ABSTRACT: 454

UNDERSTANDING DROUGHT TOLERANCE AND BREEDING SOYBEANS FOR SUSTAINABLE YIELD UNDER DROUGHT STRESS

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Drought inevitably presents a challenge to production agriculture. This challenge is increasing as a result of continuing global climate change and scarcity of water resources. The 'Team Drought', consisting of scientists from the U.S. Department of Agriculture and several universities in the U.S., has tackled the drought problem in soybean production using multidisciplinary approaches for almost two decades. Team Drought's research, funded by farmers through the United Soybean Board, addresses the complexities of drought tolerance by dissecting the physiology and genetics of yield potential under drought stress. A critical component of success was the survey of the USDA Soybean Germplasm Collection to identify plant introductions carrying favorable traits associated with drought tolerance and subsequent utilization in breeding for sustainable yields under drought stress. Two rare slow-wilting genotypes, PI 416937 and PI 471938, were discovered as having unusual physiology and genetics for drought tolerance. Slow wilting in PI 416937 appeared to be associated with an early-season soil water-conserving mechanism coupled with a restricted transpiration by partial stomata closure. PI 416937 carries five quantitative trait loci (QTL) for slow wilting, five QTL for prolific rooting, and a major QTL for limited leaf hydraulic conductance, all of which are associated with drought tolerance. PI 471938 has three QTL for slow wilting, although the mechanism is not yet clear, with each contributing to a 136 kg/ha yield increase under drought stress. Two breeding lines derived from these slow wilting sources have shown excellent yield potential, equal to or greater than that of the check cultivars in the USDA Uniform Tests across multiple environments. Prolonged nitrogen (N_2) fixation under drought stress was discovered in Jackson, PI 227557, and PI 471938. N_2 fixation activity in these genotypes was less sensitive to drying soil, thus, provides a yield advantage under water deficit conditions. Six breeding lines were developed with sustained N_2 fixation in a drying soil that have yields competitive with checks in irrigated conditions and have a 10-15% yield advantage over checks in drought stress conditions. Diverse soybean germplasm was also screened for fast and/or deep rooting characteristics.

Invited Speaker

Soybean Drought Tolerance Research in the U.S.

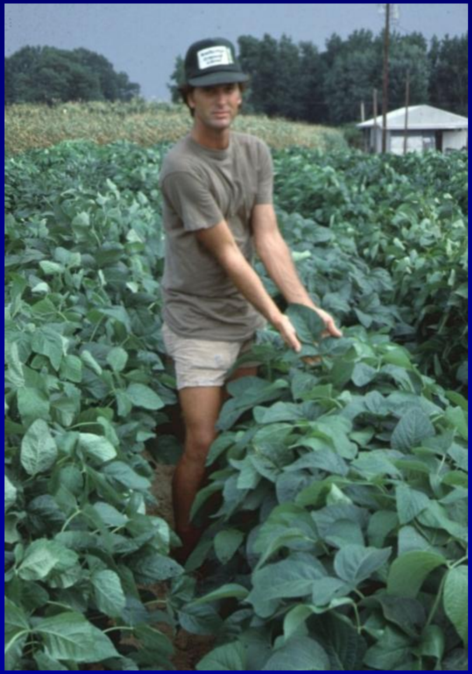
Pengyin Chen

University of Arkansas

Drought ?!!

Research Goal

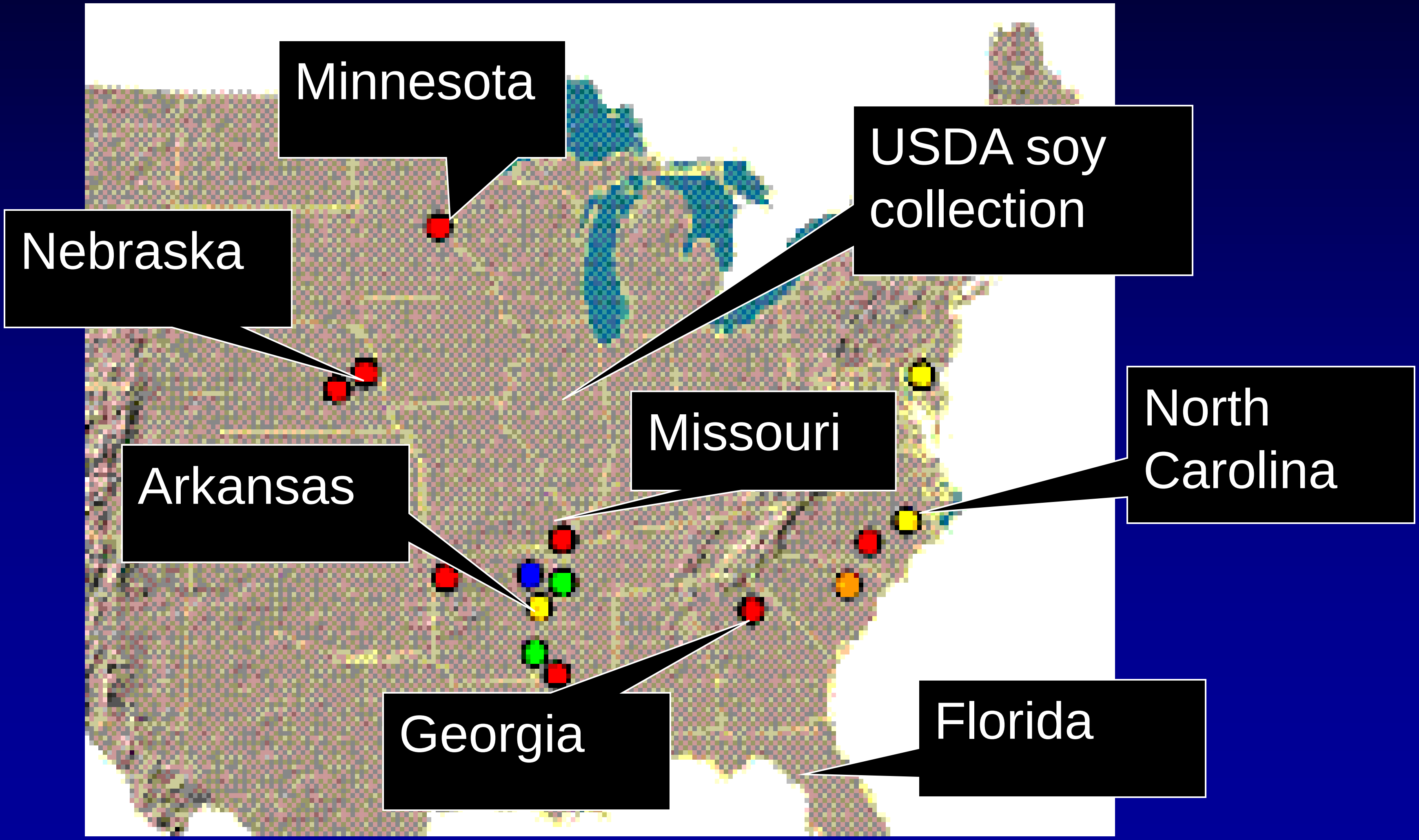
- Understanding drought tolerance
- Breeding for sustainable yield under drought stress



Research Contributions

- USDA-ARS
- North Caroline State Univ.
- Univ. of Arkansas
- Univ. of Georgia
- Univ. of Missouri
- Univ. of Minnesota
- Univ. of Nebraska
- Univ. of Florida

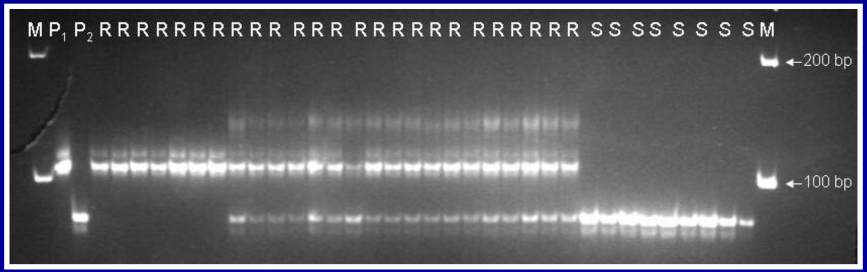
Geographic Coverage



Team Drought

Research Approach

- Physiologic
- Genetic
- Molecular
- Agronomic
- Breeding



Traits of Interest

- Slow-wilting
- N2-fixation
- Rooting
- Yield

Other Related Traits

- Water use efficiency
- Radiation use efficiency
- Leaf stomatal response to dry air
- Aquaporin protein vs. water transport
- Response to vapor pressure deficit & temperature
- Volumetric soil water content
- Shoot ureide concentration
- Acetylene reduction activity


Early 1990's
North Carolina
Tommy
Carter
Essex
PI 416937
Discovery of the Slow-Wilting Trait


Minnesota
Slow wilting type


Fast Wilting
Slow Wilting
Nebraska

Slow Wilting in Arkansas

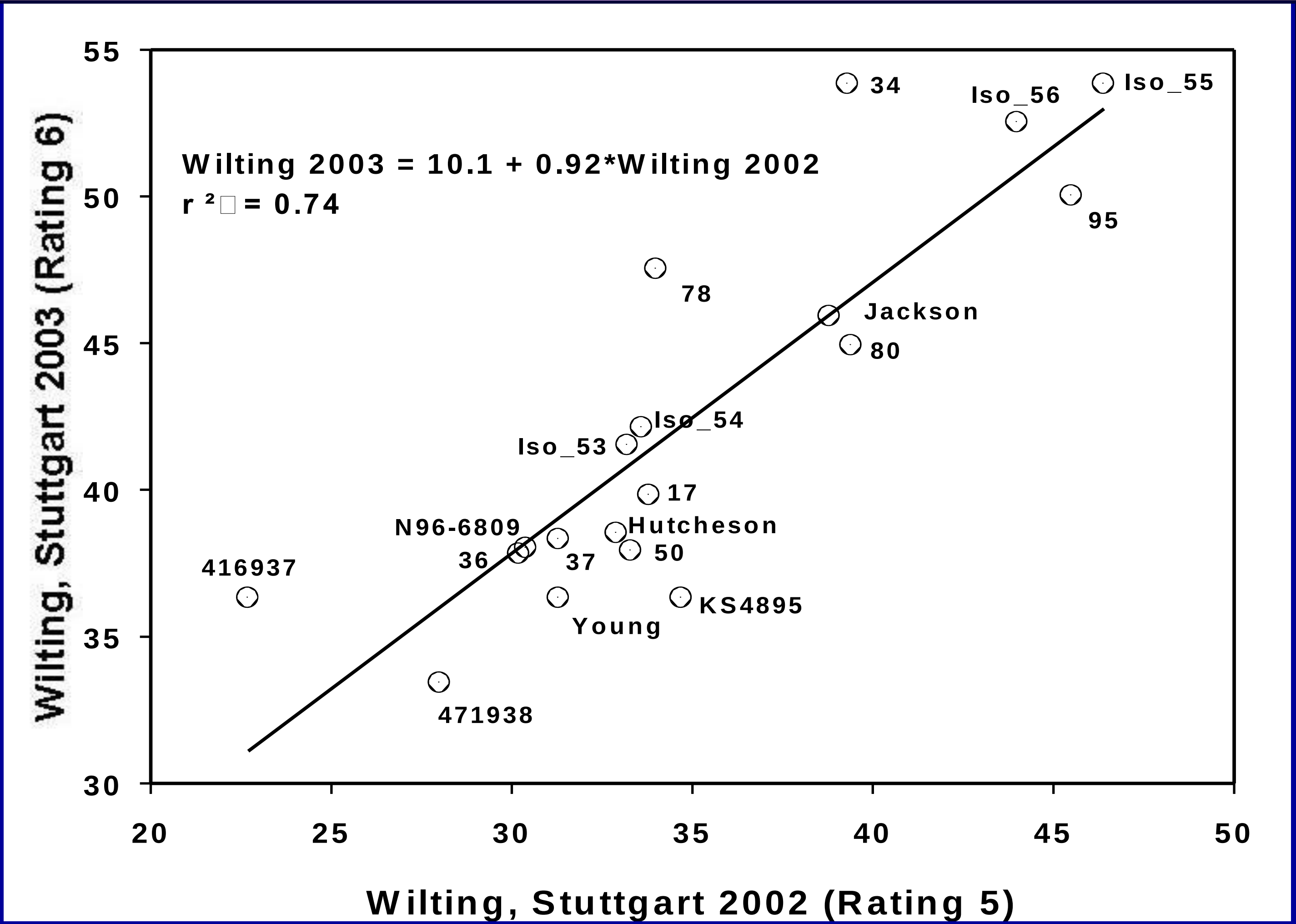
Slow Wilting

Fast Wilting

Drought in Georgia

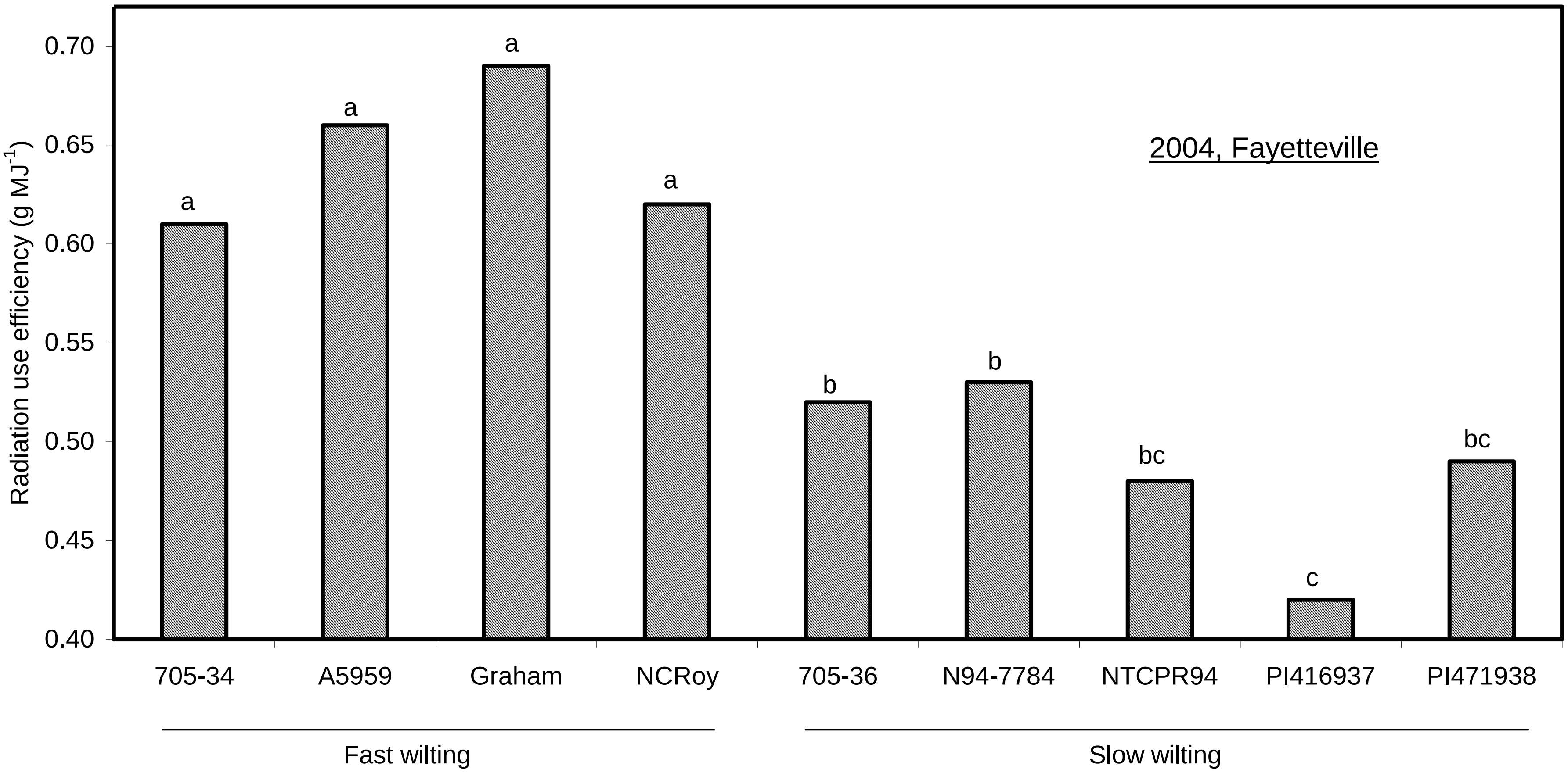
Slow Wilting Discovery

Slow Wilting → A Stable Trait



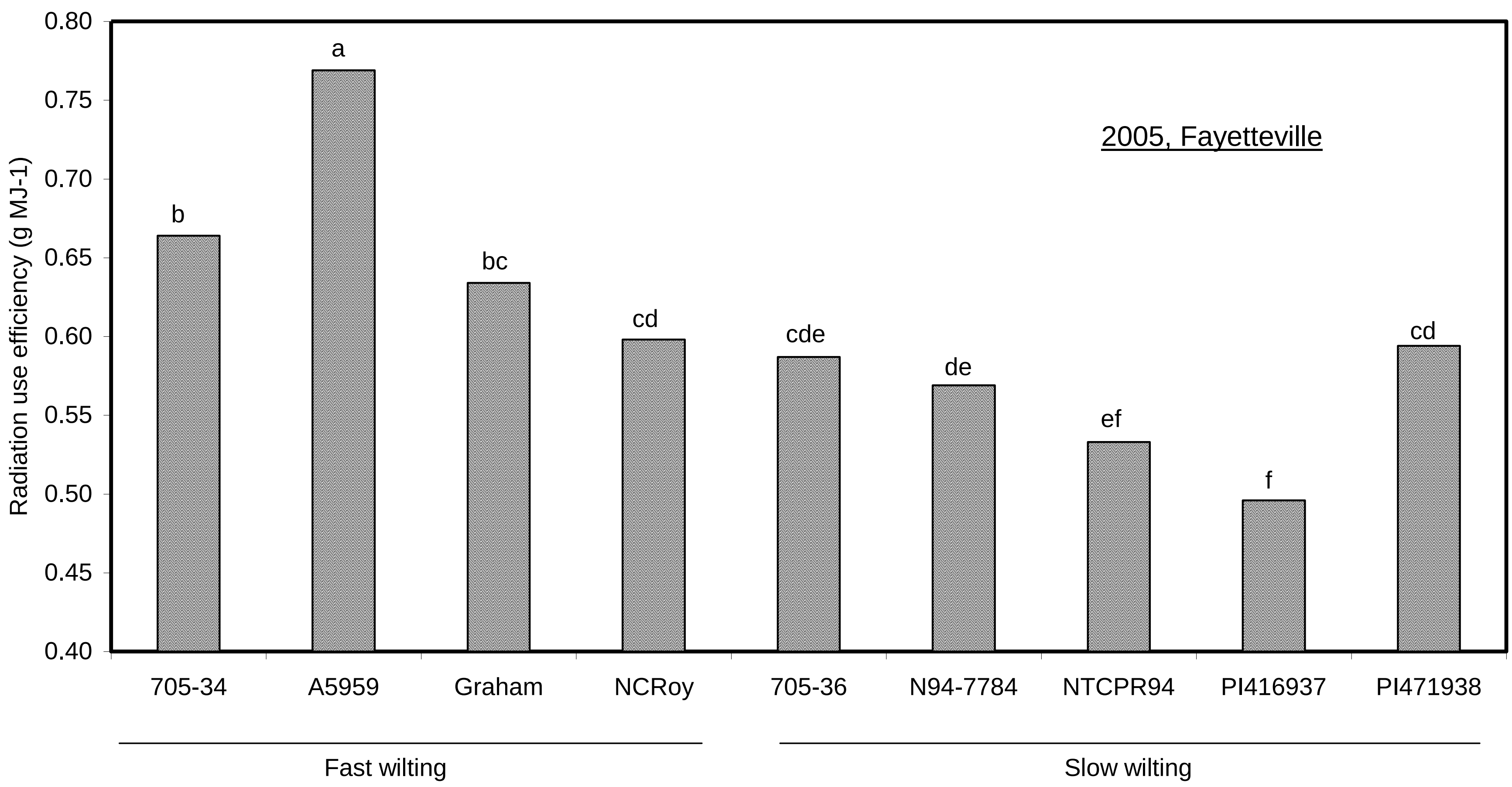
King, Purcell, and Brye. 2009. Crop Sci. 49: 290-298.

Wilting vs. Radiation Use Efficiency (RUE)



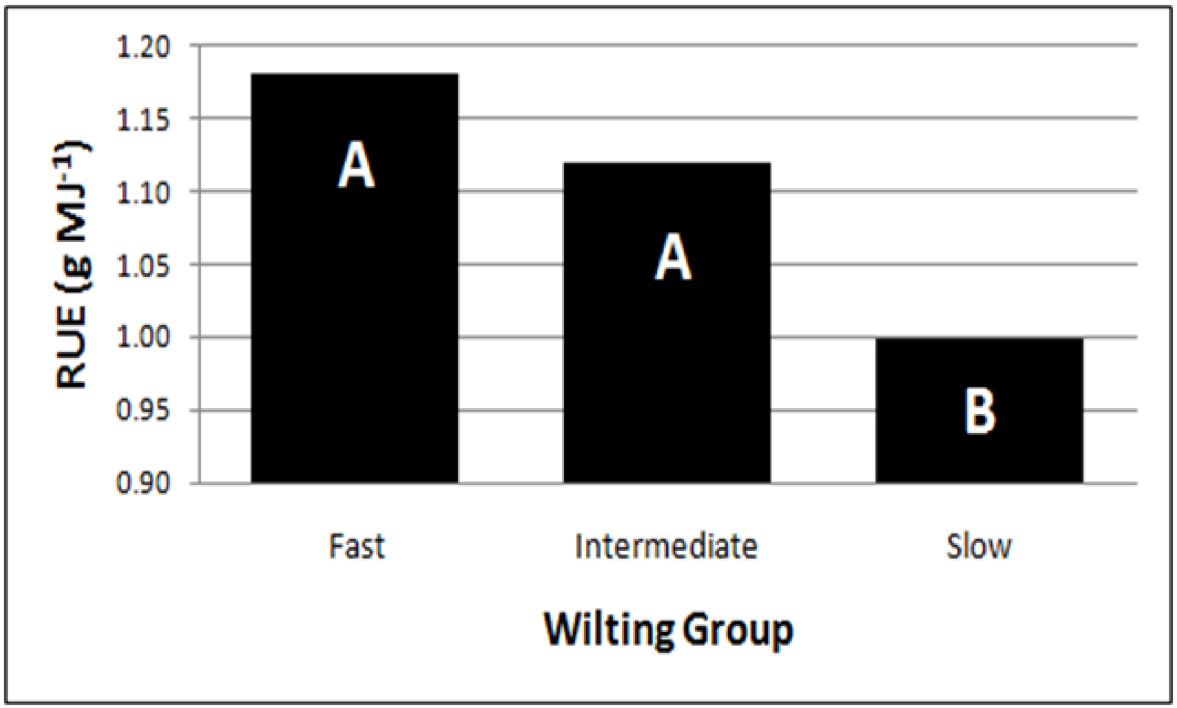
Ries, Purcell, Carter, Edwards, King. 2012. Crop Sci. 52:272-281.

Wilting vs. Radiation Use Efficiency (RUE)



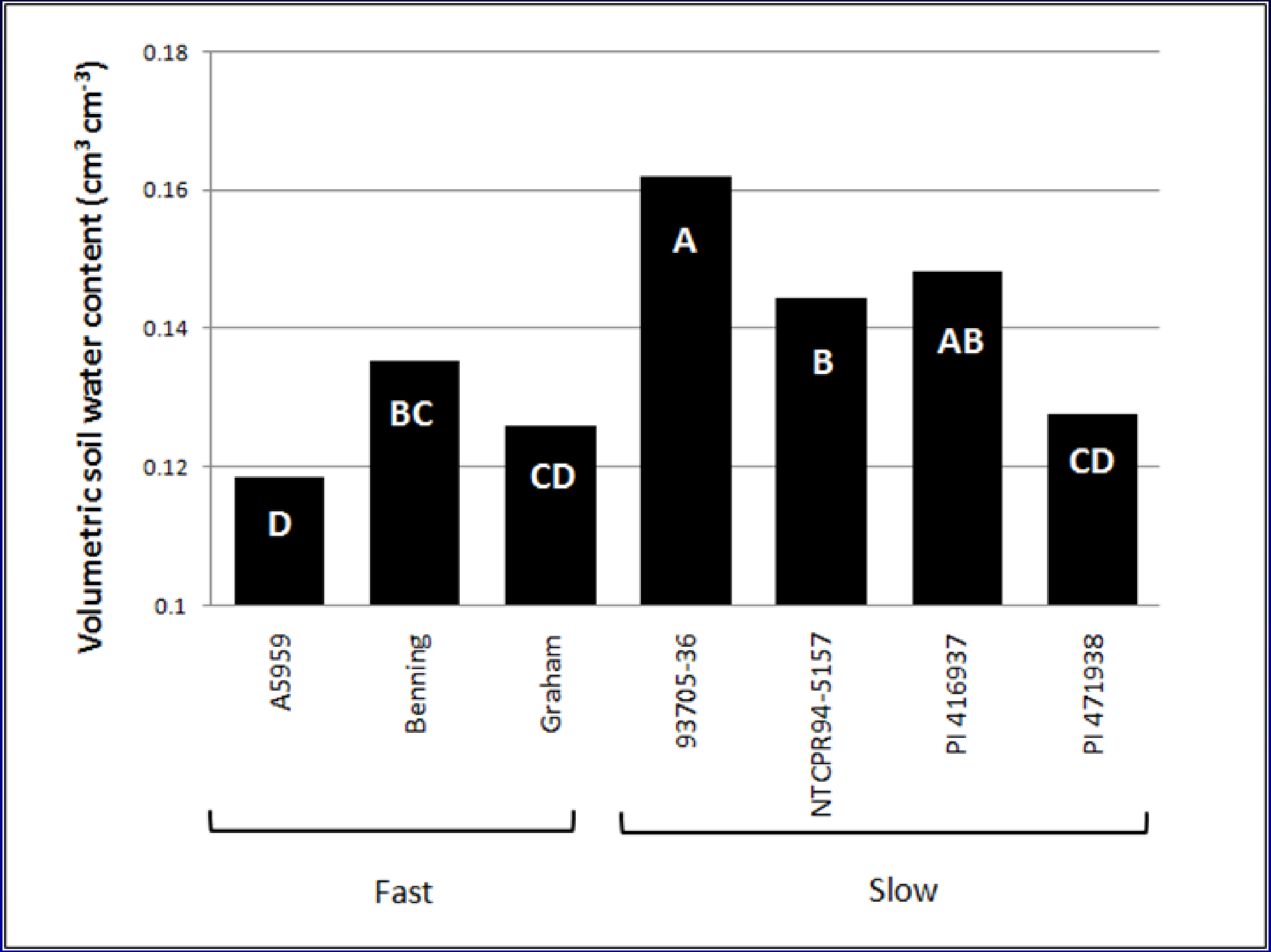
Ries, Purcell, Carter, Edwards, King. 2012. Crop Sci. 52:272-281

Source	DF	MS	F	Pr > F	R^2
Model	13	0.06	4.70	<0.0001	0.60
Error	40	0.01			
Total	53				
Wilting Group	2	0.18	13.04	<0.0001	
Genotype (Wilting Group)	6	0.03	2.15	0.07	



Ries, Purcell, Carter, Edwards, King. 2012. Crop Sci. 52:272-281

Wilting vs. Soil Water Content



Ries, Purcell, Carter, Edwards, King. 2012. Crop Sci. 52:272-281.

QTL Mapping & Yield Effect

- **Benning x PI 416937**

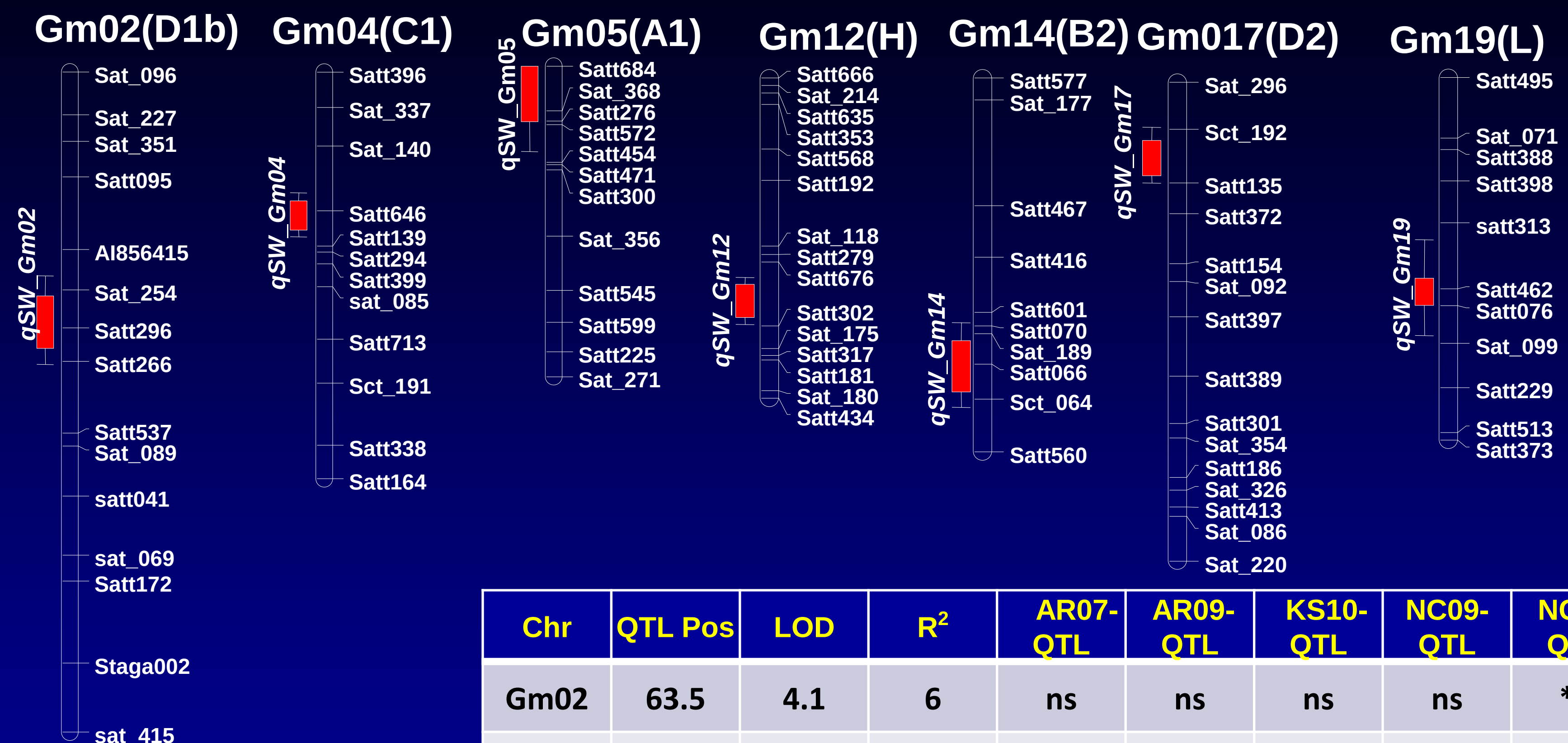
  5 environments: AR (2007, 2009), NC (2009, 2010), and KS (2010)

- **Hutcheson x PI 471938**

  14 environments (2000, 2001)

  9 irrigated & 5 non-irrigated

Canopy Wilting QTL Mapped in Benning x PI 416937

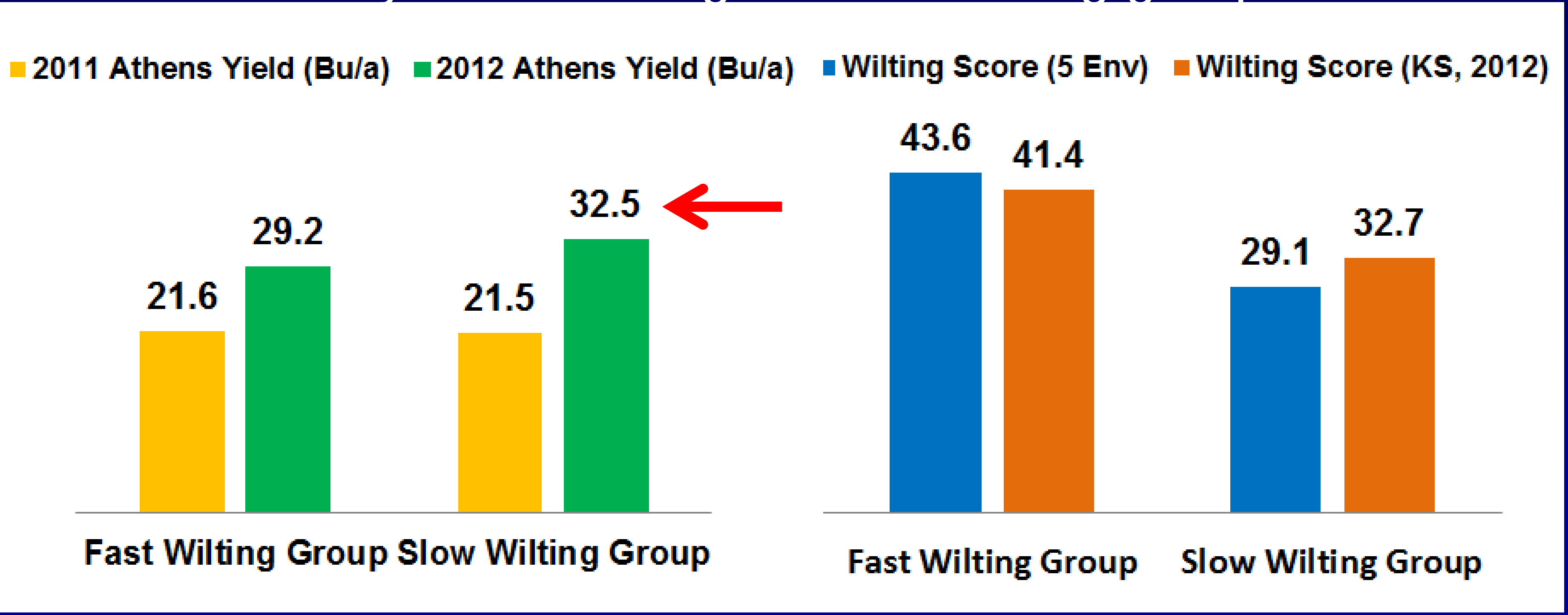


Chr	QTL Pos	LOD	R^2	AR07-QTL	AR09-QTL	KS10-QTL	NC09-QTL	NC10-QTL
Gm02	63.5	4.1	6	ns	ns	ns	ns	**
Gm04	36.9	7	9	**	ns	ns	ns	**
Gm05	8	2.6	4	**	ns	ns	**	ns
Gm12	56.8	9.1	27	**	**	**	**	**
Gm14	74.2	5.2	8	ns	ns	ns	ns	ns
Gm17	20.2	7.8	13	ns	ns	ns	**	**
Gm19	55.7	3.2	8	ns	**	**	ns	ns

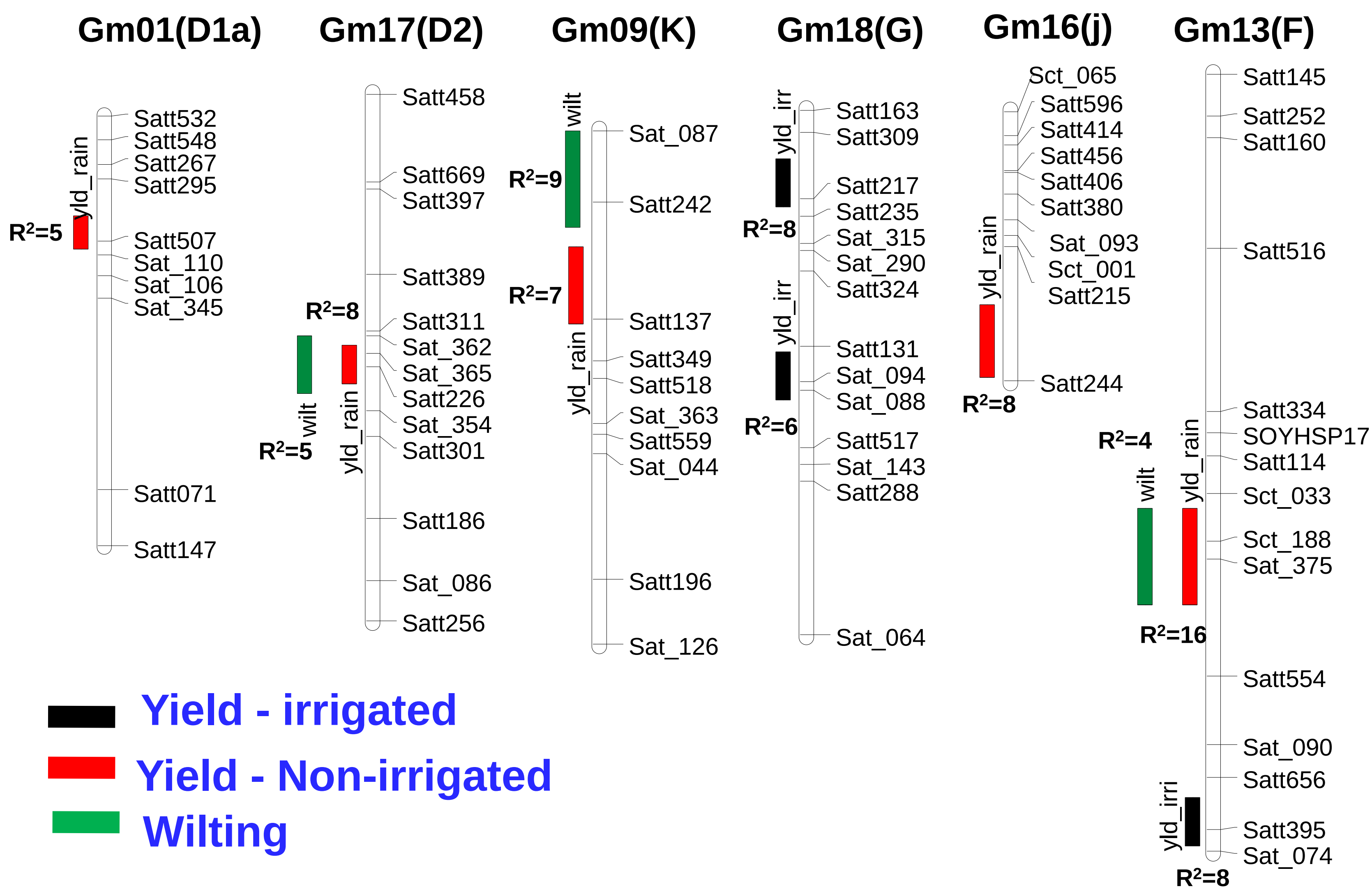
Abdel-Haleem et al, 2012
TAG 125:837 - 46

Wilting QTL Effect on Yield

- 27 RILs selected from Benning x PI416937 based on canopy wilting
- No yield difference between two groups in 2011
- 3.3 bu/a yield advantage in slow wilting group in 2012



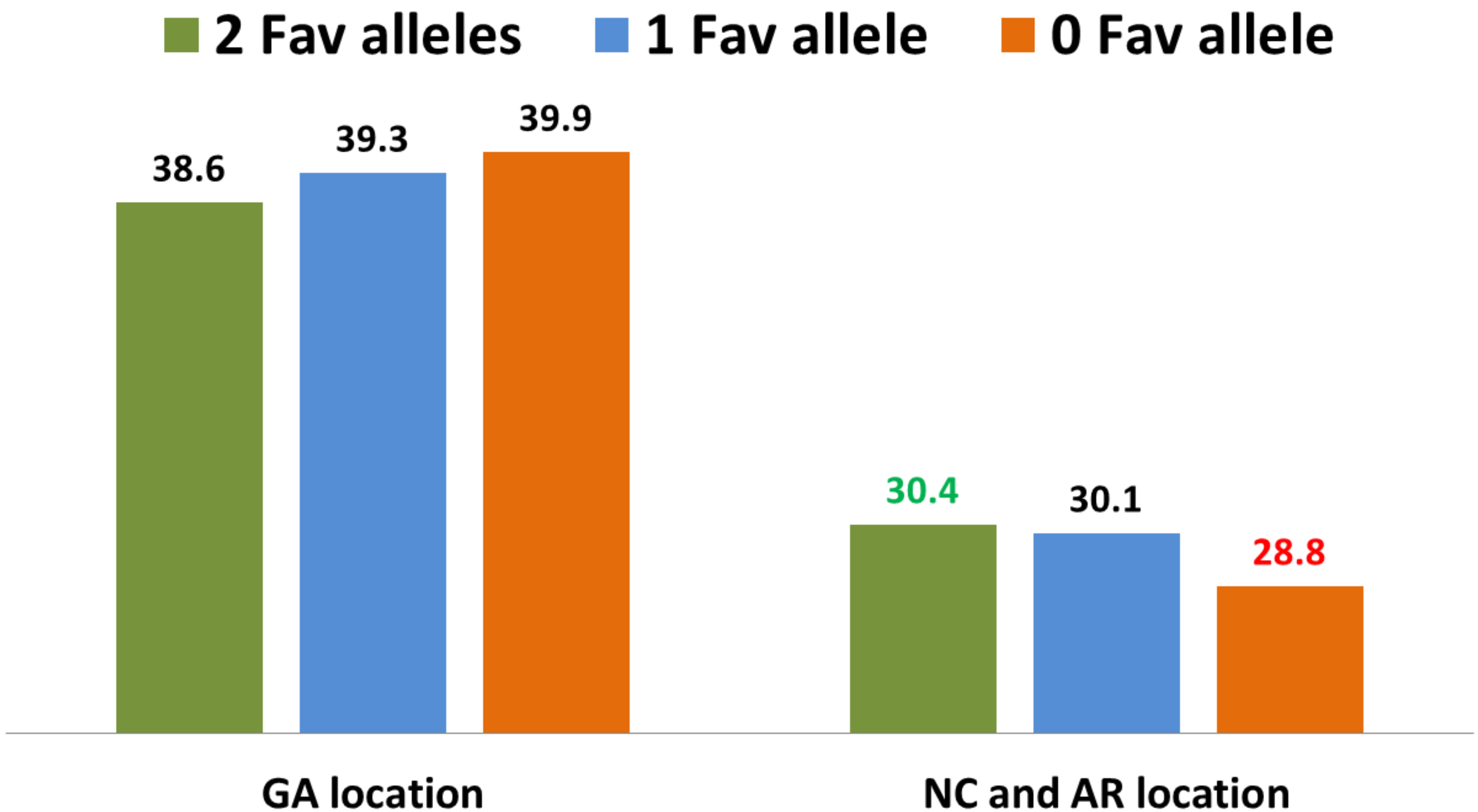
Wilting & Yield QTL in Hutcheson x PI471938 Population



Confirmation of Yield QTL from PI471938 Under Irrigated/Non-Irrigated Condition

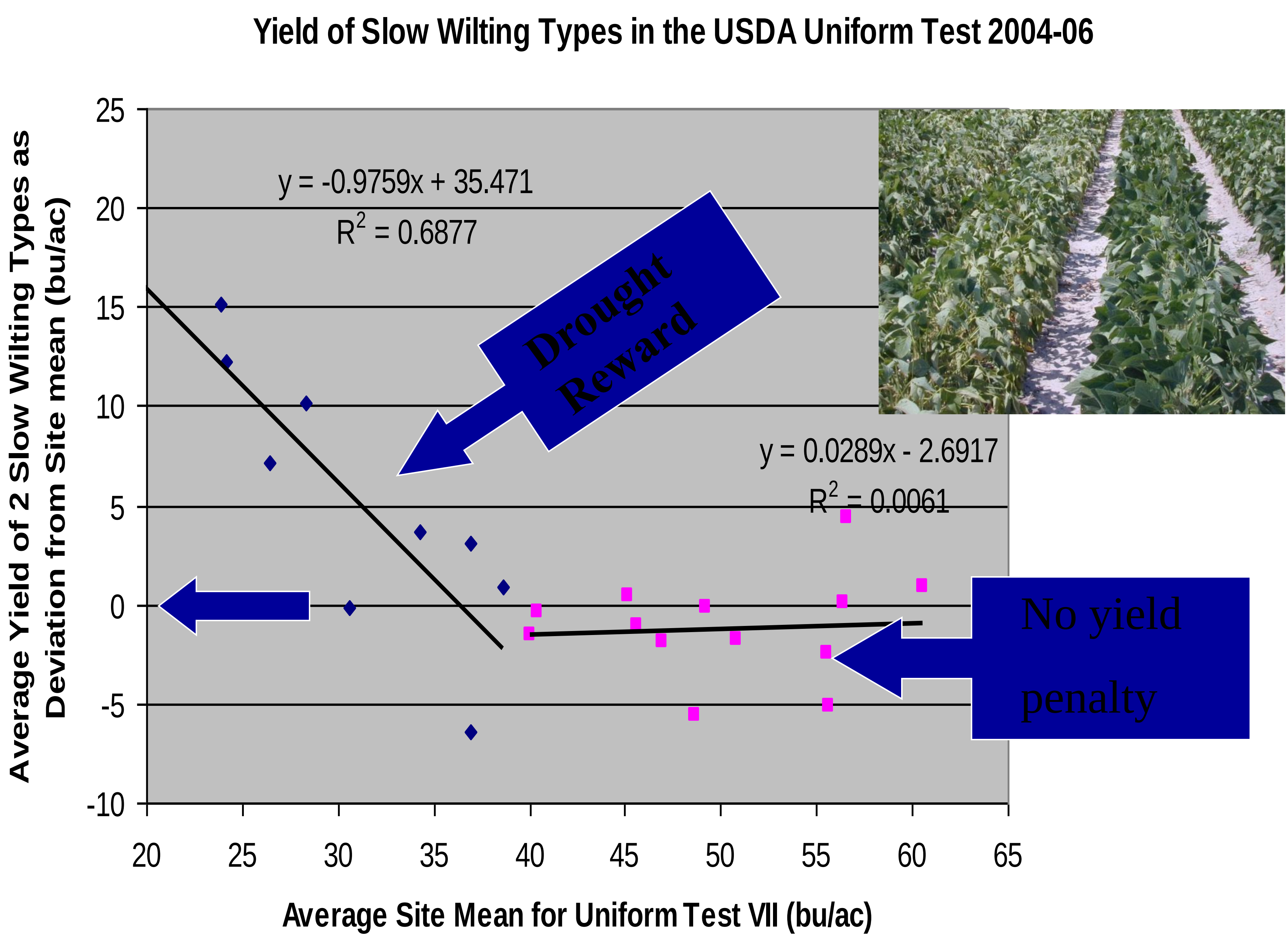
- NIL Development
  - Developed NILs using Heterogeneous Inbred Families (HIF)
  - Heterogeneous lines at QTL regions were selfed
  - Lines homozygous for PI 471938 and Hutcheson alleles were selected for testing
- Yield tests
  - NILs were tested at 12 environments (2008 – 2011)
  - AR (2009 & 2010) and NC (2008, 2009 & 2010) - irrigated
  - GA (2008, 2009, 2010 & 2011) - non-irrigated
  - Yield data were collected from replicated plots

Wilting QTL from PI471938 on Yield



7 environments (Irrigated)

5 environments (Non-irrigated)



Yield of Slow Wilting Types in the USDA Uniform Test 2004-06
Average Yield of 2 Slow Wilting Types as Deviation from Site mean (bu/ac)
Average Site Mean for Uniform Test VII (bu/ac)
y = -0.9759x + 35.471
R2 = 0.6877
y = 0.0289x - 2.6917
R2 = 0.0061
Drought Reward
No yield penalty
25
20
15
10
5
0
-5
-10
20
25
30
35
40
45
50
55
60
65

New ERA Slow Wilter in Regional Trials

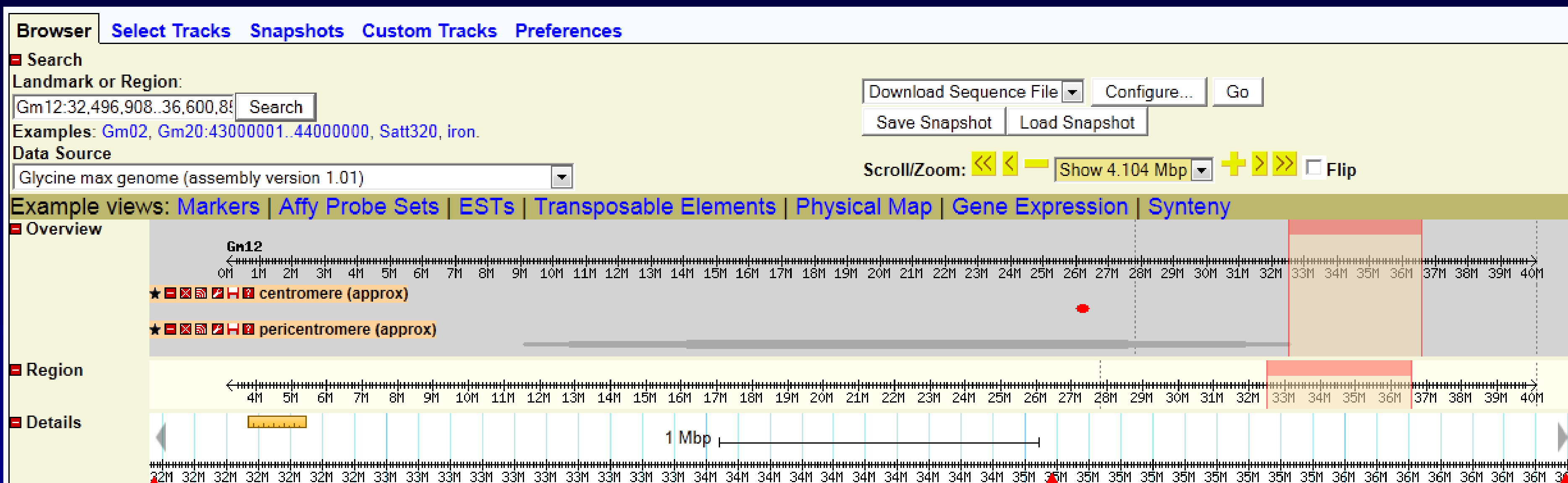
MG 8	Ent.	Hi Yield Env.	Lo Yield Env.
		> 55	< 55
		BU/	AC
NEW	N05-7432	59	45
CHECK	N8001	58	41
	Advantage	0	4
25 Loc		5	20

37% PI


New Drought Line
N05-7432
Top Yielder

Development of SNP Markers Using Infinium Chips for MABC

Glycine max genome: 4.01 Mbp between Satt676 and Sat_175 on Gm12



Satt676 Satt302 **Sat_175**

- 349 SNPs between Satt676 and Sat_175 from Infinium chip data
- 80 SNPs were polymorphic between two parental lines, Benning and PI416937
- SNP marker development for high-throughput genotyping

Converting Infinium Chip SNPs for Genotyping

Sequence

Parent 1

ACAAAGATTCGGCTAGGCGCGA**A**TCGACGCGGGCGAAGAACGTGCTTCAAA

Parent 2

ACAAAGATTCGGCTAGGCGCGA**T**TCGACGCGGGCGAAGAACGTGCTTCAAA

Allele specific Primer design

FAM tail A-specific primer

Common reverse

VIC tail T-specific primer

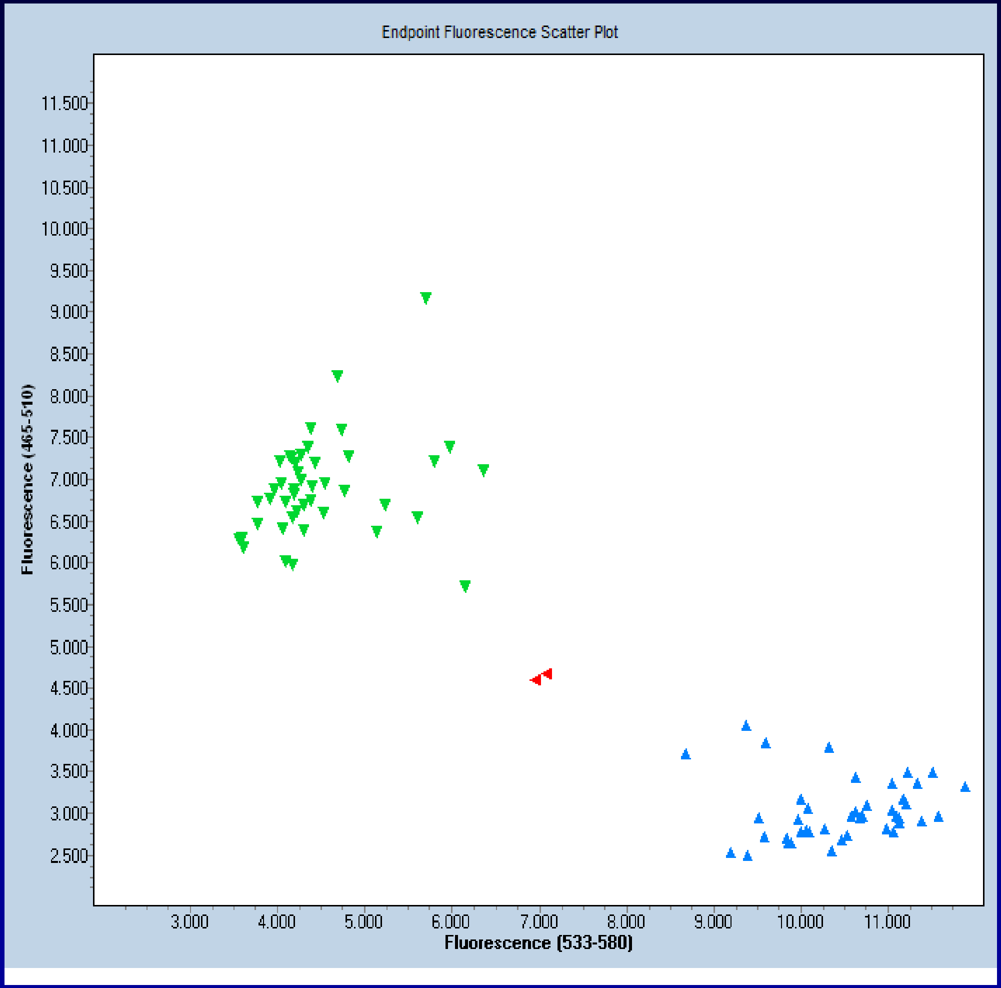
PCR and fluorescent detection

KASP SNP Assays for MABC and MAS

SNP marker developed from Gm12_34289684_C_T

- Benning CC (FAM)
- PI416937 TT (VIC)

FAM



VIC

Validation and Fine Mapping of Canopy Wilting QTL from PI416937 using RNAseq

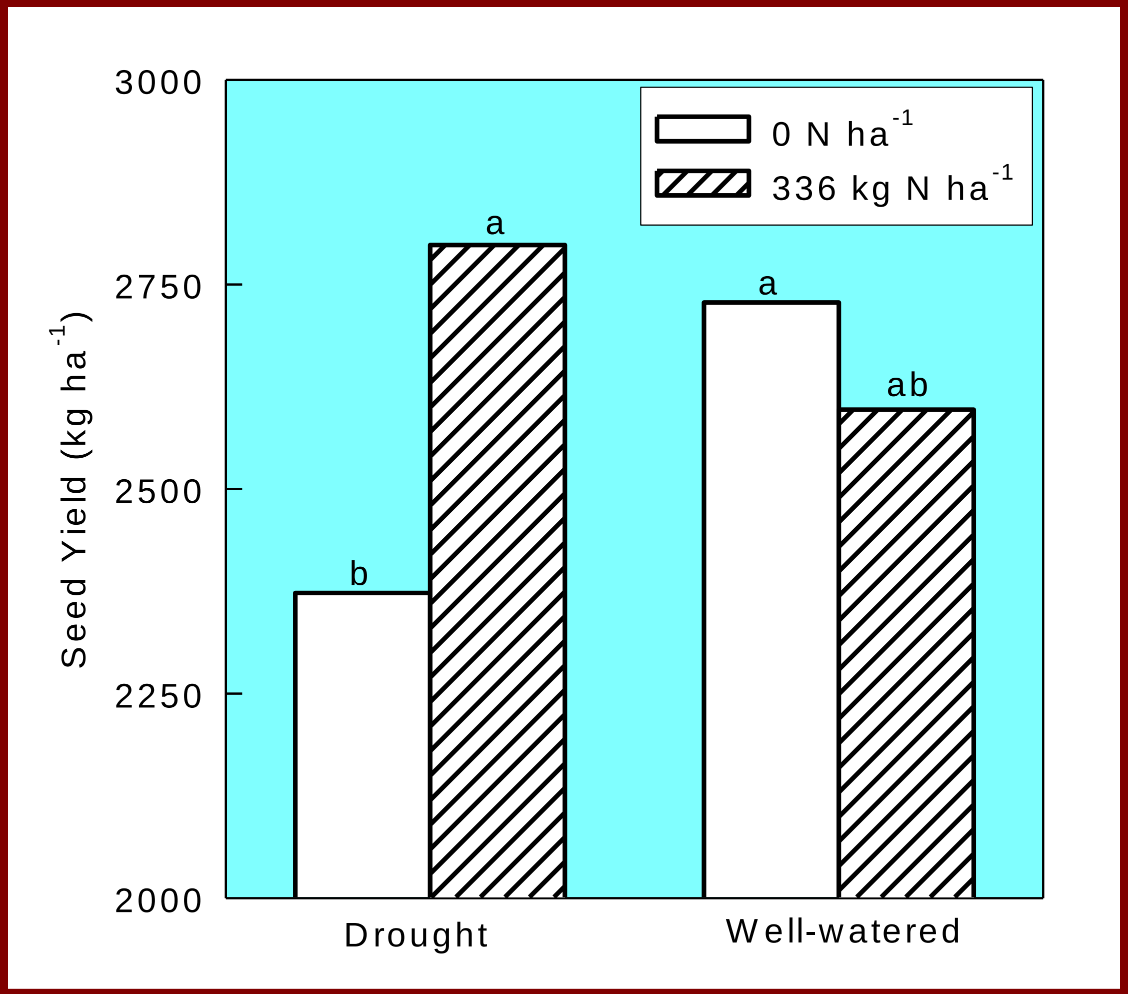
- Tissue collected from PI416937 and Benning under stress condition
- Investigate the genes overexpressed/under expressed at QTL regions
- Investigate the genes overexpressed/under expressed at a whole genome level

24hrs

PI 416937 Benning

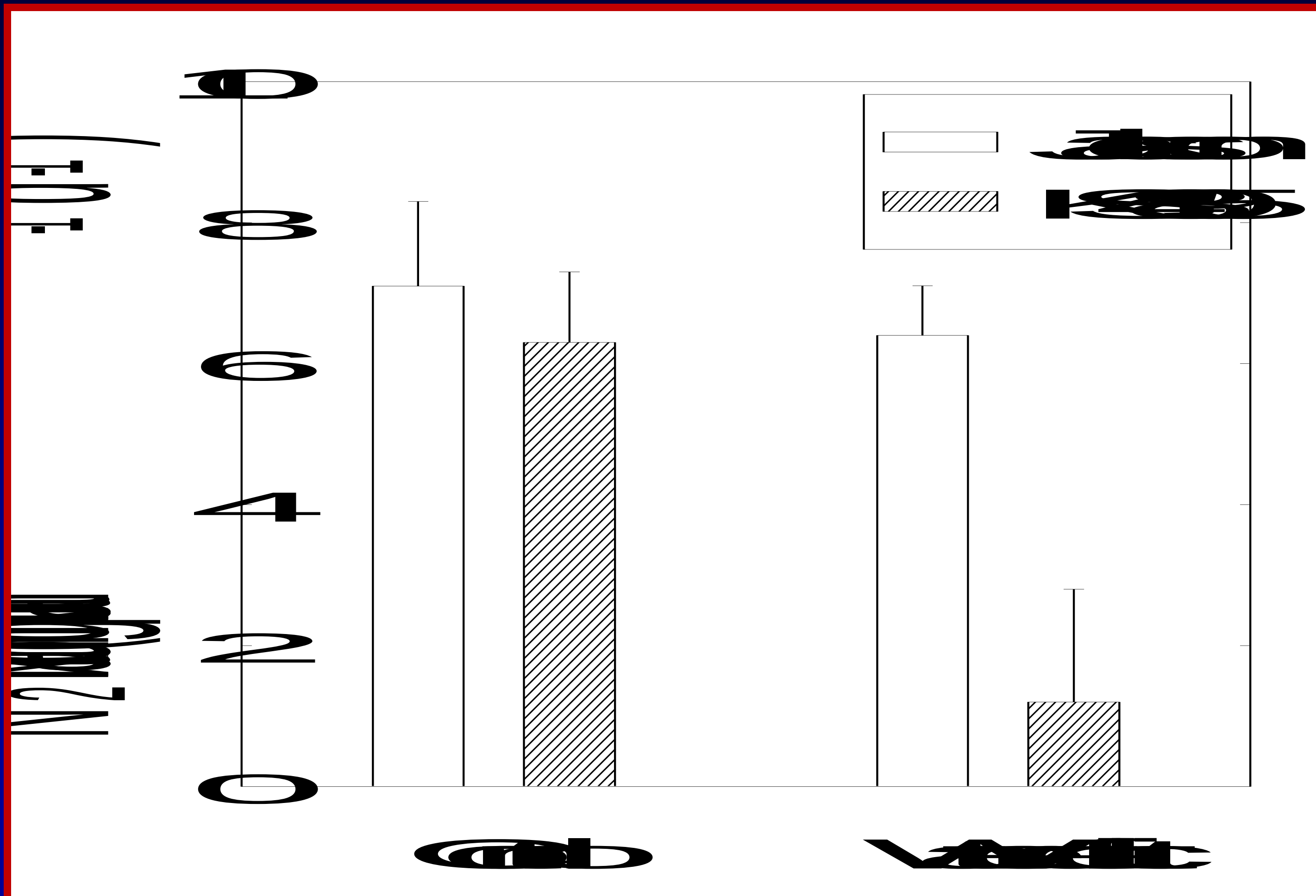
Prolonged Nitrogen Fixation Under Drought

Nitrogen vs. Yield Under Drought



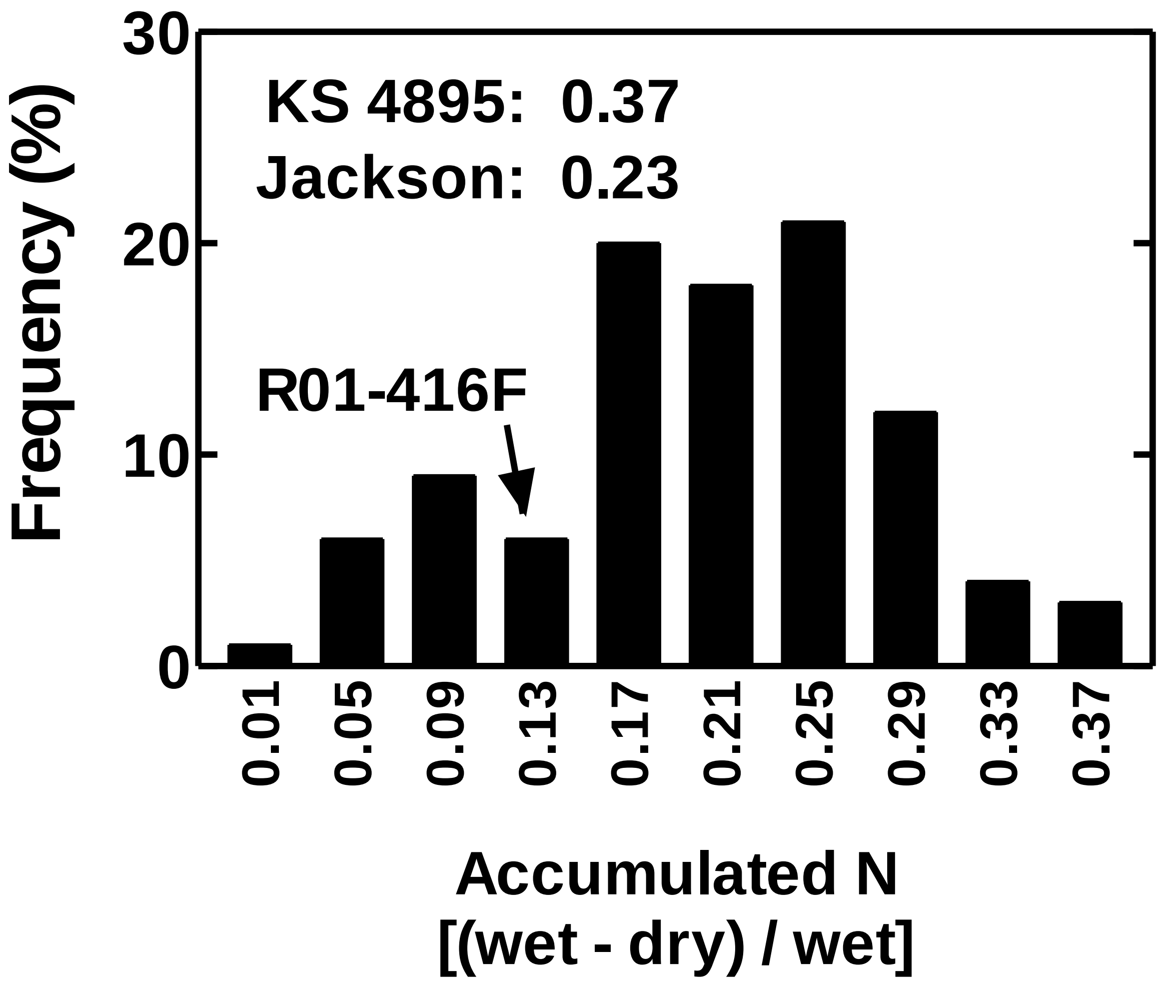
Purcell and King, 1996. J Plant Nutr 19:969-993

Genotypic Difference in N2 Fixation Under Drought

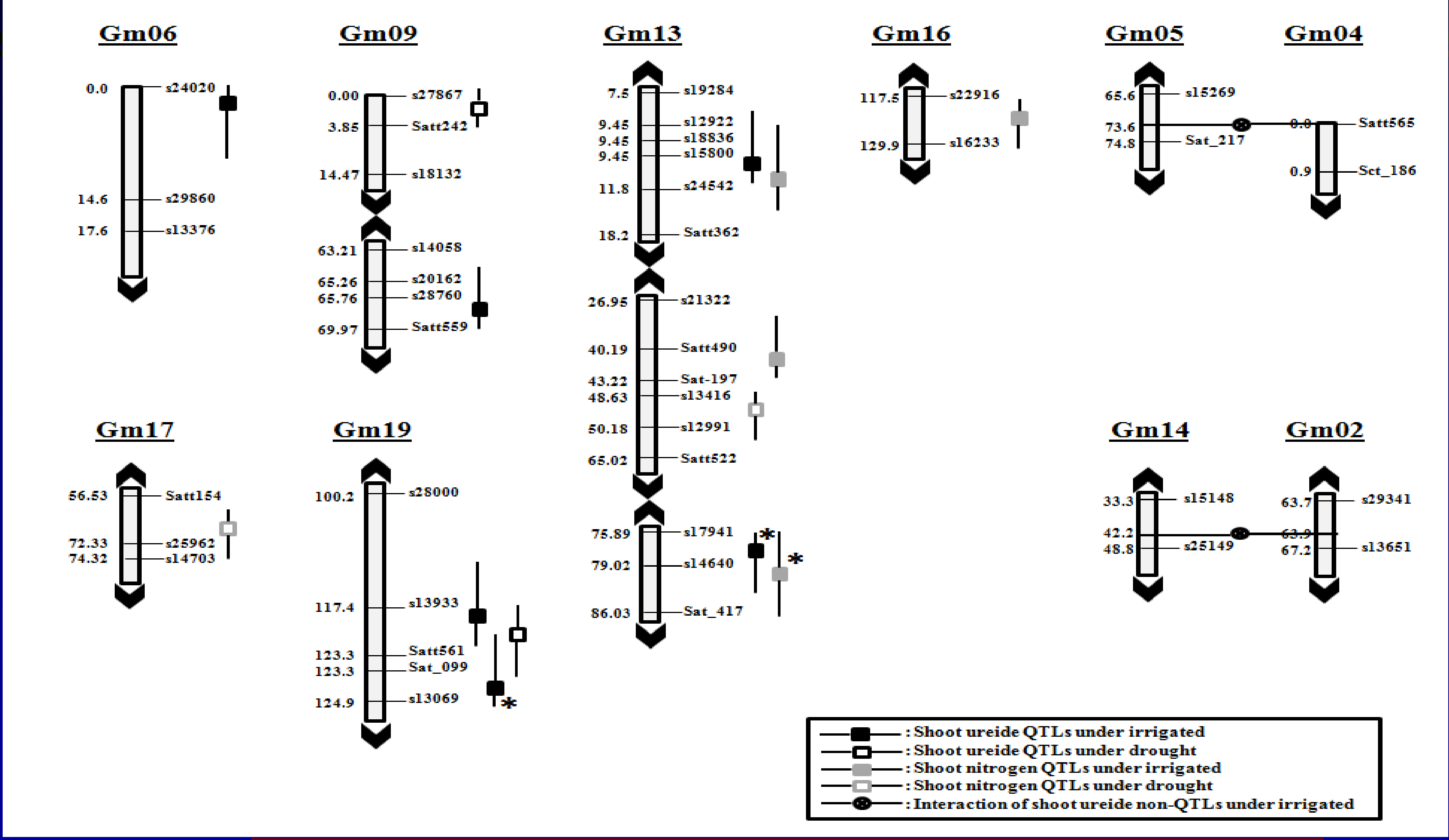


Purcell et al, 1997. Plant Soil. 196:101

N2 Distribution in Jackson x KS 4895 Population Under Drought

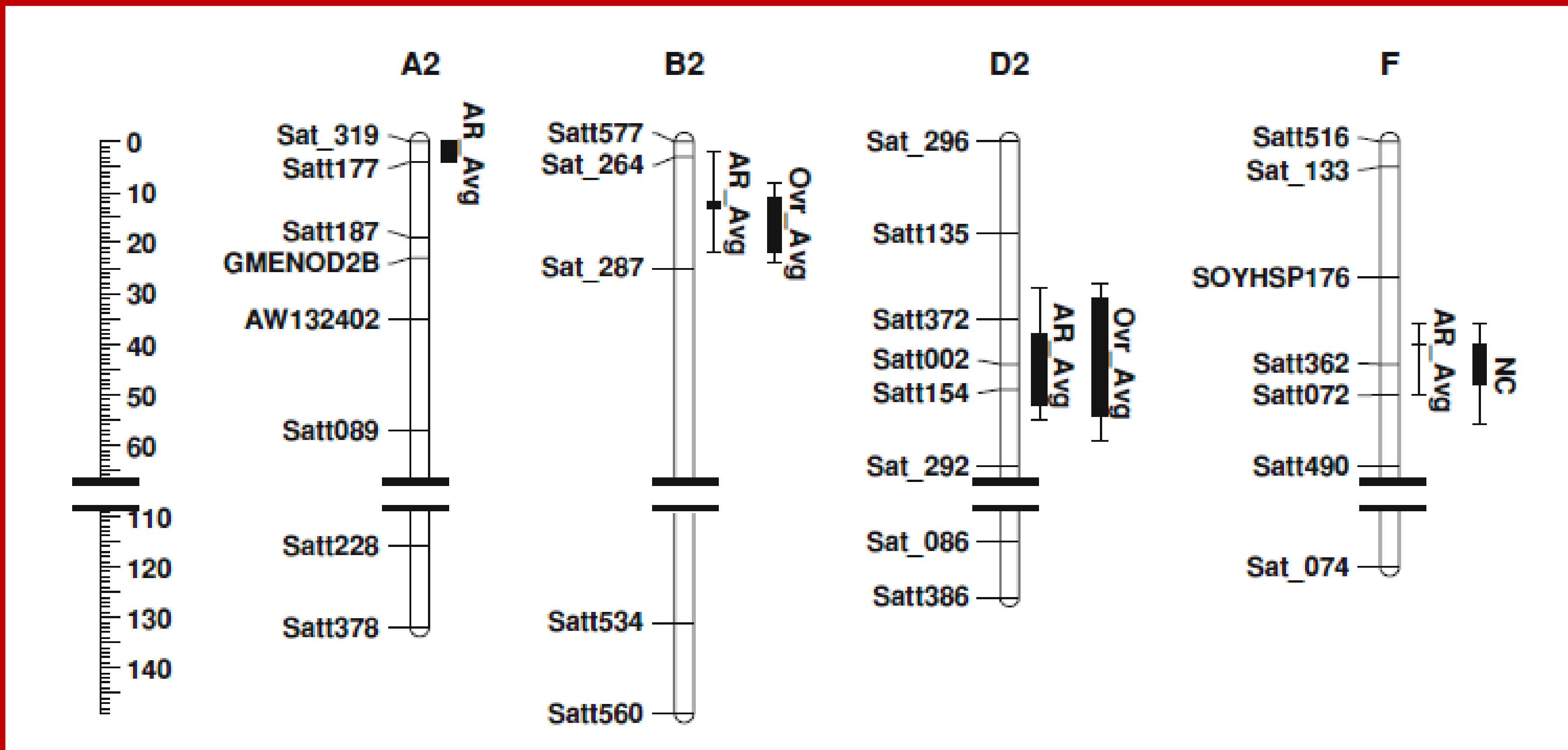


N2 Fixation QTL Under Drought



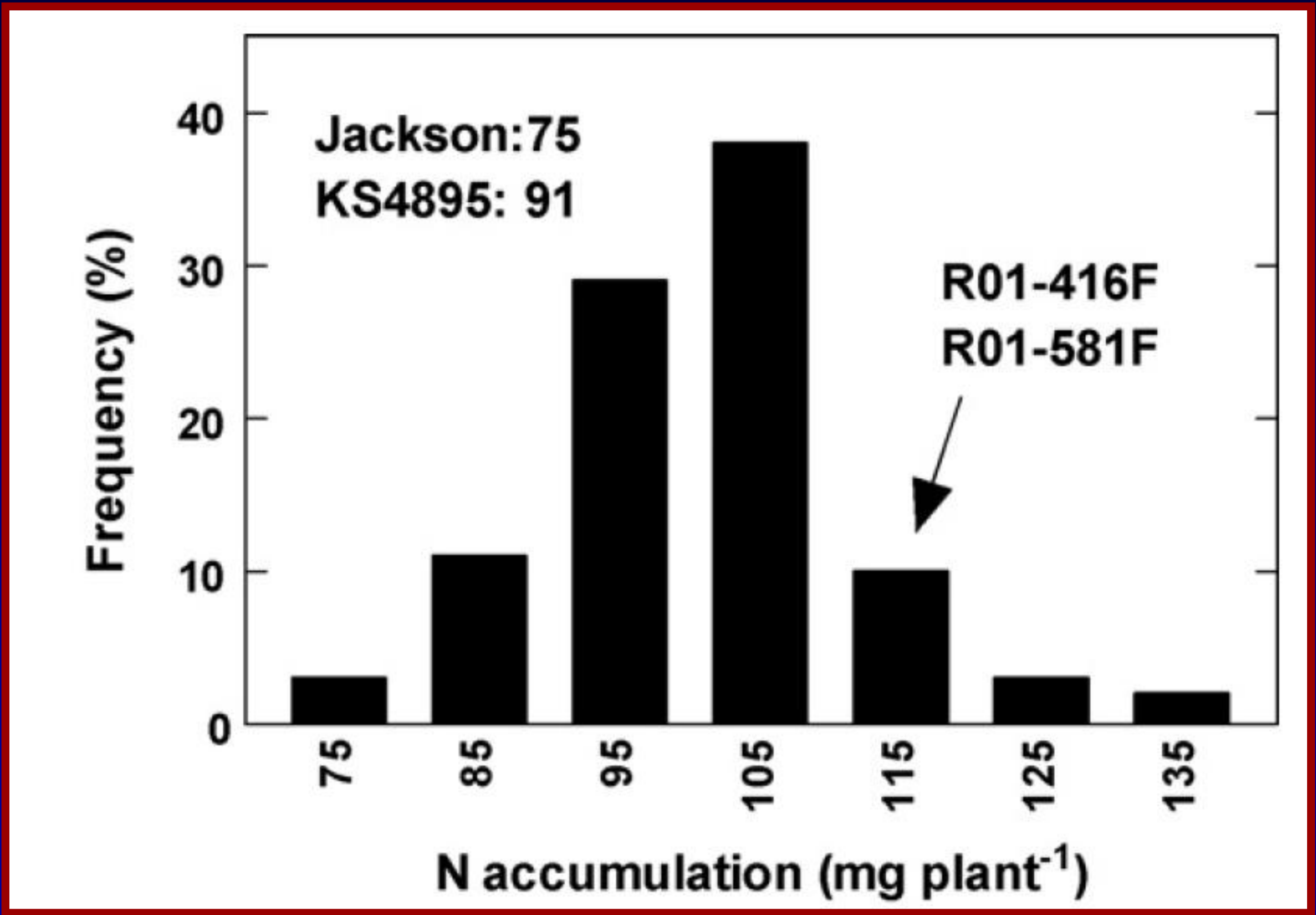
Hwang, King, Davies, Ray, Cregan, Purcell. 2013. Crop Sci. (in review).

Slow Wilting QTL in the Same N2 Fixation Population



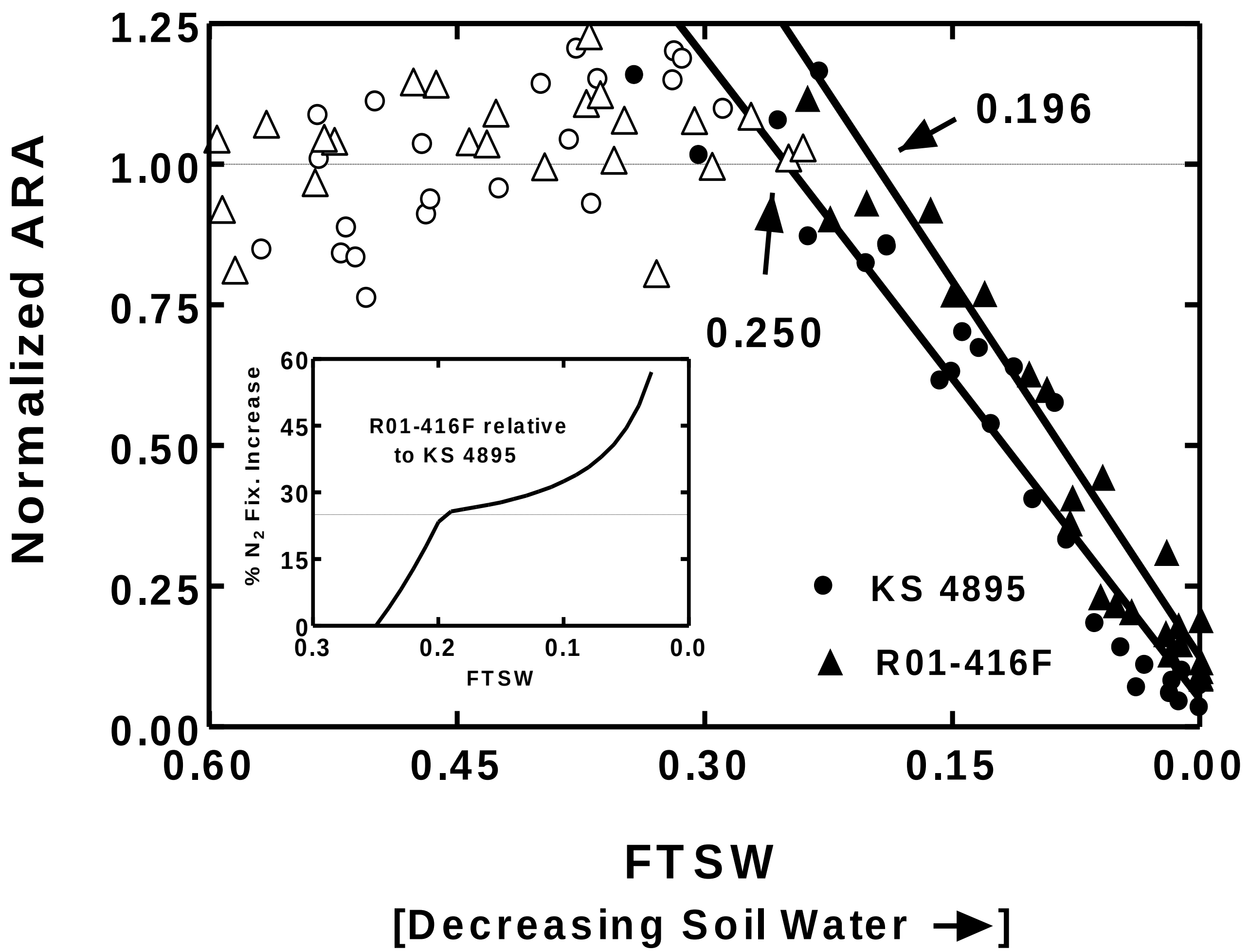
Charlson et al. (2009) Theor. Appl. Genetic. 119:587-594.

N2 Fixation vs. Yield Under Drought

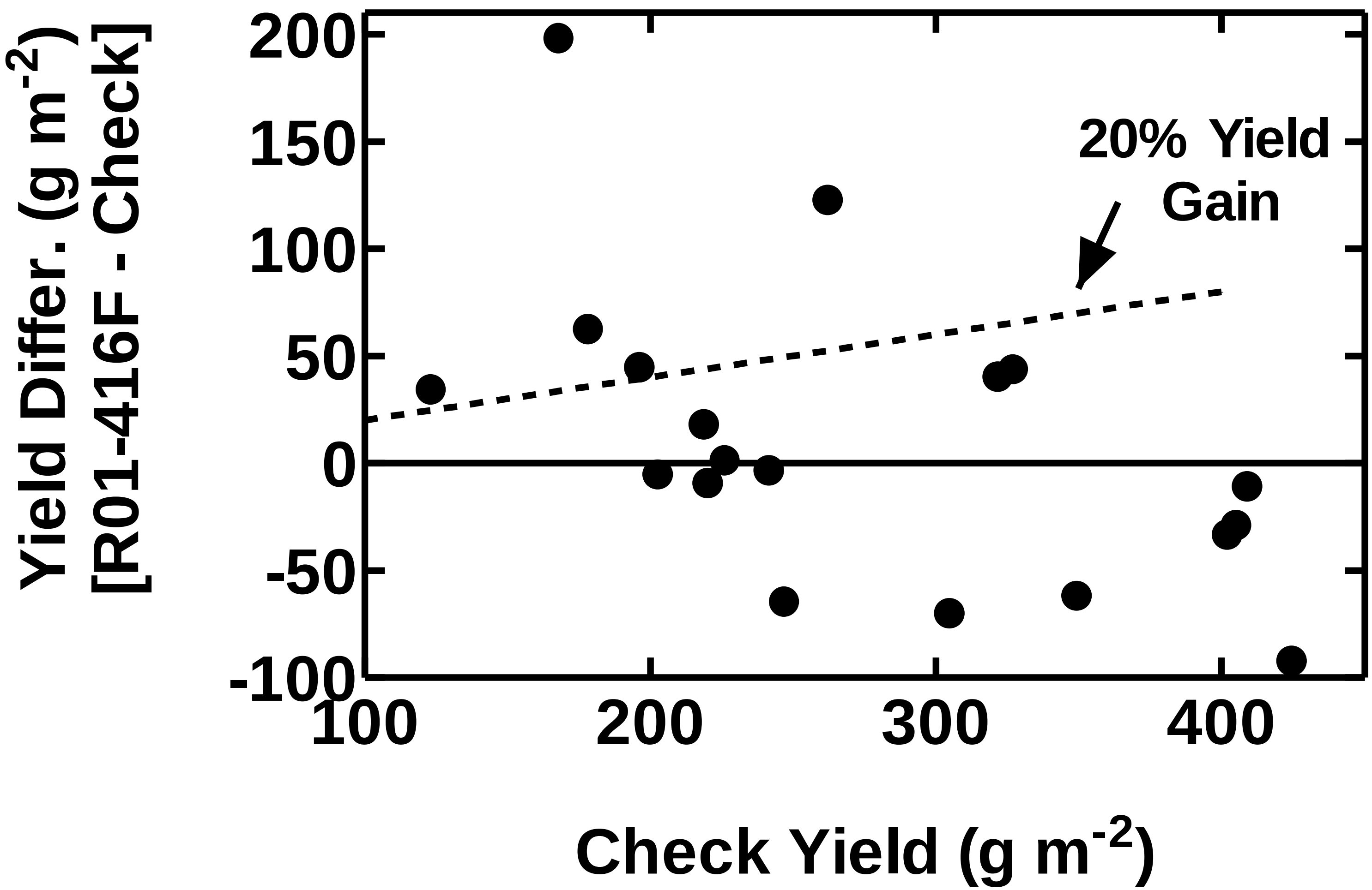


Sinclair et al, 2007. Field Crops Res 101:68-71

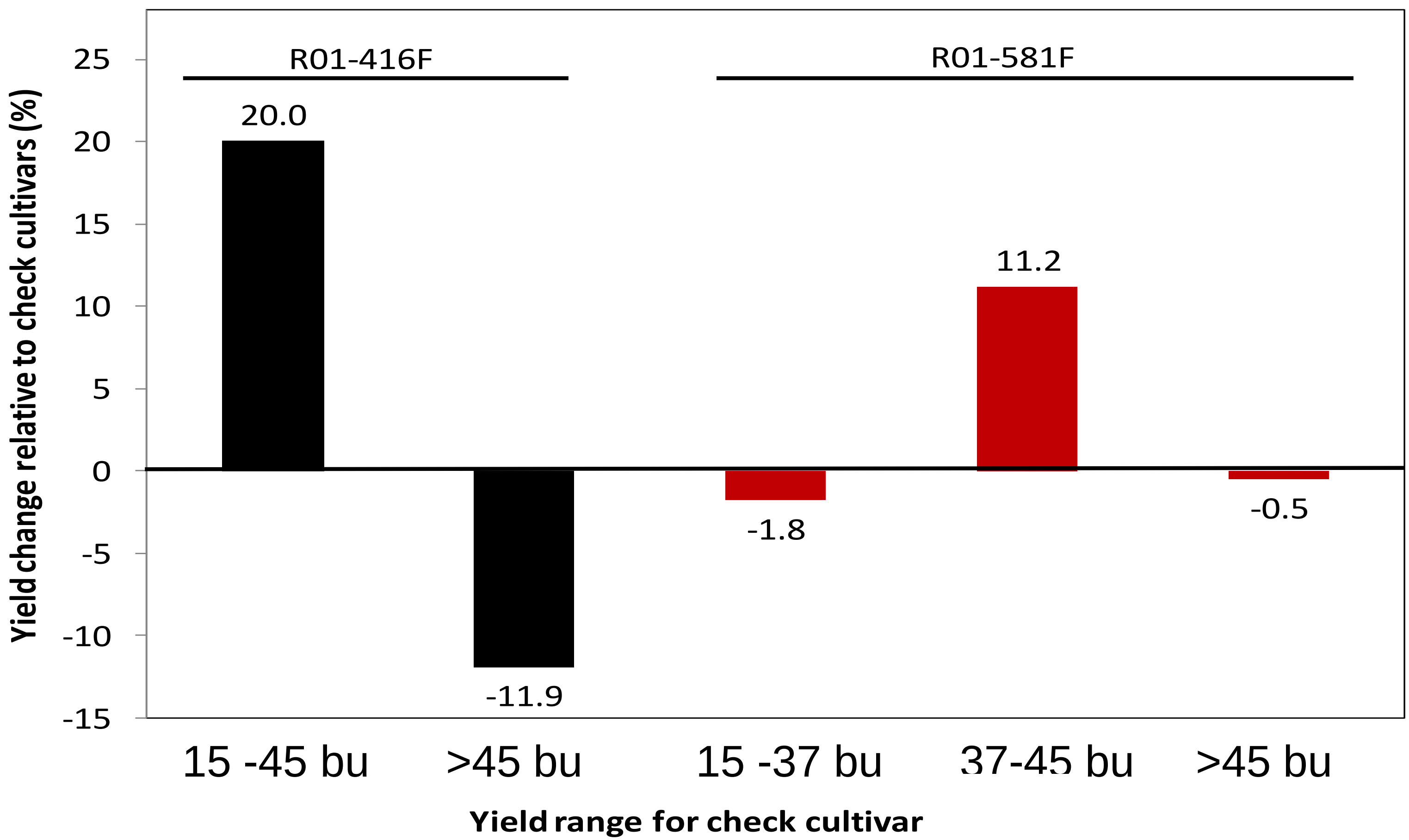
Prolonged N2 Fixation Under Drought



Yield Advantage with N2 Fixation Under Drought



Yield Advantage with N2 Fixation Under Drought



Sinclair, Purcell, King, Sneller, Chen, Vadez. 2007. Field Crops Res 101:68-71

Soybean Root Characteristics
Yield = WU x WUE x HI

Using Available Water

Gaining access to more water through improved root architecture

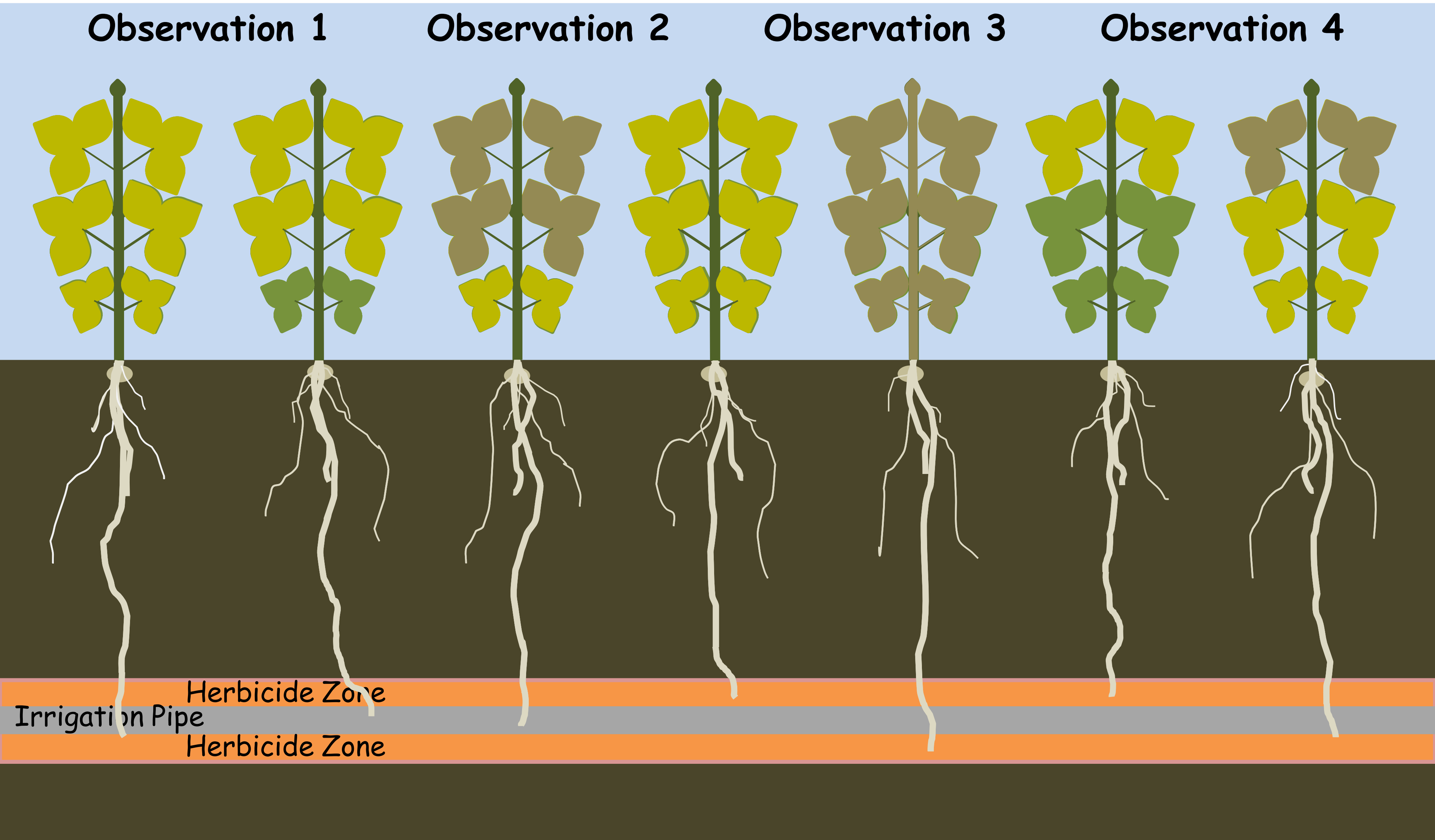
Root Characteristics

- Deep rooting
- Fast rooting
- Fibrous rooting

"Root Race"

- 40 trenches: 1.2 m deep x 30 m long
- drip irrigation line in each trench
- permanently marked trench location
- injection of herbicide
- rating of shoot symptoms

Root Race

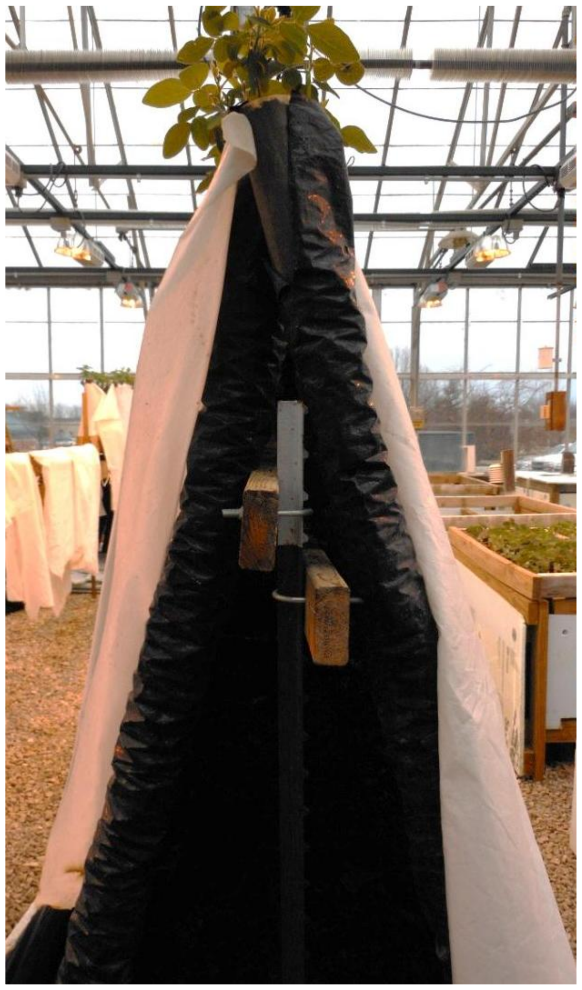

Observation 1
Observation 2
Observation 3
Observation 4
Herbicide Zone
Irrigation Pipe
Herbicide Zone

Root Race Observations – Early

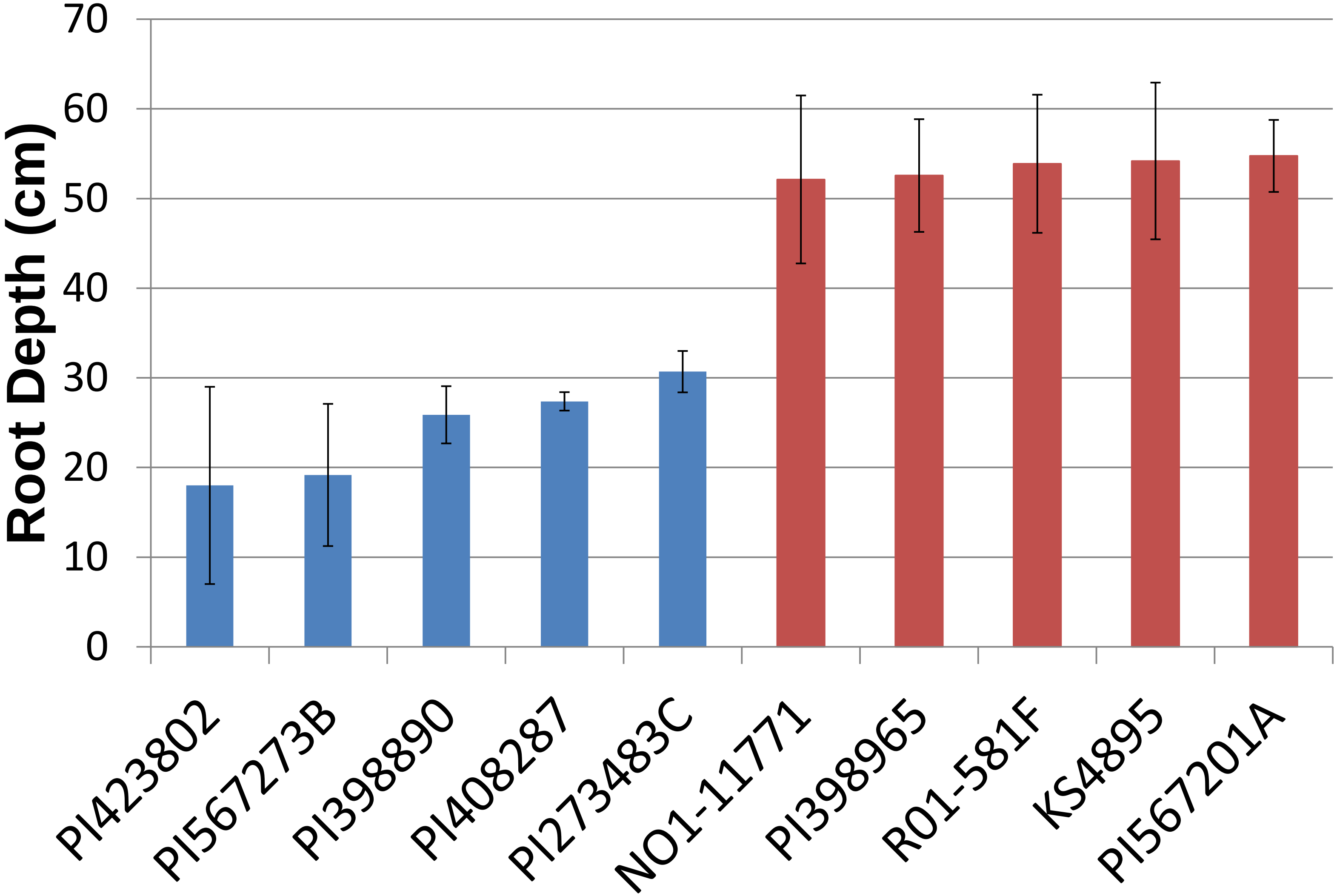
Root Race Observations – Late

Slanted Tubes

depth, elongation rate, complexity



GH Confirmation for Rooting Depth



Soybean Root Characteristics

Summary

- > 800 lines screened in the field
- > 200 lines re-examined in the greenhouse
- Characterization of 16 lines by soil coring and soil moisture depletion
- Development of RIL populations – F3
- Development of methodology for phenotyping of populations

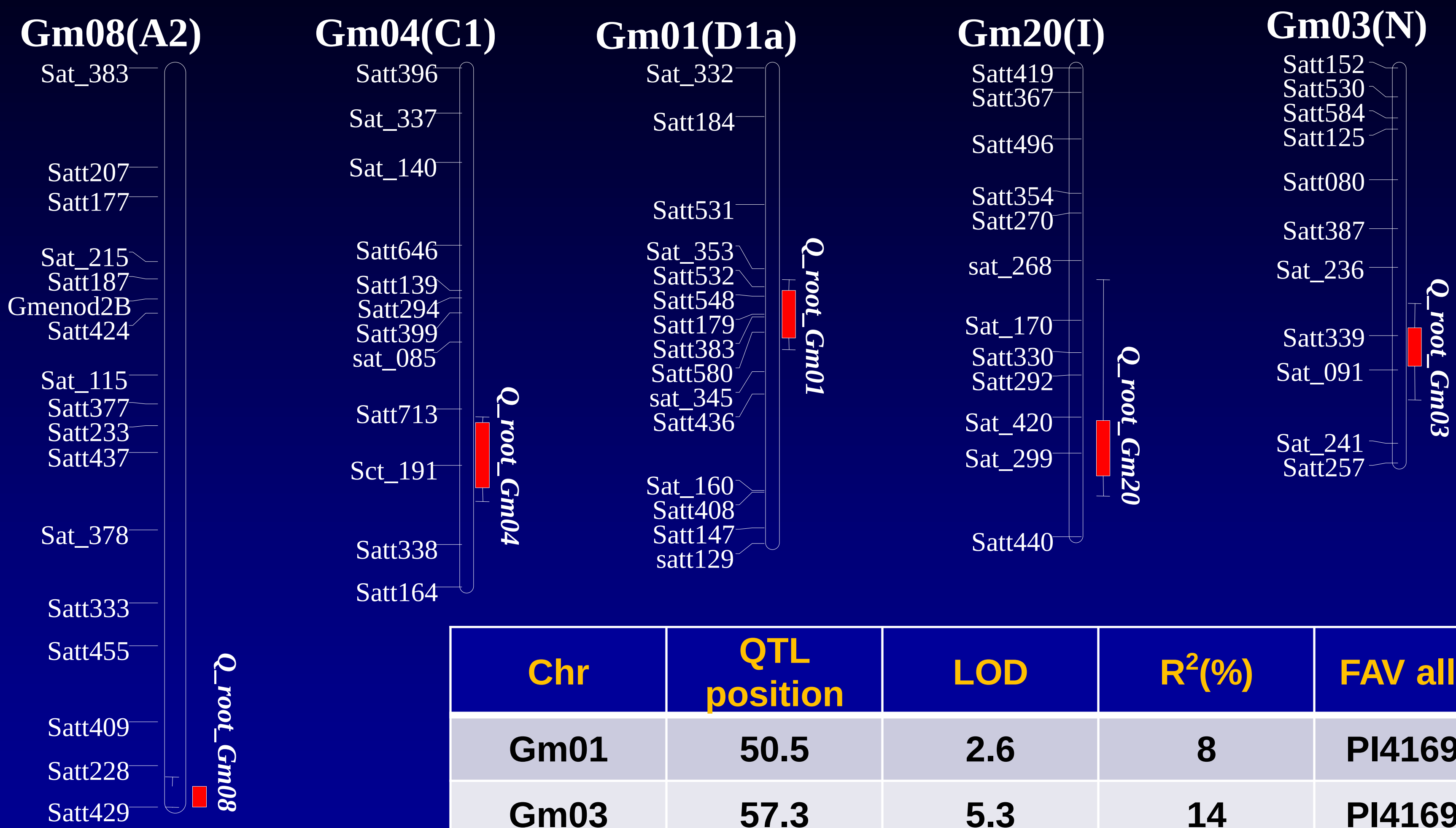
QTL for Fibrous Root

Benning x PI 416937

- **Hill plots**
- **2 locations**
- **Plots inverted at R5 using a peanut inverter**
- **Roots visually rated on the scale 1 (course roots) to 8 (high fibrous roots)**

Peanut Inverter for Root Phenotyping

Fibrous Root QTL Mapped in Benning x PI 416937



Chr	QTL position	LOD	R^2(%)	FAV allele
Gm01	50.5	2.6	8	PI416937
Gm03	57.3	5.3	14	PI416937
Gm04	77.2	3.6	7	PI416937
Gm08	149.6	5.7	13	PI416937
Gm20	77.8	3.3	8	Benning

Abdel-Haleem et al, 2010
TAG 122:935-946

Pyramiding Slow Wilting and Fibrous Root QTL from PI 471938 and PI 416937

Hutcheson x PI 471938

Slow wilting population

Bogss-RR x N98-7288

Boggs-RR x F_1

Boggs-RR x BC_1F_1

Boggs-RR x BC_2F_1

Benning x PI 416937

Fibrous root population

Bogss-RR x G00B/P175

Boggs-RR x F_1

Boggs-RR x BC_1F_1

F_1

F_2

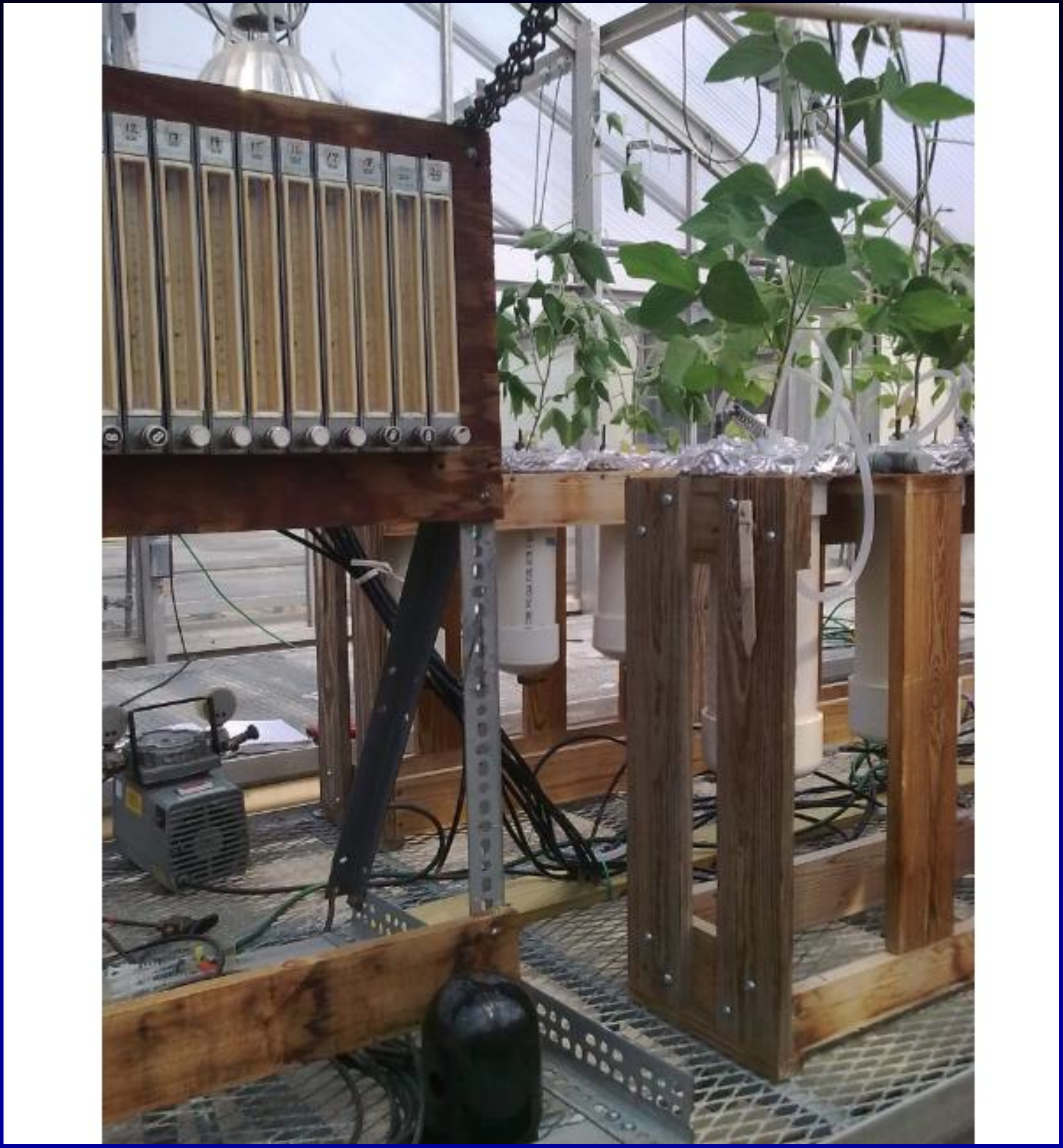
BC ($F_{2:6}$)

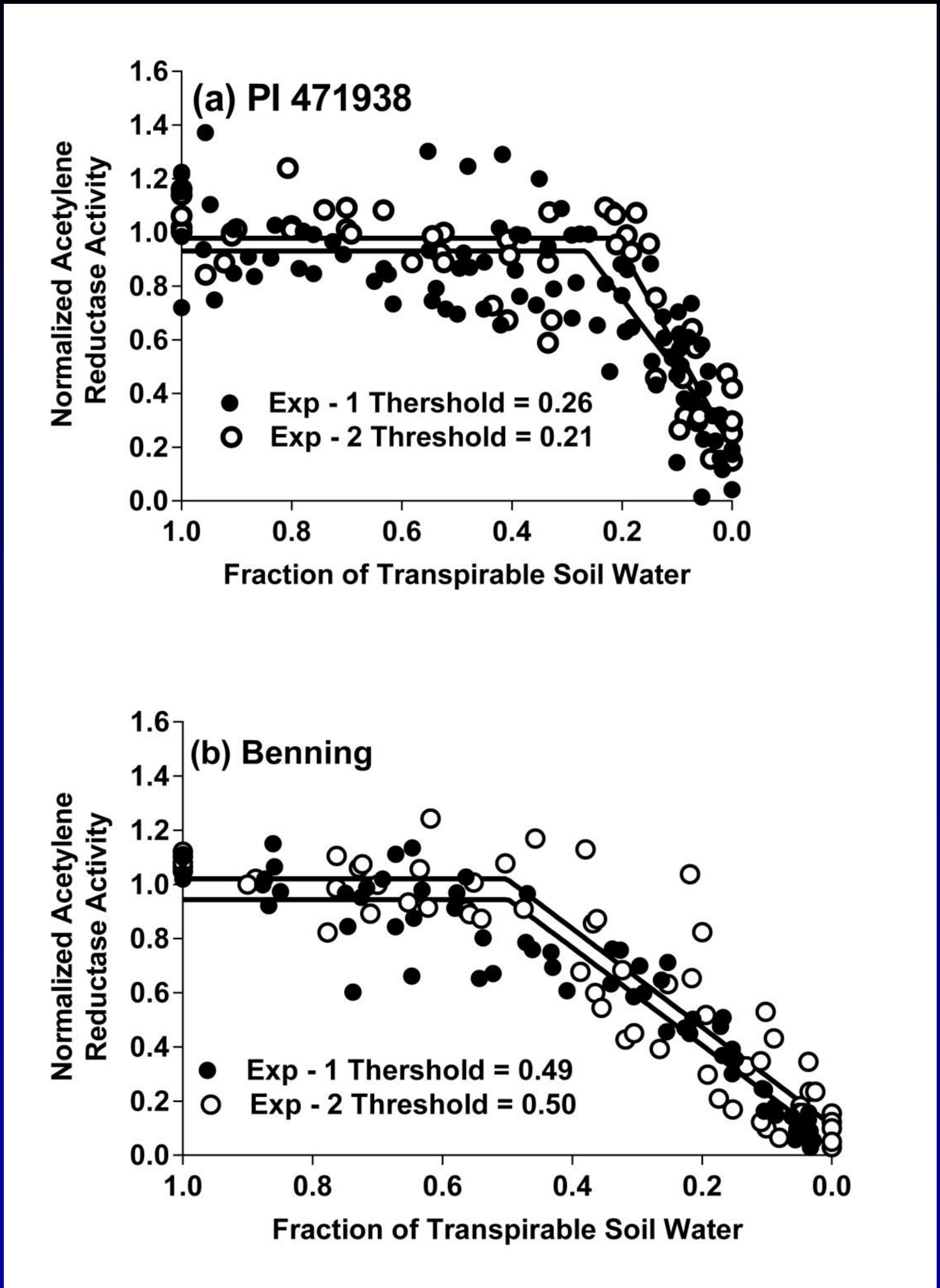
Backcross Slow Wilting and Fibrous Root QTL from PI416937 into Elite Lines using MABC

- Elite Lines
  - G00-3213
  - G00-3880
  - NE3001
- QTL
  - 6 slow wilting QTL
  - 4 fibrous root QTL

Acetylene Reduction As an index of N2 fix

PI 471938





A New Source of Prolonged N2 Fixation Under Drought in the Slow Wilting PI 471938

Drip Irrigation

Nebraska

Before vs. After Irrigation

Drought vs. Flood

Not enough water ?

Too much water ??

Related mechanisms ???

Field Flood Test

Flood Damage

Flood Tolerant Lines

UA 4805, Ozark, Osage, Anand, Manokin

NC-Roy, Young, Boggs-RR, Narrow

RA-452, PI 471931, PI 471938

Also Drought Tolerant

Drought Tolerance

- A complex Trait !!!
- Research Continues…