



# Climate Change and Agriculture: Crop Responses to Climate Change

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Crop Systems and Global Change Laboratory



# Outline

- Global Climate Change and it's Impact on Crop Productivity
- Introduction of Crop Systems and Global Change Laboratory and what we are doing
- Future study at Dale Bumpers National Rice Research Center

# Global Climate Change

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- **Increases in greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, etc) due to human activities**
- **Rising temperatures and heat waves**
- **Frequent changes in precipitation patterns and drought intensities**
- **Melting glaciers, and rising oceans and sea-levels**

# Climate change footprint

## Melting glaciers

Arctic Sea Ice  
Annual Minimum  
1979



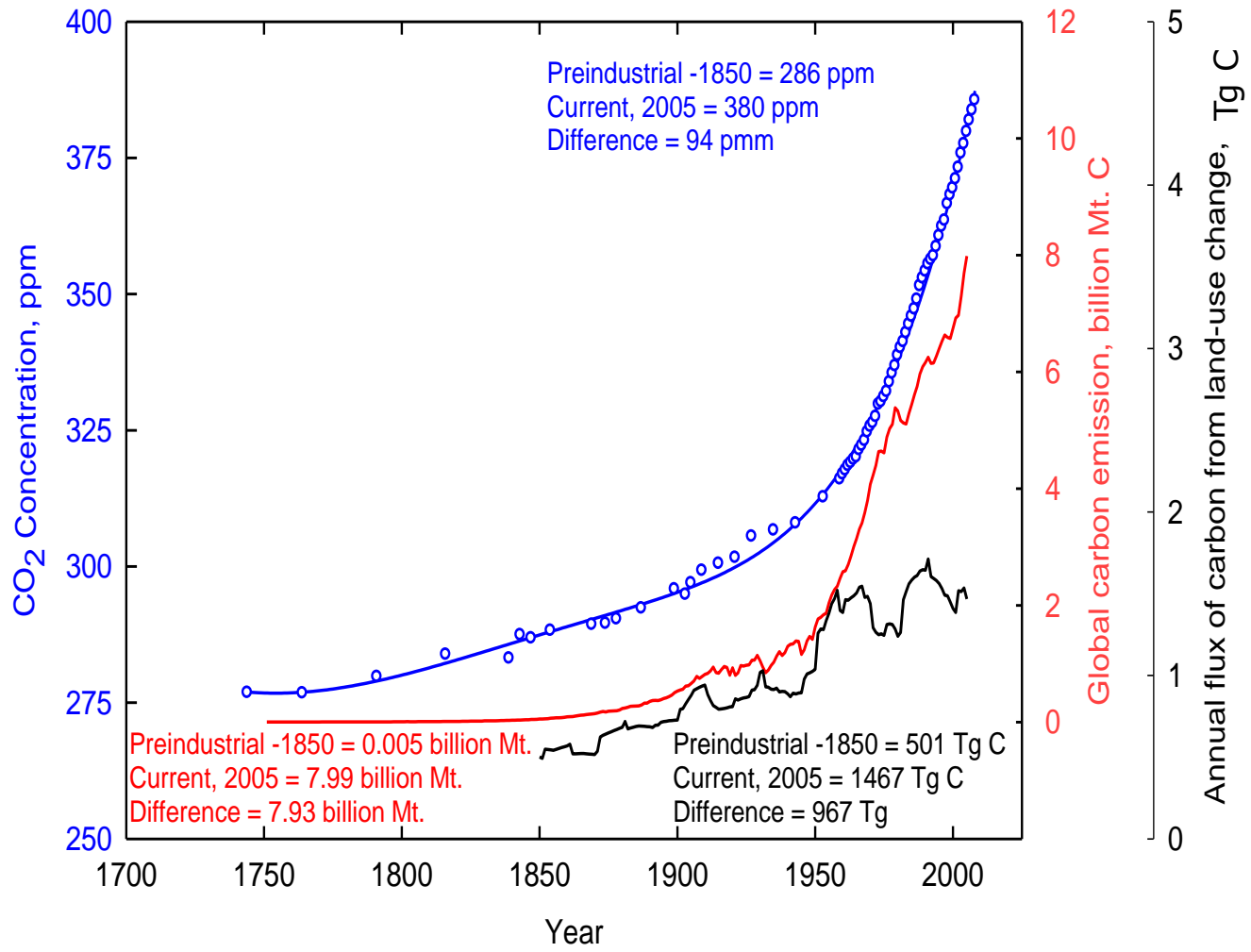
2007



Satellite passive microwave data since 1970s indicate a **3% decrease per decade in arctic sea ice extent**

# Climate change footprint

## Global carbon emissions and fluxes

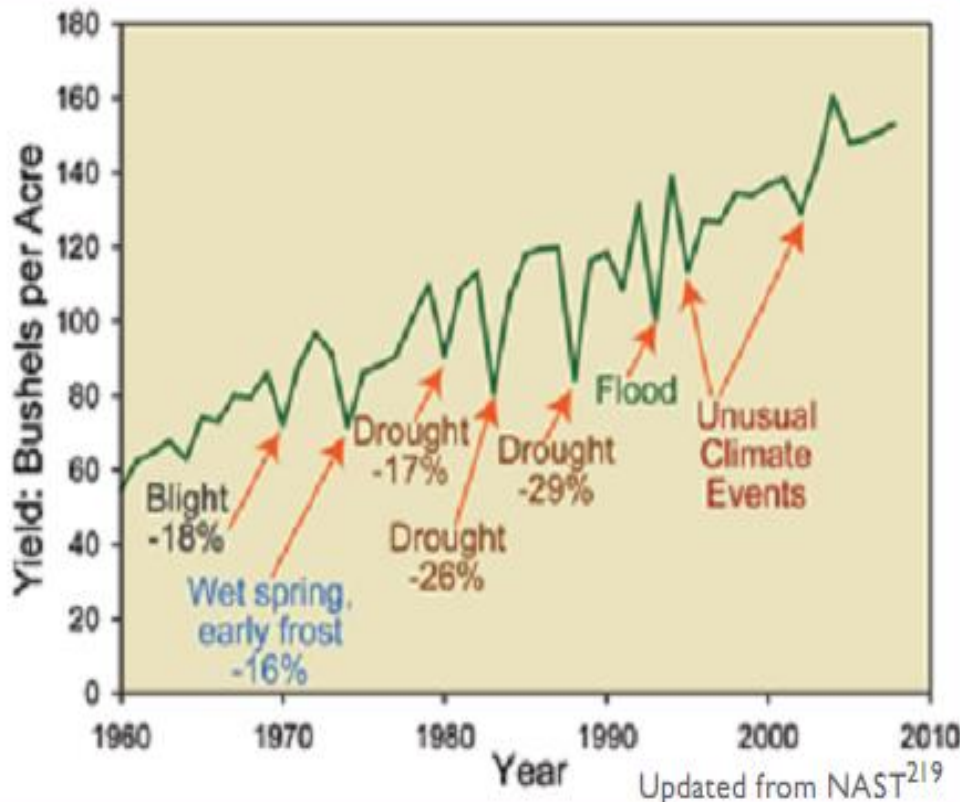


**Rapid increase  
in CO<sub>2</sub> conc.  
since the  
onset of  
industrialization**

# Climate change footprint

## Changes in crop yields

U.S. Corn Yields 1960 to 2008



While technological improvements have resulted in a general increase in corn yields, **extreme weather events have caused dramatic reductions in yields in particular years**

# Climate change footprint

## Weed management

Herbicide Loses Effectiveness at Higher CO<sub>2</sub>



*Photo by Lewis Ziska*

**Prosperities of weed growth under the elevated CO<sub>2</sub> condition.** Weeds in a plot grown at ambient CO<sub>2</sub> (L, 380 ppm), and elevated CO<sub>2</sub> (R, 680 ppm). Both plots were equally treated with herbicide at the recommended dosage.

# Climate change footprint

High temperature effects on Cotton



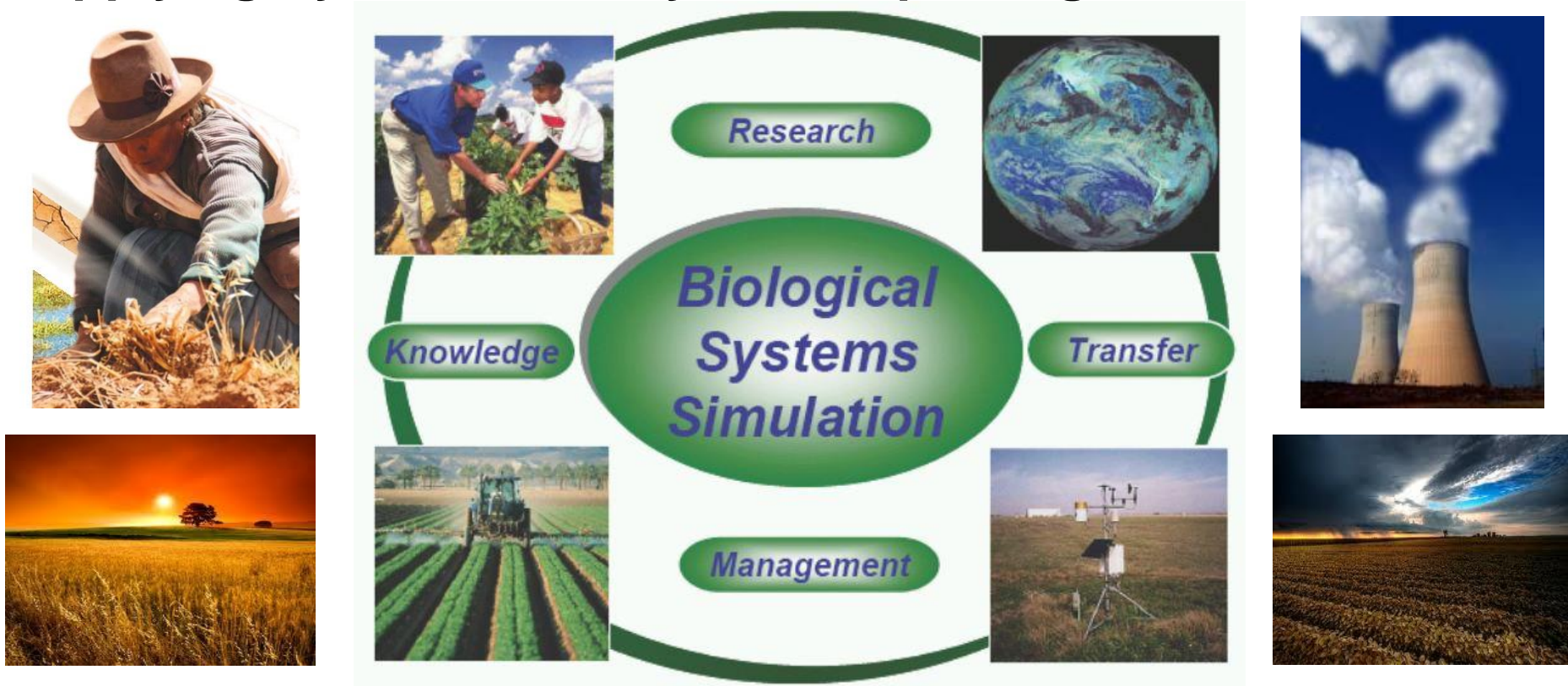
Heat-blasted Flower Buds and Flowers, San Joaquin Valley, California, USA

# Crop Systems and Global Change Laboratory (CSGCL)



# Mission in the CSGCL

## Applying Systems Theory to Complex Agricultural Problems



- Predicting Consequences of Global Environmental Change
- Adapting Crops and Management Strategies to Global Environmental Change
- Improving Crop Management Decision Making

# Crop Systems & Global Change Lab

## CRIS PROJECTS:

- Response and adaptation of Crops and Weeds to Elevated CO<sub>2</sub> and Global Warming (NP # 212)
- Mechanistic Process-Level Crop Simulation Models for Assessment of Agricultural Systems (NP # 212)

Scale		Level	Growth Condition	Approach
Micro ↓	Molecular Biology Biochemistry Cell Biology	Cell/Organ	Environmental Growth Chamber (EGC), Soil Plant Atmosphere Research (SPAR)	
	Physiology Genetics	Plant	EGC, SPAR, Open Top Channel (OTC), Free Air CO <sub>2</sub> Enrichment (FACE)	
Macro	Environmental Biology Population Biology Ecology	Population	FACE	

▪ **Applied Science (simulation model)**

*Barnaby and Ziska (2012)*

# Environmental Growth Chamber (EGC)

## Control features:

- Air temperature
- Light intensity
- Photoperiod
- Irrigation

## Monitoring features:

- Air and soil temperature
- Relative humidity
- Light intensity



Can control all the factors and study the direct effect of a factor interested

**Pro: can determine the DIRECT EFFECT of the phenotype**

# Free Air CO<sub>2</sub> Enrichment (FACE)



Hard to predict the direct reason of the phenomenon, but can predict/anticipate real situations



**Pro: controlled condition is NOT happening in REAL situation**

# Soil Plant Atmosphere Research (SPAR)

## SPAR Chambers

- Use natural sunlight and soil volume
- Control and monitor aerial and soil environments
- Monitor whole canopy gas exchange (Photosynthesis, Respiration, Transpiration)
- Measure gas leakage rates with a  $N_2O$  system to maintain accuracy
- Facilitate study of
  - Entire crop growth season
  - Root and canopy growth and development
  - Source-sink relationships
  - Assimilate partitioning
  - Physiological responses to various environmental variables

## Control features:

- Air temperature between 10 – 45 ° C
- Atmospheric  $CO_2$  concentration between 350 – 1500  $\mu mol\ mol^{-1}$
- Humidity
- Irrigation / Fertigation

## Monitoring features:

- Air, canopy, and soil temperature
- Atmospheric  $CO_2$  concentration
- Relative humidity
- Solar radiation
- Photosynthesis
- Evapotranspiration
- Respiration
- Soil moisture

## Other features:

- Canopy shade-cloth
- Root imaging and tracing

## Daylits



## Soilbins



## Root and soil measurements

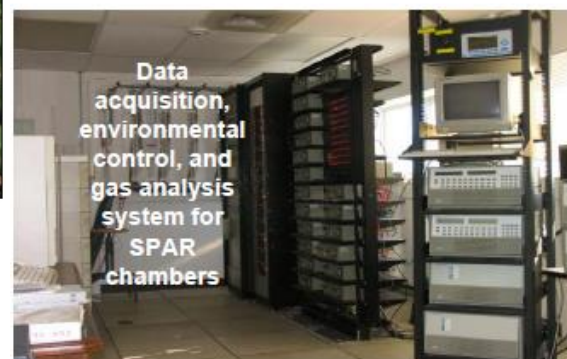


All photos were taken at Beltsville, USDA



Drs. Sicher (Right) and Timlin (Left)

Data acquisition, environmental control, and gas analysis system for SPAR chambers



Pro: combined NATURAL + CONTROLLED conditions

# CSGCL Field Sites

## Catoctin

Examining the impact of light, nitrogen and herbivory on native and invasive species (Japanese stiltgrass) competition.



## South Farm

2 FACE (Free Air Carbon dioxide Enrichment) systems to study CO<sub>2</sub> increases in field plots.



## North Farm

Evaluate impact of plastic culture on the growing season of the field grown strawberries in the mid Atlantic states.



# CSGCL Specialized Equipment

## South Farm

6 Large open top chambers  
12 Small open top chambers



## Controlled Environment Facility

Multiple Indoor Artificially Lit Growth Chambers



## SPAR Unit

12 Soilbin Chambers  
6 Chambers without soilbin



# Crop Systems & Global Change Lab

## CRIS PROJECTS:

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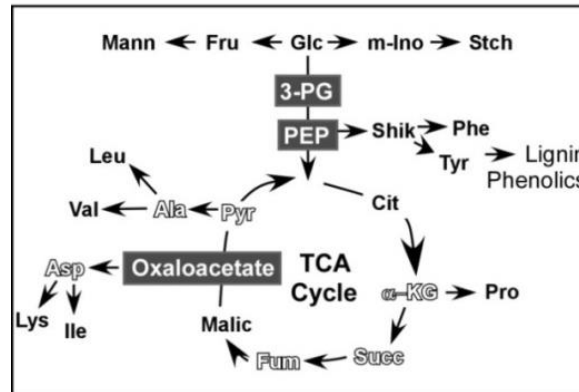
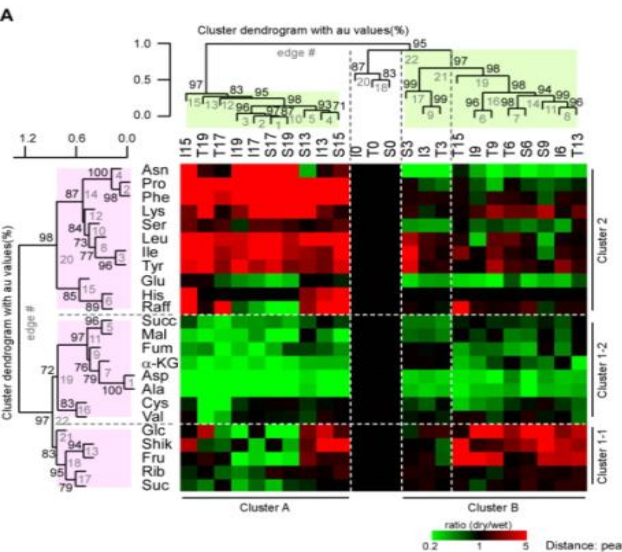
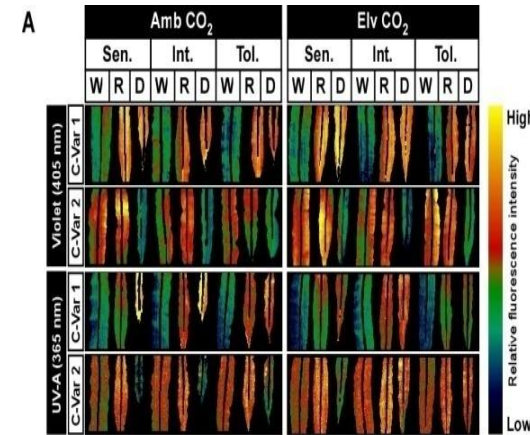
▪ **Applied Science (simulation model)**

*Barnaby and Ziska (2012)*

# Dr. Richard Sicher/Dr. Jinyoung Barnaby

## Molecular Biology/Biochemistry/Plant Physiology

- Response and Adaptation of Crops to Elevated CO<sub>2</sub> and Global Warming at the Molecular and Cellular to Whole Plant Levels
- Characterization of Stress Tolerant Germplasms using Targeted Metabolite/ Transcript Profiling and Phenomics



# Dr. James Bunce/Dr. Lewis Ziska

## Plant Physiology and Ecology

- Response and Adaptation of Crops and Weeds to Elevated CO<sub>2</sub> and Global Warming
- Elevated CO<sub>2</sub> Effects on Crop Responses to Water Stress



- 
- Food Security and CO<sub>2</sub>
  - Climate, CO<sub>2</sub> and Invasive Species
  - Climate, CO<sub>2</sub> and Weed Biology
  - Climate, CO<sub>2</sub> and Public Health



# Dr. Reddy Vangimalla/Dr. Singh Sharendu

## Plant Physiology

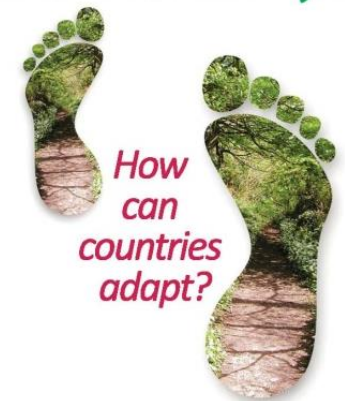
- Mechanistic Process-Level Crop Simulation Models for Assessment of Agricultural Systems
- Development, Validation, and Verification of New Modules for Soybean Model Glycim and Cotton Model GOSSYM
- Response and Adaptation of Crops to Elevated CO<sub>2</sub> and Global Warming



Cooperator	Variety	Grower Irrigated Yield bu/A	GLYCIM Irrigated Yield bu/A	% Change
K. Hood	DPL 415	51	59	14
	HYP 501	*49	58	17
J. Mullens	DPL 105	*48	64	28

\* unirrigated

*Climate Change in Asia and the Pacific*

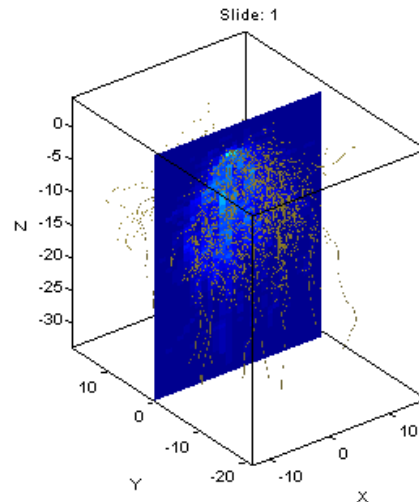
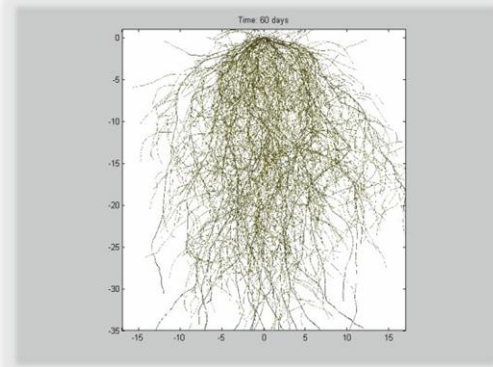


Edited by  
Venkatchalam Anbumozhi  
Meinhard Breiling  
Selvarajah Pathmarajah  
Vangimalla R. Reddy

# Dr. Dennis Timlin/Dr. Kwangmin Kang

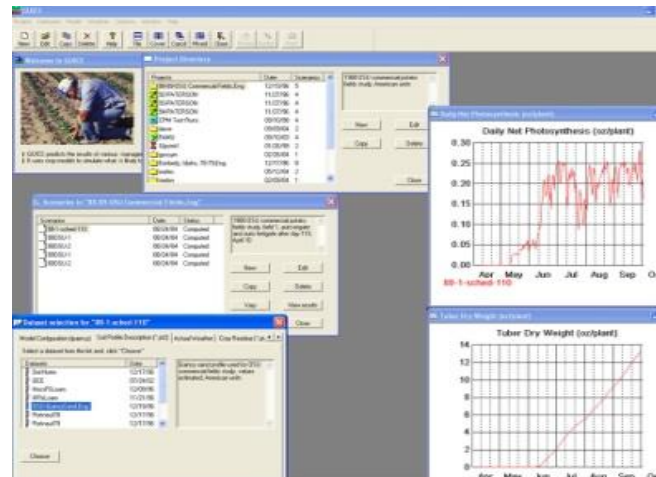
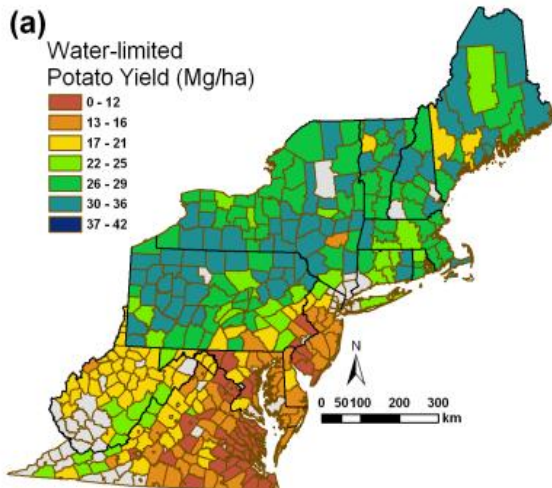
## Soil Science and Modeling

- Development and validation of the maize model MAZSIM
- Response of Corn to Elevated  $\text{CO}_2$  and Global Warming
- Develops Datasets and Improved Modules for Crop and Soil Modeling Systems.



# Dr. David Fleisher/Dr. Denis Mutibwa Engineering and Modeling

- Develop Crop Simulation Models
- Study Crop Genetic x Environment x Management Interactions
- Assess Food Security Concerns using Models
- Study Climate Change Factors on Crop Responses

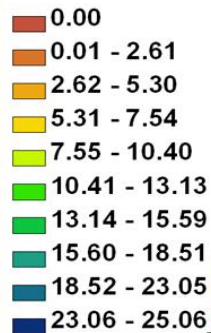


# Simulation of Potential Potato Production in the Northeast US

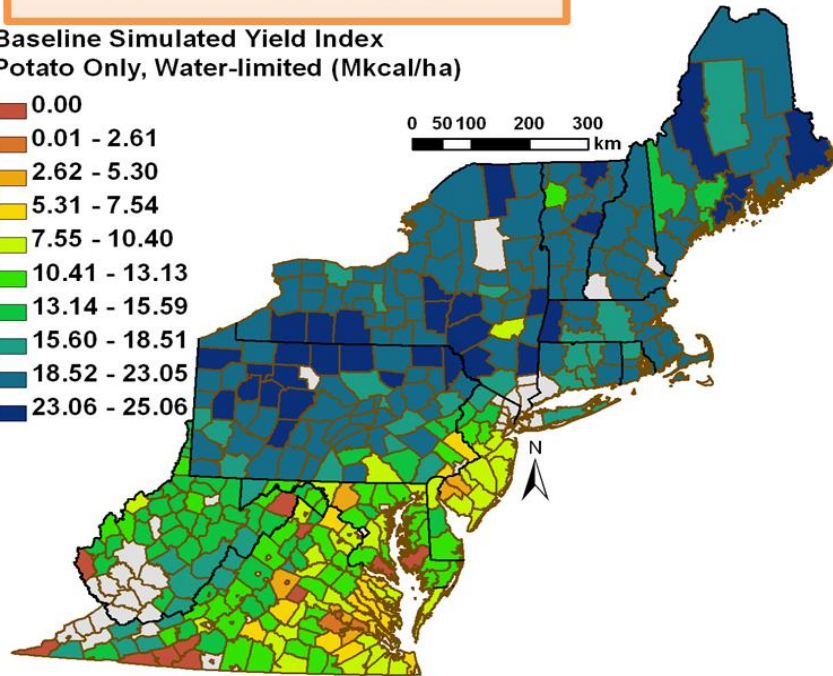
Geospatial crop model implementing the SPUDSIM

## YI - Baseline

Baseline Simulated Yield Index  
Potato Only, Water-limited (Mkcal/ha)



0 50 100 200 300 km

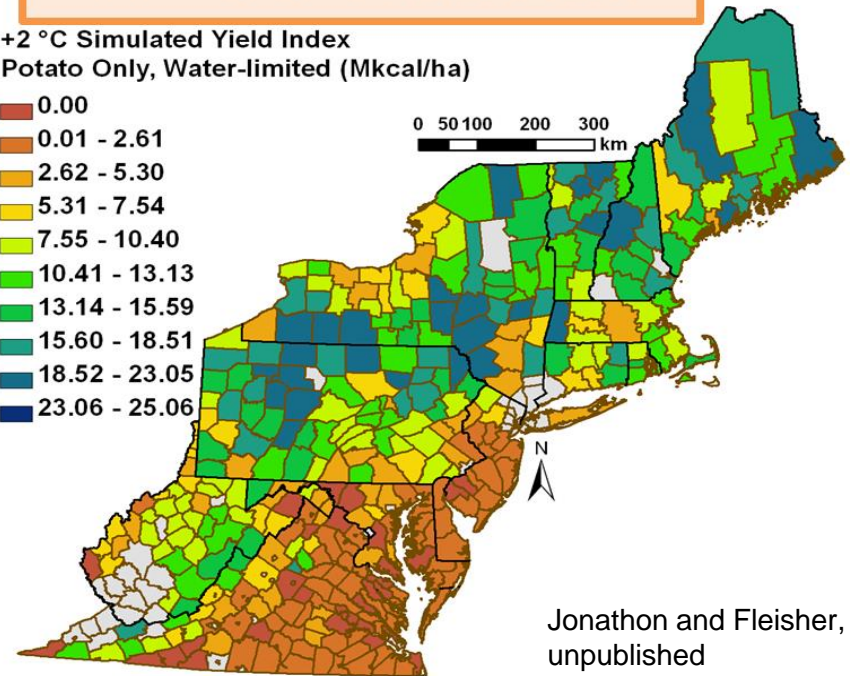


## YI - CC Scenario

+2 °C Simulated Yield Index  
Potato Only, Water-limited (Mkcal/ha)



0 50 100 200 300 km

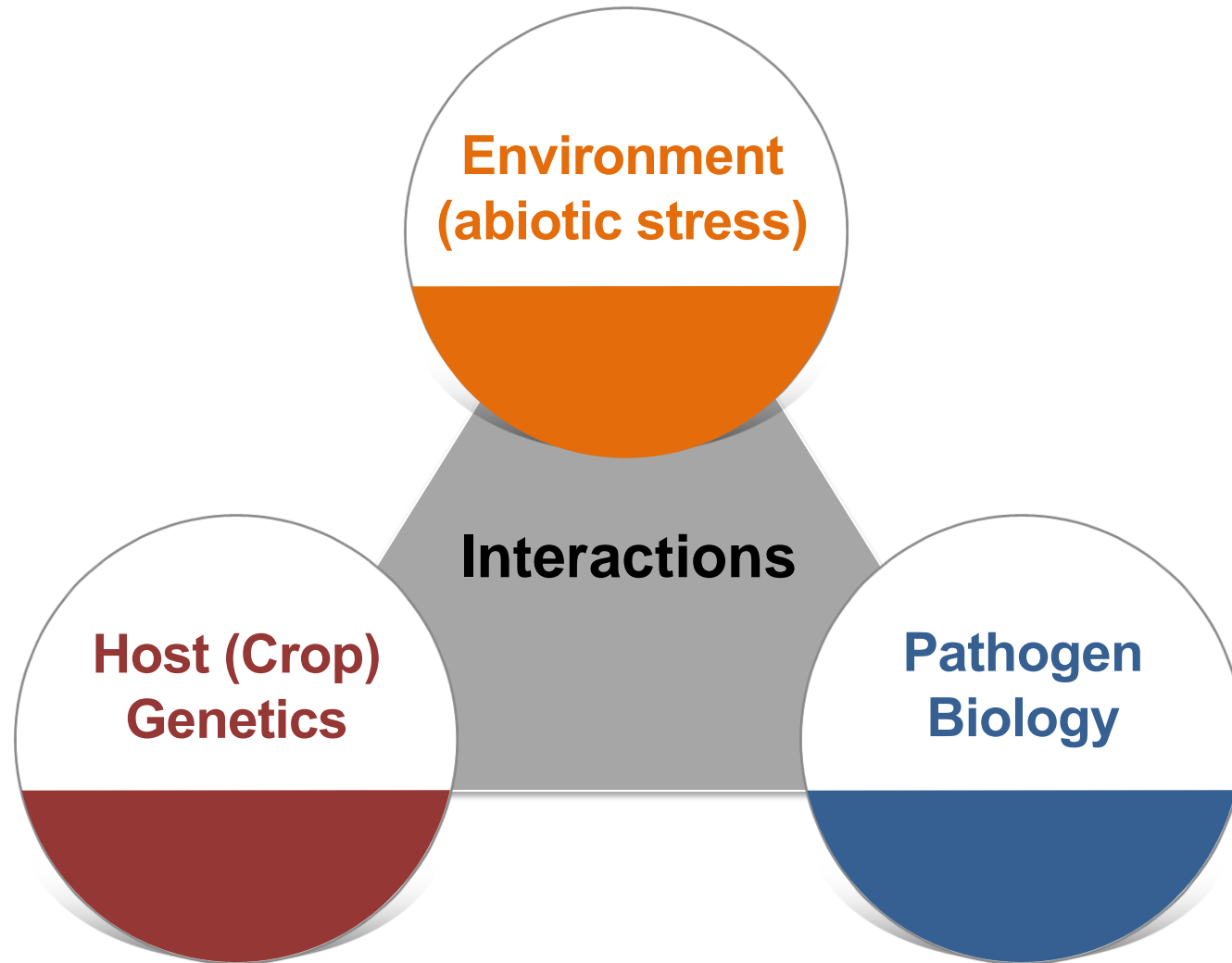


Jonathon and Fleisher,  
unpublished

(Left) current weather conditions and (Right) a hypothetical future scenario where average temperatures have increased by 2 °C

► **Negative effect on potato yield, particularly in the southern region**

# Host-Pathogen-Environment interactions



# Carbon dioxide: Increased photosynthetic stimulation

Here is what happens with added CO<sub>2</sub>



385 ppm



535 ppm



685 ppm



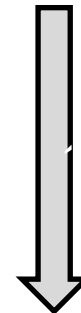
835 ppm

- ▶ Rising CO<sub>2</sub> will affect temperature, plant growth and physiology

# Three corn germplasm differing in drought tolerance

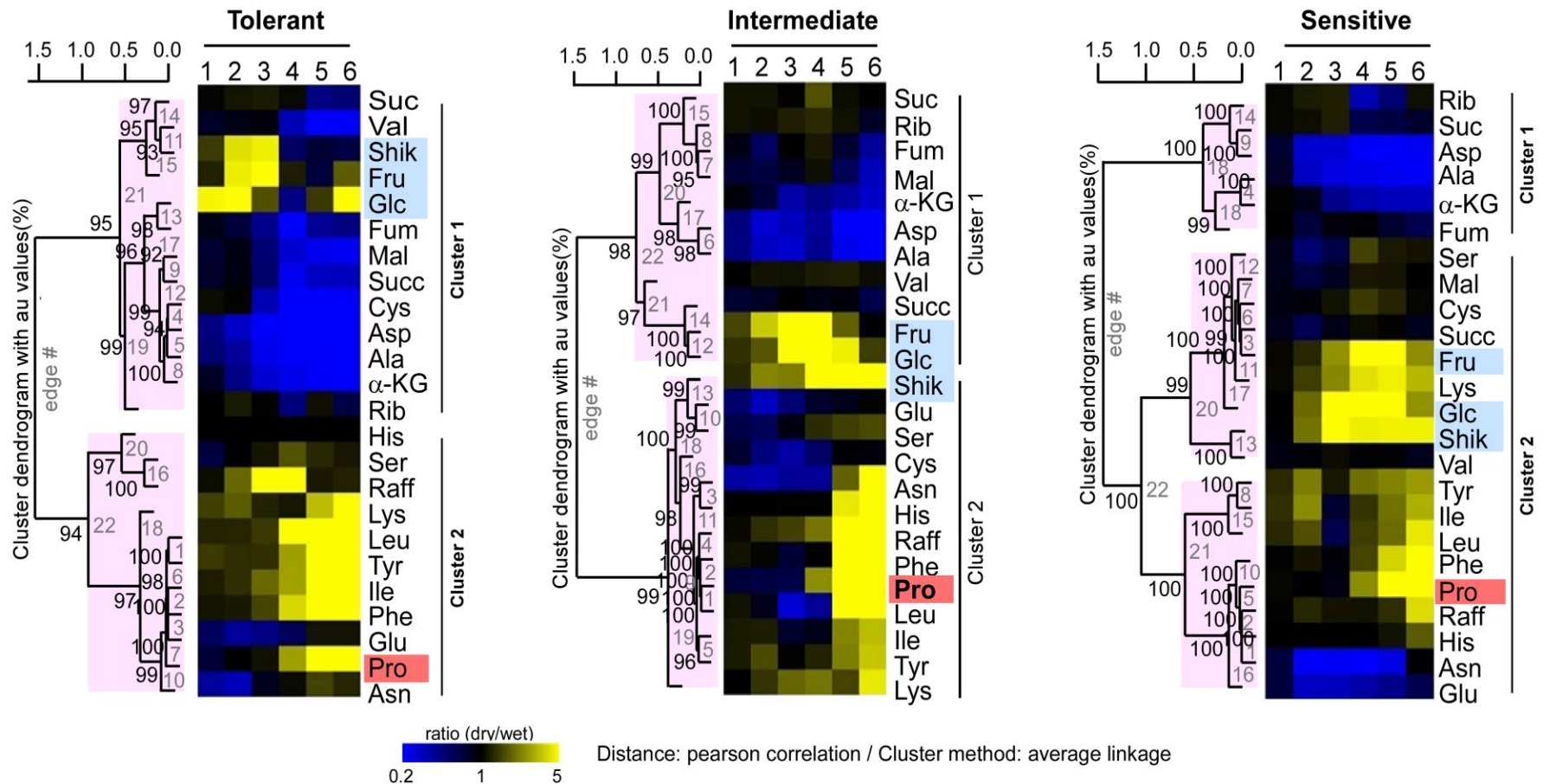


Tolerant	Intermediate	Susceptible
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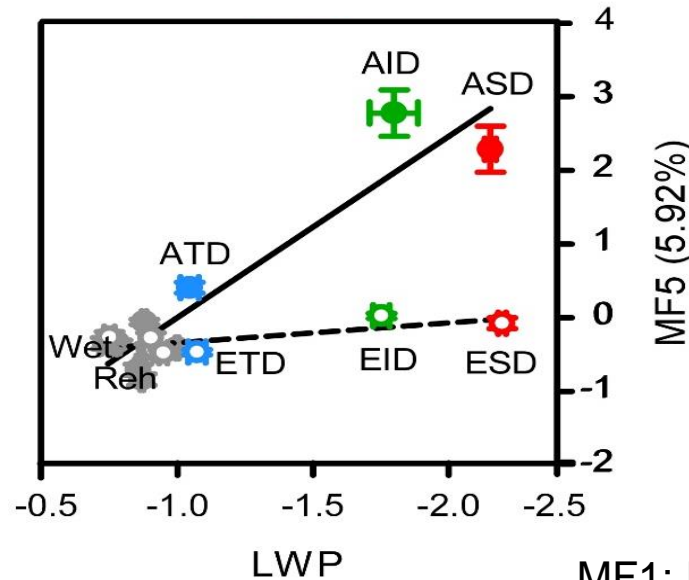
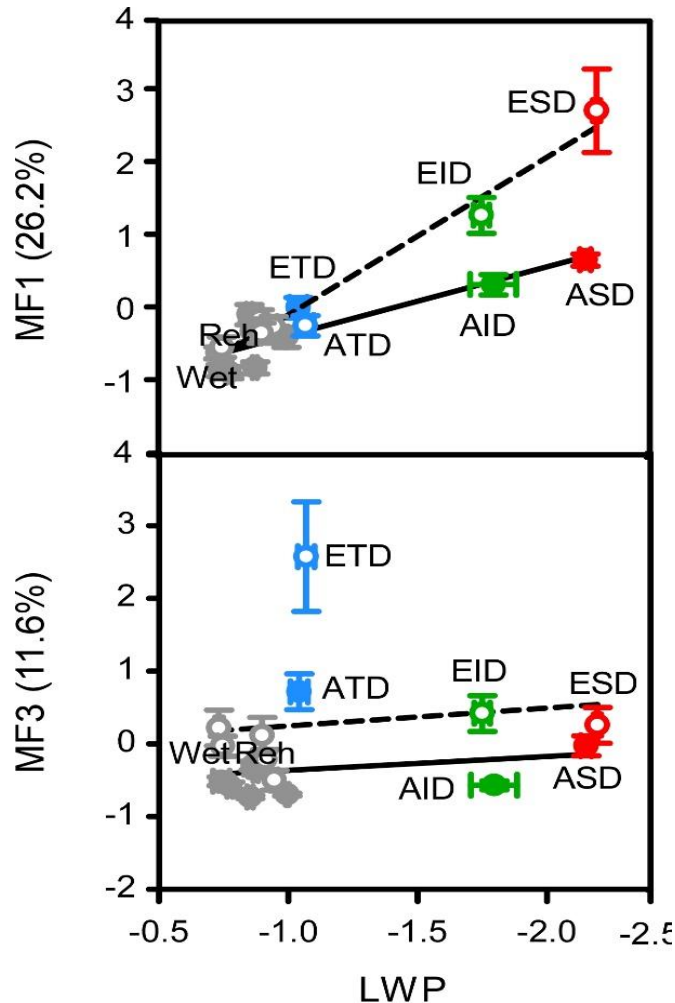
To rapidly identify stress markers  
in maize germplasm

# Maize genotypes differing in drought tolerance have changes in metabolic patterns in response to water stress



# Current stress markers may no longer be sufficient to screen superior germplasm under future climate conditions

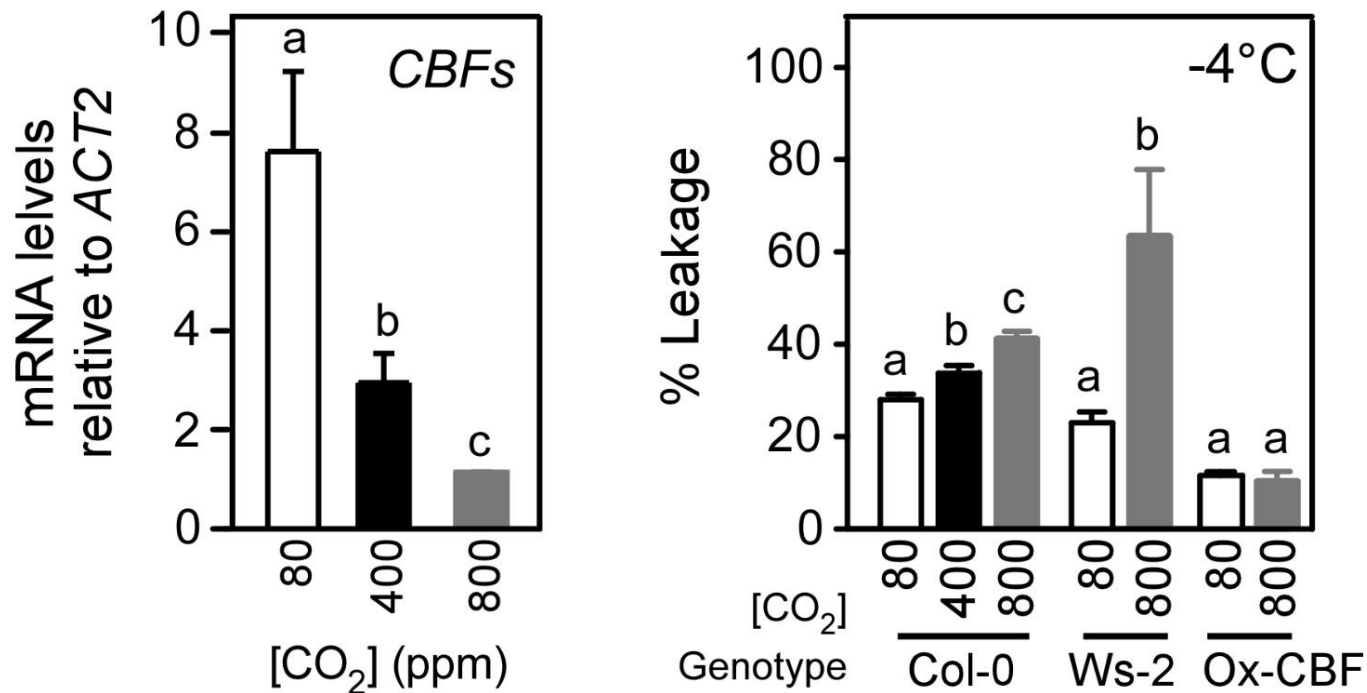
## CO<sub>2</sub> effect on plant responses to drought stress



MF1: Leu, Val, Ile, Phe, Tyr  
 MF3: Glc, Fru, Mann  
 MF5: Pro, Raff

# Rising CO<sub>2</sub> levels in the future may suppress intact cold tolerance in plants

## CO<sub>2</sub> effect on plant responses to cold stress

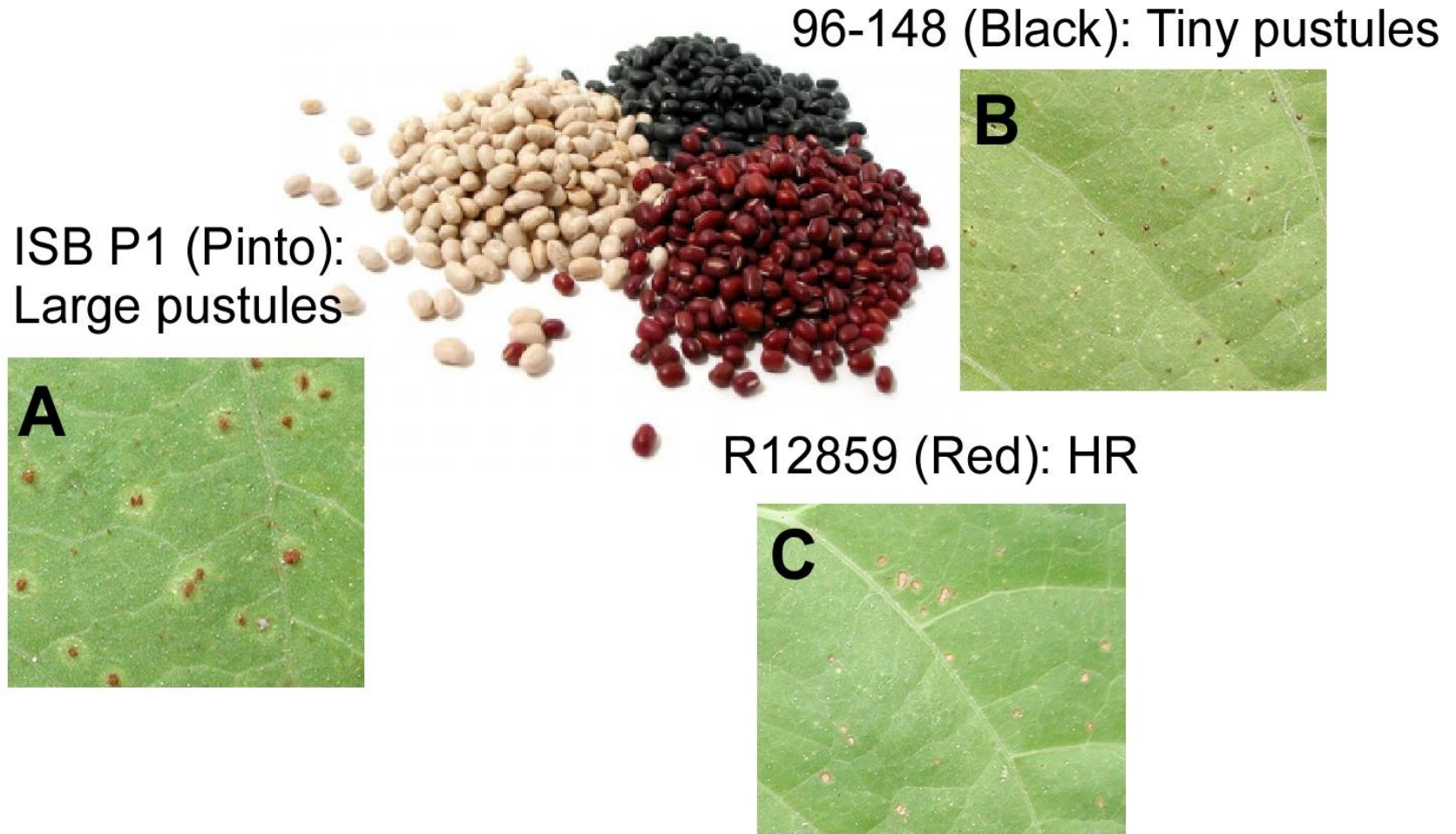


CBFs: C-repeat/dehydration responsive element binding Factor

# Does elevated CO<sub>2</sub> influence fungal infection?

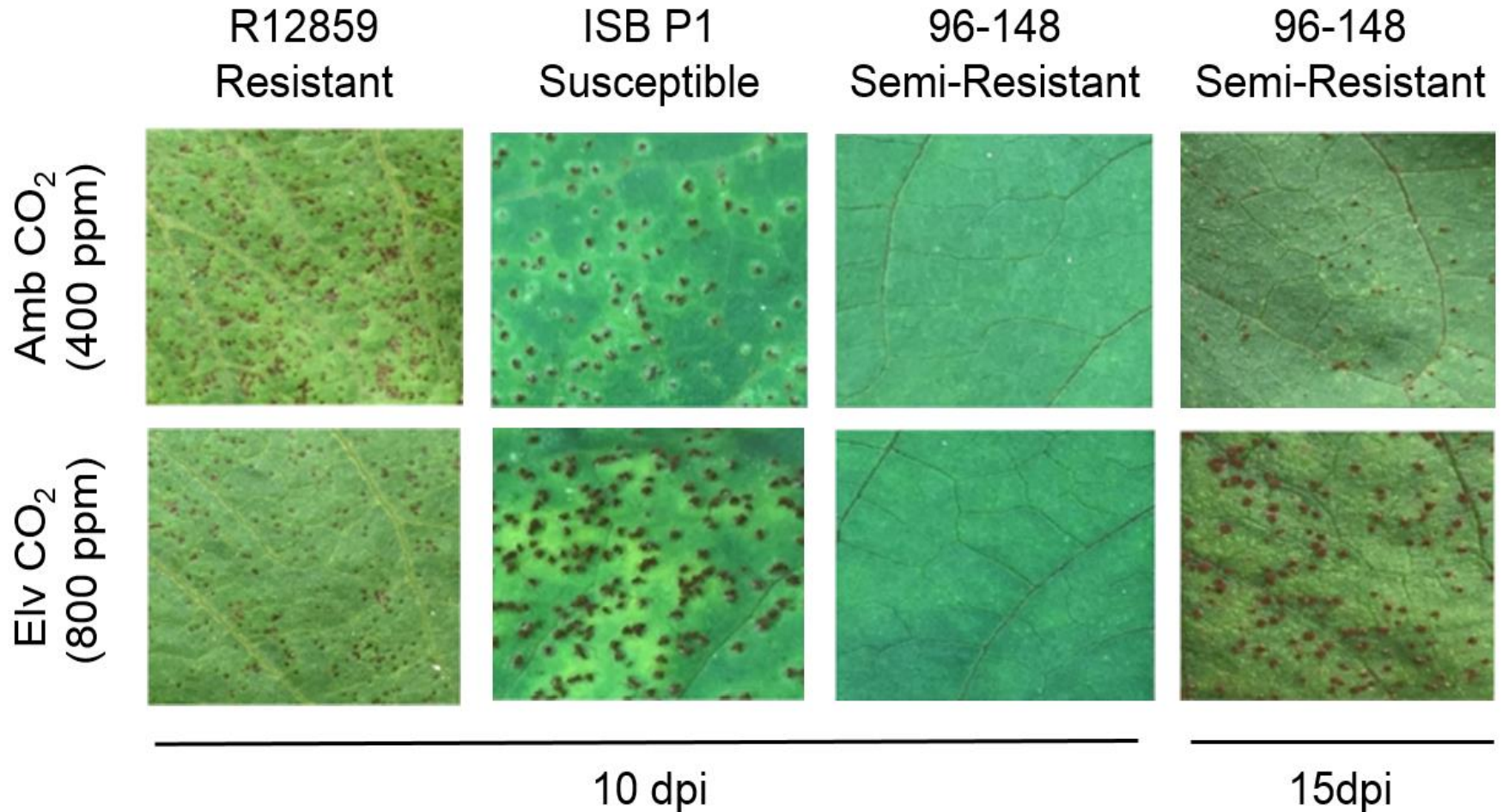


# Three bean cultivars differing in disease resistance



**Rust: *Uromyces appendiculatus***

# Bean rust may become more aggressive under elevated CO<sub>2</sub>



# Future Plans

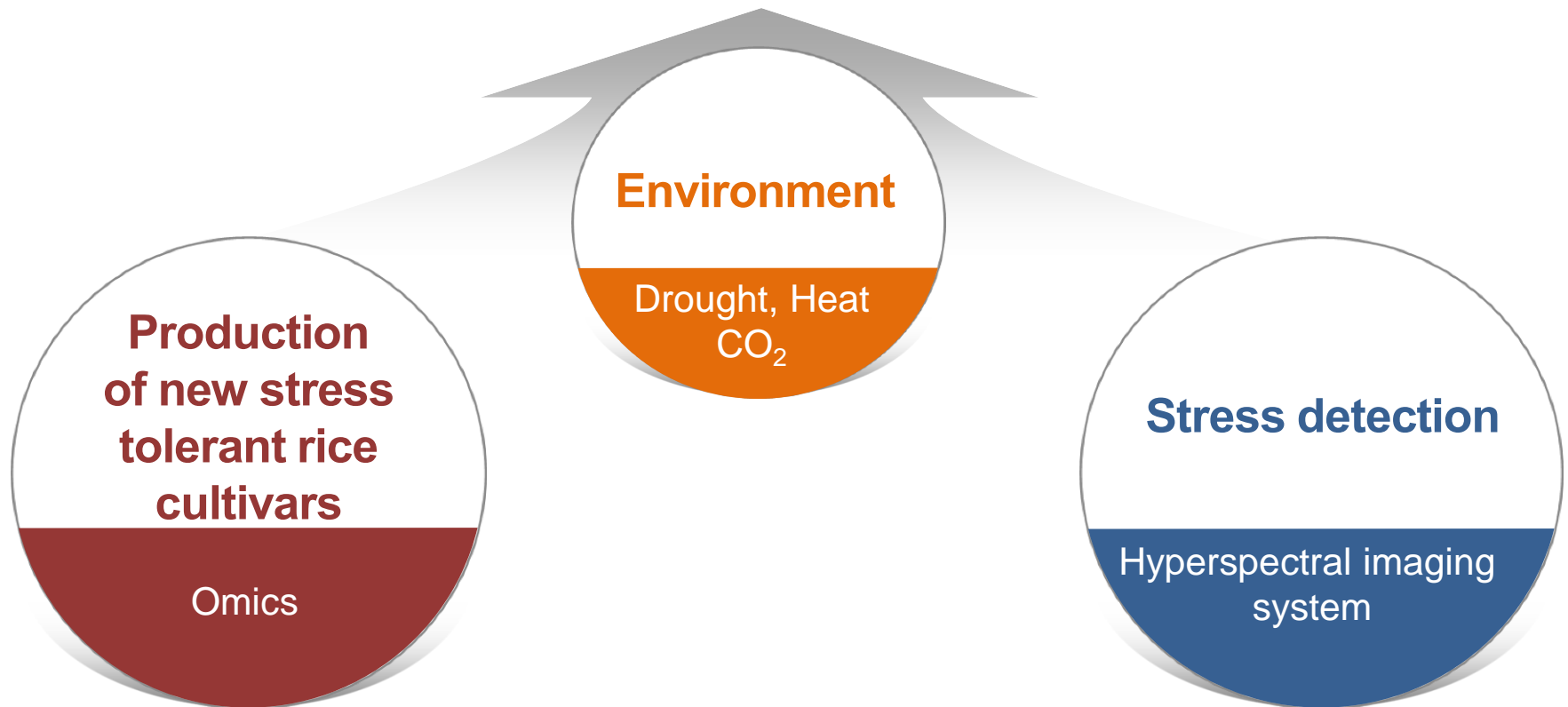


**How do I apply this to the specific issues of improving rice yield and grain quality?**

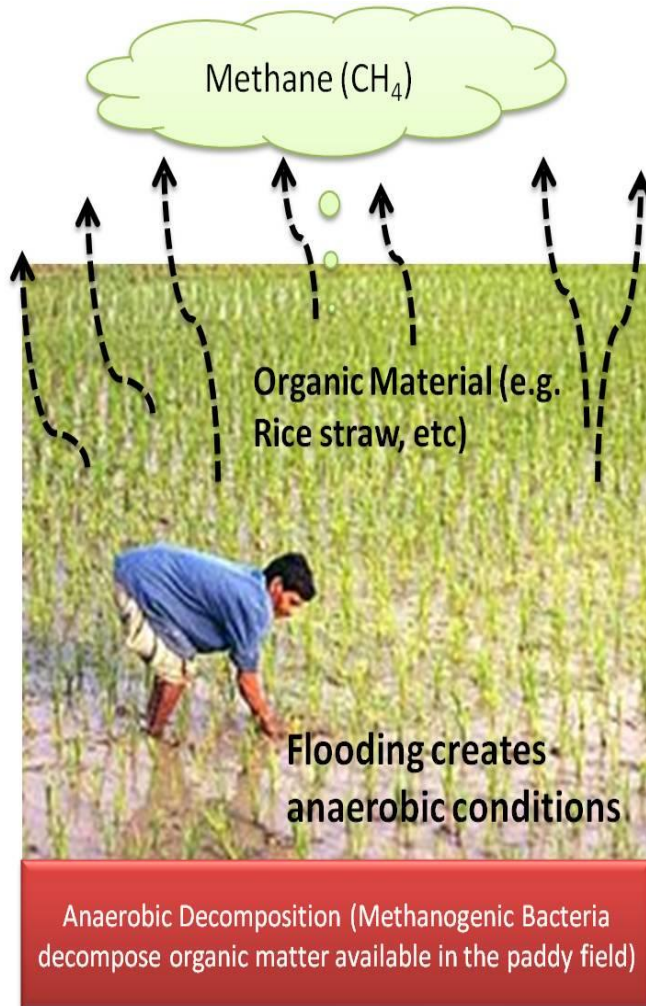


# Dale Bumpers National Rice Research Center-Stuttgart, Arkansas

## My future research

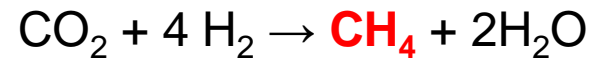


# Rice agriculture: restricting methane



**Rice Paddy Field**

- Atmospheric methane: second most important greenhouse gas after CO<sub>2</sub>
- Rice paddies: largest anthropogenic methane source (7–17% of atmospheric methane)
- The higher in [CO<sub>2</sub>] reduce plant water use soils wetter and reducing [O<sub>2</sub>] in soil favorable conditions for these microorganisms



**Sustainable technologies  
for increasing rice production  
while reducing methane fluxes  
from rice paddies**

# Rice agriculture: restricting methane



by Victor Leshyk

## Ongoing efforts:

- Farming practices
- Screening for cultivars producing reduced emission in methane



Characterizing cultivars that differ in CH<sub>4</sub> emission for phenological, anatomical & agronomic traits



Understanding the physiological and molecular mechanisms of rice-microorganism interactions that produce methane (methanotrophic bacteria)

# Expression of barley *SUSIBA2* transcription factor yields high-starch low-methane rice

**J. Su, C. Hu, X. Yan, Y. Jin, Z. Chen, Q. Guan, Y. Wang, D. Zhong, C. Jansson, F. Wang, A. Schnürer & C. Sun**

**Affiliations | Contributions | Corresponding authors**

*Nature* **523**, 602–606 (30 July 2015) | doi:10.1038/nature14673

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## **Barley *SUSIBA2* (a shift of carbon flux to *SUSIBA2* rice)**

Favored the allocation of photosynthates to aboveground biomass over allocation to roots



This altered allocation:

increased biomass and starch content in the seeds and stems  
suppressed methanogenesis, possibly through a reduction in root exudates.

# Tools to improve and accelerate the production of new stress tolerant cultivars in breeding

## Genetic Architecture of Plant Omics

<b>Genetic mapping populations</b>	<b>Omics</b>	<b>Integration</b>
Genetics Genomics	Transcriptomics Proteomics Metabolomics Phenomics	Bioinformatics

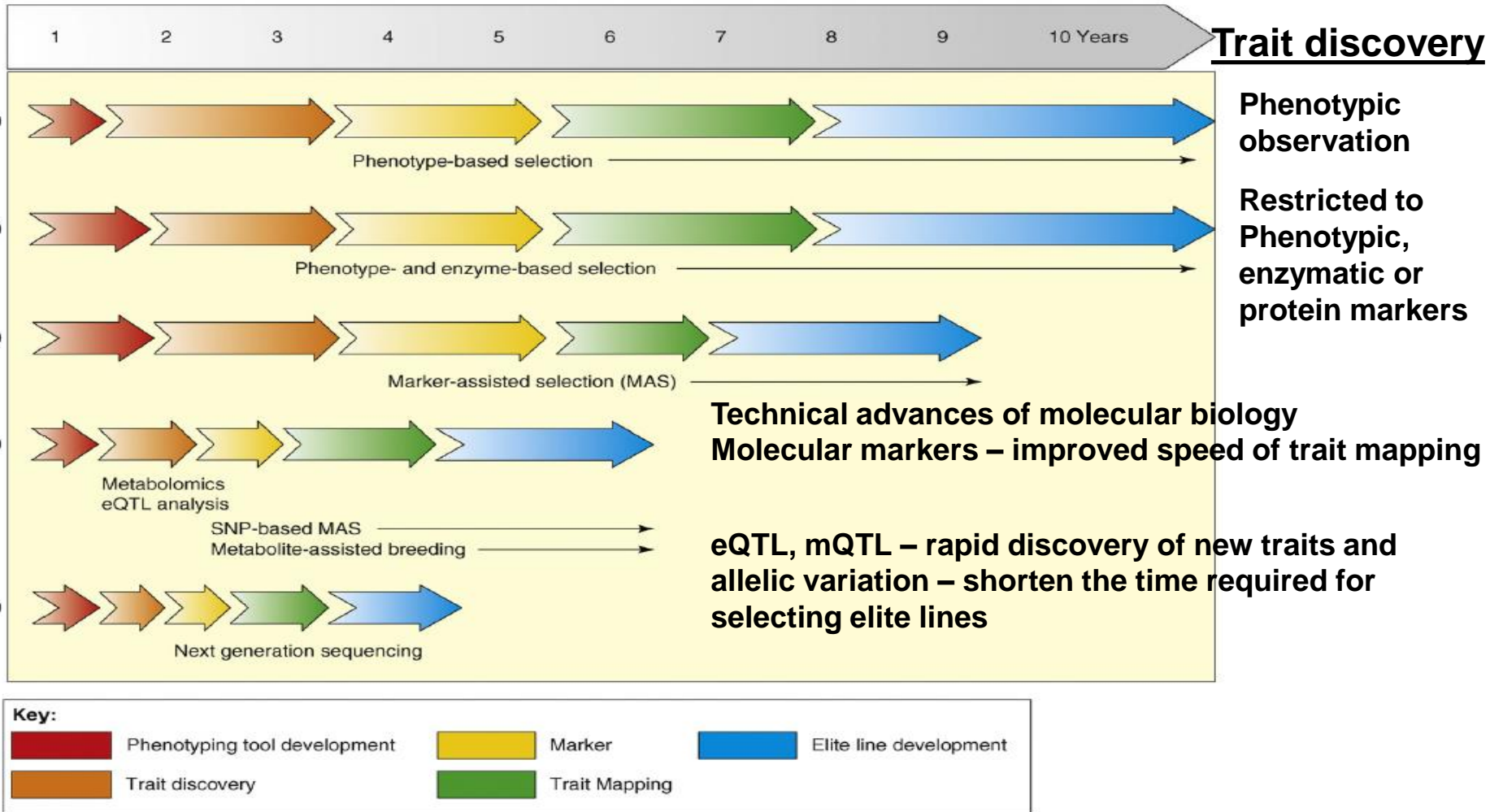


### **Application**

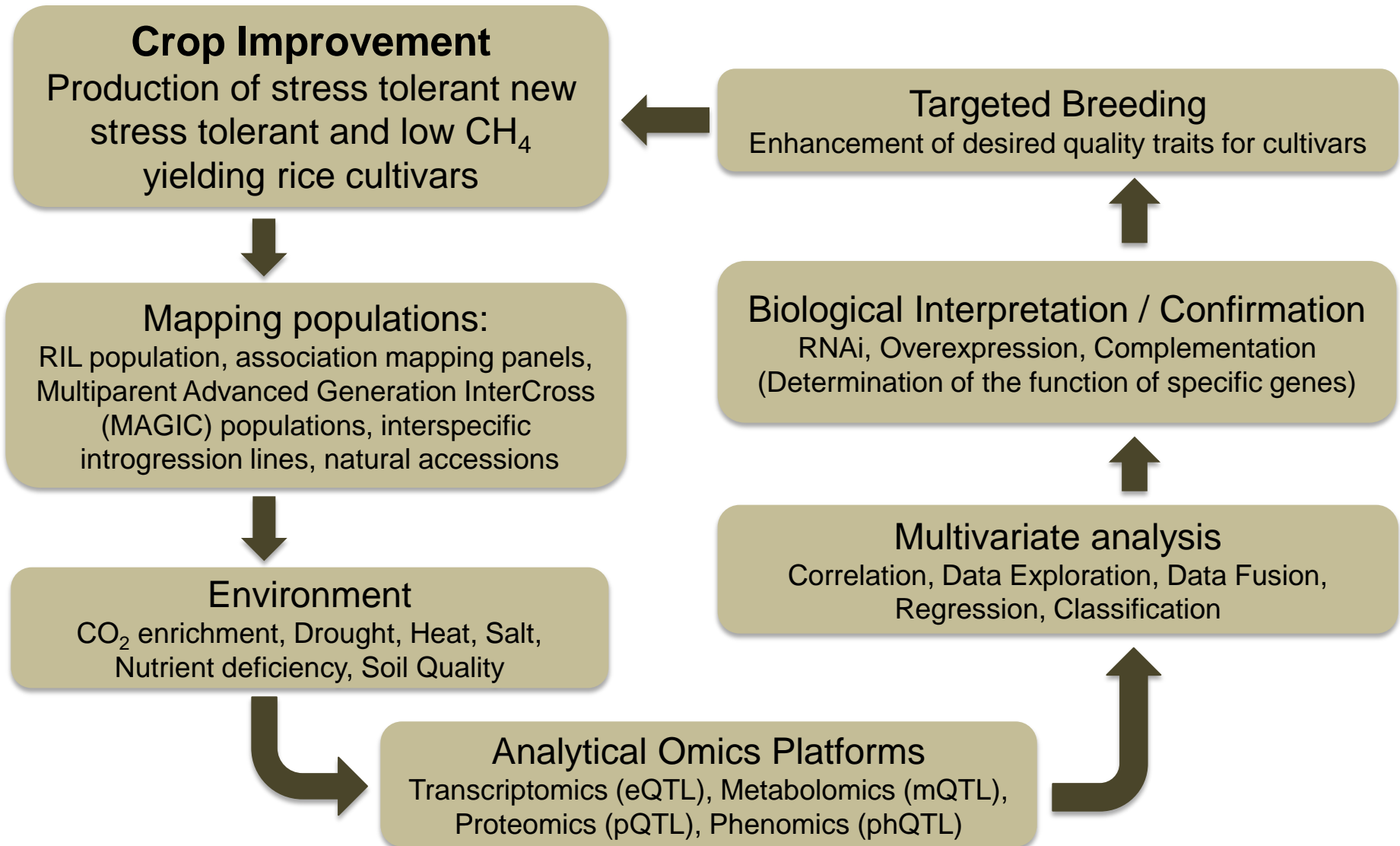
Marker-assisted selection for production of new stress tolerant and low CH<sub>4</sub> yielding rice cultivars in breeding



# Breeding Technology Pipeline



# Omics-driven analysis of genotyped experimental populations segregating for quantitative traits



# Summary

- My future research will elucidate complex interactions between rice, major fungal pathogens and environmental factors in order to improve rice yield and grain quality for sustainable food safety
- My future research will understand the emission mechanisms and evaluate the best management practices for mitigating methane emission
- A multi- and trans-disciplinary approach would considerably shorten the time required for selecting the stress elite lines
- We face new and unprecedented challenges that require new approaches to quantify the distribution, impacts, and management of crop stress

# Acknowledgements

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## **Chungnam National University, Korea**

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