Transitioning Cereal Systems to Adapt to Climate Change

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Improving Models & Data for Developing Pathways for Cropping System Adaptation to Climate Change

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AgMIP The Agricultural Model Intercomparison and Improvement Project

Outline

- Agricultural complexities
- Agriculture is adaptive, seemingly in continual transitions
- Some key questions
- Improving crop models for transitioning cropping systems to meet future food needs: next generation models
  - Increasing value of data resources
  - Incorporating breeding targets in strategic foresight analyses
- Concluding comments

Agricultural Complexities

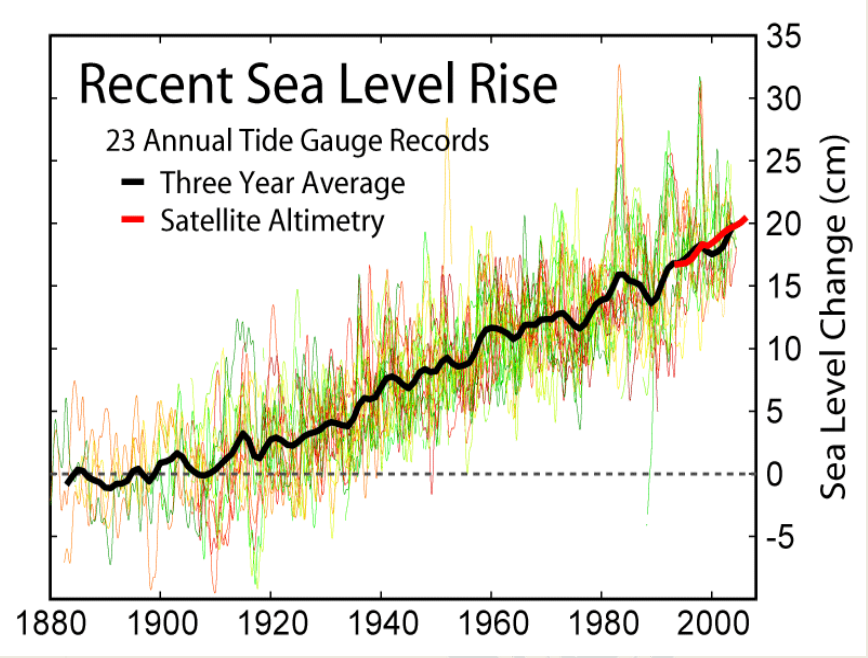
- **Climate** is suitable to support production levels with use of appropriate technologies
- **Soils** are adequate, with appropriate management to alleviate limitations
- **Energy** is available and affordable
- **Supporting industries** provide needed inputs
- **Water** supply is available with reliable infrastructure
- **Impacts on the environment** are acceptable to society
- Agriculture provides **livelihoods** for many families
- Knowledgeable farmers; they know climate, land, markets, policies, technologies, and they **adapt** to changes

Basic Premise

- Existing agricultural production systems are well established and adapted to climate, soil, markets, industry, technology, social, political, ecological conditions where they occur
- These systems, people, infrastructure, policy makers, environments are reasonably resilient to variations that occur; adjustments are continually being made to factors that can be controlled by different actors
- But…

Disruptions May Lead to Need for Changes in Production

- Climate shocks, extreme events
- Climate change, sea level rise
- Soil degradation
- Changes in policies, regulations
- Increases in populations, changes in diet
- Changes in product prices, input costs (e.g., energy)
- Changes in water supply, drought
- Changes in infrastructure
- Conflicts



Transitioning Examples

- Westward migration of agriculture in the US
  - Good climate, soil
  - Infrastructure for irrigation
  - Favorable policies for agricultural water use
  - SE Agriculture declined in parallel with increases in the West, with increases in poverty and associated problems
- Dairies moving from southern to northern Florida
  - Prompted by major pollution of Lake Okeechobee in S. Florida
  - Regulations passed to protect the lake, natural ecosystems
  - Planned migration, with financial support to dairies
  - Key Point – policies were proactive & favorable, helping families keep their livelihoods
- Many others

Some Key Questions

- What **transitions** are needed for specific future scenarios?
  - Genetics and plant breeding
  - Changes in technologies & practices
  - Changes in crops, livestock systems
  - Changes in policies, supporting industries and infrastructure
- What **information is needed** to evaluate transition options, taking into account the complexities? Regions?
- What potential **pathways should be pursued** to achieve adaptation, and **by whom**?
- What **research** is needed?

Adaptation to Climate Change

- Past Climate Change Assessments
  - Crop Models used by analysts (with economic models)
    - Simple adaptations - adjustments in planting date, and
    - Changes in varieties (mainly crop duration characteristics);
- Agricultural adaptation is likely to be much more than those factors considered in most early studies
- Assessments should consider future conditions, including populations, technologies, policies, in addition to changes in climate
- Considerable variations across regions; what are practical pathways?

Adaptation/Transitioning Complexities

- Future varieties (e.g., heat-tolerant, drought tolerant, resistance to pests/diseases, …)
- New fertilizer technologies
- Irrigation, water harvesting
- Pest & disease impacts
- Sustainable practices
- Supporting industries, policies

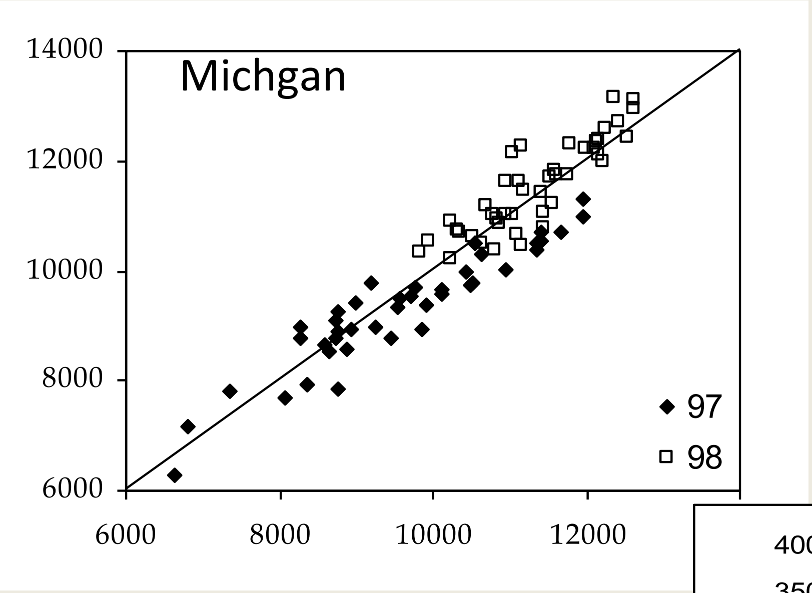
Intensive drip irrigation, plastic mulch systems, Florida

Water harvesting with Zai system, with micro-dosing nutrients, Niger

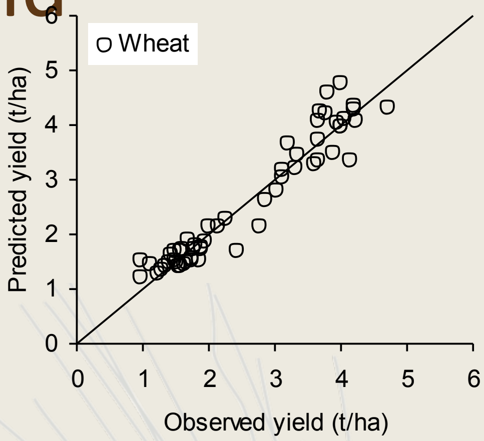
Transitioning Pathways?

- Scenarios for GHG emissions and climate
- Populations and demand for food, feed, fiber, and bioenergy
- Scenarios providing information on population, energy, land-use, emissions projections for the SSPs.
- Representative Agricultural Pathways (RAPs) - transitioning
  - Must be provided to guide scenarios for adaptation
  - Stakeholder input is critical
  - Provides guidance for analysis of adaptation (e.g., new technologies; climate change policies; changes in practices, crops, varieties)
  - Translate into model inputs (economic, livestock, economic), vet with stakeholders

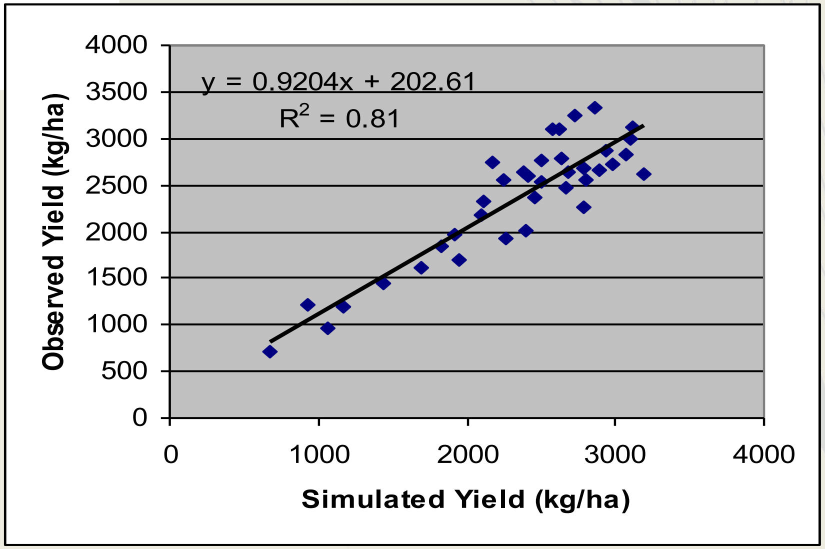
With accurate inputs, crop models can accurately predict yield



Simulated versus observed maize grain yield, two years, using field-measured spatially varying soil parameters in Michigan. R. Braga (2000).



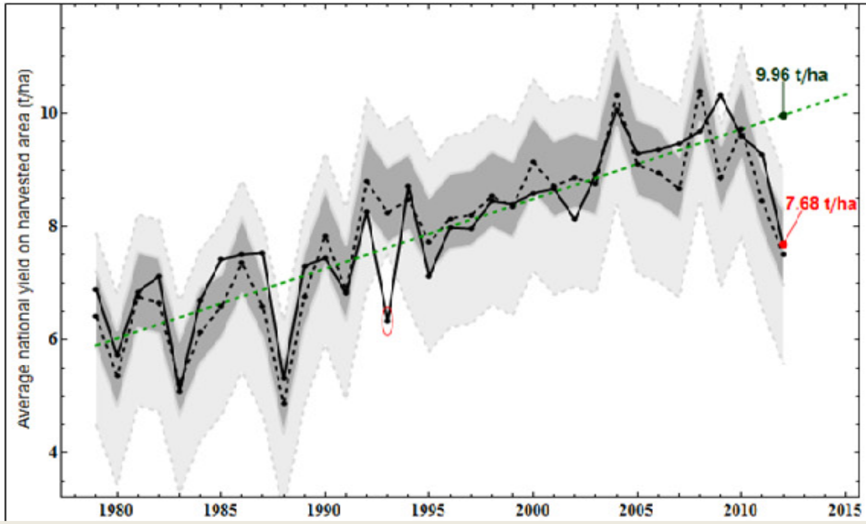
Simulated versus observed swheat yield using field-measured data from Argenta. Magrin et al.

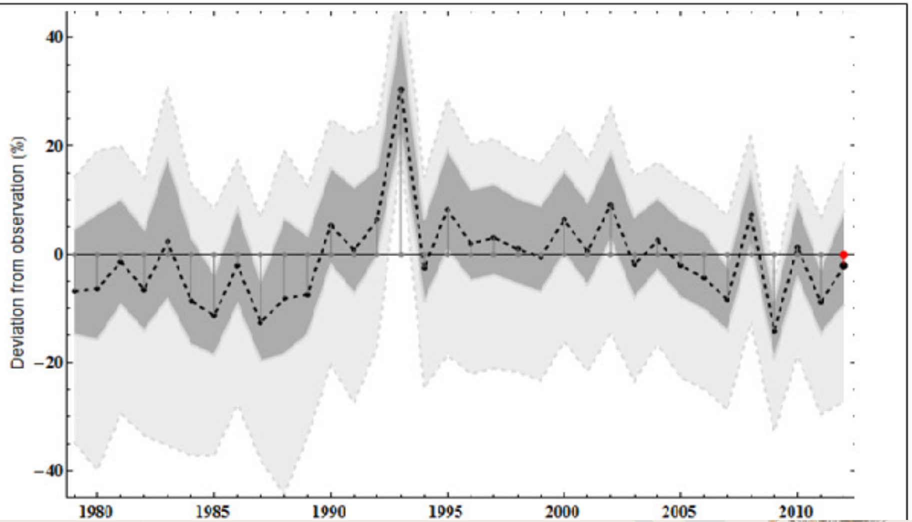


Simulated versus observed soybean yield using field-measured yield trial data from Georgia. Mavromatis et al., 2003

Example: Predicting US Corn Yield in 2012 Drought and Historical Yield Trend
J. Elliott et al., 2013 (AGMIP)

- Simulation results are aggregated to county level, compared to detrended NASS survey, bias-corrected, and projected onto the observed trend.
- We then aggregate these to state and national level.
- At national level the model performs very well in drought years 1983, 1988, and 2012 as well as in 1981, 1991, 1994, 1996-1999, 2001, 2003-2005, 2010.
- Big misses are 1993 and 2009. Smaller misses are 1985, 1987, 2002, 2007, 2008, 2011…





But, Crop Models Have Limitations

- They do not adequately incorporate modern genetic information that breeders now work with
- They do not currently incorporate biotic stresses
- They have not dealt with many of the known management adaptation options
- Evaluation of the models have been very limited, usually being done for very few combinations of environments, genetics, and management
- Next generation models need to address these

AgMIP – Agricultural Model Intercomparison and Improvement Project

www.AgMIP.org

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Oregon State University, Corvallis

Goal: Significantly advance scientific capabilities for addressing complex Ag & food security issues, global and regional, in a changing climate

UKaid from the Department for International Development

USDA

USAID

CGIAR

RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security

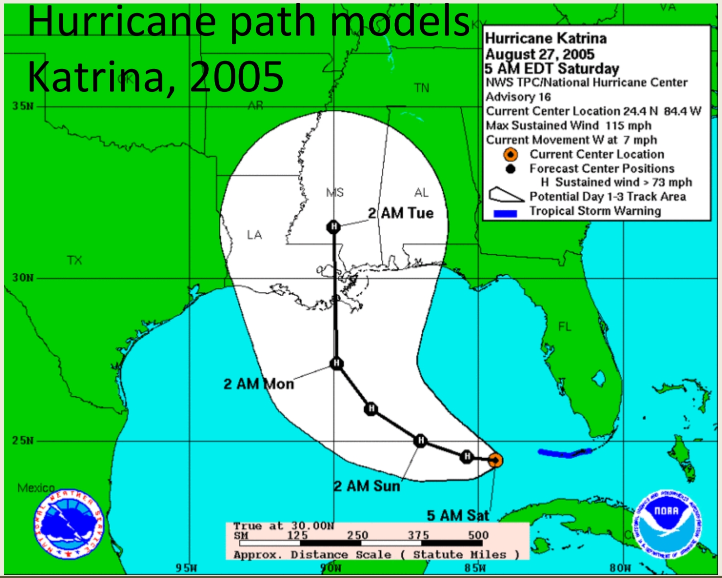
CCAFS

NASA

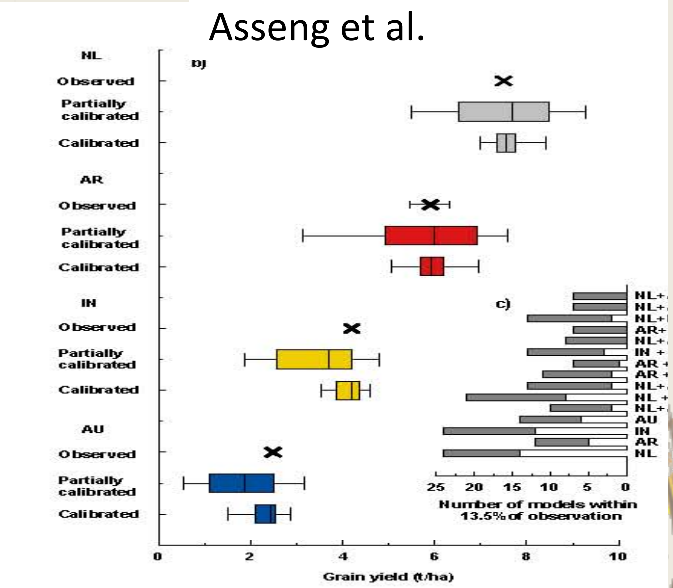
Model Uncertainty and Improvement

- How reliable are model-based results considering that different models are used in assessments? Are results more reliable if an ensemble of models is used instead of using a single model? Uncertainties?
- Multiple models are successfully used by climate modelers (for forecasting weather, hurricane/tropical storm paths, and climate change).
- Similar situation for crop models

Hurricane path models
Katrina, 2005



Wheat crop models,
Asseng et al.



AgMIP Crop Model Improvement Activities

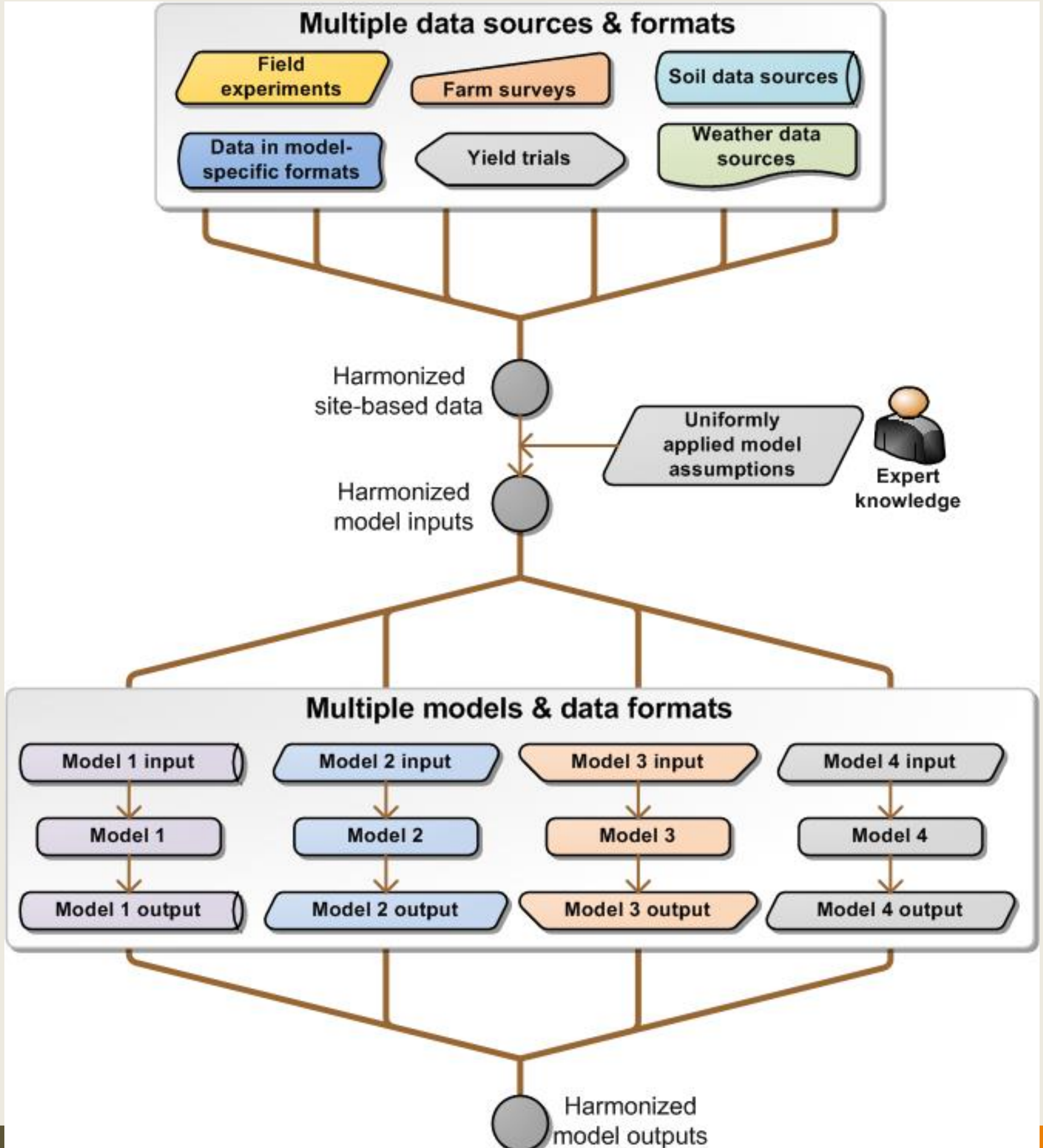
- Model intercomparisons (wheat, corn, rice, sugarcane, potato, sorghum, soil, …)
- Model evaluation relative to CO2, temperature, water, and N responses (assembling data for wide ranges of conditions)
- Evaluating approaches for incorporating pest and disease models to account for biotic stresses (3 AgMIP teams; wheat diseases, potato blight, and crop health)
- **Develop National Agricultural Research Data Network for Harmonized Data (US); linkage with CGIAR, EU, + others**
- **Incorporate genetic information, transdisciplinary effort, with crop modelers, plant breeders, geneticists, bioinformatics to improve GxExM understanding and prediction**

Crop models must be developed & tested for wide variations in crop, climate, soil, management conditions[1]

- Considerable efforts are made each year globally on crop research, most of which are "lost" after original use
- By using data combined from studies across locations and years, researchers will have a "virtual laboratory" to perform research that could not be attempted using isolated studies
- There are various national and international initiatives for making agricultural research data more open (e.g., GODAN, GEOGLAM, CGIAR, USDA, EU, AgMIP, etc.)
- Uses of harmonized quantitative data can lead to improved models with accessible evidence of their capabilities; additionally, these data can be used for meta analyses, life cycle analyses, & statistical analyses
- Agronomic data from broader studies can also be linked to genomics data to better understand and quantify G x E x M effects and new plant breeding tools

[1]A case for harmonized, open, accessible and usable agricultural data

AgMIP SSA/SA project funded by DFID, an interoperability approach



- Multiple inconsistent data sources
- Incomplete information to parameterize multiple crop models
- Multiple input and output formats for crop models

Porter et al., 2015

Proposed NARDN Objectives

Objectives:

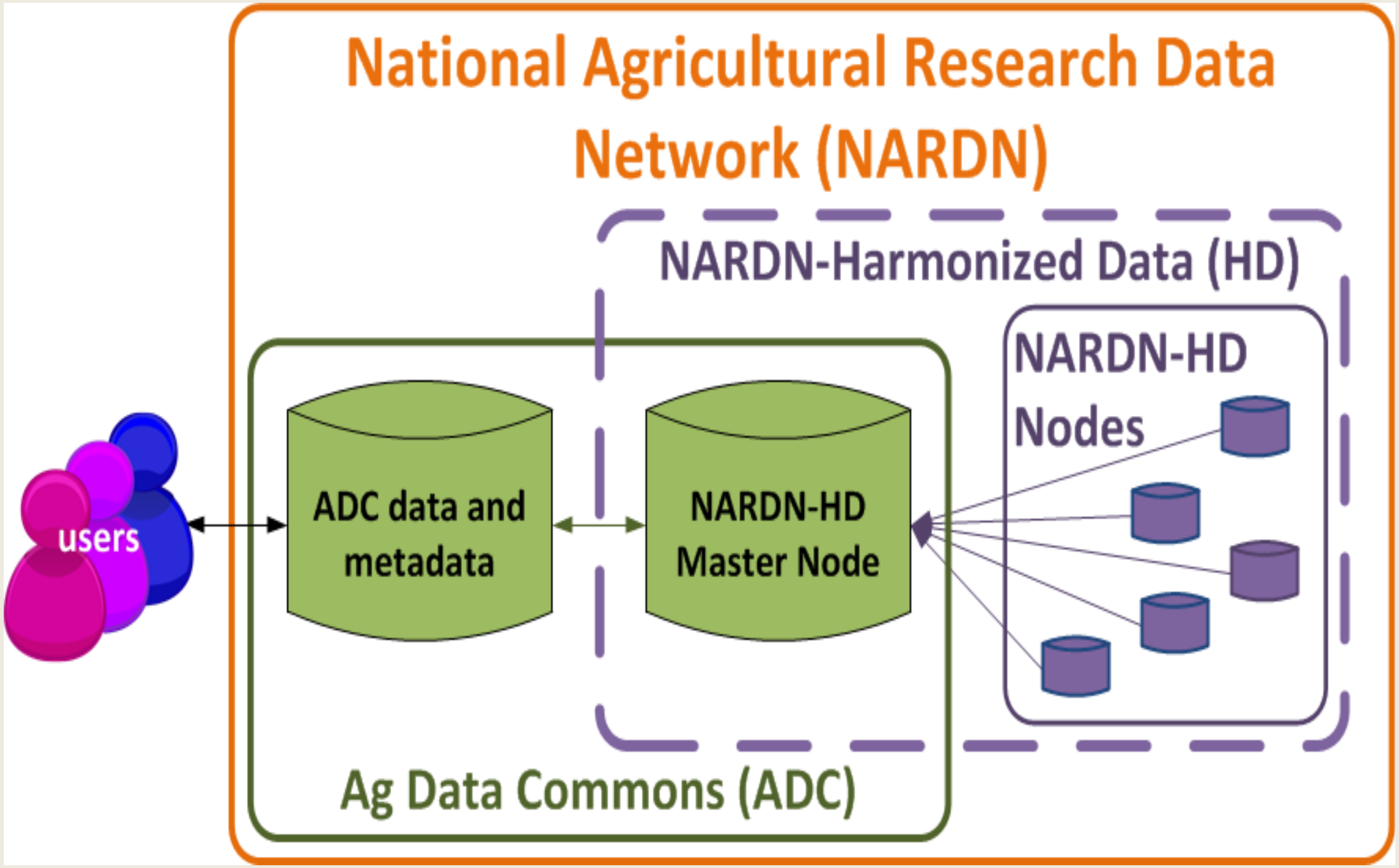
- Create a distributed network for storing harmonized crop and livestock systems research data
- Devise common metadata for these production systems
- Develop web tools for discovering, accessing and using the data
- Develop procedures and tools for researchers to routinely contribute data, complying with federal agency requirements for open data
- Develop a plan for long-term network operation, working with USDA ARS, NIFA and the NAL in the NARDN-HD design, implementation, and operation
- Coordinate this work with international efforts (CGIAR, EU, countries)

ESCOP

NAL

AgMIP

Schematic of Proposed Data Network

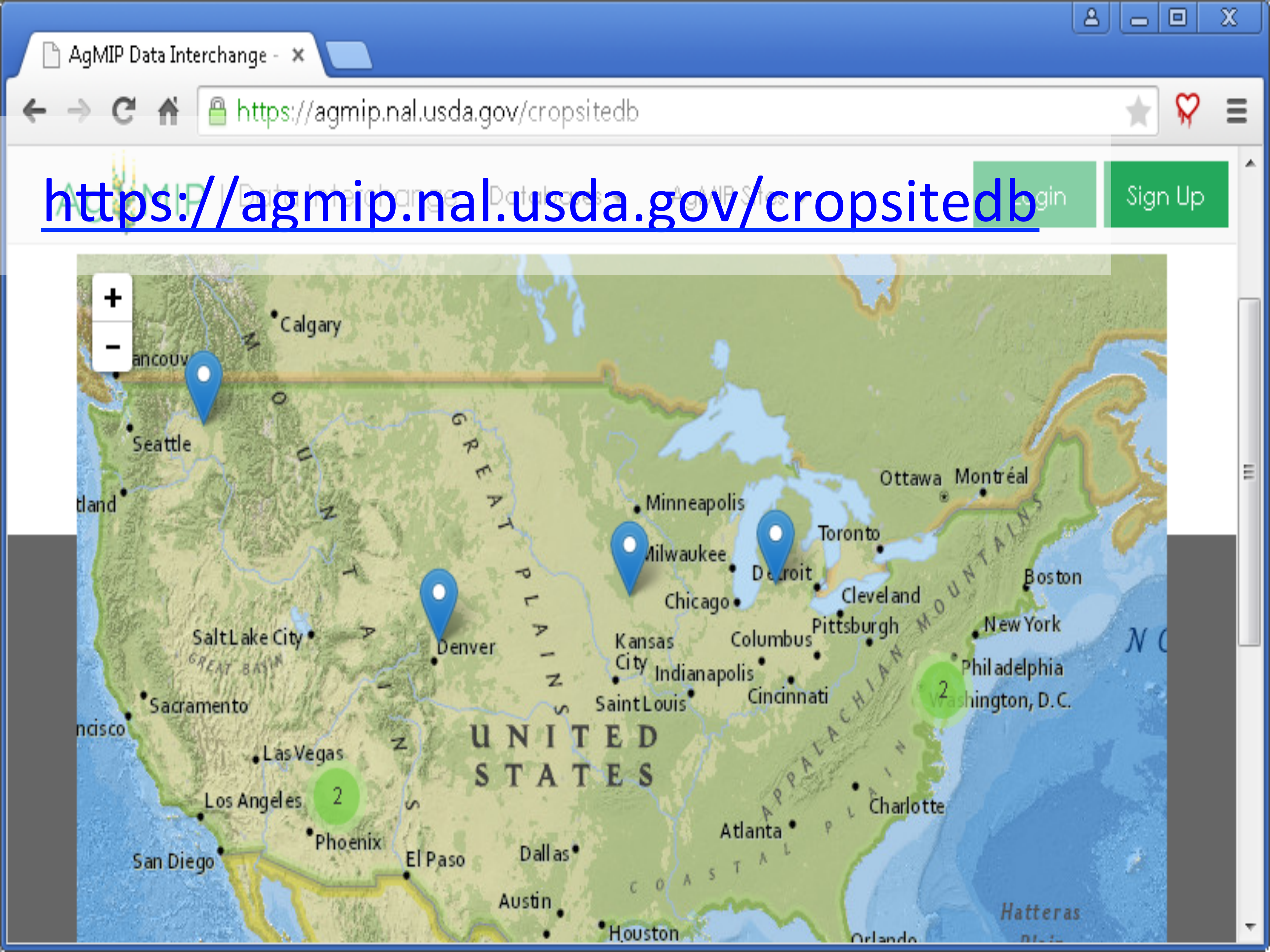


Proposed NARDN-HD showing its relationship with the NAL's Ag Data Commons and its contribution to the broader NARDN

NAL

AgMIP

https://agmip.nal.usda.gov/cropsitedb



Database interoperability: AgMIP-AgTrials cooperation

Incorporating Genetics & Plant Breeding

- Plant breeders contribute considerably to the transition/adaptation of production systems
- Tolerance to abiotic stresses (e.g., high temperature, drought, low soil fertility, salinity, flooding)
- Resistance/tolerance to biotic stresses (diseases, insects, weeds)
- How can crop models incorporate genetic knowledge and plant breeding targets in studying cereal system adaptation and transitions?

Virtual Crop Modeling

- IFPRI-led CGIAR project (Global Futures), working with UF crop modelers, plant breeders, economists
- Created "virtual" varieties with more tolerance to high temperature, drought, and with higher potential productivity – based on plant breeders in each Center
- Crop modelers interpreted breeding goals to modify parameters that include them
- Sensitivity analysis and confirmation of behavior of these, publications
- Incorporated these virtual cultivars into the IFPRI DSSAT-based crop models, feeding results into their IMPACT global partial equilibrium model

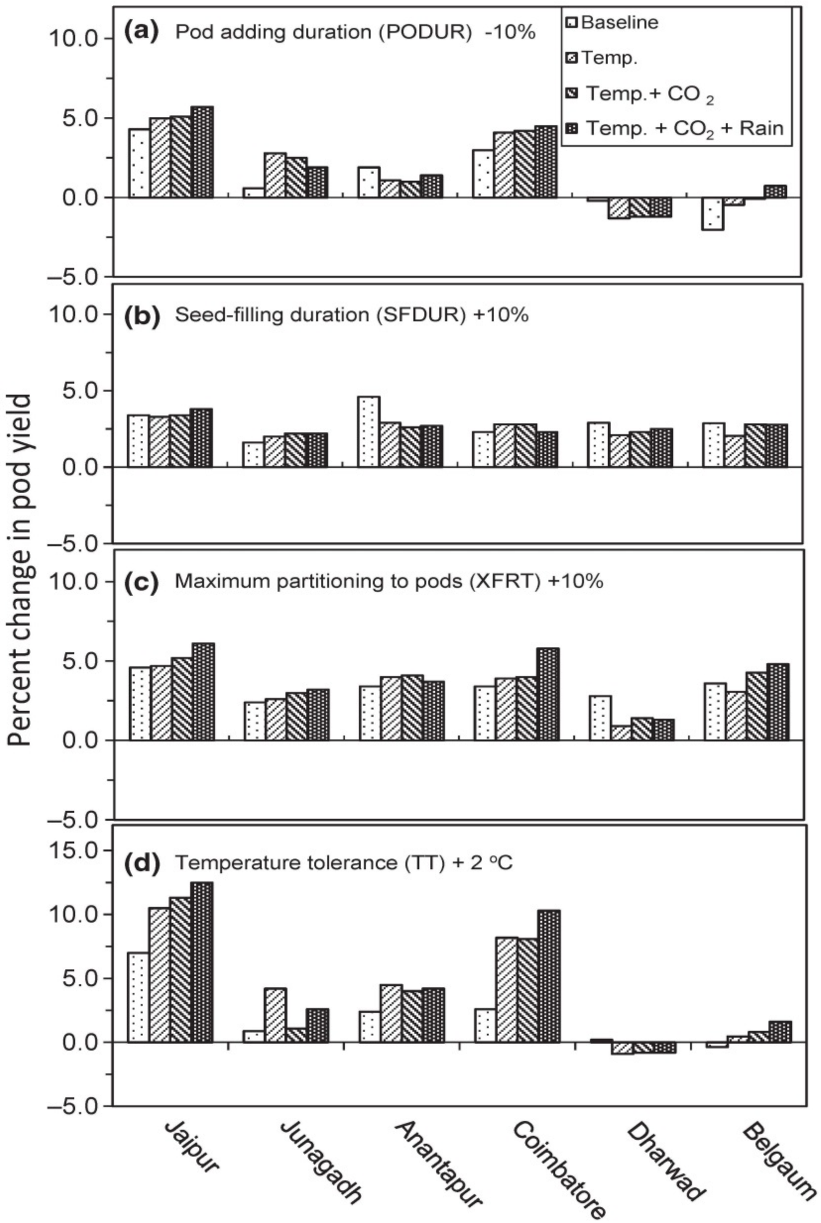


Fig. 4 Percentage change in pod yield with change in reproductive and temperature tolerance traits relative to the mean yield simulated for baseline and climate scenarios for the six sites.

Technologies to Increase Adaptation to Future Climates

Simulating "Virtual Crops", using traits targeted by plant breeders in the CGIAR Centers. Collaboration among plant breeders, crop modelers, economists, climate scientists.

Singh et al. 2012. Evaluation of Genetic Traits for Improving Productivity and Adaptation of Groundnut to Climate Change in India. J Agro Crop Sci.198:399-413

Contribution to Global Futures Project of the CGIAR, led by IFPRI

2015

Interdisciplinary Workshop on

MERGING CROP MODELING

and

GENETICS

Specialized Training for Crop Modelers, Plant Geneticists, and Breeders.

NSF

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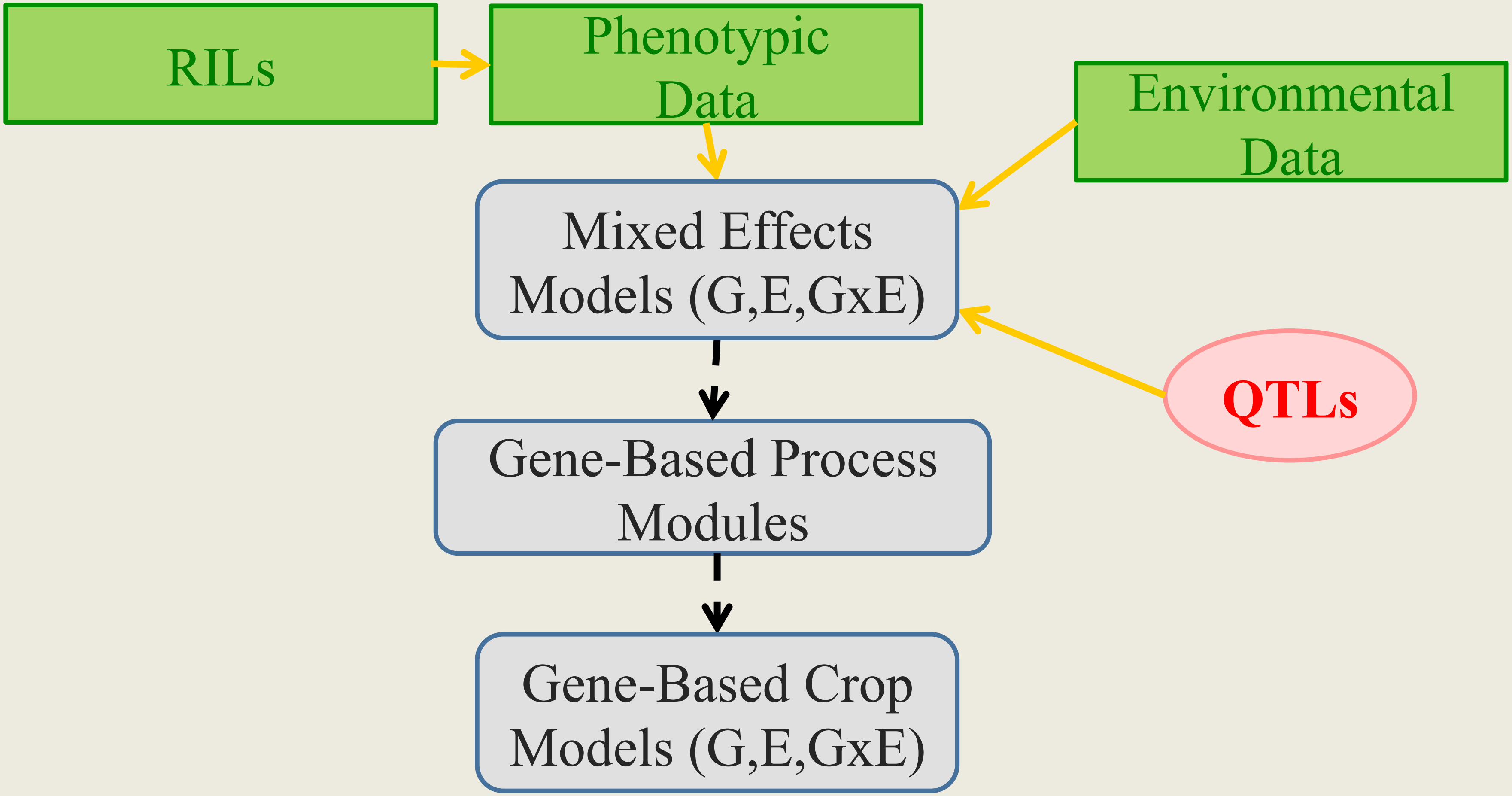
JULY 19 – 25
GAINESVILLE, FL

Combining Genetic, Environment & Management Information in Crop Models

- Goals are: to develop understanding of gene effects on plant growth processes that are then incorporated into a new generation of crop models,
- to engage geneticists, plant breeders, crop modelers, and bioinformatics experts to create capabilities for predicting G, E, M, and GxExM effects on genotypic responses
- to transition crop models to increasingly include genetic information
- to apply the models in a wide range of applications for identifying ideotypes for current and future environments that increase productivity and are more resilient to climate variability and change
- A number of authors have demonstrated the potential, but not yet operational (e.g, White and Hoogenboom, Hammer et al., Yin et al., Messina et al., Chapman et al.)

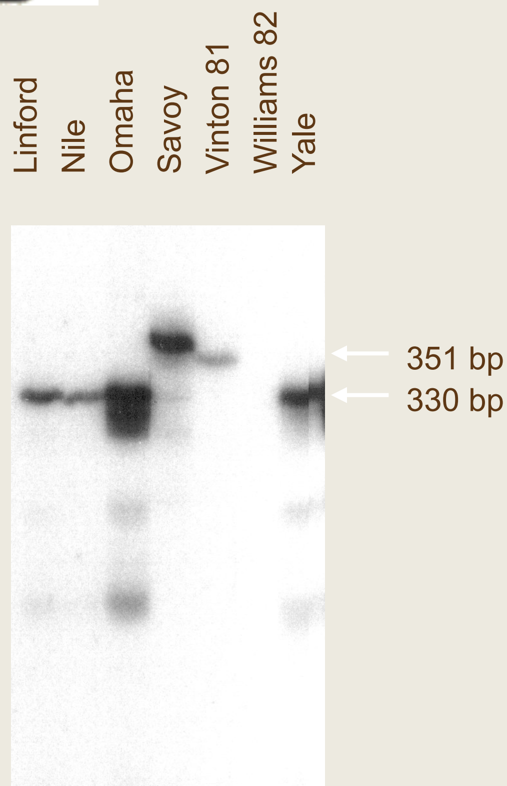
Developing Next Generation Modular, Gene-Based Crop Model



Predicting soybean maturity and yield using molecular marker information

DNA Analysis → Prediction of Performance

Satt 496



Planting dates
Row spacing
Irrigation

CROP MODEL

Yield
Maturity

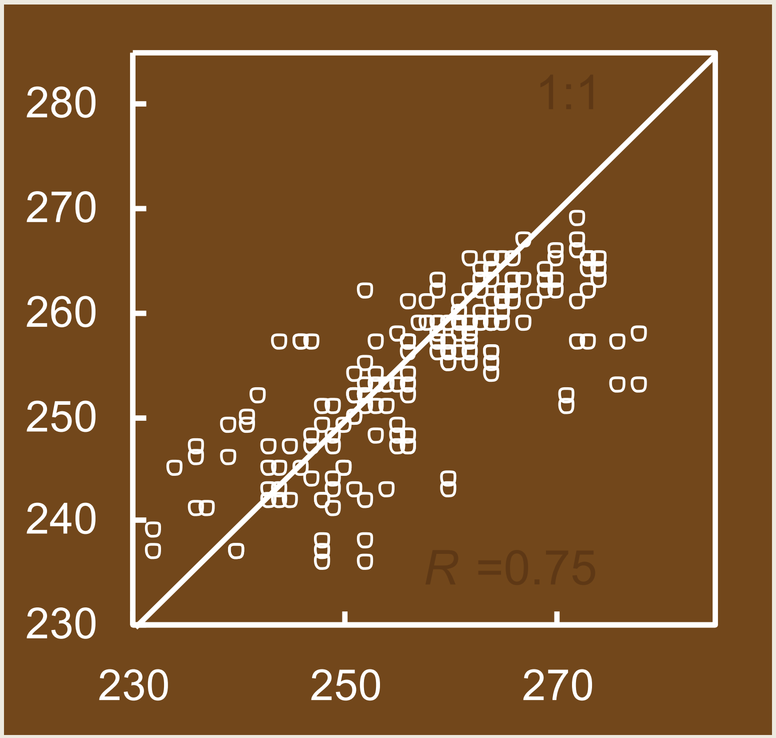
Illinois, 7 Locations
5 years 1995-99

Source: C. Messina. 2003

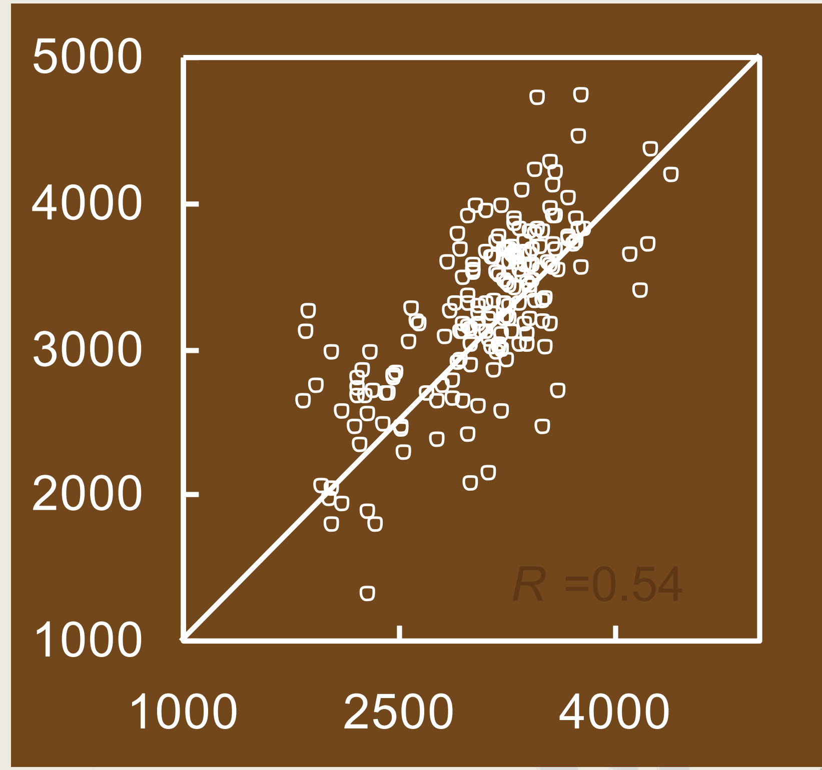
Gene Based Predictions

Soybean in Illinois

Time to Maturity



Yield

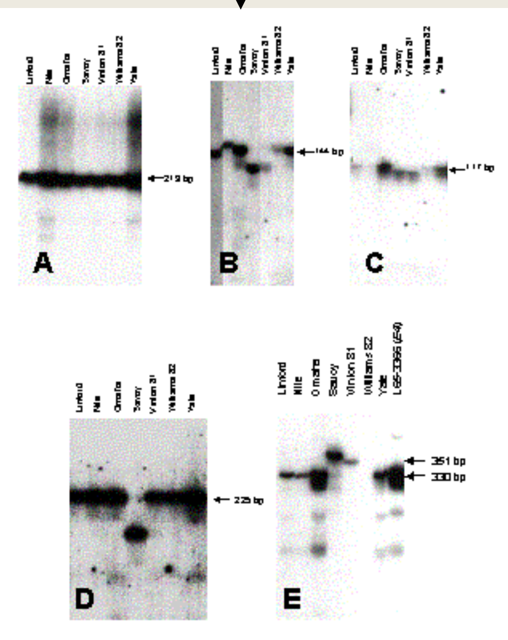


Simulated

Observed

Source: C. Messina. 2003

DNA provides information to breed crops for specific climates

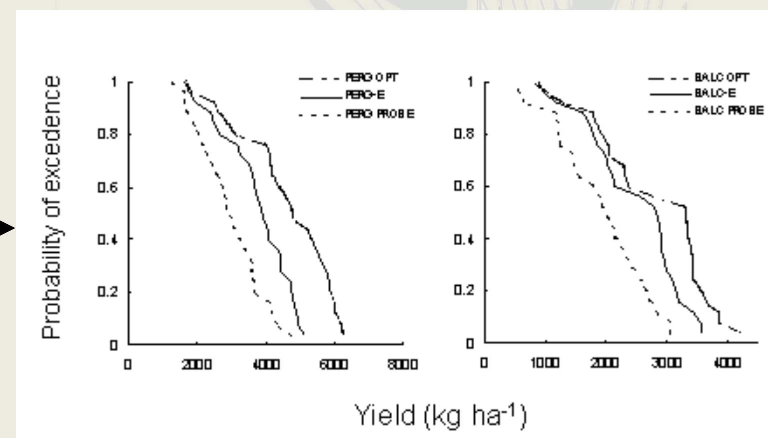


Soybean Gene Map

Climate, Site Characteristics

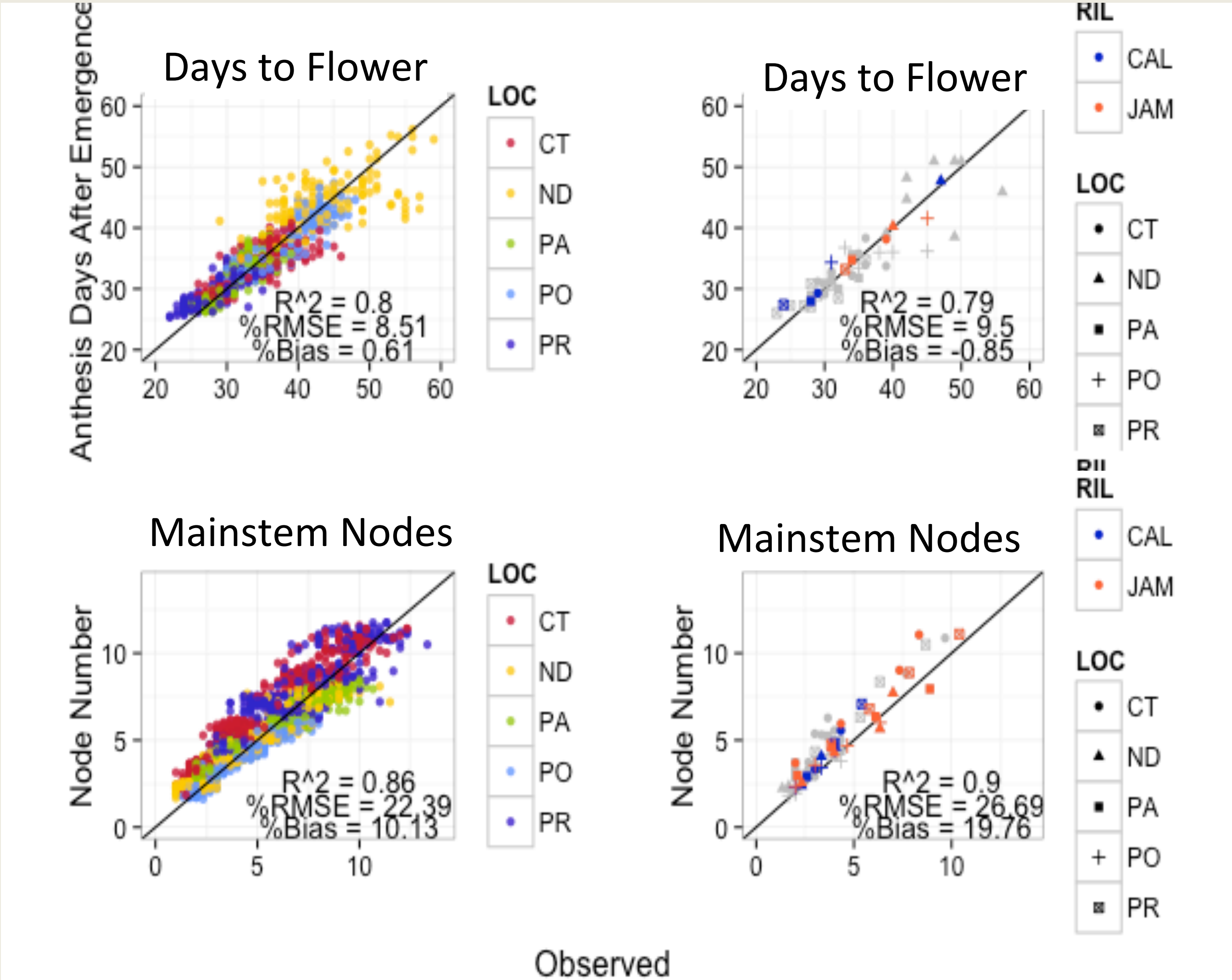
Gene-Based, Biophysical Crop Model

Optimize variety for climate: high yield, low risk of failure



Source: C. Messina. 2003

Common Bean G, E, and GxE Model for Flowering



NSF project at UF, Vallejos, Jones, Gezan, Correll, Boote, Wu)
12 genes, 5 environments with effects for temperature, day length, solar radiation, and GxE interactions

Hwang et al., in progress

Closing Comments

- With access to broader datasets, more rapid progress can be made on improving crop models, developing new ones (e.g., statistical models) and assembling evidence for meta analyses and new LCA capabilities that are forward-looking
- Virtual crops can be created, with breeders, to study future pathways for adaptation to climate change & transitions
- Rapid progress can also be made in incorporating genes into crop models; rapid, accurate, inexpensive genotyping is available
- Empirical studies on transitioning cereal systems should be combined with these efforts for preserving and using data and for considerably increasing our capabilities to understand and predict genotype performance to future climate conditions and management
- Virtual laboratory, with access to tools and data for building evidence and confidence in proposed solutions from studies

Transitioning Cereal Systems to Adapt to Climate Change

REACCH
Regional Approaches to Climate Change –
PACIFIC NORTHWEST AGRICULTURE

Thank you!

University of Idaho

Washington State University

USDA NIFA
United States Department of Agriculture
National Institute of Food and Agriculture

Oregon State University OSU

CHS

Pacific Northwest Farmers Cooperative

Monsanto