Resource Limits On Crop Grain Yield

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Crop Yields: The Sky is the Limit!

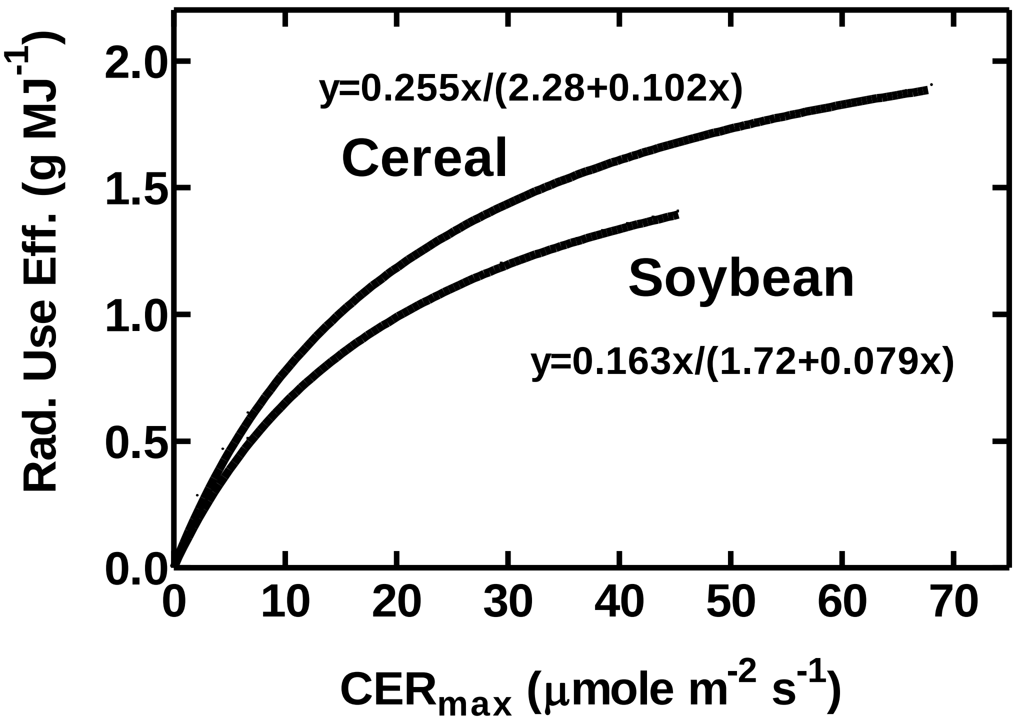
Solar Radiation

$$Y_{max} = HI \; \Sigma \, (RUE * I_{intercept})$$

Y_{max} = maximum crop yield

HI = harvest index

RUE = radiation use efficiency (mass accumulated per unit $I_{intercept}$)



C_4 (maize, sugarcane) 1.8 g MJ^{-1}

C_3 grasses (wheat, rice) 1.4 g MJ^{-1}

C_3 legumes (soybean, peanut) 1.2 g MJ^{-1}

Sinclair and Horie (1989)

$$Y_{max} = HI \ \Sigma \ (RUE * I_{intercept})$$

$HI = 0.50$

$\Sigma \ I_{intercept} = 1800 \text{ MJ m}^{-2}$

Maximum Dry Grain Yield

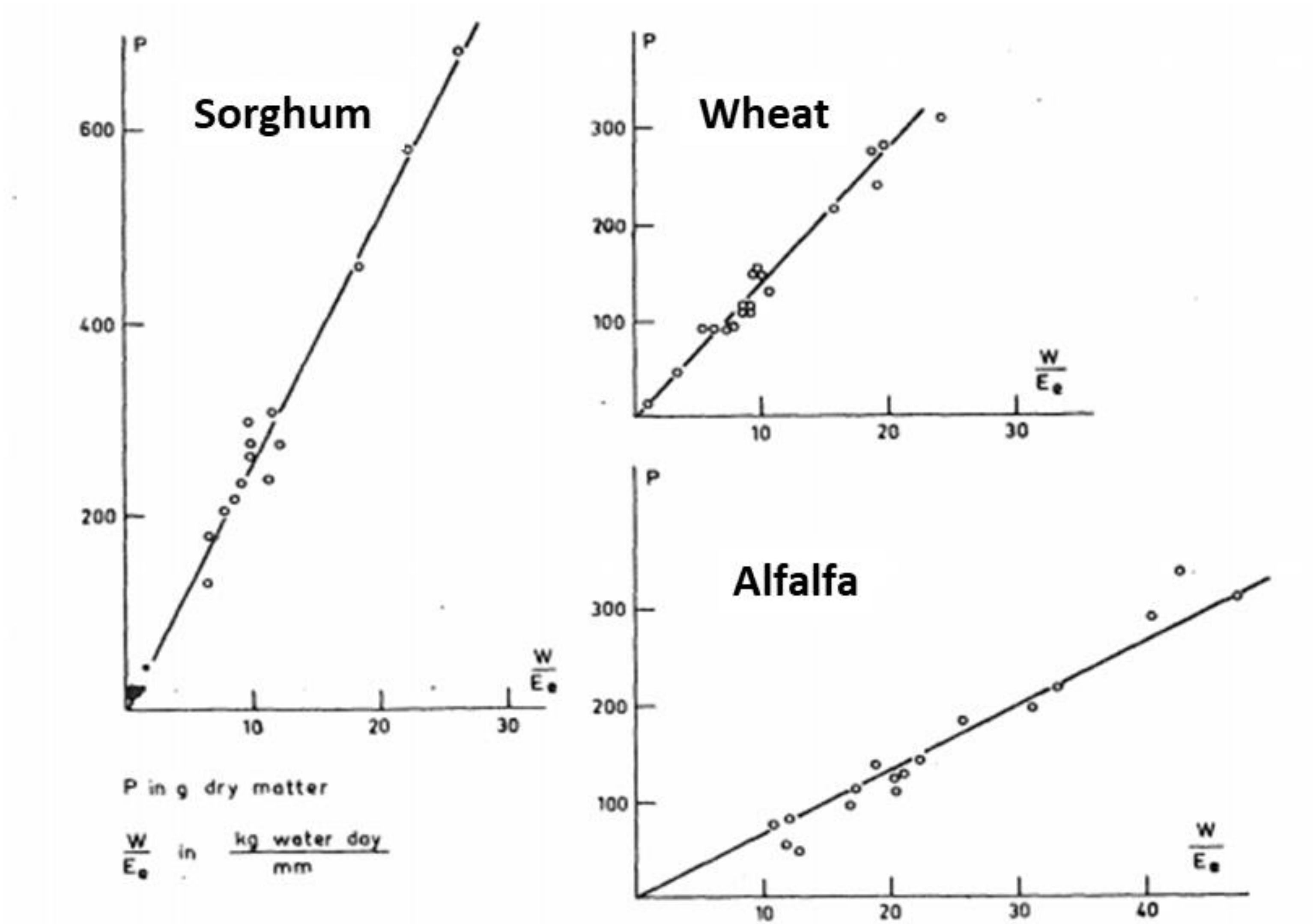
C_4 = 1620 g m^{-2}

C_3 grass = 1260 g m^{-2}

C_3 legume = 1080 g m^{-2}

Field Resource Limitations: Water and Nutrients

Water: Growth vs. Water loss / Humidity



Woodruff (1699); de Wit (1958)

Many studies ignore de Wit in favor of phenomenological equation

$$\text{Yield} = \text{HI} \bullet \text{WUE} \bullet \text{T}$$

Where T = water for transpiration

- **Focus on ambiguous WUE**
- **Dominating variable atmospheric humidity ignored**

Mechanistic Derivation

$$\int Y \, dt = HI \cdot k \cdot \int (T/VPD) \, dt$$

HI = harvest index

k = species transpiration constant

T = water available for transpiration

(e* - e) = vapor pressure deficit

Sinclair and Tanner (1983)

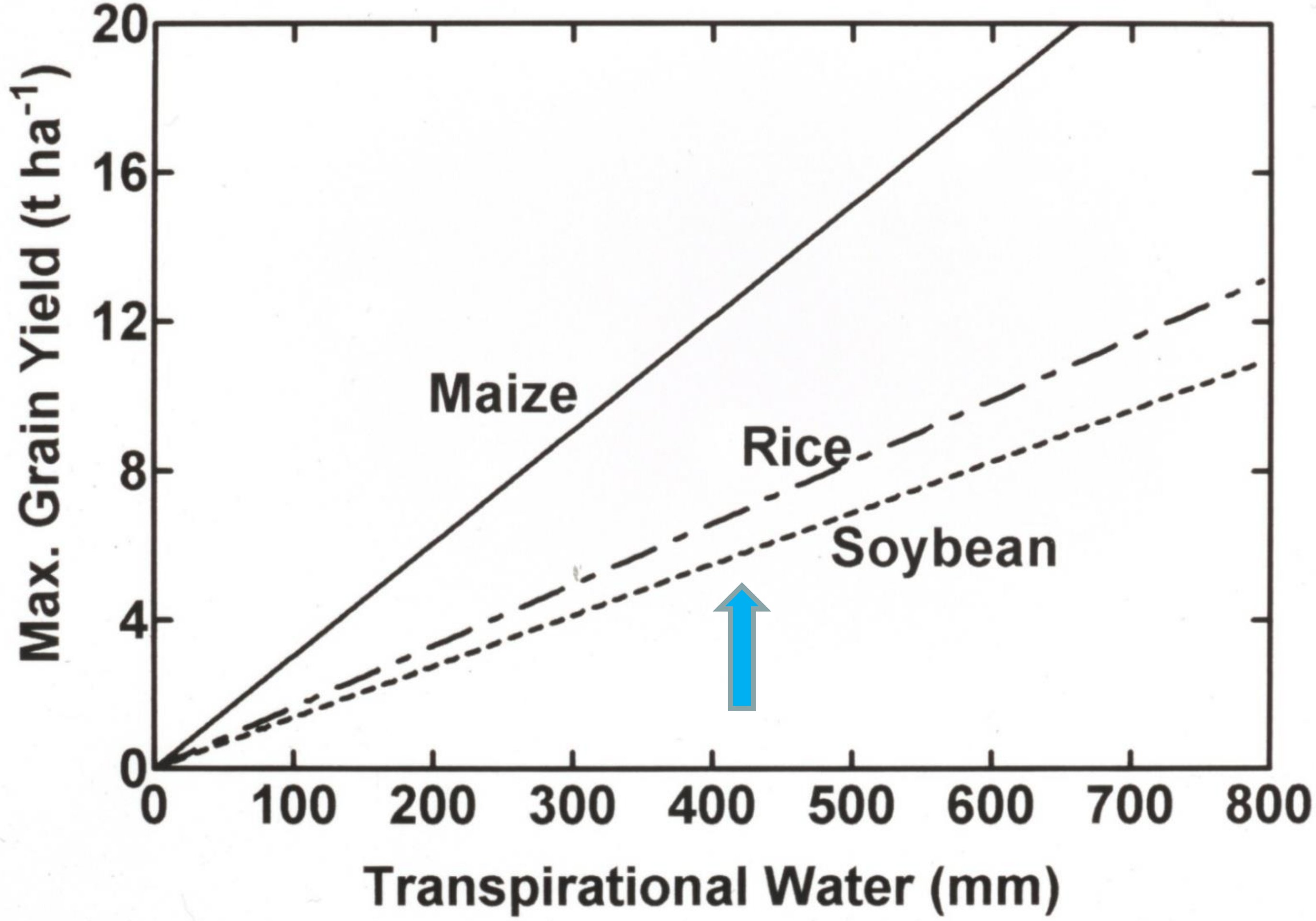
Derived Transpiration Constant (k)

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

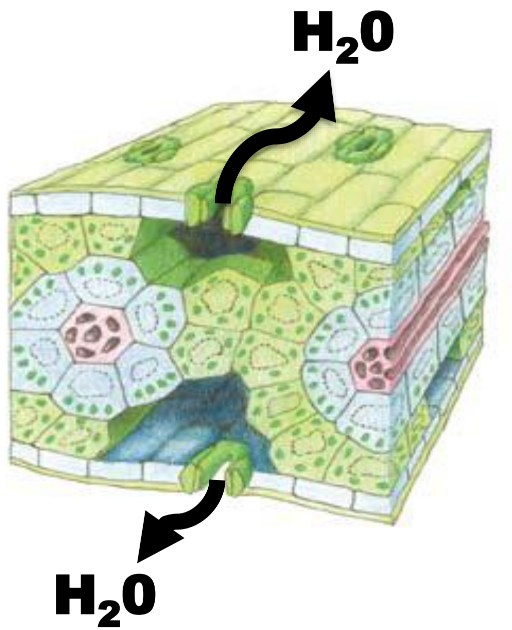
(Consistent with de Wit slopes)

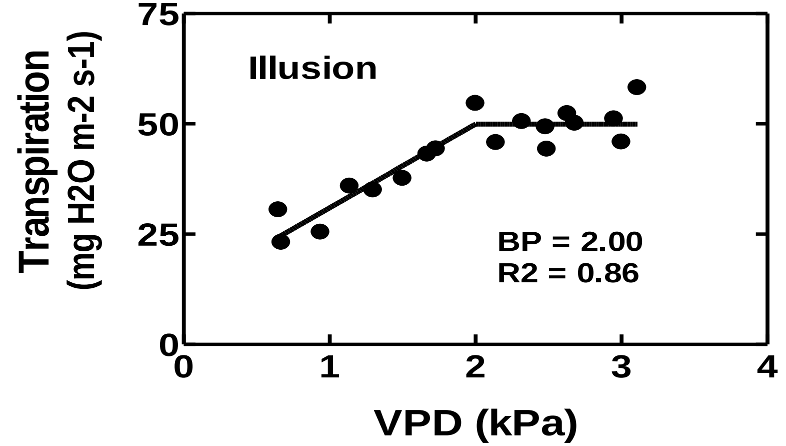
$$\int Y\,dt = HI \cdot k \cdot \int (T/VPD)\,dt$$

Assume HI = 0.5, VPD = 2 kPa

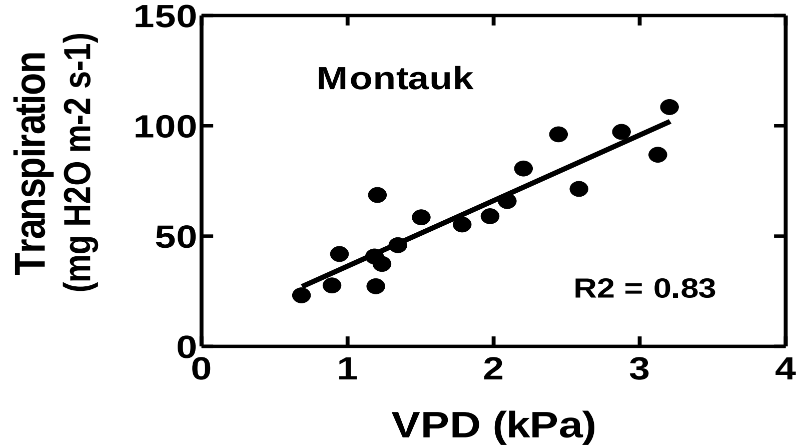


Effective VPD can be < atmospheric VPD



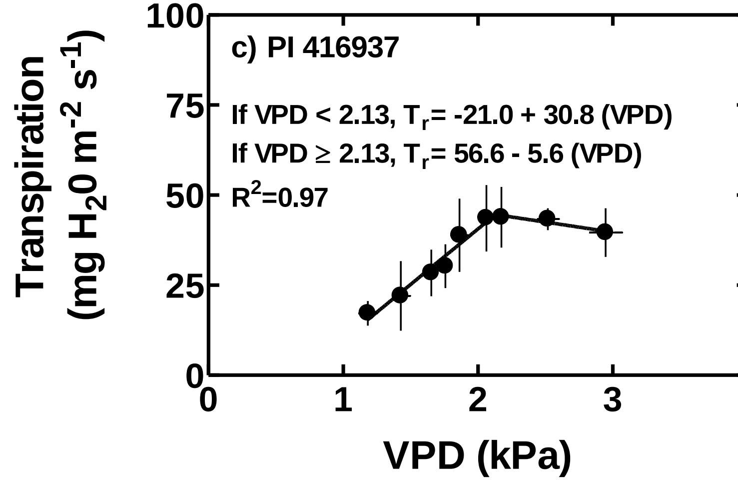


Partial Stomata Closure at Elevated VPD



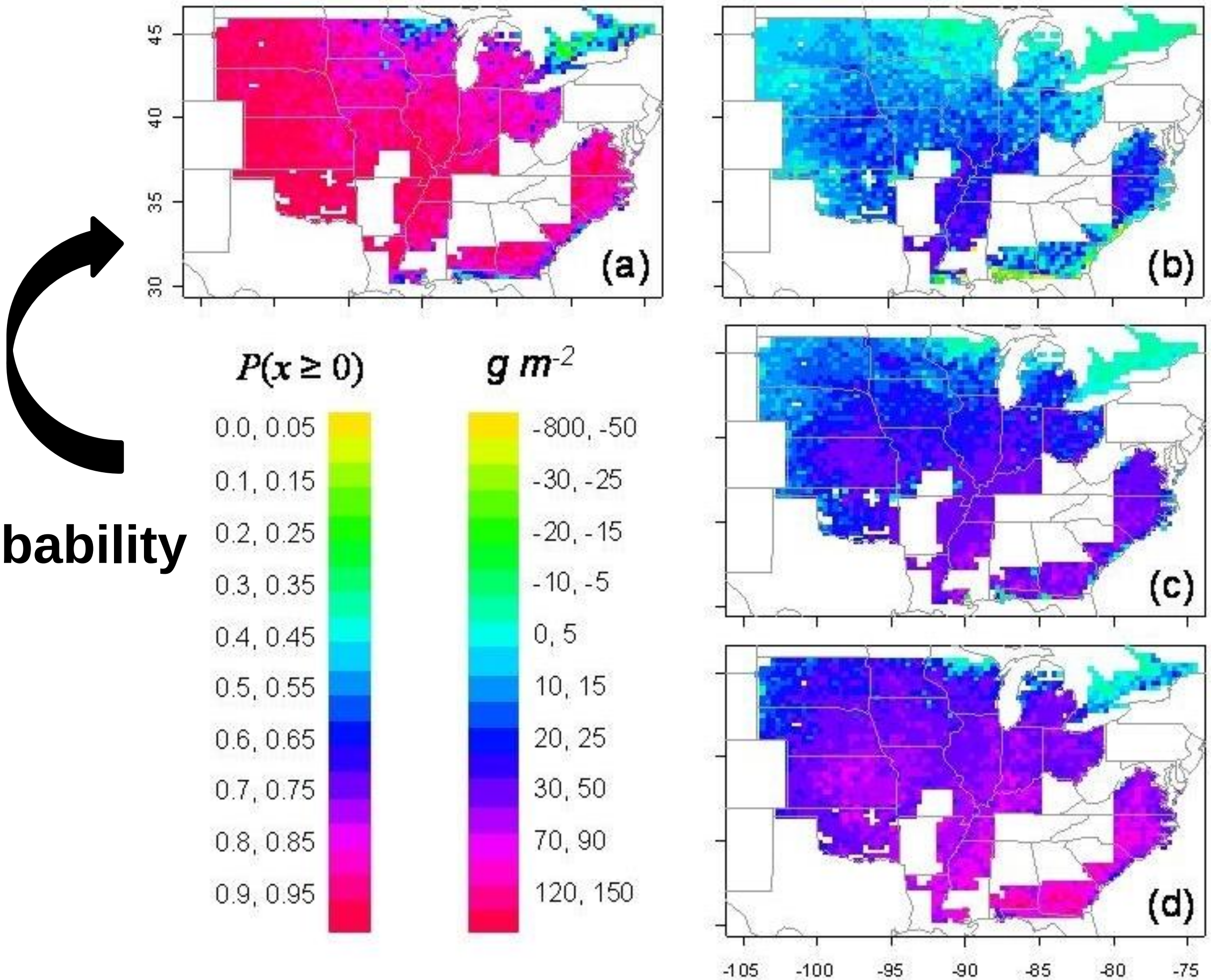
Jafarikouhini et al. (2020)

PI 416937
Commercial parent



Normal **PI 416937**

Simulated Yield Response of Soybean to Elevated VPD



probability

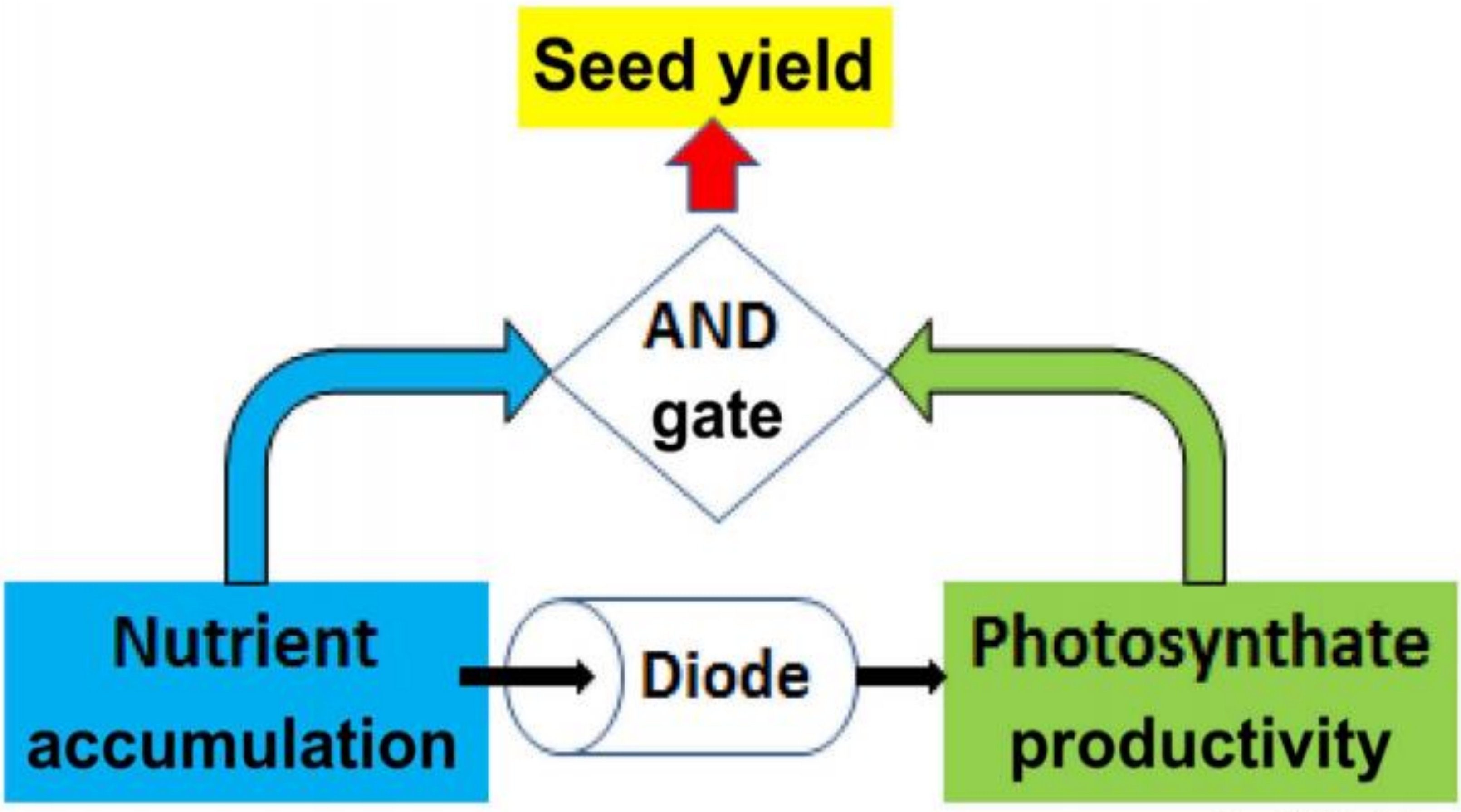
75 %
(wet)

Median

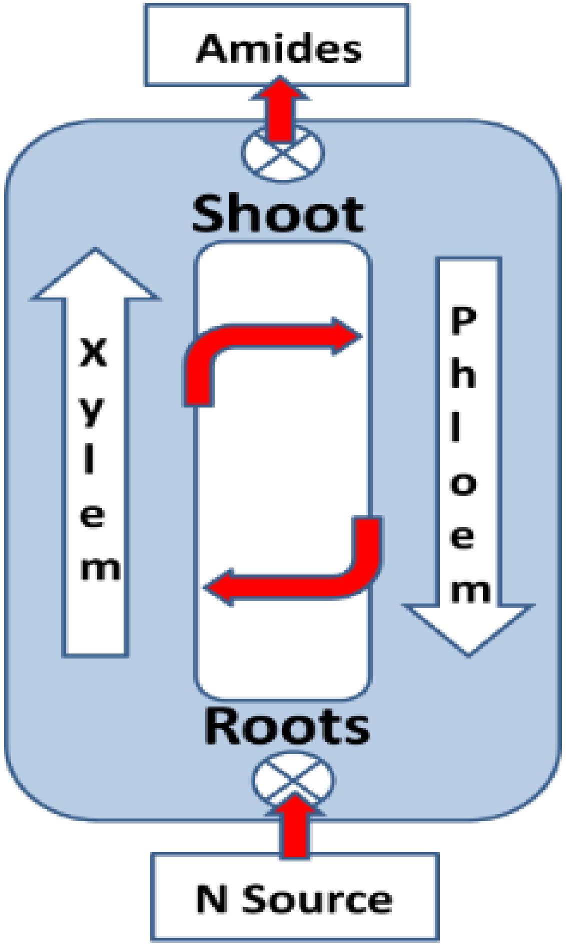
25 %
(dry)

Sinclair et al. (2010)

Nutrient Limitation



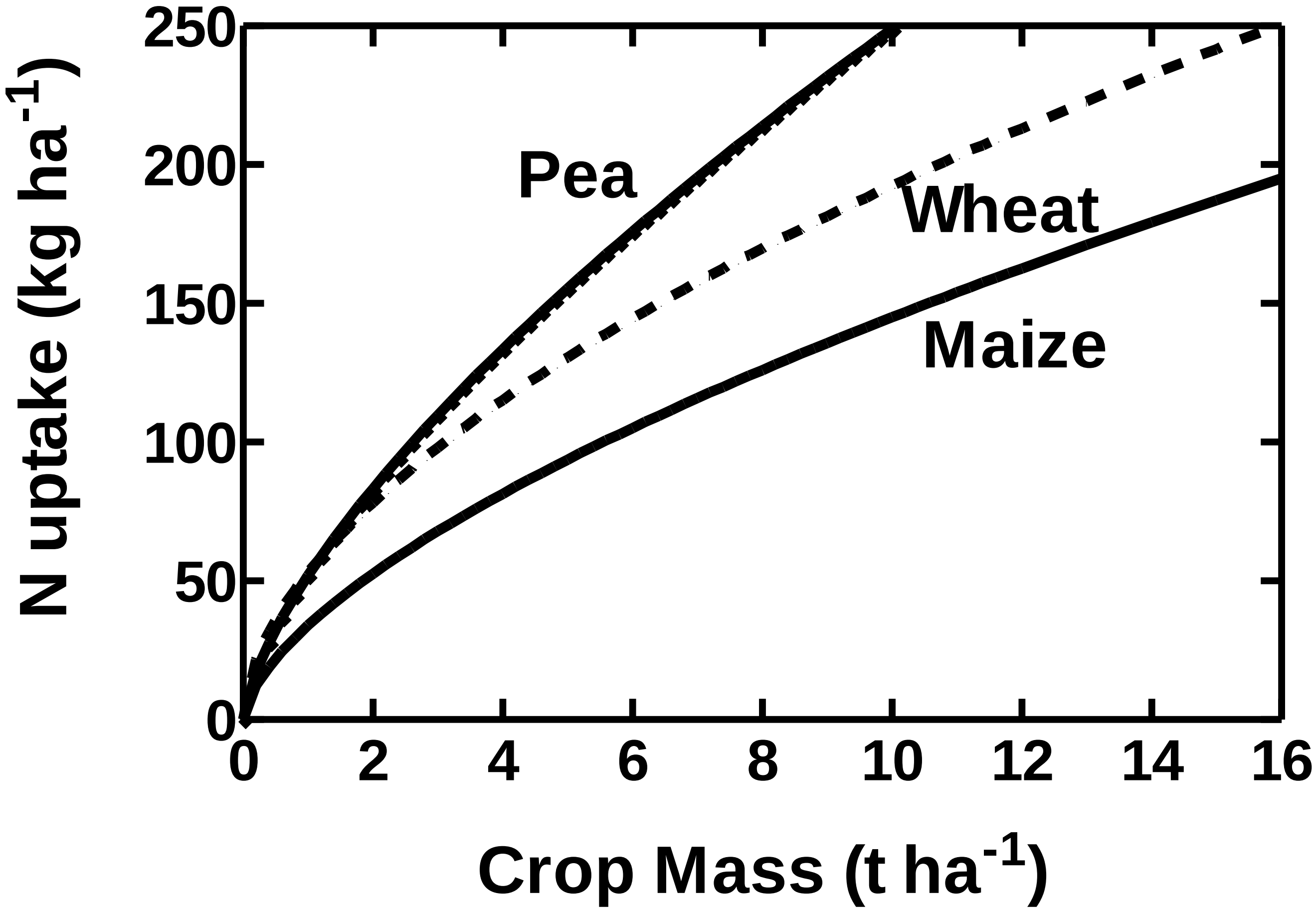
Increase Plant Nitrogen Use Efficiency?



- **Rapid transport loop in plant providing N to all tissues**
- **Feedback regulation on N uptake**
- **N harvested / N uptake**
  ➔ NHI ≥ 0.75

Cooper and Clarkson (1989)

Challenge: N Uptake and Storage



Lemaire et al. (2008)

Crop Grain Yield Limited by Nitrogen Accumulation (N_{up})

$$Y = N_{up} * NHI / G_N$$

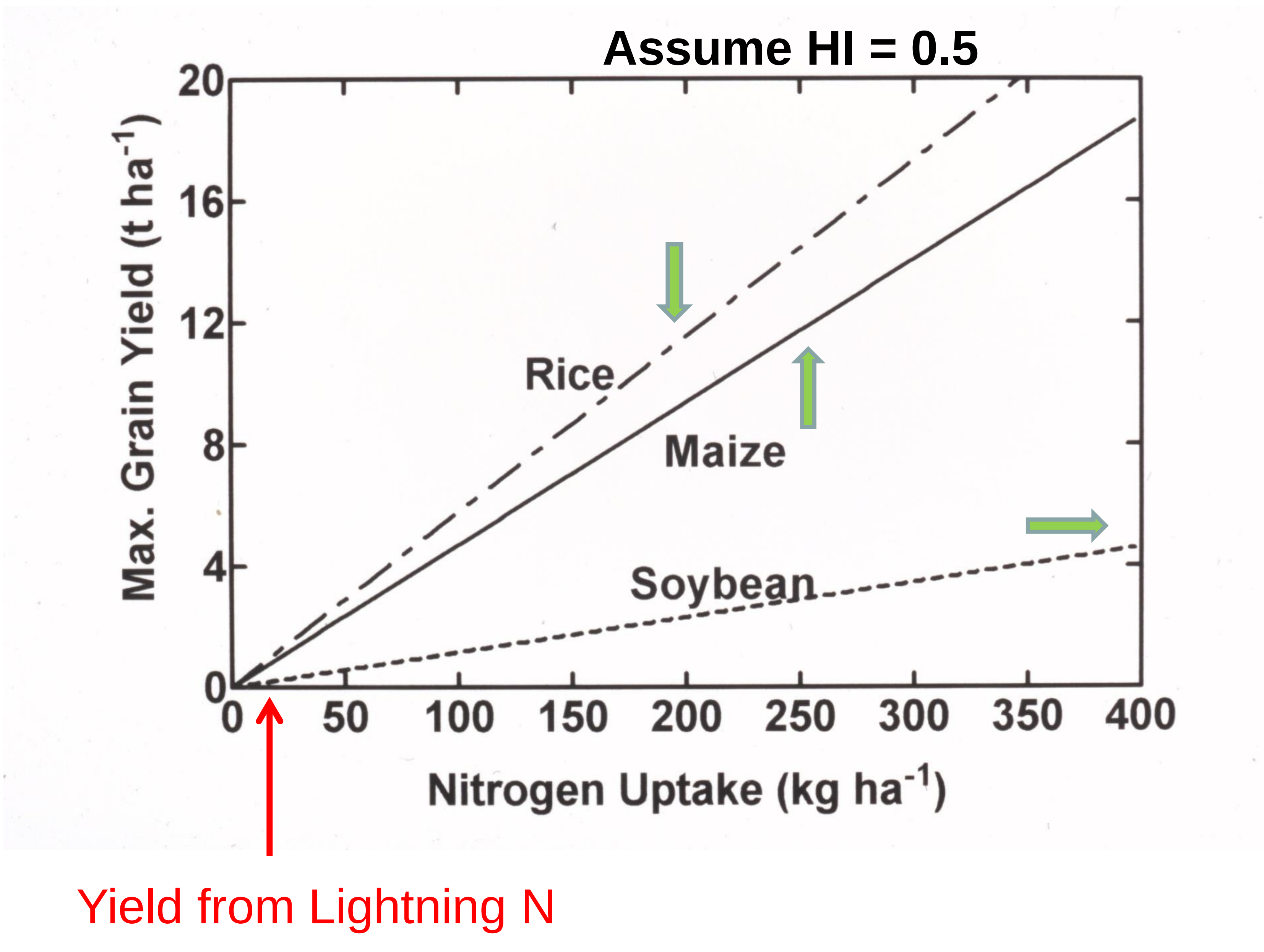
Y = grain yield

NHI = nitrogen harvest index

G_N = nitrogen fraction in grain

N Fraction of Grain (G_N)

Rice:	**0.013 gN g^{-1}**
Maize:	**0.016 gN g^{-1}** **(currently 0.013)**
Wheat:	**0.022 gN g^{-1}**



Assume HI = 0.5
Max. Grain Yield (t ha-1)
20
16
12
8
4
0
Rice
Maize
Soybean
0
50
100
150
200
250
300
350
400
Nitrogen Uptake (kg ha-1)
Yield from Lightning N

Decrease feedback limitation on N Uptake

- **Opportunities to increase plant storage (?) (e.g. stem storage, vegetative storage proteins)**

- **Uptake during seed growth (?)**

“Take Home”: Crop Grain Yield

- In developed countries, era of ever increasing crop grain yields is coming to a close.
- Some “tweaks” of plants for yield increase possible (5 to 10%), but plant complexity makes this challenging.
- Increasing focus on targeted “defensive strategies” to address new biological and weather stresses.