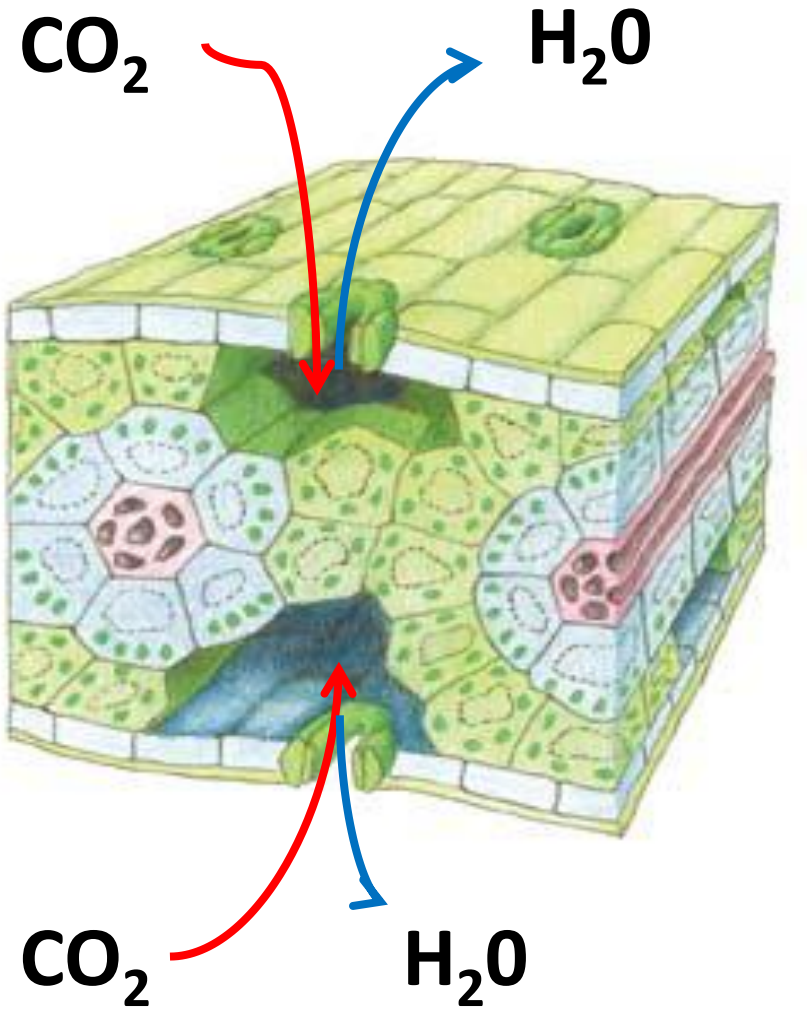
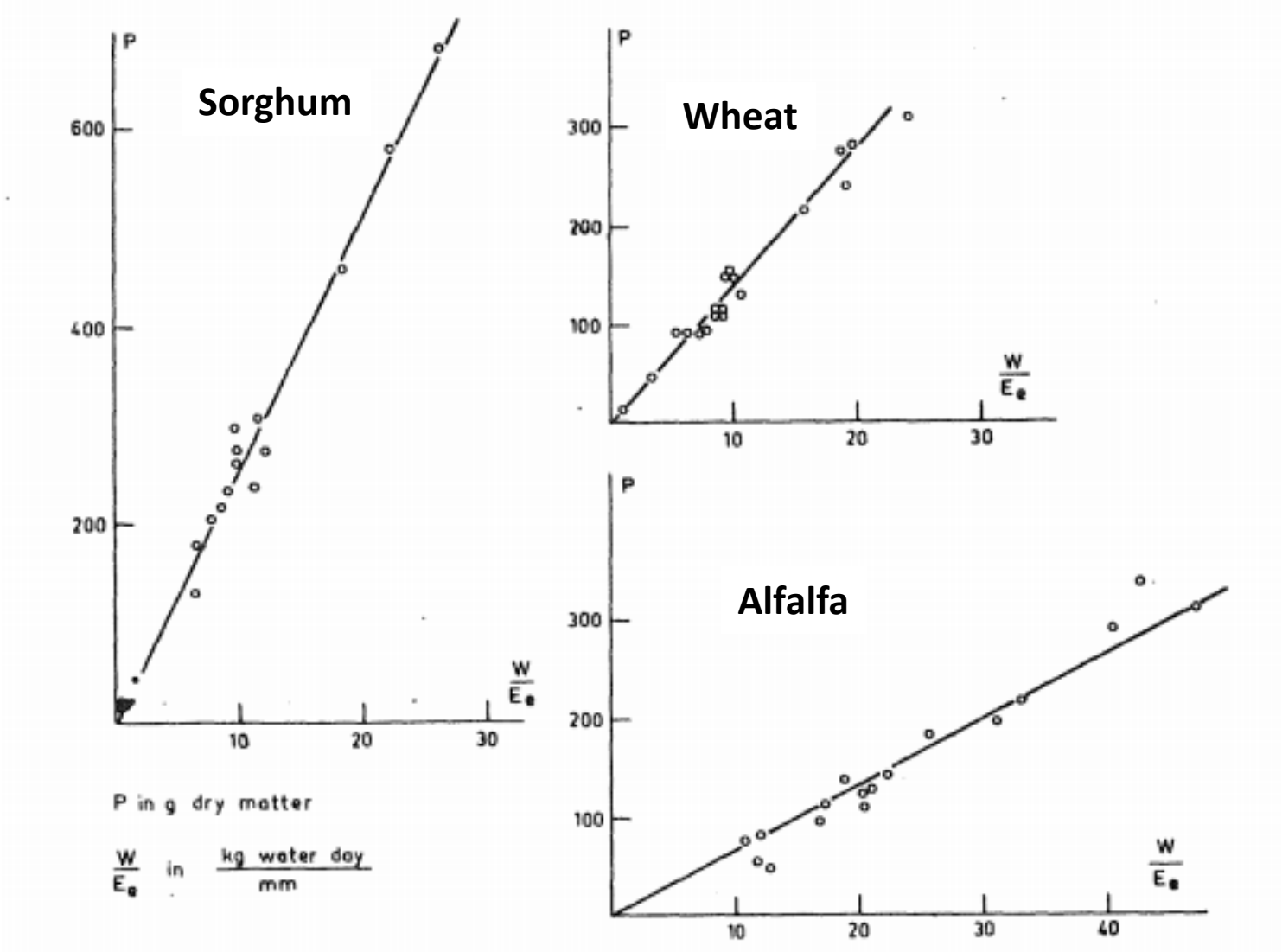
Altering Crops to Sustain Yields under Decreased and Variable Rainfall Resulting from Climate Change

Back to Basics





C.T. deWit (1958)

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

where: G = plant growth

T = transpiration

(e^*-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 (k_d) [defines slope of de Wit's curve]

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

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

k_d is essentially constant within a species, although it will increase with increased atmospheric CO_2

Therefore, curious solution to increasing crop growth on limited water (T) is to somehow decrease (e*-e)

Crop alterations to decrease (e*-e)?

Crop alterations to decrease daily (e*-e)

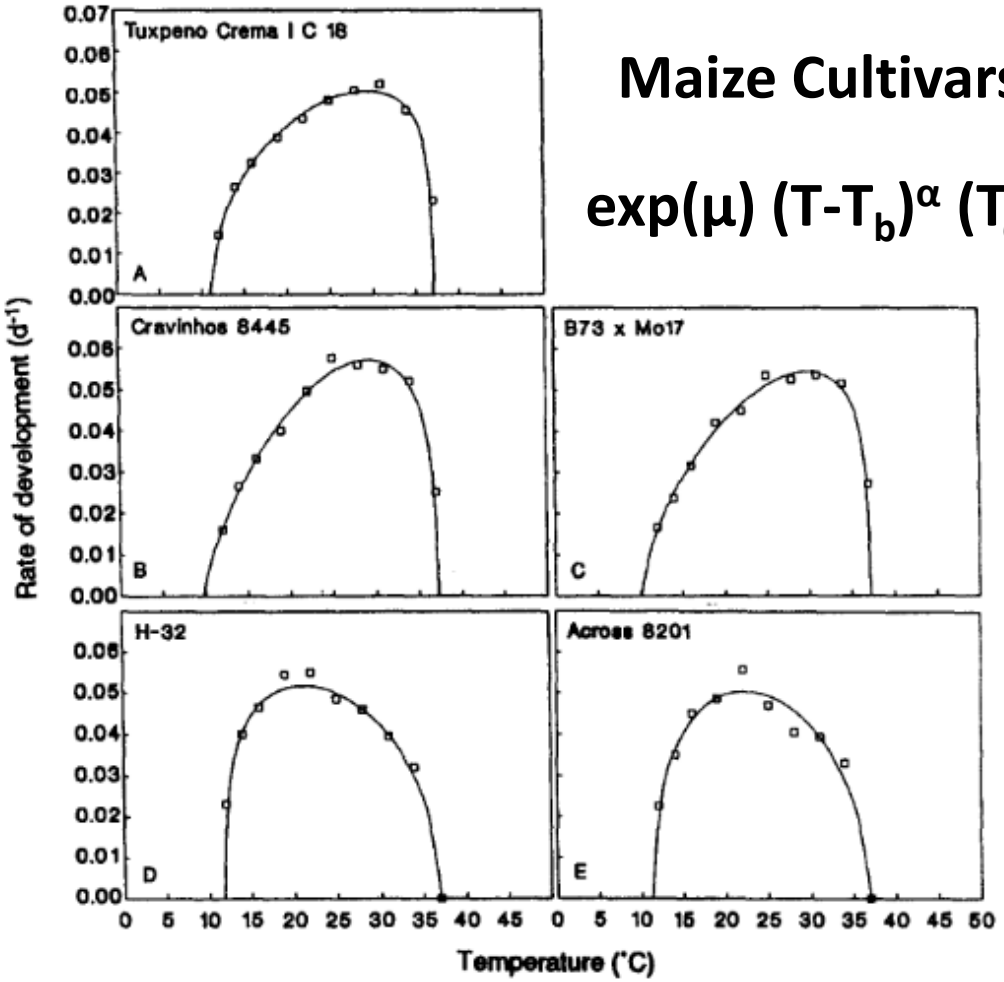
Management

- Select cool-season (low e*-e) species

Genetics

- Low-temperature adapted varieties
- Water conservation traits

Low-Temperature Adapted Genotypes

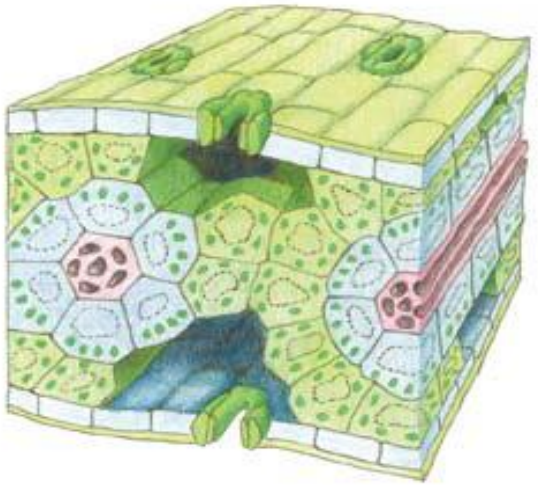


Maize Cultivars

$$\exp(\mu)\,(T-T_b)^{\alpha}\,(T_c-T)^{\beta}$$

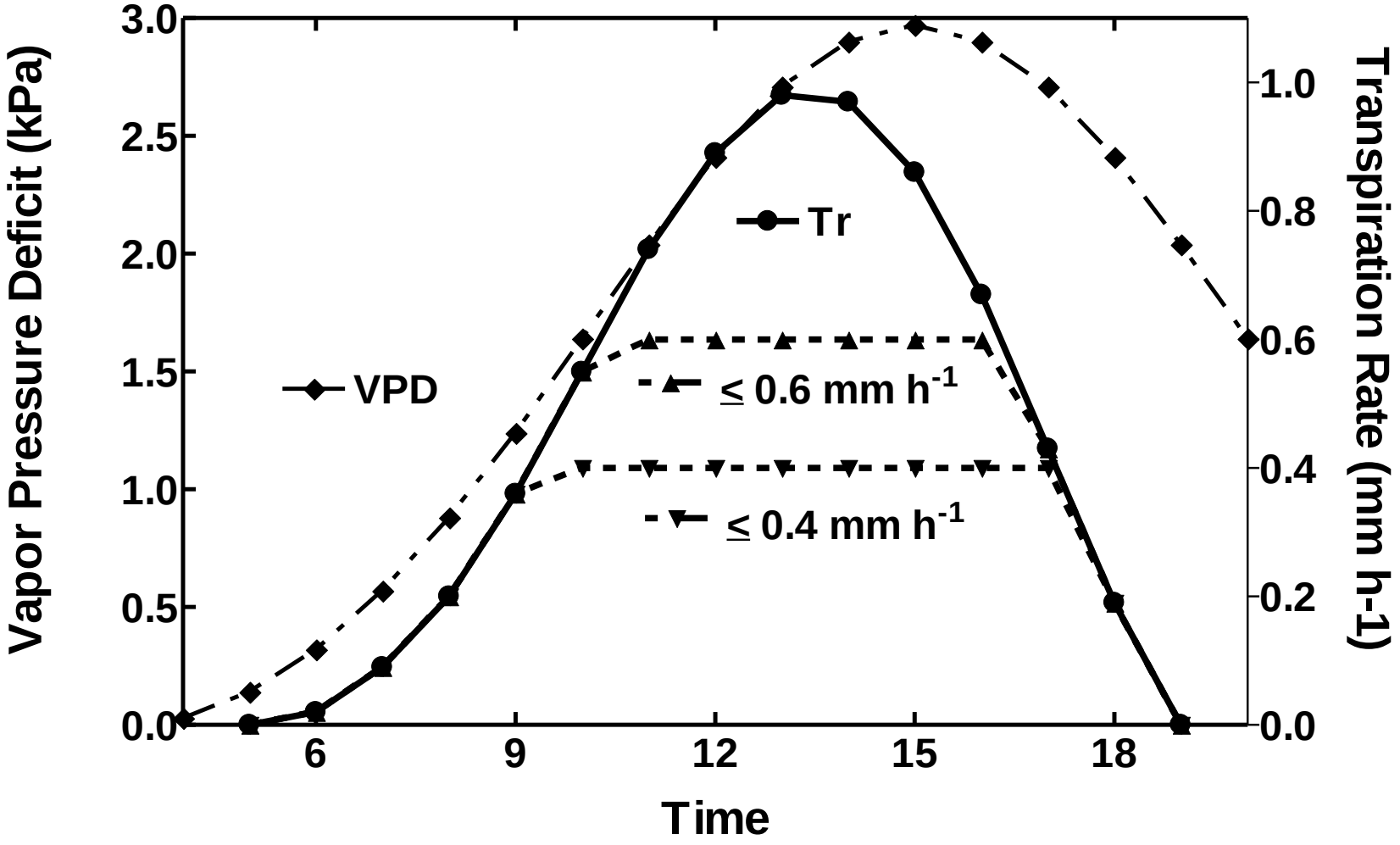
Yin et al. 1995. Agr For Met 77:1

Genetics: Water Conservation Traits for More Effective Use of Water

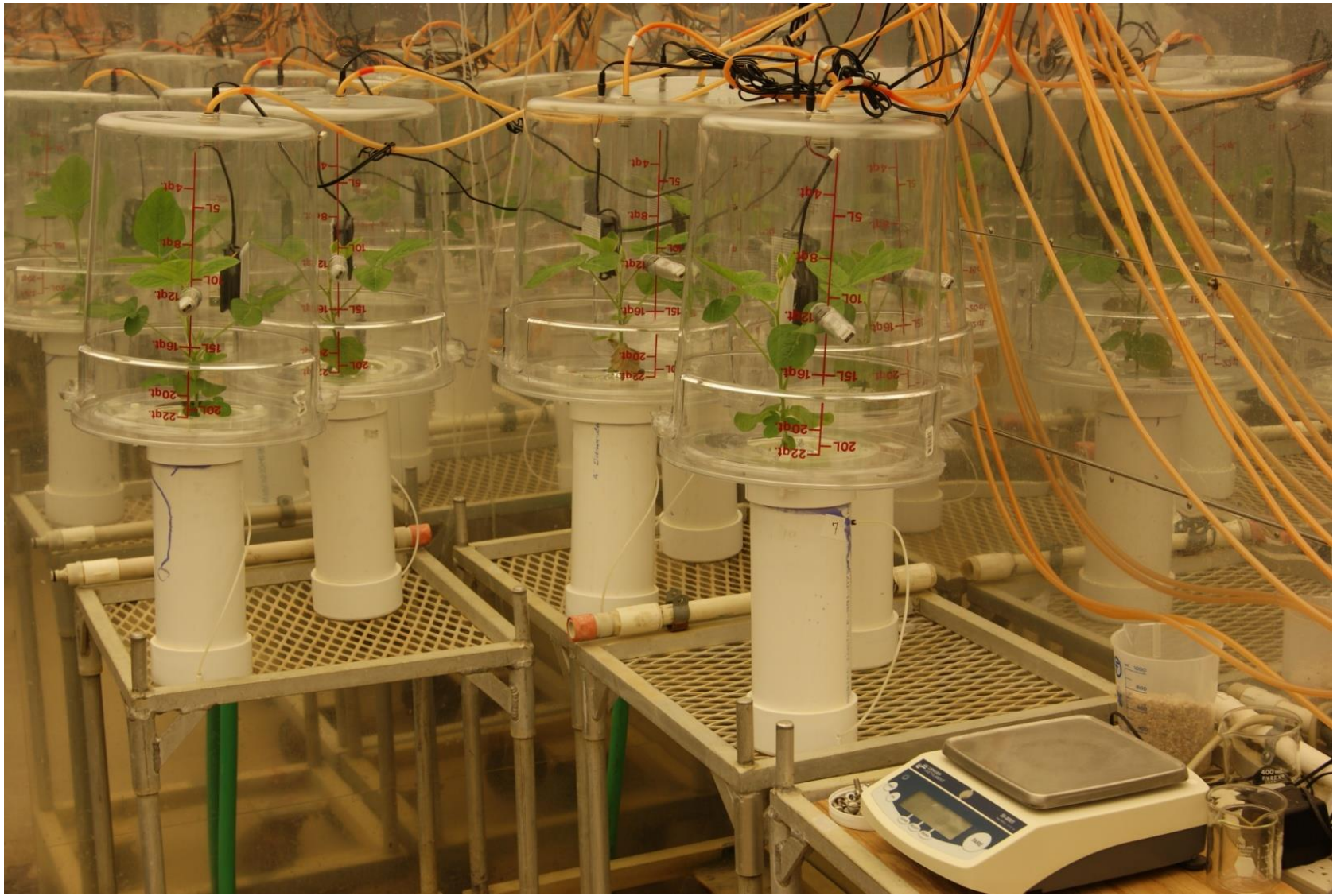


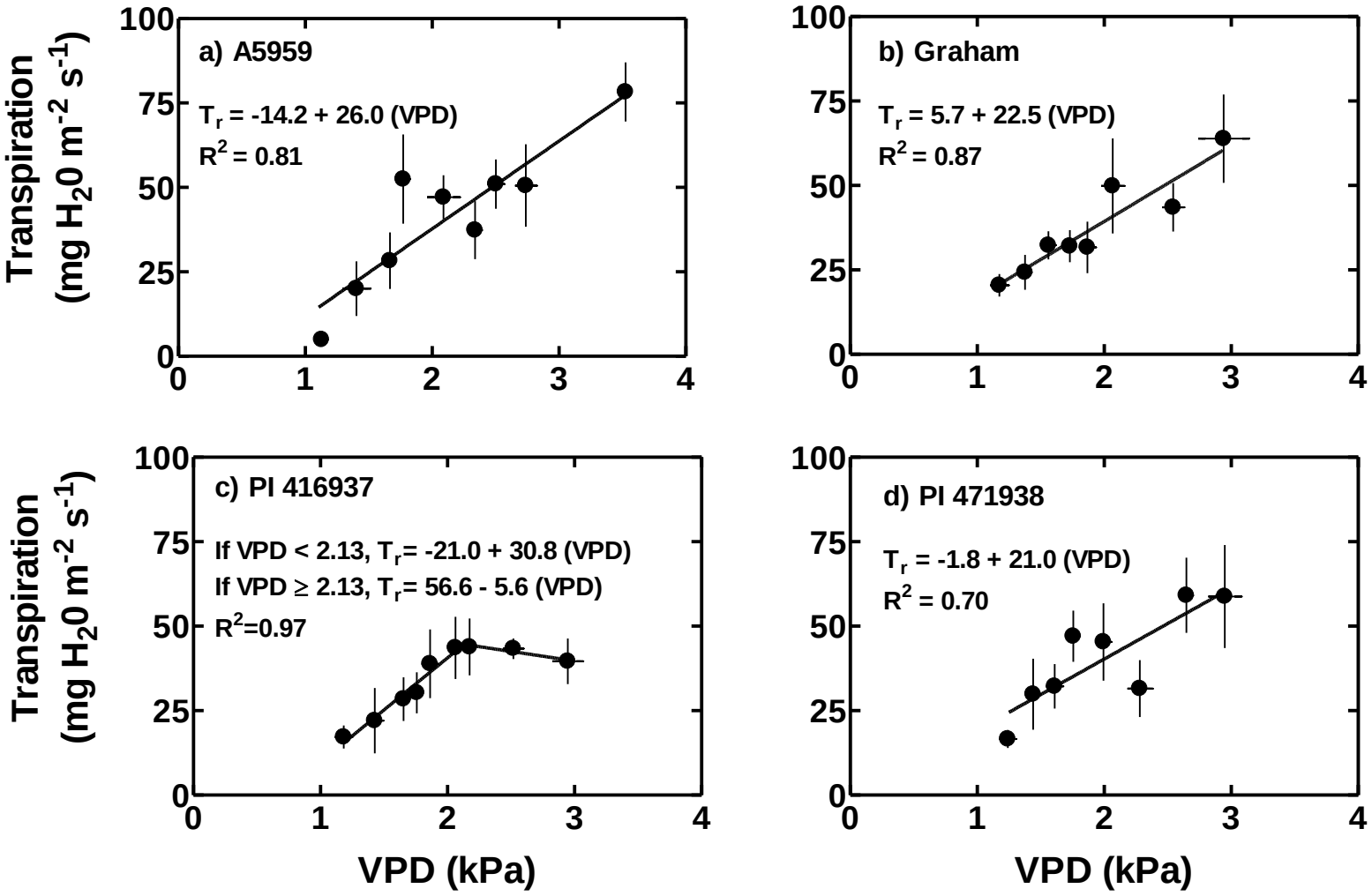
- Decrease early season water use
- Increased water availability late in season to sustain physiological activity during seed growth

Water Conservation:
Transpiration Limitation at elevated VPD



Chamber: Direct response to VPD

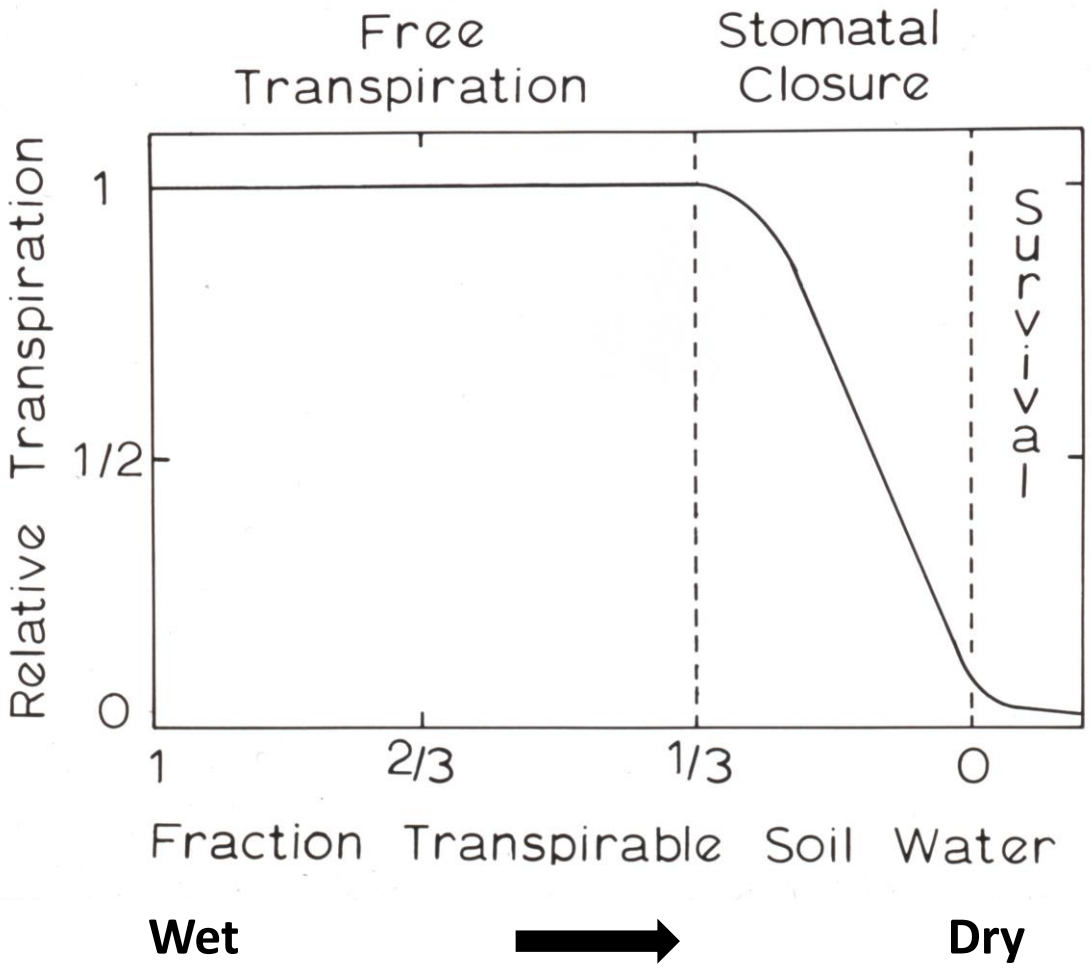



a) A5959
T_r = -14.2 + 26.0 (VPD)
R^2 = 0.81
b) Graham
T_r = 5.7 + 22.5 (VPD)
R^2 = 0.87
c) PI 416937
If VPD < 2.13, T_r= -21.0 + 30.8 (VPD)
If VPD ≥ 2.13, T_r= 56.6 - 5.6 (VPD)
R^2=0.97
d) PI 471938
T_r = -1.8 + 21.0 (VPD)
R^2 = 0.70
Transpiration (mg H_20 m^{-2} s^{-1})
VPD (kPa)
0
25
50
75
100
1
2
3
4

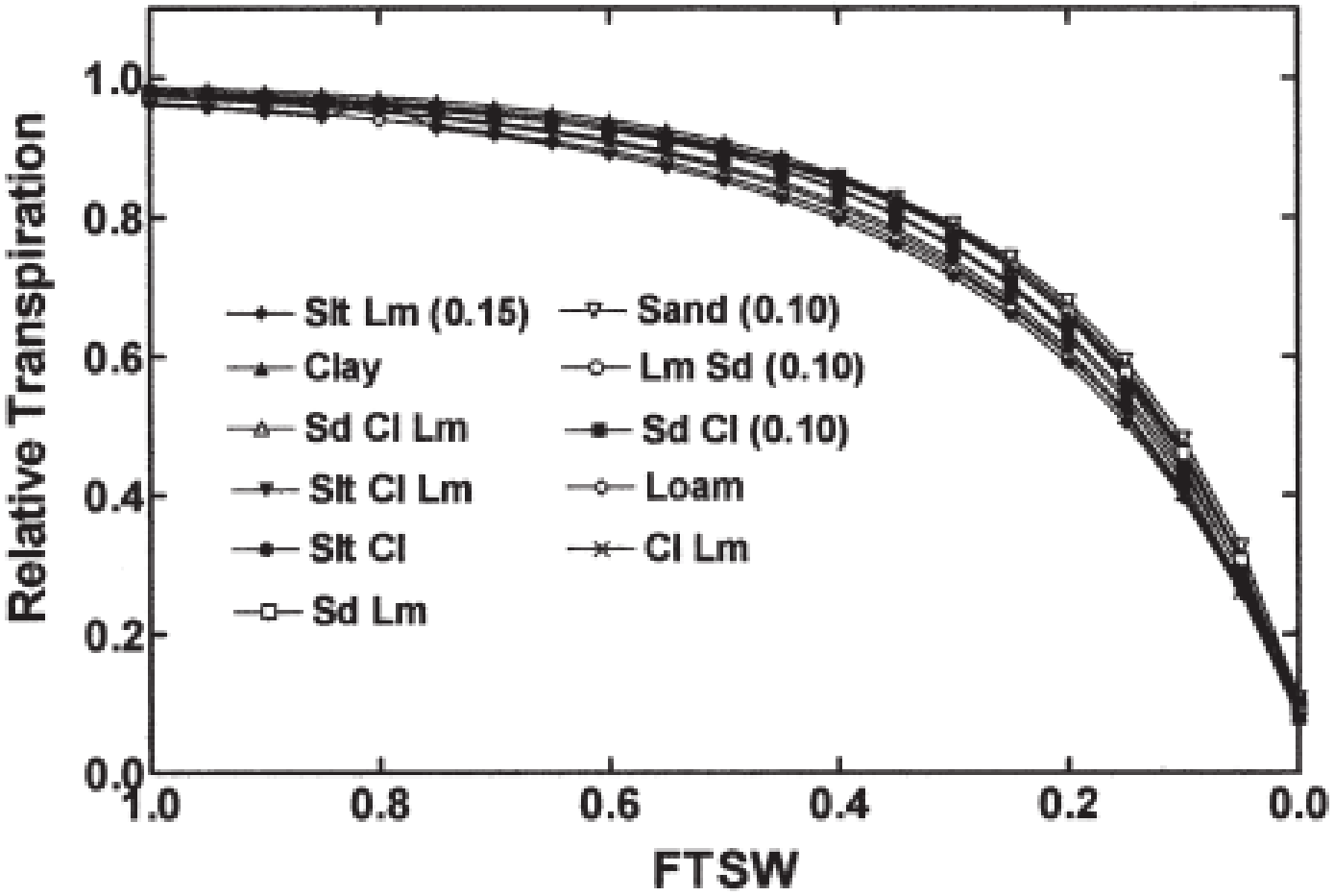
Slow-wilting by PI 416937


Pioneer® brand
Optimum® AQUAmax™ product P1151HR
Competitive Check

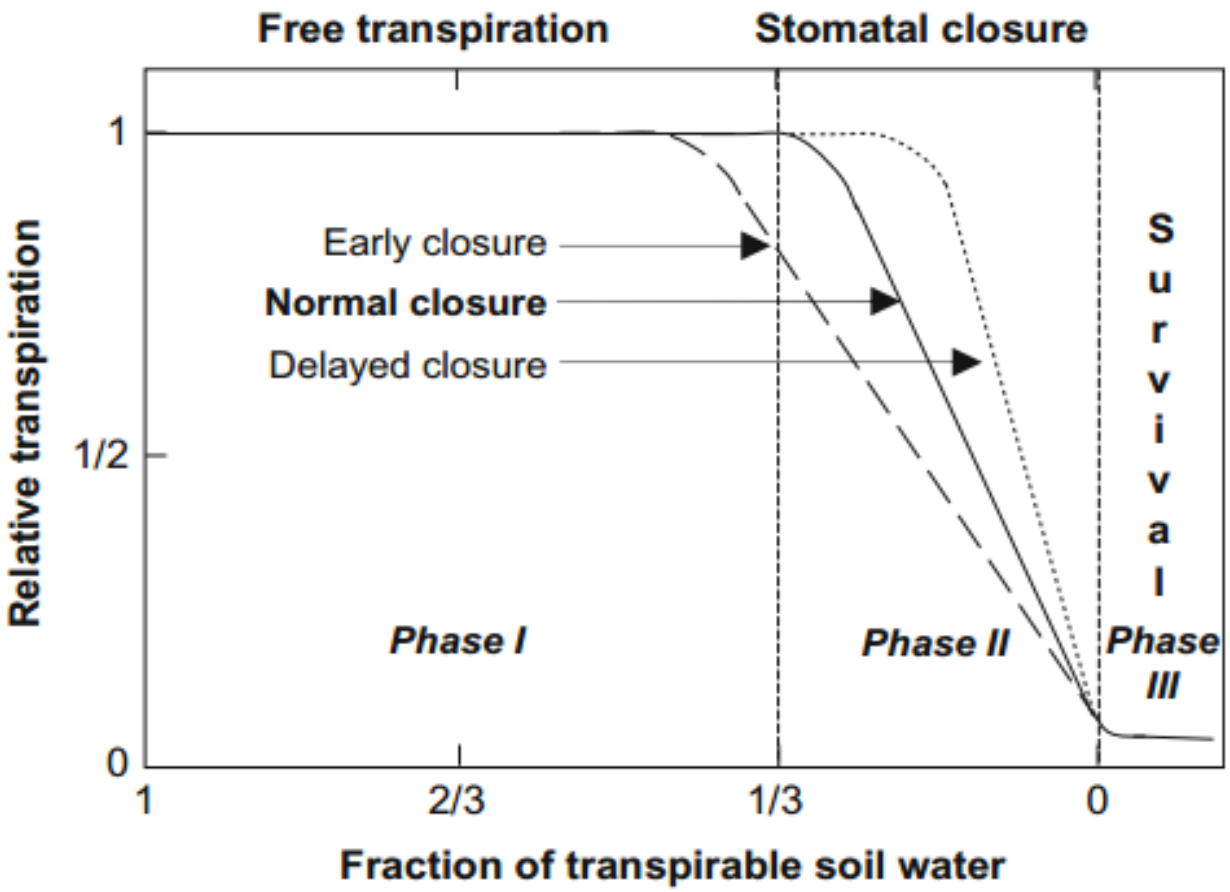
Water conservation:
Plant Response to Soil Drying

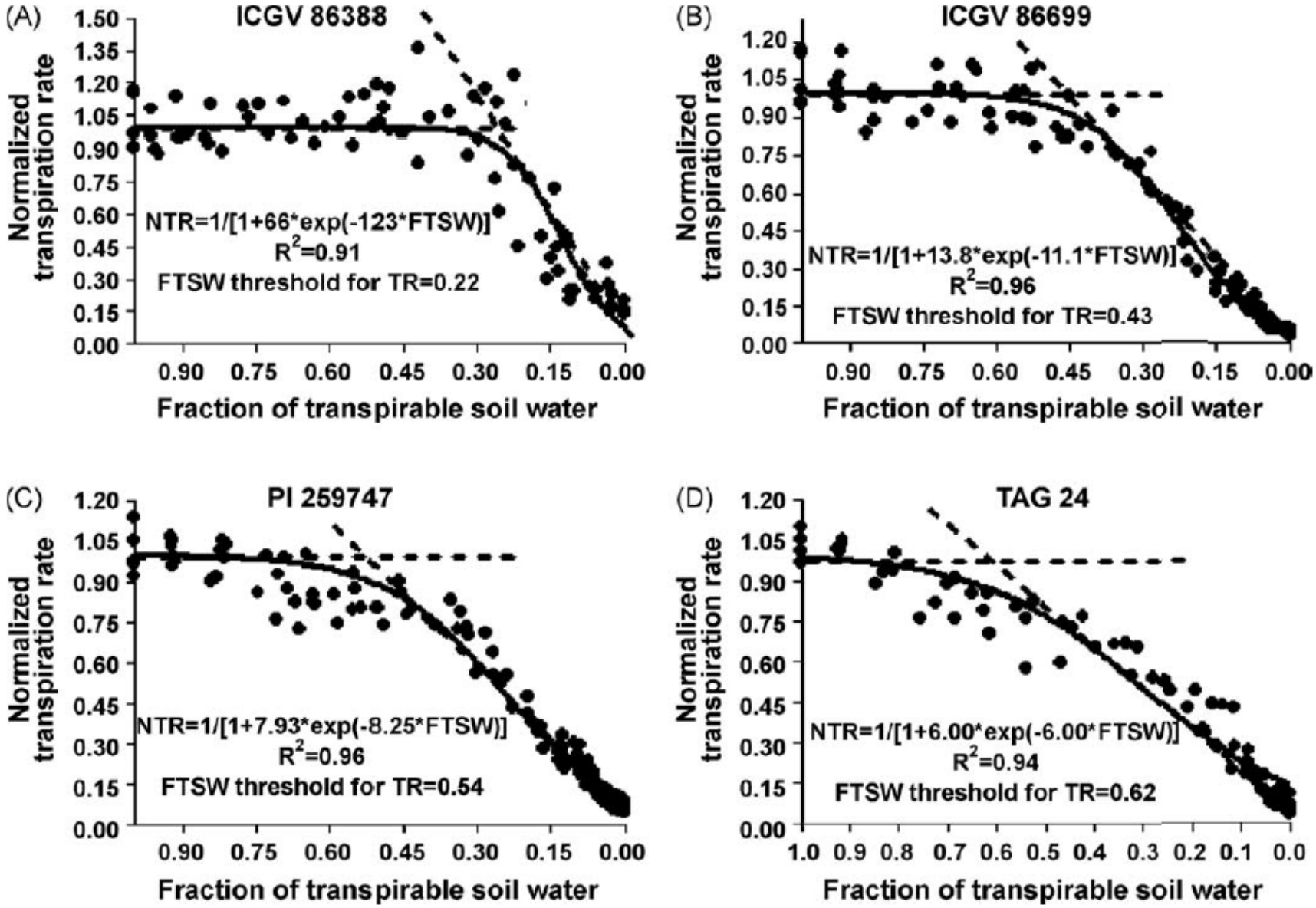


Theoretical Transpiration Response to Soil Drying



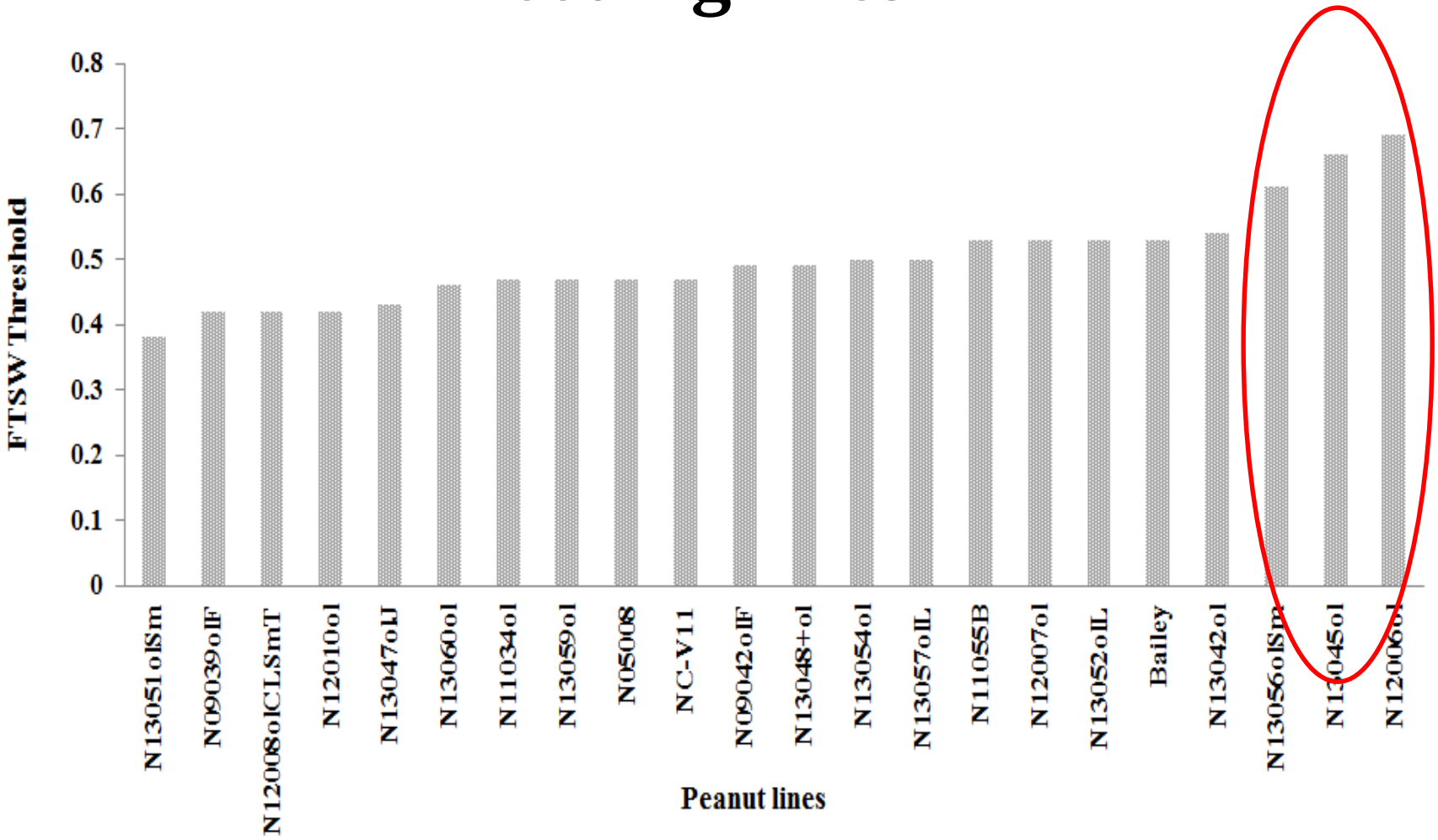
Water Conservation by Early Stomata Closure with Soil Drying

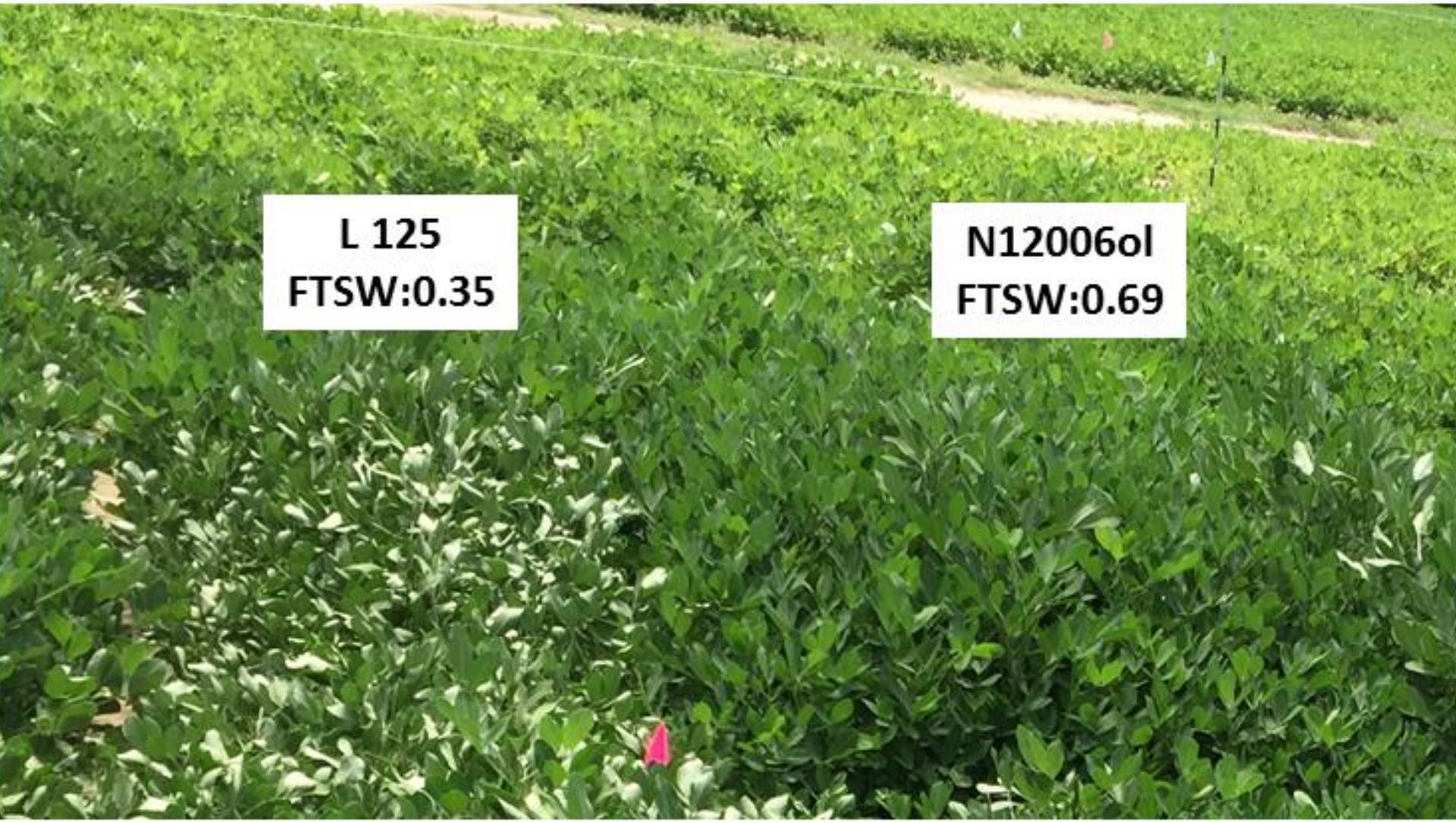




Devi et al. (2009) Field Crops Res. 114:280

Breeding lines




L 125
FTSW:0.35
N12006ol
FTSW:0.69

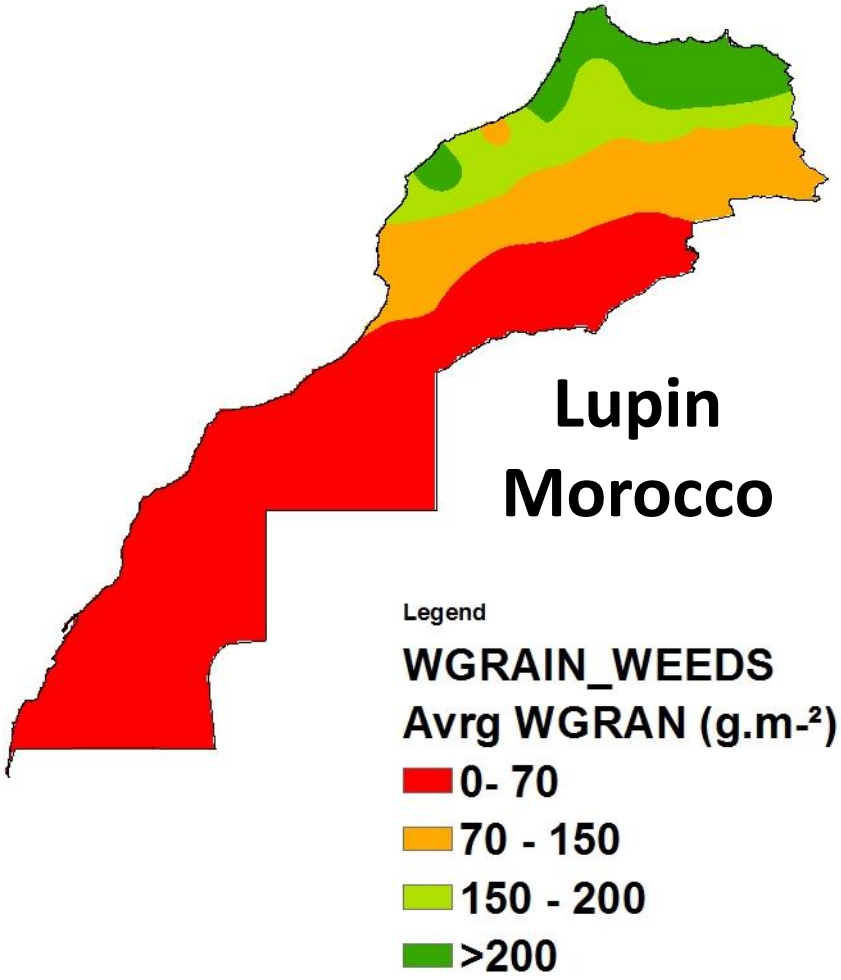
Impact of Trait Modification on Yield?

Model:

Where?

How much?

How often?



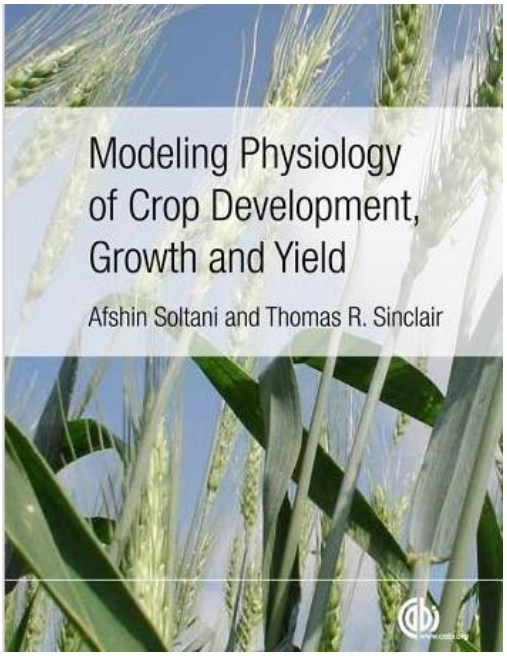
Model Approach

1. Only two levels of hierarchy
   a. Organizational: Canopy ⟶ Crop
   b. Temporal: Daily ⟶ Season
2. Use "summary" descriptions based both on experimental and theoretical evidence

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 based on all available data

Simple Simulation Model (SSM)



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

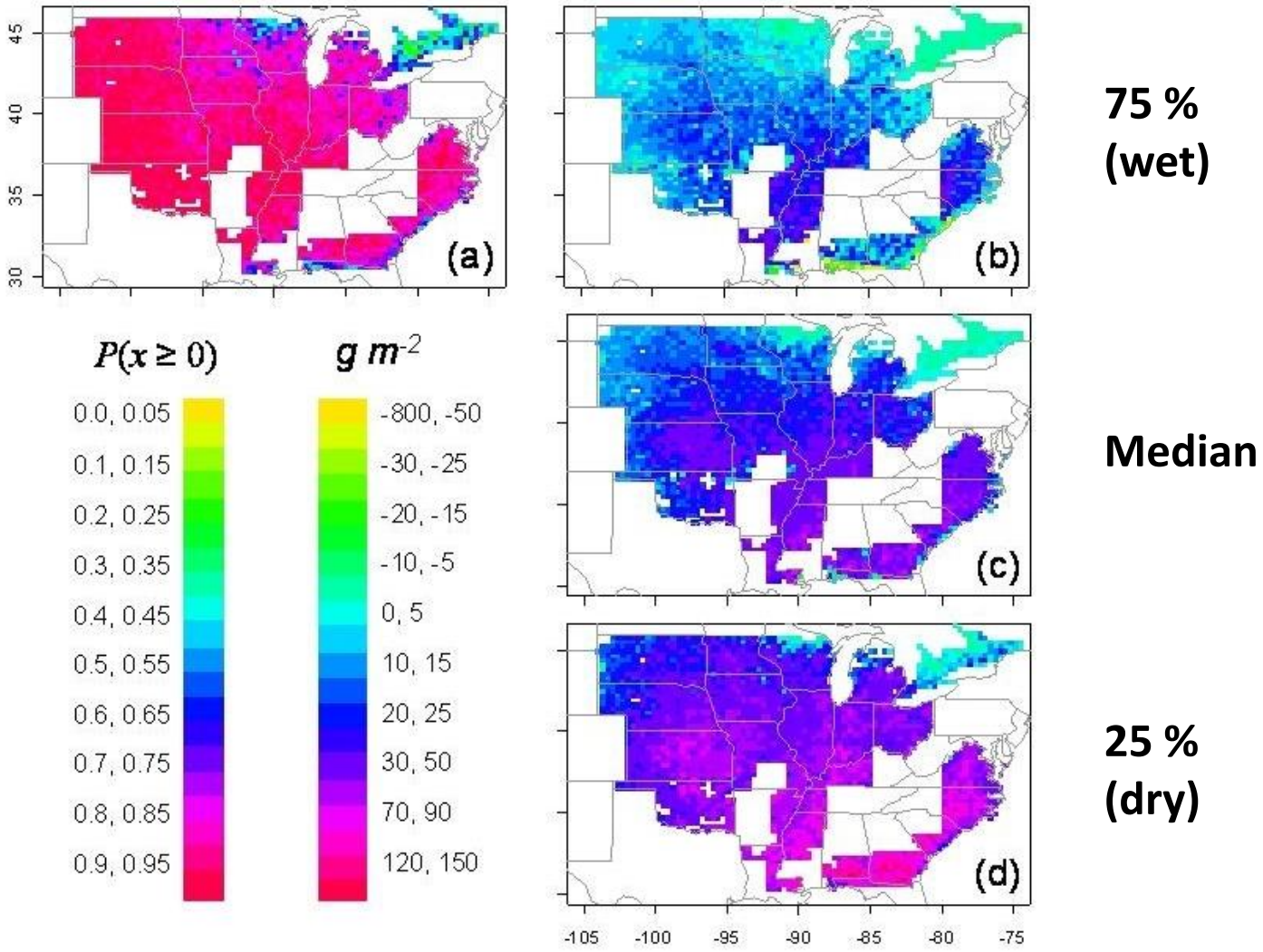
GIS Data Base

(Pioneer Hi-Bred International, Inc.)

- **30 x 30 km grid system for U.S cropping areas (2655 grids for soybean)**
- **Weather (approx. 50 years for most grids)**
- **Soil**
- **Soybean Maturity Group**
- **Sowing Date**

Each test required >130,000 model runs

Simulated Yield Response to Incorporation of VPD Response



75 % (wet)

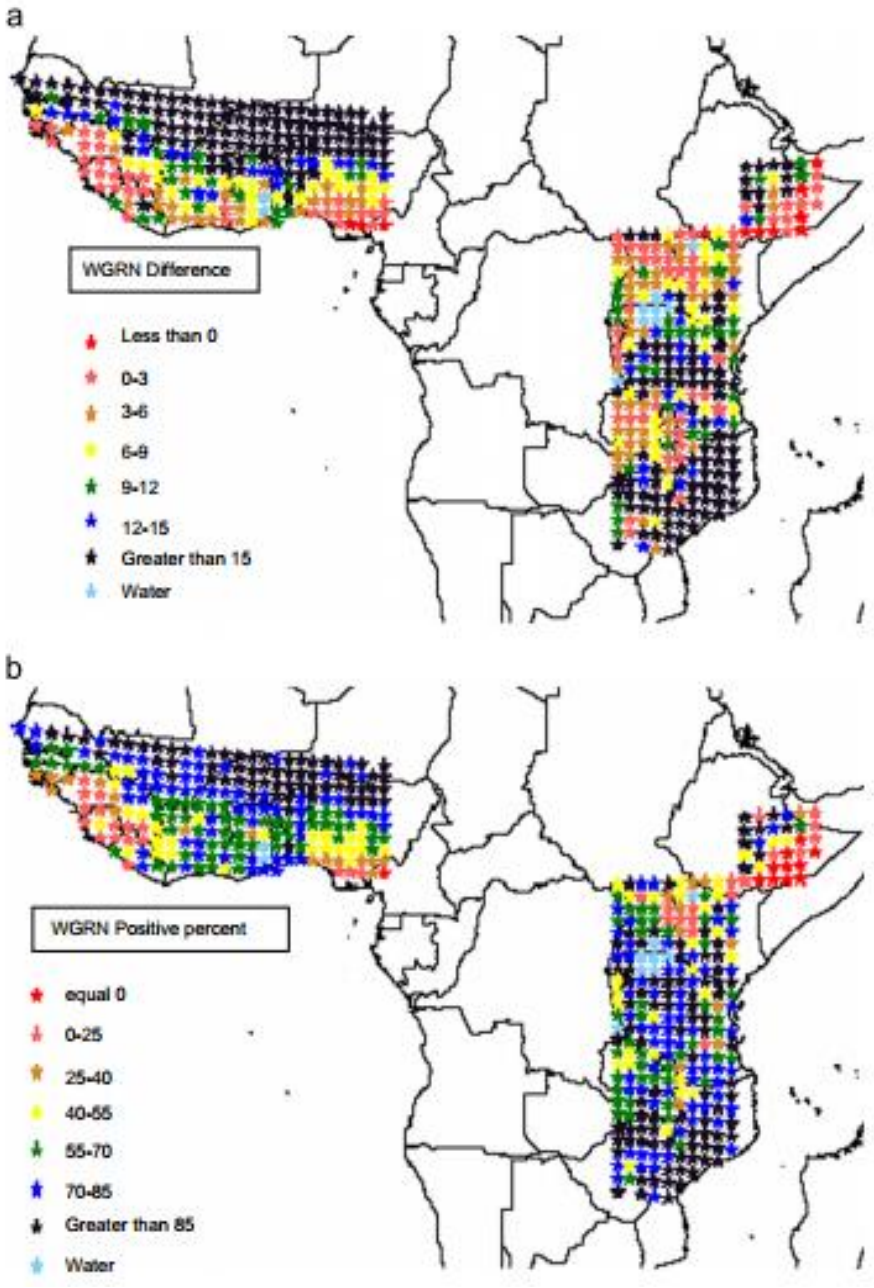
Median

25 % (dry)

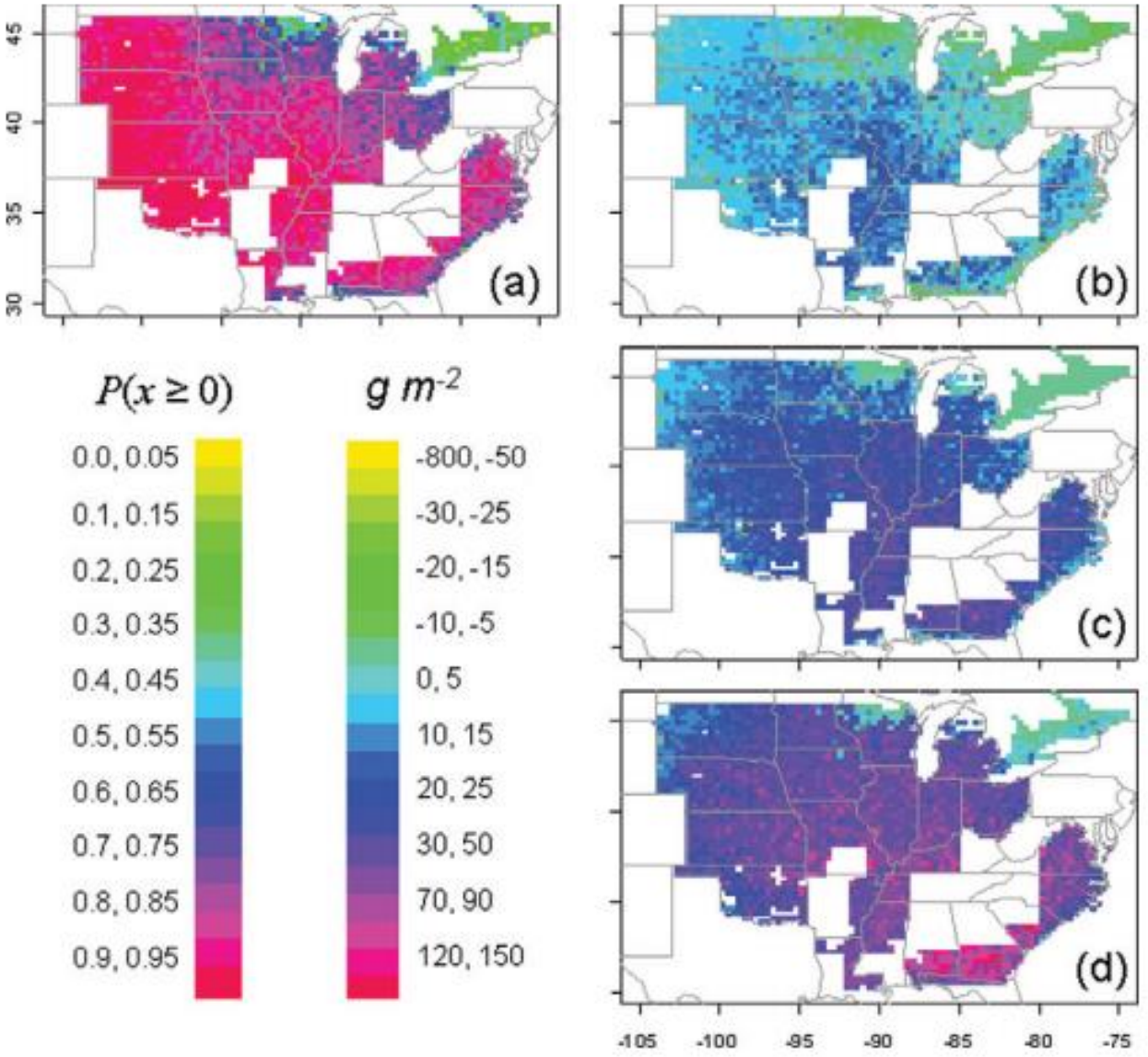
VPD Response

Ave. Yield Change ($g\ m^{-2}$)

Probability



Simulated Benefit of Early Stomatal Closure in Soybean



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

Solutions to Decreased and Variable Rainfall

Management

- Cool-season (low e*-e) species

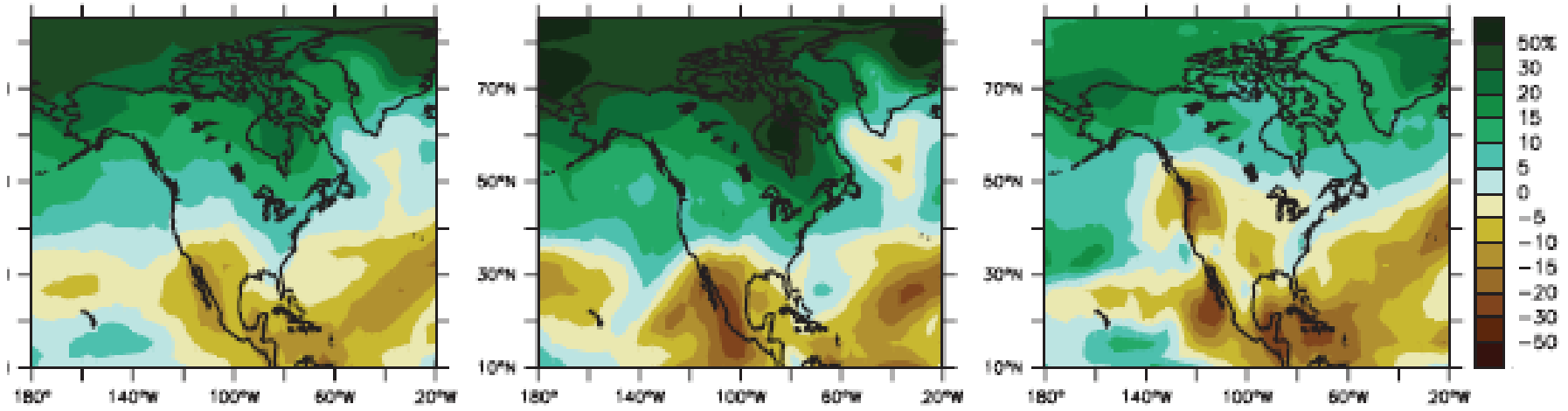
Genetic

- Low-temperature adapted varieties
- Partial stomatal closure under elevated (e*-e)
- Partial stomatal closure early in soil drying

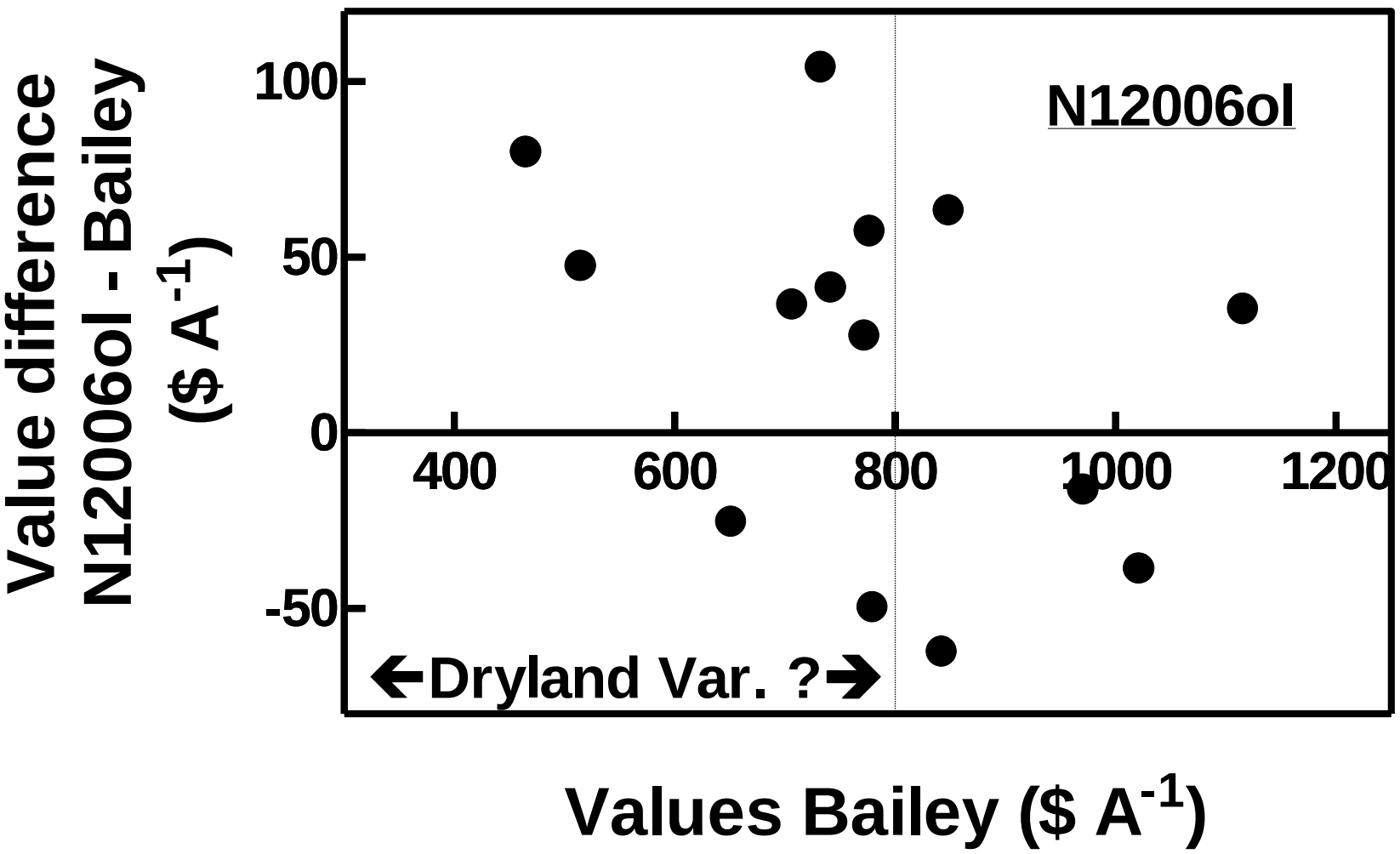
Annual

Dec/Jan/Feb

Jun/Jul/Aug



Intergovernmental Panel on Climate Change Fourth Assessment. 2007.
Working Group I Report "The Physical Science Basis"
Chapter 11. Regional Climate Projections


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