Breeding for Physiological Improvement of Crop Yield

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How can a Physiologist work ***with*** a Breeder?

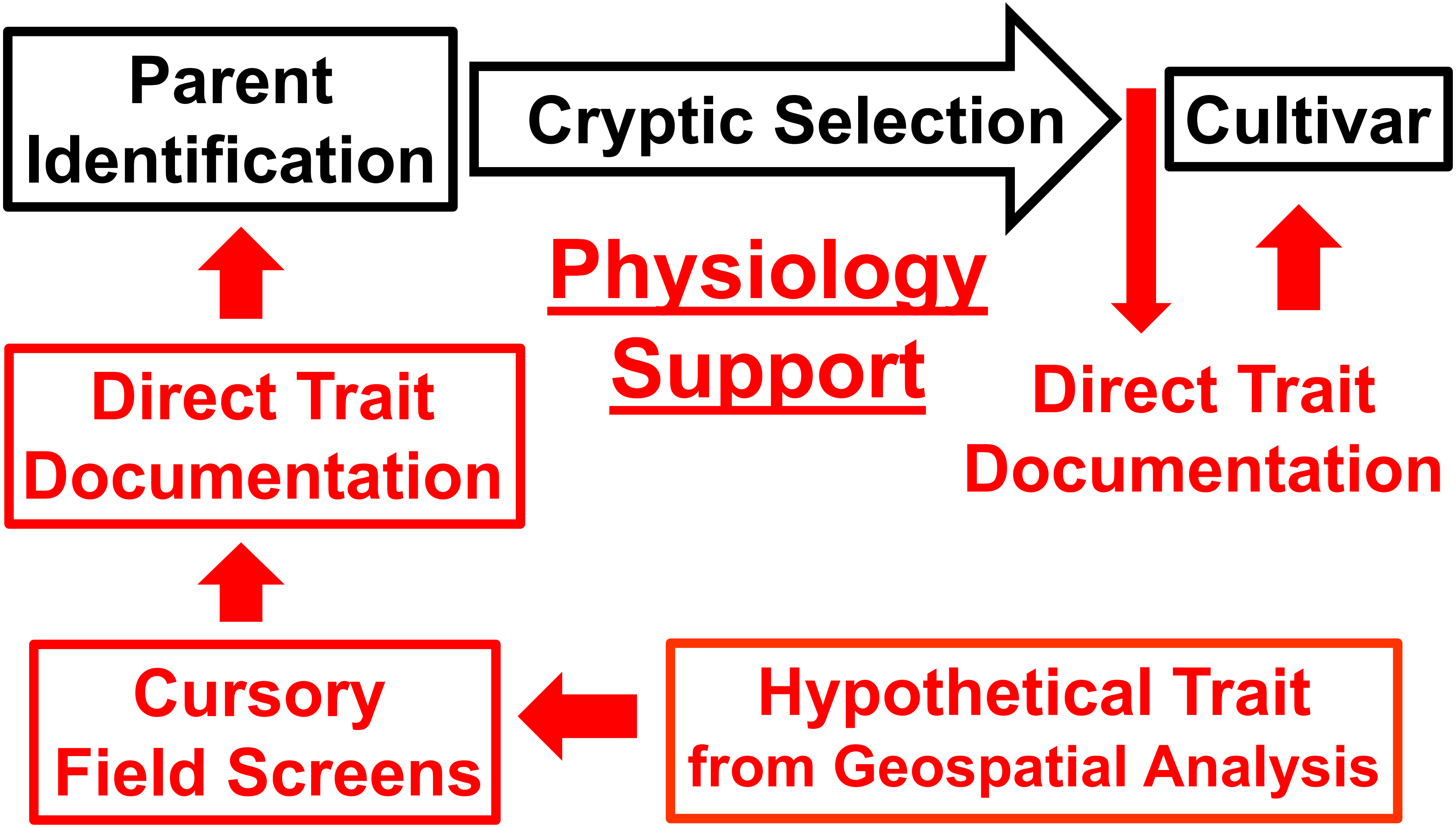
GOAL: Put superior cultivars in farmers' fields

Major Inputs to Support Breeding

1. A *priori* <u>geospatial yield assessment</u> of location and environment appropriate for specific physiological process.

2. Develop and apply <u>multi-tier screening</u> to identify genotypes expressed desired physiological response.

Breeding Path



Geospatial Assessment by Model

Red Flags

1. "Calibrated" models
   a. Makes model empirical fits to data
   b. SSM not calibrated

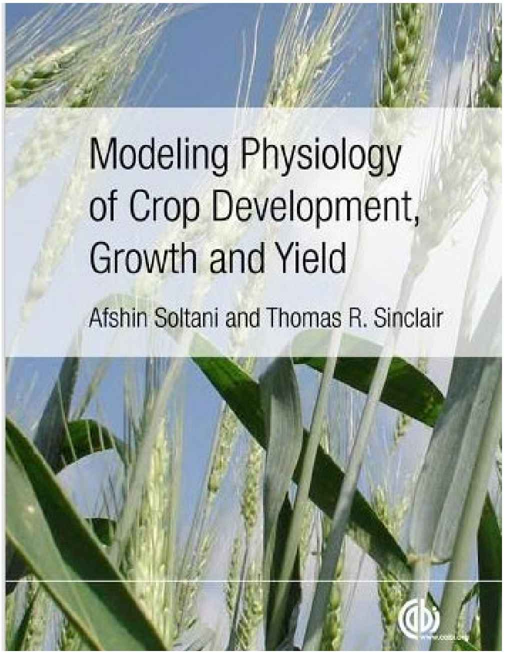
2. "Validated" models
   a. Hypotheses cannot be validate, i.e. biological models
   b. Robustness evaluation using all available data

<u>Model Approach</u>

1. Only <u>two levels</u> of hierarchy
   a. Organizational: Canopy ➡ Crop
   b. Temporal: Daily ➡ Season

2. Use “<u>summary</u>” descriptions justified by both experimental and theoretical evidence

Simple Simulation Model (SSM)



- Leaf area development function of temperature and soil water
- Growth function of RUE, radiation interception, and soil water
- Transpiration function of growth

Transpiration Prediction
Failings of Energy Balance Approach

- Energy balance is instantaneous description, not integral
- Penman Eqn. is not descriptive for vegetative surfaces
- Empirical in application
- Penman- Monteith requires ill-defined “canopy conductance”
- ‘Crop coefficient’ purely empirical

$$T = G \bullet (e^*\text{-}e) / k_d$$

where: G = plant growth

T = transpiration

$(e^*\text{-}e)$ = atm. vapor pressure deficit

$$k_d = b\ c\ (P\ C_a/1.5\ p\ \varepsilon)\ (L_D/L_T)$$

b = photosynthate conversion to plant mass

$c = (1 - C_i/C_a)$; C3 = 0.3, C4 = 0.7

Tanner and Sinclair (1983)

Transpiration Efficiency Coefficient (k_d)

C_4 (maize, sorghum, millet)	9 Pa
C_3 grasses (wheat, rice)	6 Pa
C_3 legumes (soybean, peanut)	5 Pa

Key SSM Inputs

- Ontogeny Intervals (cum. temperature)
- Phyllochron
- Leaf area = f(node number)
- Species parameters
  - Radiation Use Efficiency
  - Transpiration Coeffient (k_d)
- Response functions to Fraction Transpirable Soil Water
- Linear increase in harvest index

Daily Weather Input

GIS Data Base

(Pioneer Hi-Bred International, Inc.)

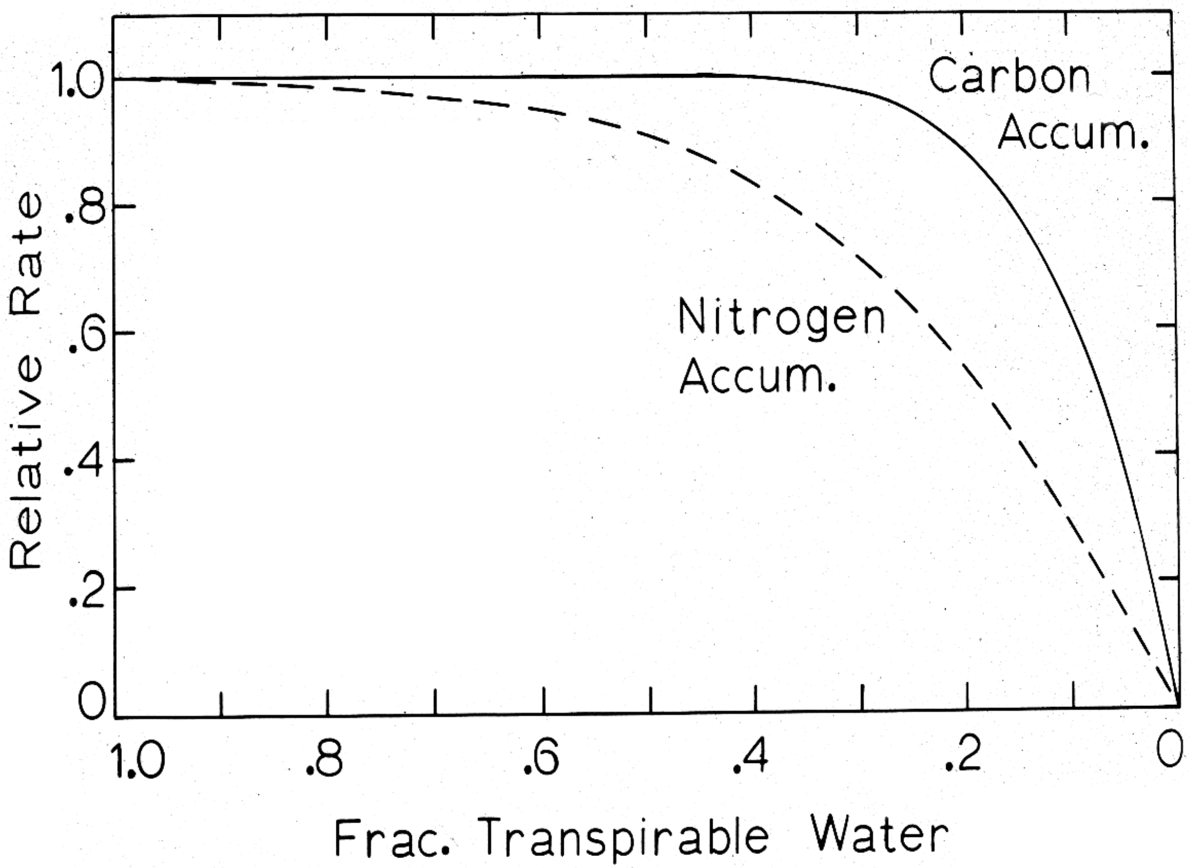
- **30 x 30 km grid system for U.S cropping areas (2655 grid locations)**
- **Weather (50 years for most grids)**
- **Soil**
- **Crop ontogeny by grid location**
- **Sowing Date**

Each test required >130,000 model runs

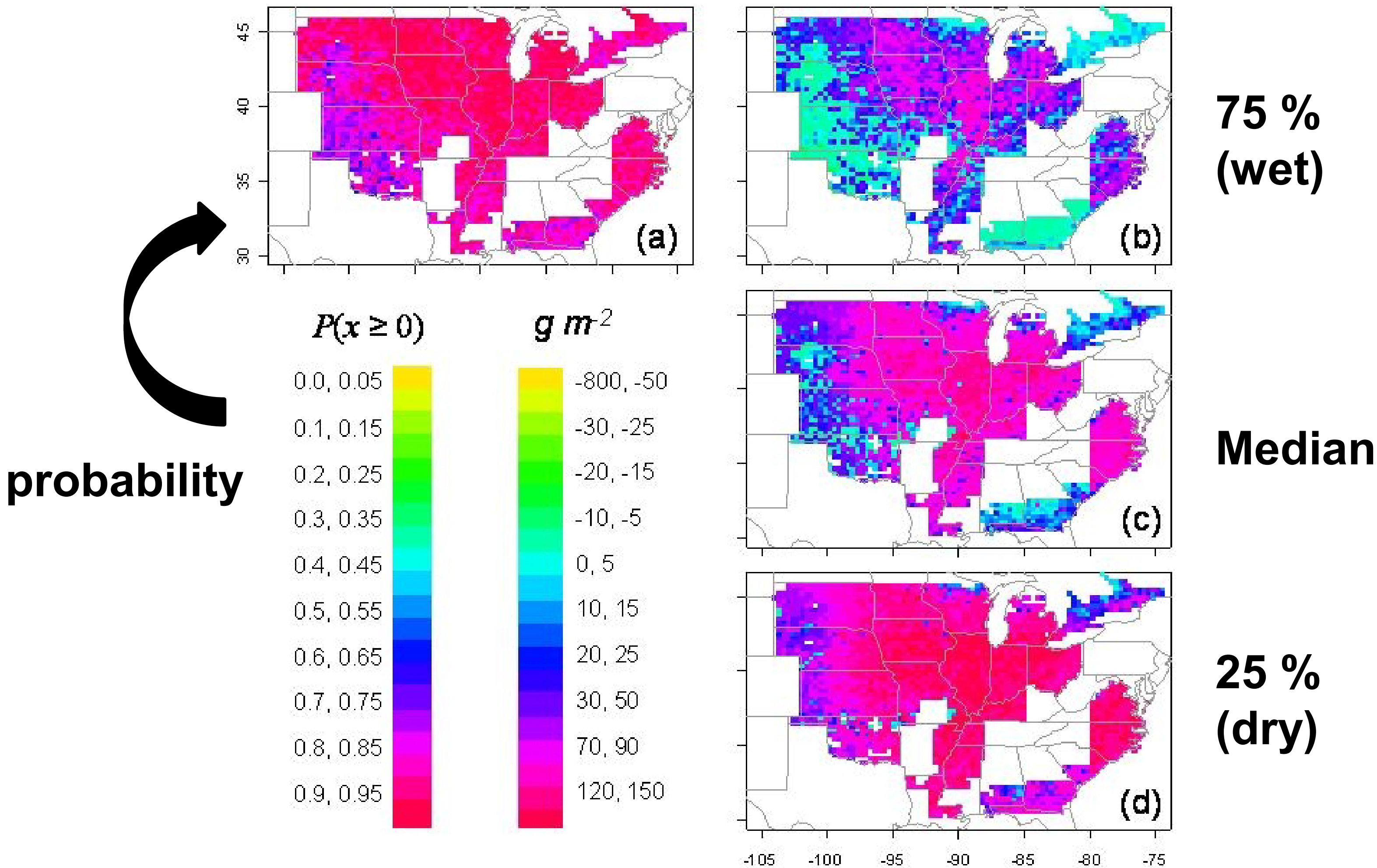
Case Studies

1. Nitrogen fixation drought resilience in soybean.
2. Stomata closure at low values of vapor pressure deficit.
3. Early stomata closure with soil drying in peanut.

Case 1: Soybean N_2 Fixation Limited by Soil Water



Simulated Yield Response to N_2 Fixation Drought Resilience



Sinclair et al. (2010)

Identification of N_2 Tolerant Germplasm

~ 3 500 plant introductions

Initial Field Screen | Low petiole ureide

~ 250 PI selections

Field screen | N accum. under drought

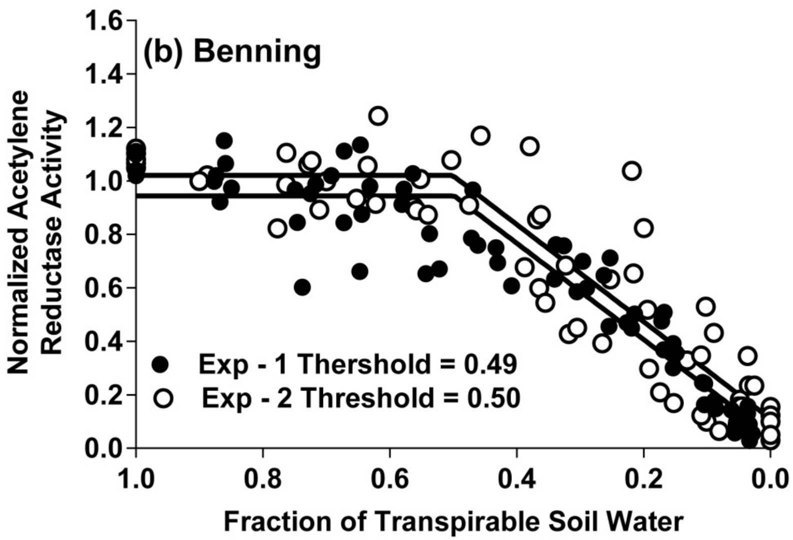
24 PI selections

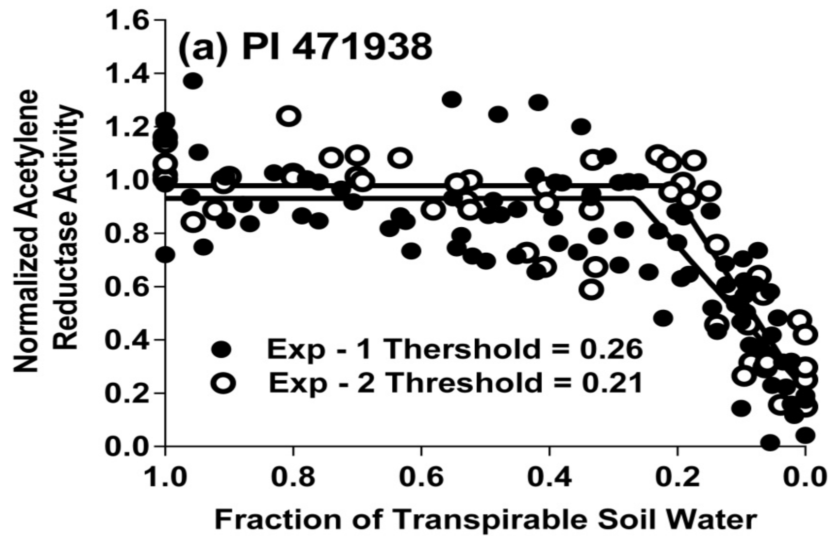
Glasshouse test | ARA with drying soil

11 Tolerant PIs

Normal - sensitive

Selected - tolerant



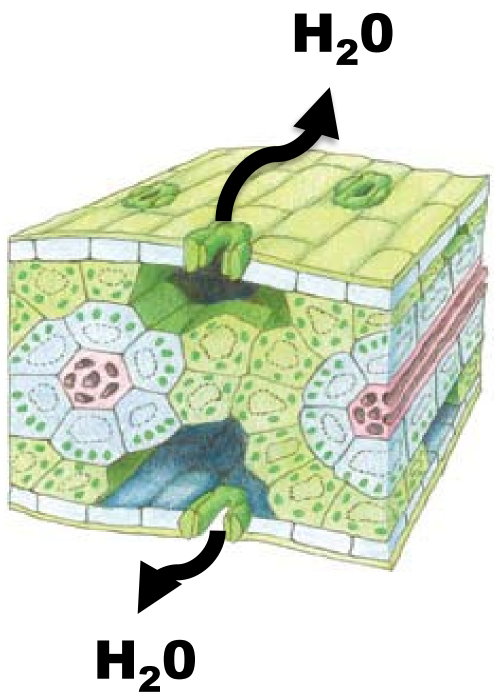


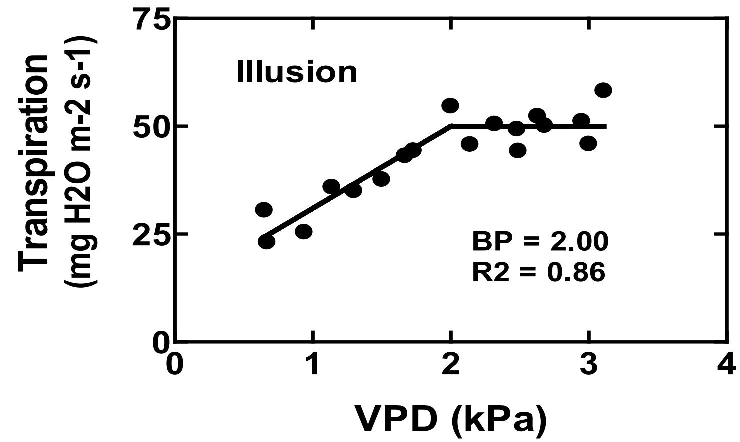
Soil Drying

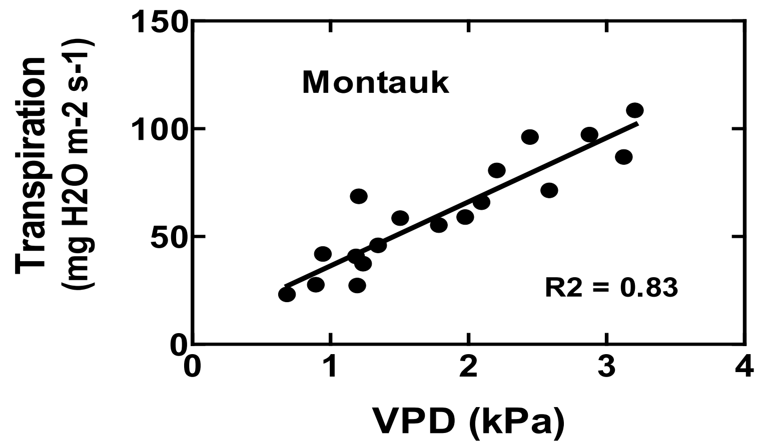
Cultivars: Elite Breeding Lines (AR & NC)

				N_2 Fixation Drought Tolerance		Limited Transpiration	
	Maturity Group	Parental Pedigree[1]	Antecedents[2]	Rank	Antecedent With Trait	Rank	Antecedent With Trait
R02-1325	V	93705-35-1 x PI 227557	93705-35-1 = Jackson x KS 4895	1	50% PI 227557 25% Jackson	8	No known source
N05-7432 (N8002)	VIII	N7002 x N98-7265	N7002 = N7001 x Cook N98-7265 = Hutcheson x PPI 471938	2	25% PI 471938	3	12.5% PI 416937
R05-5559	V	UA4805 x PI 471938	UA4805 = Hartz 5545 x KS 4895	3	50% PI 471938	linear	No known source
N04-9646	VII	Boggs x NTCPR94-5157	Boggs = G81-152 x Coker 6738 NTCPR94-5157 = Davis x N73-1102 N73-1102 = Tracy x Ransom	4	No known source	4	No known source
N06-7194	VIII	N98-7265 x N93-110-6	N98-7265 = Hutcheson x PI 471938 N93-110-6 = Young x PI 416937	5	25% PI 471938	5	25% PI 416937
R09-1069	V	R01-52F x Ozark	R01-52F = R93-5455 x Minsoy R93-5455 = Jackson-derived line x PI 416937 Ozark = Holladay x DP 415	6	6.25% Jackson	1T	12.5% PI 416937
N06-7543	VII	NC-Roy x N8001	NC-Roy = Holladay x Brim N8001 = N7001 x Cook	7	No known source	7	12.5% PI 416937
R07-5235	V	R01-52F x R02-6268F	R01-52F = R93-5455 x Minsoy R93-5455 = Jackson-derived line x PI 416937 R02-6268F = KS 4895 x Jackson	8	31.25% Jackson	9	12.5% PI 416937
R09-1121	V	R01-888F x R05-5559	R01-888F = Jackson x KS 4895 R05-5559 = UA 4805 x PI 471938	9	25% Jackson 25% PI 471938	1T	No known source
R07-7044	V	Lonoke x NTCPR94-5157	Lonoke = Manokin x Asgrow 6297 NTCPR94-5157 = Davis x N73-1102 N73-1102 = Tracy x Ransom	10	No known source	6	No known source

Case 2: Partial Stomata Closure at Elevated VPD

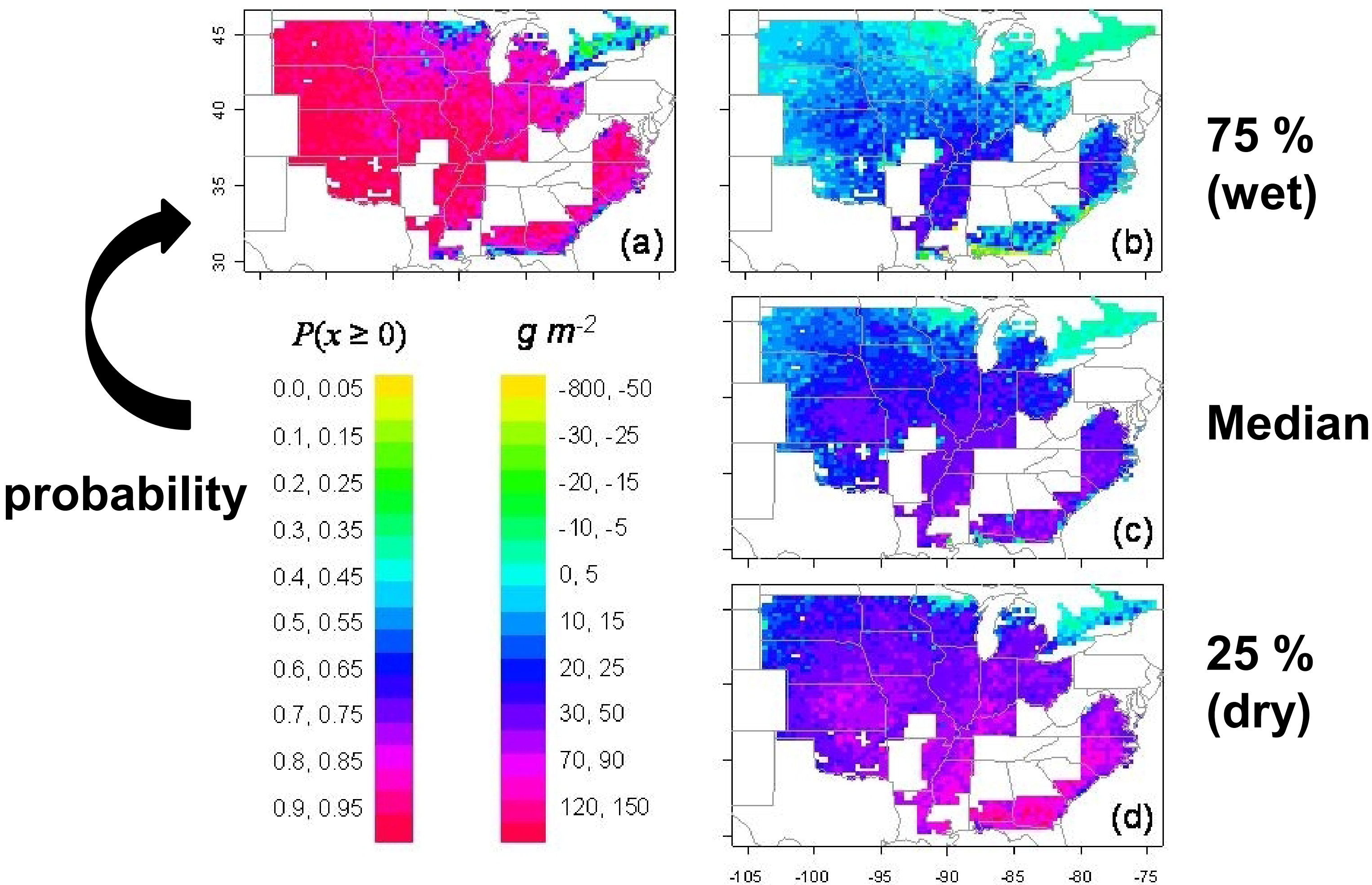






Jafarikouhini et al. (2020)

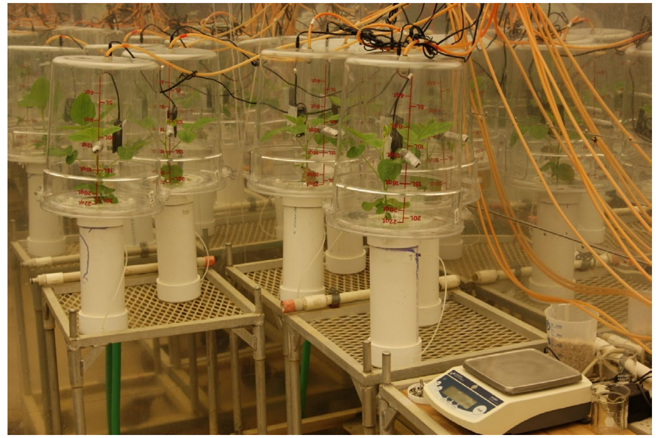
Simulated Yield Response of Soybean to Elevated VPD

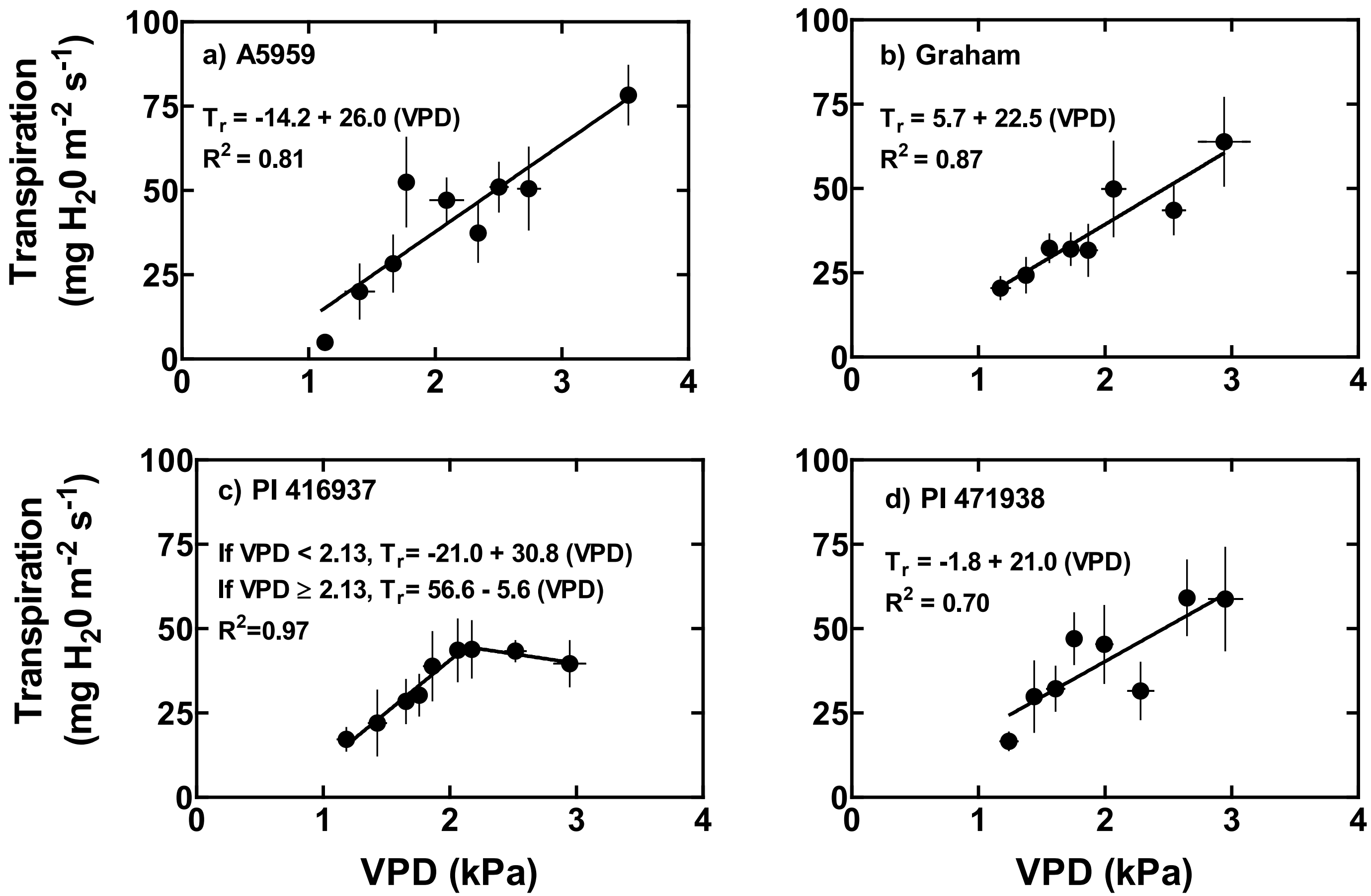


Sinclair et al. (2010)

Initial Field Screen

Normal **PI 416937**





Transpiration (mg H20 m-2 s-1)
a) A5959
Tr = -14.2 + 26.0 (VPD)
R2 = 0.81
b) Graham
Tr = 5.7 + 22.5 (VPD)
R2 = 0.87
c) PI 416937
If VPD < 2.13, Tr= -21.0 + 30.8 (VPD)
If VPD ≥ 2.13, Tr= 56.6 - 5.6 (VPD)
R2=0.97
d) PI 471938
Tr = -1.8 + 21.0 (VPD)
R2 = 0.70
VPD (kPa)

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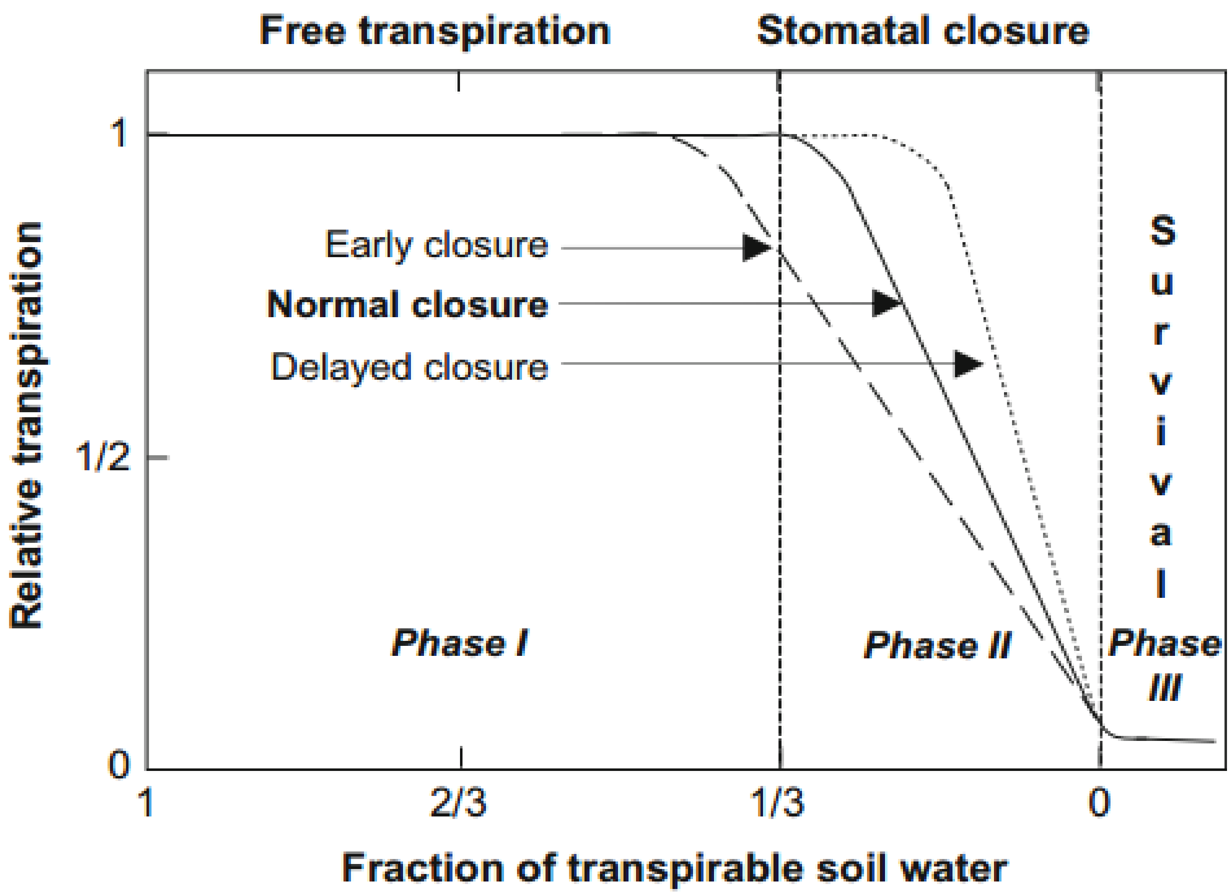
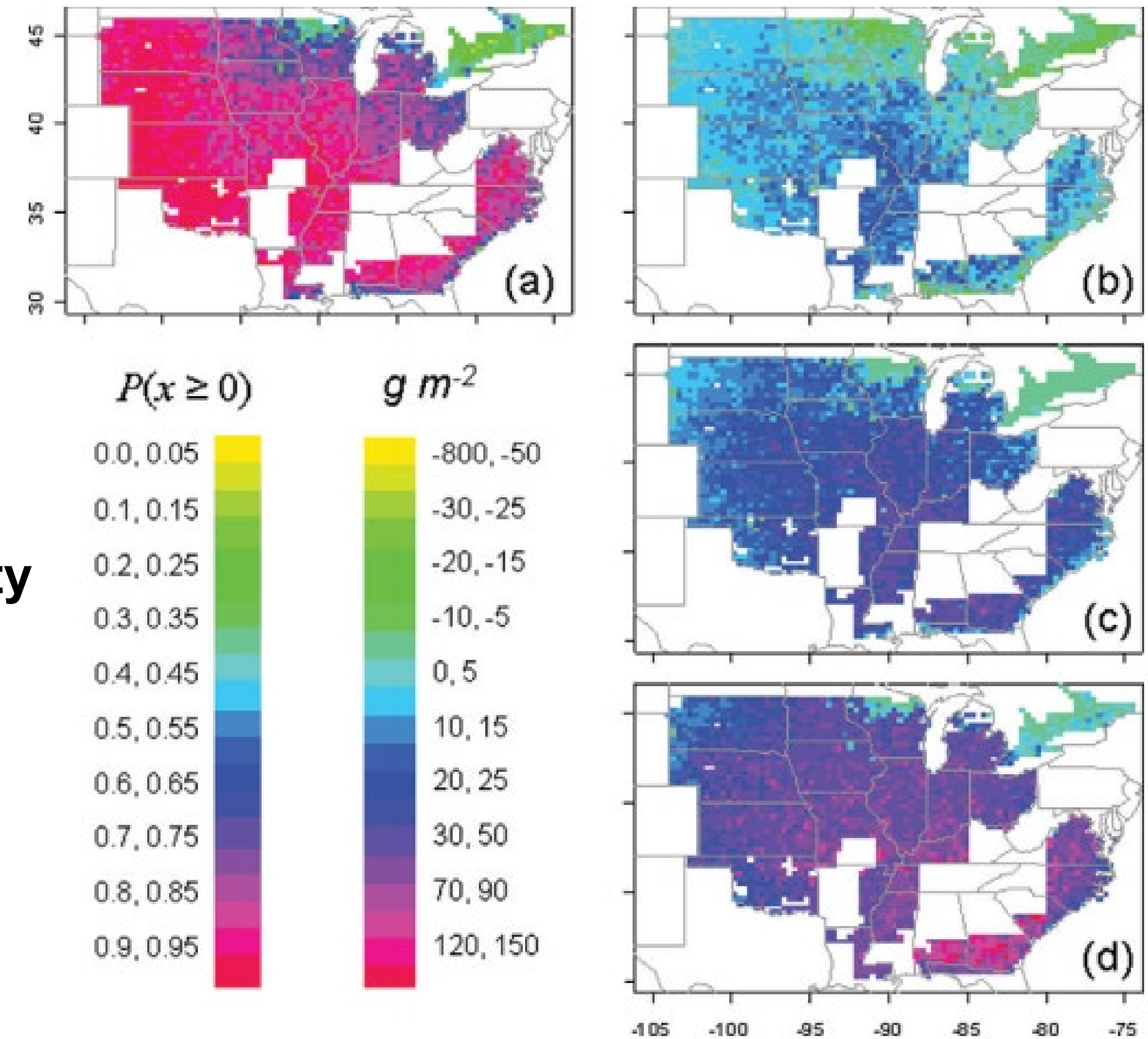
Competitive Check

Case 3: Water Conservation by Early Stomata Closure with Soil Drying



Simulated Benefit of Early Stomatal Closure



probability

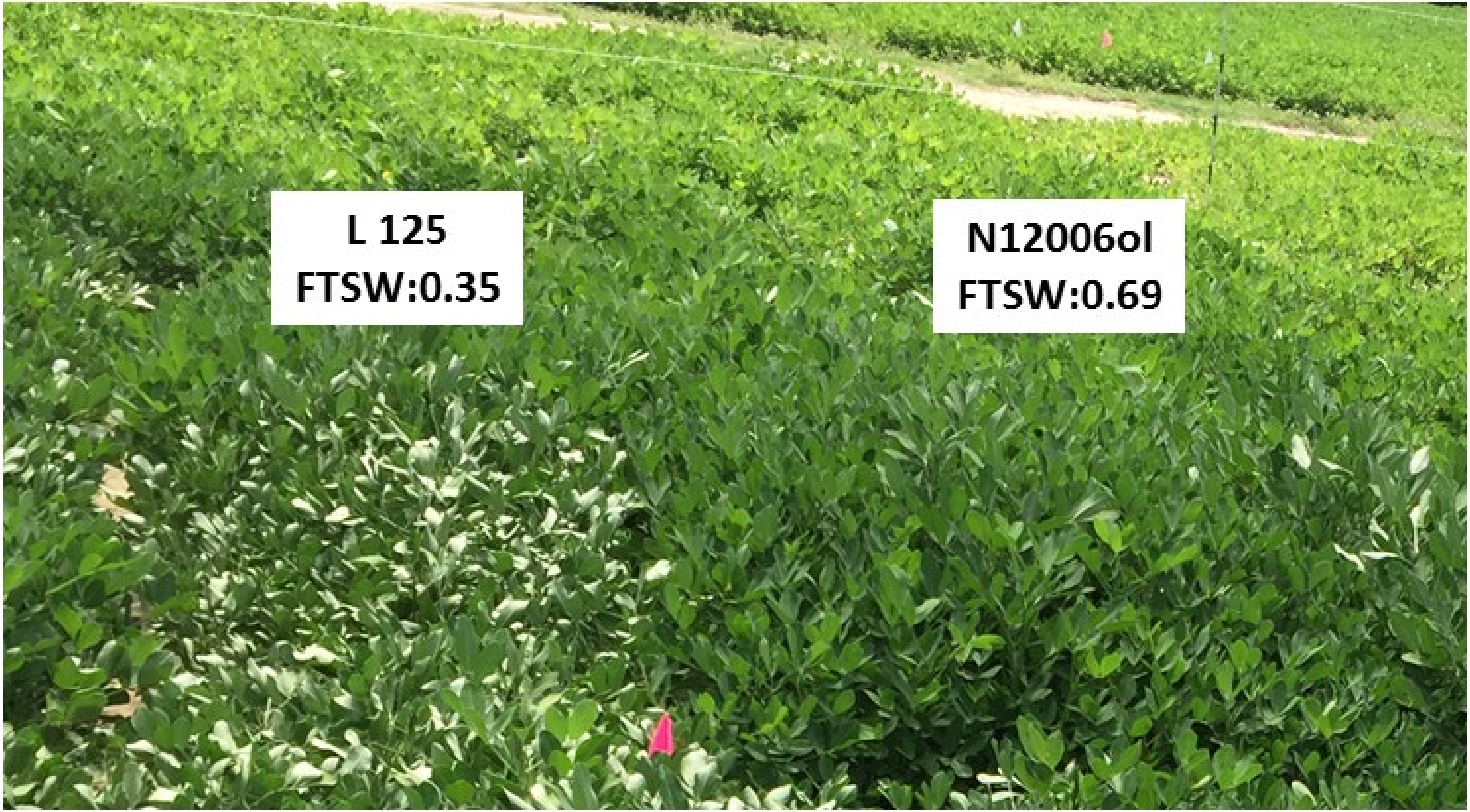
75 % (wet)

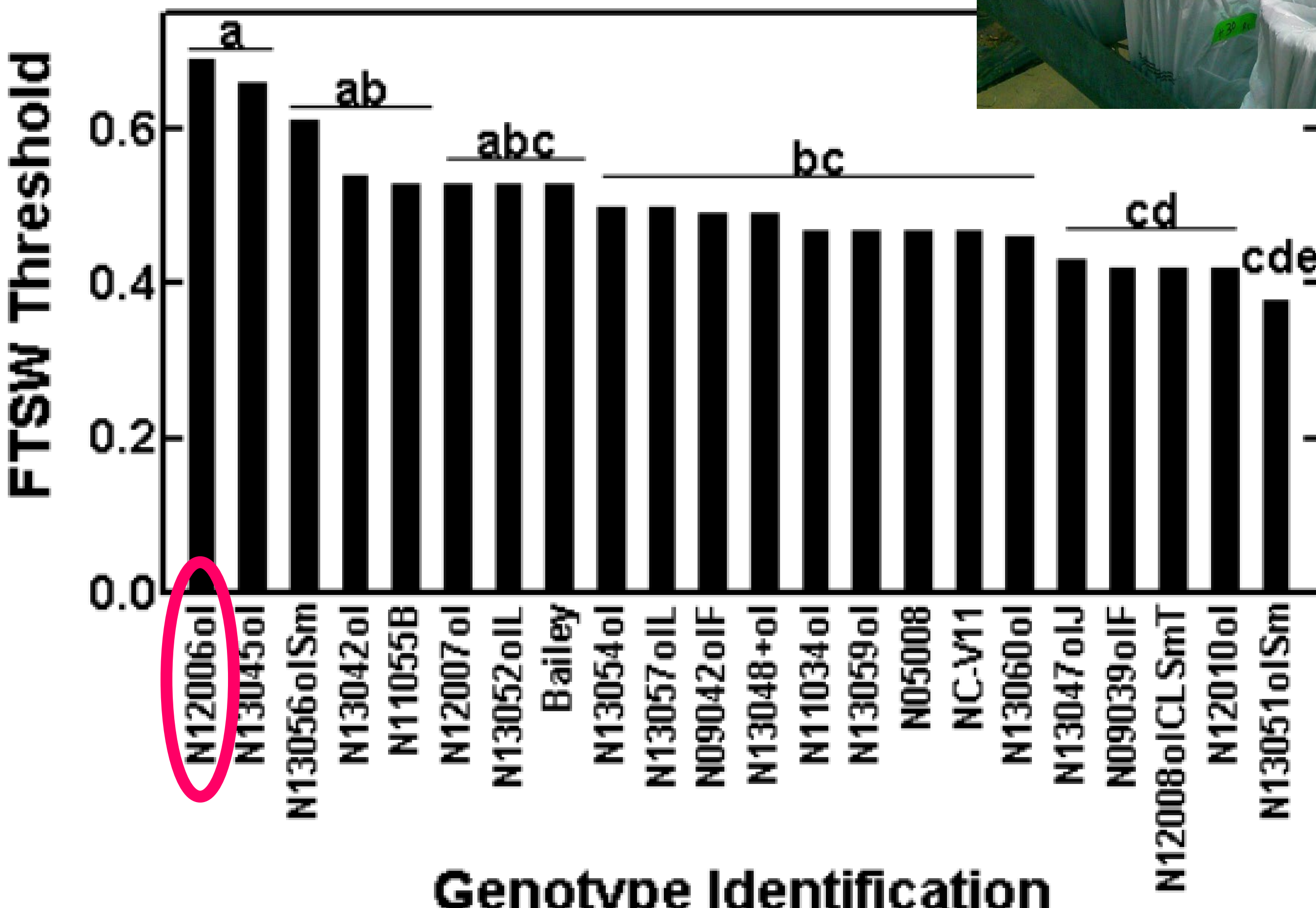
Median

25 % (dry)

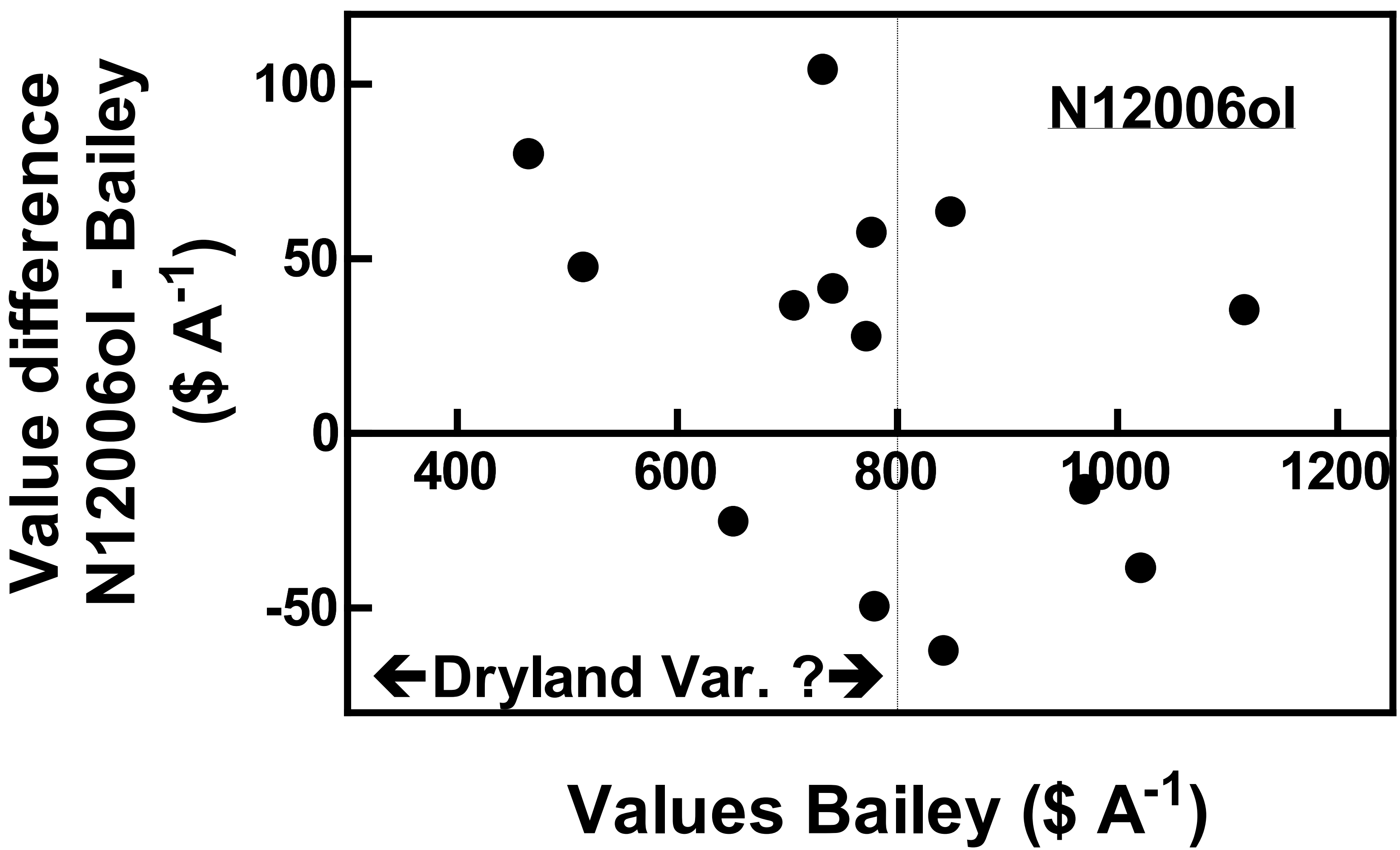
Sinclair et al. (2010) Agronomy Journal 102:475

Initial Visual Field Screen



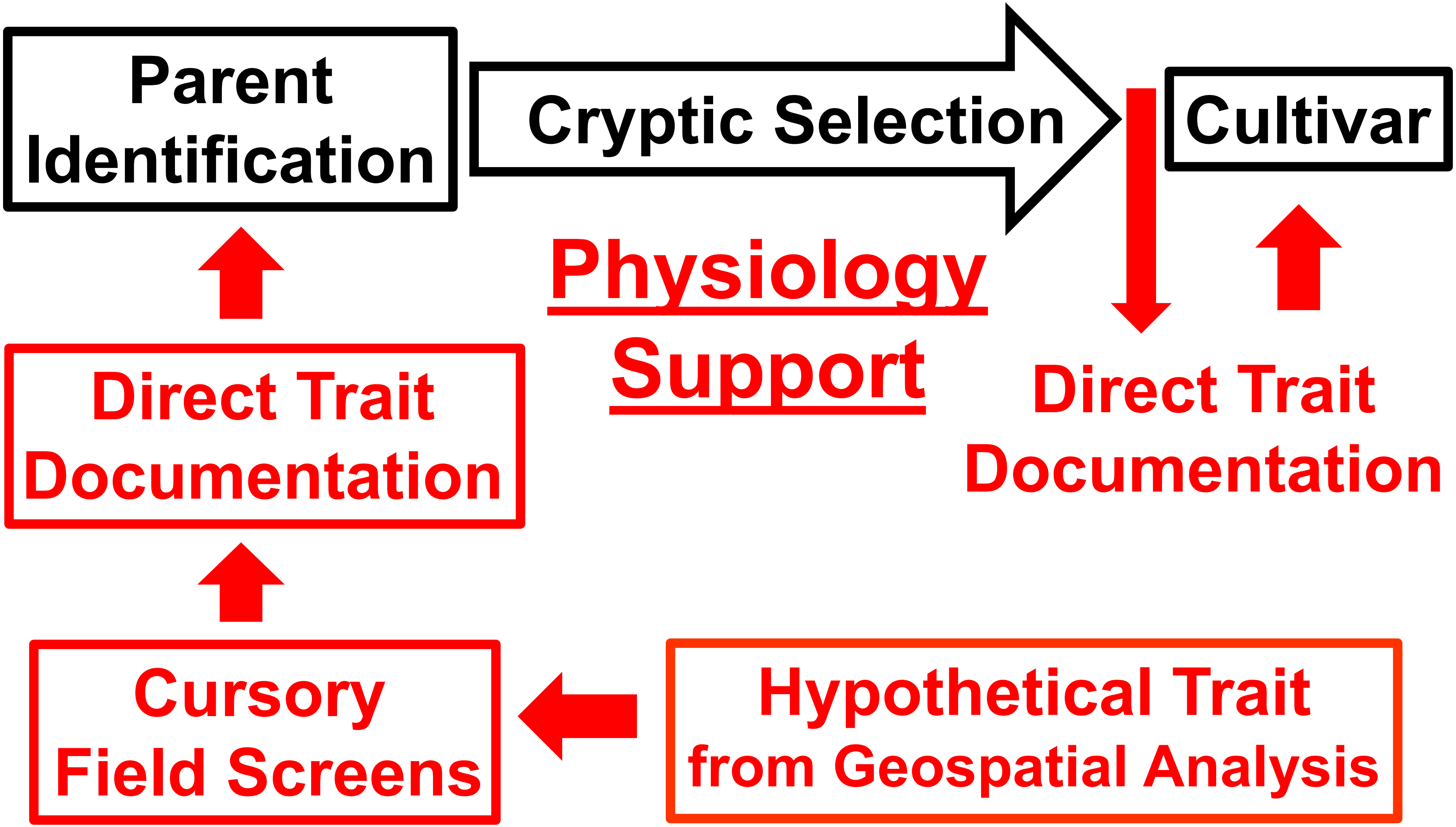


FTSW Threshold
0.0
0.2
0.4
0.6
a
ab
abc
bc
cd
cde
N12006ol
N13045ol
N13056olSm
N13042ol
N11055B
N12007ol
N13052olL
Bailey
N13054ol
N13057olL
N09042olF
N13048+ol
N11034ol
N13059ol
N05008
NC-V11
N13060ol
N13047olJ
N09039olF
N12008olCLSmT
N12010ol
N13051olSm
Genotype Identification



Value difference
N12006ol - Bailey
($ A-1)
100
50
0
-50
400
600
800
1000
1200
N12006ol
←Dryland Var. ?→
Values Bailey ($ A-1)

Breeding Path



Physiological Input and Breeding

Approach

- Mechanistic model for geospatial analysis
- Develop tiers of physiological screens for parent selection
- Confirmation of trait expression in high-yielding progeny

Chemically Induced VDP Response