Environmental Factors
Rainfall and Irrigation

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Environmental and Cultural Factors Limiting Potential Yields

- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature (Extremes)
- Water, rainfall and irrigation
- Wind
- Nutrients (N and K)
- Others, ozone etc.,
- Growth Regulators (PIX)

Water Security?

Water Security?

http://www.bbc.com/news/av/world-africa-42866178/why-cape-town-is-shutting-off-its-water-supply

Water Security?

"Any one who can solve the problem of water will be worthy of two Nobel prizes – one for Peace and one for Science" - John F. Kennedy in 1968

Water and Irrigation - Objectives

The objectives of this lecture are to:

- Learn about the importance of water for ecosystem services, and to learn about the availability of fresh water for industrial, human, and irrigation purposes.
- Learn about irrigation trends across major regions.
- Learn about the influence of water on plants and ecosystems in general.
- Learn about water content of various plant parts.
- Learn about the interrelationships among soil, root, and leaf water potential and transpiration relationships under water deficit conditions.

Water

Water plays essential roles in plants as a:

- ✓ Constituent
- ✓ Solvent
- ✓ Reactant in various chemical processes
- ✓ Maintenance of turgidity

Therefore, everyone who grows plants, whether a single plant in pot or hundreds of acres of corn or cotton, is aware of the importance of water for successful growth, and finally economic product or yield.

Water

- Water on a global scale is plentiful. However,
  - ✓ 97% of it is saline.
  - ✓ 2.25% is trapped in the glaciers and ice.
  - ✓ the rest, 0.75% is available in fresh water aquifers, rivers, and lakes.
- About 70% of the available fresh water is used for agricultural production, 22% for industrial purposes, and 8% for domestic purposes.
- Increasing competition for domestic and industrial purposes is likely reduce the water available for agriculture in the future.

World's fresh water ecosystems and goods and services

- Fresh water ecosystems occupy less than 1% of Earth's surface but deliver goods and services of enormous global value.
  - ✓ Inland fisheries capture accounts 12% of all fish consumed by humans.
  - ✓ Irrigated agriculture supplies amounts about 40% of the world's food crops.
  - ✓ Hydropower provides about 20% of world's electricity production.
  - ✓ About 12% of all animal species live in fresh water, and most other species depend in some way on fresh water ecosystems for their survival.

Water and Plants

- Plants use large amounts of water in the growth process, with important consequences for agriculture and the distribution of plant communities.
- The distribution of plants over the earth's surface is controlled by the availability of the water (amount and seasonal distribution of precipitation) where ever temperature permits growth.
- Water is involved in nearly every aspect of plant activity, ranging from the transport of mineral nutrients and metabolites to growth, metabolism, and gene action.

Irrigated Cropland – World Statistics

Global Distribution - Rain-fed and Irrigated Areas

Rain-fed Areas

Irrigated Areas

Source: International Water Management Institute

Total cropland area = Total area available for irrigation (TAAI) + Rainfed area

	Area, millions ha			
Continents	TAAI	Irrigated	Rainfed	Total cropland
Africa	8.7	10.3	189.0	197.7
Asia	290.6	369.6	327.4	617.9
Australia	11.9	5.4	36.8	48.6
Europe	33.9	32.4	227.9	261.8
North America	35.4	31.8	190.7	226.1
Oceania	0.12	0.14	1.5	1.58
South America	17.8	17.0	158.4	176.3
Total	**390.5**	**466.8**	**1131.5**	**1530.1**

Worldwide Distribution of Irrigated Areas - 1984

(Adapted from Hoffman et al., 1990)

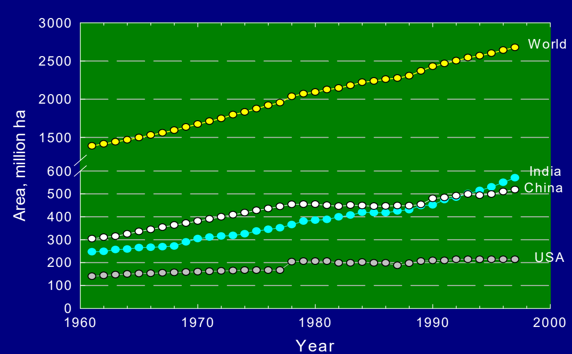
Country	Irrigated area million ha	Percent of world total	Percent of cultivated area
Asia	137	62	30
North America	25	9	8
Russia	21	9	8
Europe	16	7	11
Africa	10	5	6
South America	8	4	6
Central America	7	3	18
Australia and Oceania	2	1	4
Developing countries	160	71	20
Industrialized countries	66	29	9
World	226	100	15

Countries with major irrigated areas, 1996

(Adapted from Hoffman et al., 1990)

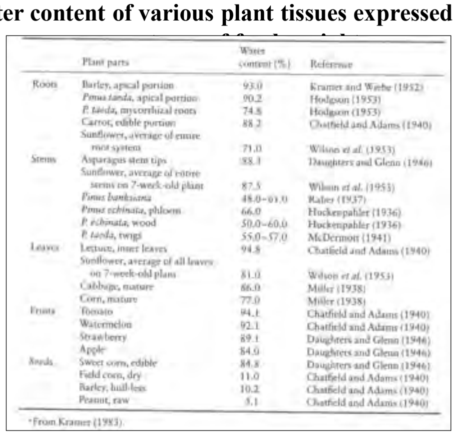
Country	Irrigated area million ha	% of country's cultivated land irrigated
India	55	33
China	47	48
Russia	21	9
United States	19	10
Pakistan	16	77
Indonesia	7.3	34
Iran	5.8	39
Mexico	5.3	21
Spain	3.3	16
Turkey	3.3	12
Thailand	3.2	16
Egypt	3.2	100
Japan	3.0	63
Italy	3.0	25
Romania	3.0	28

Temporal Trends in Irrigated Area World, India, China and USA



Water Status and Plant Growth

Water content of various plant tissues expressed as



	Plant parts	Water content (%)	Reference
Roots	Barley, apical portion	93.0	Kramer and Wiebe (1952)
	Pinus taeda, apical portion	90.2	Hodgson (1953)
	P. taeda, mycorrhizal roots	74.8	Hodgson (1953)
	Carrot, edible portion	88.2	Chatfield and Adams (1940)
	Sunflower, average of entire root system	71.0	Wilson *et al.* (1953)
Stems	Asparagus stem tips	88.1	Daughters and Glenn (1946)
	Sunflower, average of entire stems on 7-week-old plant	87.5	Wilson *et al.* (1953)
	Pinus banksiana	48.0–61.0	Raber (1937)
	Pinus echinata, phloem	66.0	Huckenpahler (1936)
	P. echinata, wood	50.0–60.0	Huckenpahler (1936)
	P. taeda, twigs	55.0–57.0	McDermott (1941)
Leaves	Lettuce, inner leaves	94.8	Chatfield and Adams (1940)
	Sunflower, average of all leaves on 7-week-old plant	81.0	Wilson *et al.* (1953)
	Cabbage, mature	86.0	Miller (1938)
	Corn, mature	77.0	Miller (1938)
Fruits	Tomato	94.1	Chatfield and Adams (1940)
	Watermelon	92.1	Chatfield and Adams (1940)
	Strawberry	89.1	Daughters and Glenn (1946)
	Apple	84.0	Daughters and Glenn (1946)
Seeds	Sweet corn, edible	84.8	Daughters and Glenn (1946)
	Field corn, dry	11.0	Chatfield and Adams (1940)
	Barley, hull-less	10.2	Chatfield and Adams (1940)
	Peanut, raw	5.1	Chatfield and Adams (1940)

[a] From Kramer (1983).

Area of Total World Land Surface Subject to Environmental Limitations of Various Types

Limitation	Area of world soil subject to limitation (%)
Drought	27.9
Shallow soil	24.2
Mineral excess or deficiency	22.5
Flooding	12.2
Miscellaneous	3.1
None	10.1
Total	100
Temperature	14.8 (over laps with other stresses)

Water

Table 12.1 Record Yields, Average Yields, and Yield Losses Due to Diseases, Insects, Weeds, and Unfavorable Physicochemical Environments for Majoe U.S. Crops[a]

Crop	Record[b] yield	Average[c] yield	Average losses[c]: Diseases	Insects	Weeds	Physicochemical[d]	%
Maize	19,300	4,600	836	836	697	12,300	64
Wheat	14,500	1,880	387	166	332	11,700	81
Soybean	7,390	1,610	342	73	415	4,950	67
Sorghum	20,100	2,830	369	369	333	16,000	80
Oat	10,600	1,720	623	119	504	7,630	72
Barley	11,400	2,030	416	149	356	8,430	74
Potato	94,100	28,200	8,370	6,170	1,322	50,000	53
Sugar beet	121,000	42,600	10,650	7,990	3,330	54,400	45
Mean percentage of record yield	100	21.5	5.1	3.0	3.5	66.9	67

Note: Values are kilograms per hectare. Record and average yields are as of 1975.
[a] In the original work (Boyer, 1982), weed losses were considered to be physicochemical because the losses were attributable to competition for light, nutrients, and so on. On the other hand, weeds are of biological origin and it may be argued that the losses should be included with insects and diseases. For simplicity, the latter approach is taken here, which slightly alters the values calculated for each loss in comparison with Boyer (1982).
[b] From Wittwer (1975).
[c] Calculated according to U.S. Department of Agriculture (1965).
[d] Physicochemical losses calculated as record yield—(average yield + disease loss + insect loss + weed loss).

Distribution of Insurance Indemnities and Crop Losses in the US – 1939 to 1978

Table 12.3 Distribution of Insurance Indemnities for Crop Losses in the United States from 1939 to 1978[a]

Cause of crop loss	Proportion of payments (%)
Drought	40.8
Excess water	16.4
Cold	13.8
Hail	11.3
Wind	7.0
Insect	4.5
Disease	2.7
Flood	2.1
Other	1.5

[a] From U.S. Department of Agriculture (1979).

The Cost of Drought and High Temperature?

- According to the Agriculture Department's Risk Management Agency (RMA), nearly *$12.3 billion* were paid to U.S. producers for losses incurred in 2013 year due to *drought, high temperatures and failed irrigation, combined.*
- Apart from *these extreme events*, environmental stresses are robbing the potential yield that we could achieve.
- Developing tools to mange crops for stressful environments are key for successful harvest.

Range of Soils and Available and Non-available Water

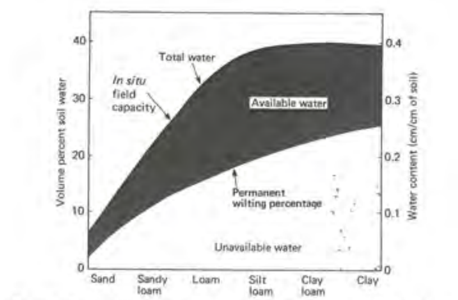


Figure 4.1 Diagram showing the relative amounts of available and unavailable water in soils ranging in texture from sands to clay. Amounts are expressed as percentages of soil volume and centimeters of water per centimeter of soil. After Cassel (1983), from Kramer (1983).

Net Primary Production and Precipitation

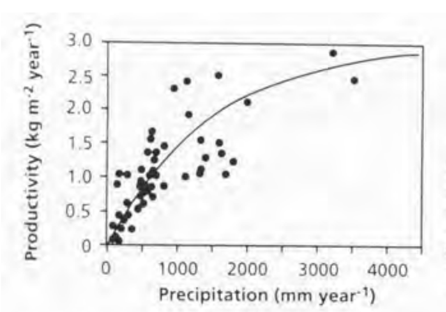
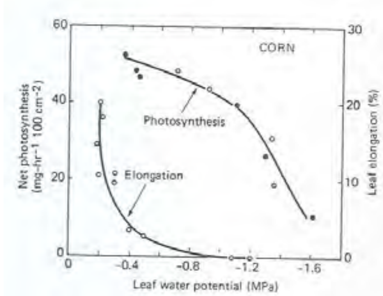
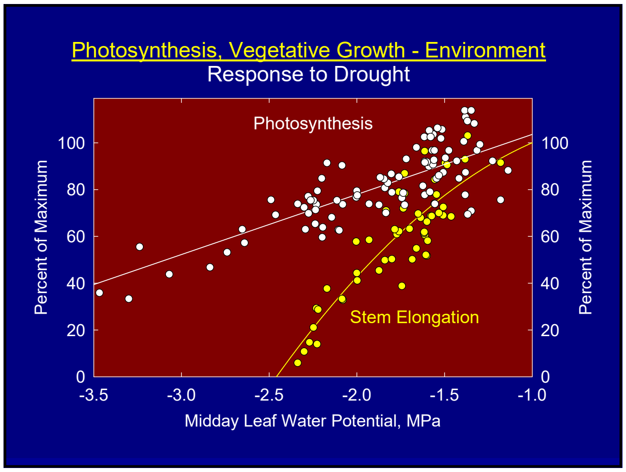


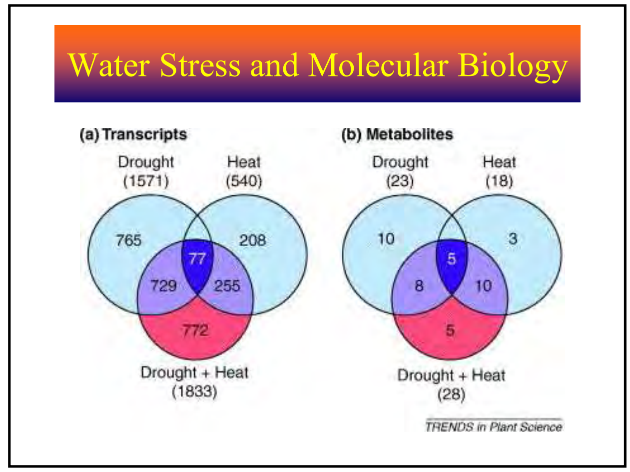
FIGURE 1. Correlation between net primary production and precipitation for the major world ecosystems (Lieth 1975).

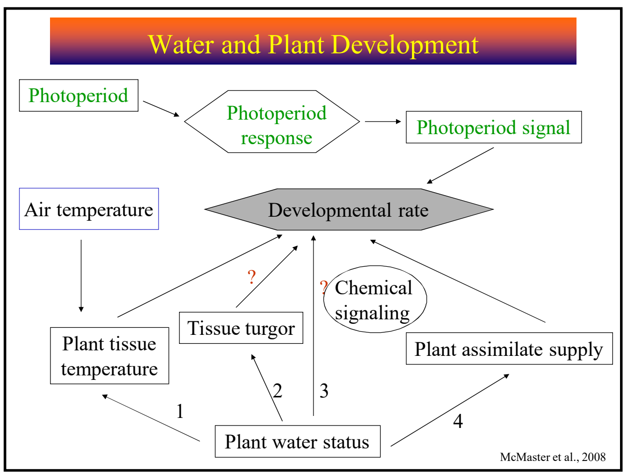
Relationship among Leaf Water Potential, Leaf Elongation, and Photosynthesis of Corn.

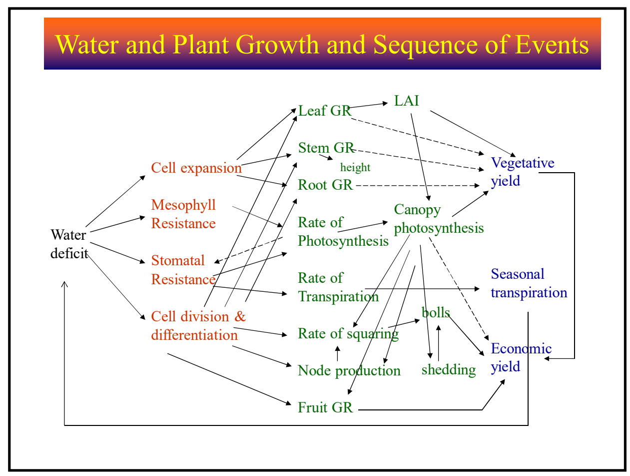


Note that leaf elongation almost ceases before there is much significant reduction in photosynthesis (Kramer, P.J, and JS. Boyer. 1995, page 19)

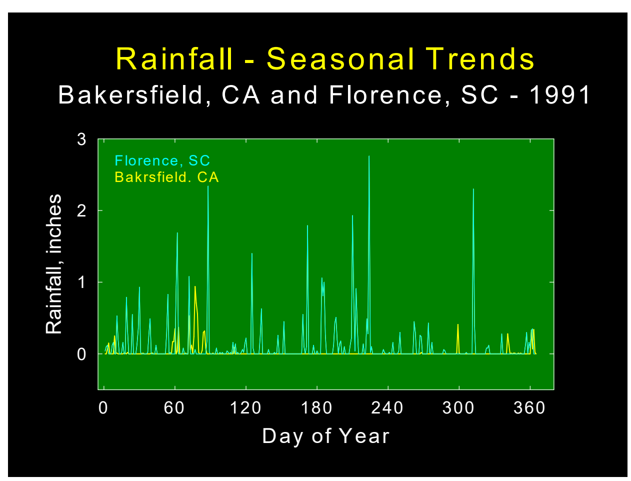

Photosynthesis, Vegetative Growth - Environment
Response to Drought
Photosynthesis
Stem Elongation
Percent of Maximum
Midday Leaf Water Potential, MPa
0
20
40
60
80
100
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0


Water Stress and Molecular Biology
(a) Transcripts
Drought (1571)
Heat (540)
765
208
77
729
255
772
Drought + Heat (1833)
(b) Metabolites
Drought (23)
Heat (18)
10
3
5
8
10
5
Drought + Heat (28)
TRENDS in Plant Science

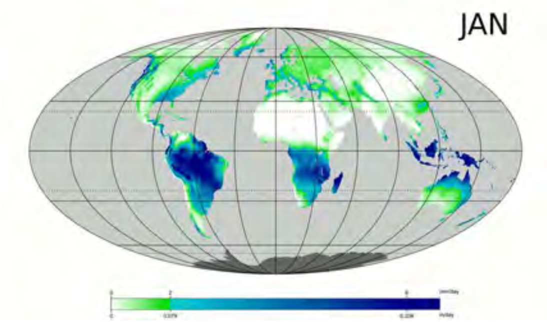

Water and Plant Development
Photoperiod
Photoperiod response
Photoperiod signal
Air temperature
Developmental rate
?
?
Chemical signaling
Tissue turgor
Plant tissue temperature
Plant assimilate supply
1
2
3
4
Plant water status
McMaster et al., 2008


Water and Plant Growth and Sequence of Events
Water deficit
Cell expansion
Mesophyll Resistance
Stomatal Resistance
Cell division & differentiation
Leaf GR
LAI
Stem GR
height
Root GR
Rate of Photosynthesis
Canopy photosynthesis
Rate of Transpiration
Rate of squaring
bolls
Node production
shedding
Fruit GR
Vegetative yield
Seasonal transpiration
Economic yield


Rainfall Trends


Rainfall - Seasonal Trends
Bakersfield, CA and Florence, SC - 1991
Florence, SC
Bakrsfield, CA
Rainfall, inches
Day of Year
0
1
2
3
0
60
120
180
240
300
360

Global Rainfall –Temporal and Seasonal Trends



http://en.wikipedia.org/wiki/File:MeanMonthlyP.gif

Global Rainfall –Temporal and Seasonal Trends

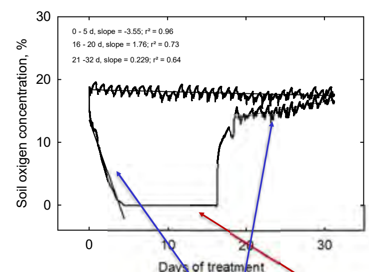
Mawsynram, Meghlaya, India
2000-2010: 483 inches, 12,268 mm, the wettest place on Earth

In 1861, the total rainfall at Cherapunji, India was: 22,987 mm (904.9 inches, highest recorded); it received 9,300 mm (366 in) in July 1861

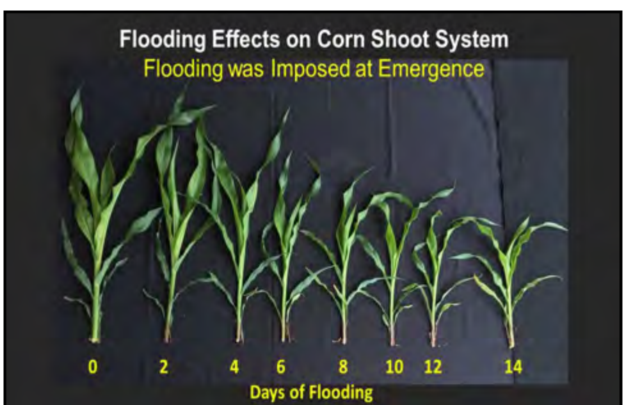
Mississippi Average: 57.14 inches, 1,371 mm
17.71 inches in 1992 December

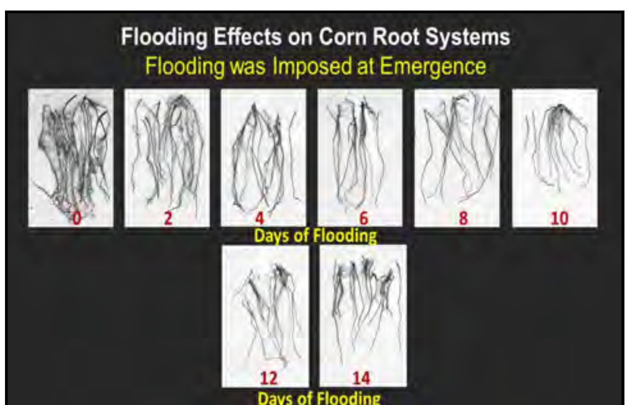
Water Status
Flooding

Water Status - Flooding



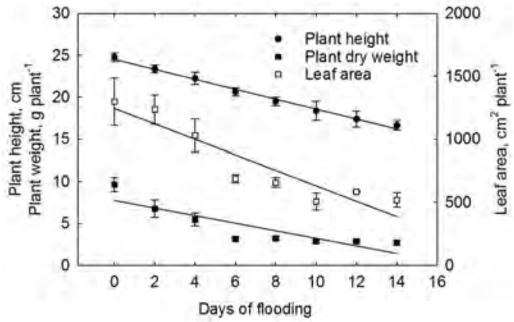
During flooding soil oxygen will be replaced by water and plants will go under hypoxia (low O_2) and anoxia (no O_2) conditions.



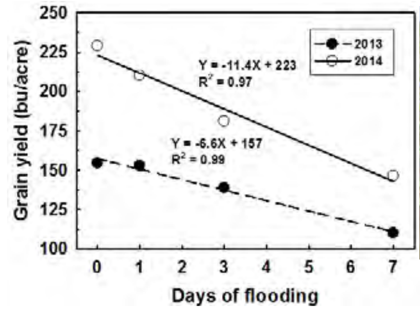


Water Status – Flooding

Corn Responses to Flooding



Water Status - Flooding

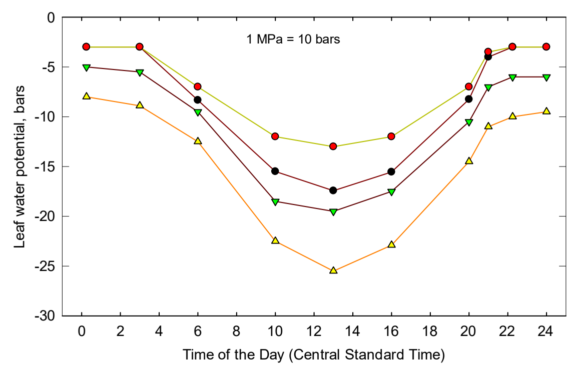


Researchers observed a 6.6 and 11.4 bu/acre corn yield decrease for each day of flooding during 2013 and 2014, respectively, in Missouri.

http://www.mississippi-crops.com/2017/05/04/flooding-in-corn-and-soybeans/

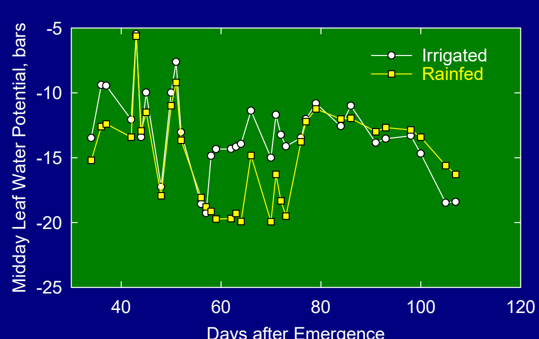
Water Status
Seasonal and Diurnal Trends

Leaf Water Potential - Diurnal Trends

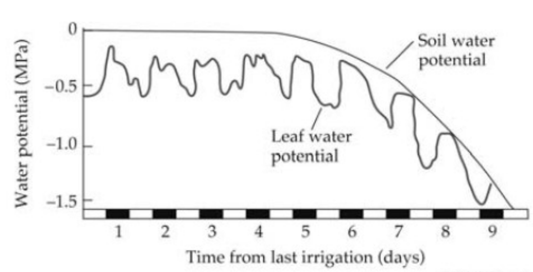


Seasonal Trends - Midday Leaf Water Potential

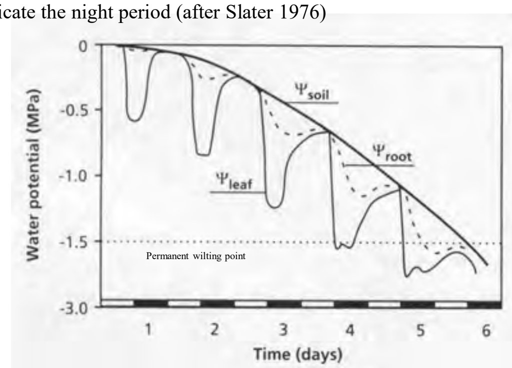
Irrigated and rainfed cotton, MSU North Farm -1995



Typical diurnal changes in leaf and soil water potentials of a transpiring plant rooted in soil allowed to dry from a water potential near zero to a water potential at which wilting occurs. The dark bars indicate the night period (after Slater 1976)



Typical diurnal changes in leaf, root and soil water potentials of a transpiring plant rooted in soil allowed to dry from a water potential near zero to a water potential at which wilting occurs. The dark bars indicate the night period (after Slater 1976)



Typical diurnal changes in transpiration rate, leaf, root and soil water potentials of a transpiring plant rooted in soil allowed to dry from a water potential near zero to a water potential at which wilting occurs. The dark bars indicate the night period (Fitter and Hay, 2002)

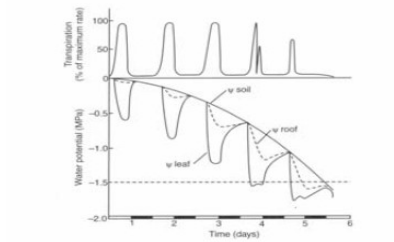


Figure 4.9

Schematic representation of the changes in leaf, root surface, and bulk soil water potentials, and in the rate of transpiration, associated with the exhaustion of the available soil water over a five day period. See text for full description (adapted from Slatyer, 1967).

Reference/Reading Material

- McMaster et al. 2008. Simulating crop phenological responses to water deficits, CSSA publication (Read).
- Volmar, K.M. and W. Woodbury. 1995. Plant-Water-Relationships. In: Handbook of Plant and Crop Physiology, by M. Pessarakli. Marcel Dekker, Inc, New York (Must Read).
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