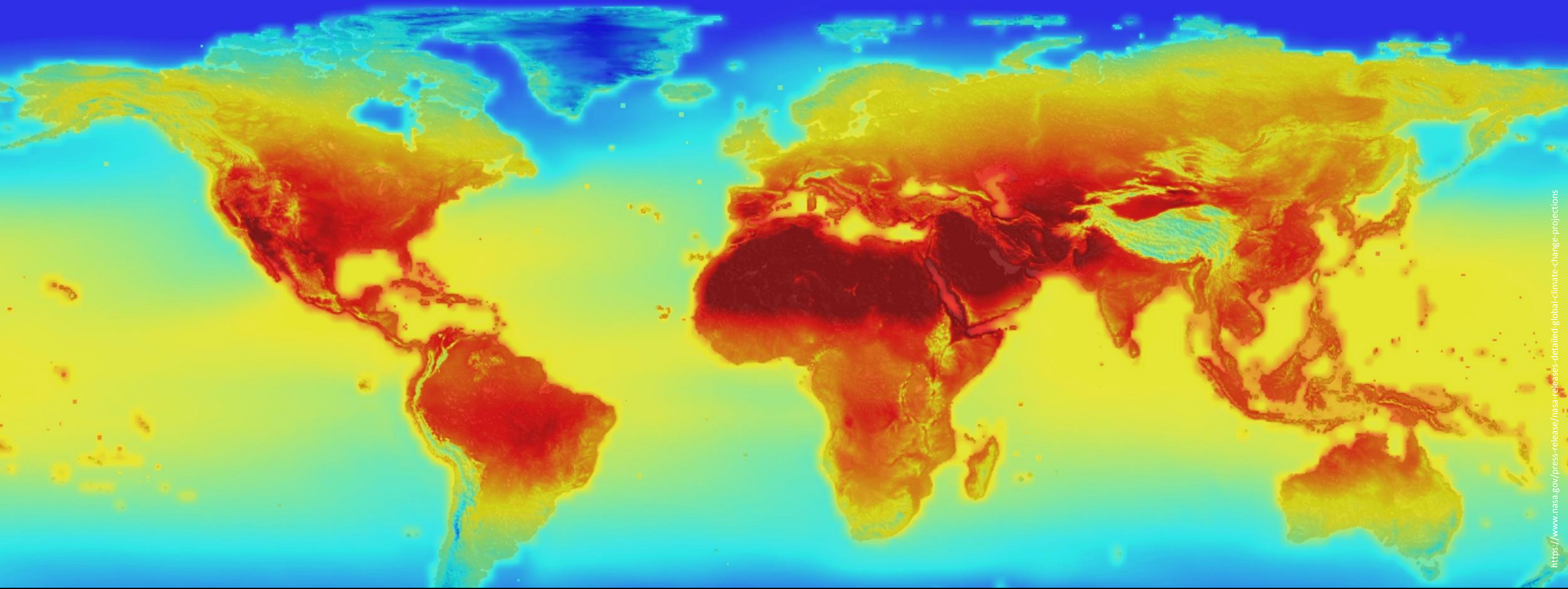



# Integration of Phenomics and Quantitative Genetics to Improve Cotton Resiliency

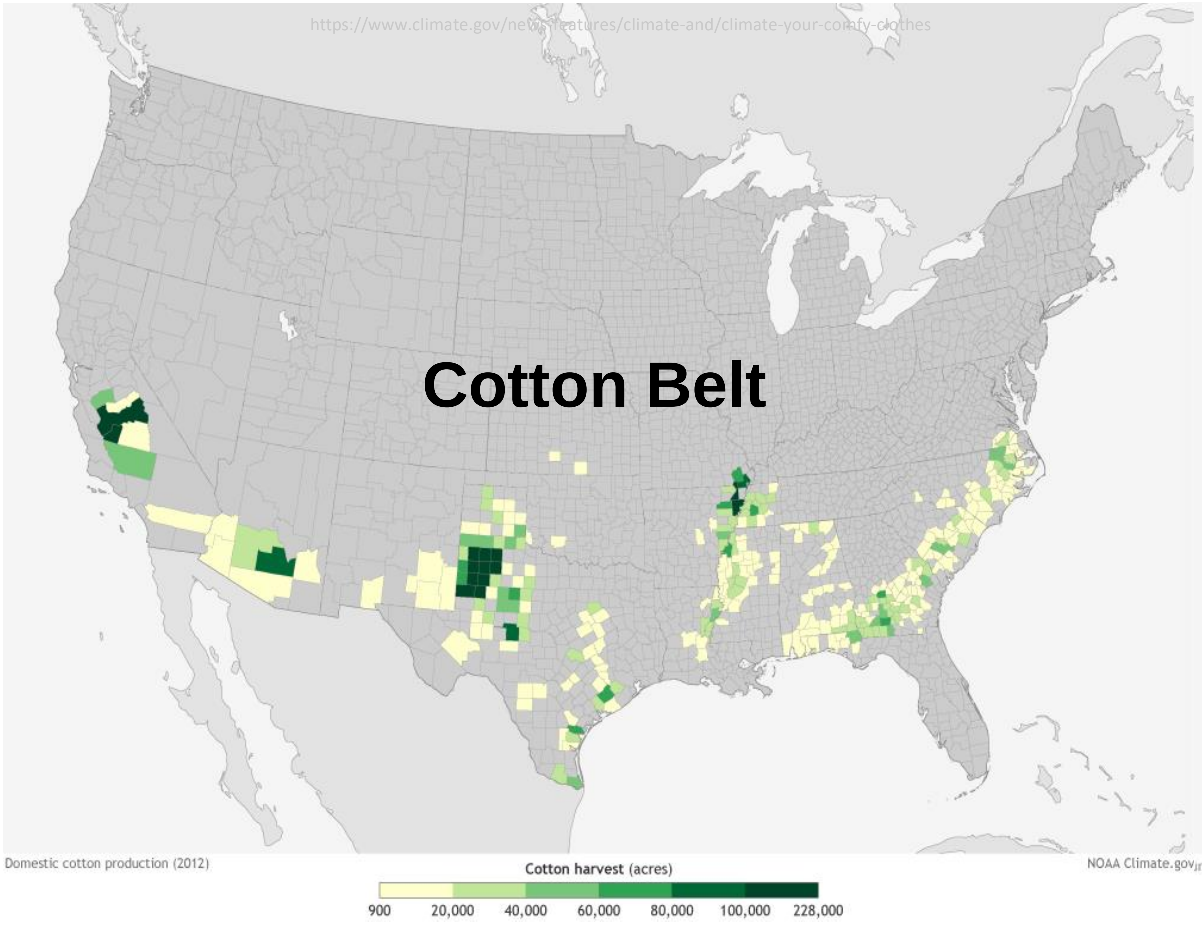
Duke Pauli, PhD
Cotton Inc. Fellow, Gore Lab, Cornell University
(University of Arizona, Jan 1st, 2018)

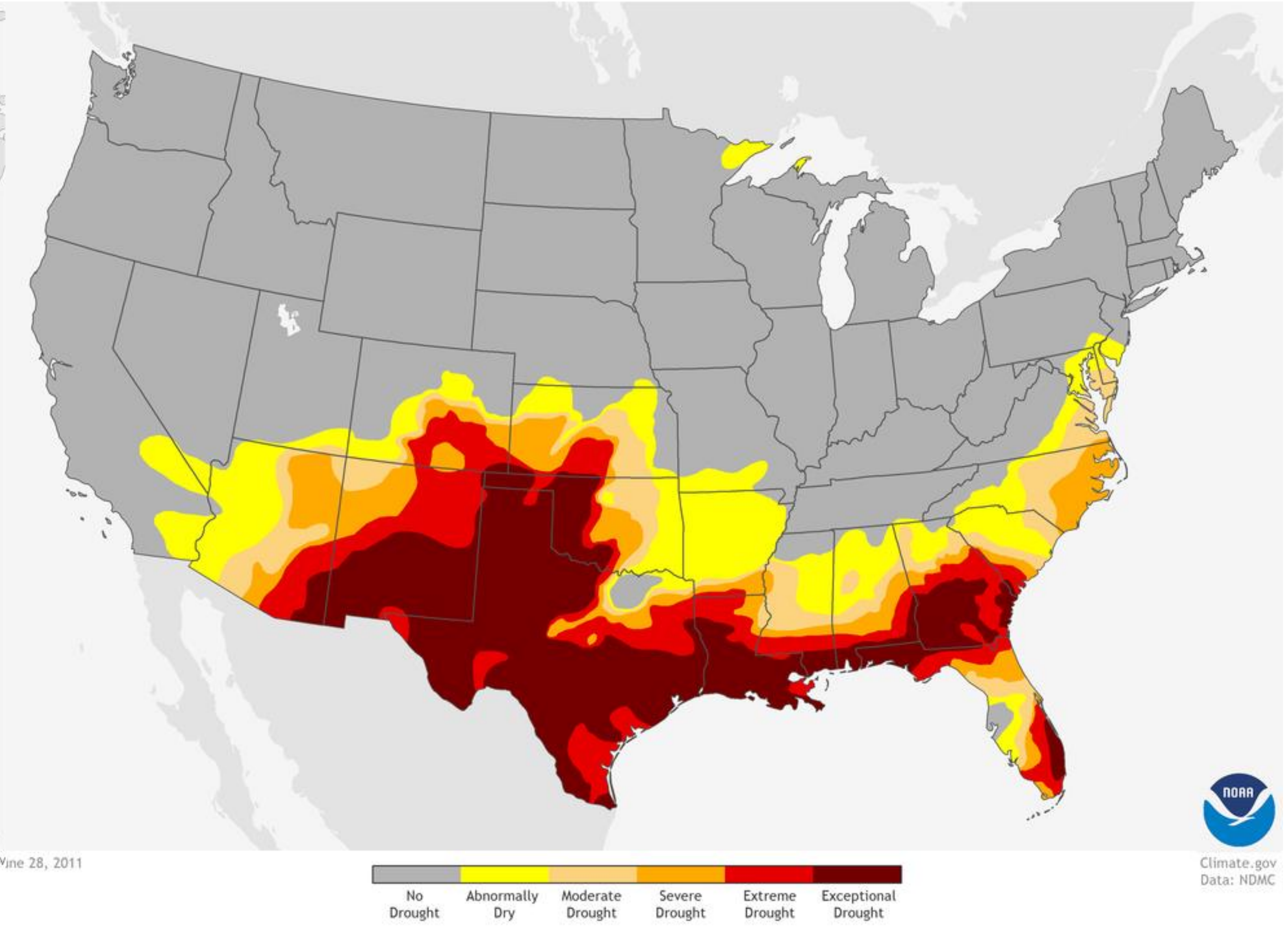
2017 Cotton Breeders' Tour

Garfield County, TX

Sustainable agricultural production is threatened by increasingly variable weather patterns and diminishing fresh water

**Photo: Jay Janner**

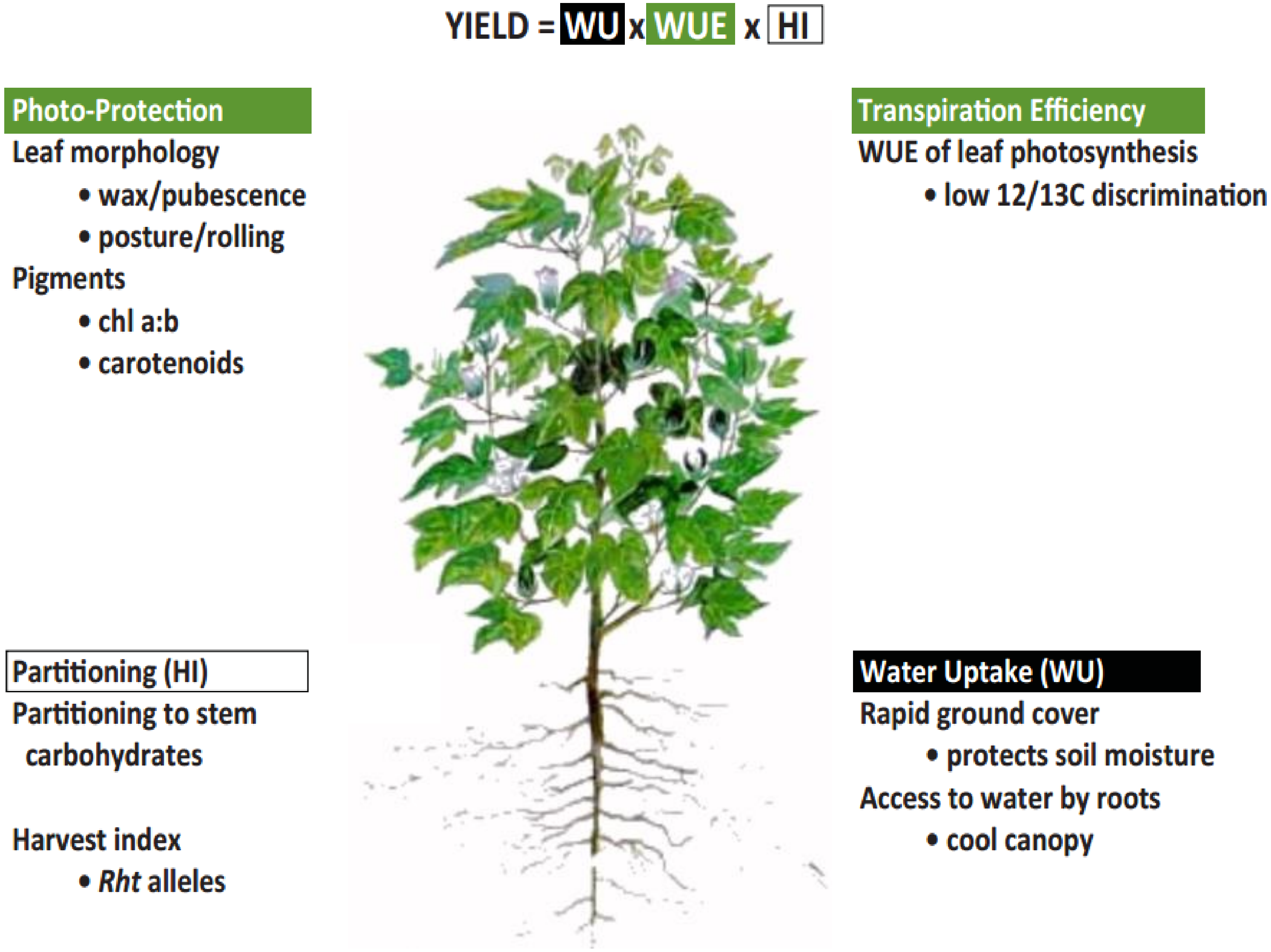



- Drought of 2011, 2.2 billion dollar economic loss in cotton production
- 55% of planted acres abandoned
- Global data supports same pattern in other cotton producing regions
- **Challenge: Developing drought and heat stress tolerant varieties**

# Plant breeding as a solution

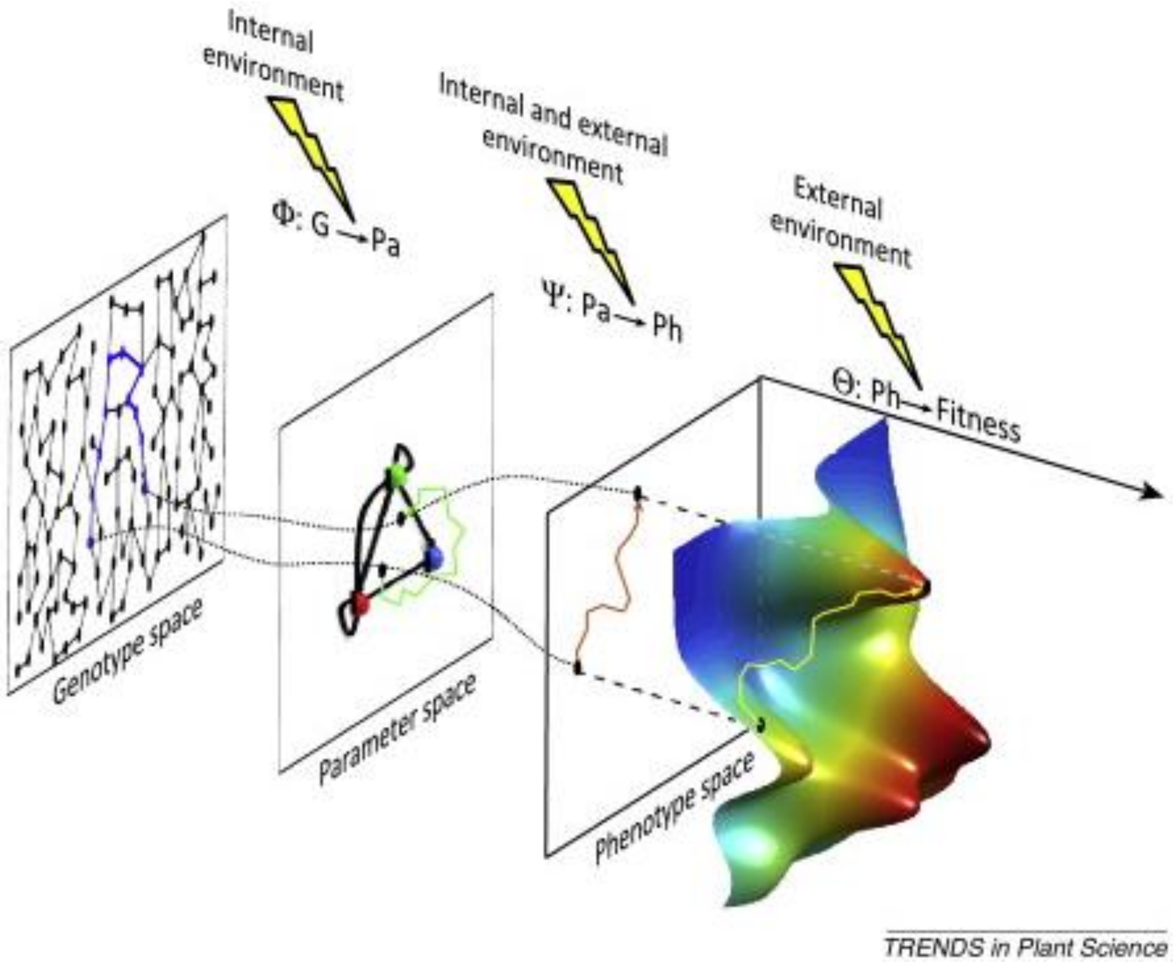
- The drought "phenotype" is a whole plant response
  - A phenotype entirely reliant on the environment in which it is expressed
  - No "single gene" solution
- Improvement must be at the whole plant level
  - Understand the underlying biology and genetics of stress-responsive traits
- Integrate physiology and genetics to increase genetic gain and more efficiently develop stress resilient cultivars




Adapted from: Physiological Breeding: Interdisciplinary Approaches to Improve Crop Production, Reynolds et al. (2011)
Cotton plant image from: http://www.soilcropandmore.info/crops/CottonInformation/insect/B-933/b-933.htm

# Genetics of abiotic stress tolerance

- Can we collect meaningful, physiologically relevant data under field conditions?
- Is there exploitable variation for stress-adaptive traits in cotton?
- What is the temporal basis of QTL expression patterns in cotton?
- Can physiological traits predict agronomic traits?




Adapted from Gutierrez and Maere, (2014) Trends in Plant Science 19:5

# High-Throughput Phenotyping (HTP) is essential

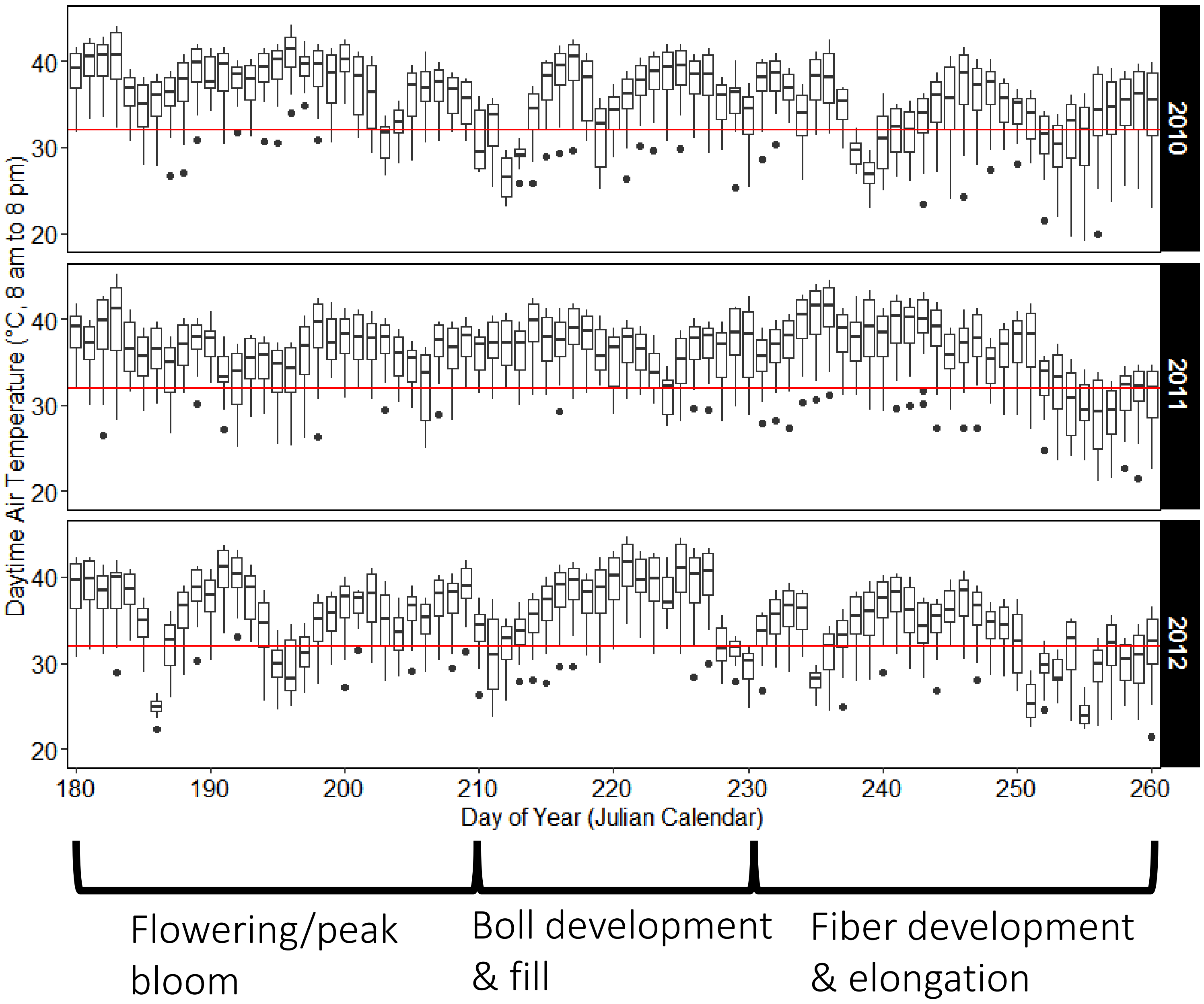
- Evaluate plants under ***field*** conditions (imperative for drought research)
- Measure throughout trait development
- Utilize larger populations
- Lower cost and minimized subjectivity

http://www.flatoutdelta.com/Landscapes/FlatOutDelta/i-z7rknbQ

# HTP Field Experiment at MAC/USDA-ARS in Maricopa, AZ

# HTP Experimental Design

- **Maricopa Agricultural Center:** clear skies, limited rain, high temperatures
- **Managed Stress:** Precision irrigation provided consistent drought and heat conditions
- **Two Irrigation Regimes:**
  - Water-limited (Dry, 50% daily ET)
  - Well-watered (Wet, 100% daily ET)
  - Drip irrigation, FAO-56 Crop ET model for wet and dry regimes
  - Subsurface drip irrigation
  - Initiated at flowering




Red line at 32°C is the temperature at which yields are significantly impacted

# HTP Experimental Design

- TM-1×NM24016 mapping population
  - 95 recombinant inbred lines (RILs)
  - Community resource
  - TM-1 is the reference genome
- Field design, arranged as (0,1) alpha lattice
  - 9 meter long single row plots
  - Two replications per irrigation regime


# Phenotyped Traits

- HTP Canopy
  - Temperature, NDVI, height
- Physiological
  - ABA, CID, Chlorophyll
- Agronomic
  - Lint yield, boll size
- Fiber quality
  - Length, strength, fineness
- Seed ionomics

# HTP: Proximal sensors, platform, and vehicle

- Active, multispectral crop canopy sensor
  - Canopy reflectance
- Infrared thermometer
  - Canopy temperature
- Ultrasonic transducer
  - Canopy height
- Data Loggers
  - Onboard data storage
- GPS-RTK
  - Geolocating each collected data point with position and time stamp

Modified high-clearance tractor

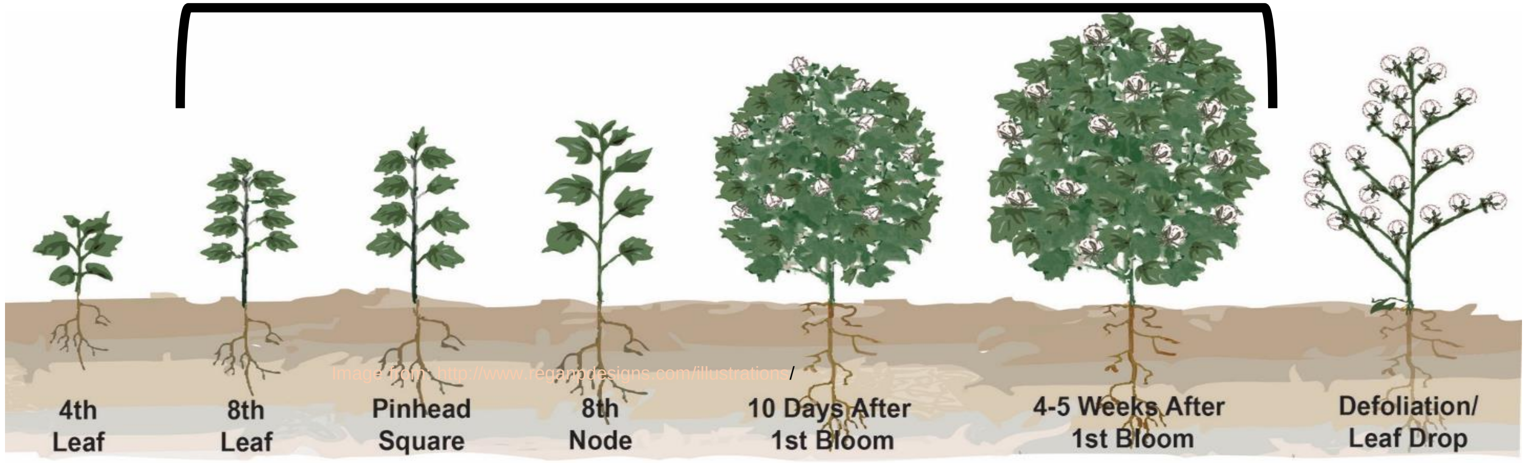
Average speed of 2.82 km/h
1 data point/meter (1 Hz)

Andrade-Sanchez et al. 2014 Functional Plant Biology

# Longitudinal assessment of phenotypes over time

- Canopy traits
  - Canopy temperature – plant-water relations
  - NDVI – used to quantify change in canopy architecture as a function of wilting
  - Canopy height & LAI – whole plant response

Canopy data collection initiated at flowering, collected weekly




# HTP Geoprocessed Canopy Temperature Data

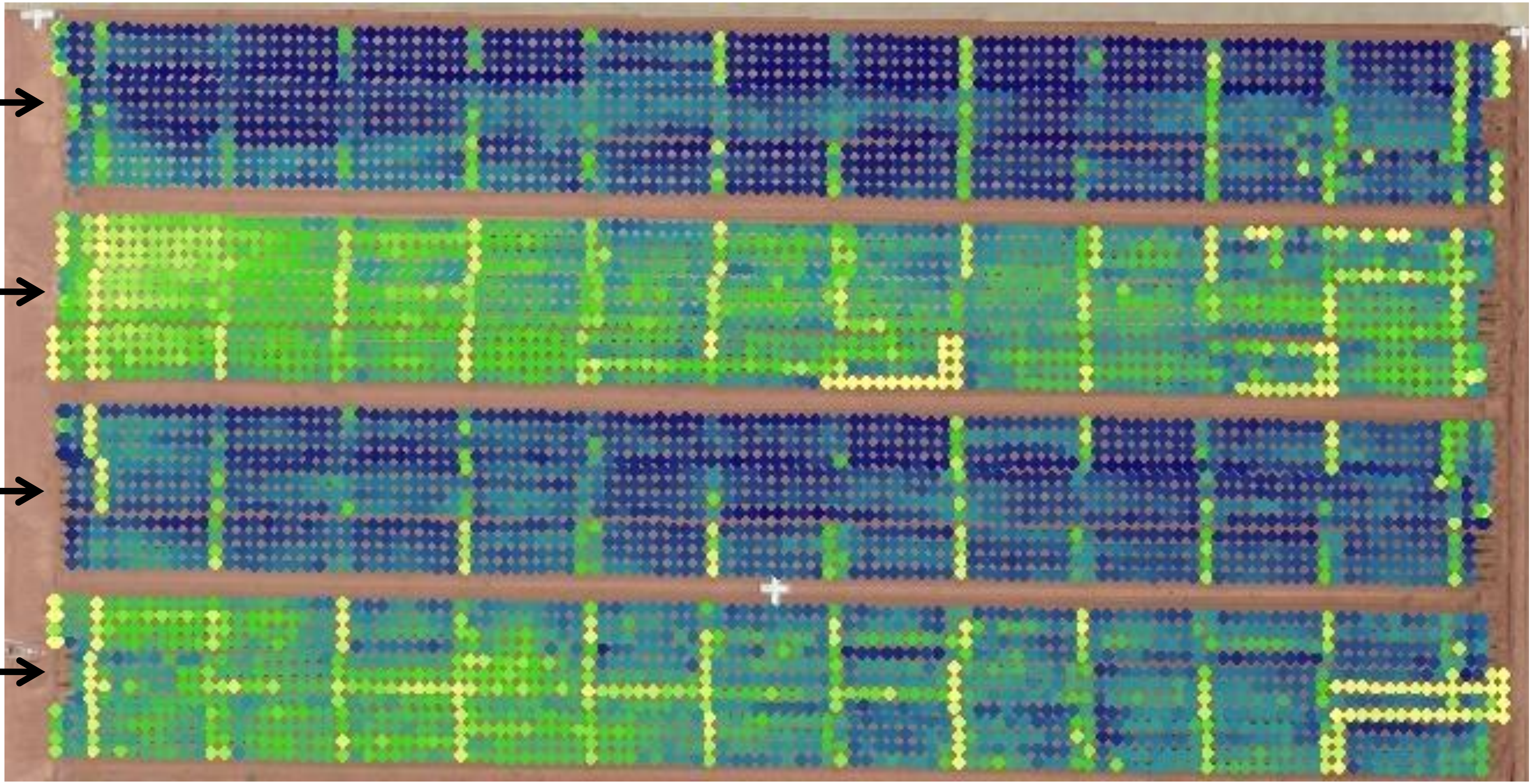
- Each circle represents a canopy temperature data point, multiple measurements per plot
- Data from August 12, 2010 at 1 pm (MST)
- Well-watered (Wet) is approximately 3-10°C cooler than water-limited (Dry)

Wet Rep 2: 28-36°C →

Dry Rep 2: 33-49°C →

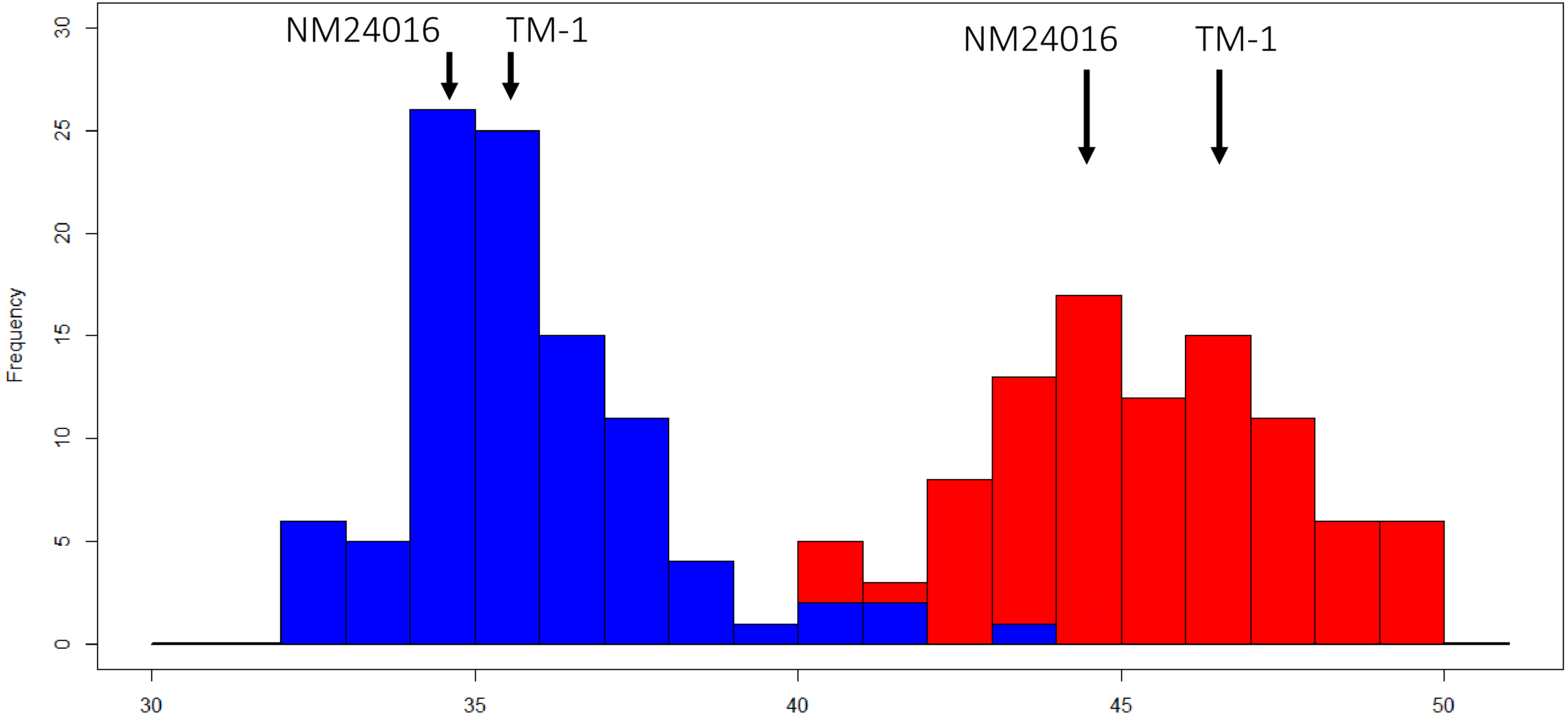
Wet Rep 1: 29-36°C →

Dry Rep 1: 31-46°C →



# Transgressive variation for canopy temperature (°C)

## Wet and Dry Plots at 1 pm on Day 222, 2012

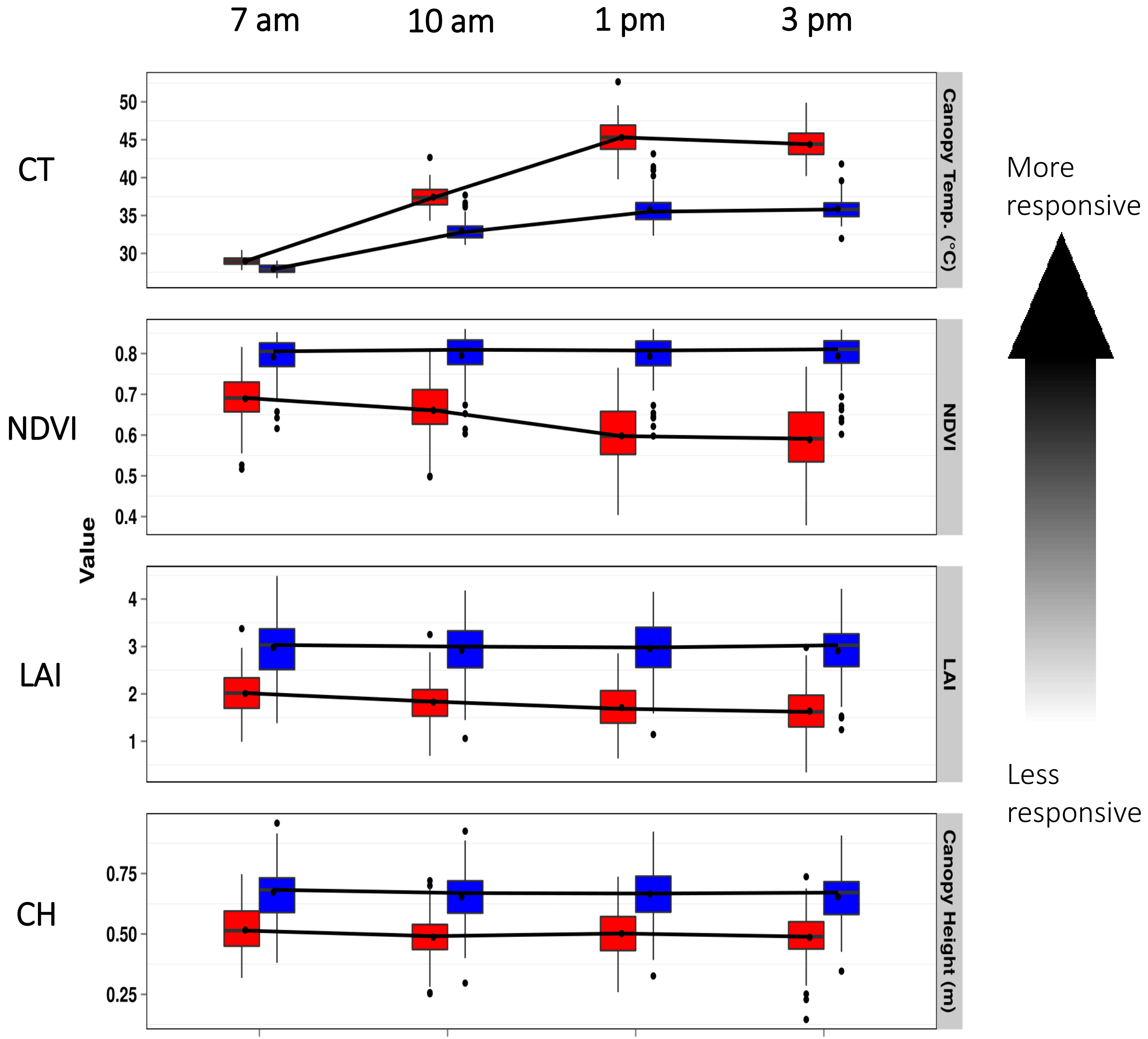



| Wet | Dry |
| --- | --- |
| Mean = 35.7°C | Mean = 45.2°C |
| SD = 1.9 | SD = 2.3 |
| $H^2$ = 0.83 | $H^2$ = 0.90 |

# Differential time-by-treatment interactions for canopy traits

Wet and Dry Plots at 1 pm on Day 222, 2012

- CT = Canopy temperature
- NDVI = Normalized difference vegetation index
- LAI = Leaf area index
- CH = Canopy height



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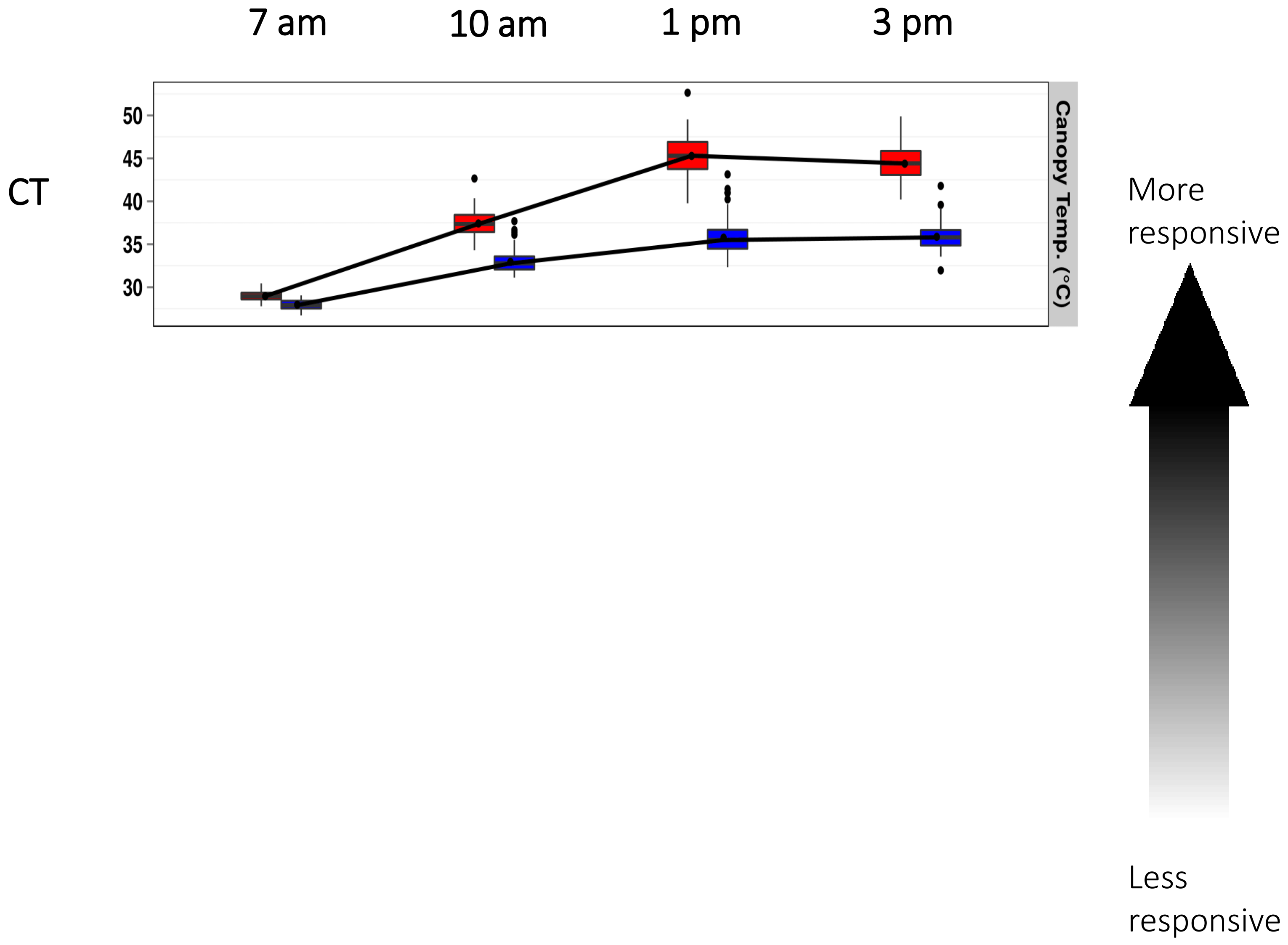
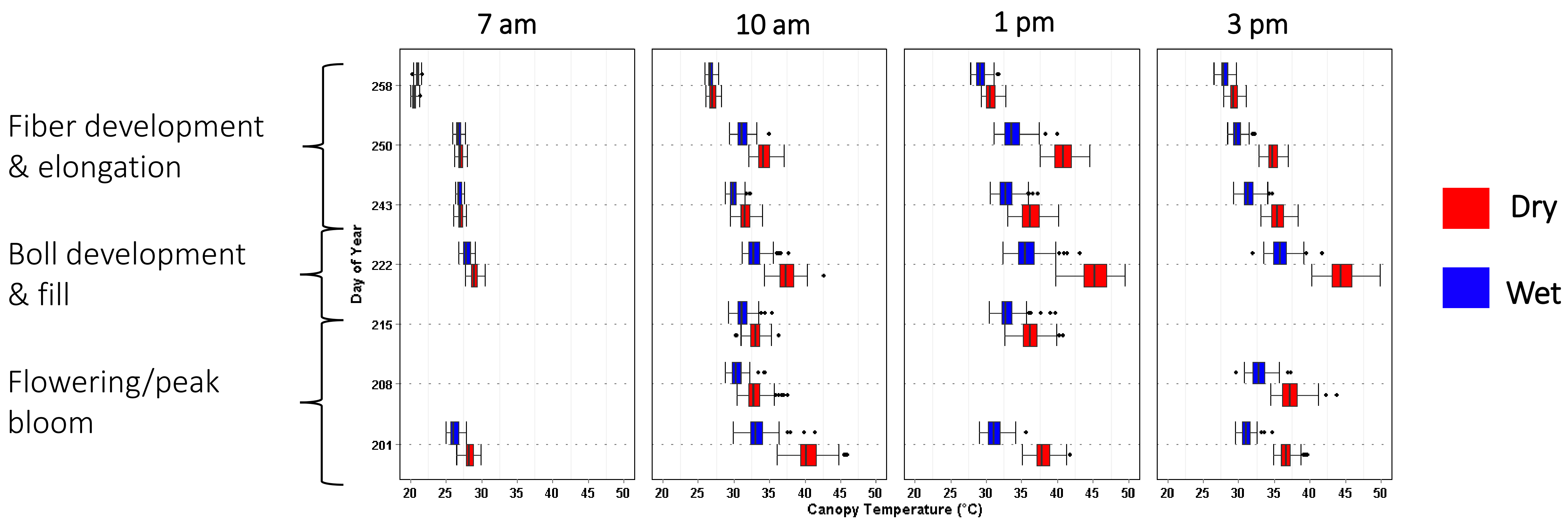


# Dynamic response of canopy temperature to irrigation regime at multiple times and days




Phenotypic variation for canopy temperature at each time of day that data were collected under two irrigation treatments from 19 July – 14 Sept. 2012

# Canopy temperature measurements are more highly correlated within a plant growth stage

| Day | 188 | 195 | 202 | 216 | 223 | 230 | 237 | 244 | 251 |
|---|---|---|---|---|---|---|---|---|---|
| 188 | | 0.89 | 0.66 | 0.74 | 0.53 | 0.42 | 0.34 | 0.30 | 0.42 |
| 195 | 0.83 | | 0.76 | 0.81 | 0.60 | 0.47 | 0.38 | 0.37 | 0.45 |
| 202 | 0.70 | 0.82 | | 0.79 | 0.74 | 0.70 | 0.66 | 0.63 | 0.60 |
| 216 | 0.65 | 0.76 | 0.74 | | 0.89 | 0.75 | 0.57 | 0.56 | 0.53 |
| 223 | 0.57 | 0.62 | 0.65 | 0.78 | | 0.82 | 0.62 | 0.60 | 0.46 |
| 230 | 0.53 | 0.56 | 0.55 | 0.82 | 0.87 | | 0.88 | 0.84 | 0.68 |
| 237 | 0.43 | 0.44 | 0.40 | 0.60 | 0.66 | 0.87 | | 0.93 | 0.77 |
| 244 | 0.41 | 0.39 | 0.35 | 0.62 | 0.67 | 0.88 | 0.94 | | 0.82 |
| 251 | 0.40 | 0.38 | 0.30 | 0.52 | 0.53 | 0.76 | 0.87 | 0.93 | |

Dry

Wet

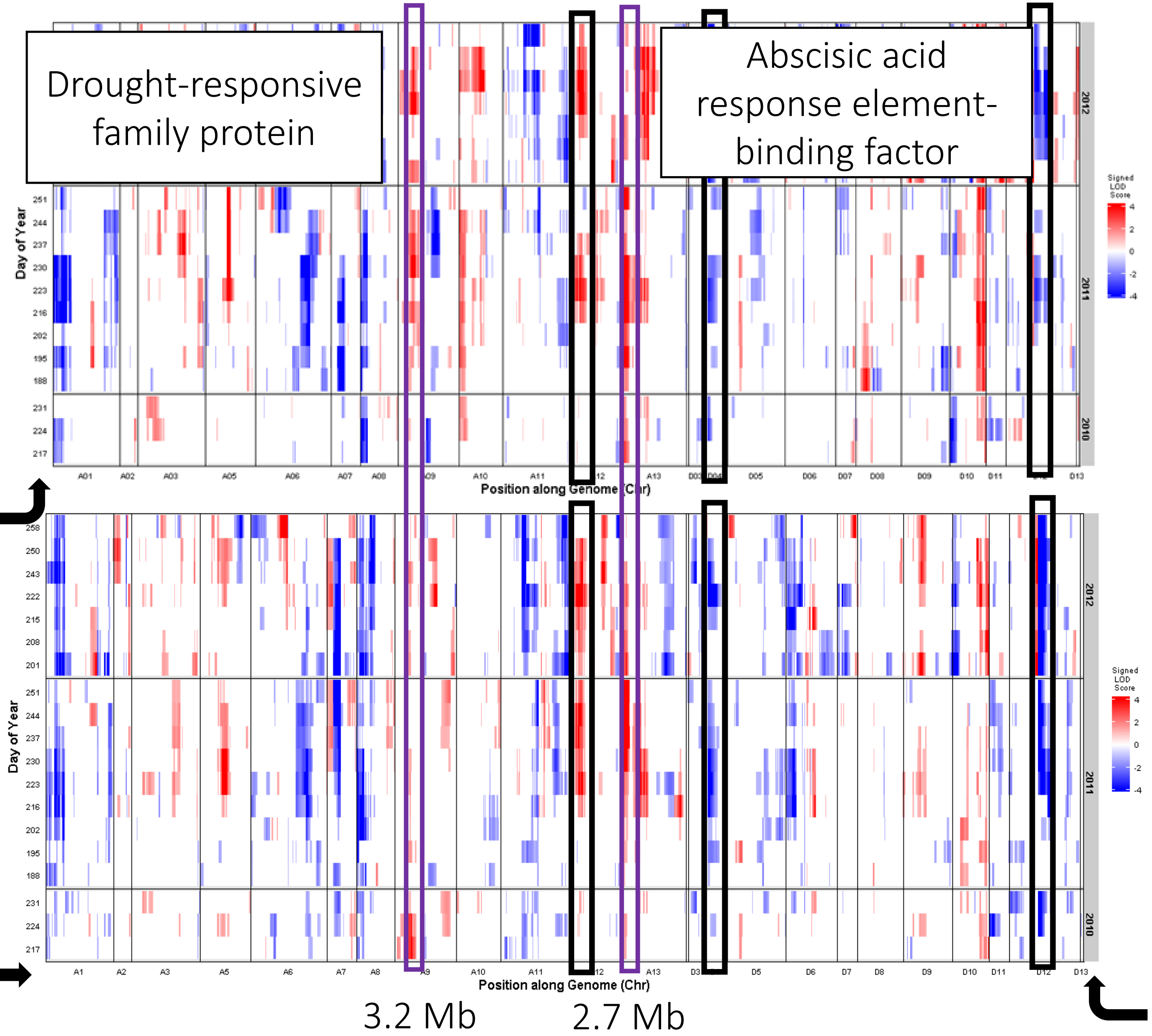
Flowering/peak bloom

Boll development & fill

Fiber development & elongation

Pearson's correlations for mean canopy temperature under two irrigation treatments from 7 July – 8 Sept. 2011

# Distinct temporal patterns of genetic effects control variation in canopy temperature




Day of year

Position along genome

Dry Treatment

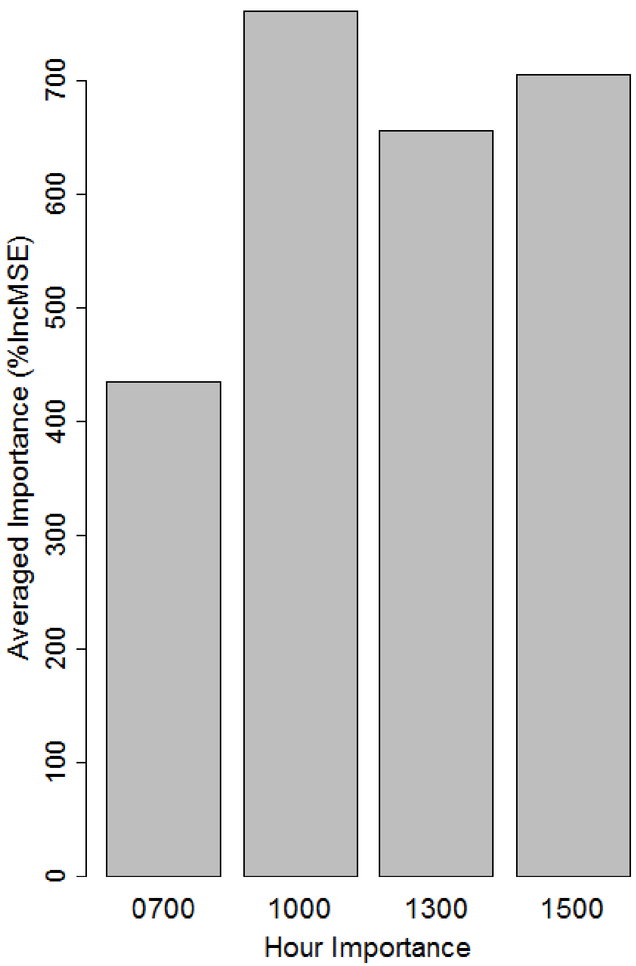
Wet Treatment

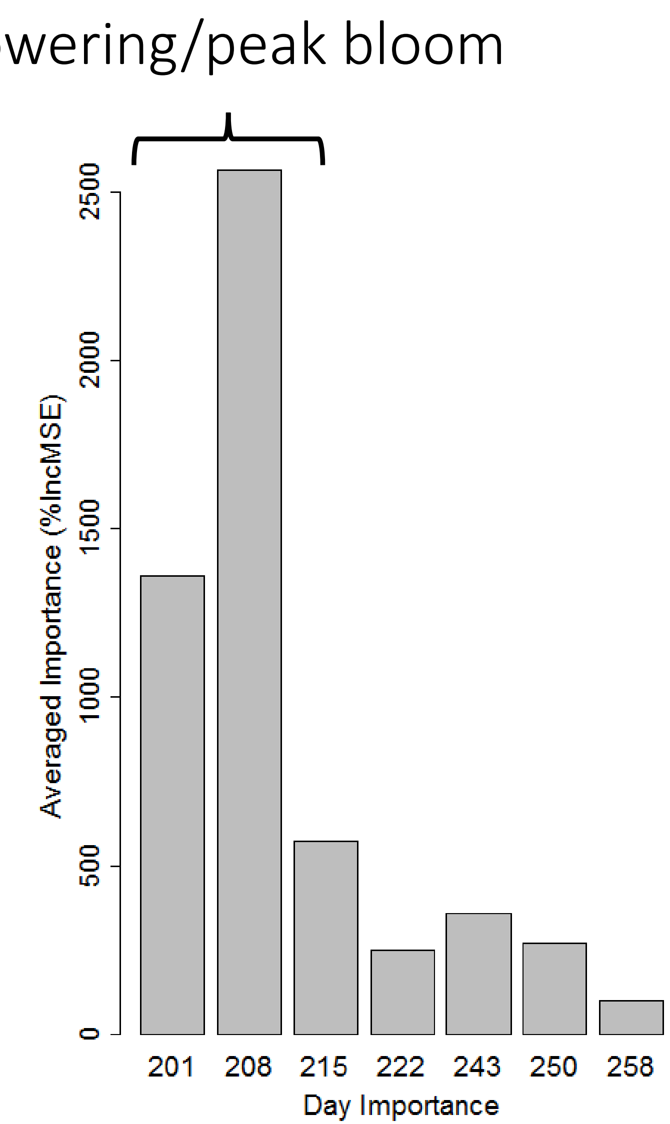
= Increase canopy temp.

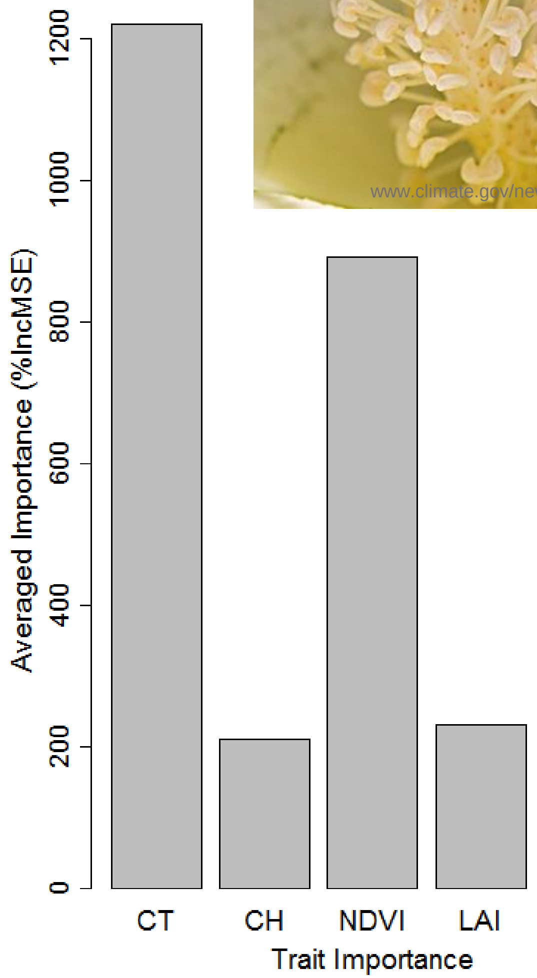
= Decrease canopy temp.

Individual years

# Canopy temperature at flowering/peak bloom is most predictive of lint yield

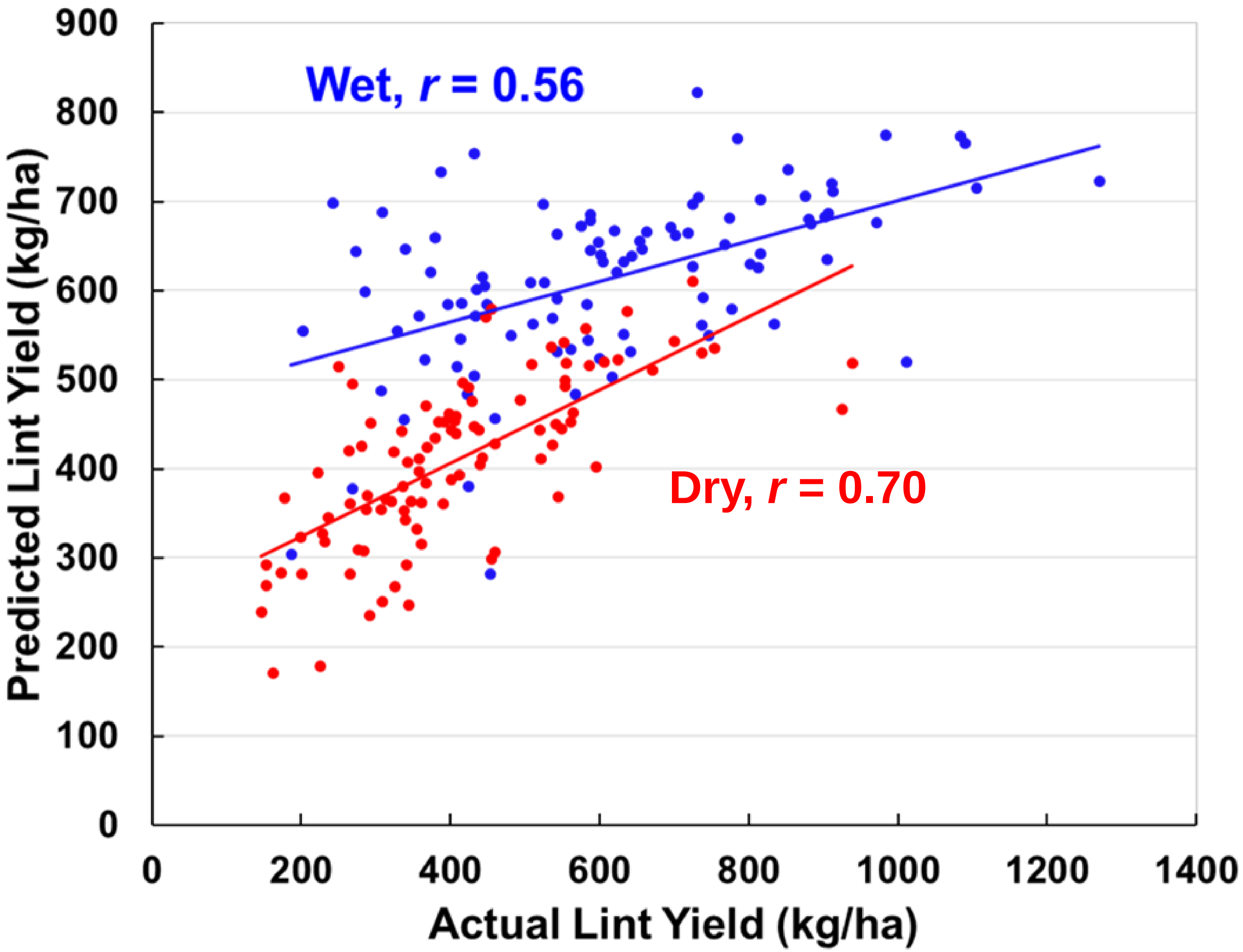



High prediction accuracies of lint yield using canopy temperature data from flowering/peak bloom

# 2012 lint yield



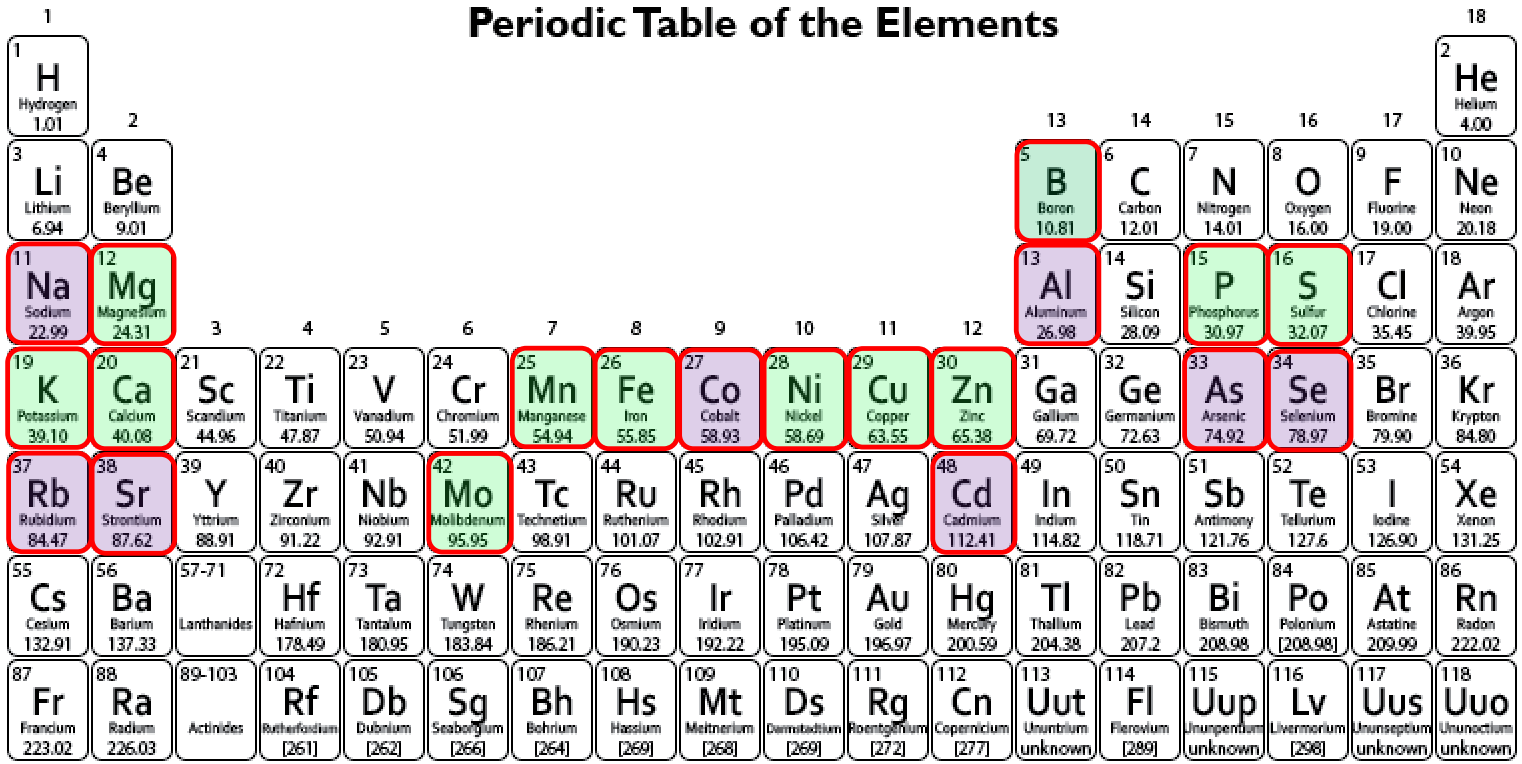
# Understanding environmental effects:

## Phenotype = Genotype + Environment + Genotype×Environment

- Current phenotyping efforts only tell half the story (the top half)
- In-field root phenotyping in its infancy
- How do plants interact with their soil environment?

# Ionomics: another HTP technology

- Ionomics: rapid profiling of elemental concentration, 20 elements
- Elements are essential components of every cell
- Change in elemental concentration due to:
  - **Abiotic stress (drought)**
  - **Soil composition**
  - Plant morphology
  - Development stage of plant
- Provide information about overall health and function of the plant

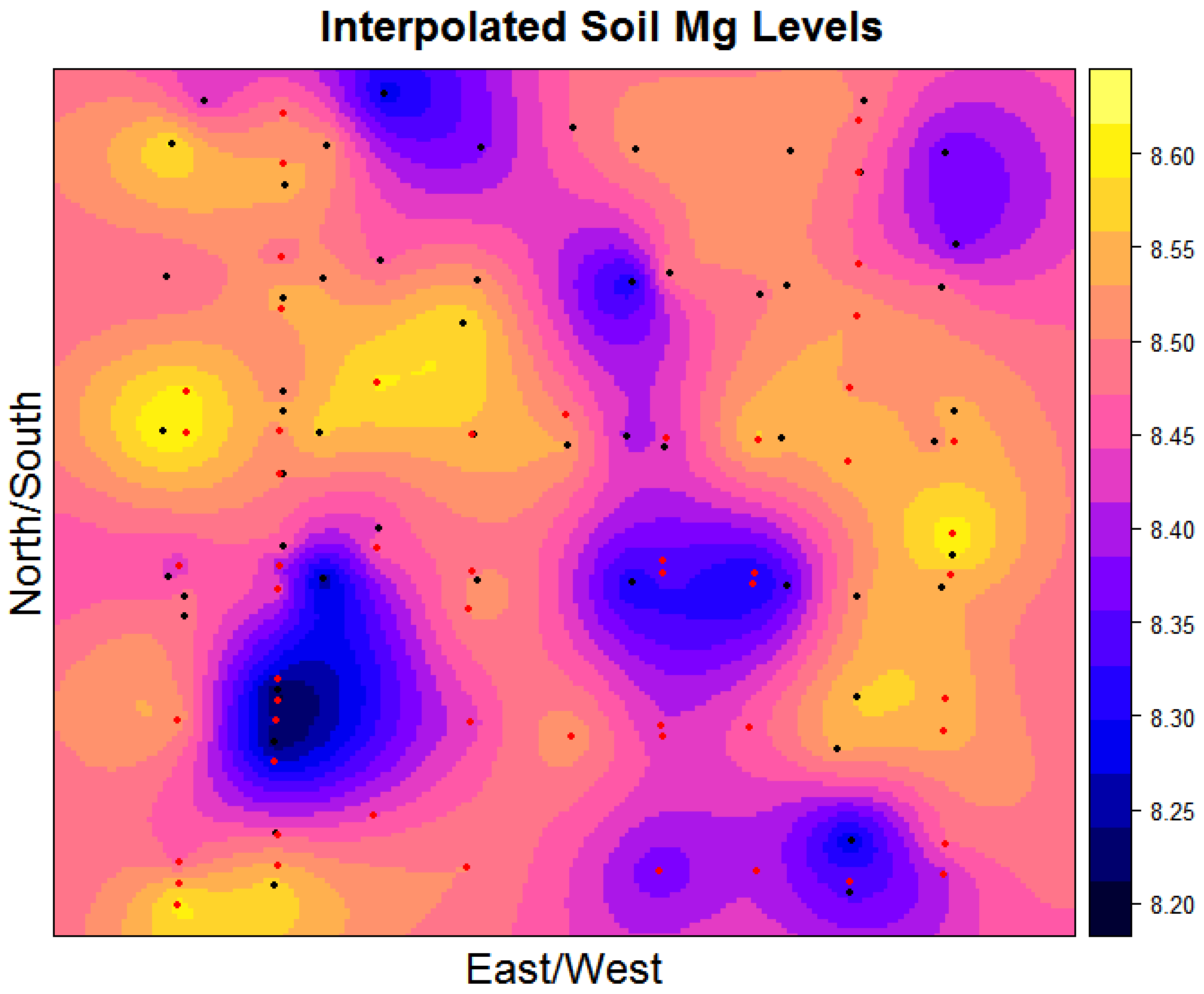



https://sciencenotes.org/kids-periodic-table/

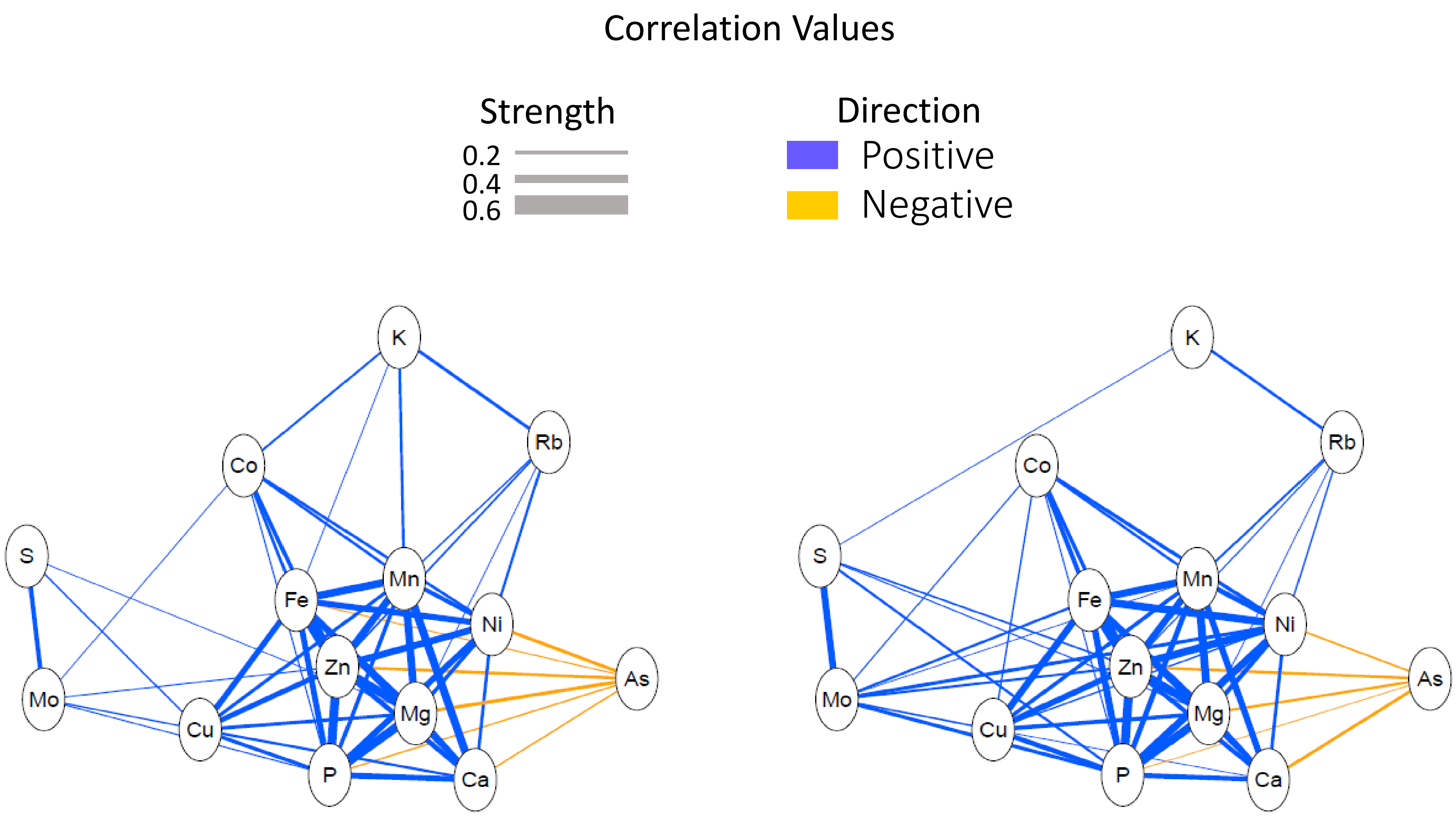
- Green boxes = essential elements for plant growth and health
- Purple boxes = nonessential and trace elements

# Soil environment is highly heterogeneous

- Magnesium concentration of soil where HTP experiments were carried out, samples taken from 5 depths
- Red & black circles = sampling locations
- Yellow = high magnesium content
- Blue = low magnesium content
- Soil magnesium concentrations were significantly correlated with seed magnesium concentrations



# Ionome is highly interrelated genotypically

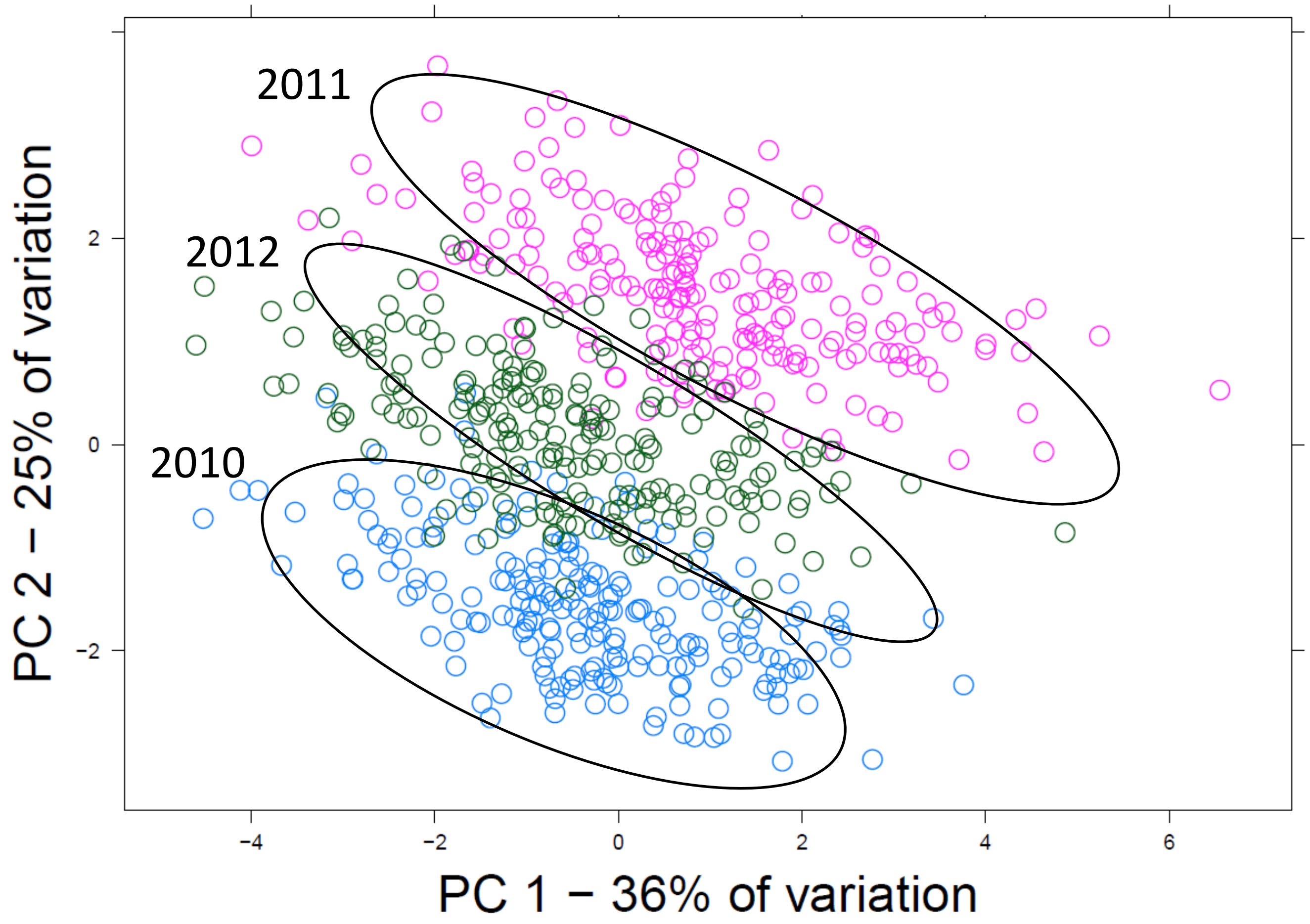



Genotypic Correlations Dry

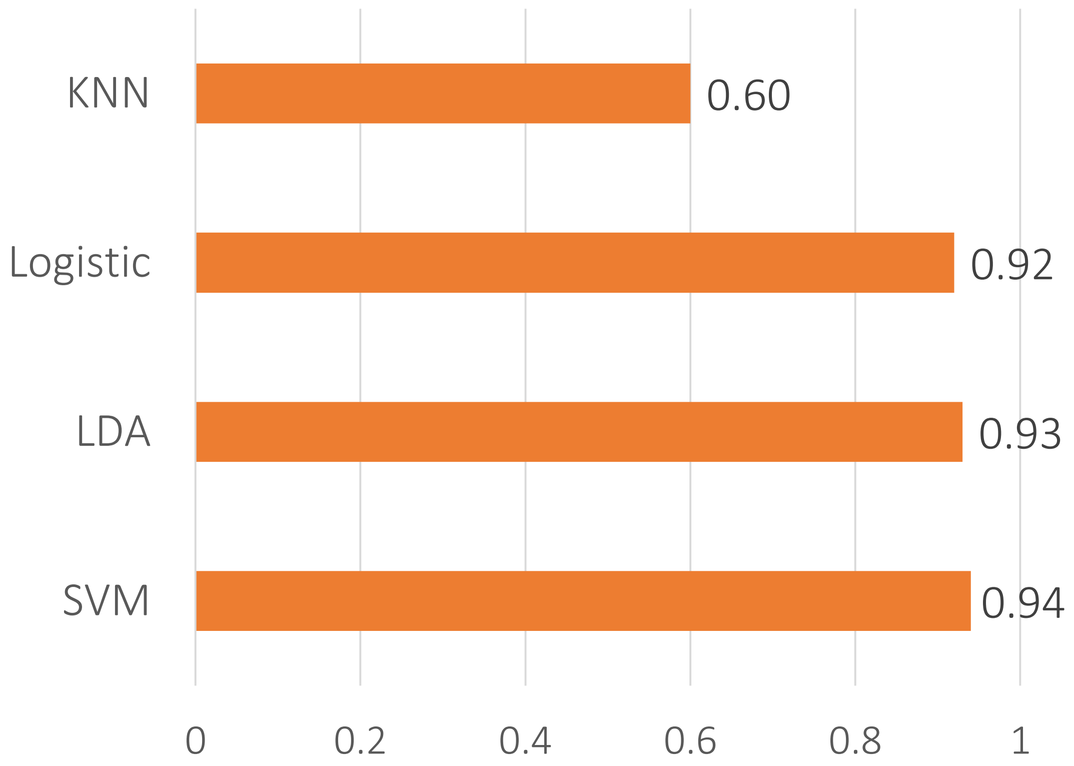
Genotypic Correlations Wet

# The ionome predicts abiotic stress

Strong Year Effect



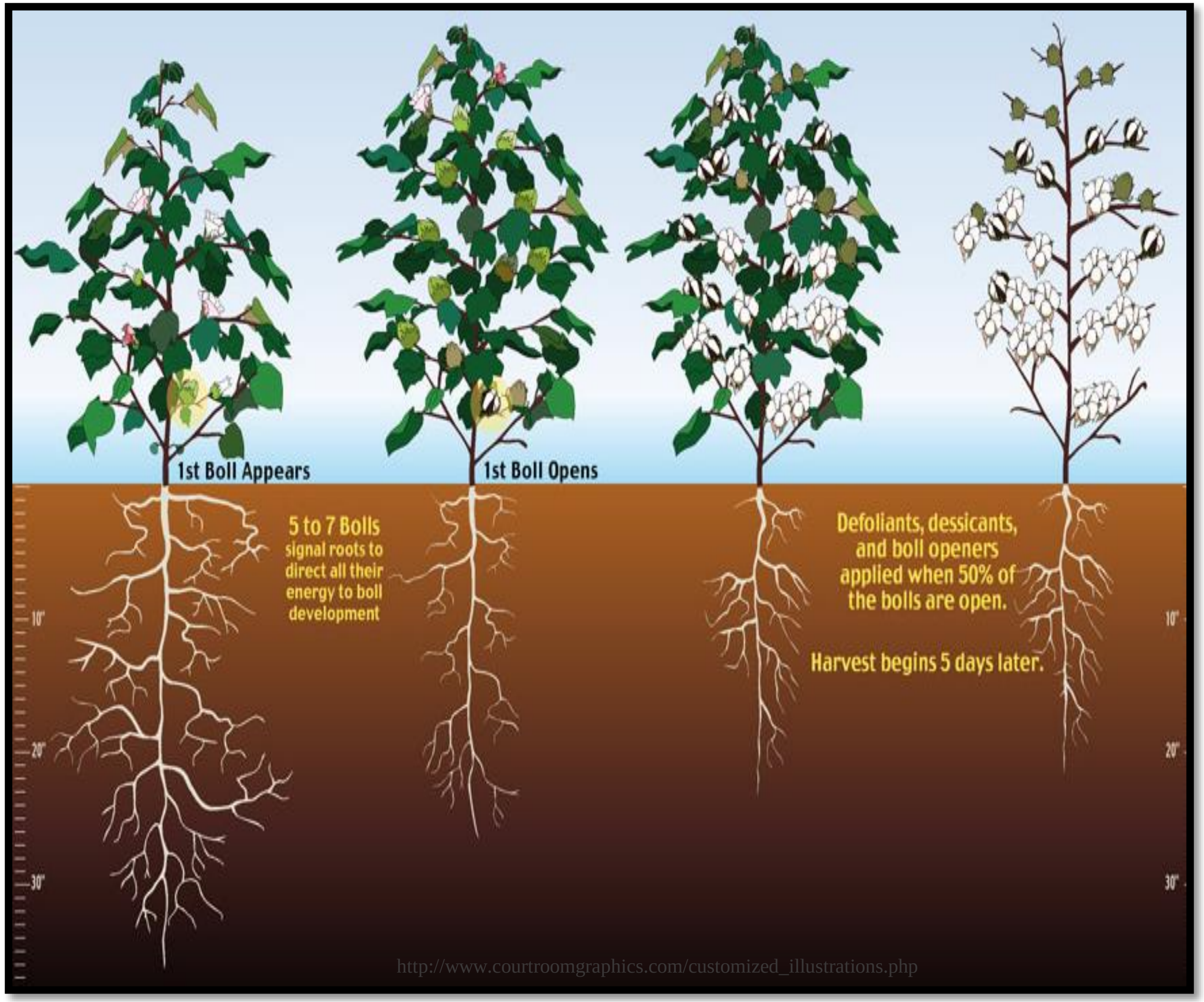

Prediction Accuracies




Prediction of irrigation treatment achieved accuracy of 94%

# Summary of Cotton HTP Experiments

- Field-based HTP
  - Novel platform
  - Dynamic traits
  - Temporal QTL
  - Yield prediction
- Ionomics HTP
  - Incorporation of environment
  - Interrelated system
  - Predictive of stress



# Acknowledgements


**Cornell University**

Gore lab
Yupei Lui
Elodie Gazave
Tim Setter
Abraham Stroock
Piyush Jian

**NMSU**

Jinfa Zhang

**Donald Danforth Center**

Ivan Baxter
Greg Ziegler

**U.S. ALARC Maricopa, AZ**

Andrew French
Jeffrey White
Douglas Hunsaker
Elizabete Carmo-Silva
Kelly Thorp
Joel Gilley
Kristen Harbour
Virginia Moreno
Sara Wyckoff
Brian Nadon
Mike Salvucci
Bob Strand

**University of Arizona**

Pedro Andrade-Sanchez
John Heun

**Kansas State University**

Jesse Poland

**USDA-ARS**

Richard Percy
David Fang

**Purdue University**

Min Zhang

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