Sensitivity of Cotton to Water-Deficit Stress

Derrick Oosterhuis and Dimitra Loka
University of Arkansas

Outline of Talk

(Sensitivity of Cotton to Water Stress)

- Effects of water stress
- Sensitivity by growth stage
- Effects on yield

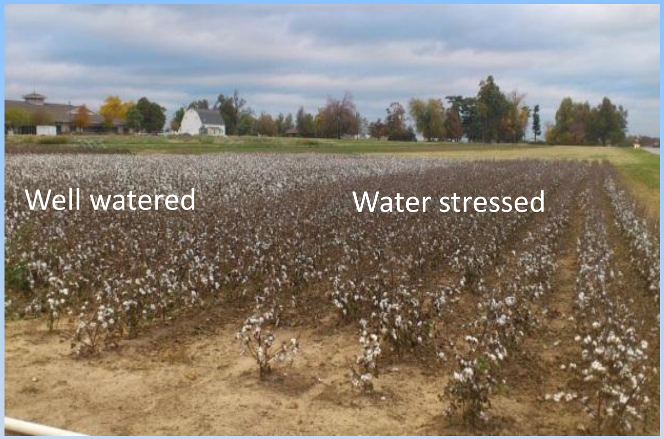
There are obviously many concepts of Water Stress!

Effects of Water Stress

Water is essential for plant growth and development and effects plant morphology as well as critical physiological functions, the results of which are manifested in poor growth and decreased yield and fiber quality.

Morphology

- Leaf area
- Plant height
- Branching
- Fruiting points
- Root depth and proliferation



Plant Physiological Response to Water Deficit
The Onset of Water Stress

Process Affected (in order)

Increasing severity of stress

- Cell growth (division & enlargement)
- Proteins
- Enzymes affected (e.g for N)
- Hormones (Abscisic acid)
- Stomatal closure
- Photosynthesis decreased
- Sugar concentration decreased

= YIELD REDUCTION

Sensitivity by Growth Stage

I have used extracts from the following publications:

- "***Irrigation Management for Humid regions***". 2012. Published by Cotton Incorporated.
- "***Water-Deficit Stress in Cotton***". By Loka et al., 2011. Published in Stress Physiology in Cotton edited by D.M. Oosterhuis, published by the Cotton Foundation, Memphis, TN.
- "***Water-Deficit Stress and Reproductive Development in Cotton***". By Loka and Oosterhuis, 2012. Published in Flowering and Fruiting in Cotton edited by D.M. Oosterhuis and J.T. Cothren, Cotton Foundation, Memphis, TN. *(in press)*

Sensitivity by Growth Stage

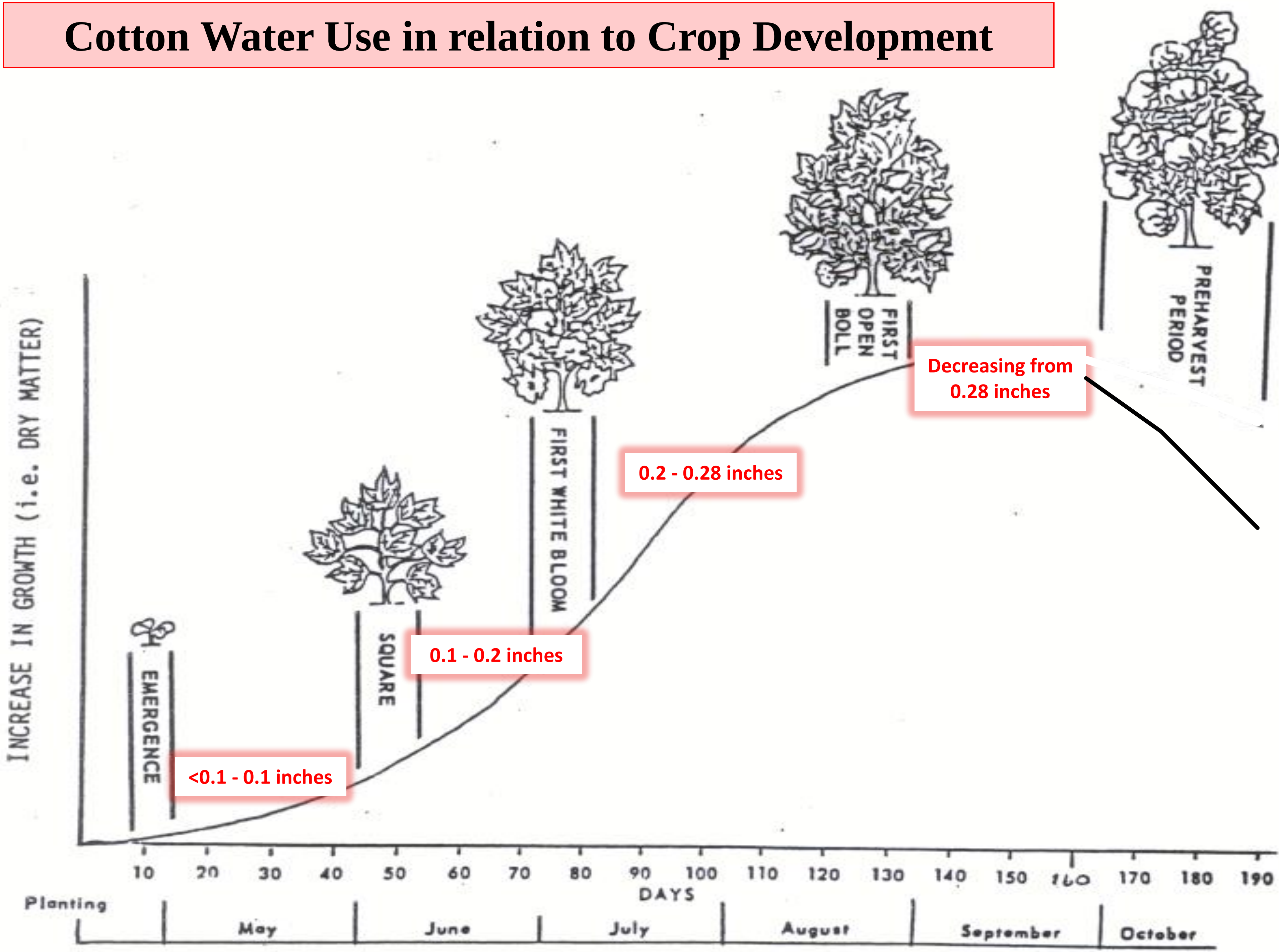
- The sensitivity of cotton to water stress varies by growth stage.

Phases of cotton development:

1. Planting to Emergence
2. Emergence to First Square
3. First Square to First Flower
4. First Flower to Peak Bloom
5. Peak Bloom to Open Bolls

There is still some debate about the most sensitive stages during development in relation to yield, although sensitivity during flowering and early boll development is well recognized *(Constable and Rawson, 1981; Turner et al., 1986; Loka et al., 2011).*

Cotton Water Use in relation to Crop Development



1. Planting to Emergence

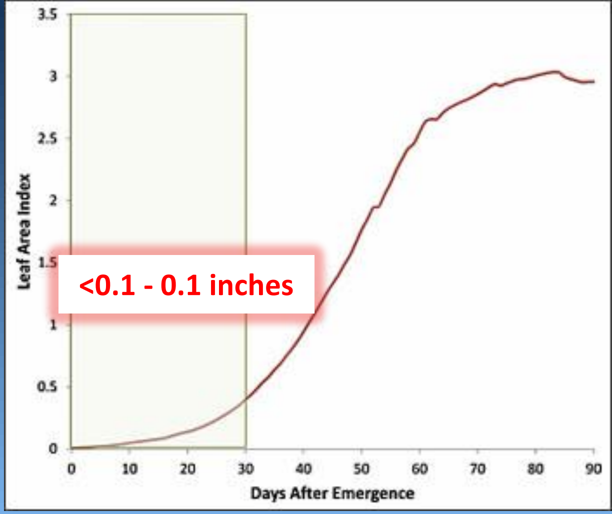
- Water is critical for germination, but excessive water can hinder germination.

- Irrigation here is only for arid areas, sandy soils, and mainly for the establishment of stand.

- Prior to first square, water stress typically has little impact on cotton yield or fiber quality.

- Once the seeds have germinated, there must be sufficient water for root proliferation to increase the area for water and nutrient uptake.

2. Emergence to First Square



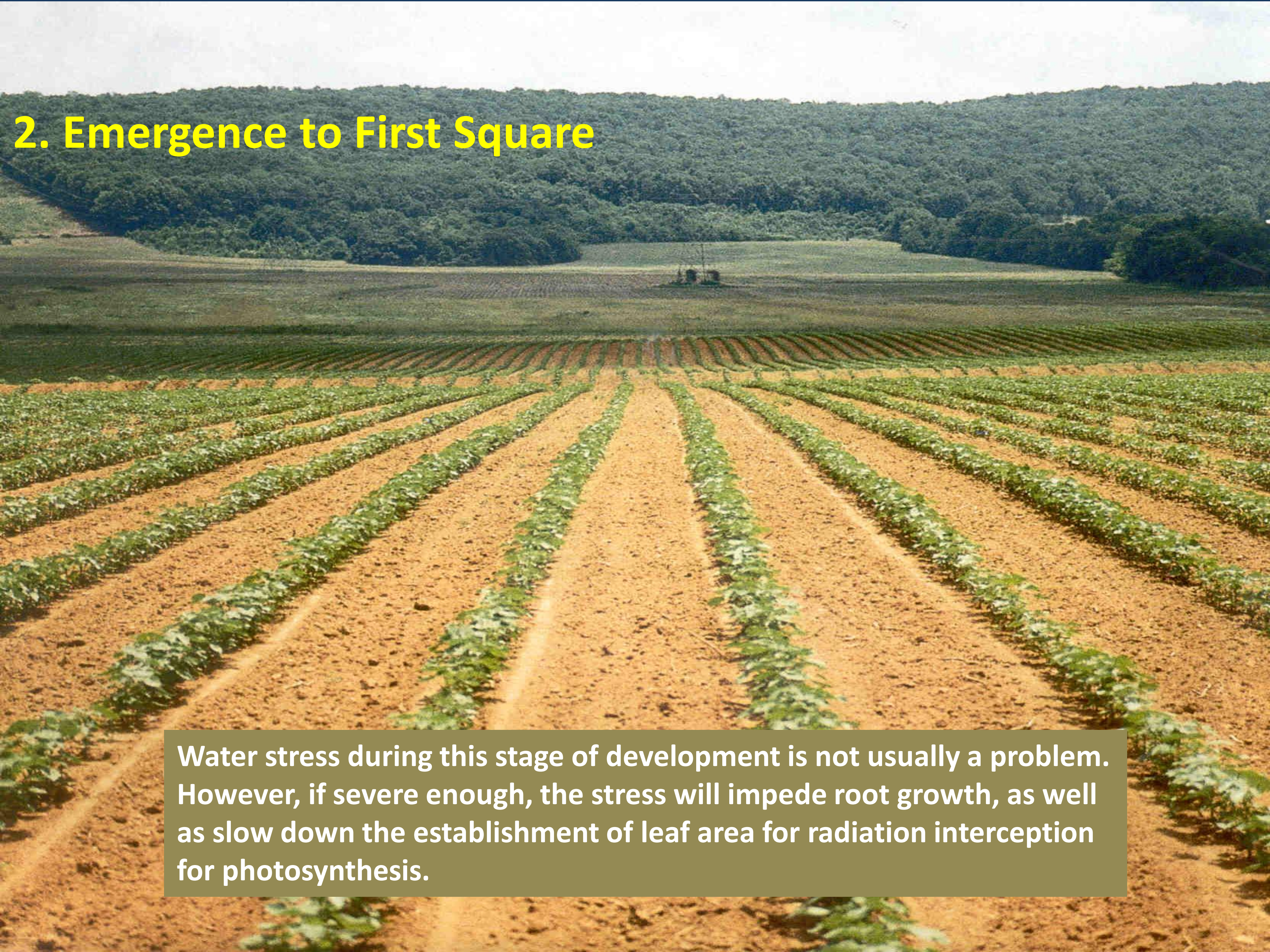
- Water use by cotton in this stage: from <0.1 to 0.1 inches of water per day.

- Early season water deficit after stand establishment is often not an issue if there is adequate water for emergence and early seedling development.

- Water demand at this time is low and young cotton plants partition significant resources to the roots.

- Unless soil water deficit is extremely severe, irrigation at this time contributes relatively little to yield.

- There is some evidence that a mild water deficit early in the season can stimulate root production, especially encouraging deeper root systems, and help acclimate plants to water scarce conditions; thereby beginning (or priming) a cascade of plant responses that increases water-use efficiency

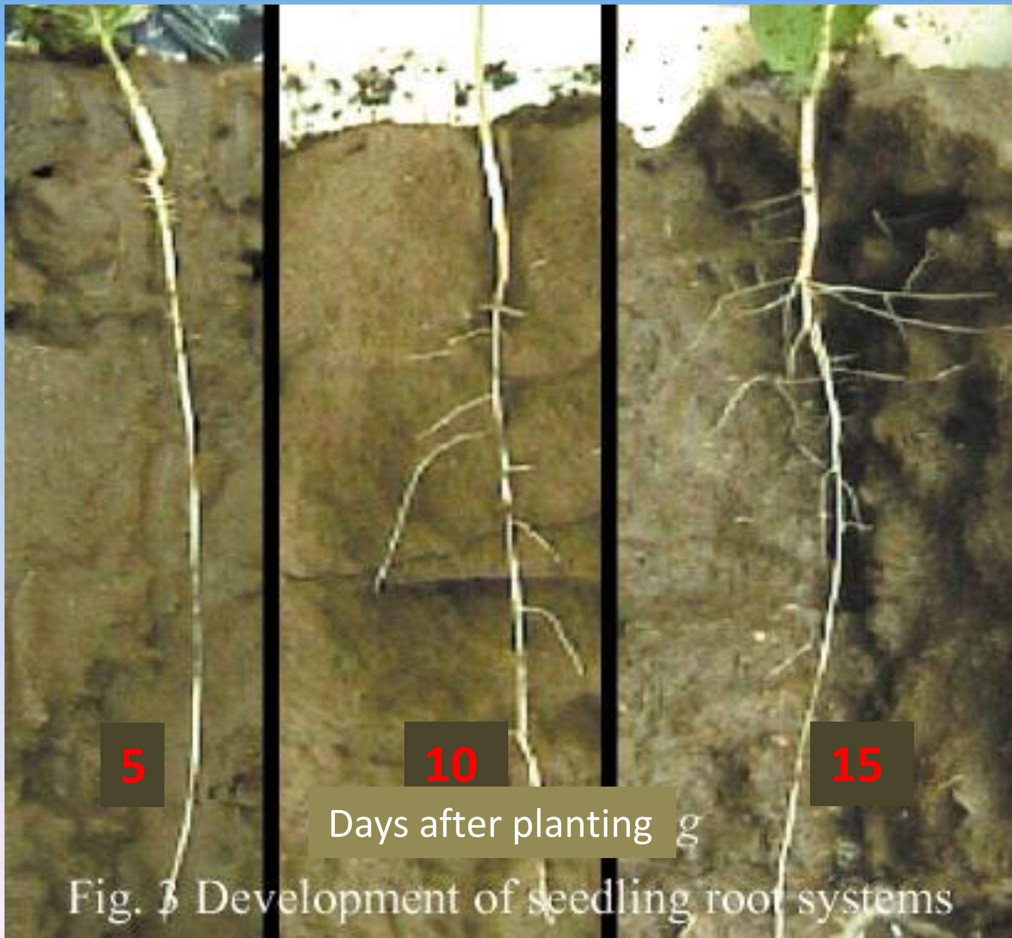


2. Emergence to First Square

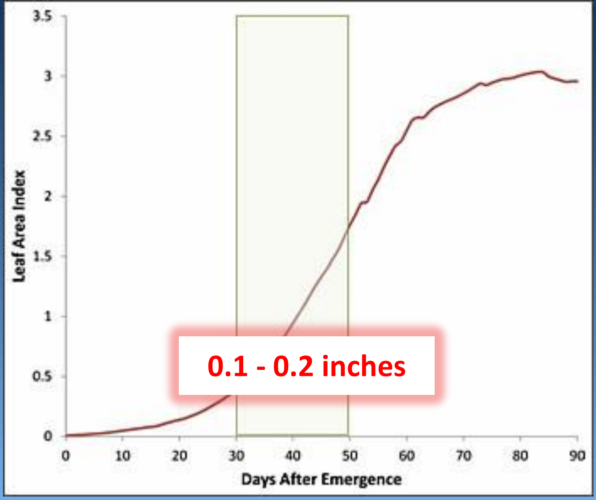
Water stress during this stage of development is not usually a problem. However, if severe enough, the stress will impede root growth, as well as slow down the establishment of leaf area for radiation interception for photosynthesis.

2. Emergence to First Square

Cotton seedling root systems develop early and rapidly, growing at up to 2 inches a day.



3. First Square to First Flower



- Water use by cotton – increases from 0.1 to 0.2 inches of water per day as plants grow.

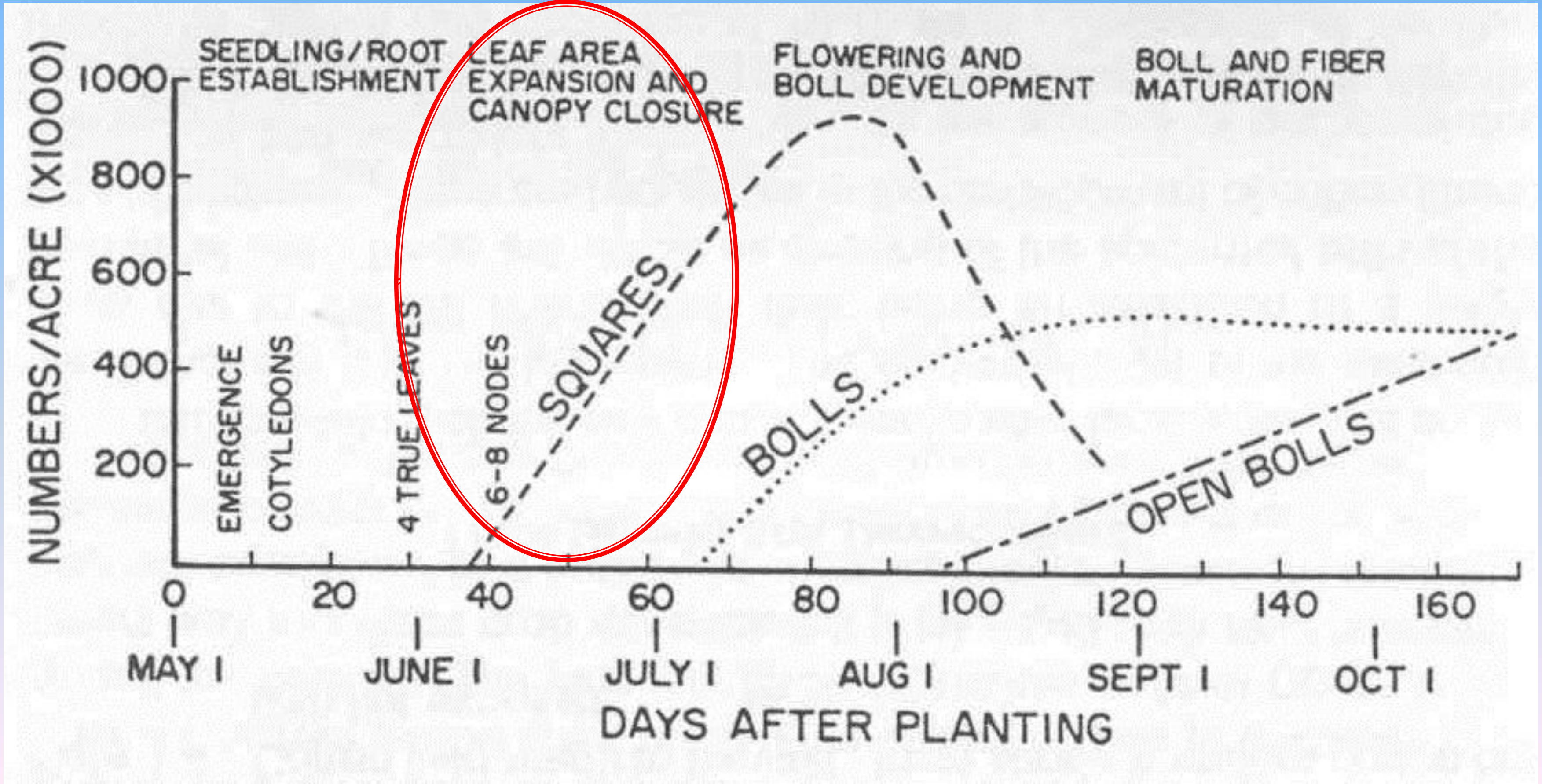
- The approximate 21 days from first square to first bloom is a critical time for avoiding severe water deficit stress. During this period, cotton vegetative growth is very rapid and the number of potential fruiting sites for the crop is determined, especially in short season environments.

- This is the period when plants are most rapidly taking up phosphorus and potassium from the soil because of rapid root growth. The maximum depth of the rooting system can be achieved relatively quickly and often exceeds 36 inches in depth. Maximum depths may be reached within 40 to 60 days after planting.

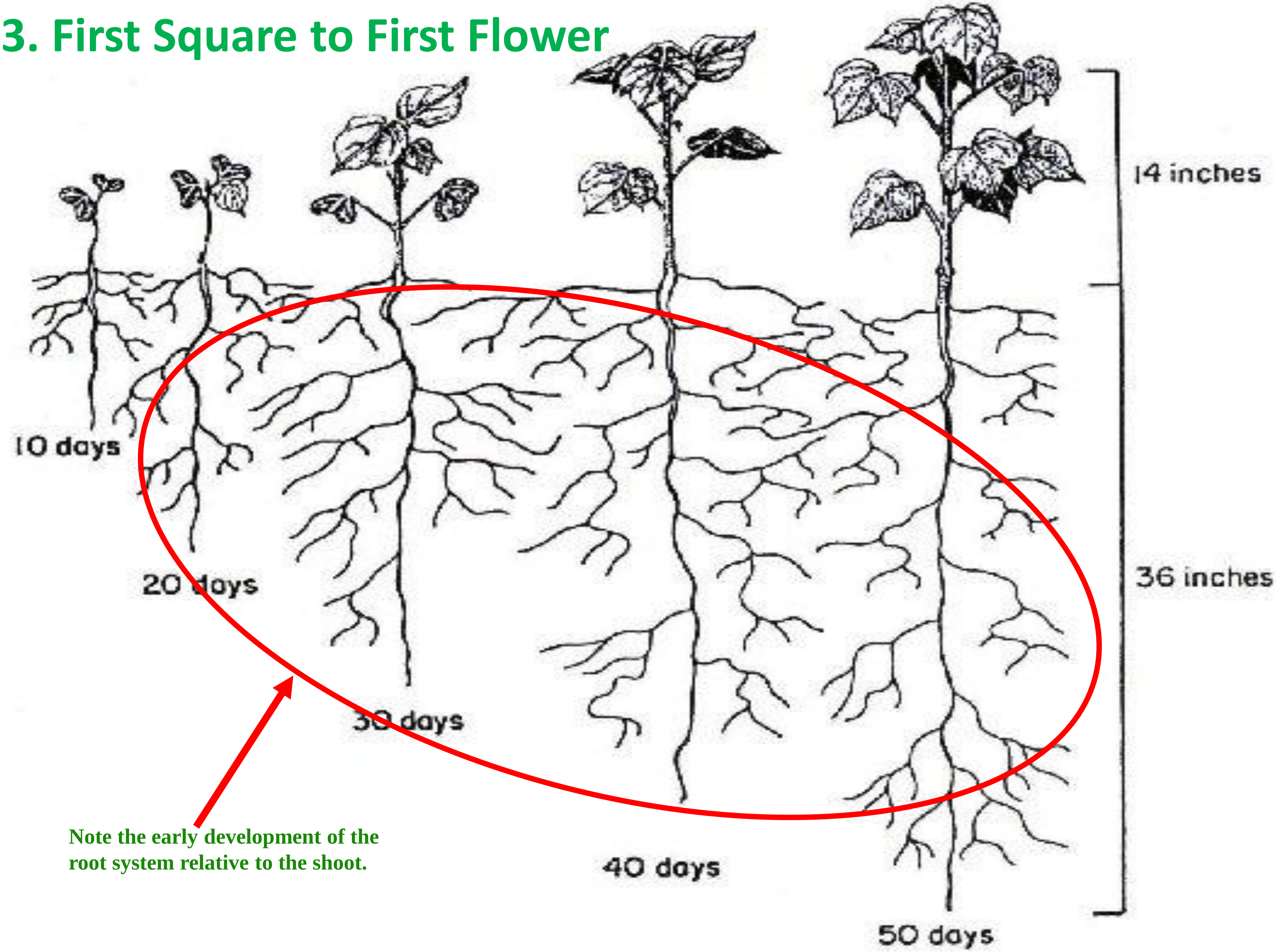
- Severe water deficit stress during this period is especially damaging to the cotton crop in short-season environments.

3. First Square to First Flower

During this stage the majority of the resources go into the development of the root system, and particularly into growing the leaf area and canopy necessary for radiation interception and photosynthesis for the developing reproductive units.



3. First Square to First Flower



Note the early development of the root system relative to the shoot.

3. First Square to First Flower

One of the main reasons why this stage is sensitive to water-deficit stress is because leaf photosynthesis is decreased and there is a reduced ability to translocate the remaining photosynthate to the developing fruiting sites. Thereby affecting root growth and potential number of fruiting sites.

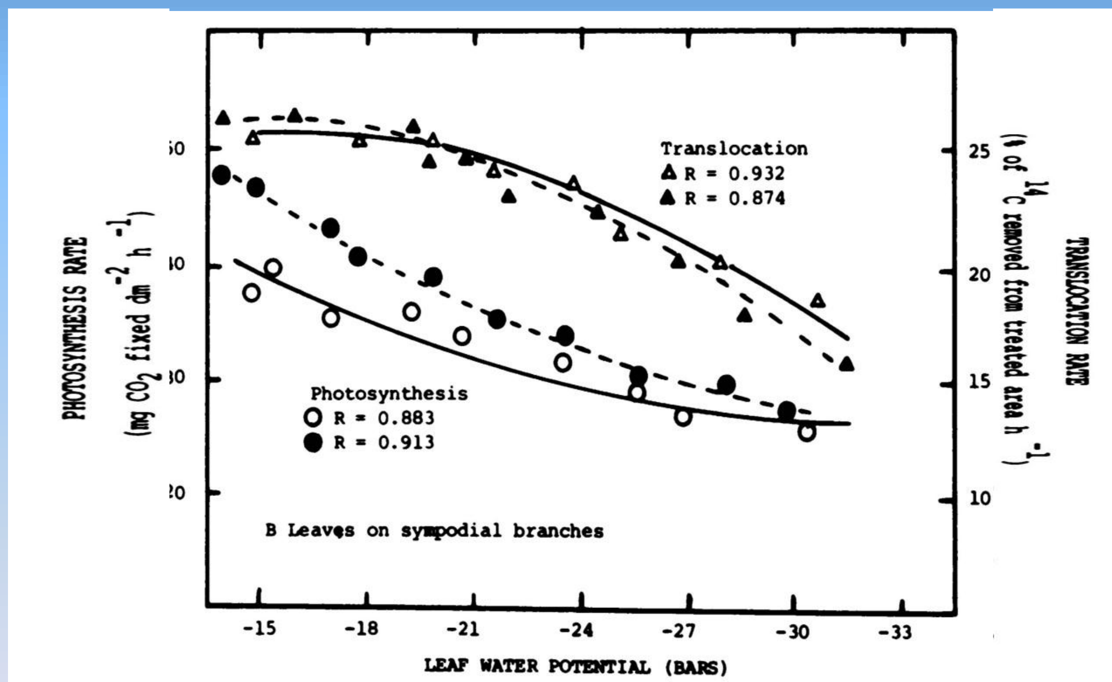
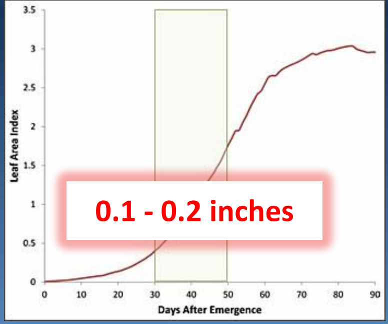


Figure 2. Response of photosynthesis and translocation rates to increasing water deficit in cotton as a function of leaf type and growth stage (○, ▲: flower bud development; ●, Δ: boll-filling period). From Sung and Krieg (1979).

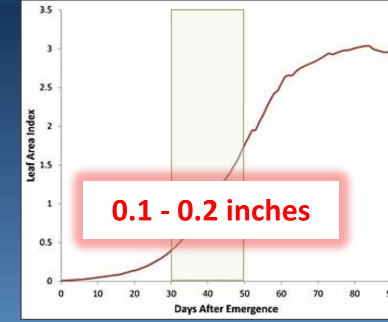
3. First Square to First Flower



- **There are some reports of increased number of flowers and bolls per plant and yield increases when irrigation was withheld at the preflowering stage** *(El-Zik et al., 1977; Mauney et al., 1980).* **This is disputed and potentially dangerous.**

- **Some reports that limited supply of water before flowering increased fruit retention, but reduced nodes, fruiting branches, and fruiting sites (Rijks, 1965; Stockton et al., 1971), whereas increased flowering rates with increased irrigation were reported by Bruce and Romkens (1965) and Lashin et al. (1971).**

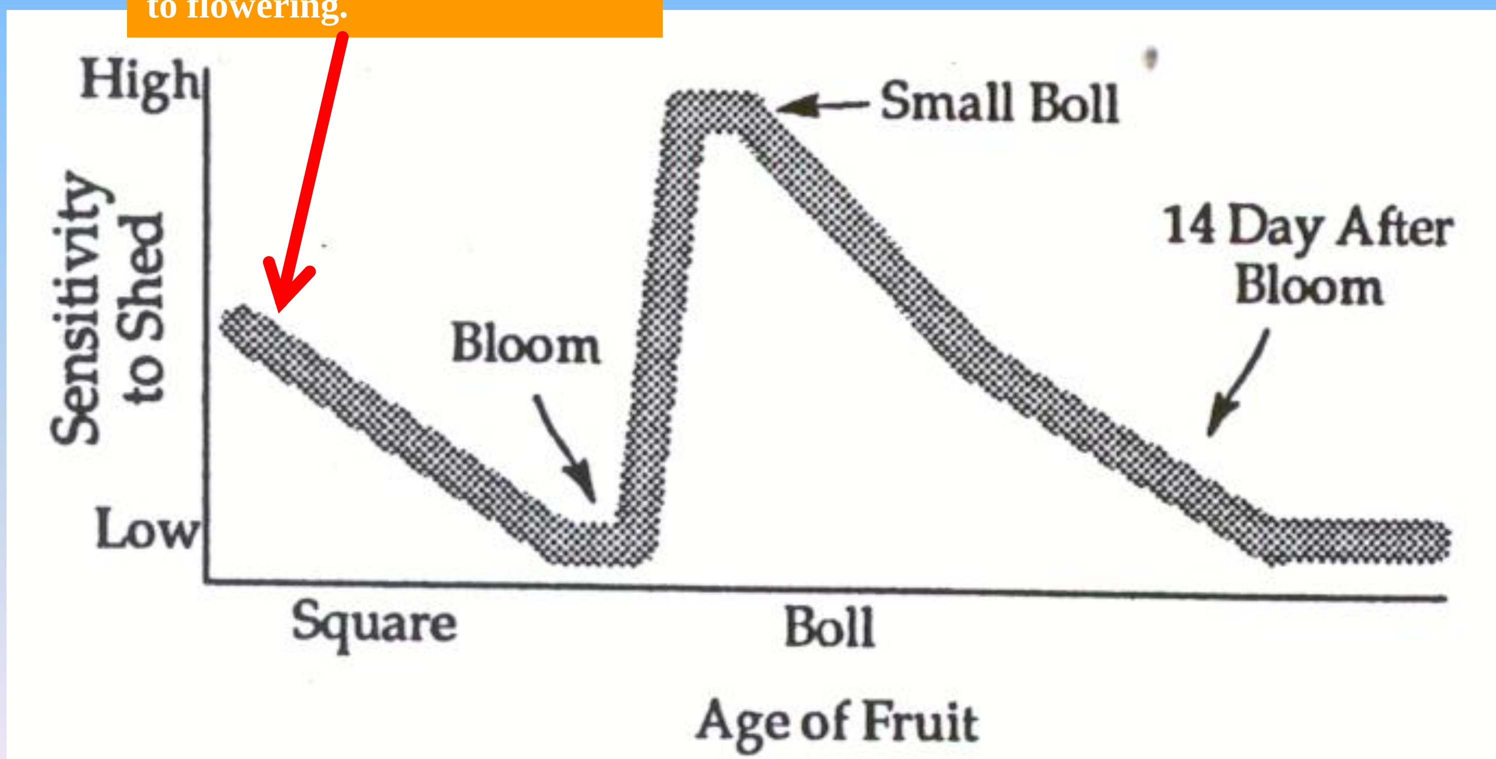
- **Krieg (2000) concluded that inhibition of flowering site initiation rather than square shedding was the reason for decreased fruiting sites due to water-deficit stress prior to flowering.**



3. First Square to First Flower

- **Young squares more prone to abscise when plants subjected to lower than optimal moisture, with their most sensitive period being the first week after visibility** *(McMichael, 1979); Ungar et al., 1989).*

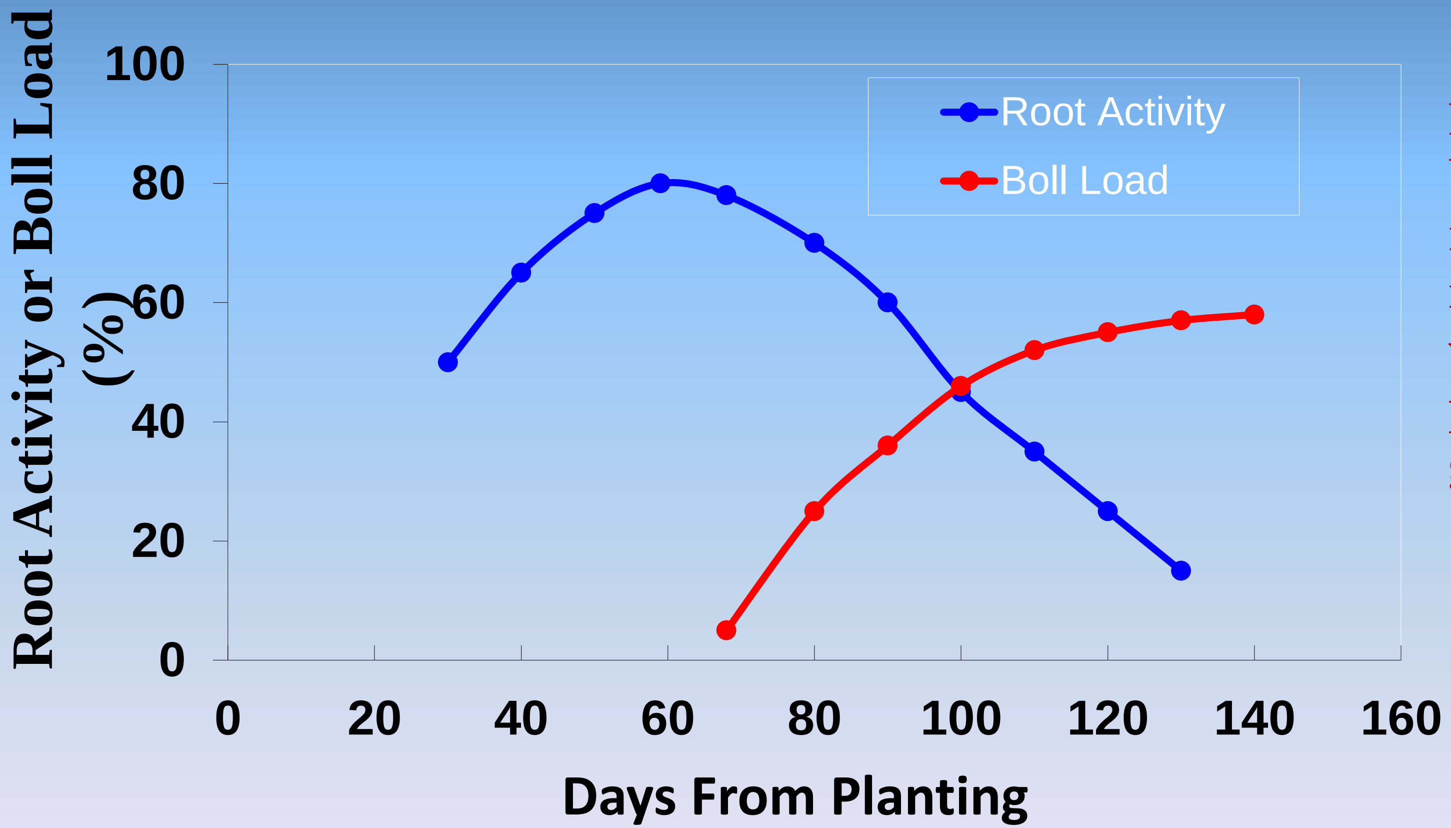
Sensitivity of squares to shed decreases from pinhead square to flowering.



The sensitivity of Squares and Bolls to Shedding

4. First Flower to Peak Bloom

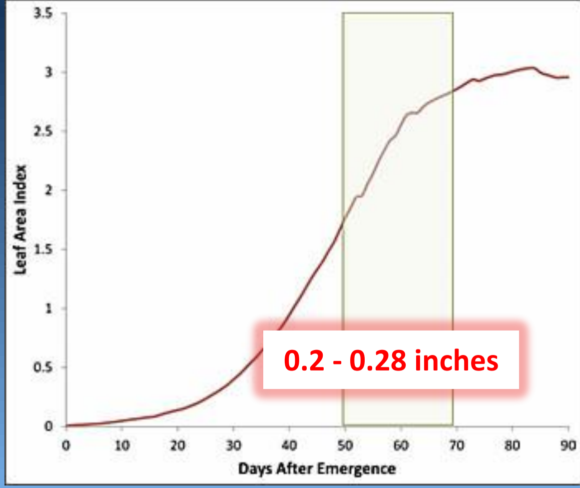
As the reproductive boll load begins to develop it becomes the major sink for resources at the expense of the root system.



Relationship between decreased root growth and increased boll load versus days after planting for field-grown cotton.

(From Oosterhuis 1998)

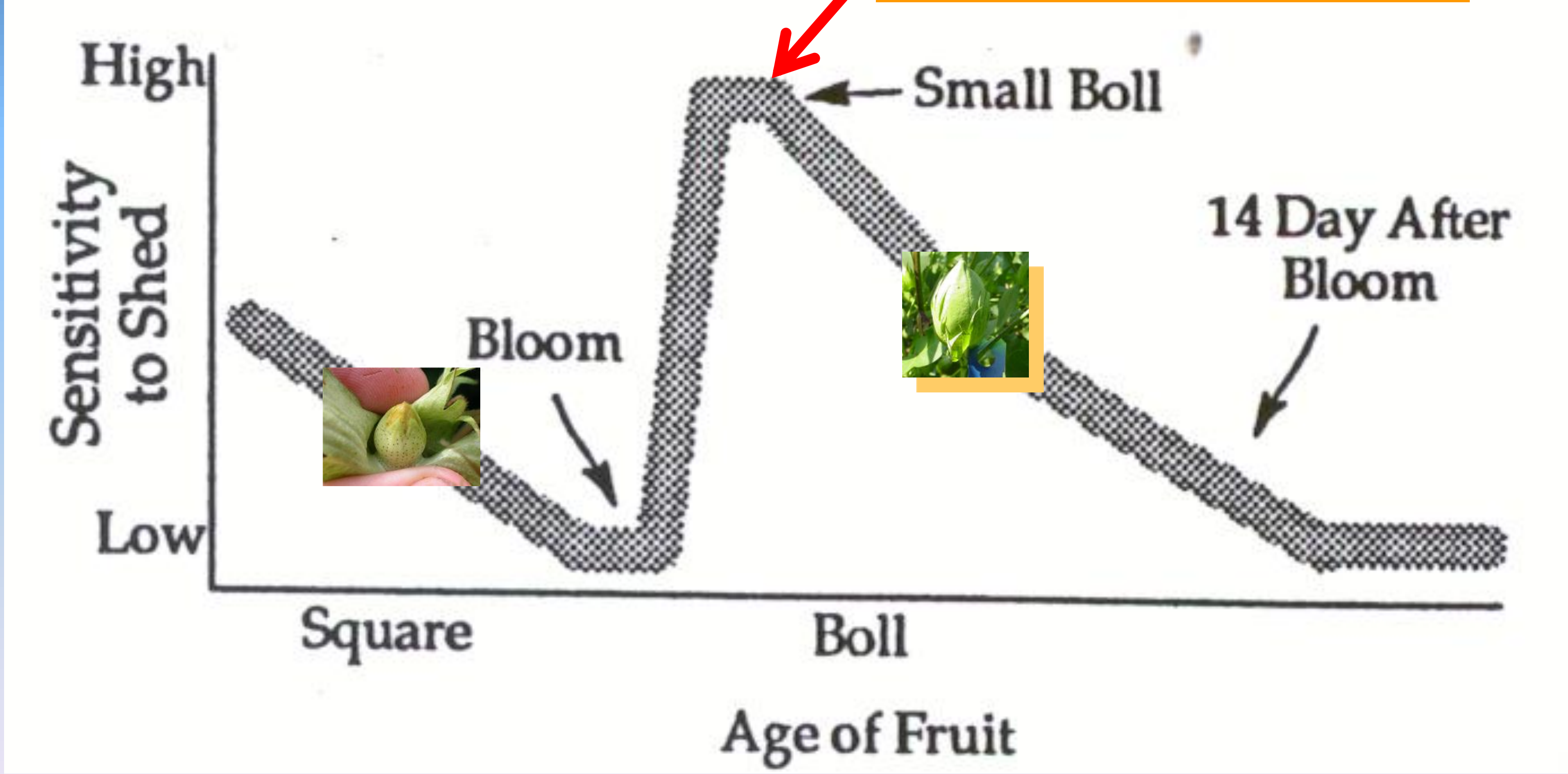
4. First Flower to Peak Bloom



- Water use by cotton – increases from 0.2 to 0.28 inches of water per day as plants develops through this stage.
- Water-deficit stress early in this growth stage reduces plant growth which reduces the number of fruiting sites that are initiated.
- In addition, severe water-deficit stress can also reduce boll number through shedding of young bolls and results in substantial yield loss.
- During early bloom, squares are generally not lost due to water deficit stress, so if square shedding is observed, other causes should be investigated.
- Water-deficit stress at this time also impacts yield by reducing the size of surviving bolls.
- Severe stress reduces fiber quality through shorter staple and higher micronaire.
- At this growth stage, maximum rooting depth is achieved but lateral roots continue to grow throughout the rooting profile so that the final size of the root system may not be reached until 90 days after planting.

4. First Flower to Peak Bloom

Most sensitive stage of a single boll (4-6 days after anthesis). Highest shedding occurs. Effects yield the most.

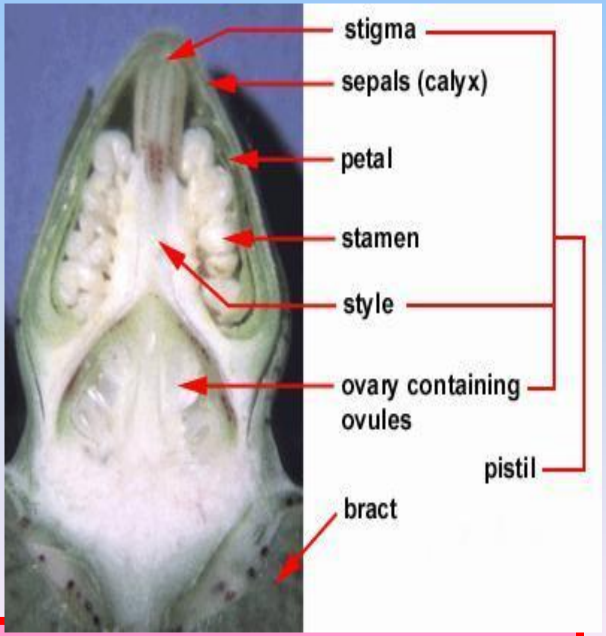


The sensitivity of Squares and Bolls to Shedding

4. First Flower to Peak Bloom

- Cotton white flowers do not abscise, but actually sustain expansion under extreme water-deficit conditions, even after leaf emergence and expansion have been arrested. However, significant reductions in yield are observed when water-deficit stress occurs during flowering.

- There is not much known about the water relations of the cotton flower, although this stage represents the critical events of anthesis, pollination and fertilization.

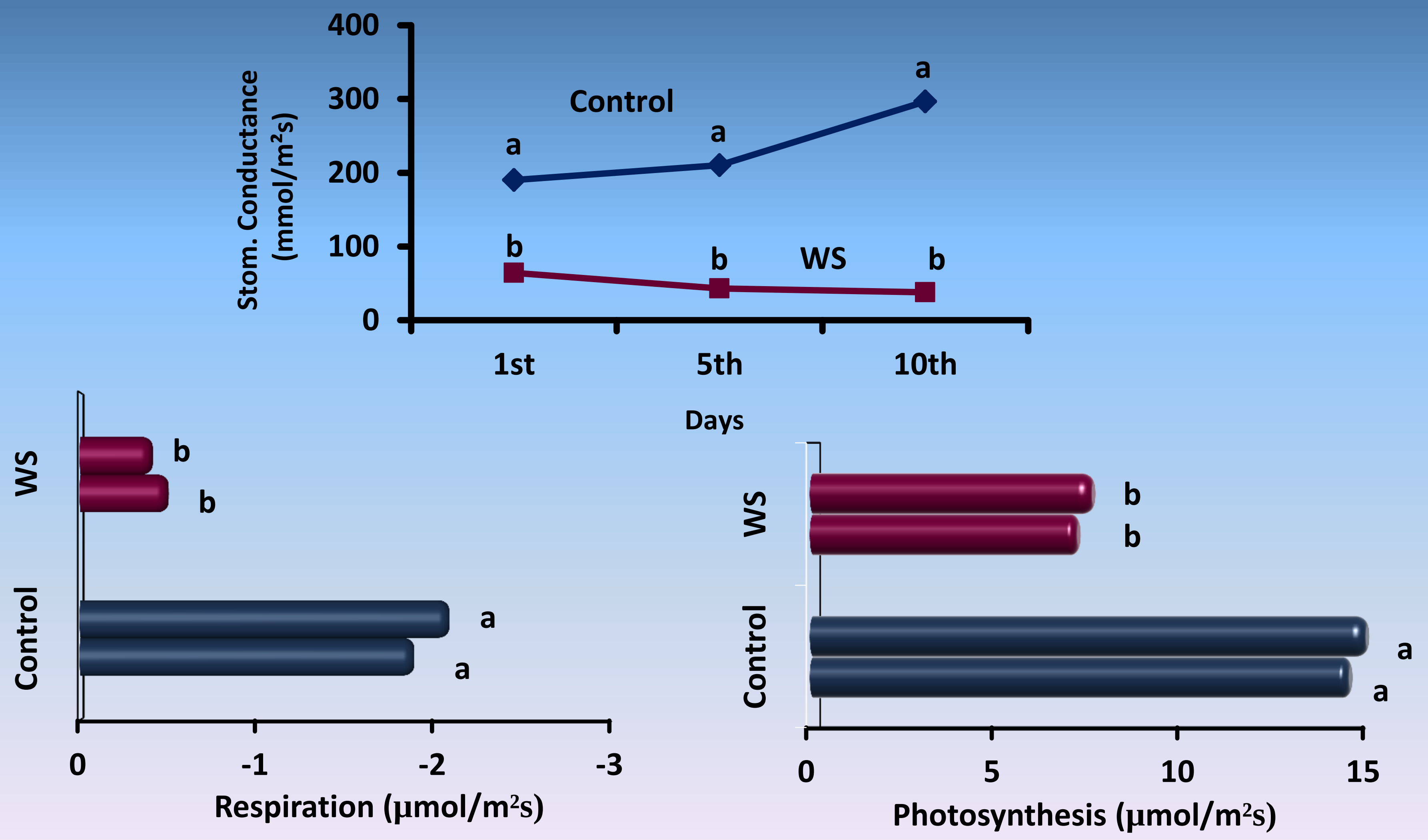


Cross section of a cotton floral bud

Events occurring in the flower (pistil) are very sensitive to environmental stress.
However, there is some buffering that occurs to protect the processes occurring in the pistil during this critical stage of development.

4. First Flower to Peak Bloom

Effect of Water-Deficit Stress on Leaf Gas Exchange

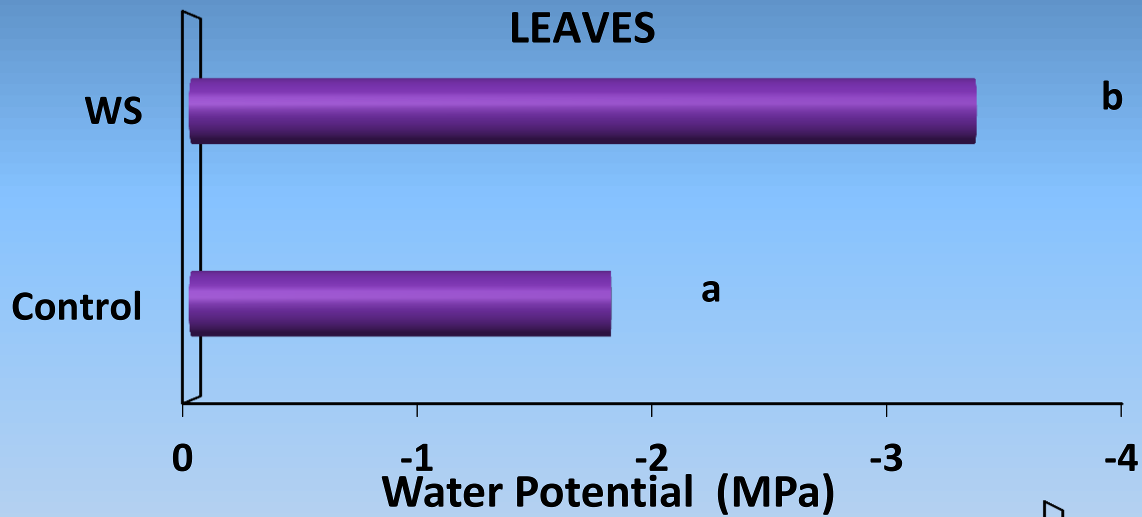


Measurements were taken on the 5th and 10th day after the induction of water-deficit stress

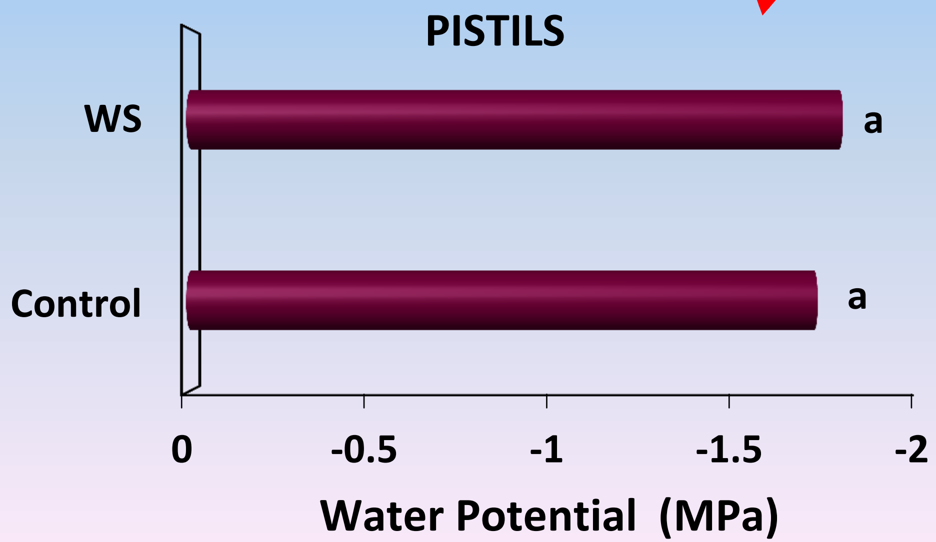
(From Loka,2011)

4. First Flower to Peak Bloom

Water-Deficit Stress on Water Potential of Cotton Leaves and Pistils



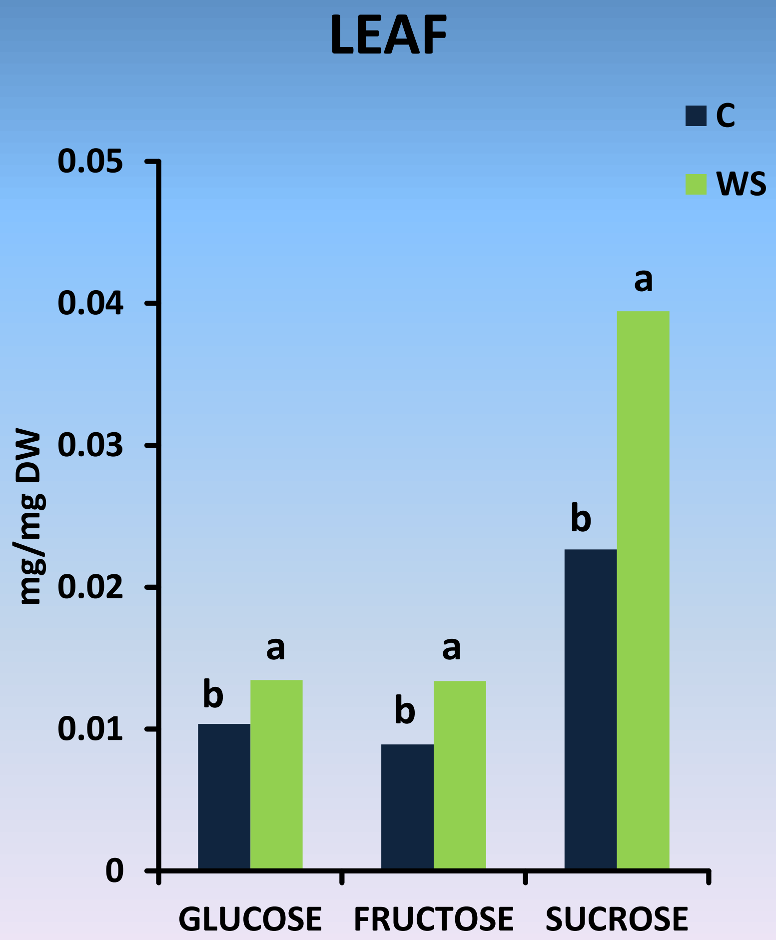
The ovary is fairly well buffered against the effects of water stress.

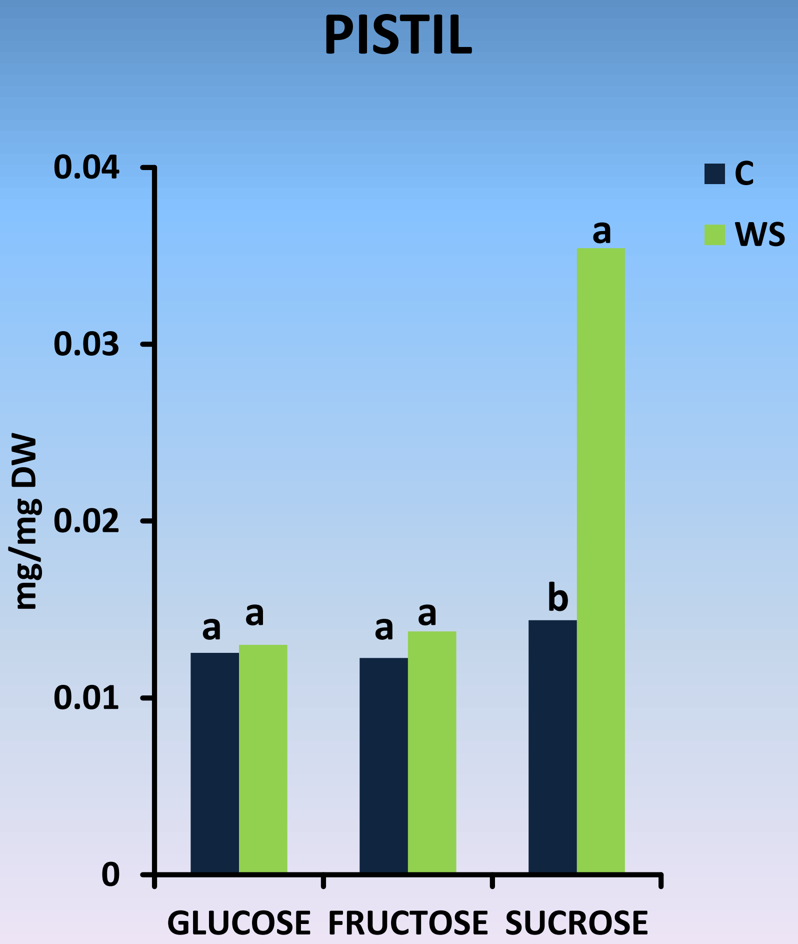


From Loka,2011

4. First Flower to Peak Bloom

Effect of Water Deficit on Leaf and Pistil Carbohydrates



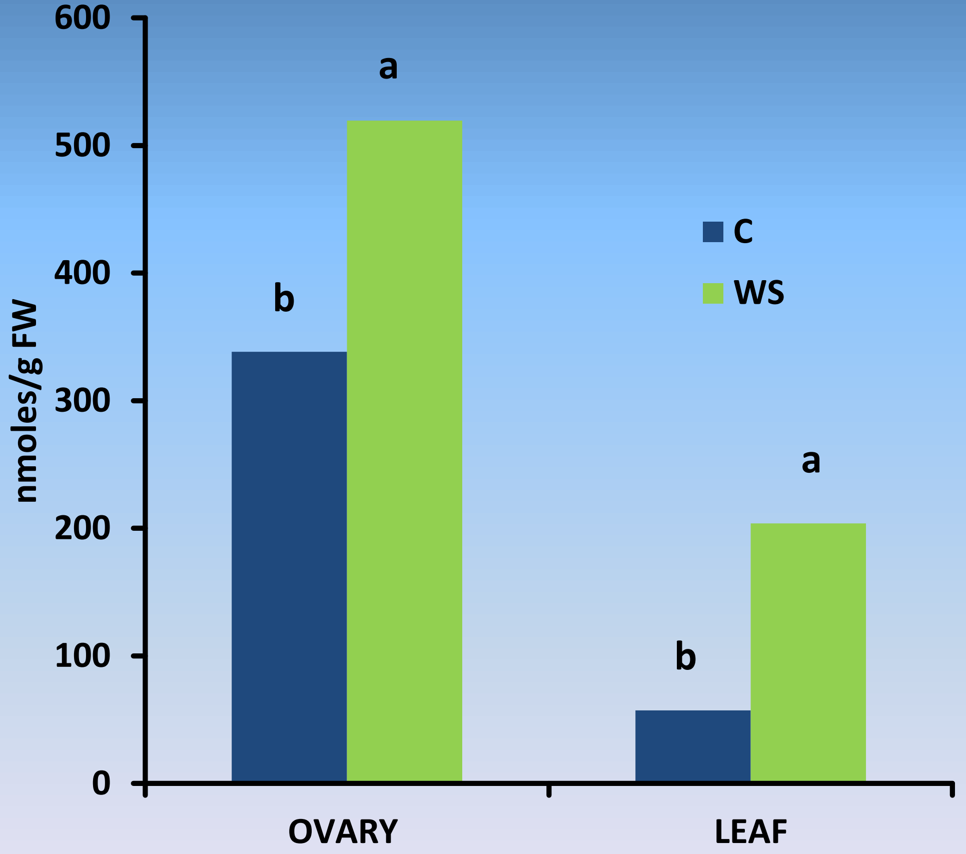


Columns with the same letter are not significantly different (P≤0.05)

4. First Flower to Peak Bloom

Effect of Water Deficit on Polyamine (putrescine) Content of Cotton Ovary and Leaf

Polyamines are involved in flower induction, pollination, seed set and stress tolerance mechanisms.

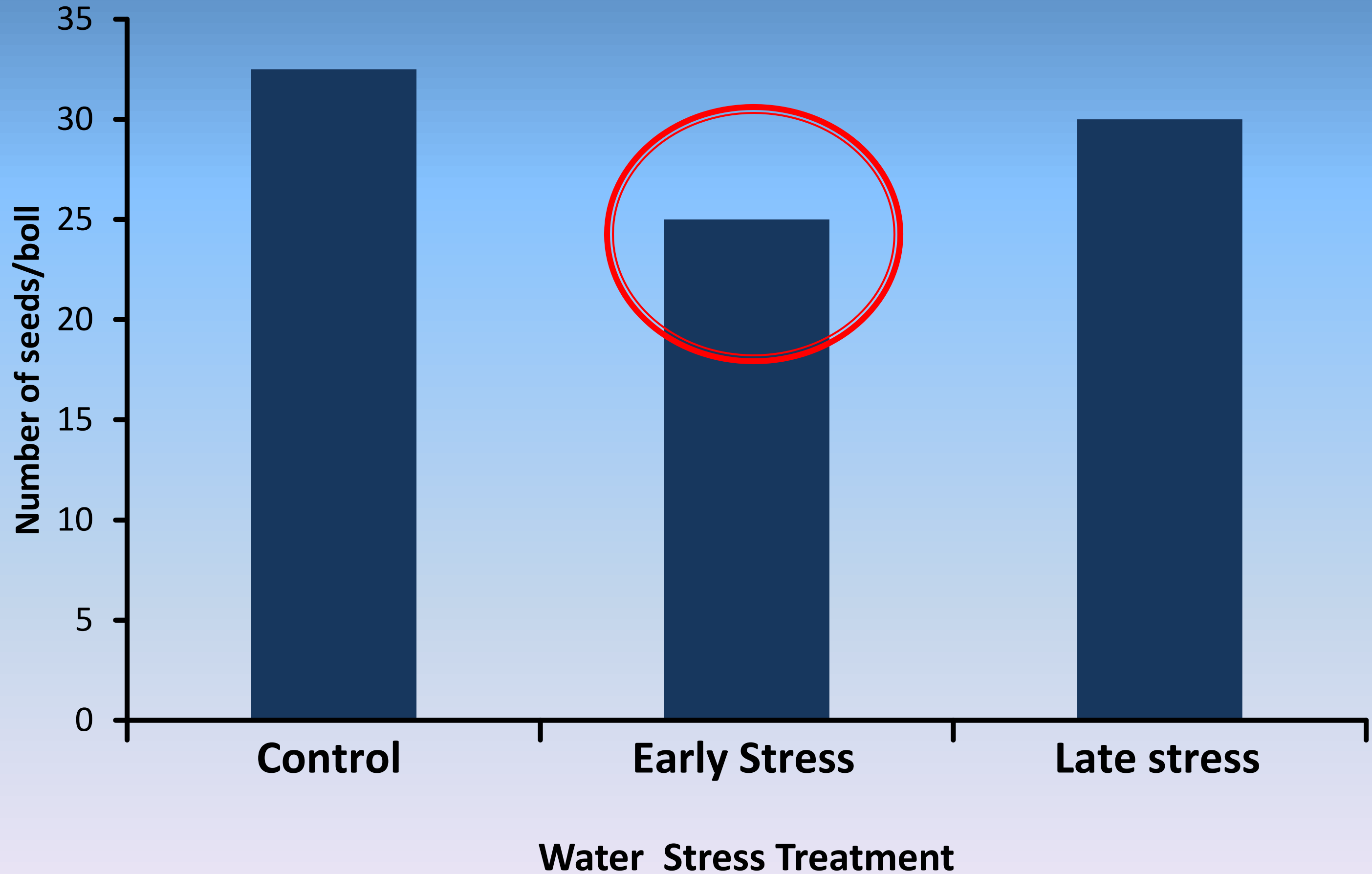


Columns with the same letter are not significantly different (P≤0.05)

(From Loka and Oosterhuis, unpublished)

4. First Flower to Peak Bloom

Effect of Early (Squaring) and Late (Flowering) Water Stress on Number of Seeds/boll



(From Loka,2011)

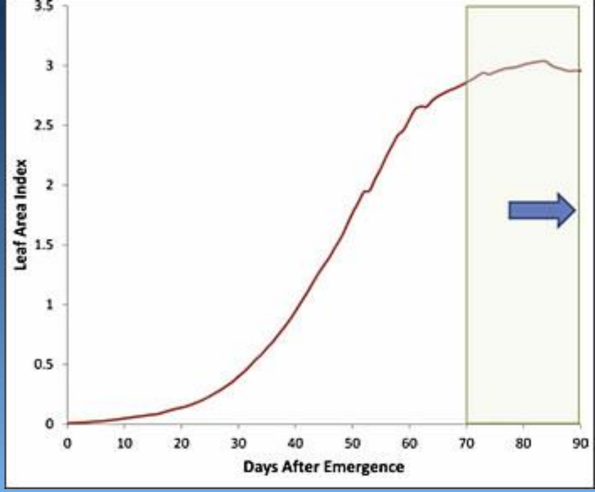
4. First Flower to Peak Bloom

Pollen viability and Pollination

- Water stress during early squaring results in pollen sterility in wheat, oats, barley, corn, and rice due to perturbations in carbohydrate metabolism.
  (Saini and Aspinall, 1981, Saini, 1997)
- Water stress during flowering resulted in reductions in pollen viability, pollination and fertilization in rice, corn, beans, and chickpea due to floral abnormalities.
  (Hsiao, 1982; O'Toole and Namuco, 1983; Westgate and Peterson, 1993)
- **However, no definitive information exist on cotton pollen viability under water stress.**

- Water stress occurs in combination with heat stress:
  - Under heat stress, pollen germination and viability are significantly reduced.
    (Burke et al., 2004; Kakani et al., 2005)
  - Under heat stress, pollen tube growth and successful fertilization are significantly reduced.
    (Burke et al., 2004; Kakani et al., 2005)
  - **So we could conclude that similar events may be occurring under water deficit, although the pistil does seem to be buffered from water stress.**

5. Peak Bloom to Open Bolls



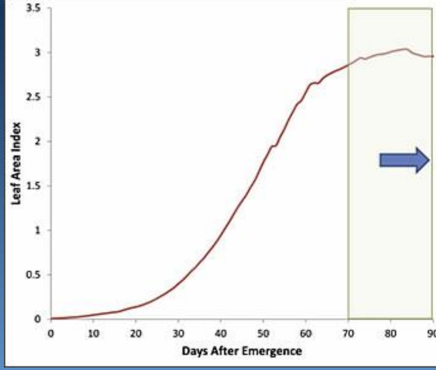
- Water use by cotton decreases from 0.28 inches of water per day as plants age.

- Water-deficit stress during this growth stage is less critical than during squaring and early flowering. Water stress during this period can result in square and young boll shedding. However, these losses of late fruit have less impact on yield than loss of early season bolls.

- Fiber quality parameters affected by stress at this time are fiber length and micronaire, particularly in the young bolls, due to carbohydrate shortages.

- After bolls start opening, plants should be allowed to become water stressed to allow for better harvest conditions. Stress at this time hastens boll opening, makes defoliation easier, and reduces regrowth

5. Peak Bloom to Open Bolls



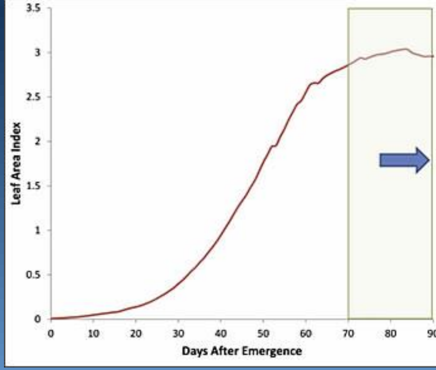
A limited supply of water during boll development can result in significantly lower yields *(Radin et al., 1992 etc.).*

Developing bolls are particularly sensitive to water stress during the first 14 days after anthesis, when they generally abscise. However, after that period, bolls are retained.

Cotton bolls appear to be less sensitive to water-deficit stress than the leaves since they are significantly resistant to water loss and are essentially non-transpiring.
(McMichael and Elmore, 1976; Radin and Sell, 1975; Wullschleger and Oosterhuis, 1990 etc).

Water use of a cotton boll: 23.4 ml H_2O/g dry weight *(Van Iersel and Oosterhuis, 1994).*
Phloem contributes approx. 75% of all water in a boll (due to xylem connections developing late).

5. Peak Bloom to Open Bolls



Hormonal balance in bolls is significantly affected by water-deficit stress.

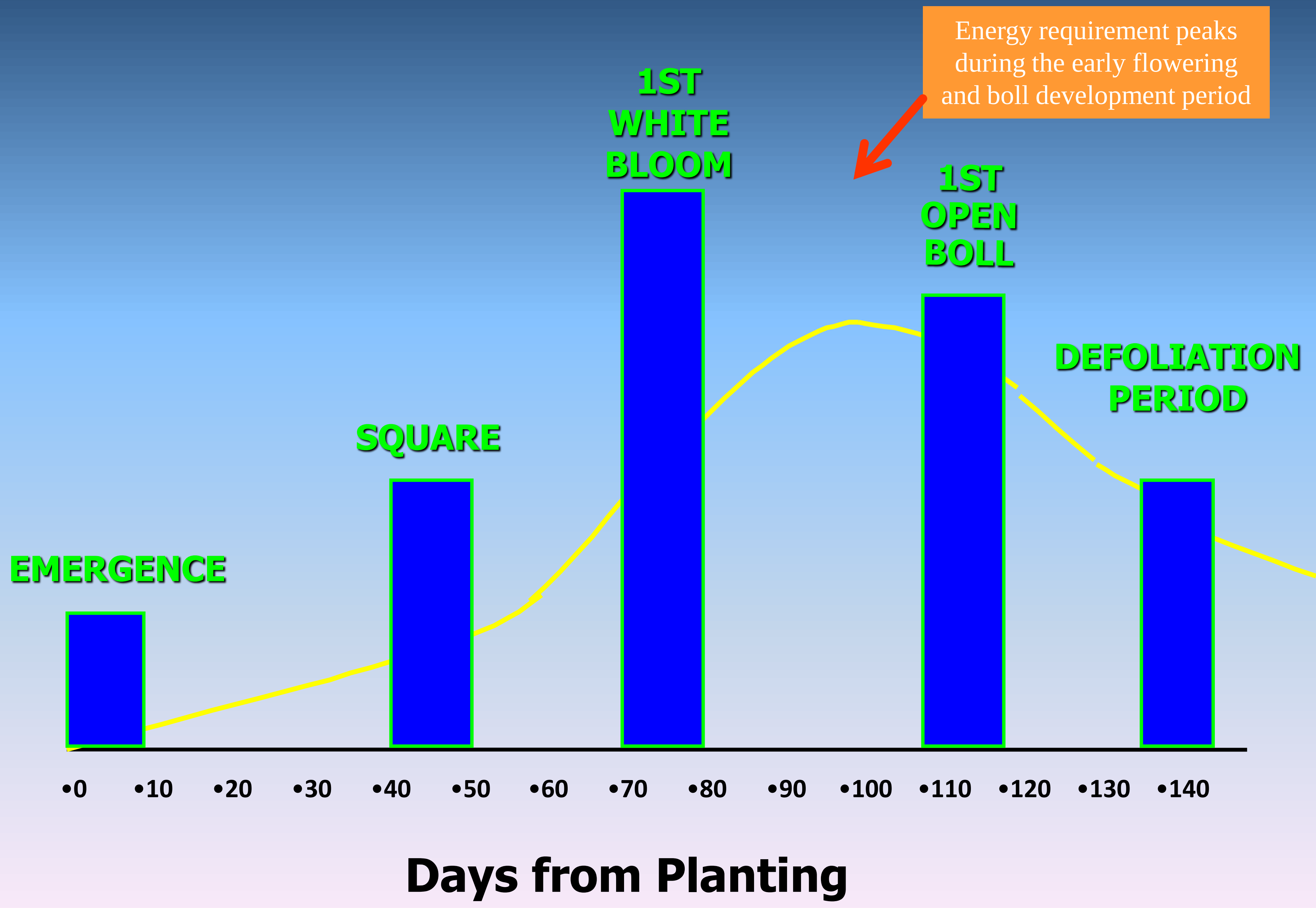
Ethylene evolution rates and Abscisic acid levels of 3-day old bolls increased under conditions of limited water supply *(Guinn 1976).*

Whereas, free and conjugated IAA of 3-day old bolls followed a differential pattern with free IAA decreased with water deficit, while conjugated IAA increased *(Guinn and Brummett, 1988).*

The specific interaction of the major hormones during water stress in cotton is still not clear.

It has been concluded that if water-deficit stress occurs after flowering, young fruits are more likely to abort due to decreased carbon and nitrogen supply as well as perturbations in hormone metabolism *(Krieg and Sung, 1986).*

Energy Requirement Curve During Cotton Development



Water Stress and Yield

Water-deficit stress significantly compromises plant development and yield.

Generally, through reduced leaf area and photosynthesis *(Hsiao, 1973)* **and reduced boll production from fewer flowers and bolls** *(Stockton et al., 1961; Gerik et al., 1996).*

There is a positive correlation between yield and the number of bolls produced *(Grimes et al., 1969).* **Irrigation has been clearly shown to improve boll production and retention** *(Ritchie et al., 2009 etc)*

Decreasing water potentials increase shedding *(McMichael et al., 1973)* **and pollen sterility** *(Saini and Westgate, 2000***), which leads to lower boll numbers and fewer seeds per boll.**

Fiber properties are relatively insensitive to water stress, unless the stress is extremely severe. Leaf water potentials <-2.8MPa can reduce fiber length since cotton fiber elongation is primarily dependent on turgor . Micronaire can also be reduced . Motes will also increase.
(Bennett et al., 1976; Dhindsa et al., 1975; Marani and Amirav, 1971)

Summary and Conclusions

- Water-deficit stress has a significant effect on cotton's growth, development, and yield.
- The effects of water stress depend on the severity and duration of the stress, the growth stage at which stress is imposed, and the genotype of the plant.
- The cotton crop is sensitive to water shortage at all growth stages, but particularly reproductive development is the most sensitive period to drought stress.
- Although mechanisms for tolerating water stress exist, these have not been well exploited in cotton for improved genotype development.


Any Questions?