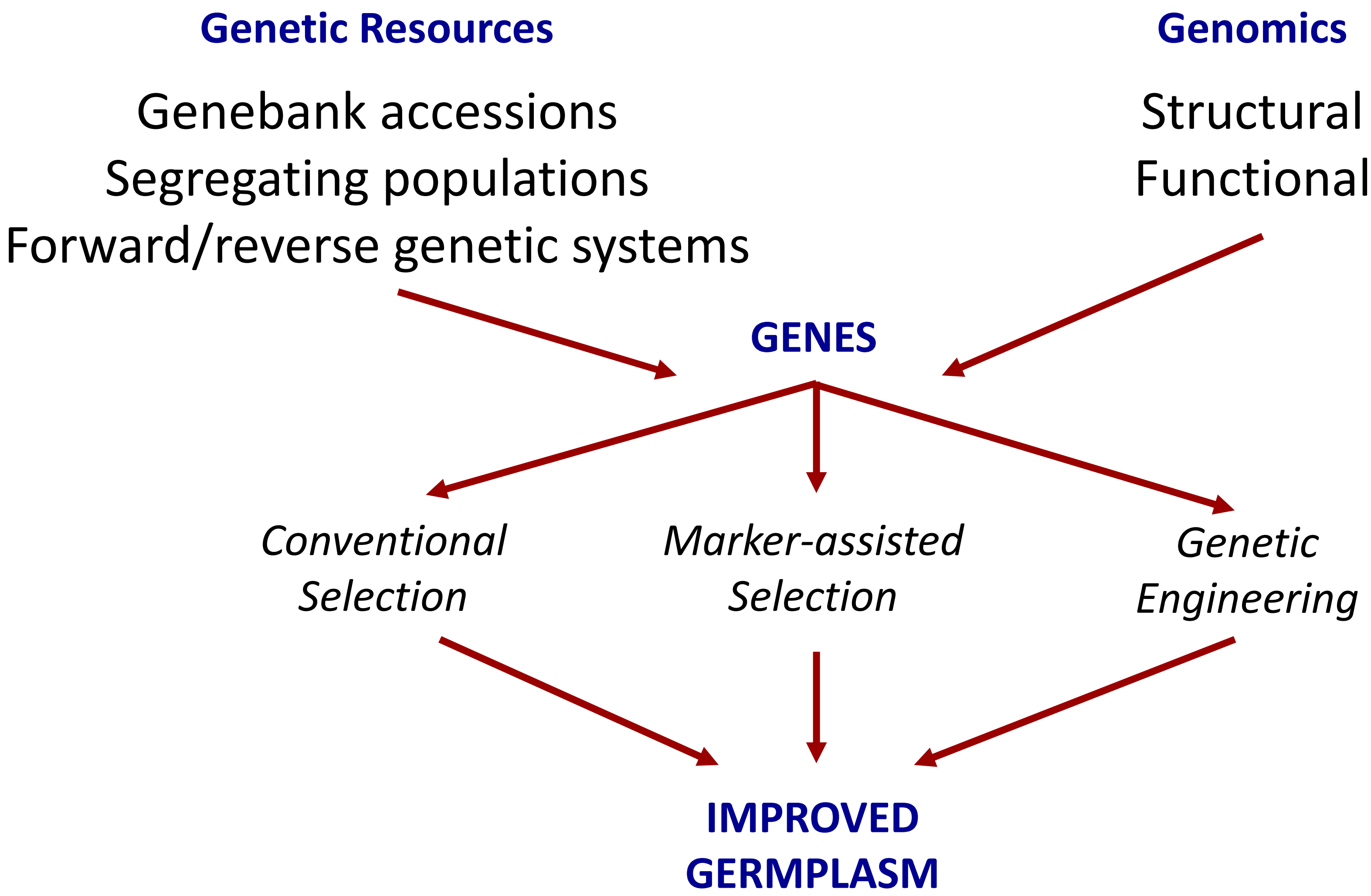


**Source: Norman E. Borlaug (2005)**

# Agrobiodiversity for intensifying sustainably crop yields and for adapting to climate change

- **Genetic broadening** or for introgression in plant breeding
- **Intra-specific crop diversification** (mixture of distinct landraces or cultivars having genetic variation within each population) could provide a means for controlling effectively pathogens and pests over large areas
- **Genetically enhanced seed-embedded technology** to adapt crops to variable environments due to changing climate

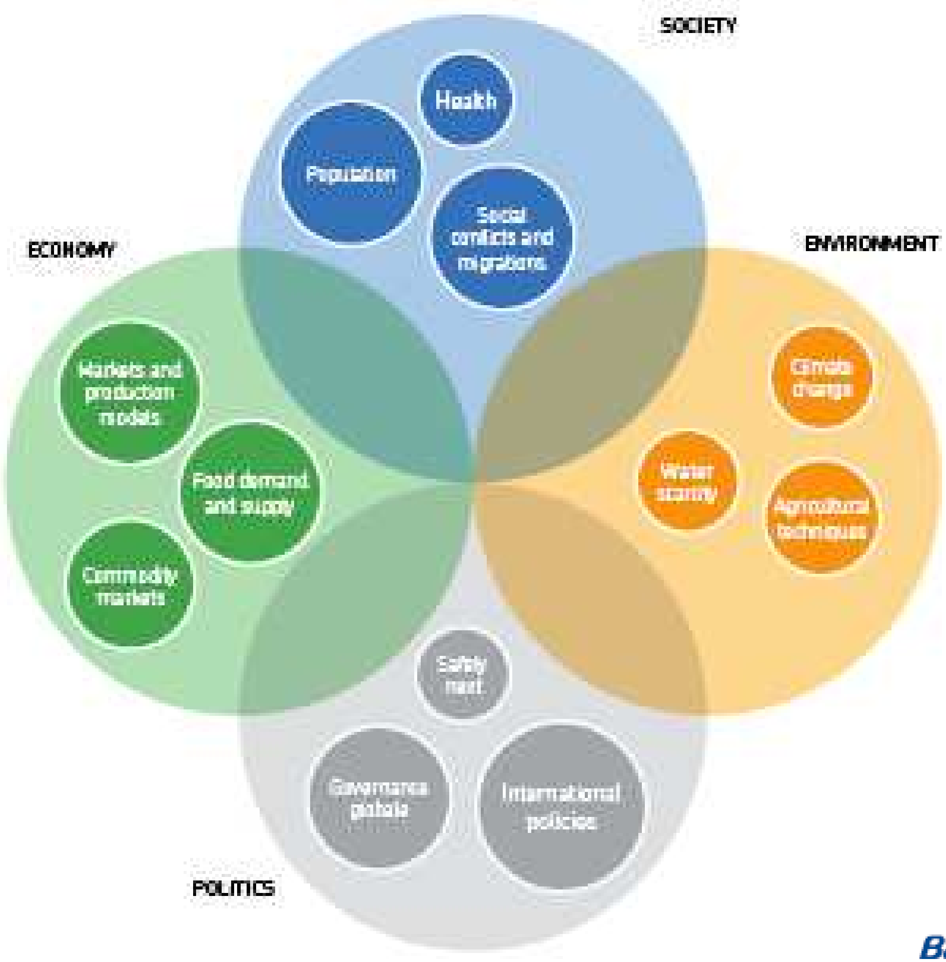
# Plant Breeding Options



# Sustainable Crop Genetic Enhancement

- Identifying a useful character
- Manipulating its genetic variation
- Putting genes into a usable form
- DNA markers monitor chromosomal changes from selection
- Genetic engineering enhances useful variation if not available in crop gene pools

# Food security: a multidimensional issue




Source: The European House-Ambrosetti, 2011.

# Agrobiodiversity for a multi-functional agriculture: 7 Fs + "1"

- Food ←
- Feed
- Fiber
- Flower
- Fuel
- Fun
- Feedstock

…

- Pharmaceutical