Current research questions in Plant Science
and
Initiatives of the Global Plant Council

Wilhelm Gruissem
ETH Zurich

ERA-CAPS 1st Grant Holders Workshop
Rome, June 12-13, 2014

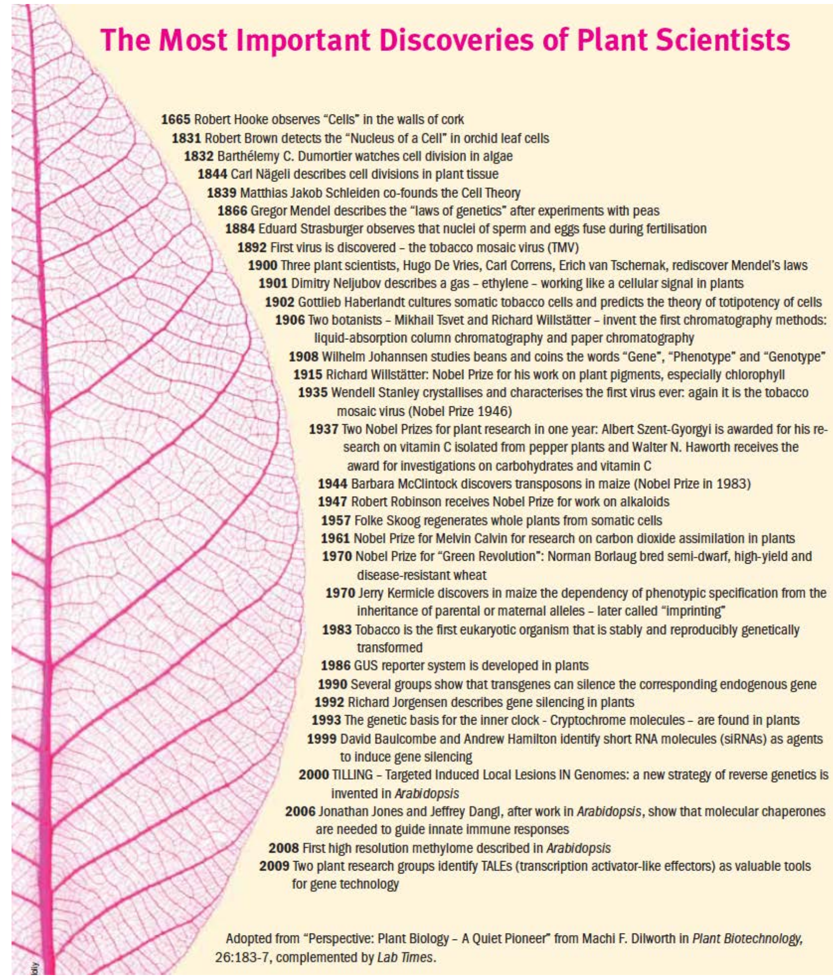
Plant science has contributed greatly to our basic understanding of biology, but pioneering achievements are often ignored

Plant Biotechnology 26, 183–187 (2009)

Invited Review

Perspective: Plant biology—A quiet pioneer

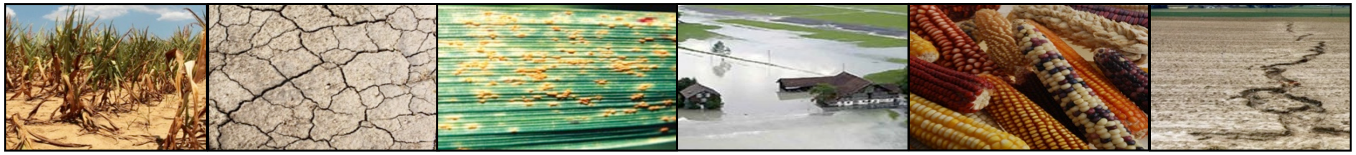
Machi F. Dilworth[a,*]



The Most Important Discoveries of Plant Scientists

1665 Robert Hooke observes "Cells" in the walls of cork
1831 Robert Brown detects the "Nucleus of a Cell" in orchid leaf cells
1832 Barthélemy C. Dumortier watches cell division in algae
1844 Carl Nägeli describes cell divisions in plant tissue
1839 Matthias Jakob Schleiden co-founds the Cell Theory
1866 Gregor Mendel describes the "laws of genetics" after experiments with peas
1884 Eduard Strasburger observes that nuclei of sperm and eggs fuse during fertilisation
1892 First virus is discovered – the tobacco mosaic virus (TMV)
1900 Three plant scientists, Hugo De Vries, Carl Correns, Erich van Tschemak, rediscover Mendel's laws
1901 Dimitry Neljubov describes a gas – ethylene – working like a cellular signal in plants
1902 Gottlieb Haberlandt cultures somatic tobacco cells and predicts the theory of totipotency of cells
1906 Two botanists – Mikhail Tsvet and Richard Willstätter – invent the first chromatography methods: liquid-absorption column chromatography and paper chromatography
1908 Wilhelm Johannsen studies beans and coins the words "Gene", "Phenotype" and "Genotype"
1915 Richard Willstätter: Nobel Prize for his work on plant pigments, especially chlorophyll
1935 Wendell Stanley crystallises and characterises the first virus ever: again it is the tobacco mosaic virus (Nobel Prize 1946)
1937 Two Nobel Prizes for plant research in one year: Albert Szent-Gyorgyi is awarded for his research on vitamin C isolated from pepper plants and Walter N. Haworth receives the award for investigations on carbohydrates and vitamin C
1944 Barbara McClintock discovers transposons in maize (Nobel Prize in 1983)
1947 Robert Robinson receives Nobel Prize for work on alkaloids
1957 Folke Skoog regenerates whole plants from somatic cells
1961 Nobel Prize for Melvin Calvin for research on carbon dioxide assimilation in plants
1970 Nobel Prize for "Green Revolution": Norman Borlaug bred semi-dwarf, high-yield and disease-resistant wheat
1970 Jerry Kermicle discovers in maize the dependency of phenotypic specification from the inheritance of parental or maternal alleles – later called "imprinting"
1983 Tobacco is the first eukaryotic organism that is stably and reproducibly genetically transformed
1986 GUS reporter system is developed in plants
1990 Several groups show that transgenes can silence the corresponding endogenous gene
1992 Richard Jorgensen describes gene silencing in plants
1993 The genetic basis for the inner clock - Cryptochrome molecules – are found in plants
1999 David Baulcombe and Andrew Hamilton identify short RNA molecules (siRNAs) as agents to induce gene silencing
2000 TILLING – Targeted Induced Local Lesions IN Genomes: a new strategy of reverse genetics is invented in *Arabidopsis*
2006 Jonathan Jones and Jeffrey Dangl, after work in *Arabidopsis*, show that molecular chaperones are needed to guide innate immune responses
2008 First high resolution methylome described in *Arabidopsis*
2009 Two plant research groups identify TALEs (transcription activator-like effectors) as valuable tools for gene technology

Adopted from "Perspective: Plant Biology – A Quiet Pioneer" from Machi F. Dilworth in *Plant Biotechnology*, 26:183-7, complemented by *Lab Times*.

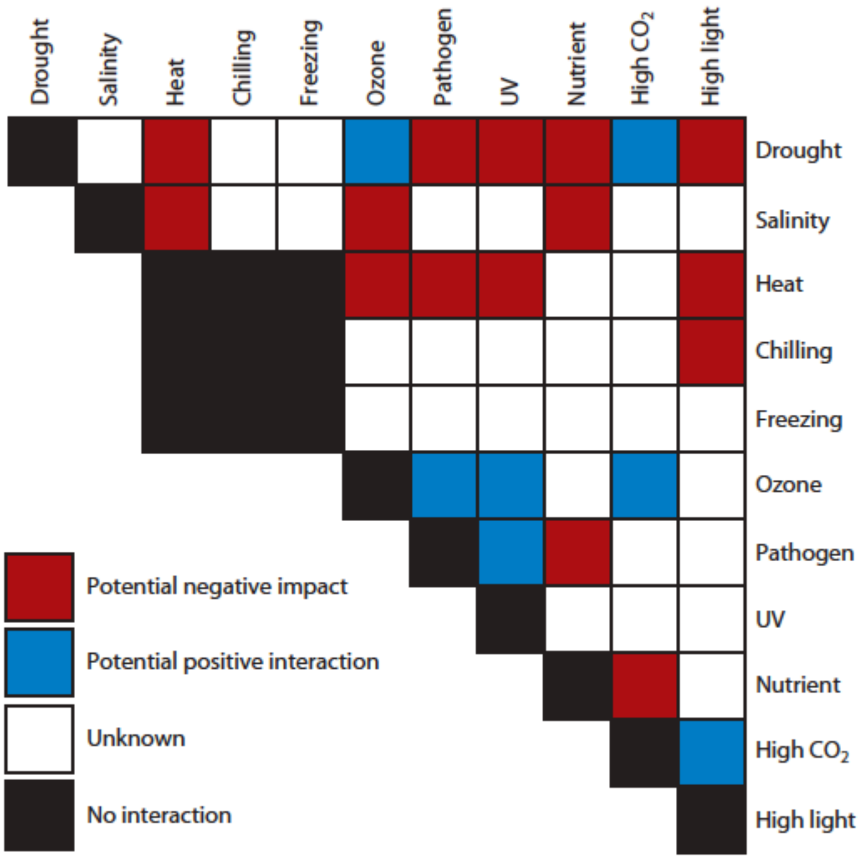


Many traits that are of interest to plant scientists and breeders can be investigated in model plant systems

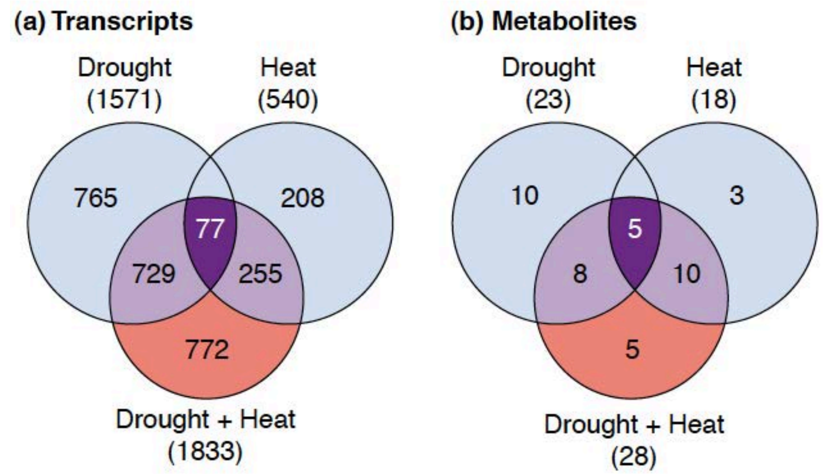
- Drought (including surrogates)
- Low Nitrogen (including surrogates)
- Cold and Freezing
- Heat (all stages)
- Light (e.g., shade tolerance)
- UV tolerance
- Photosynthetic efficiency
- Low pH and aluminum
- High pH
- Growth rate
- Flowering time
- Stay green and maturity
- Plant architecture
- Fertility
- Organ size
- Stature
- Stalk thickness

- Ozone
- High CO_2
- High Nitrogen
- Carbon/Nitrogen
- Seed morphology
- Biotic, fungal
- Composition
    - seed oil
    - seed protein
    - lignin
    - sterols
- and others

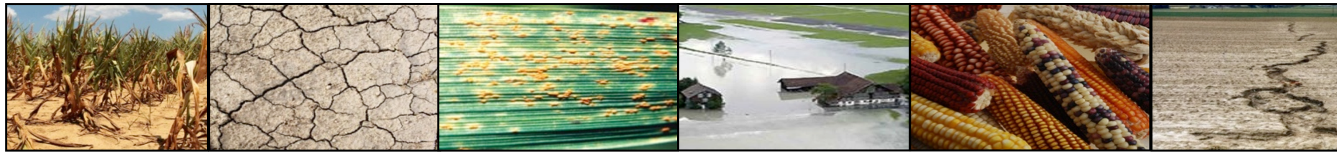
The combinatorial effect of stress on plant growth and development remains largely unknown



Mittler and Blumwald (2010) Ann Rev Plant Biology 61: 443-462



Mittler (2006) Trends in Plant Science 11: 15-19



Rising CO_2 levels and global climate change do not have the expected positive effect on yield increases for most crops

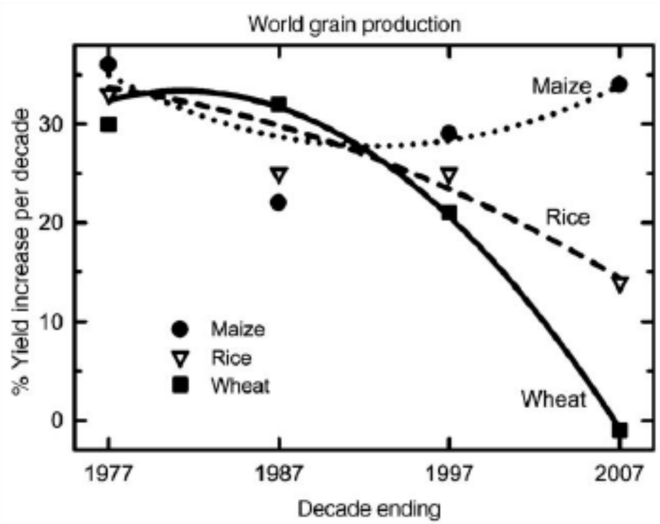


Table 1

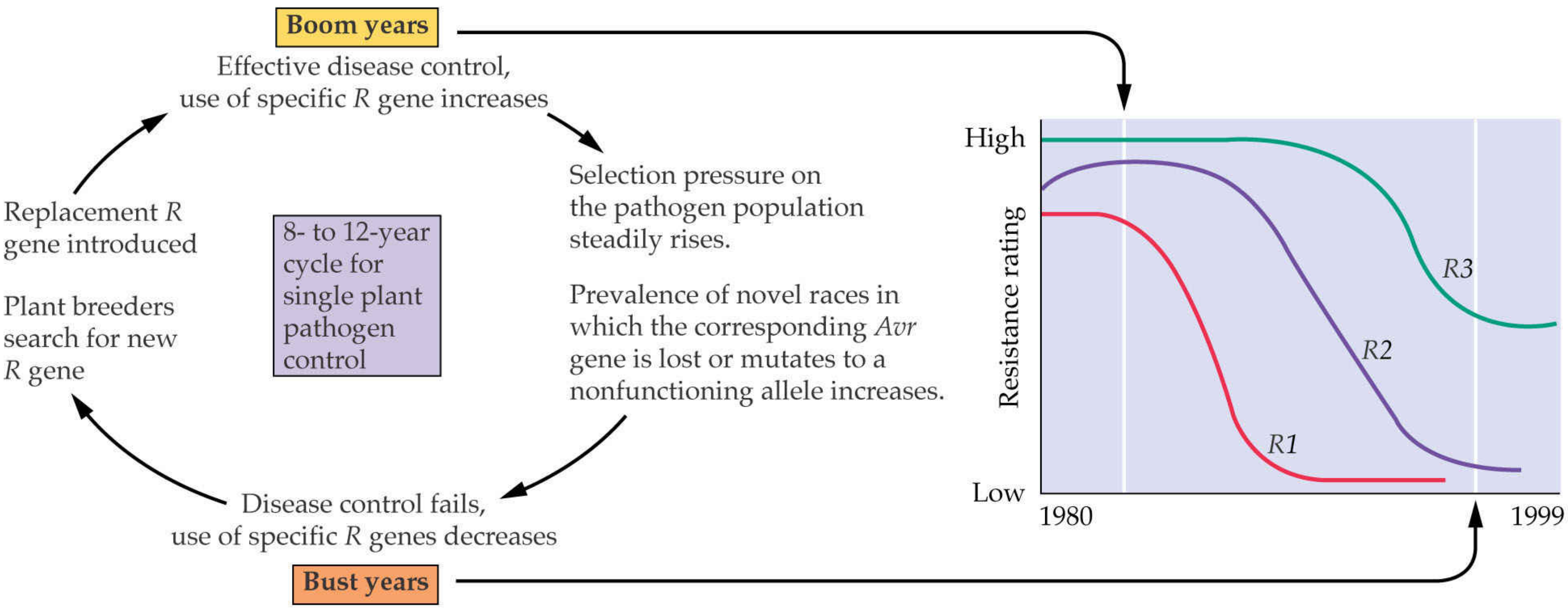
Summary of expected effects of atmospheric and climatic change on yields of our major grain crops, outlining caveats including possible interactions between temperature, water and atmospheric composition

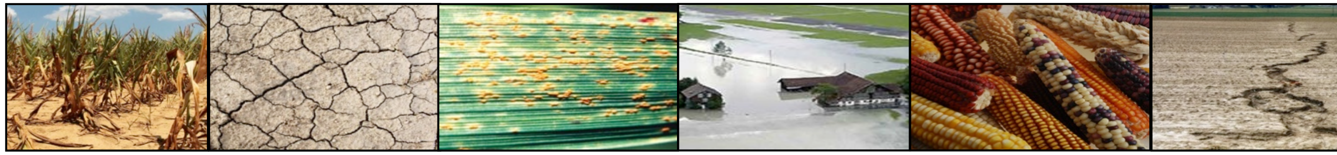
Atmospheric variable	Yield	Caveats
Increased temperature (high latitudes[a])	↑↑	↓Optimal climate zones will move onto suboptimal soils ↓Daylength will complicate adaptation to higher latitudes ↑Rising CO_2 may amplify effect of increased temperature in C_3 crops
Increased temperature (low latitudes)	↓↓↓	↓↓Exacerbate drought by increasing evapotranspiration ↓↓Increased probability of lethal high temperature events ↓Will increase probability of damaging ozone events ↑Rising CO_2 will offset increased photorespiration
Drought (high latitudes)	↓	↑Decreased incidence of water logging, allowing earlier harvesting and less interference with farm operations ↑Rising CO_2 will lower evapotranspiration ↓Increased probability of crop failure ↓↓Pollination and grainset could be impaired
Drought (low latitudes)	↓↓↓	↑Rising CO_2 will lower evapotranspiration ↓↓Increased probability of crop failure ↓↓↓Pollination and grainset could be impaired ↓Exacerbates risk of leaves reaching lethal high temperatures
Rising [CO_2]	↑↑↑	↓Observed effect under open field conditions lower than anticipated and little or absent in C_4 crops ↑Partial protection against drought ↑Partial protection against ozone ↑Benefit in decreasing C_3 crop photorespiratory losses, increases with temperature ↓Decreased leaf latent heat loss will increase probability of attaining lethal high temperatures
Overall	??	There have been almost no field scale studies of how temperature, drought and rising CO_2 interact in affecting our major grains. Predictions are based largely on chamber studies which bear almost no resemblance to farmers fields, or on year-to-year variation in climate which fail to include the unprecedented projected future changes in atmospheric composition. As a result, all predictions of future global grain supply have to be viewed as highly tentative

[a] High latitudes, ca. >50° and low latitudes ca. <45°.

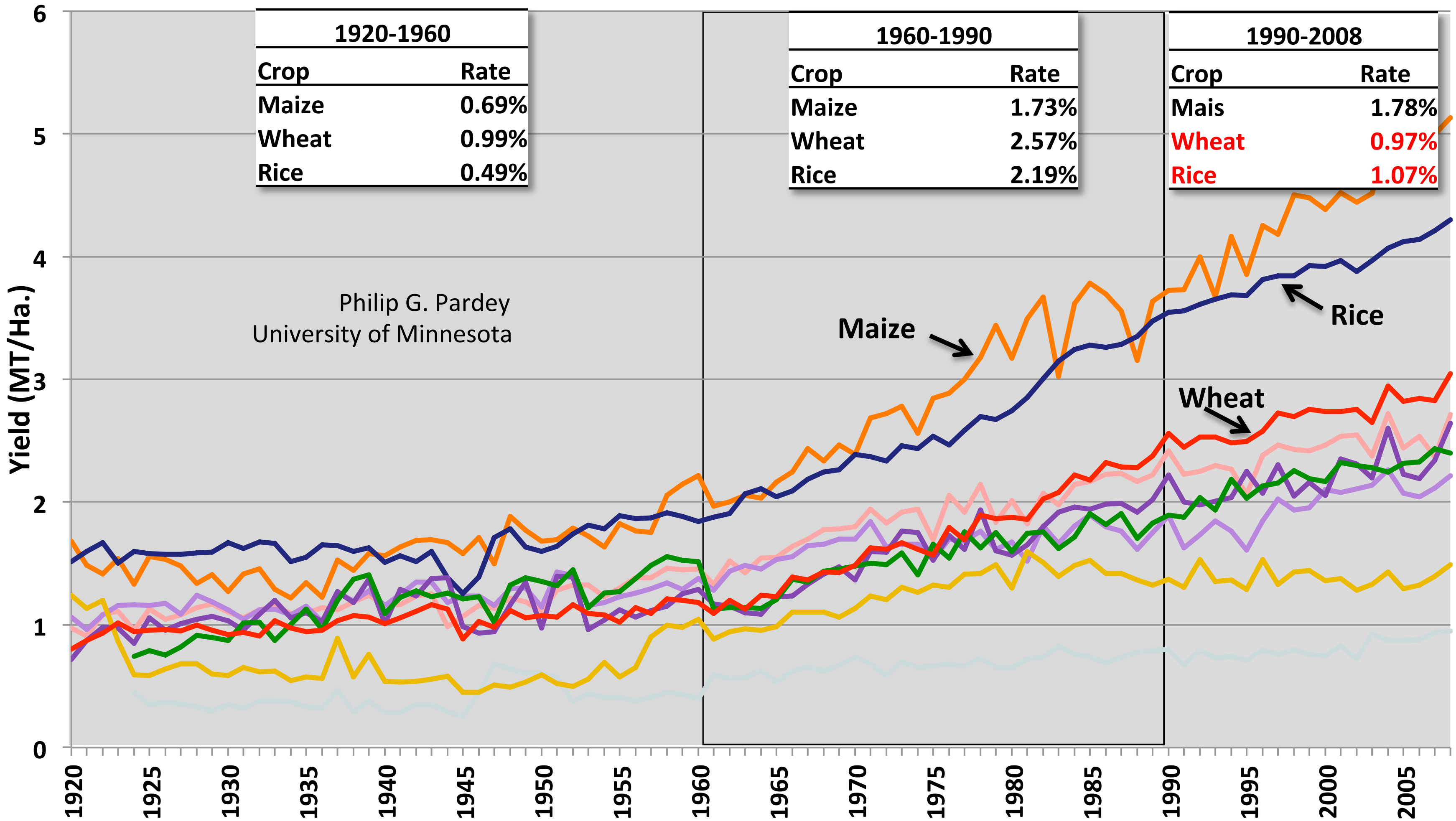
Long and Ort (2010) Curr Opin Plant Biology 13: 241-248

Resistance genes can be bred into crop plants to control disease but this is often not a durable success





Average global crop yield per area is decreasing

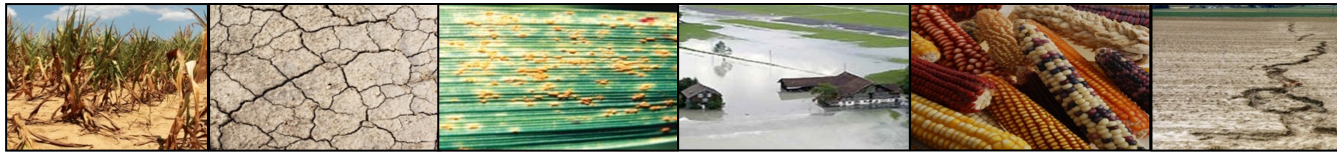


1920-1960	
Crop	Rate
Maize	0.69%
Wheat	0.99%
Rice	0.49%

1960-1990	
Crop	Rate
Maize	1.73%
Wheat	2.57%
Rice	2.19%

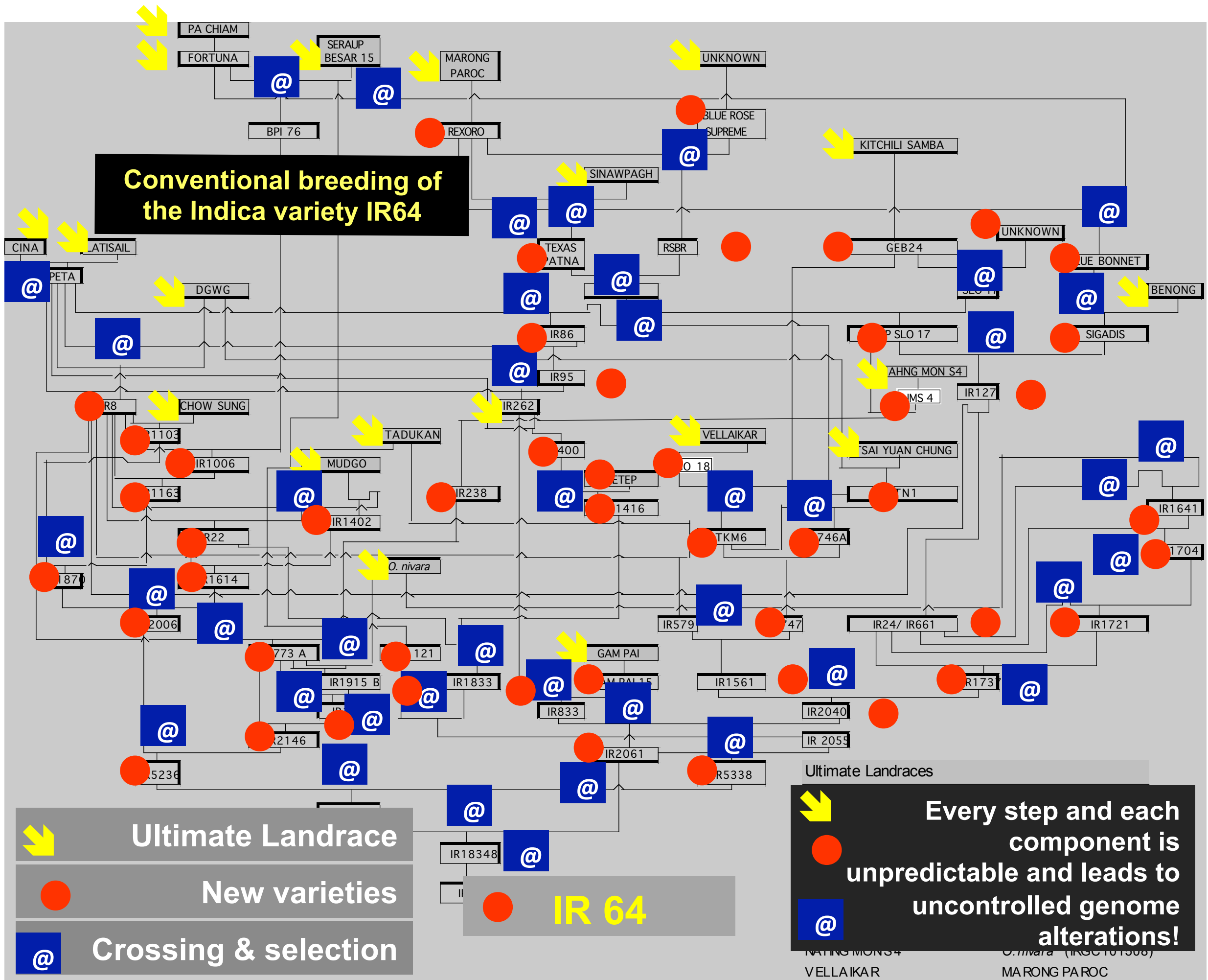
1990-2008	
Crop	Rate
Mais	1.78%
Wheat	0.97%
Rice	1.07%

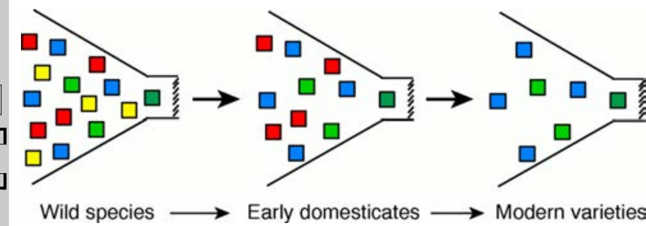
Can we repeat the Green Revolution with less impact on the environment by developing nutrient- and water-efficient crops?



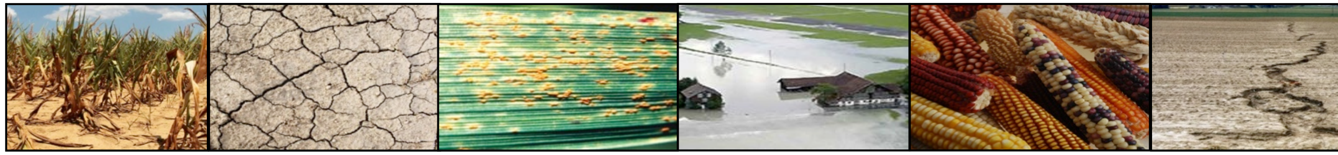
The rice mega-variety IR 64 is a good example of how breeders have shaped crop genomes…

…but at which cost?

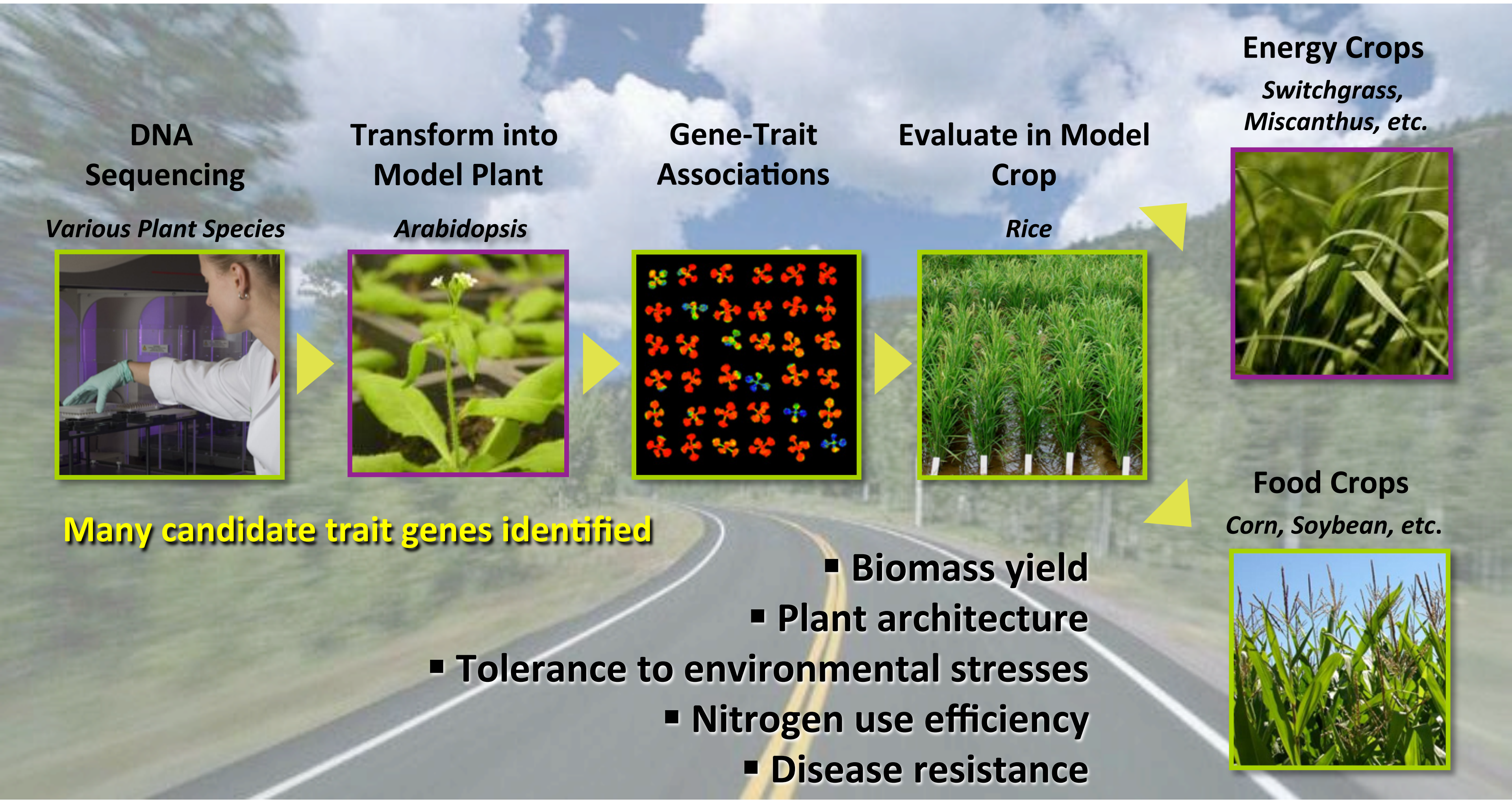




Challenges in Plant Science



We need new methods for rapid candidate trait gene identification and efficient mobilization into breeding programs

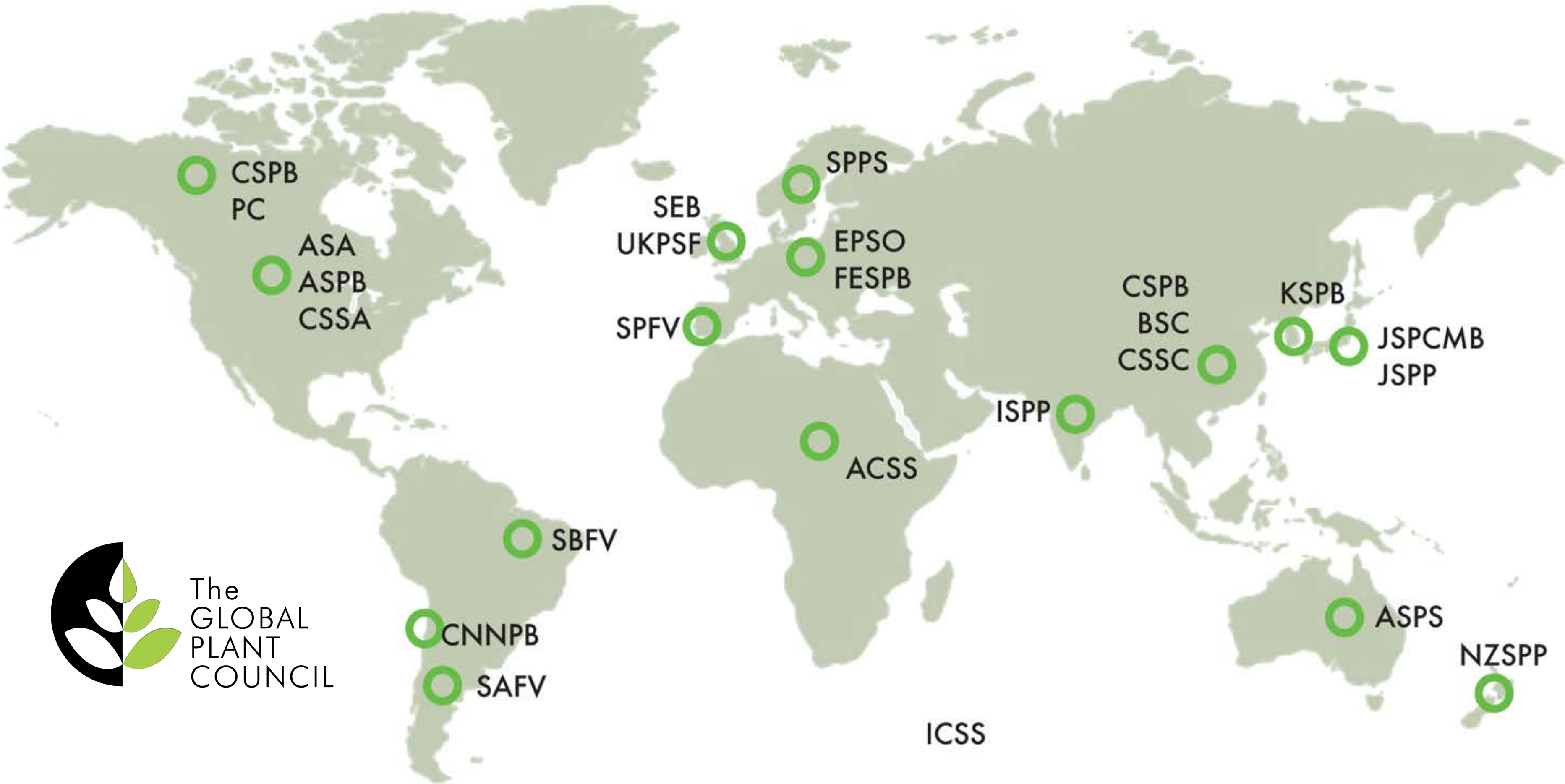


GPC has identified several challenges for which global plant research needs to find solutions

The GLOBAL PLANT COUNCIL

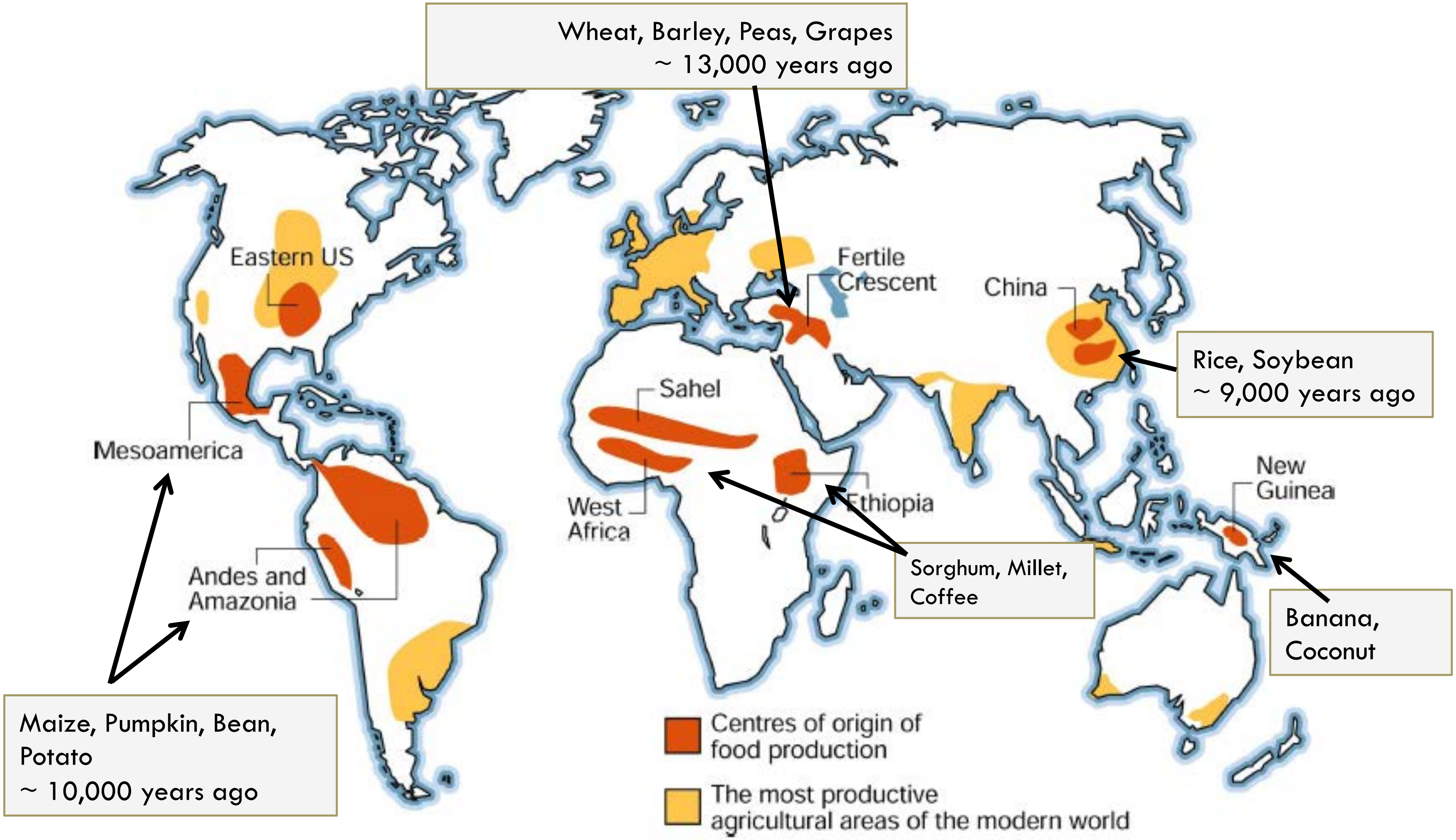
- Digital Seed Bank—utilizing crop biodiversity for accelerated breeding
- Crop biofortification
- Development of perennial crops
- Increasing/enriching agricultural crop species
- Sustainable adaptation
- Yield stability
- Plant-environment metagenome
- Medicinal plant-based products
- Sharing Data, Information and Resources

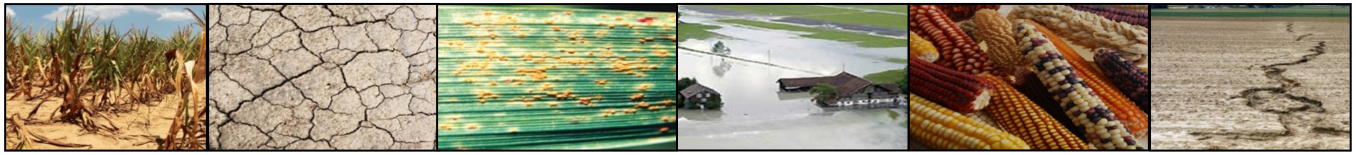
The GPC is a coalition of 28 plant and crop science societies to promote plants for solutions to global challenges



The GLOBAL PLANT COUNCIL

Our crops have specific origins of cultivation and diversity, but today they are utilized globally





Only three cereal crops deliver nearly 60% of the global calories

Most important crops for food and feed calorie supply

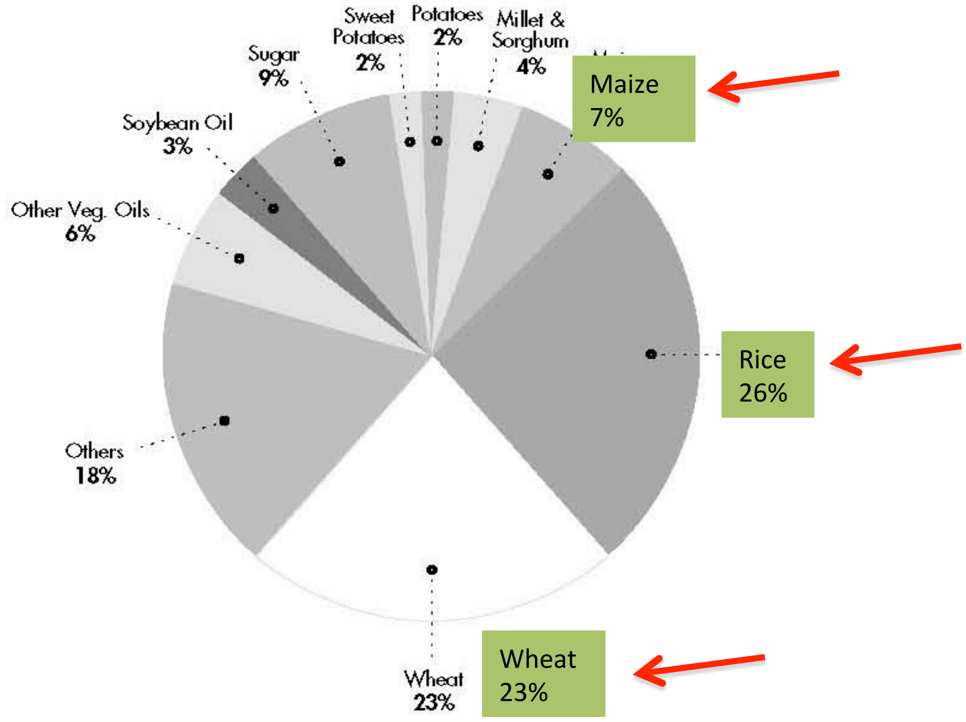


Figure 1.2

Source: FAO Food Balance Sheets, 1984-1986, Rome (1991)

The Green Revolution greatly improved crop production and food security, but also decreased crop diversity

THE HINDU

Home News Opinion Sport Business Arts Life & Style S & T Education Health

INTERNATIONAL NATIONAL STATES THE INDIA CABLES THE PAKISTAN CABLES

NEWS » STATES » KARNATAKA

MYSORE, April 6, 2012

From 1,10,000 varieties of rice to only 6,000 now

Year	High-yielding varieties in %	Traditional varieties in %
66-67	3	97
68-69	41	59
70-71	50	50
72-73	54	46
74-75	61	39
76-77	68	32
78-79	72	28
80-81	77	23
1981	80	20

Spreading monoculture is a potential threat to food security

- Rice diversity is decreasing

  - in 1986, the single rice variety “IR36” was grown on 11 million hectares in Asia
  - in China, all rice F1 hybrids grown on 15 million hectares share the same male sterility genes
  - all modern rice varieties have the same dwarfing gene

- Wheat diversity is decreasing

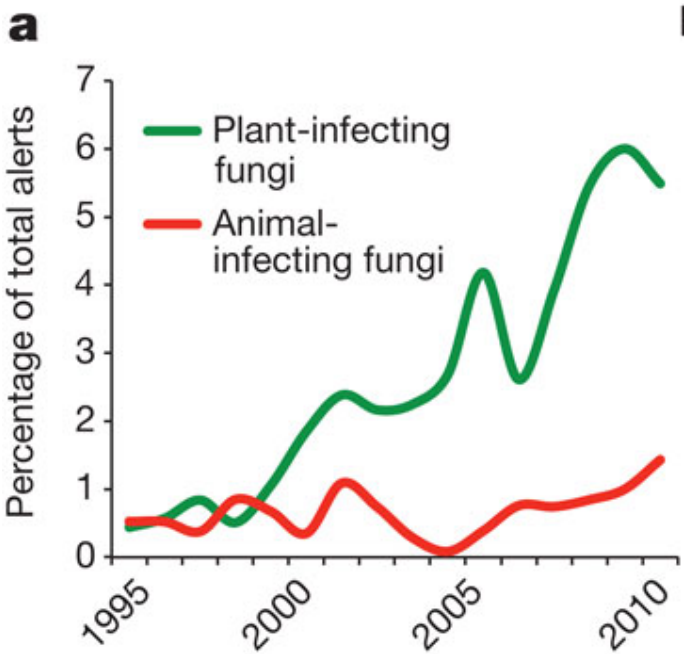
  - in 1983, 67% of the wheat fields in Bangladesh were planted to a single variety
  - in Ireland, 90% of the total wheat area is planted to six varieties
  - in 1949, China used over 10,000 varieties for production, in 1970 on 1,000 remained in use

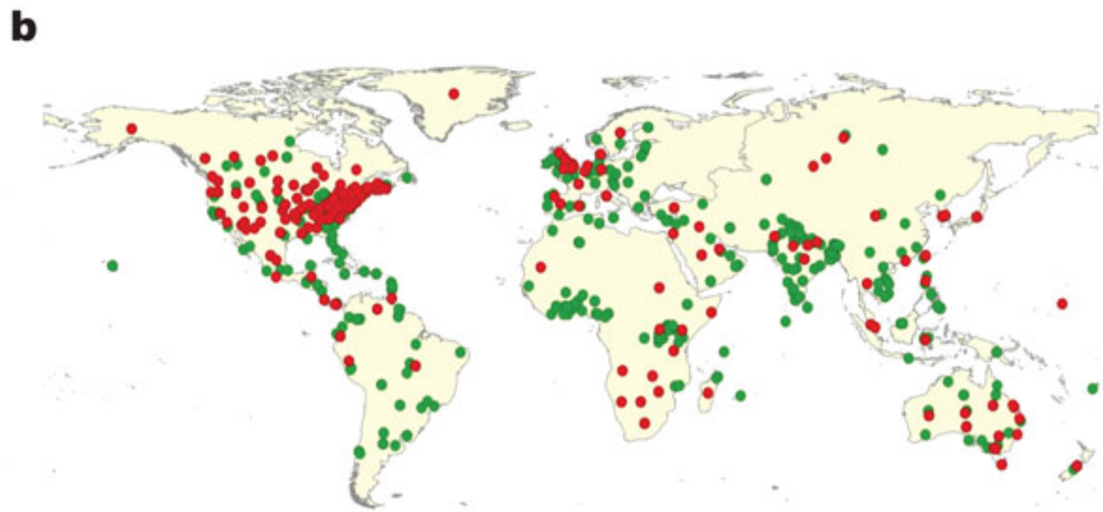
- Diversity of other crops is decreasing

  - in the Netherlands, for example, the three top varieties of nine major crops covered from 81 to 99% of the respective areas planted.
  - one cultivar accounted for 94% of the spring barley planted

Source: FAO

Monocultures favor the spread of increasingly virulent pathogens



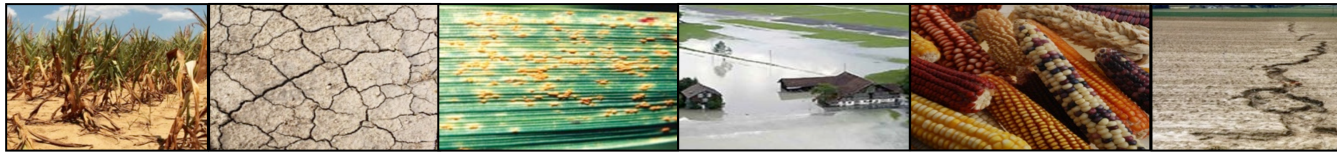


Emerging fungal threats to animal, plant and ecosystem health

Matthew C. Fisher, **Daniel. A. Henk**, **Cheryl J. Briggs**, **John S. Brownstein**, **Lawrence C. Madoff**, **Sarah L. McCraw** & **Sarah J. Gurr**

Affiliations | **Contributions** | **Corresponding authors**

Nature **484**, 186–194 (12 April 2012) | doi:10.1038/nature10947



The International Rice Gene Bank Collection is a rich source of resistance alleles to fight the devastating rice blast disease

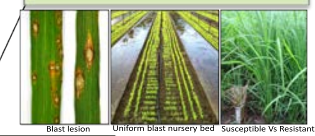
- IRGC-International Rice Genebank Collection
- World's largest collection of rice germplasm
- Over **112,000** registered accessions
- from **117** source countries

We are using this source of rice accessions for allele mining

Rice germplasm accessions from IRRI rice gene bank

Genotypic screening for blast R genes using molecular markers

Phenotypic screening for blast resistance using various *M. grisea* isolates



Resistant genotypes with novel R alleles

Sequence based allele mining; Isolation of candidate genes

Sequencing and identification of allelic variants

Molecular evolution and co-evolutionary relationship of R & AVR gene system

Functional validation of identified R genes/alleles

Molecular basis of resistance and rice-blast fungus interactions

Novel & potent blast resistant genes/ alleles identified.
Introgression into breeding programs

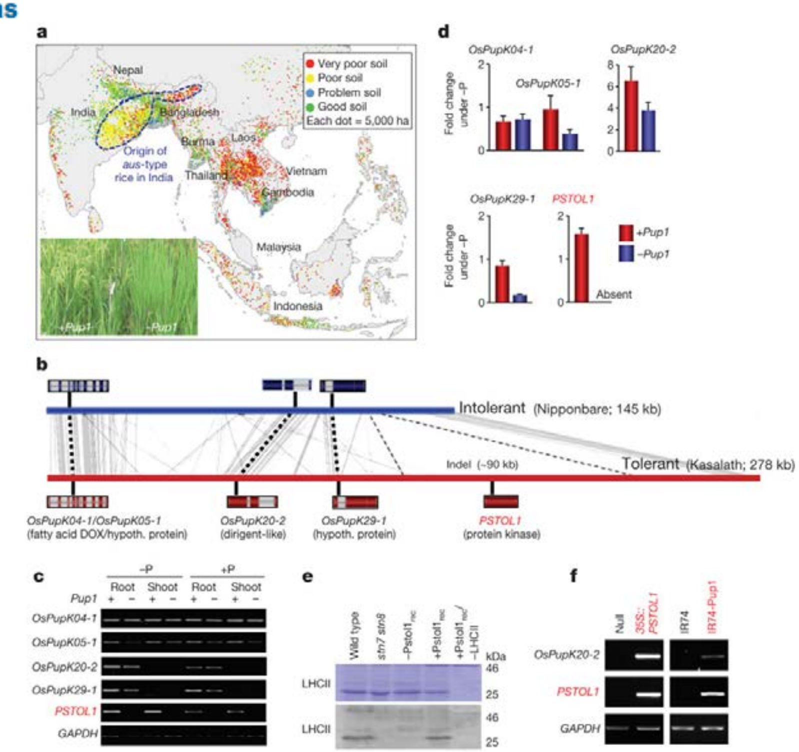
The Kasalath PSTOL1 gene is a good example of genes present in diverse rice varieties but not in elite mega-varieties

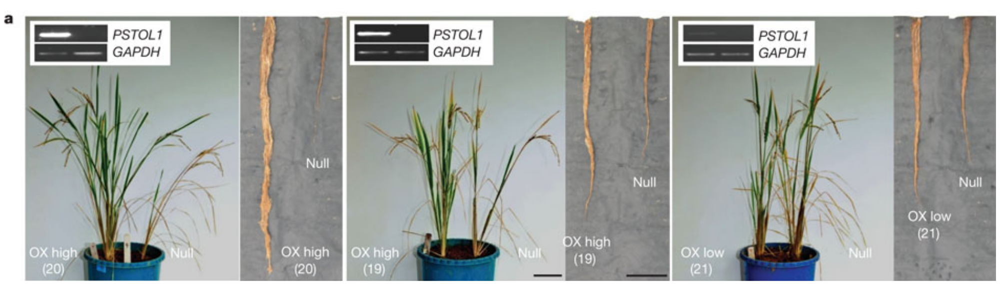
The protein kinase Pstol1 from traditional rice confers tolerance of phosphorus deficiency

Rico Gamuyao, Joong Hyoun Chin, Juan Pariasca-Tanaka, Paolo Pesaresi, Sheryl Catausan, Cheryl Dalid, Inez Slamet-Loedin, Evelyn Mae Tecson-Mendoza, Matthias Wissuwa & Sigrid Heuer

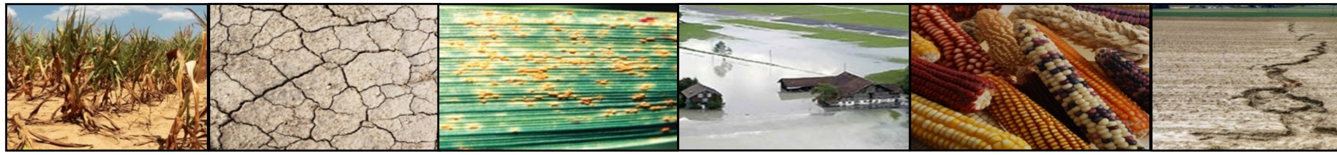
Affiliations | Contributions | Corresponding author

Nature **488**, 535–539 (23 August 2012) | doi:10.1038/nature11346

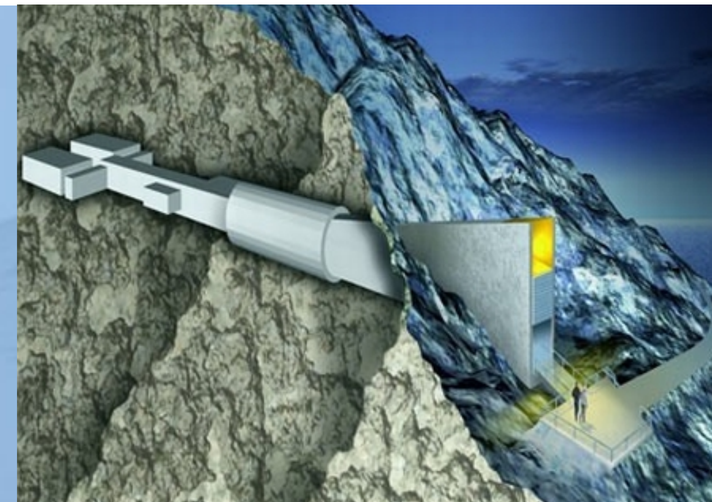




Seed banks are treasure troves of genetic diversity and novel genes/alleles that we must explore for breeding resilient crops



Storing crop germplasm in the Svalbard Global Seed Vault is a step in the right direction, but how useful is this for future breeding?



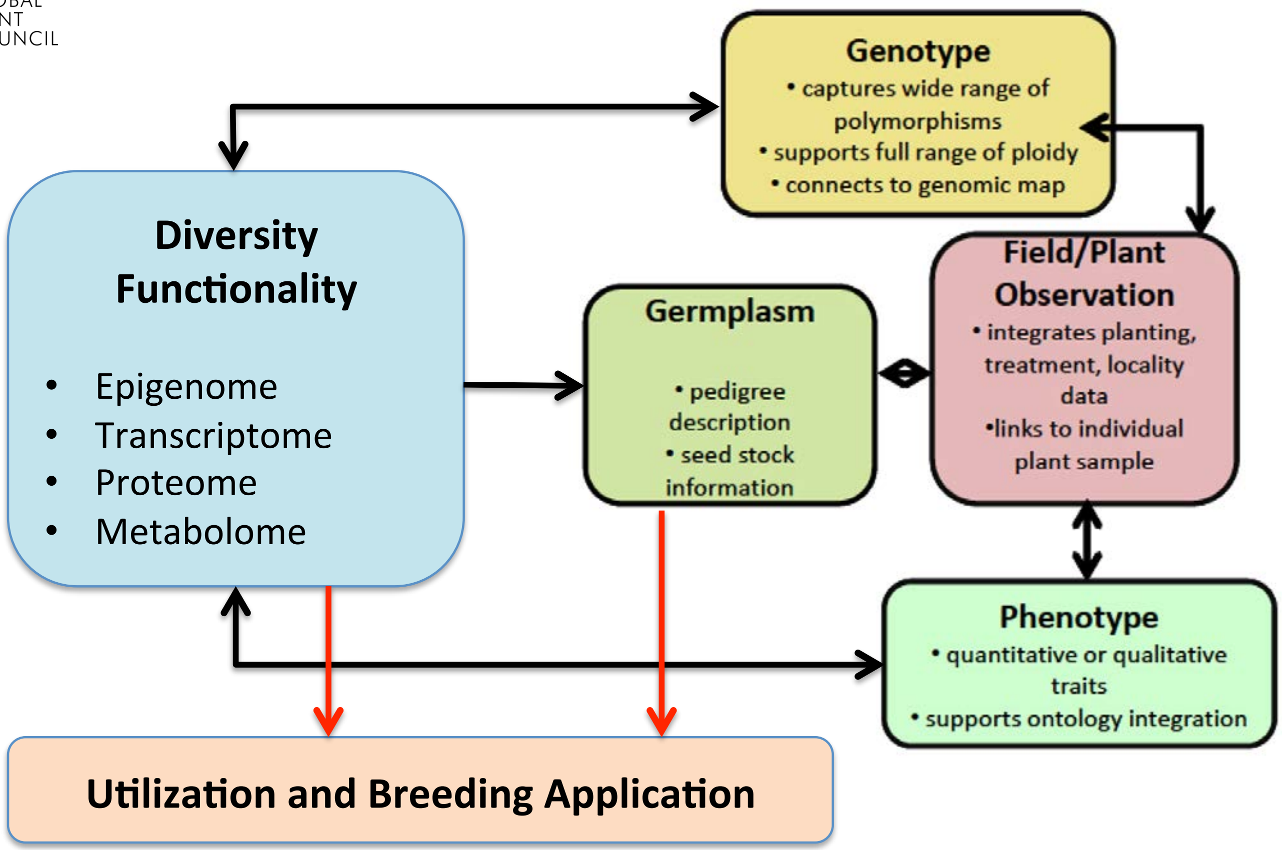
The Digital Seed Bank and Div*Seek* will link Gene Banks with utilization of crop diversity and breeding applications

The GLOBAL PLANT COUNCIL

Digital Seed Bank

Div*Seek*

GLOBAL CROP DIVERSITY TRUST
A FOUNDATION FOR FOOD SECURITY



Why build the Digital Seed Bank?

Advantages:

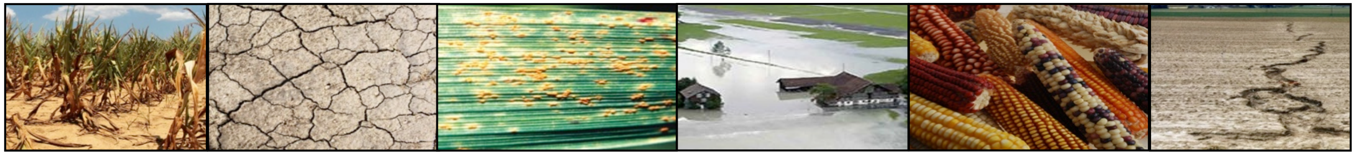
- Provides unprecedented information for development of novel breeding strategies
- Can be built jointly by expert centers around the world with currently available technologies
- Links molecular and biochemical information to genotype and phenotype information (e.g., SNP to gene expression and epigenetic allele status)
- Establishes a quantitative understanding of genes and networks that underlie crop biodiversity
- Facilitates the molecular and biochemical understanding of quantitative trait expression
- Allows cross-species comparison of molecular and biochemical networks responding to e.g., environmental stress to identify common and specific regulatory mechanisms
- Data can be used in e.g., large-scale metabolic modeling for prediction and testing of emergent crop properties

Disadvantages:

- Restricted sampling (1,000 diverse accessions of selected crops, e.g., cassava, maize rice, wheat)
- Data collection restricted to organs, developmental stages

Challenges:

- Standardization of methods, (meta) data types and curation, statistical analyses, ontologies, database management
- Integrated data analysis (works for genotype X epigenome X gene expression X proteins, but still difficult for metabolites because of redundancies)




Thank you for your attention.