Soybean Yield Response to Scarce or Abundant Water <Retrospect and Prospect>

James E Specht
University of Nebraska
(and many, many collaborators)

Acknowledgements

- Funding provided by the United Soybean Board, North Central Soybean Research Program, Nebraska Soybean Board and UNL) supported much of the soybean yield-related research discussed in this presentation.

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NCSRP NORTH CENTRAL SOYBEAN RESEARCH PROGRAM

The North Central Soybean Research Program, a collaboration of 12 state soybean associations, invests soybean checkoff funds to improve yields and profitability via university research and extension.

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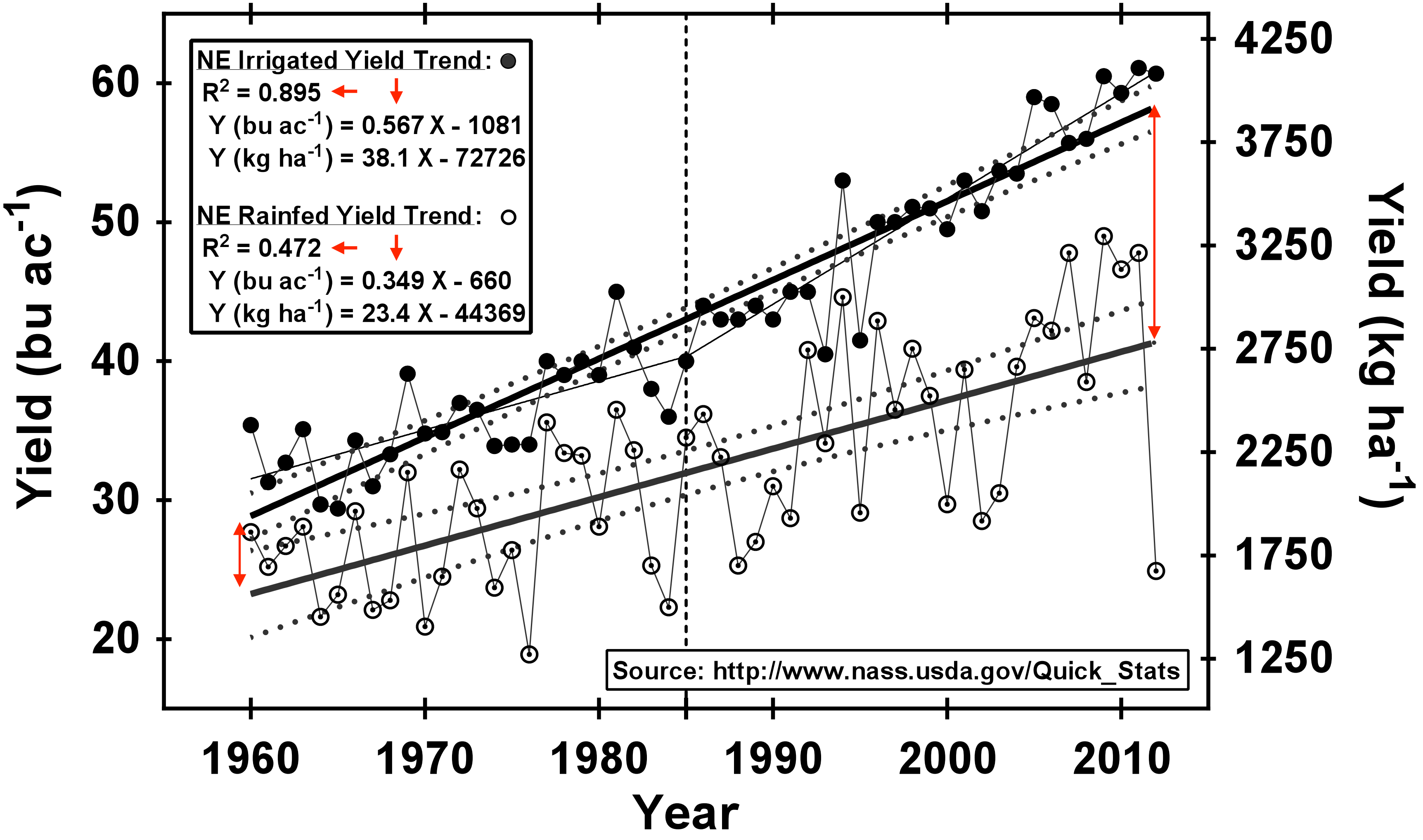
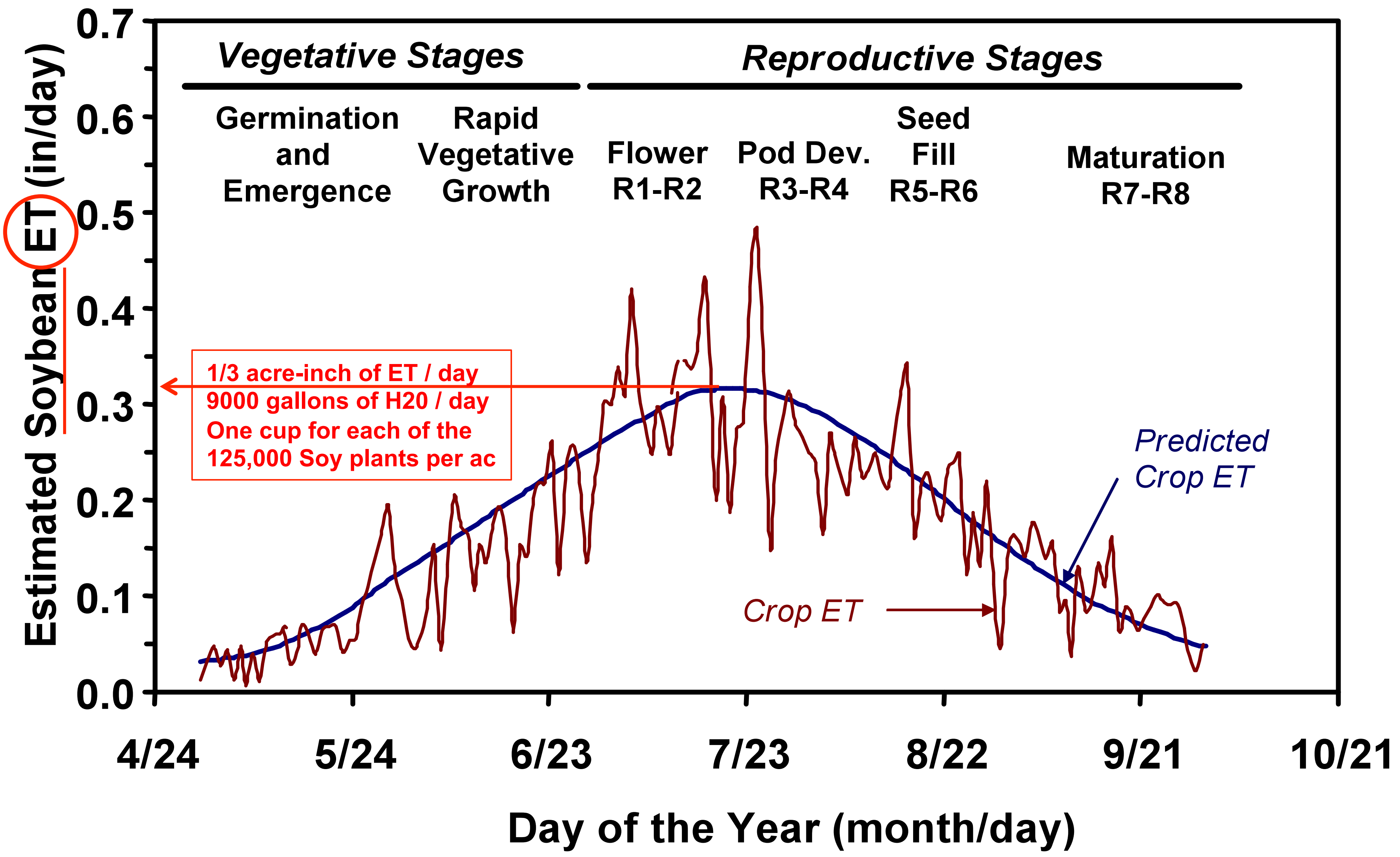
Nebraska Irrigated and Rainfed Soybean Yield Trends 1960 to 2012



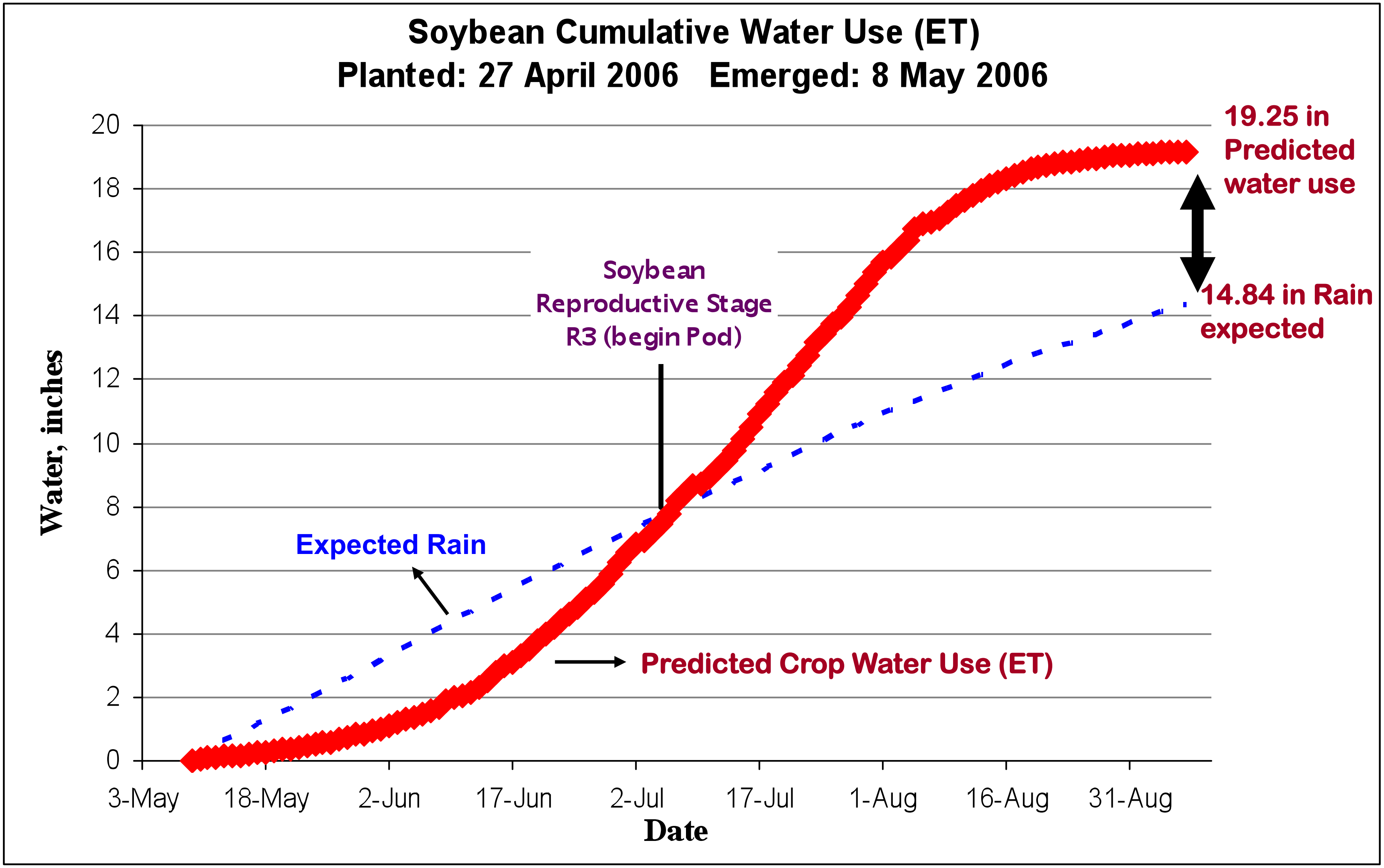
*****<u>**There are three seed yield penalties associated with an insufficient seasonal water supply**</u>*****

Less absolute yield; slower annual rise in on-farm yield; greater year-to-year variation in yield.



(Graph courtesy of Bill Krantz, Nebr NE R&E Ctr)

Rainfall Amounts versus Crop Water Use (ET)



Plants and Water

- An **acre-inch** of water (~~rain or irrigation~~) is **27,154** gallons of water spread over 43,560 square feet (= one **acre**). There are 16 cups to the gallon.

- A soybean crop (125,000 plants per acre) producing **70** bushels of seed per acre at the end of a **140-day** growing season may require about **20** acre-inches of E**T**, which is **20** x **27,154** = **543,080** gallons per acre, and all of the **Transpiration** in **ET** comes from water gathered from moist soil zones by the **plant's root hairs**. Note: 4.34 gallons (70 cups) per plant for the entire 140 days. **At peak crop water use (0.3 ac-in/day) one cup per plant per day!**

- **The (recommended) average human DAILY water intake is ONE gallon**, so **543,080** gallons of water would also constitute a **140-day** supply of daily drinking water for **3,880 humans**.

- Los Angeles has a population density of 11 humans per acre (i.e., **one person per 4,000 sq ft)**. For these 11 humans, the amount of **543,080** gallons of water would constitute a **135-year** supply of daily drinking water.

A water tower in a small town holds about 300,000 gallons of water

Brian Diers' Home Town

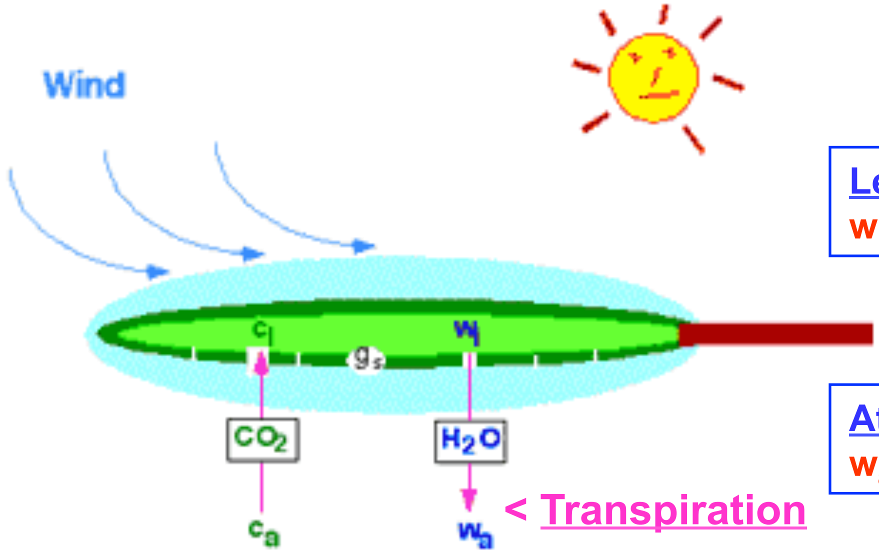
Photosynthesis > $CO_2 + 2H_2O + \underline{\text{solar energy}} \rightarrow O_2 + CH_2O + H_2O$

CH_4

Methane

CO_2 Comp. Point
C4 Leaf Interior
c_i = 0 - 5 ppm
C3 Leaf Interior
c_i = 40 - 60 ppm

Atmosphere CO_2
(as of Feb 2014)
c_a = 396 ppm



< **Transpiration**

Leaf Interior 99.3% RH 20C
w_i = 0.953 mol m^{-3} | 2.32 kPa

Atmosphere 50% RH 2 0C
w_a = 0.480 mol m^{-3} | 1.17 kPa

Photosynthesis: $A = \frac{g}{1.6}(c_a - c_i)$

Transpiration: $E = g(w_i - w_a)$

$$\boxed{WUE = \frac{A}{E} = \frac{c_a - c_i}{1.6(w_a - w_i)}}$$

C4 *vs.* C3

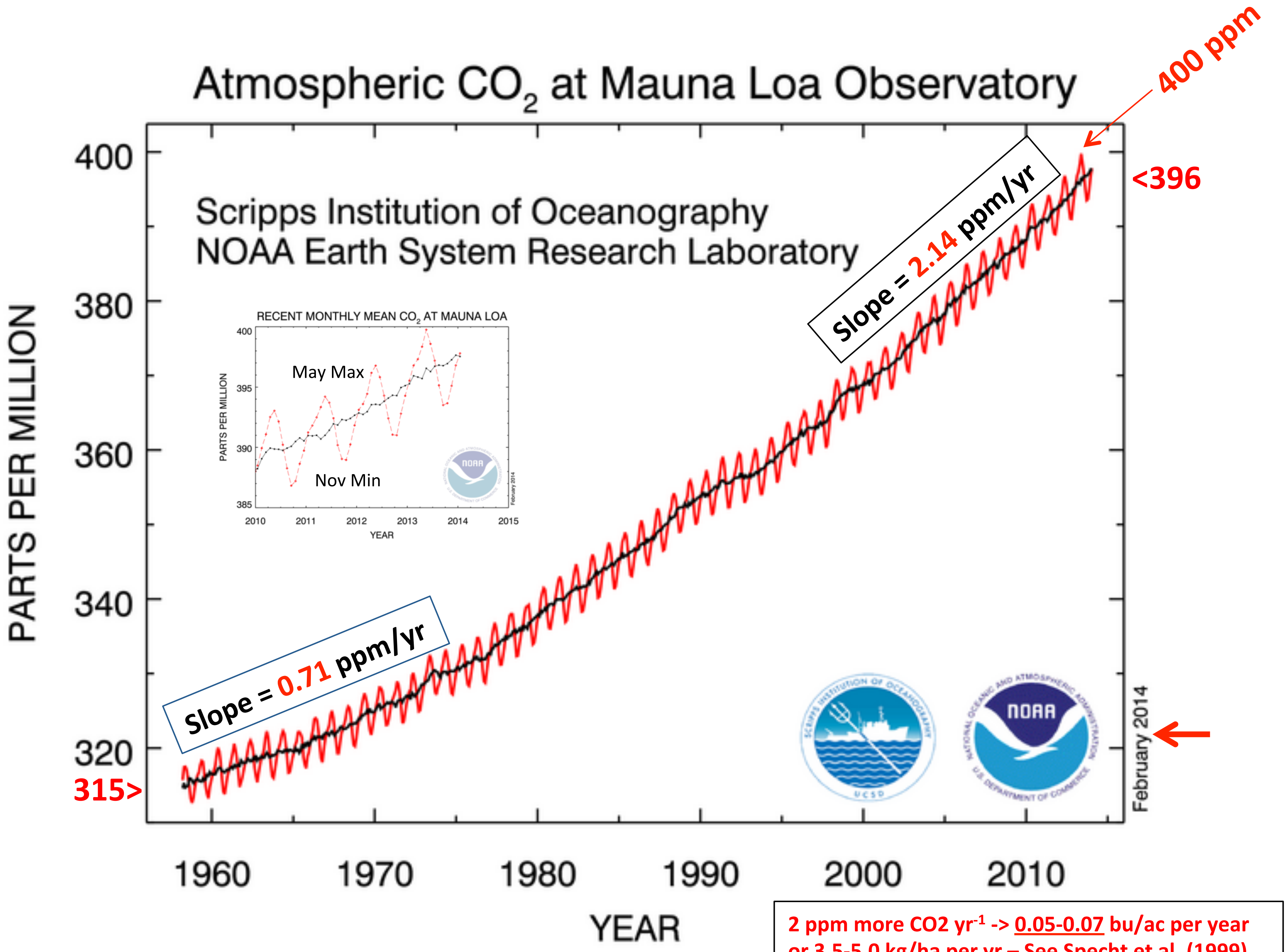
VCD|VPD

For a sunlit soybean leaf (C3 type of photosynthesis):

During the time it takes for <u>1</u> CO_2 molecule to pass thru an open stomatal pore,
<u>400</u> H_2O molecules simultaneously escape from that same pore !!!!

Plants must thus exchange 164 lbs of H_20 to acquire 1 lb of CO_2
(~ 6.1g CO_2 per 1000g H_2O)

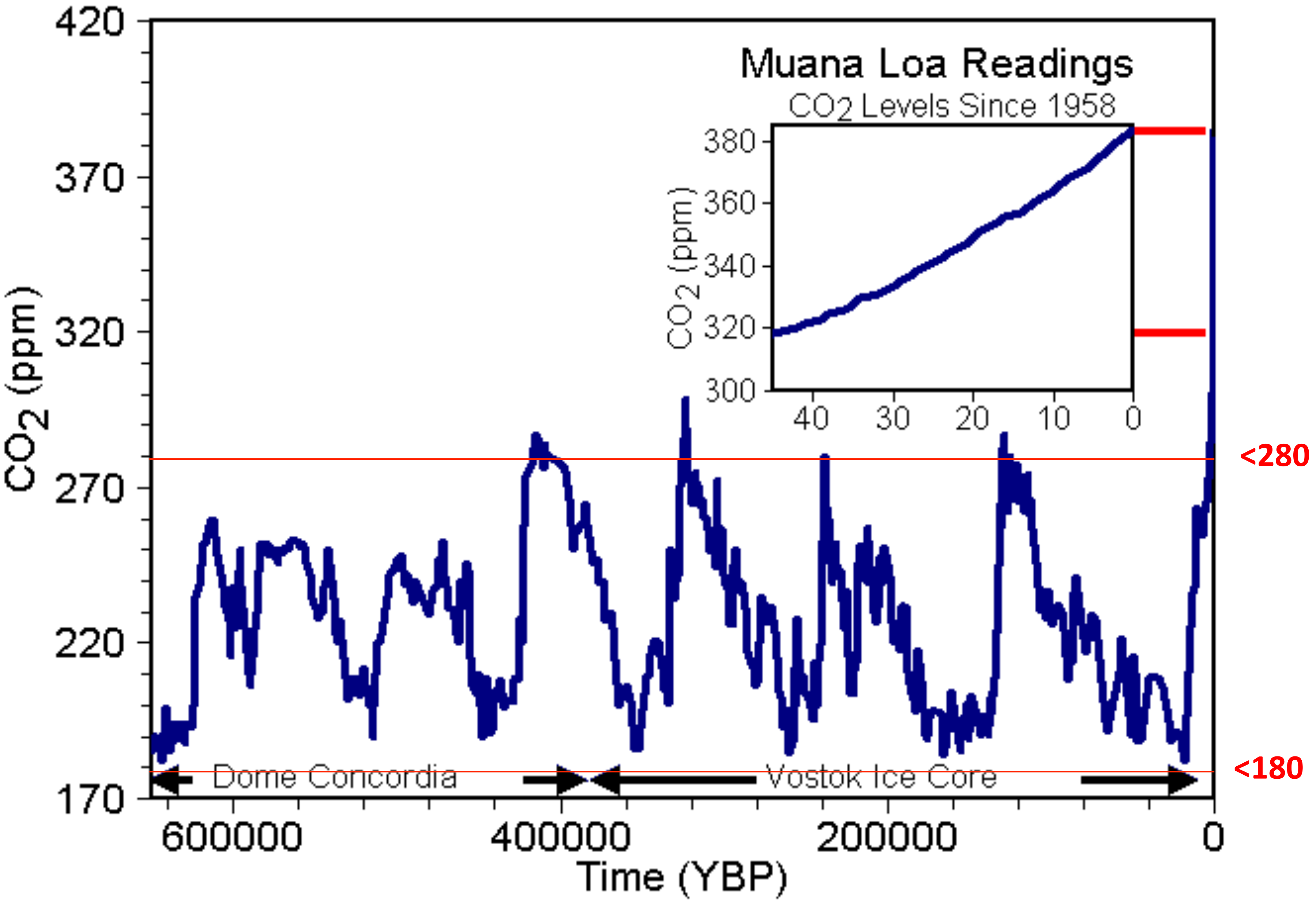
Source: Park Nobel. 2009. Physicochemical and Environmental Plant Physiology (4th Ed.)



Atmospheric CO_2 at Mauna Loa Observatory

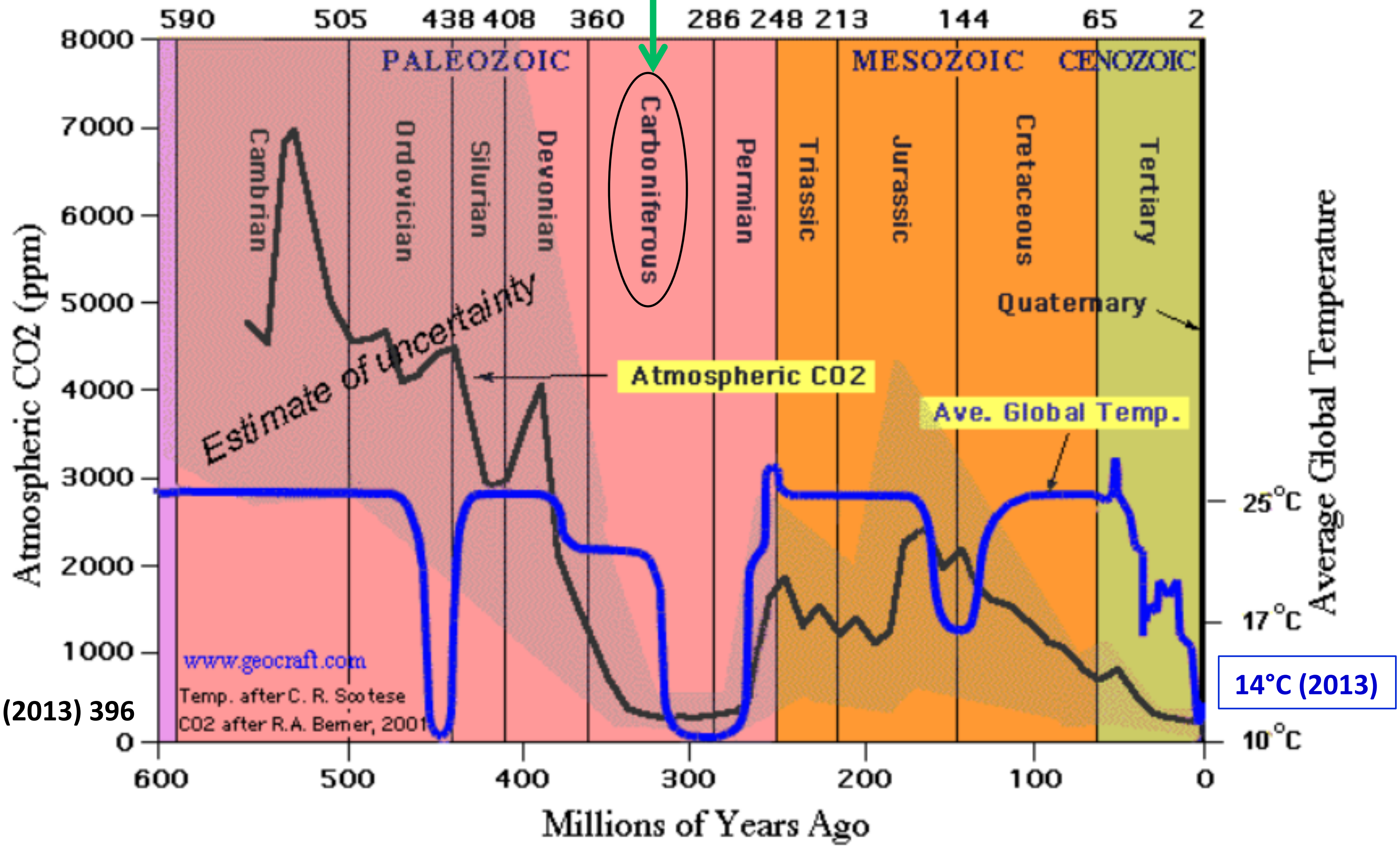
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

2 ppm more CO2 yr^{-1} -> <u>0.05-0.07</u> bu/ac per year
or 3.5-5.0 kg/ha per yr – See Specht et al. (1999)
(*versus* on-farm Soy yield trend of 0.35 bu/ac yr)



Muana Loa Readings
CO2 Levels Since 1958
380
360
340
320
300
CO2 (ppm)
40
30
20
10
0
420
370
320
270
220
170
CO2 (ppm)
Dome Concordia
Vostok Ice Core
600000
400000
200000
0
Time (YBP)
<280
<180

COAL !



(2013) 396

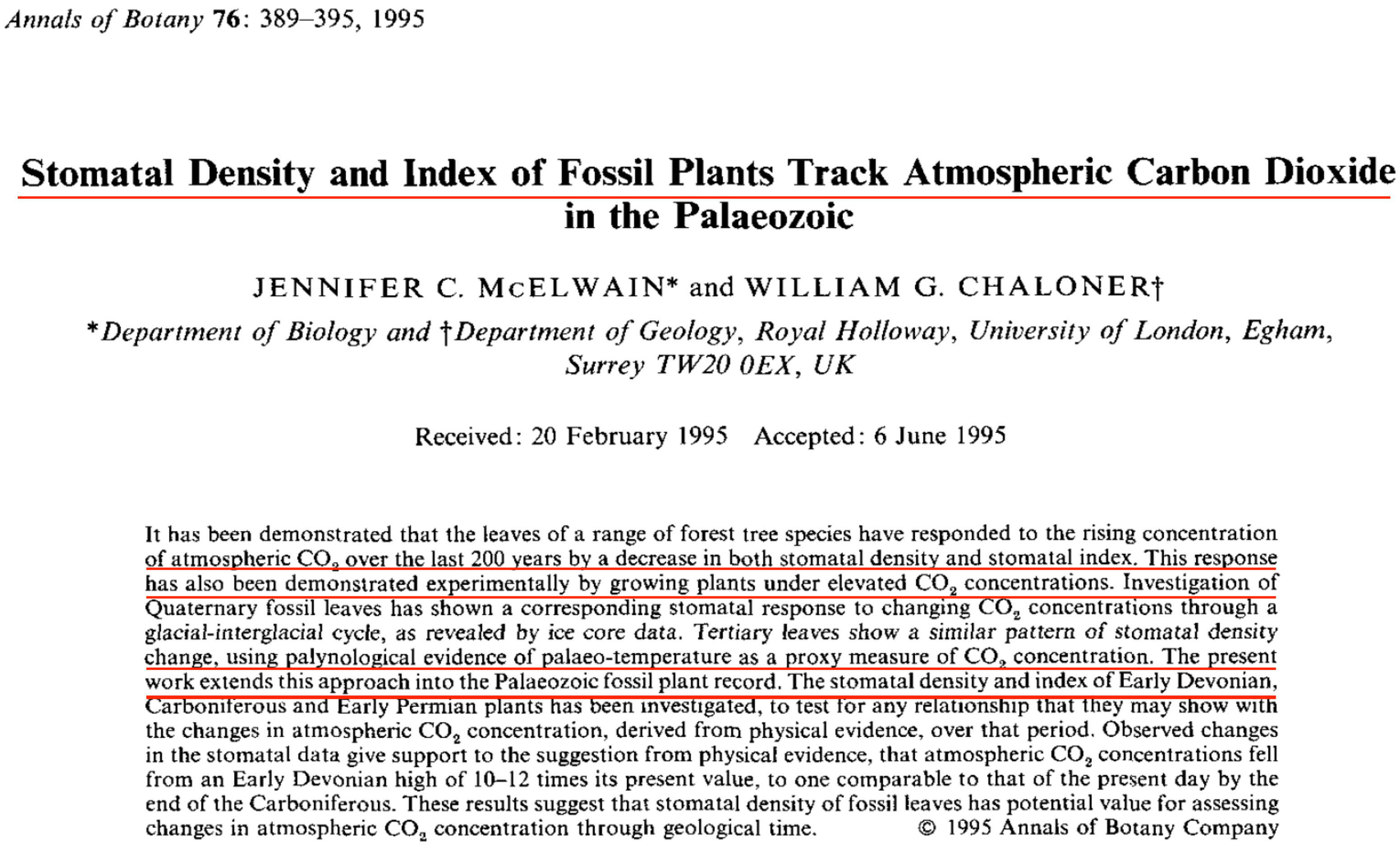
14°C (2013)

Source: Berner, R.A. and Z. Kothavala. 2001. GEOCARB III: A revised model of atmospheric CO2 over Phanerozoic time. Amer. J. Sci. 301:182-204

Carbon Dioxide & Vegetation

- The evolution of C4 photosynthesis is considered to be a response to low atmospheric CO2 levels. Rapid expansion of the C4 species (mechanism and anatomy) occurred about 7 million years ago.
- Doubling the concentration of CO2 from 180 to 360 ppm halved transpiration *vs.* photosynthesis. **Stated in another way, doubling of the CO2 concentration was like "doubling the rainfall as far as plant water available is concerned"**

  Source: G.D. Faruqhar, 1997, Science 278:1411.



Annals of Botany **76**: 389–395, 1995

Stomatal Density and Index of Fossil Plants Track Atmospheric Carbon Dioxide in the Palaeozoic

JENNIFER C. McELWAIN* and WILLIAM G. CHALONER†

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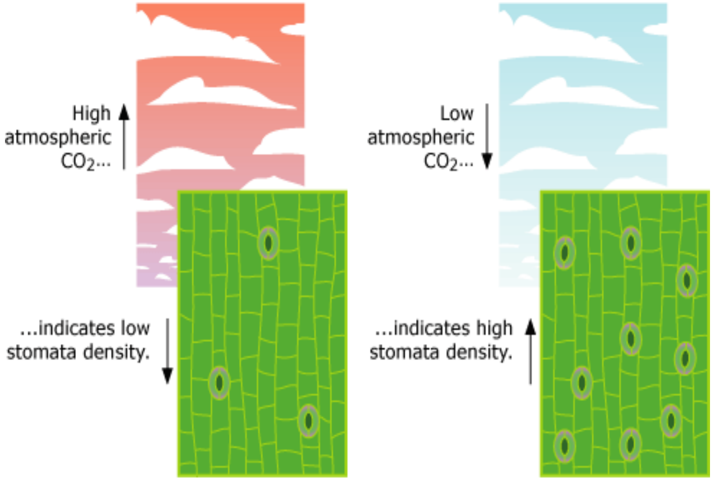
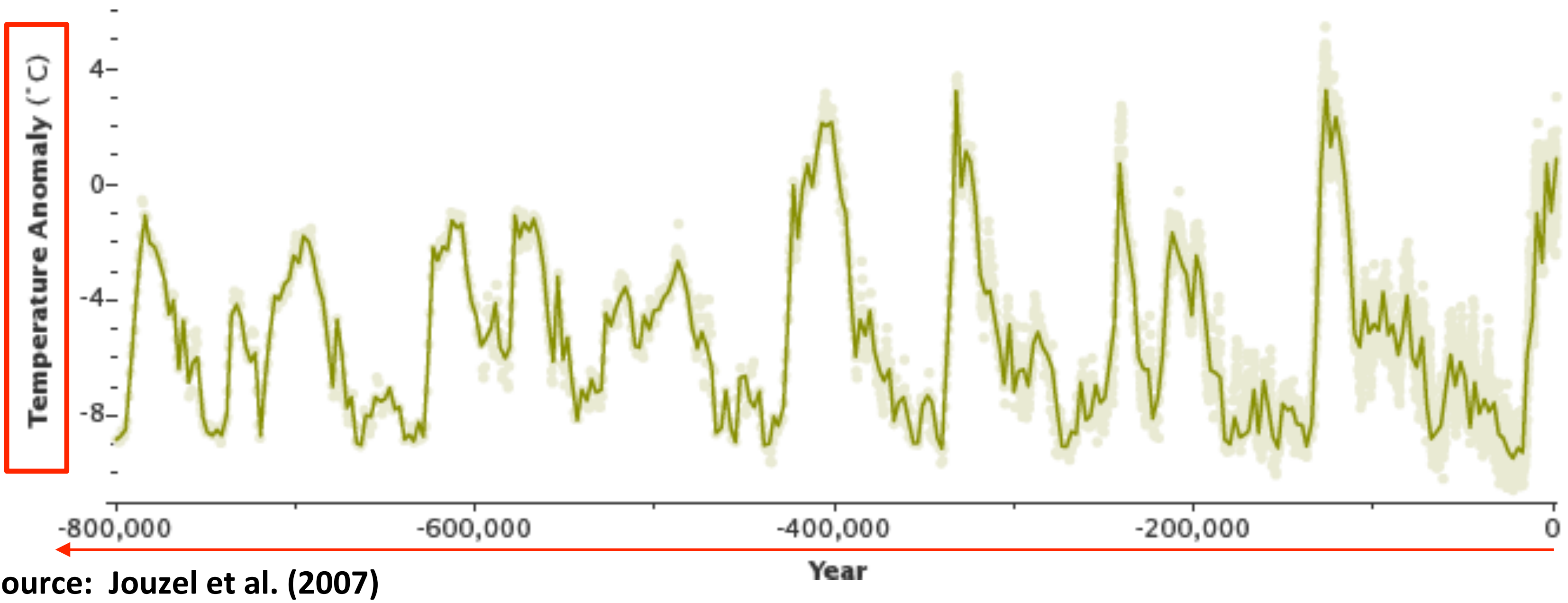
Surrey TW20 0EX, UK

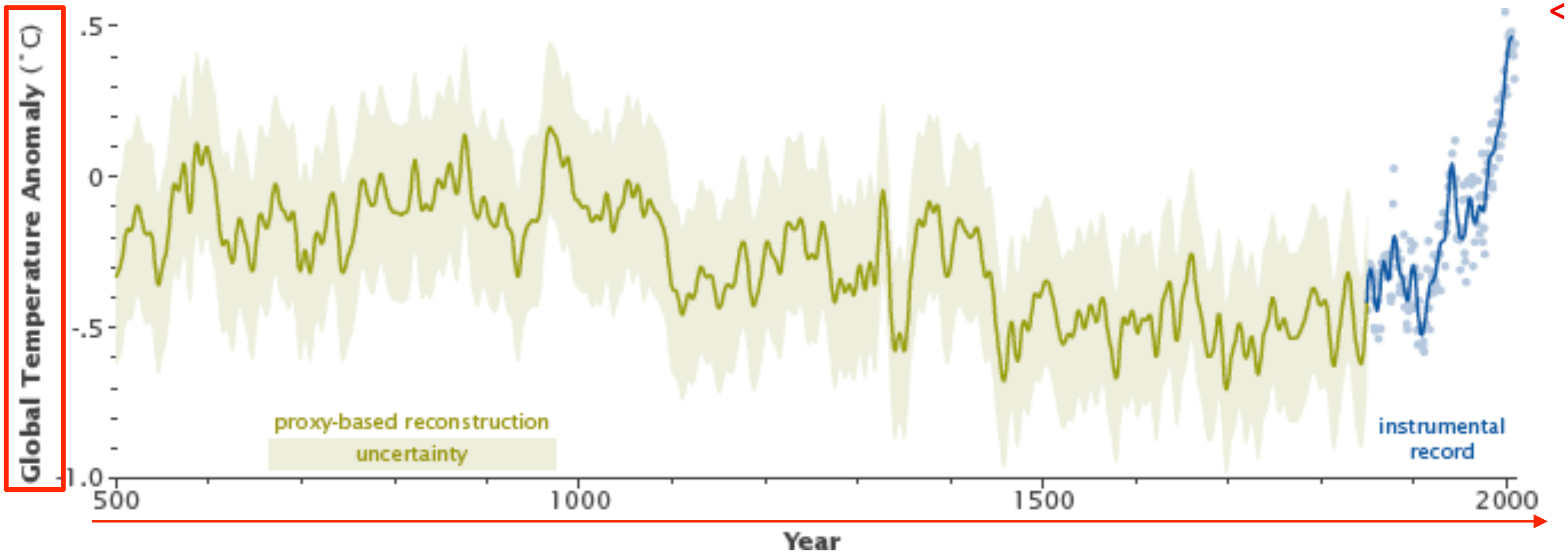
Received: 20 February 1995 Accepted: 6 June 1995

It has been demonstrated that the leaves of a range of forest tree species have responded to the rising concentration of atmospheric CO_2 over the last 200 years by a decrease in both stomatal density and stomatal index. This response has also been demonstrated experimentally by growing plants under elevated CO_2 concentrations. Investigation of Quaternary fossil leaves has shown a corresponding stomatal response to changing CO_2 concentrations through a glacial-interglacial cycle, as revealed by ice core data. Tertiary leaves show a similar pattern of stomatal density change, using palynological evidence of palaeo-temperature as a proxy measure of CO_2 concentration. The present work extends this approach into the Palaeozoic fossil plant record. The stomatal density and index of Early Devonian, Carboniferous and Early Permian plants has been investigated, to test for any relationship that they may show with the changes in atmospheric CO_2 concentration, derived from physical evidence, over that period. Observed changes in the stomatal data give support to the suggestion from physical evidence, that atmospheric CO_2 concentrations fell from an Early Devonian high of 10–12 times its present value, to one comparable to that of the present day by the end of the Carboniferous. These results suggest that stomatal density of fossil leaves has potential value for assessing changes in atmospheric CO_2 concentration through geological time.





Source: Jouzel et al. (2007)

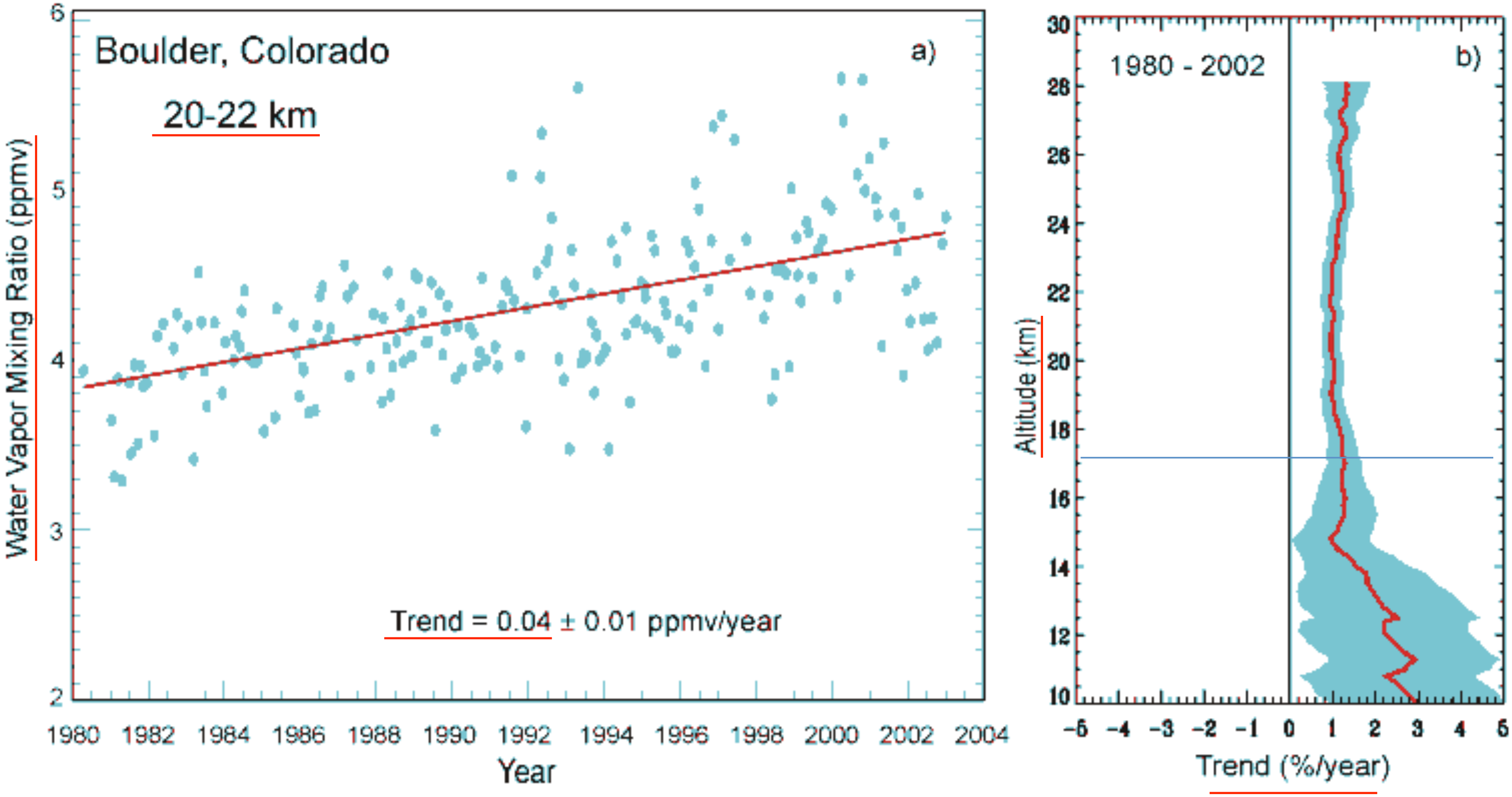


< 14°C

Source: Mann et al. (2008)

A useful measure of the amount of water vapor in the air is the mixing ratio, r, which is defined as: r = mv/md where mv = mass of vapor and md = mass of dry air.

Source: Dessler et al. (2013) Stratospheric water vapor feedback, *Proc. Natl. Acad. Sci.*, 110:18,087-18,091.



As the lowest layer of the atmosphere, called the troposphere (surface to ~17 miles in the middle latitudes), is warmed, the air there becomes more humid. With greater humidity, there is greater (global) precipitation and thus more clouds!

Photosynthesis > $CO_2 + \boxed{2H_2O} + \underline{\text{solar energy}} \rightarrow O_2 + CH_2O + \boxed{H_2O}$

CH_4
Methane

CO_2 Comp. Point
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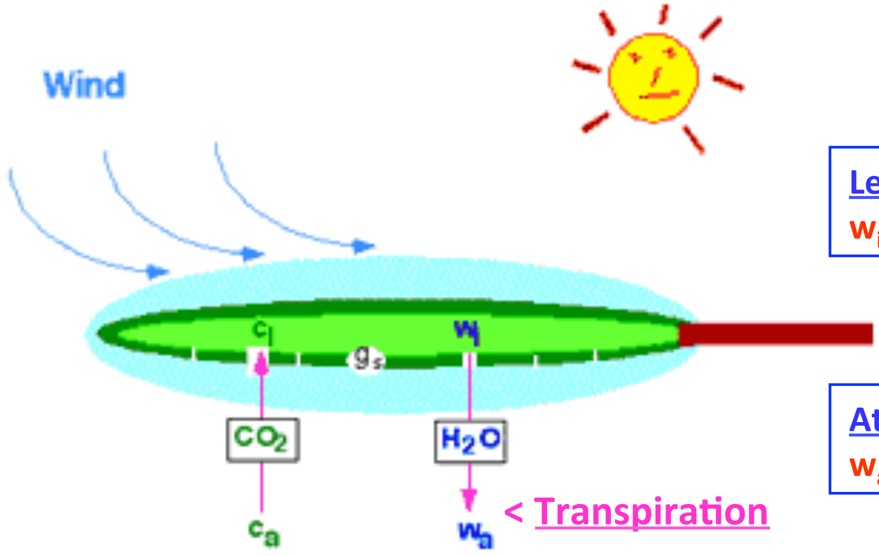

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$$WUE = \frac{A}{E} = \frac{c_a - c_i}{1.6(w_a - w_i)}$$

C4 *vs.* C3

VC|VPD

For a sunlit soybean leaf (C3 type of photosynthesis):
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400 H_2O molecules simultaneously escape from that same pore !!!!

Plants must thus exchange 164 lbs of $H_2 0$ to acquire 1 lb of CO_2
(~ 6.1g CO_2 per 1000g H_2O)
Source: Park Nobel. 2009. Physicochemical and Environmental Plant Physiology (4th Ed.)

Some Key Papers That Influenced My Research Thinking/Focus Relative to Transpiration and WUE

- **Passioura, J.B**. 1977. Grain yield, harvest index, and water use of wheat. J. Aust. Inst. Agric. Sci. 43: 117-120.
- **Rosielle, A.A. and J. Hamblin**. 1980. Theoretical aspects of selection in stress and non-stress environments. Crop Sci. 21:943-946.
- **Tanner, C.B. and T.R. Sinclair.** 1983. Efficient water use in crop production: research or re-search. pp. 1-28 in H. Taylor et al. (eds.) Limitations to Efficient Water Use in Crop Production.
- **Sinclair et al.** 1984. Water use efficiency in crop production. Bioscience 34:36-40.
- **Araus, J.L. et al. 2002**. Plant breeding and drought in C3 cereals:
- What should we breed for? Ann. Bot. 89:925-940
- **Sadras, V.O. and J.F. Angus.** 2006. Benchmarking water-use efficiency of rainfed wheat in dry environments. Aust. J. Agr. Res. 57:847-856.

Crop Productivity and Water Scarcity

Passioura, J.B. 1977. Grain yield, harvest index, and water use of wheat.
J. Aust. Inst. Agric. Sci. 43: 117-120.

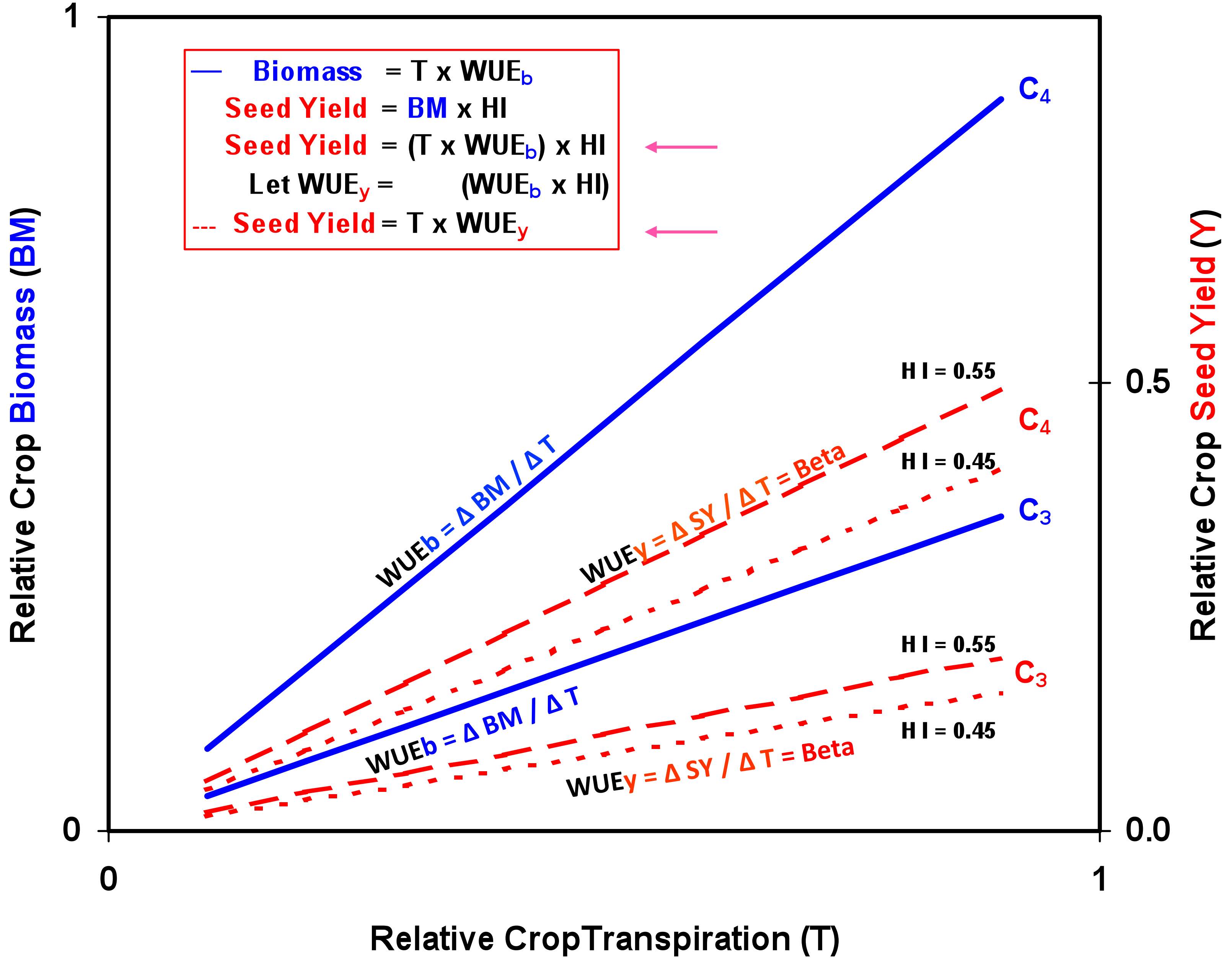
- Seed yield (SY) in water-limited environments is effectively a function of three largely independent entities: water-use efficiency (WUE_{bm}), transpired water amount (T), and harvest index (HI).

$$BMY = (WUE_{bm} \times T) \qquad \{y = \underline{b} \cdot x\}$$

$$SY = (WUE_{bm} \times T) \times HI$$

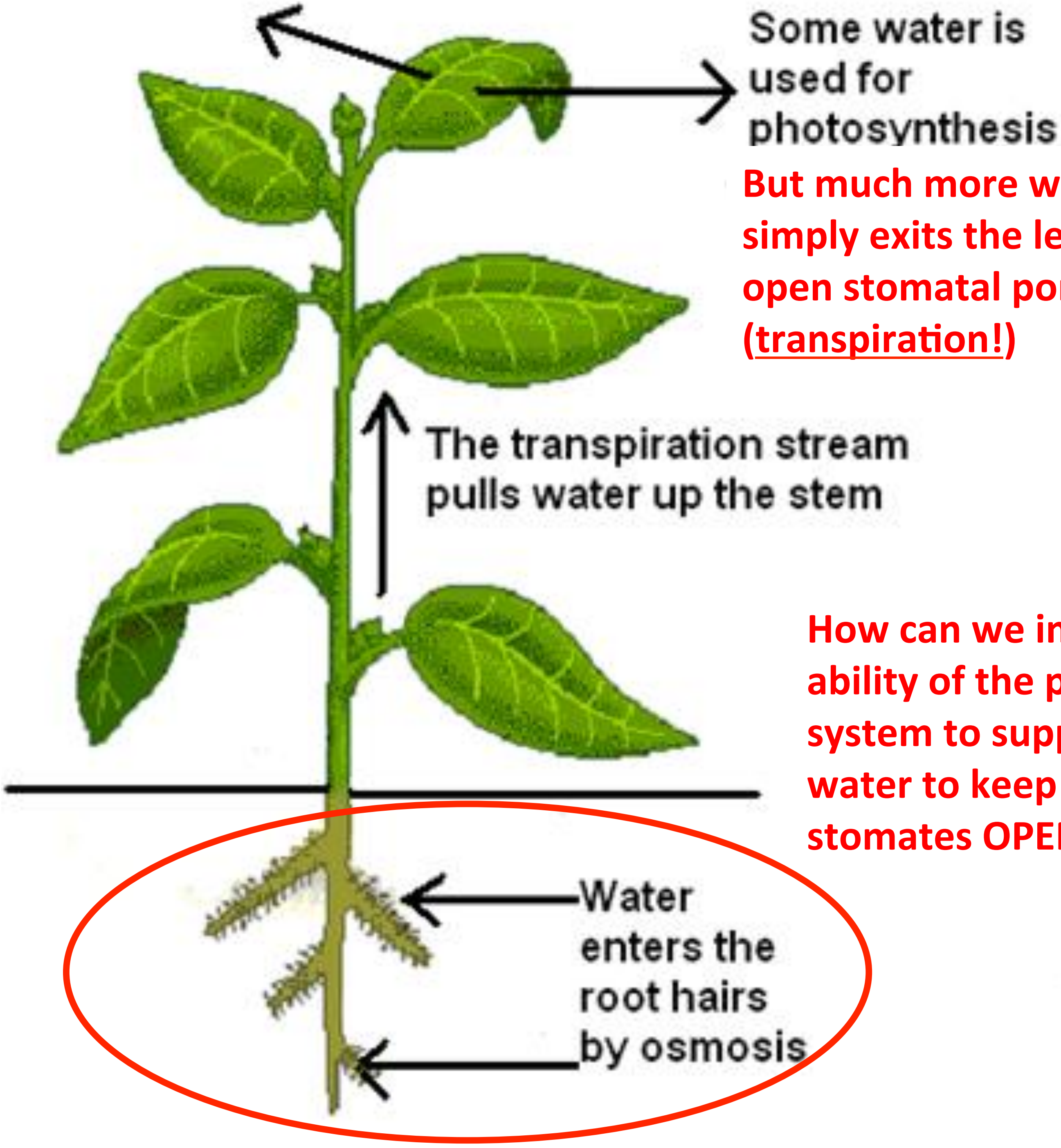
kg Seed / ha = Δ kg BM / Δ kg Water
× kg Transpired Water / ha
× kg Seed fraction / kg BM

WUE = change in crop mass per unit change in crop transpiration



"In conclusion, the inescapable fact is that crop production is inextricably linked to crop transpiration. To increase crop biomass production, more water must be used in transpiration"

Sinclair et al. 1984. Water use efficiency in crop production. Bioscience 34:36-40.

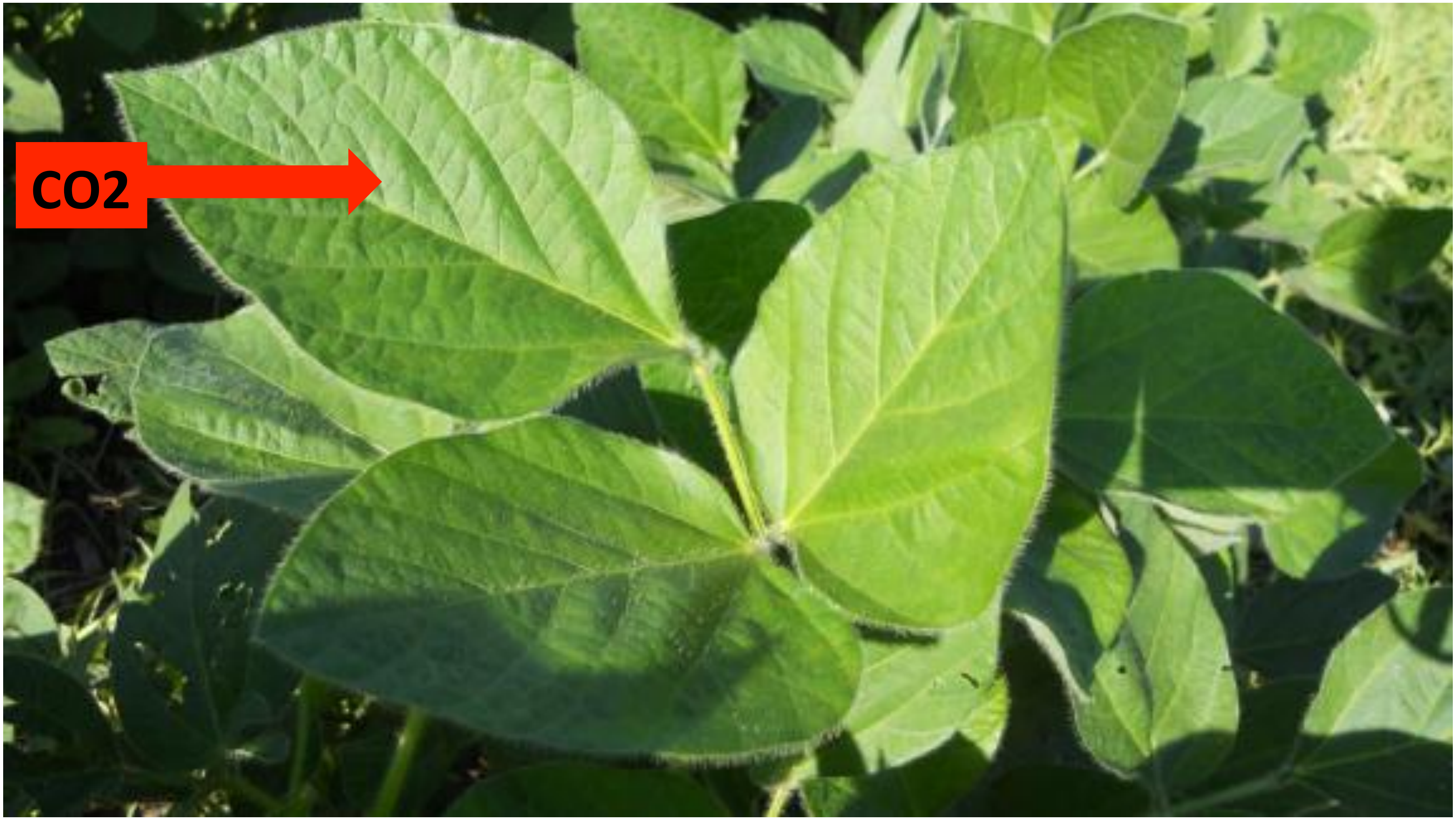


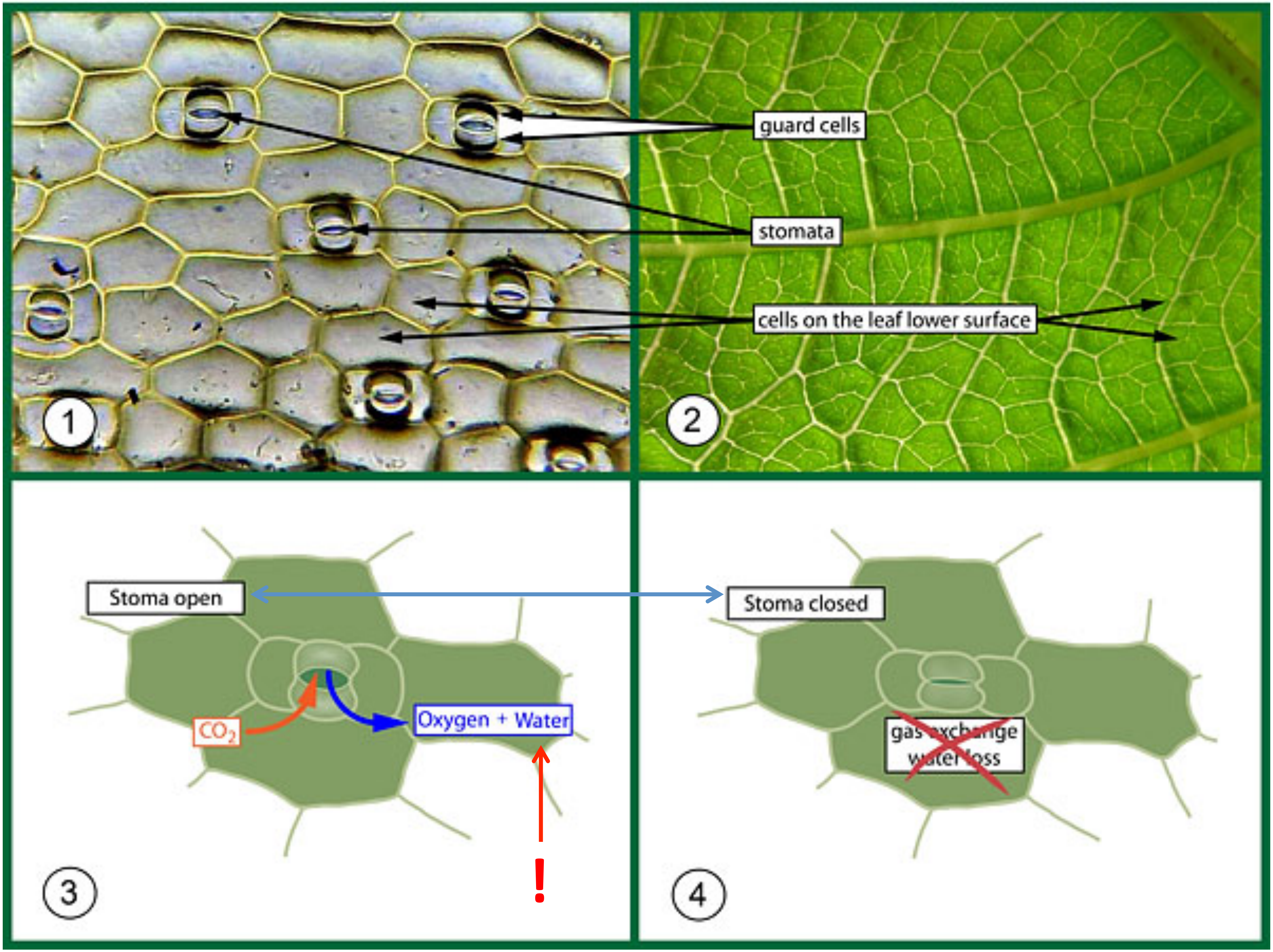
But much more water simply exits the leaf via open stomatal pores (transpiration!)

How can we improve the ability of the plant root system to supply enough water to keep those stomates OPEN!

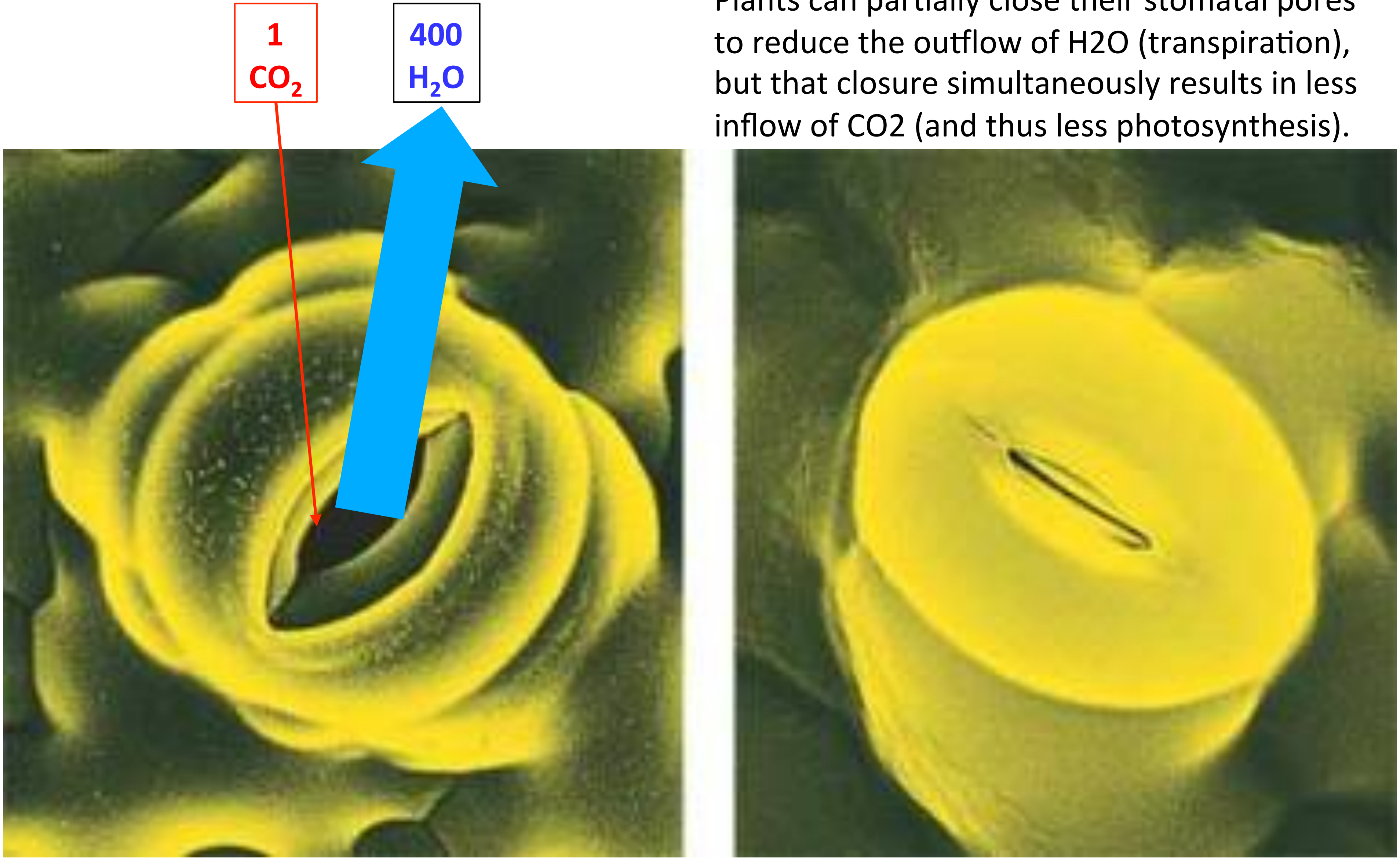
Photosynthesis >

$$CO_2 + 2H_2O + \underline{\text{solar energy}} \rightarrow O_2 + CH_2O + H_2O$$



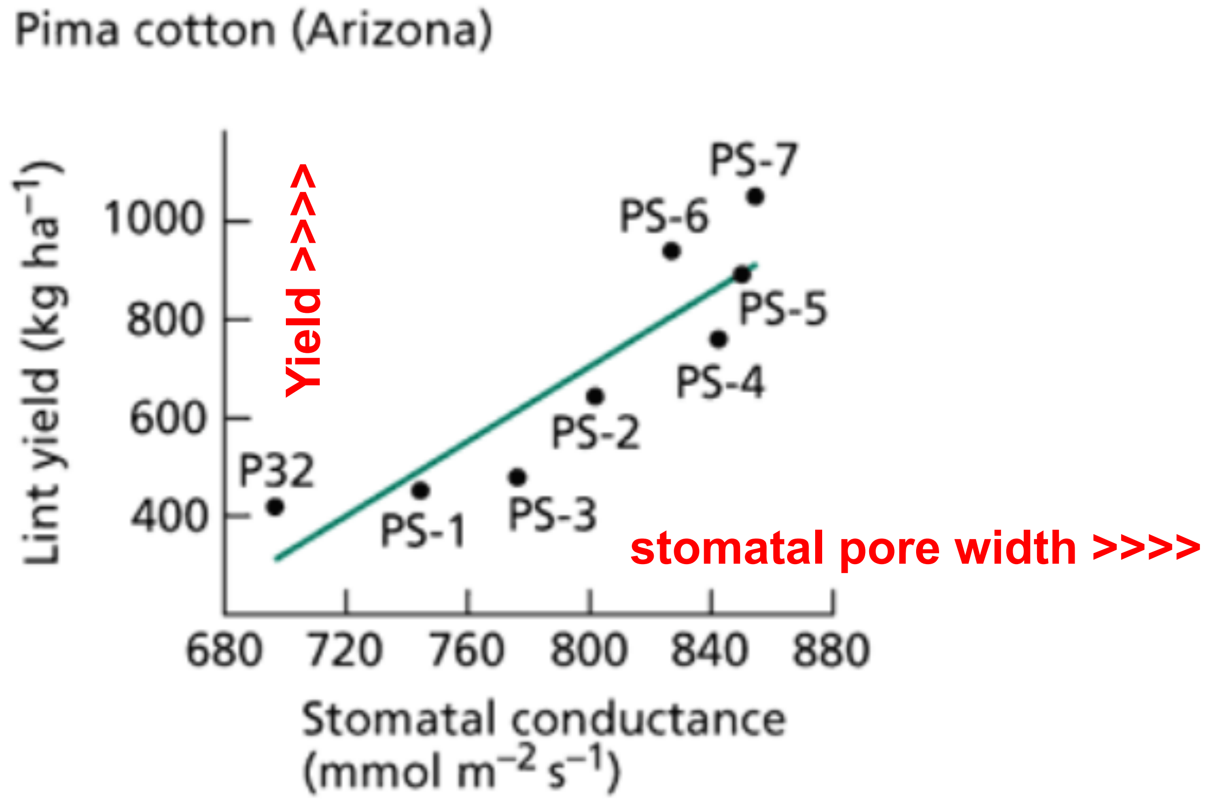

guard cells
stomata
cells on the leaf lower surface
1
2
Stoma open
Stoma closed
CO$_2$
Oxygen + Water
!
gas exchange
water loss
3
4

Plants can partially close their stomatal pores to reduce the outflow of H2O (transpiration), but that closure simultaneously results in less inflow of CO2 (and thus less photosynthesis).



Soybean varieties selected for a less wide open stomatal pore each day (or earlier closure when the number of days between rainfall events widen) are called “water-conservers”, but less wide pores allow less CO2 in the leaf for photosynthesis, so they are also “slow-growers”. (Less RUE)

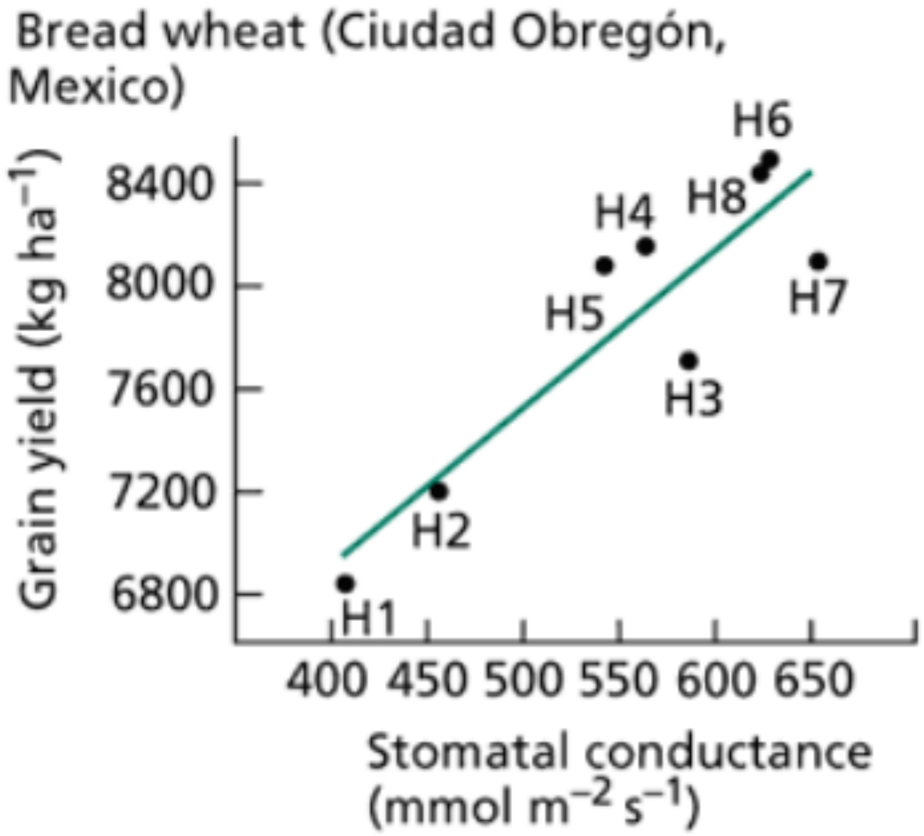
Breeders selecting for greater yield have generated ever-higher-yielding new variety releases whose stomatal pores are generally wider open (during the day) than prior releases. This finding is consistent with the fact plants must exchange water for carbon dioxide, thus inextricably linking high yields with open stomates so long as enough water is available for transpiration when the pores are open!



Web Figure 26.1.A Stomatal conductance has increased in parallel with agronomic yields in irrigated Pima cotton (Gossypium barbadense) selected for higher yields at a high temperature. The figure shows the relationship between lint yield and stomatal conductance in a historical series of Pima cotton grown in Arizona. The abbreviations P32 and PS-1 through PS-7 designate successive commercial releases between 1949 and 1996. (From Lu et al. 1998.)

Source: http://5e.plantphys.net/search_result.php?search_in=all&term=stomatal+conductance

Ditto!

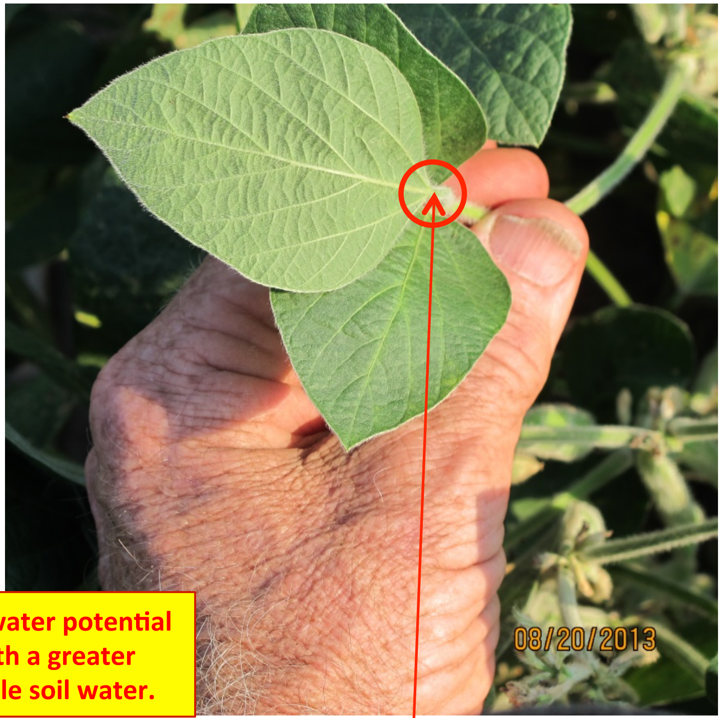


Web Figure 26.1.C The relationship between grain yield and stomatal conductance in a historical series of semidwarf bread wheat grown in Ciudad Obregón, Mexico. The abbreviations H1 through H8 designate successive commercial lines released by the International Maize and Wheat Improvement Center between 1962 and 1988. (From Lu et al. 1998.)

Source: http://5e.plantphys.net/search_result.php?search_in=all&term=stomatal+conductance

But if there is not enough water to keep stomates open, then . . . .

08/20/2013



08/20/2013

Leaflet inversion began when leaf water potential was -1.4 MP and was associated with a greater than 60% depletion of plant available soil water.

08/20/2013

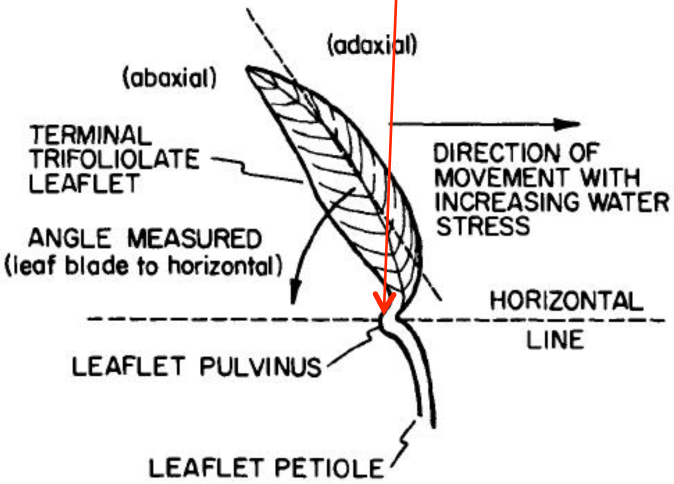
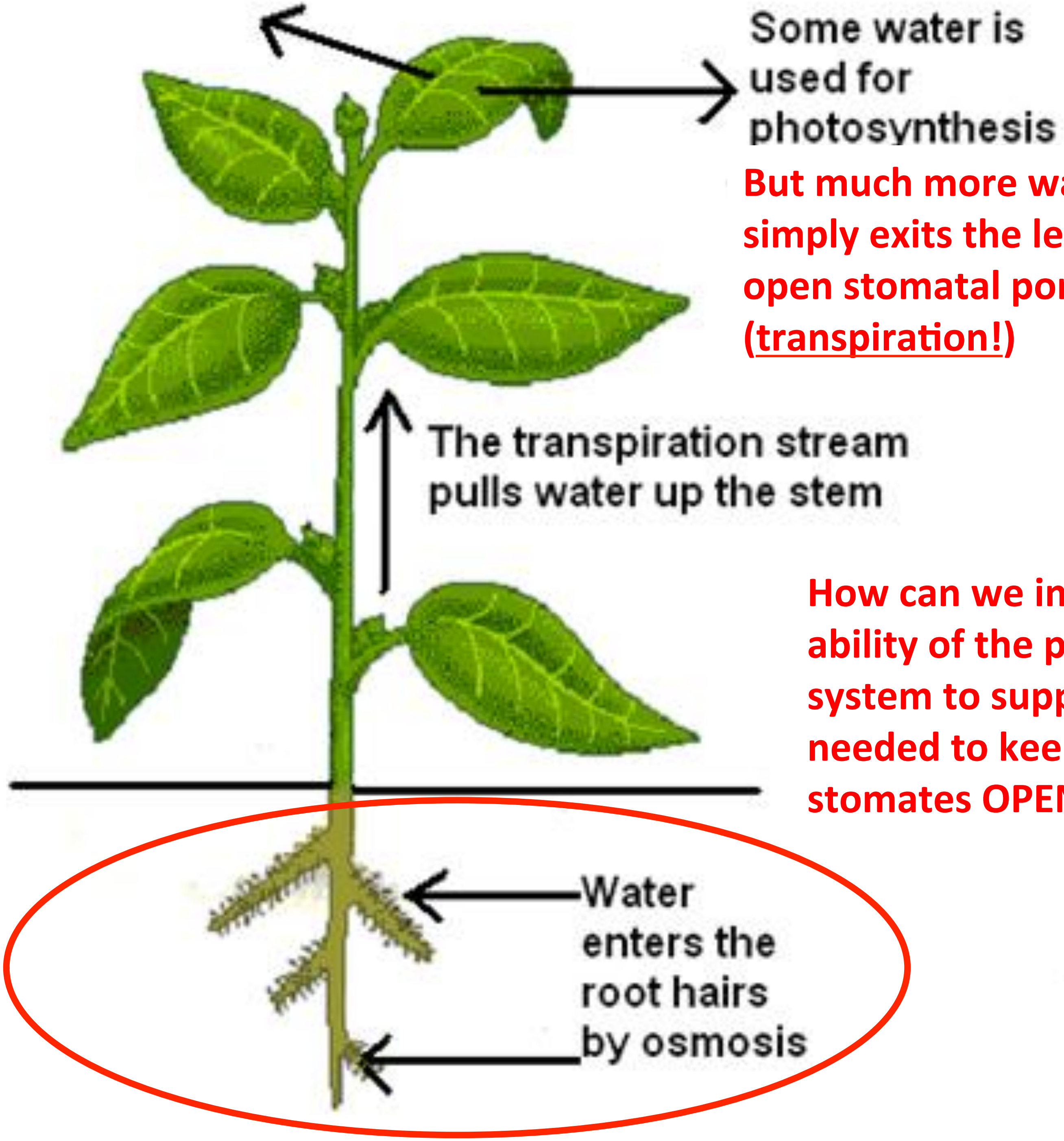


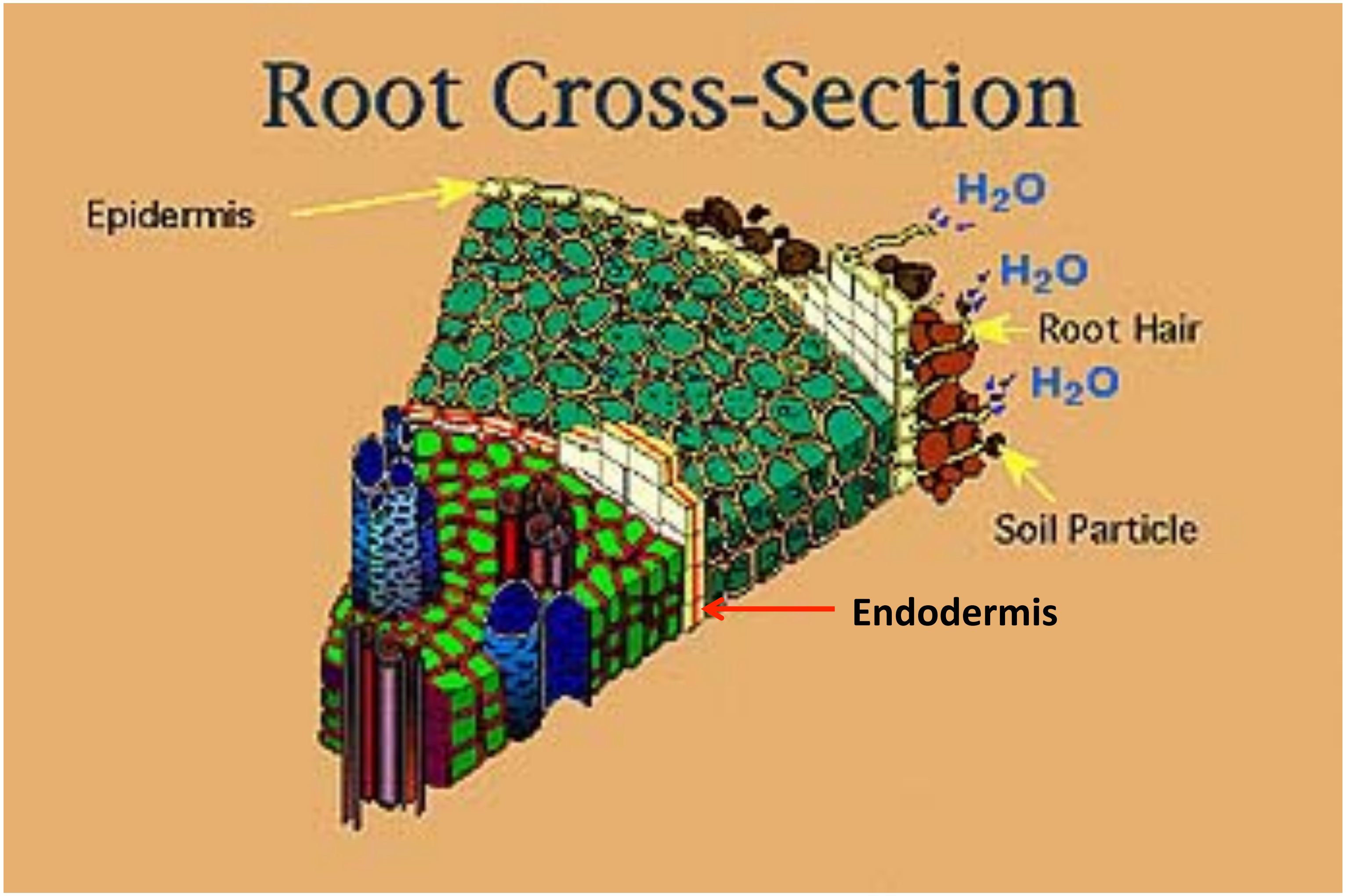
Fig. 1. Representation of a terminal soybean leaflet showing the leaflet, pulvinus, angle measured, and direction of leaflet movement with increasing water stress.

Source: Oosterhuis et al. (19xx) Crop Sci. 25:1101-1106

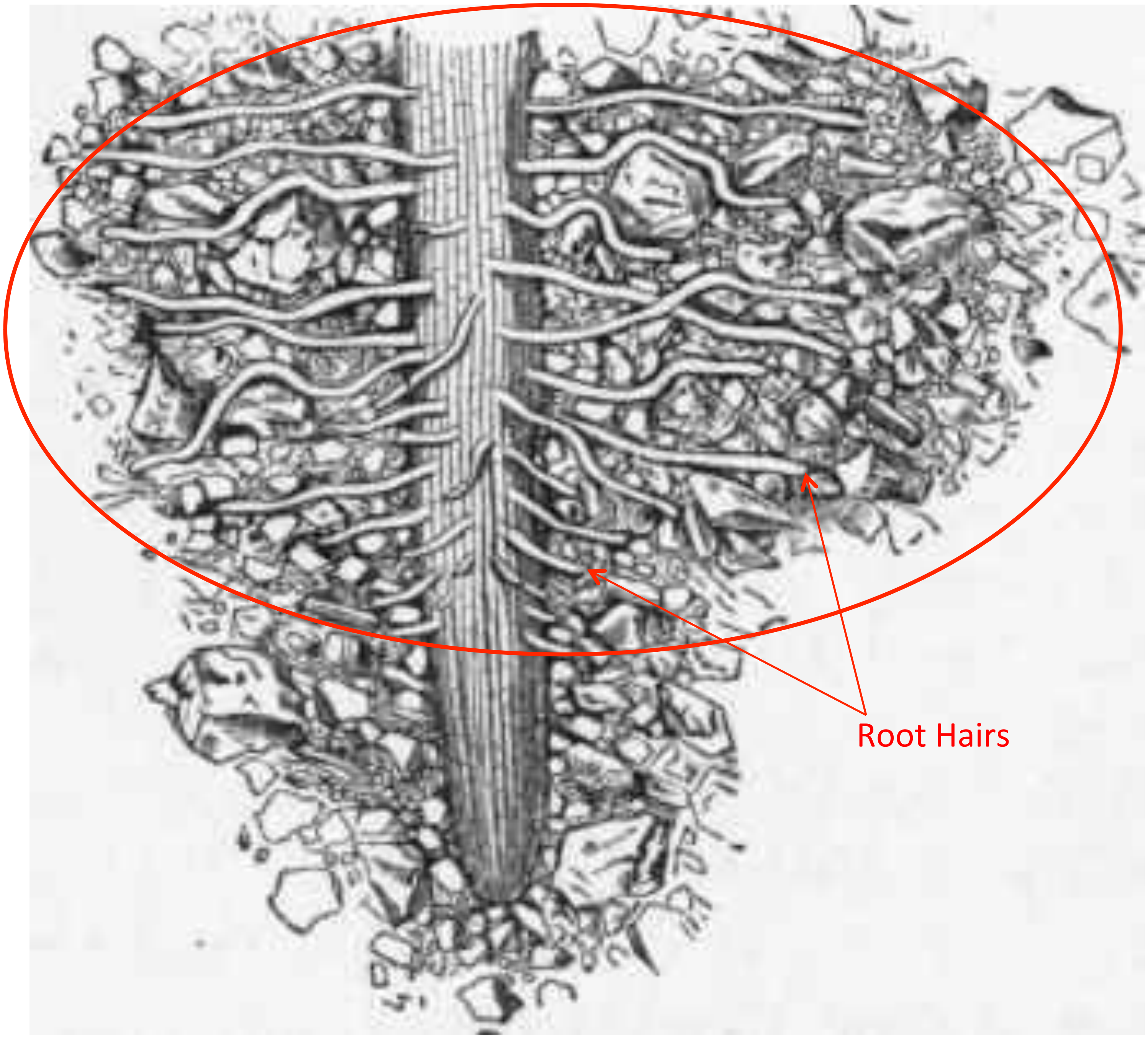


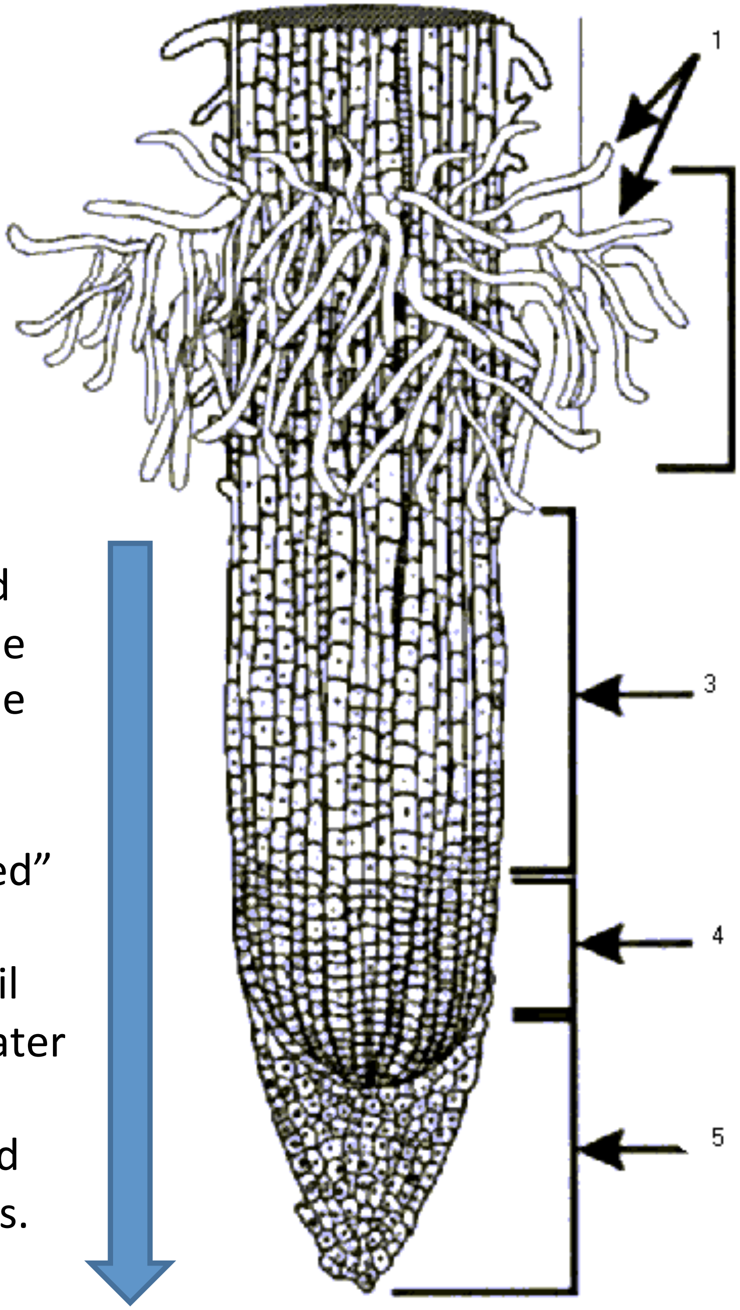
But much more water simply exits the leaf via open stomatal pores (transpiration!)

How can we improve the ability of the plant root system to supply the water needed to keep those stomates OPEN!


Root Cross-Section
Epidermis
H_2O
H_2O
Root Hair
H_2O
Soil Particle

Endodermis


Root Hairs



1 Individual Root Hairs

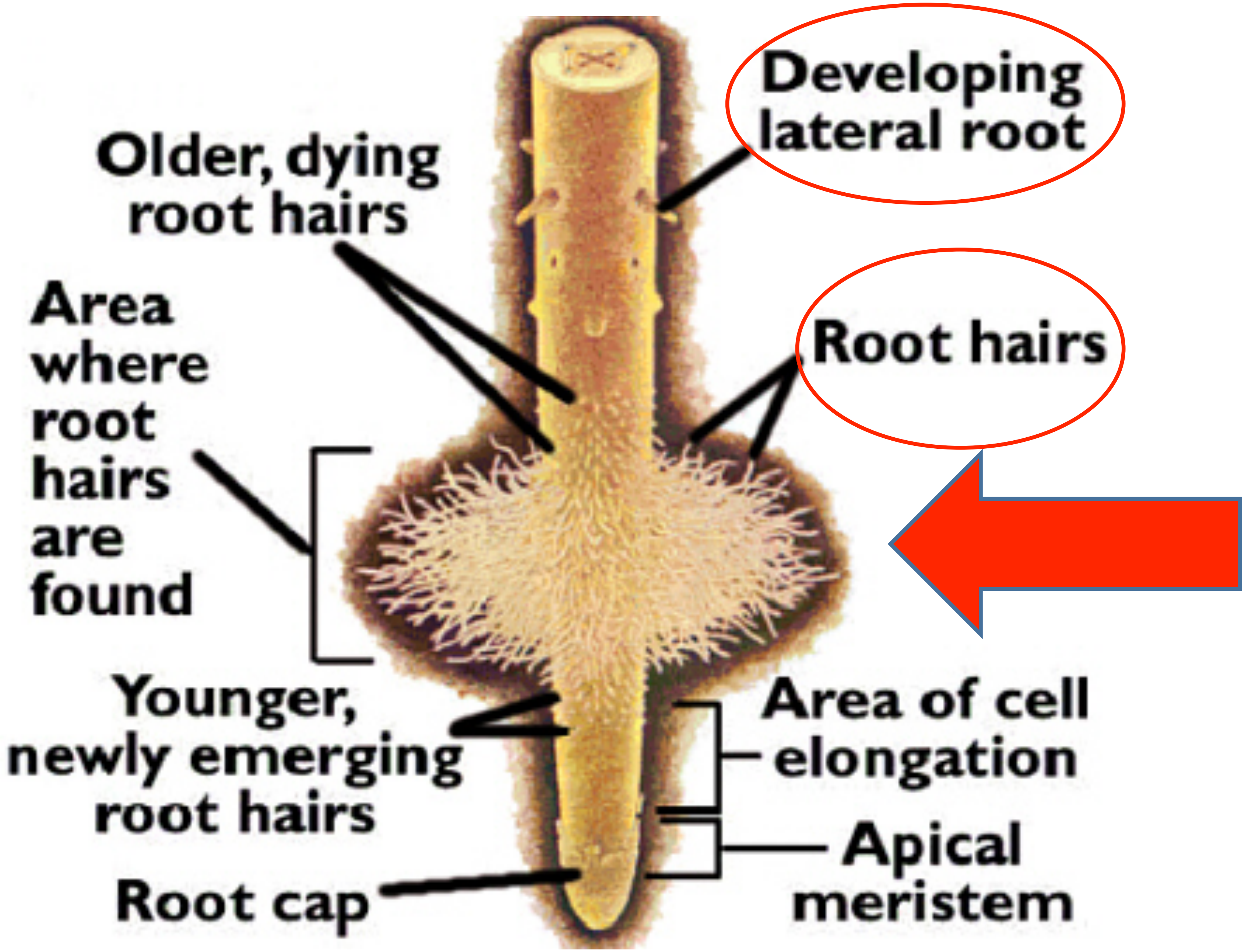
2 Root Hair Zone

3 Cell Elongation Zone

4 Cell Division Zone

5 Root Cap

Cell division and elongation in the region below the root hair zone causes the root tip to be "pushed" into water- and nutrient-rich soil zones where water and nutrients can be extracted by the root hairs.


Older, dying root hairs
Developing lateral root
Area where root hairs are found
Root hairs
Younger, newly emerging root hairs
Area of cell elongation
Apical meristem
Root cap

Root Hairs on Nodal Root of V2 Corn Seedling

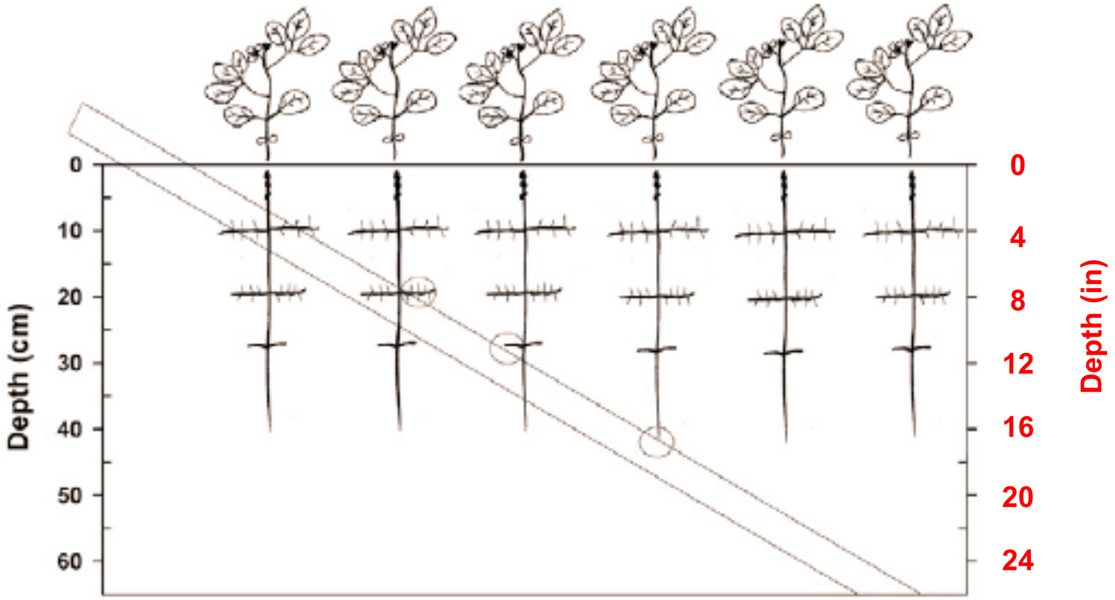
Soybean Root Development Relative to Vegetative and Reproductive Phenology

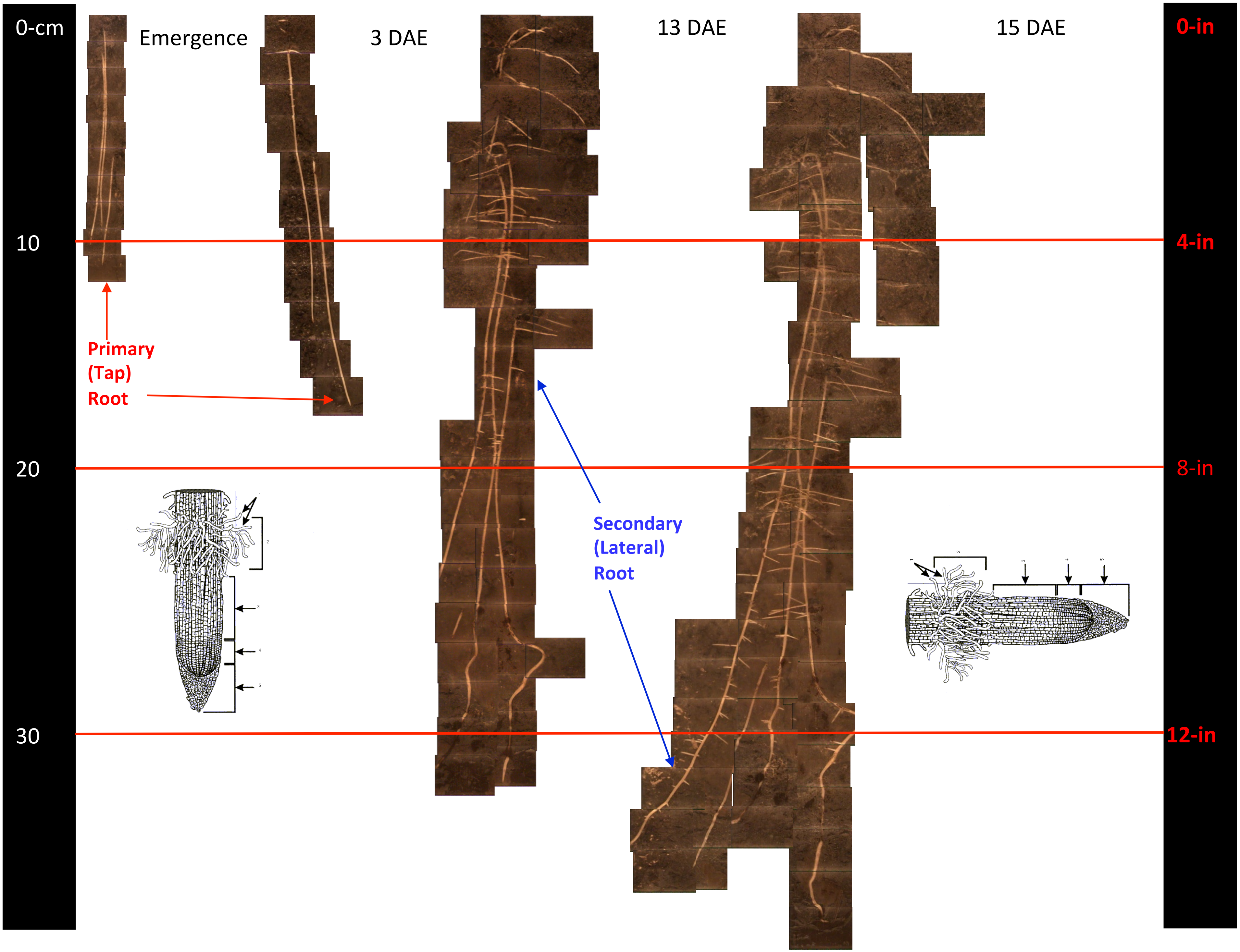
Jessica A. Torrion, Tri D. Setiyono, Kenneth G. Cassman,
Richard B. Ferguson, Suat Irmak, and James E. Specht*

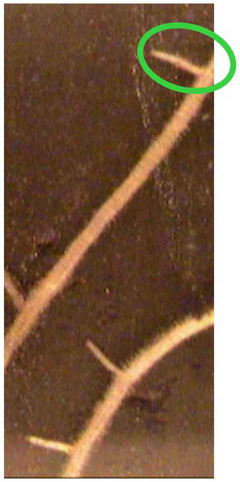
Agron. J. 104:1702–1709 (2012)

ABSTRACT

Knowledge of soybean [*Glycine max* (L.) Merr.] primary, secondary, and tertiary root tip locations in the soil vs. seasonal time would enhance modeling of soybean development. The seasonal progression of root tip development and shoot phenology was evaluated in situ using an imaging device inserted into minirhizotron tubes installed in the soil at an in-row 30° angle. Primary root tip extension was linear (i.e., 1.5 and 1.2 cm d^{-1} each year) until the full-seed stage. Emergent 5-mm secondary roots were routinely detected about 10-cm above the primary root tip, and thus present in a soil layer 11 d after the primary root tip had passed through that layer. Secondary roots followed a similar temporal pattern. Primary root tip location in the soil paralleled a 17°C soil temperature isoline. The 3.7-d phyllochron of main-stem node accrual between first node and seed fill may be a calibratable proxy for inferring correspondent root tip depths.



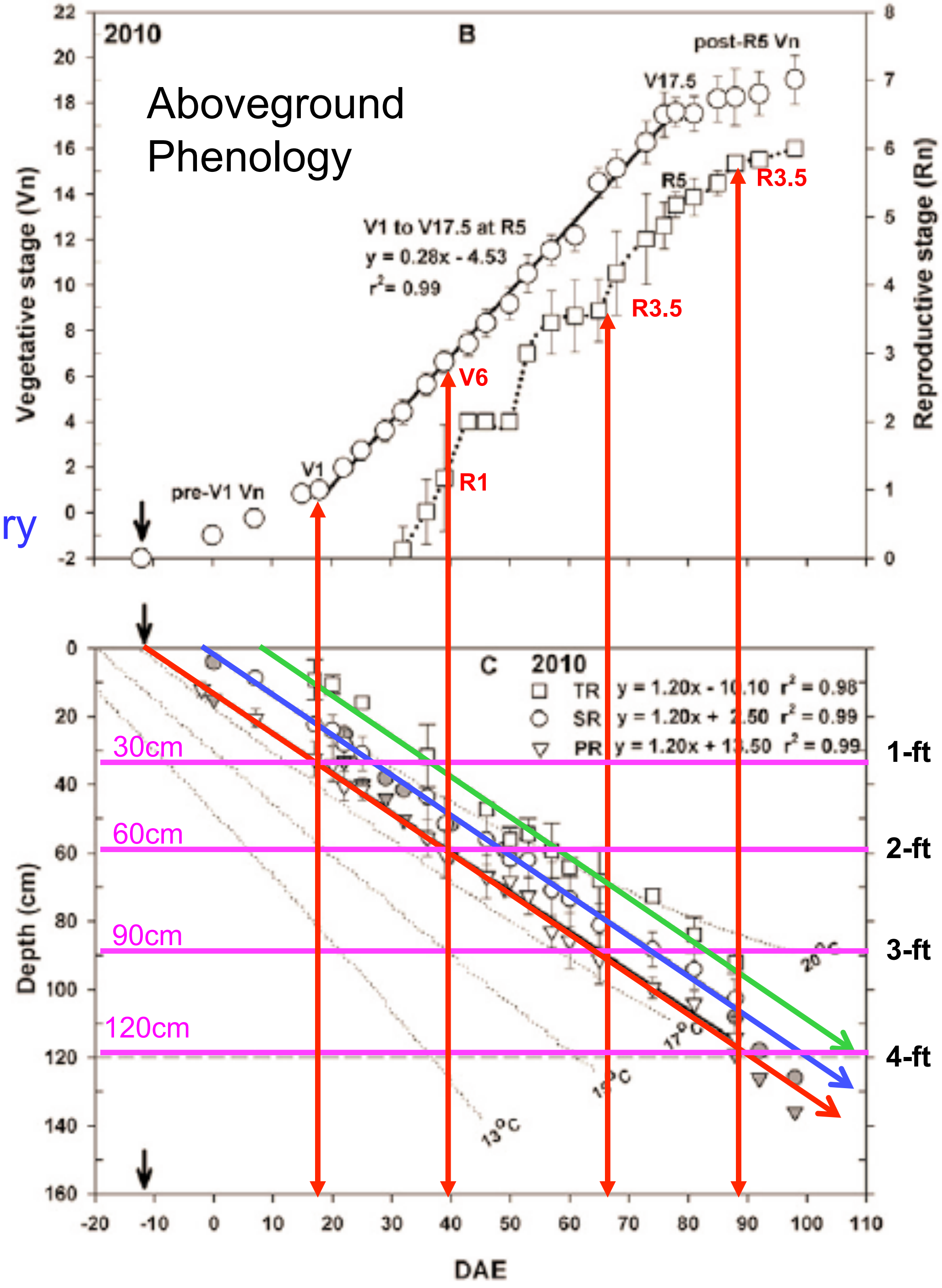

0-cm
10
20
30
Emergence
3 DAE
13 DAE
15 DAE
0-in
4-in
8-in
12-in
Primary (Tap) Root
Secondary (Lateral) Root



Tertiary Root

Secondary (Lateral) Root

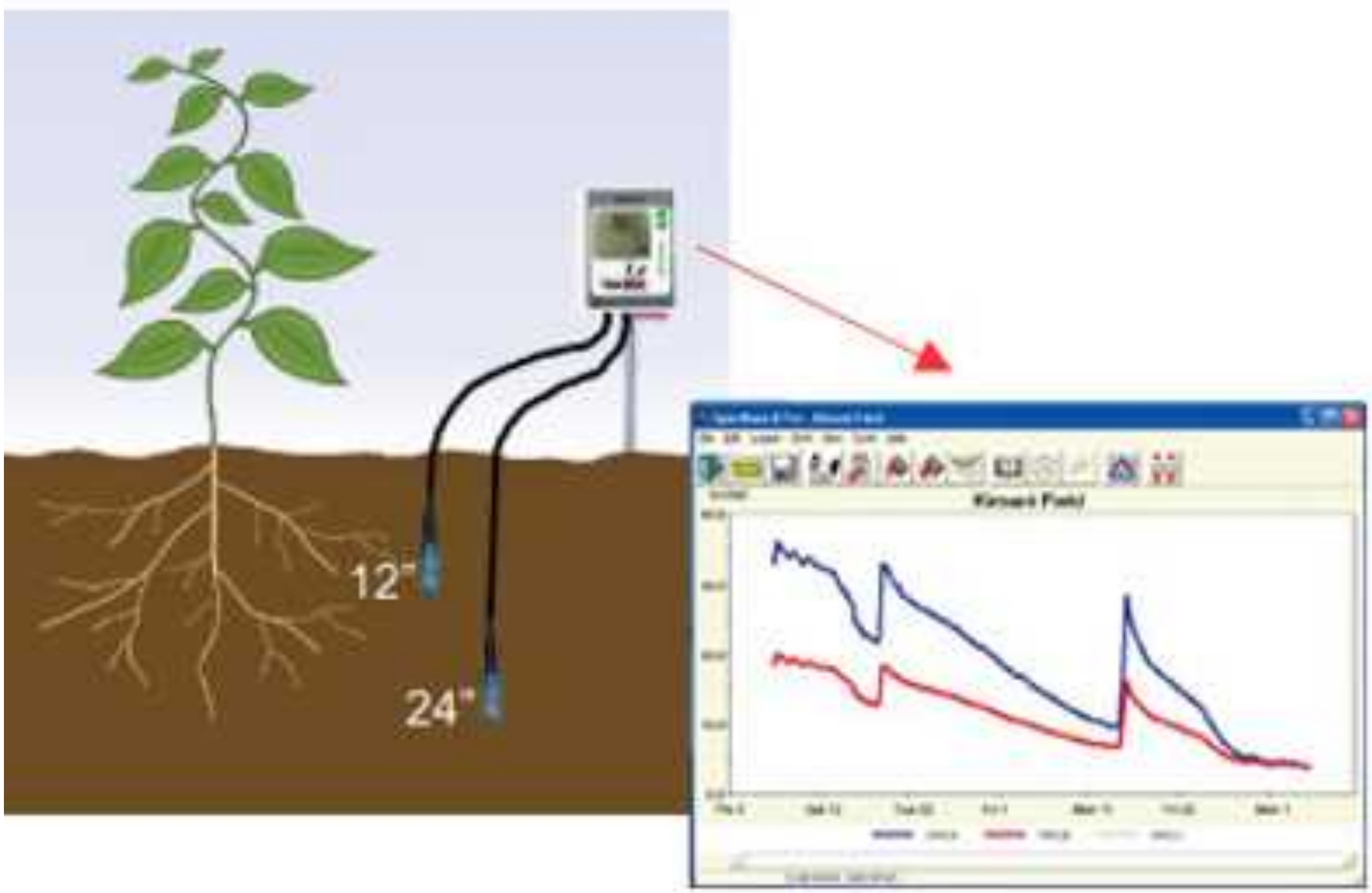
Primary (Tap) Root



Tap Root Tip Extends Down <u>1.2 cm per day</u> =

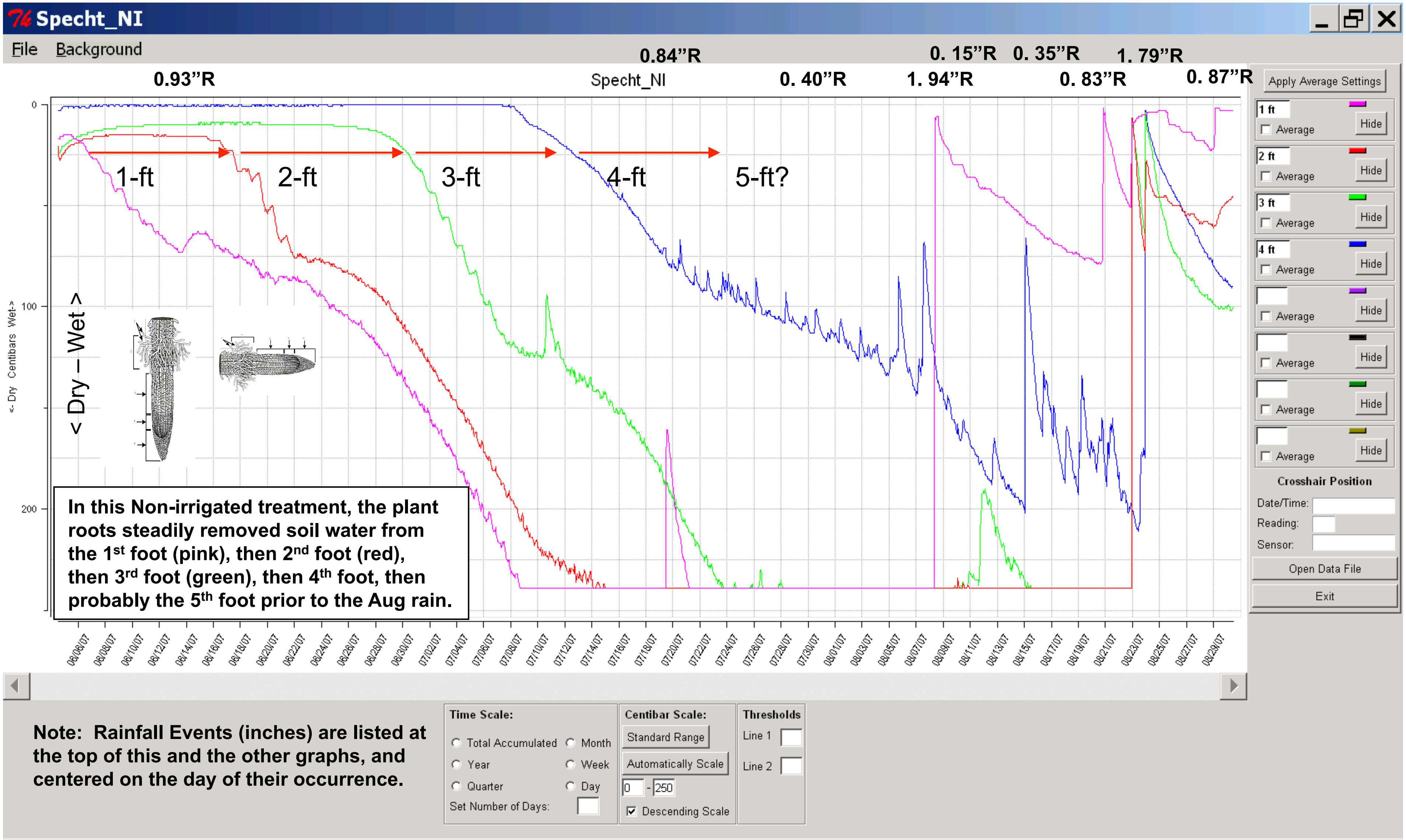
<u>0.5 inch per day</u>

on the day that seed germinates



Station and data showing multiple depths

T4 (Non-Irrigated) Rainfed Treatment – Soy Drip Irrigation Experiment



0.93"R 0.84"R 0. 40"R 0. 15"R 1. 94"R 0. 35"R 0. 83"R 1. 79"R 0. 87"R

0 - 250

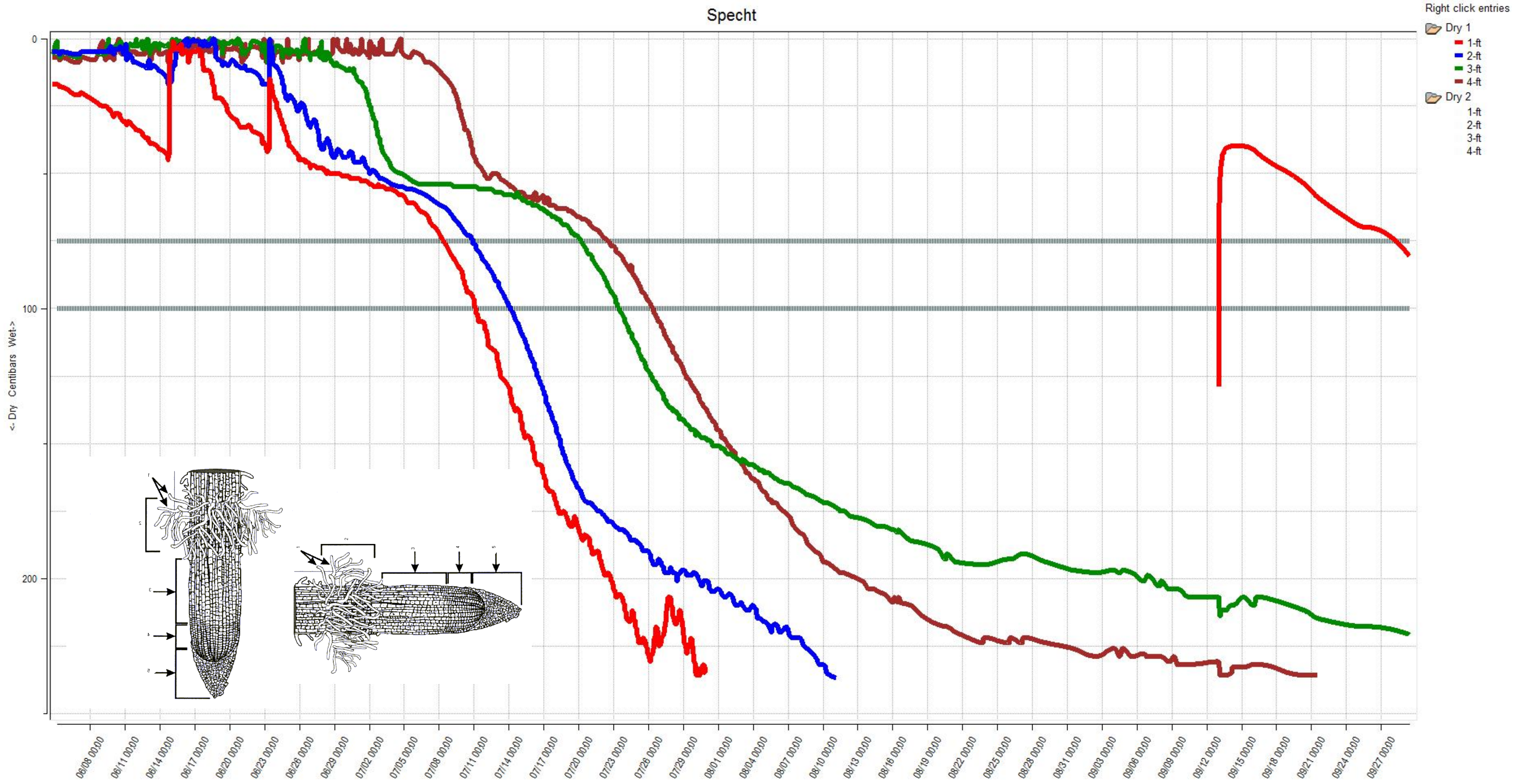
☑ Descending Scale

In this Non-irrigated treatment, the plant roots steadily removed soil water from the 1st foot (pink), then 2nd foot (red), then 3rd foot (green), then 4th foot, then probably the 5th foot prior to the Aug rain.

Note: Rainfall Events (inches) are listed at the top of this and the other graphs, and centered on the day of their occurrence.

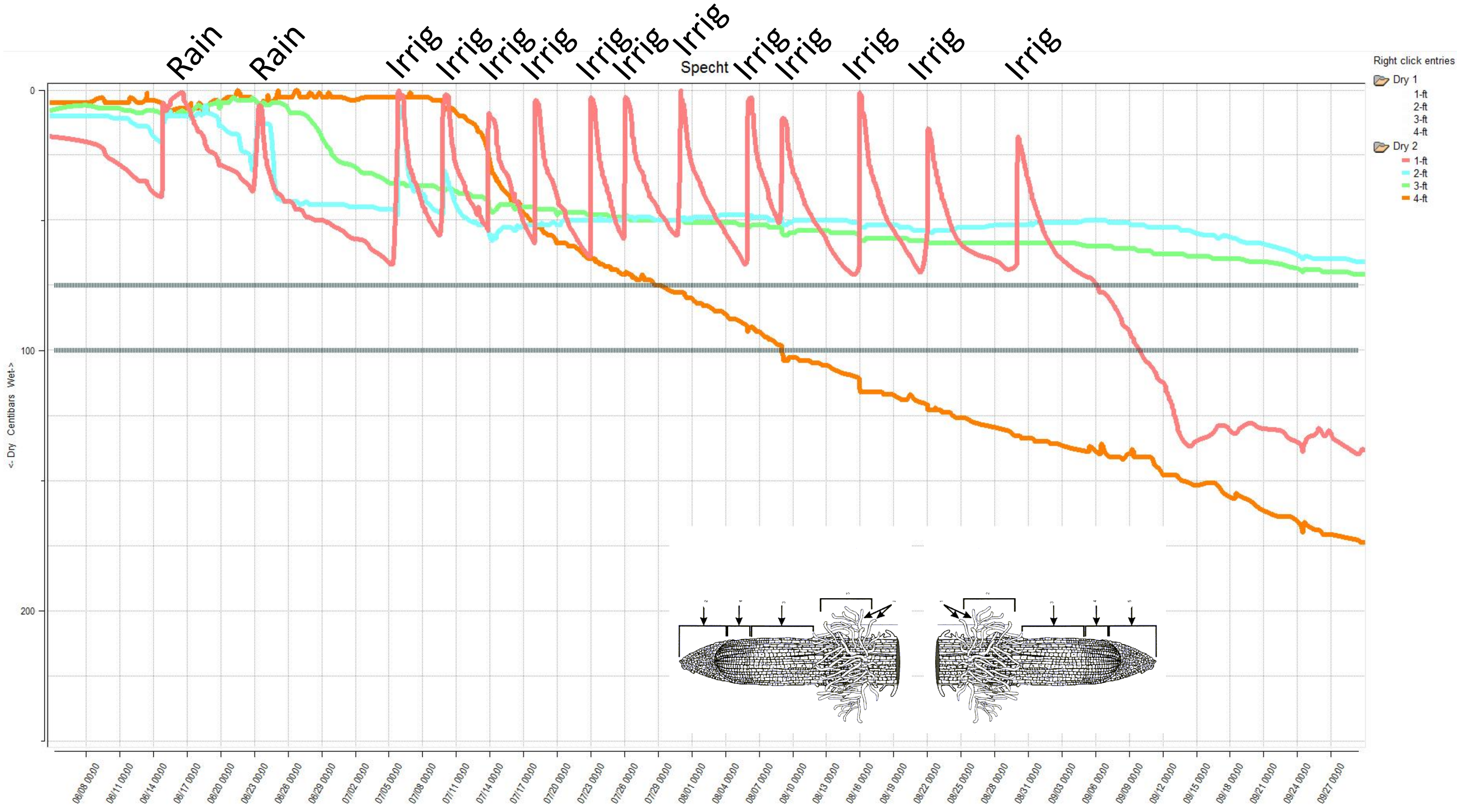
According to Irmak et al. (2006), the inches of soil water depletion per foot associated with a given soil matric potential for a Sharpsburg Soil are: 0-20cb=0in; 33cb=0.20in; 50cb=0.45in; 60cb=0.50in; 70cb=0.60in; 80cb=0.65in; 90cb=0.70in; 100cb=0.80in; 150cb=0,90in; 200cb=1.00in. And in the same soil type, the allowable soil water depletion per foot of soil root depth are 1.4 for 1.5ft; 1.8 for 2.0ft; 2.2 for 2.5ft; 2.7 for 3.0ft.

No Rainfall Field – Sensor depths of 1-ft = red, 2-ft =blue, 3-ft = green, & 4-ft = brown



2013

Irrigated Field - Sensor depths of 1-ft = pink, 2-ft = light blue, 3-ft = light green, & 4-ft = orange



2013

Crop Water Productivity

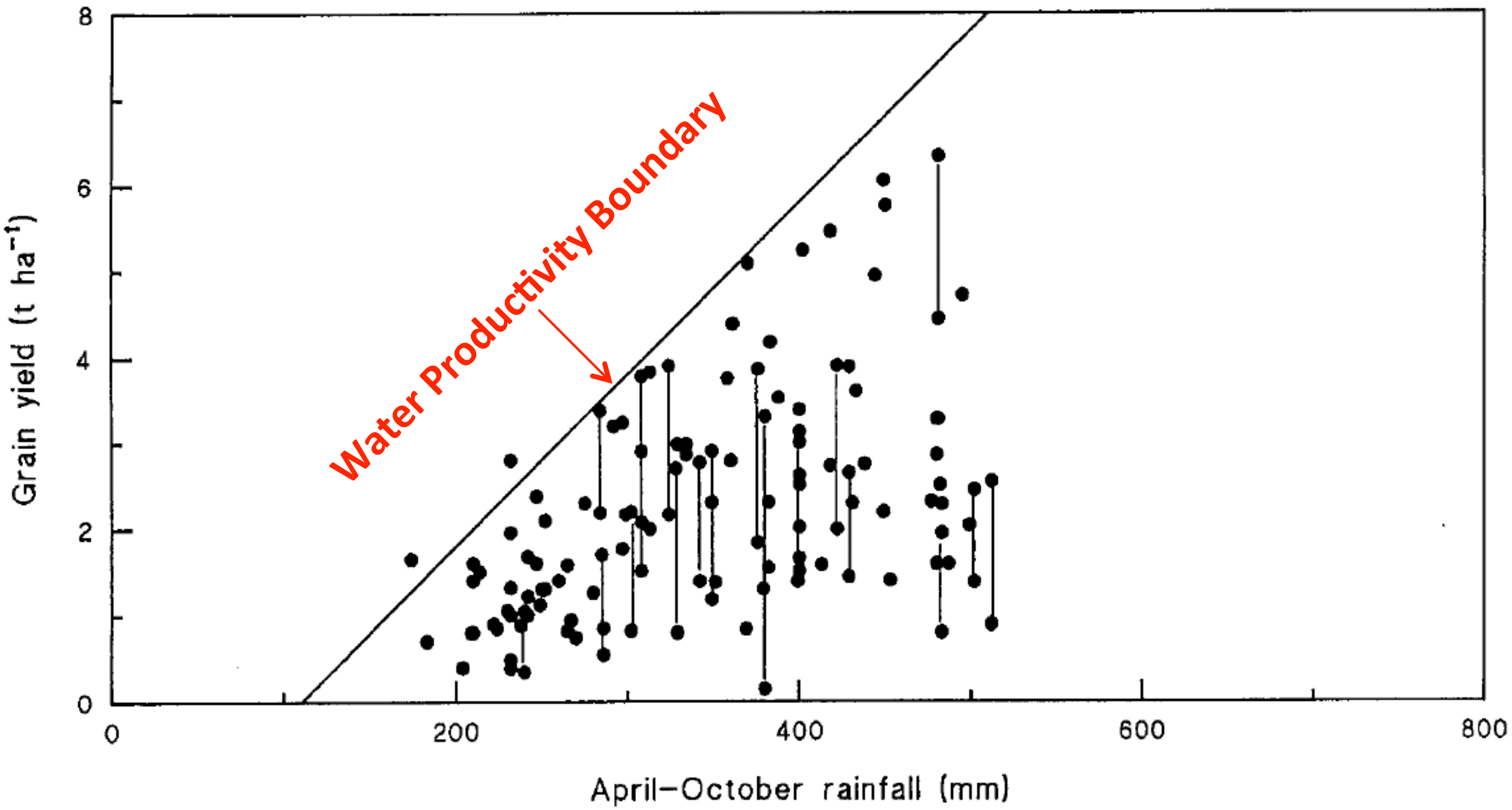


Fig. 1. Relationship between wheat yield and water use from experiments conducted by French and Schultz (1984). The points represent yields measured in experiments conducted over many seasons and locations. The line represents the highest transpiration efficiency (TE) observed, and the intercept on the abscissa represents soil evaporation (E_s). The vertical lines join data points representing different crop management treatments at a single experiment.

Source: Angus, JF and AF van Herwaarden. 2001. Increasing water use and water use efficiency in dryland wheat. Agron. J. 93:290-298.

Sadras, VO and JF Angus. 2006. Benchmarking water-use efficiency of rainfed wheat in dry environments. Aust. J. Agr. Res. 57:847-856

Water Productivity Limit:
- It likely will be difficult to move data points beyond this boundary without extraordinary physiological alteration of the crop to improve its CO2 to H2O exchange ratio (i.e., yield-to-water response limit).

V. O. Sadras and J. F. Angus

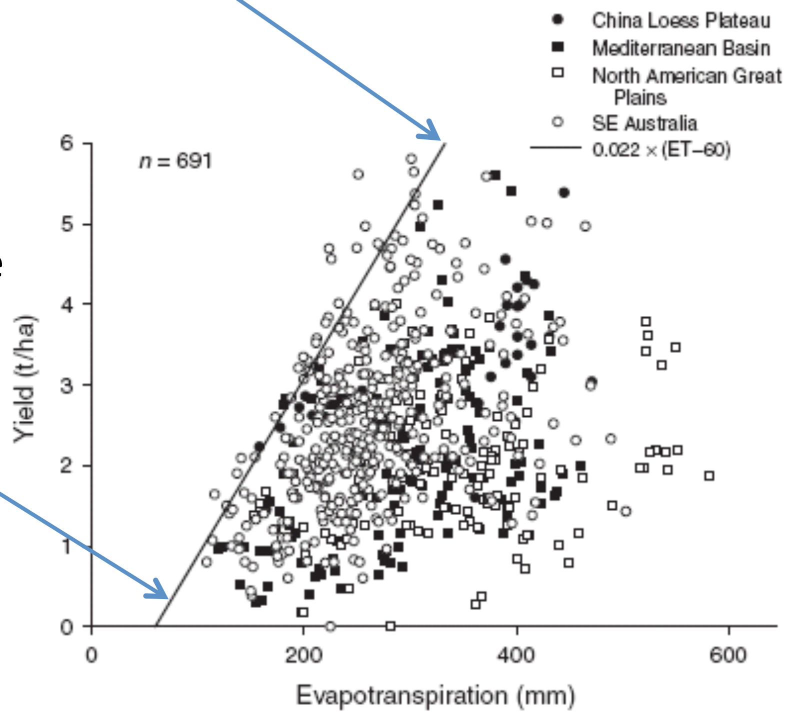


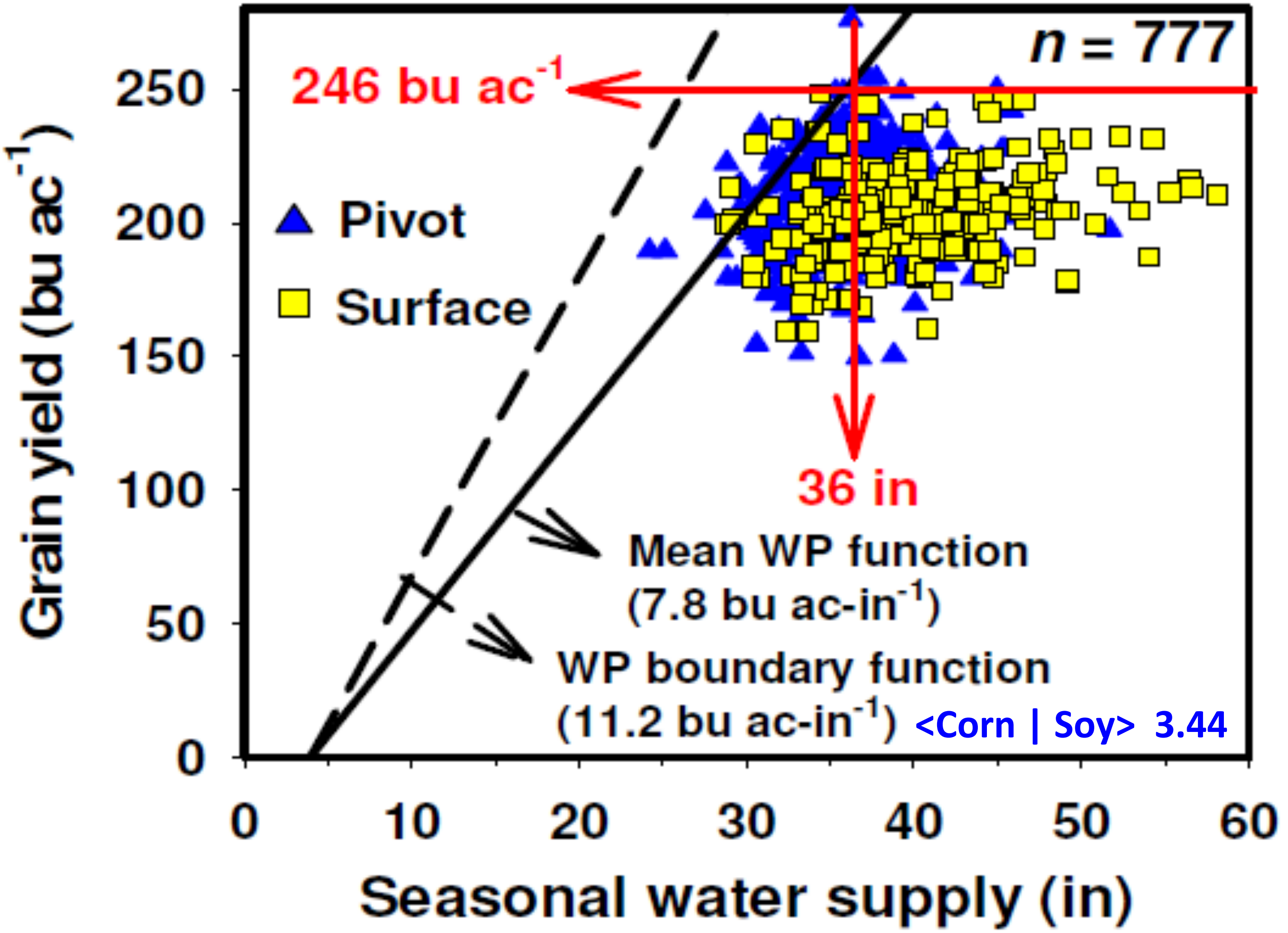
Fig. 5. Scatter plot of grain yield and seasonal evapotranspiration in 4 mega-environments. The line uses French and Schultz (1984*a*) frontier concept, with *x*-intercept = 60 mm (Sadras and Roget 2004) and slope = 22 kg grain/ha.mm (Angus and van Herwaarden 2001).

Water Productivity Limits?

Corn: 11.0 bu ac^{-1} ac-in^{-1}

Soy: 3.39 bu ac^{-1} ac-in^{-1}

W = k (ET – Es)/(e* - e), where W = grain yield (kg/ha), ET = evapo-transpiration (mm), Es = soil evaporation (mm), e* and e = saturated and actual vapor pressure (kPa), and k = a crop specific constant (kPa/mm). ET axis values reflect the difference between the soil water content in the crop root zone at emergence and at physiological maturity, plus the sum of all rainfall during this period.



Soy> 76

Figure 4. Farmer's yields as a function of seasonal water supply. Dashed and solid lines are the WP benchmarks.

Source: Patricio Grassini et al.

Benchmarking yield and efficiency of corn & soybean cropping systems in Nebraska

Patricio Grassini, Jessica A. Torrion, Kenneth G. Cassman, James E. Specht

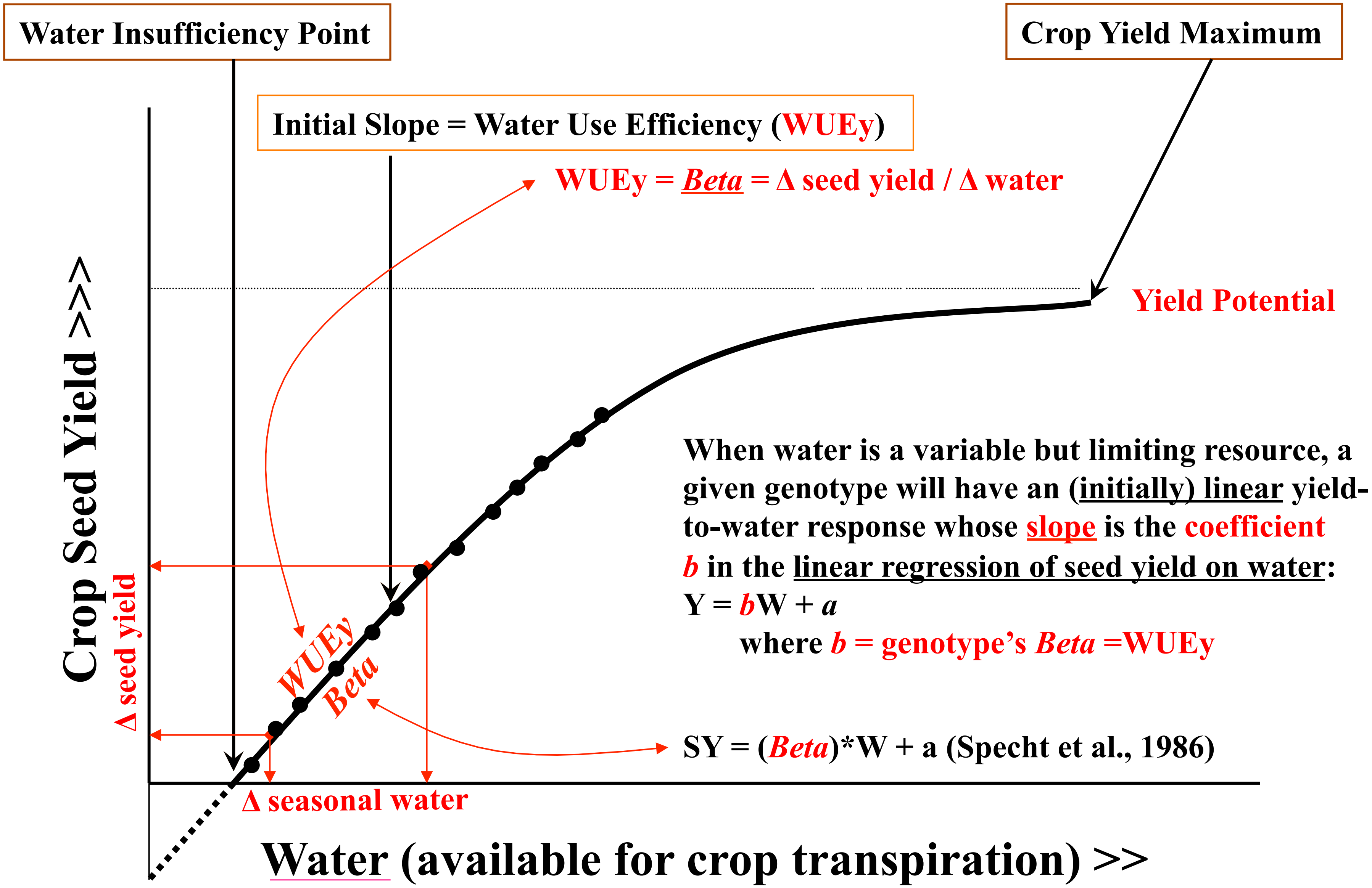
Department of Agronomy and Horticulture
University of Nebraska-Lincoln

University of Nebraska Lincoln

Soybeans
Nebraska Soybean Board

Nebraska's NRDs
Helping You Conserve Natural Resources for 35 Years
1972-2007

SY = (WUEb x HI) x T (Passioura, 1977) [let WUEy = WUEb x HI]



Water Insufficiency Point

Crop Yield Maximum

Initial Slope = Water Use Efficiency (WUEy)

WUEy = *Beta* = Δ seed yield / Δ water

Yield Potential

Crop Seed Yield >>>

Δ seed yield

WUEy

Beta

Δ seasonal water

Water (available for crop transpiration) >>

When water is a variable but limiting resource, a given genotype will have an (initially) linear yield-to-water response whose slope is the coefficient *b* in the linear regression of seed yield on water:

$Y = bW + a$

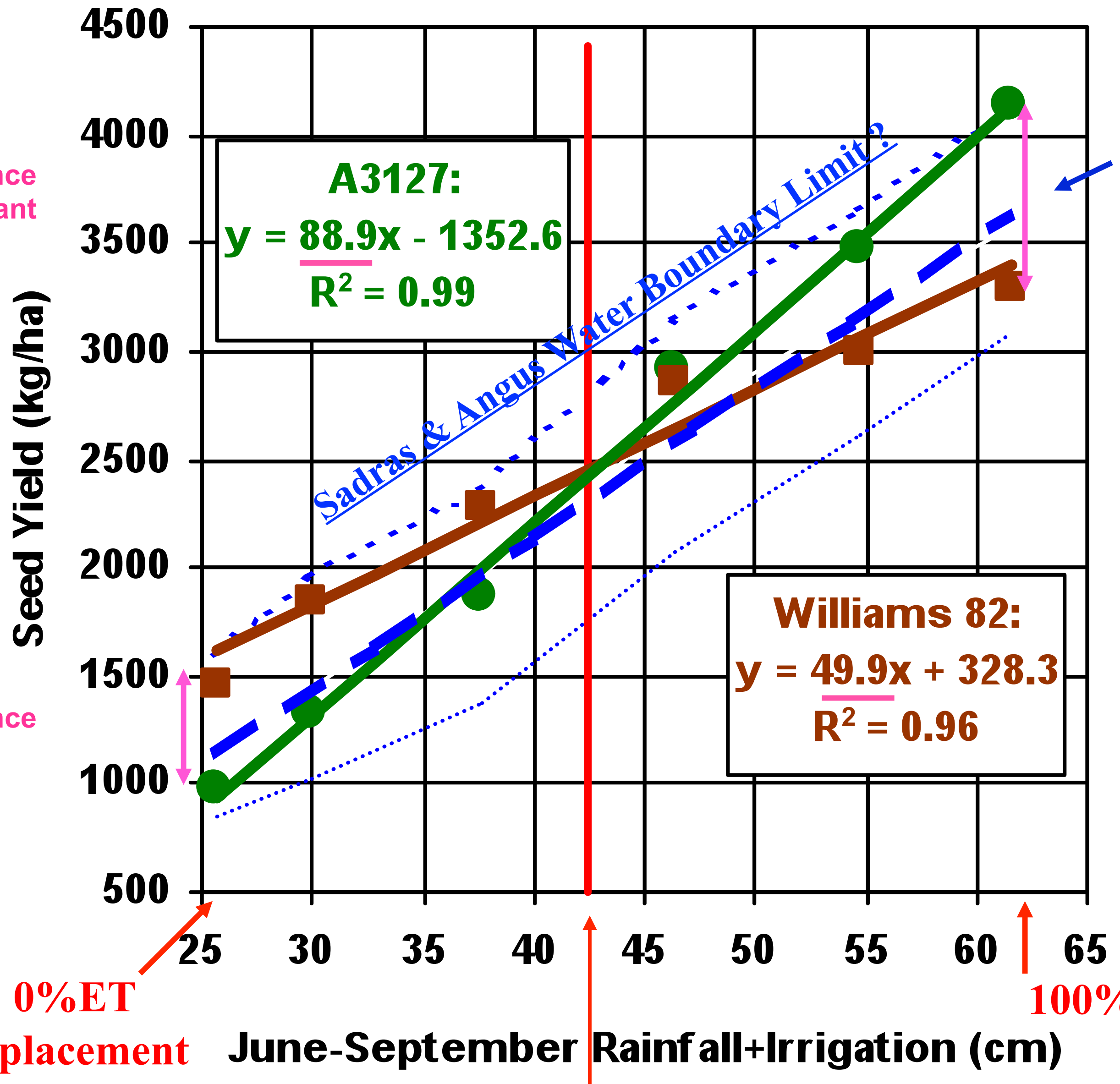
where *b* = genotype's *Beta* =WUEy

SY = (*Beta*)*W + a (Specht et al., 1986)

Keep in mind that this *yield-to-water response curve* is specific for the above (reference) genotype; its WUE will initially be constant, but will eventually decline on approach its yield maximum (plateau).

Seed Yield Phenotype (P) = Genotype (G) + Water Environment (W) + Interaction (G x W).

Useable G x W arises when genotypes have consistent differing yield response-to-water slopes (see below).



A3127:
y = 88.9x - 1352.6
R^2 = 0.99

Williams 82:
y = 49.9x + 328.3
R^2 = 0.96

Cultivar yield difference when water is abundant

Cultivar yield difference when water is scarce

Dashed blue line = Mean Yield **Beta** for all 16 Cultivars.

Blue boundary lines = observed response limits!

88.9kg/ha per cm =
3.36 bu/ac per in

49.9kg/ha per cm =
1.88bu/ac per in

0%ET replacement

100%ET replacement

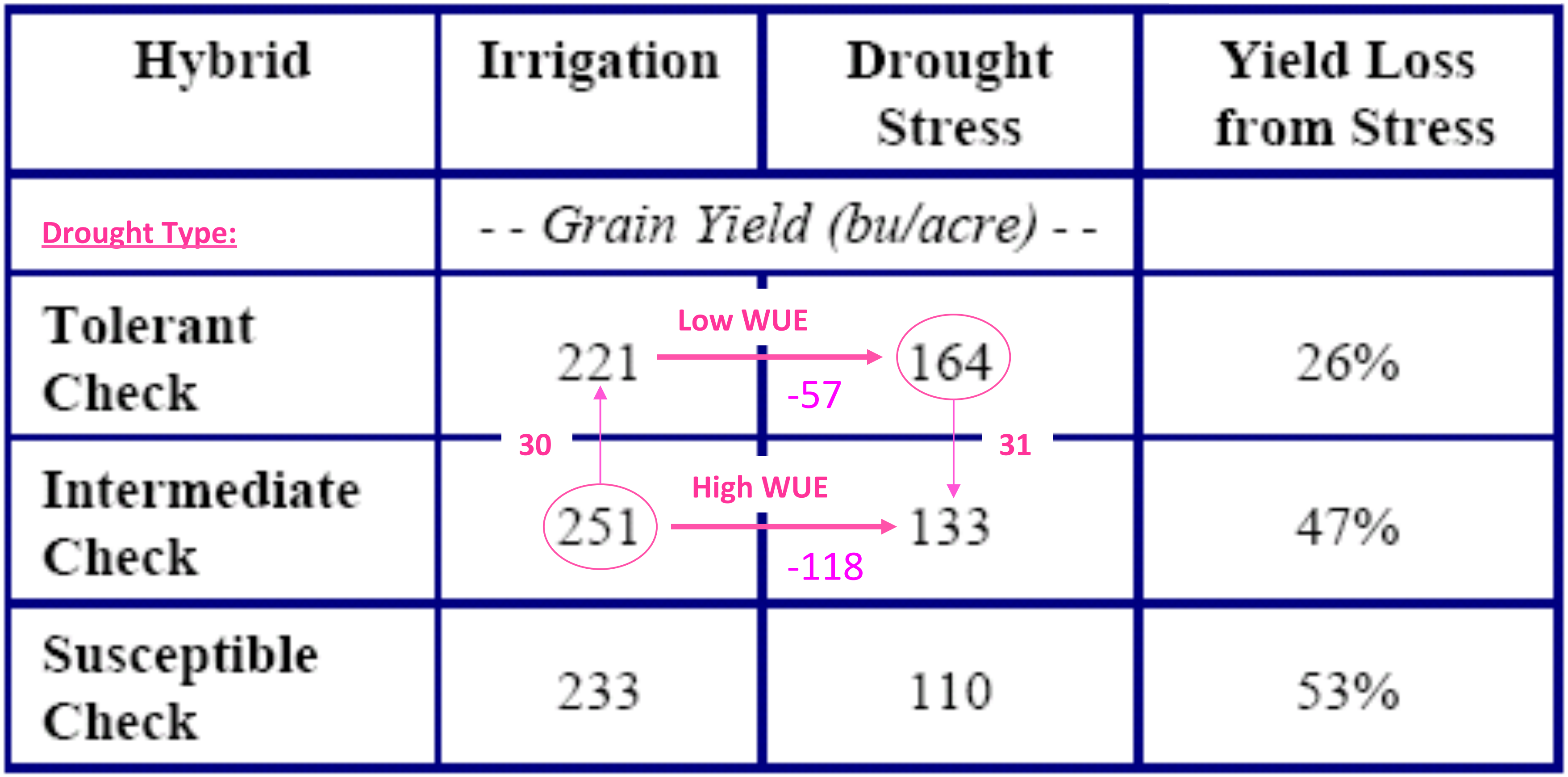
Historical “Normal” Rainfall Amount

The Case in Soybean

Specht et al. (1986)

Table 1. Variation in hybrids for drought tolerance.

The Usual Viewpoint



Hybrid	Irrigation	Drought Stress	Yield Loss from Stress
Drought Type:	*- - Grain Yield (bu/acre) - -*		
Tolerant Check	221	164	26%
Intermediate Check	251	133	47%
Susceptible Check	233	110	53%

Low WUE

-57

30

31

High WUE

-118

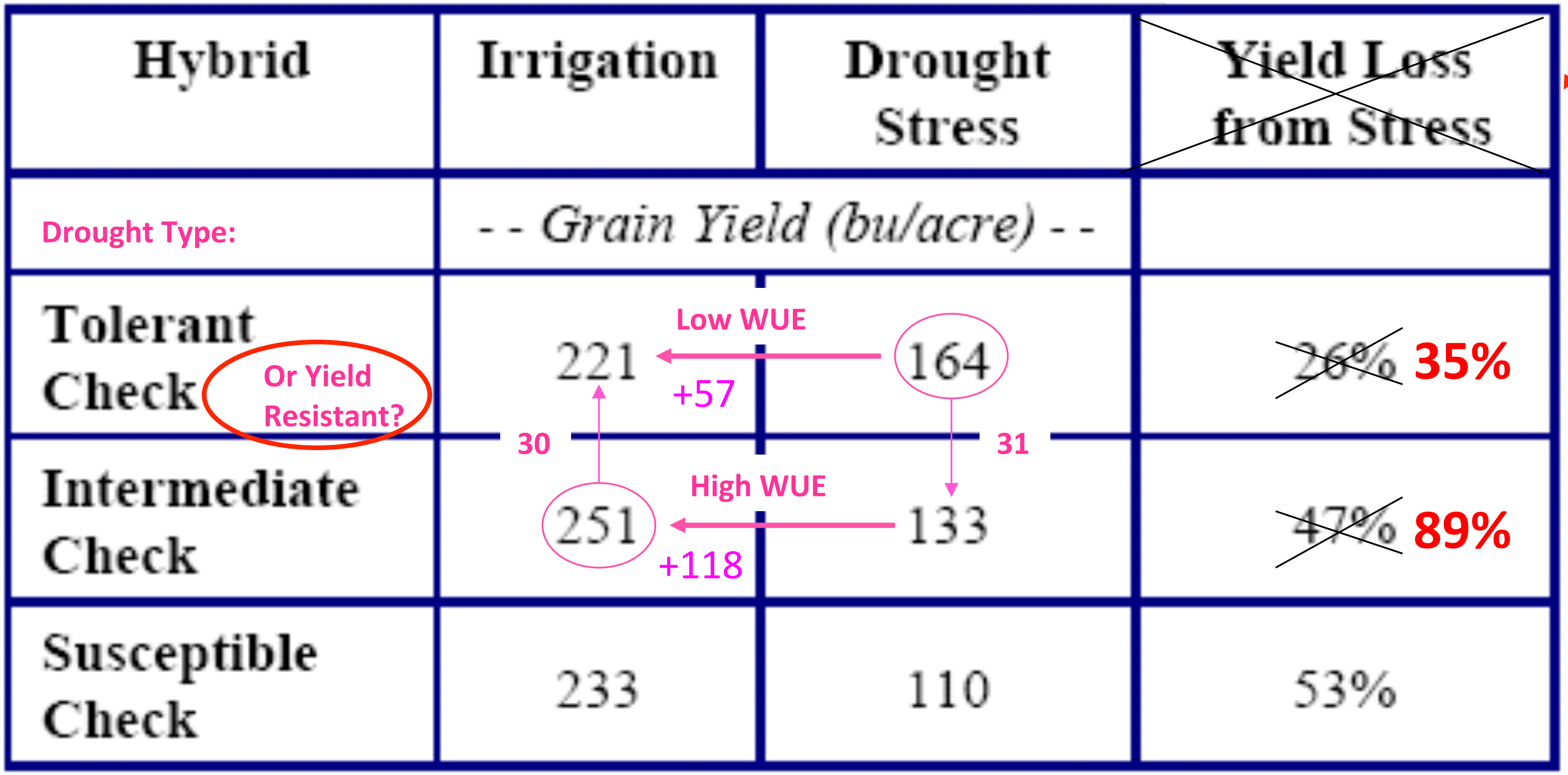
The Case in Corn

Pioneer – Crop Insights 16:1-5 (2006)

Yield Gain with Rain

Table 1. Variation in hybrids for drought tolerance.

<u>**Producer's Viewpoint**</u>



Hybrid	Irrigation	Drought Stress	~~Yield Loss from Stress~~
Drought Type:	*- - Grain Yield (bu/acre) - -*		
Tolerant Check Or Yield Resistant?	221	164	~~26%~~ **35%**
Intermediate Check	251	133	~~47%~~ **89%**
Susceptible Check	233	110	53%

The Case in Corn

Pioneer – Crop Insights 16:1-5 (2006)

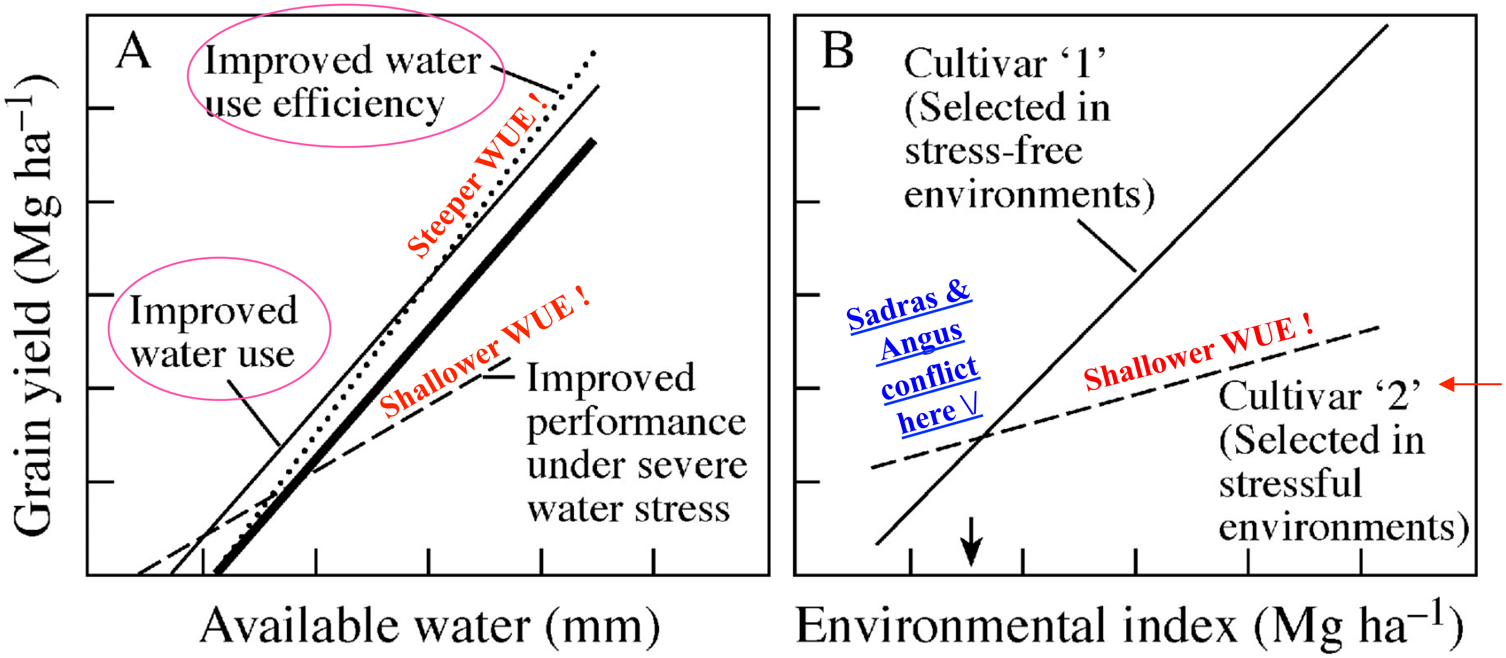
Quantitative genetic theory provides an explanation for the **positive correlations often reported between (stability) regression coefficient value and mean productivity**; a line with high tolerance to stress would normally have a **low regression coefficient stability.**

Selection for mean productivity will generally <u>increase</u> mean yields in <u>both</u> <u>stress</u> (Ys) and <u>non-stress</u> (Y) environments.

<u>Selection for tolerance to stress</u> (minimize Y – Ys) will generally result in a <u>reduced</u> mean yield in non-stress (Y) environments and (thuse coincidently) <u>decreased</u> mean productivity.

Stress tolerance (i.e., less difference: Y – Ys) and mean productivity [(Yns + Y) / 2] show <u>negative genetic correlations</u>, when the <u>genetic variance</u> in the stress (Ys) environments is <u>less</u> than the genetic variance in the non-stress (Y) environments.

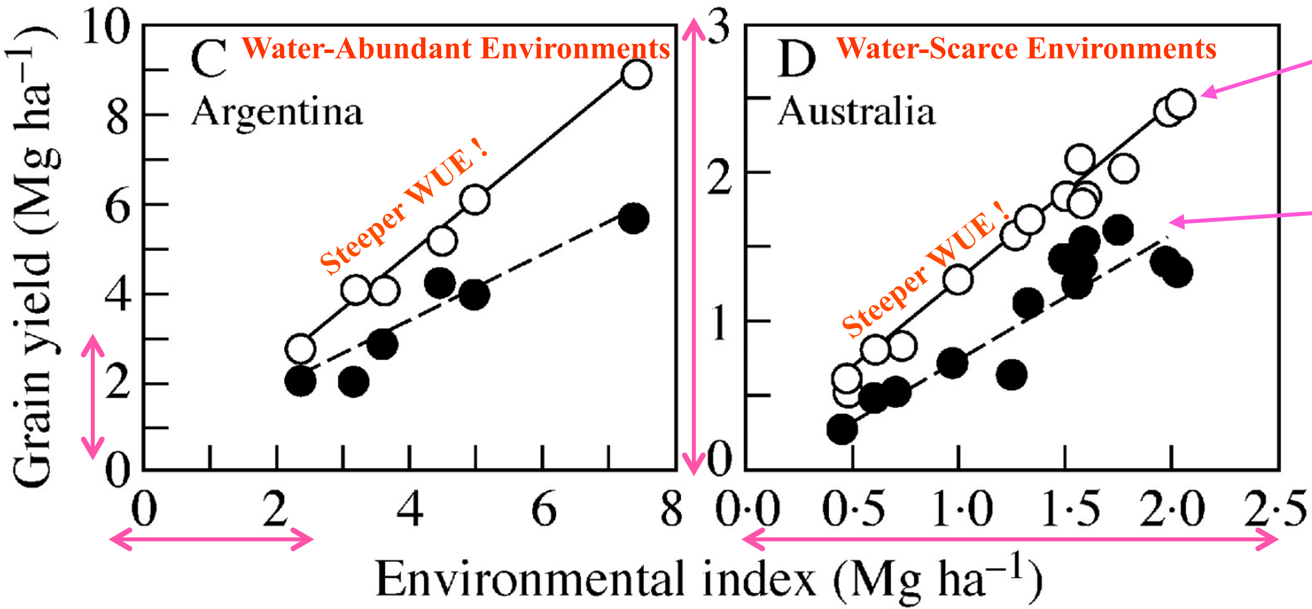
Rosielle and Hamblin (1980)



Drought Tolerant or Yield Resistant?

Open Circles = mean yields of a set of "New" Wheat Cultivars

Solid Circles = mean yield of A set of "Old" Wheat Cultivars



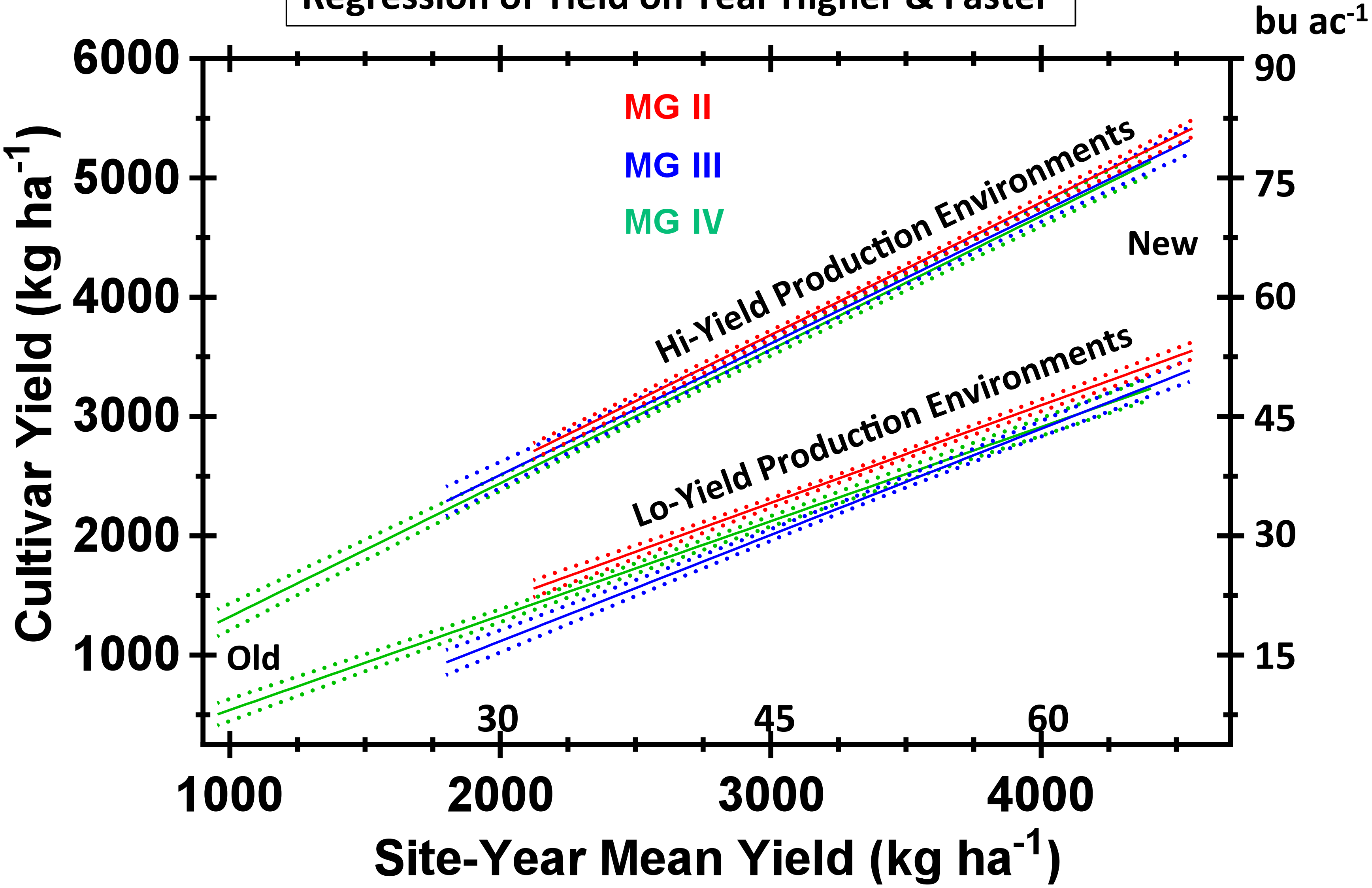
"New" cultivars perform better than "Old" cultivars at all yield levels associated with a given production environment !

The Case in Wheat

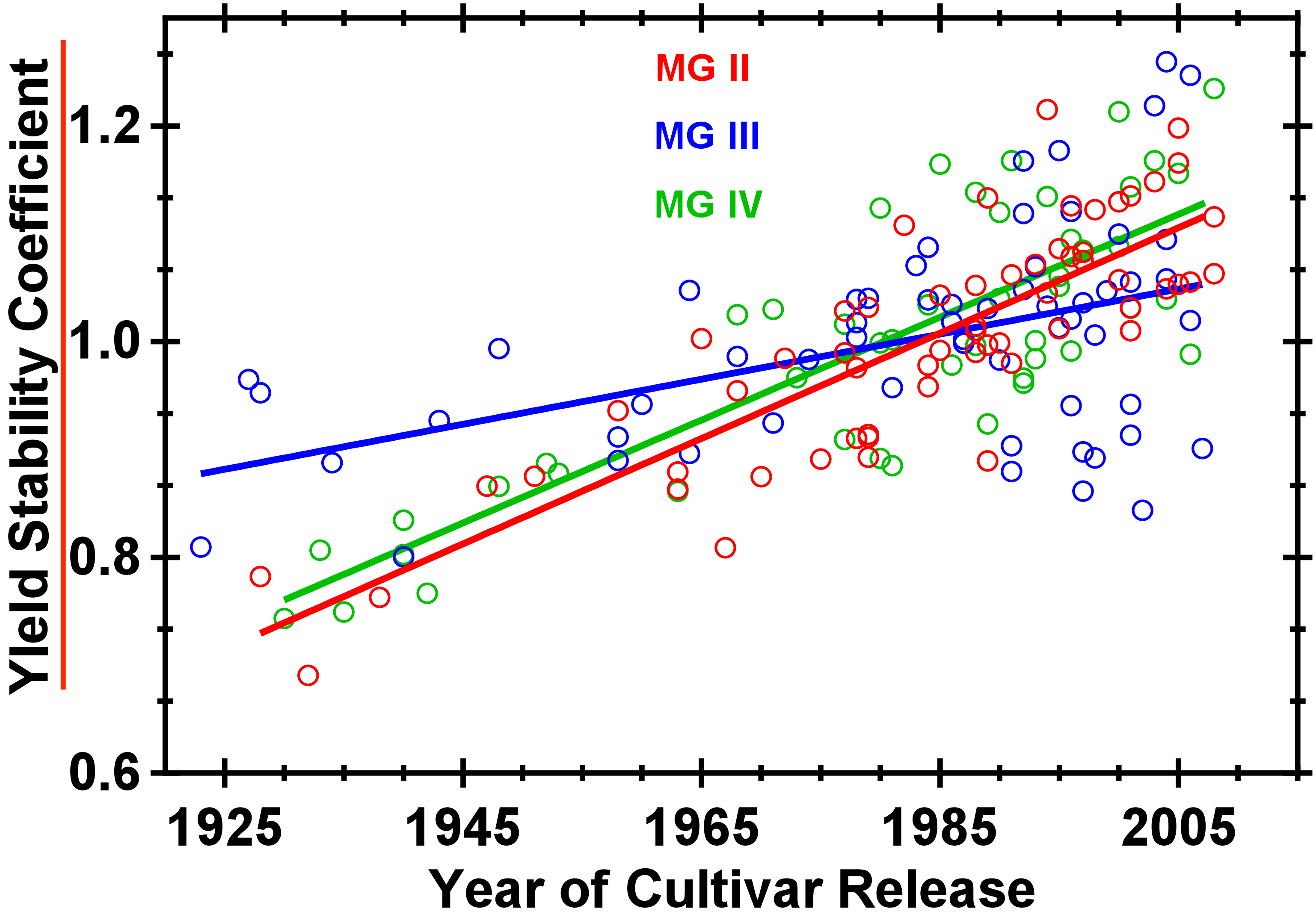
Araus, JL et al. 2002. Plant breeding and drought in C3 cereals: What should we breed for? Ann. Bot. 89:925-940

U.S. MG Genetic Improvement Over Time

Regression of Yield on Year Higher & Faster

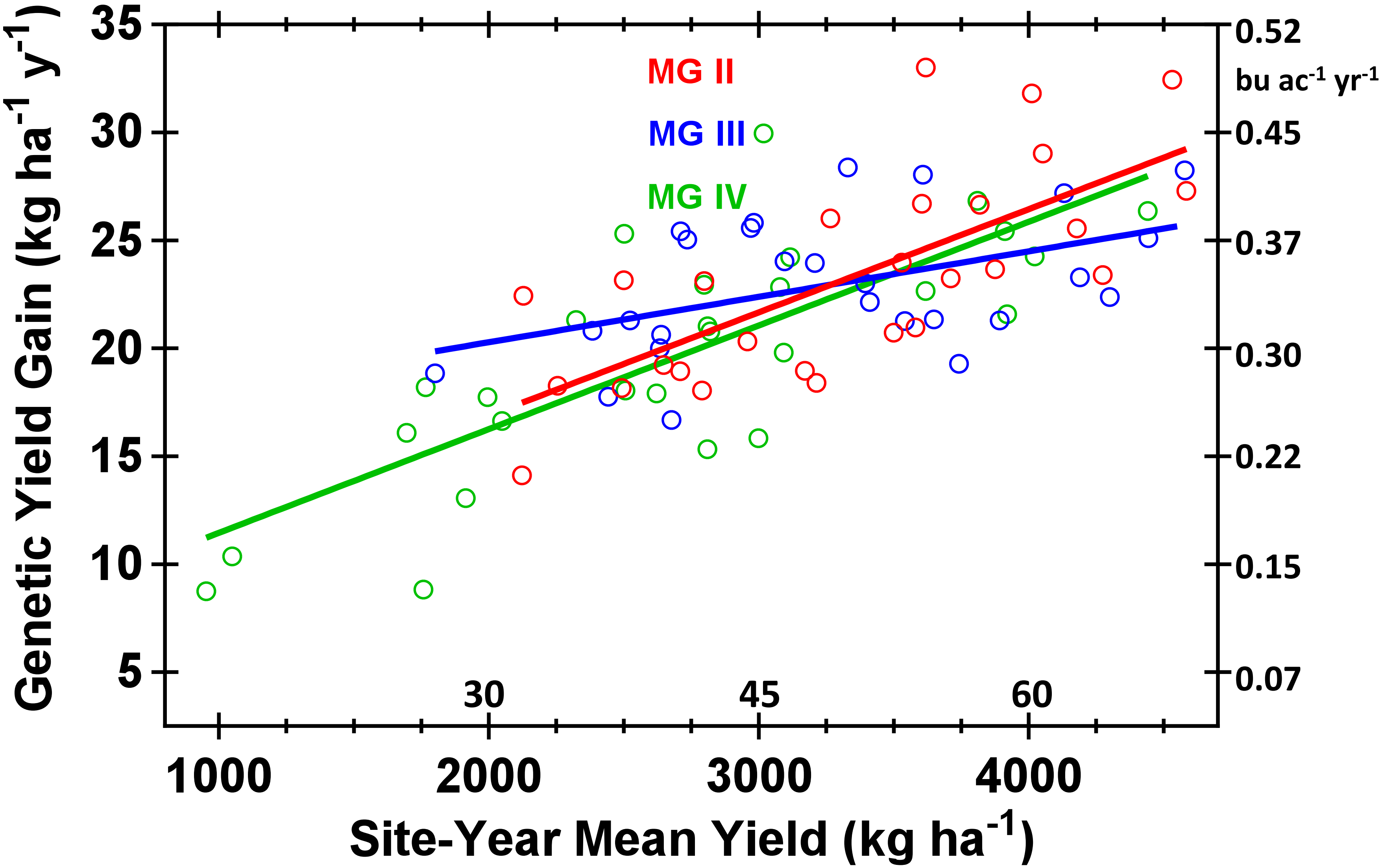


Stability Analysis



U.S. MG Genetic Improvement Over Time

Genetic Yield Gain Rates Measurably Greater in Higher Yield Fields



The Final Frontier?

- **Plants must exchange water for carbon**. The parameter **WUE** is, in fact, the ***exchange coefficient***. The relationship between crop biomass (BM) accumulation or seed yield (SY) and cumulative crop transpiration (T) is defined by the well-known linear conceptual equation of Passioura (1977): $\mathbf{SY = WUE_b \times T \times HI}$ or that of Specht (1986, 2001): $\mathbf{SY = WUE_y \times T}$

- **A greater WUE ensures more carbon gain per unit of water transpired** (i.e., "***more crop per drop***"), but the **above equations also shows that more (not less) seasonal T is also required to more produce food, fibre, and biofuel** (Sinclair et al. 1984)

- Breeders selecting for greater **SY** have certainly improved **HI** and have also steepened yield *beta* ($\mathbf{WUE_y}$). Any further substantive future improvement in **Soybean WUE** would require a biotechnological conversion of the soybean from a **C3** to a **C4** form of photosynthesis!

- Genetic improvement in soybean **SY** could possibly be achieved by genetic modification of the root system to enable the plant to gather plant available soil water that is not used each season (i.e., **increase seasonal T in above equation**).

  Sustainable improvement in crop yield, by definition, should result in the crop transpiring, during each growing season, ALL of the annually rechargeable, available soil water by season end.

The Final Frontier?

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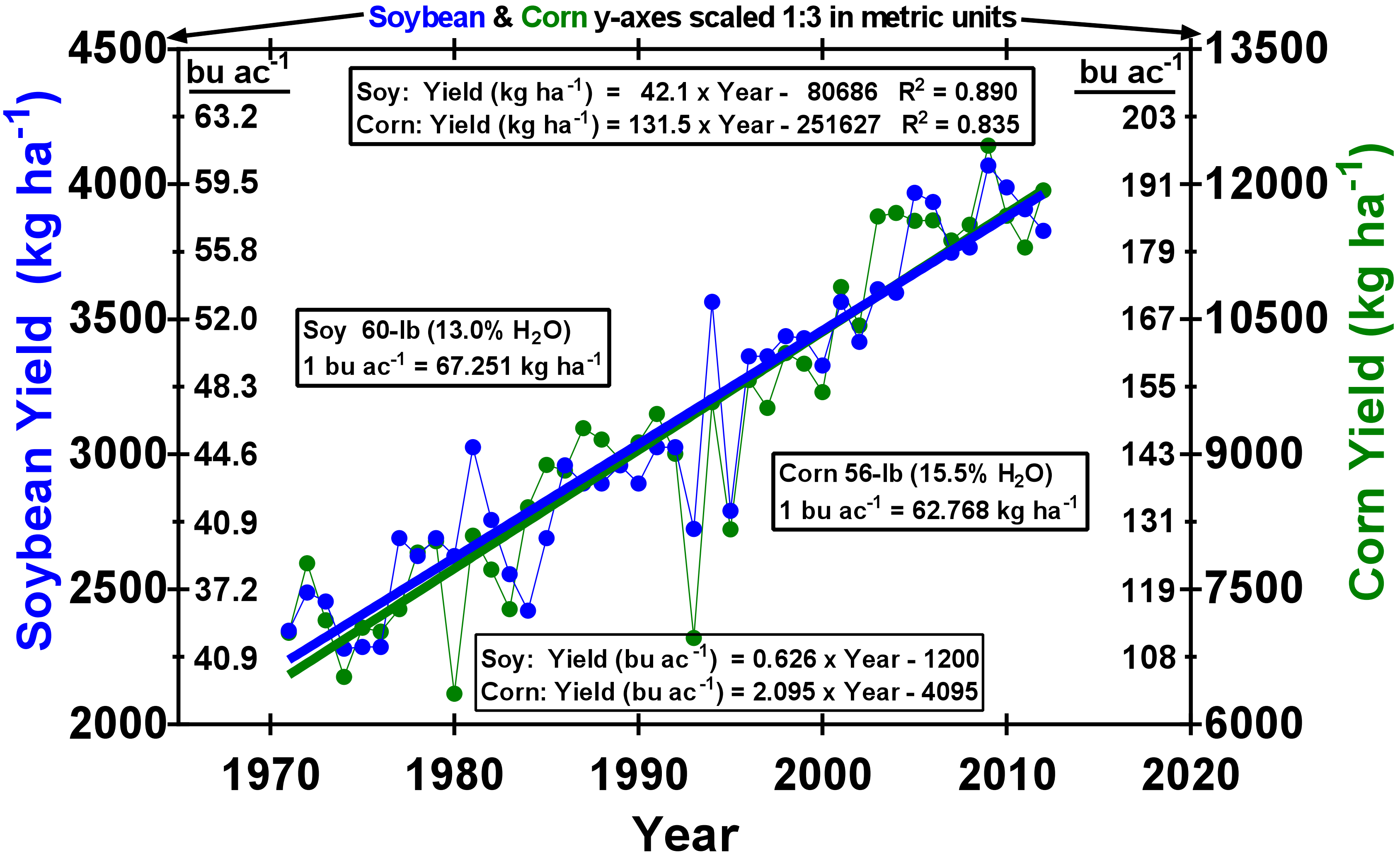

Source: http://www.nass.usda.gov/Statistics_by_State/Nebraska/index.asp

Thanks for Your Attention!
Any Questions?

Some Notable Quotes from Yogi Berra:

The future *just ain't what it used to be*.

I never predict the future and *I predict I never will*.

We're lost, *but we're making good time*.

In theory, there is no difference between theory and practice,
***but in practice, there is*.**