Foliar fertilization: Principals and Practices

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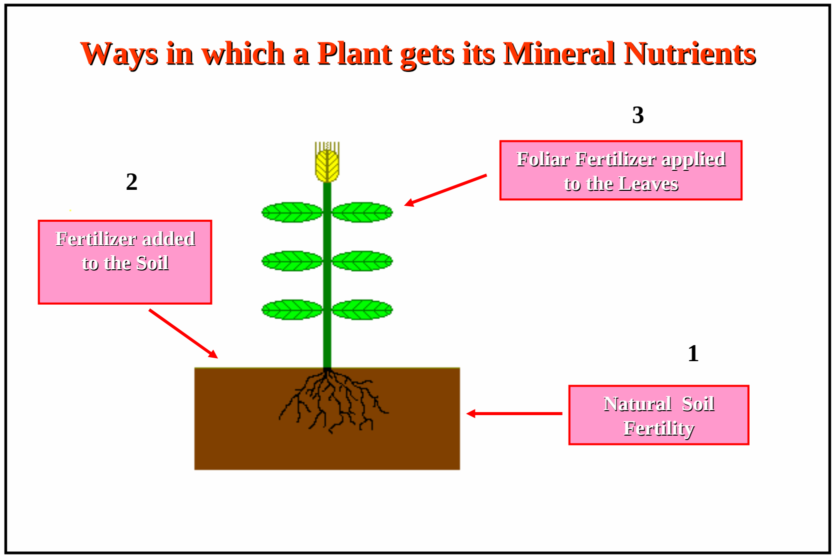
Outline of My Talk:

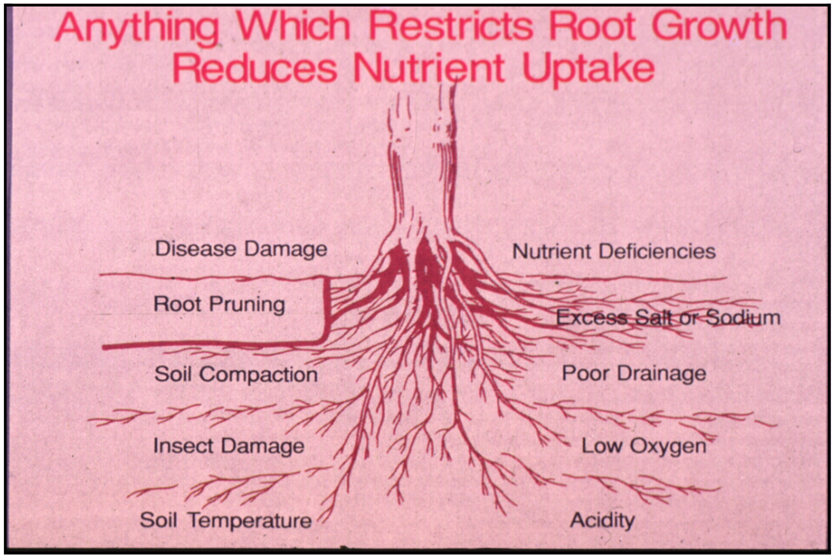
Characterization of the leaf Surface, Absorption of Foliar-Applied Chemicals, and factors Affecting the Efficiency of Uptake

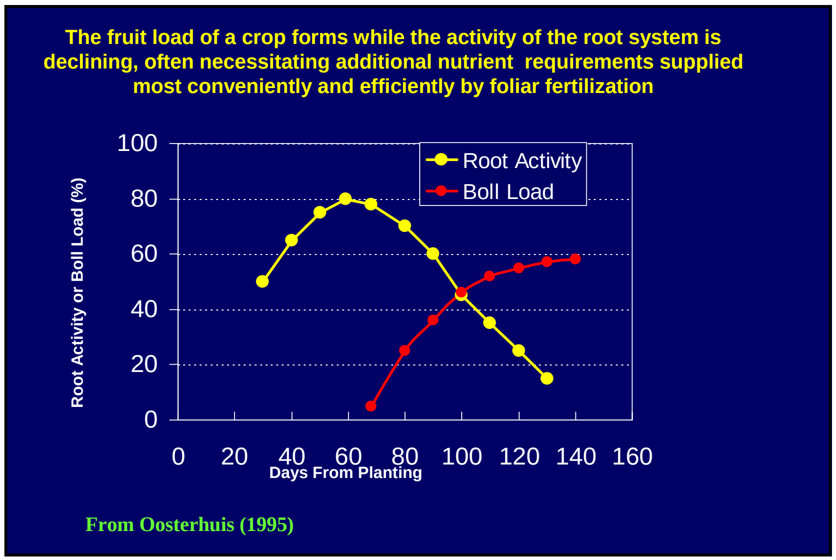
- Requirements of Plant Nutrition
- Definition of Foliar fertilization
- Absorption of foliar-applied nutrients
- Structure and Function of the leaf cuticle
- Factors affecting foliar fertilization
- Some new information on the use of EDTA in foliar sprays
- Advantages and Disadvantages of foliar fertilization

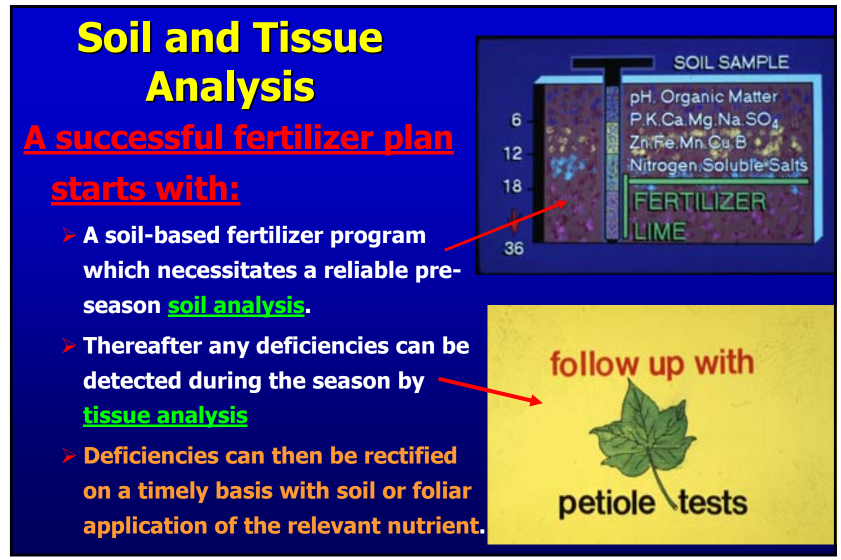
Plant Nutrition

- Proper plant nutrition for optimal productivity in crops requires that nutrient deficiencies be avoided.
- However, deficiencies occur for a variety of reasons, most of which can be rectified by:
  - Use of soil and tissue tests
  - Timely applications of nutrients
  - An understanding of crop requirements


Ways in which a Plant gets its Mineral Nutrients
3
Foliar Fertilizer applied to the Leaves
2
Fertilizer added to the Soil
1
Natural Soil Fertility


Anything Which Restricts Root Growth Reduces Nutrient Uptake
Disease Damage
Nutrient Deficiencies
Root Pruning
Excess Salt or Sodium
Soil Compaction
Poor Drainage
Insect Damage
Low Oxygen
Soil Temperature
Acidity


The fruit load of a crop forms while the activity of the root system is declining, often necessitating additional nutrient requirements supplied most conveniently and efficiently by foliar fertilization
Root Activity
Boll Load
Root Activity or Boll Load (%)
0
20
40
60
80
100
0
20
40
60
80
100
120
140
160
Days From Planting
From Oosterhuis (1995)


Soil and Tissue Analysis
A successful fertilizer plan starts with:
A soil-based fertilizer program which necessitates a reliable pre-season soil analysis.
Thereafter any deficiencies can be detected during the season by tissue analysis
Deficiencies can then be rectified on a timely basis with soil or foliar application of the relevant nutrient.
SOIL SAMPLE
pH, Organic Matter
P,K,Ca,Mg,Na,SO4
Zn,Fe,Mn,Cu,B
Nitrogen,Soluble Salts
FERTILIZER
LIME
6
12
18
36
follow up with
petiole tests

Definition of Foliar Fertilization

- **The application of foliar sprays of one or more mineral nutrients to plants to supplement traditional soil applications of fertilizers.**

Foliar Fertilization Historically

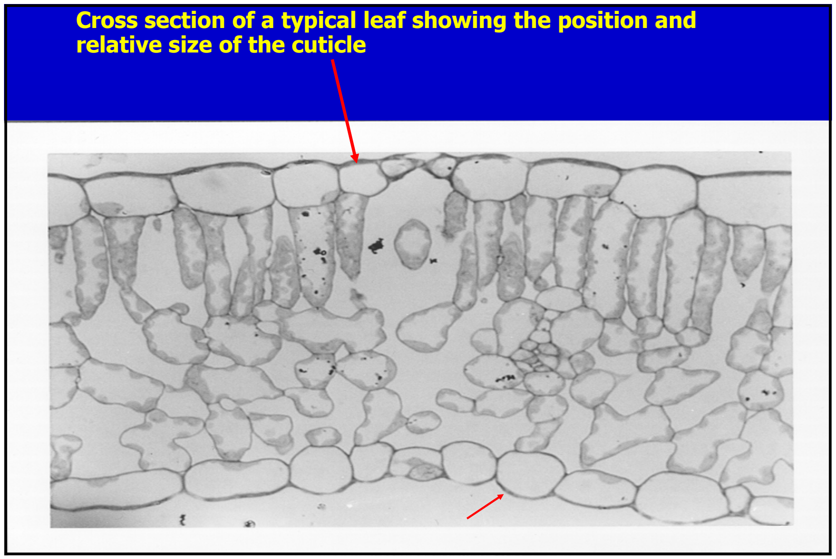
- **There is a wealth of literature about foliar fertilization which was first used as long ago as 1844 to correct plant chlorosis with foliar sprays of iron (Gris, 1844).**
- **Used widely and for many years in horticulture (fruit and vegetables)**
- **In row-crop agriculture the practice has only caught on in the past two decades, although there is still some speculation about the benefits and correct implementation of this practice (Oosterhuis, 2003).**

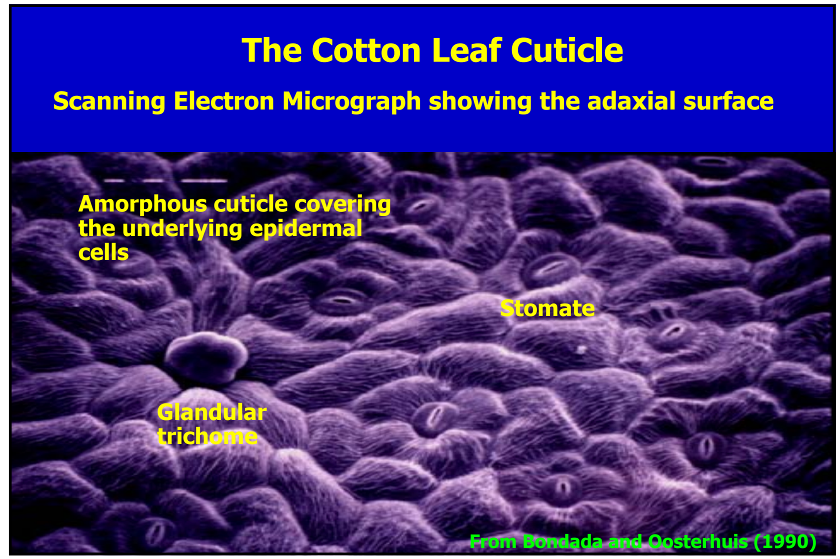
Mechanism of Foliar Fertilization

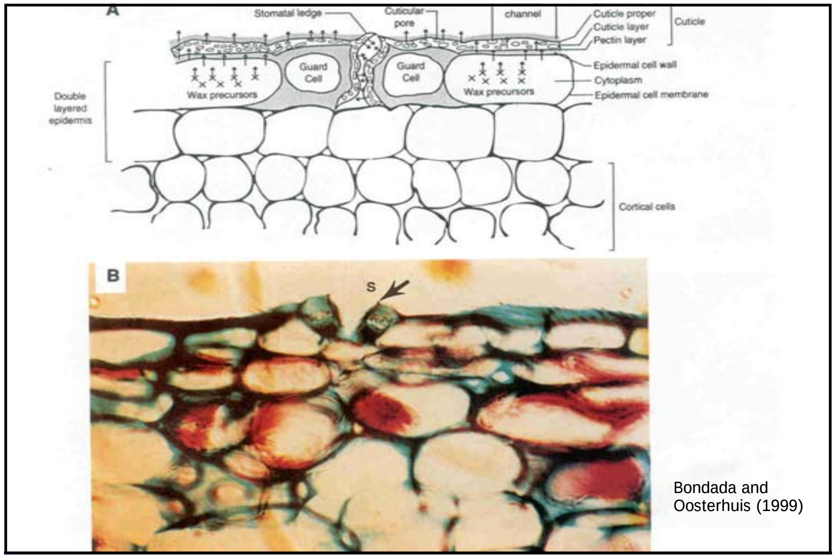
- In order for a foliar fertilizer nutrient to be utilized by the plant for growth, it must first gain entry into the leaf prior to entering the cytoplasm of a cell in the leaf.
- To achieve this the nutrient must effectively penetrate the the outer cuticle and the wall of the underlying epidermal cell.
- Once penetration has occurred, nutrient absorption by the cell is similar to absorption by the roots.
- Of all the components of the pathway of foliar-applied nutrients, the cuticle offers the greatest resistance.

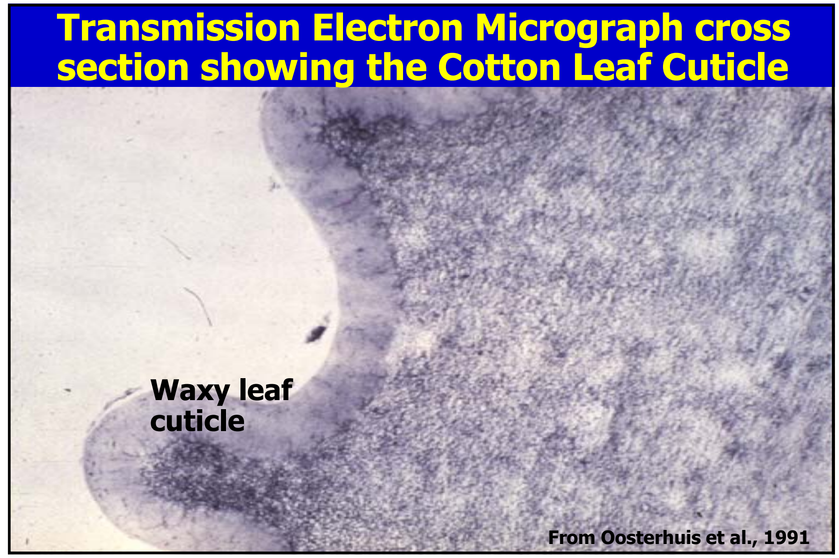
The Leaf Cuticle

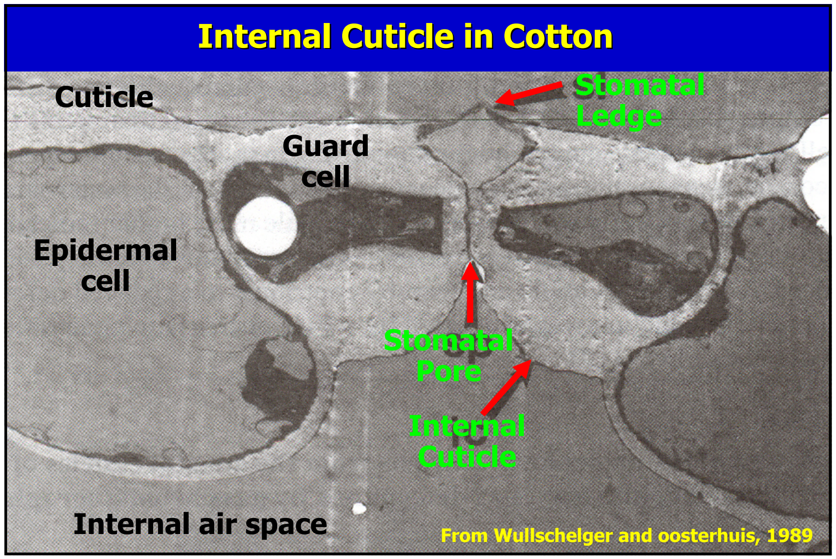
- The leaf Cuticle is is a thin covering on the outside of the leaf and other organs which protects the plant from the extremes of the environment.
- The cuticle is dynamic and responds to changes in the environment and also to management:
  - e.g. drought stress and extreme temperatures.

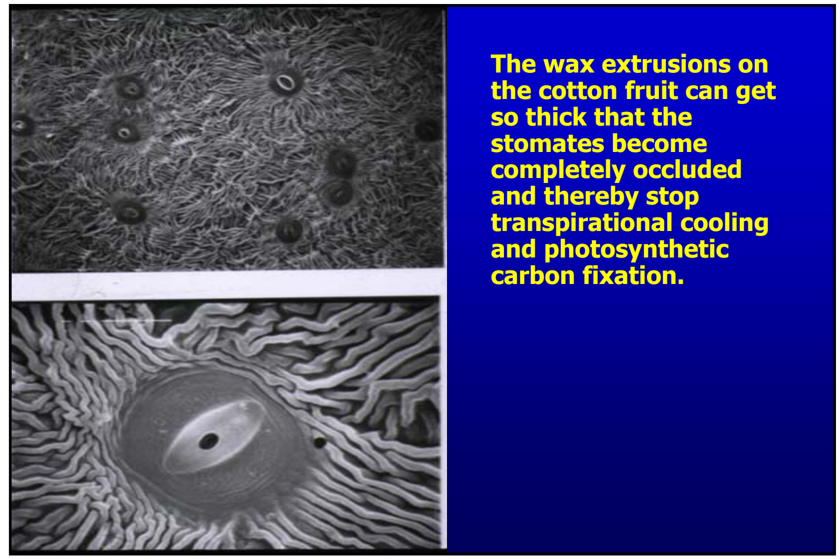

Cross section of a typical leaf showing the position and relative size of the cuticle

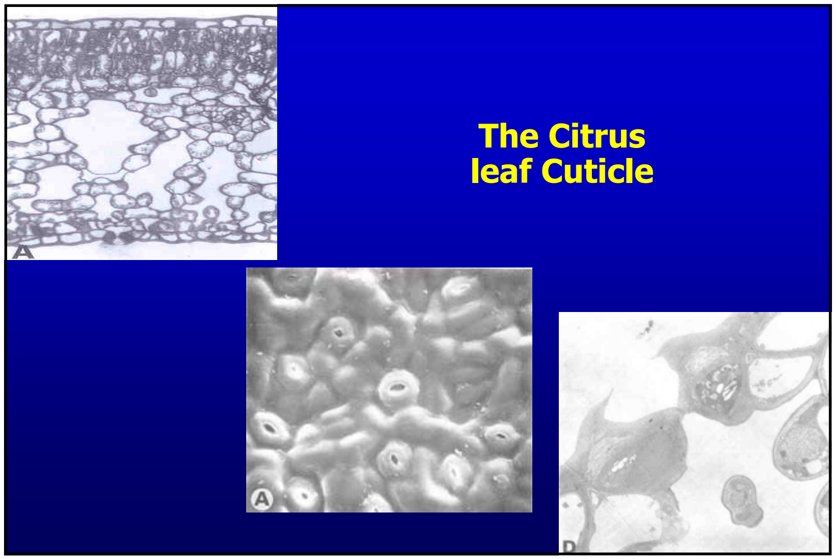

The Cotton Leaf Cuticle
Scanning Electron Micrograph showing the adaxial surface
Amorphous cuticle covering the underlying epidermal cells
Stomate
Glandular trichome
From Bondada and Oosterhuis (1990)


A
Stomatal ledge
Cuticular pore
channel
Cuticle proper
Cuticle layer
Pectin layer
Cuticle
Guard Cell
Guard Cell
Wax precursors
Wax precursors
Epidermal cell wall
Cytoplasm
Epidermal cell membrane
Double layered epidermis
Cortical cells
B
S
Bondada and Oosterhuis (1999)


Transmission Electron Micrograph cross section showing the Cotton Leaf Cuticle
Waxy leaf cuticle
From Oosterhuis et al., 1991


Internal Cuticle in Cotton
Cuticle
Stomatal Ledge
Guard cell
Epidermal cell
Stomatal Pore
Internal Cuticle
Internal air space
From Wullschelger and oosterhuis, 1989


The wax extrusions on the cotton fruit can get so thick that the stomates become completely occluded and thereby stop transpirational cooling and photosynthetic carbon fixation.



Movement of Nutrients Through the Cuticle

- Originally it was held that movement of solutes occurred in ectodesmata (teikodes). However, it is now believed that cuticles are traversed by numerous hydrophilic pathways permeable to water and small solute molecules (Marschner, 1995).

- These pores have a diameter of <1nm, with a density of about 10^{10} pores/cm (Schonherr, 1976), and are lined with negative charges increasing in density towards the inside, facilitating movement of cations (Tyree et al., 1990).

- Actual movement through the cuticle depends on the nutrient concentration, molecular size, organic or inorganic form, time as a solution on the leaf surface, charge density across the cuticle etc.

Changes in the Leaf Cuticle with Water Deficit Stress

- Cuticle thickness was increased by 33%.
- Cuticle composition changed to predominantly high molecular weight (longer chain) waxes which increased the hydrophobicity.
- This caused a resultant decrease in uptake of agrochemicals (urea, defoliants etc).

(From Oosterhuis et al., 1991)

Changes in the Composition of the Adaxial Cuticle of Well-watered and Water-stressed Stressed Leaves of Field-grown Cotton.

Epicuticular Composition	Molecular Composition	Epicuticular Wax Composition: Well-watered	Epicuticular Wax Composition: Water-stressed
Tricosane	$C_{23}H_{48}$	+	-
n-Tetracosane	$C_{24}H_{50}$	+	-
Pentacosane	$C_{25}H_{52}$	+	+
Hexaconsane	$C_{26}H_{54}$	+	tr
Octocosane	$C_{28}H_{58}$	+	++
n-Nonacosane	$C_{29}H_{60}$	tr	++
Decasane	$C_{30}H_{62}$	tr	++
Octocosanol	$C_{28}H_{58}O$	+	++
Fucosterol	$C_{29}H_{48}O$	+	++

+ wax present, - wax absent, tr trace amount of wax

From oosterhuis et al., 1991

Select Examples of Foliar Fertilization

to illustrate the principals

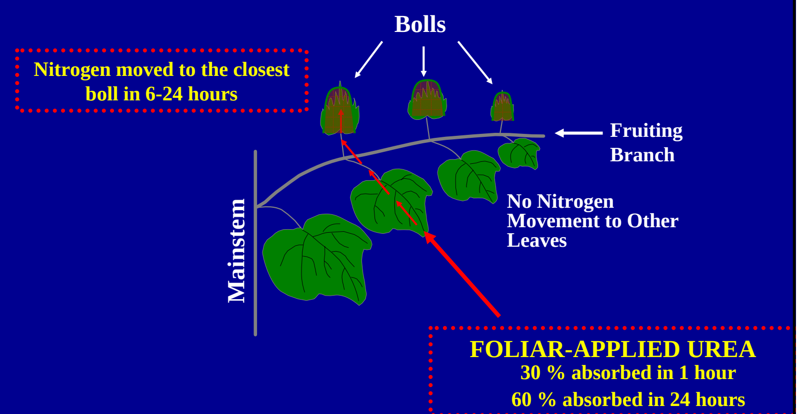
Foliar Fertilization with Nitrogen

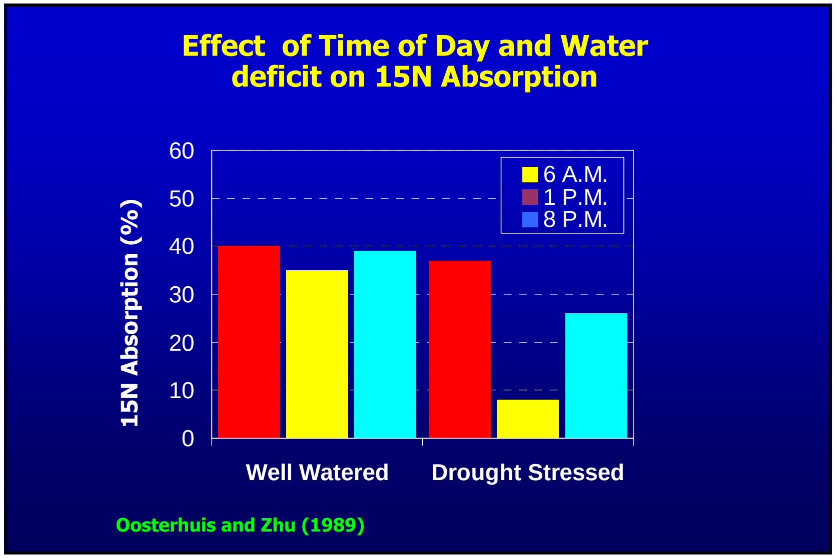
Importance of Nitrogen

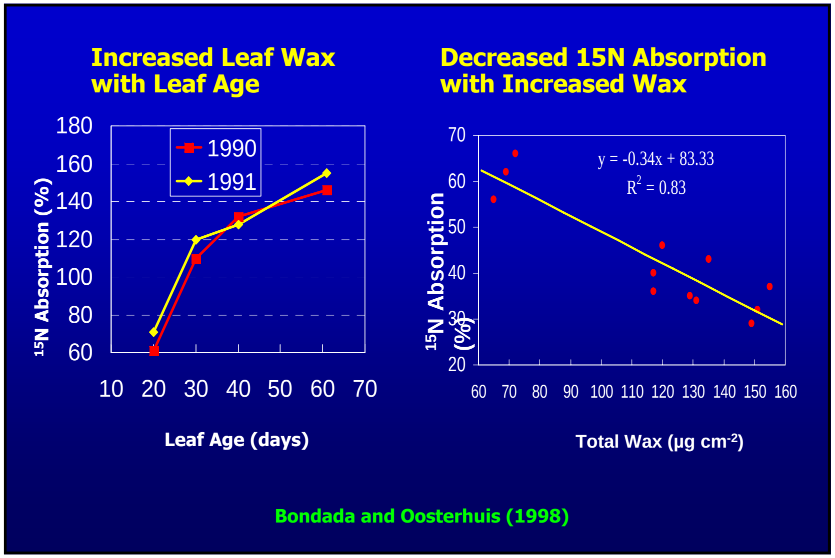
N deficient cotton

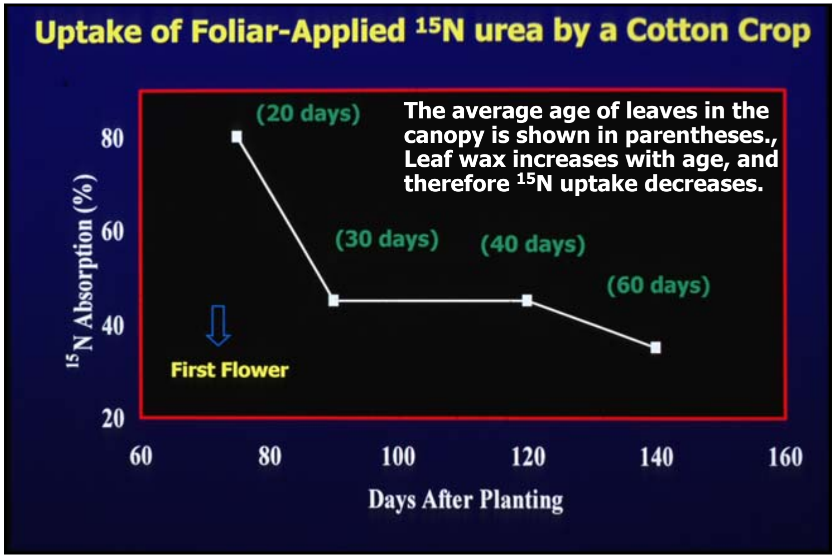
- Nitrogen (N) is the element needed in the greatest amount and is often limiting
- N is a constituent of proteins, nucleic acids, hormones and chlorophyll

The Uptake of Foliar-Applied Urea by Cotton Leaves and Movement to the Boll




Effect of Time of Day and Water deficit on 15N Absorption
15N Absorption (%)
60
50
40
30
20
10
0
6 A.M.
1 P.M.
8 P.M.
Well Watered
Drought Stressed
Oosterhuis and Zhu (1989)


Increased Leaf Wax with Leaf Age
Decreased 15N Absorption with Increased Wax
15N Absorption (%)
1990
1991
Leaf Age (days)
y = -0.34x + 83.33
R2 = 0.83
Total Wax (µg cm-2)
Bondada and Oosterhuis (1998)



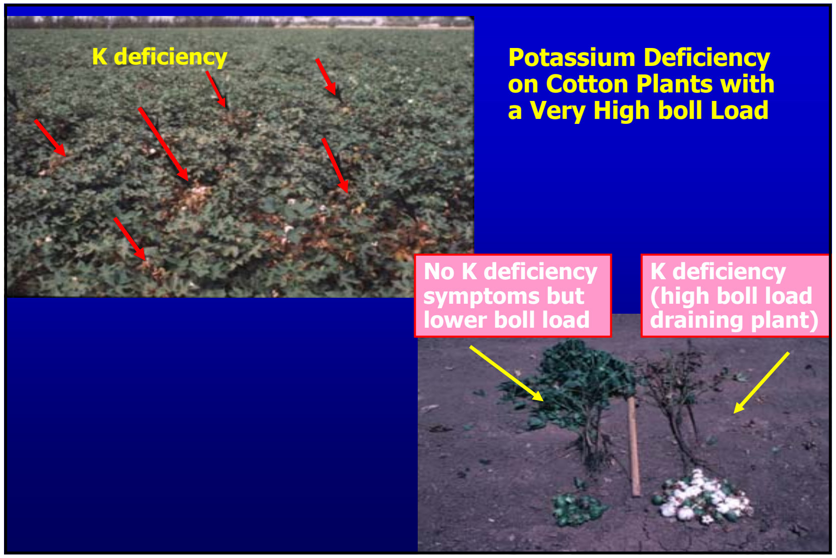
Foliar Fertilization with Potassium

Importance of Potassium (K)

- plant water relations
- plant metabolism
- photosynthesis &translocation
- fiber development and quality

Reasons for the widespread K deficiency in the US Cotton Belt

- **Occurs in soils not considered low in K. Cotton is relative inefficient at absorbing K from soils compared to other crops.**
- **The decrease in root activity as the boll load develops (during peak K demand).**
- **Modern deficiencies are due to the early-maturing, higher yielding, faster fruiting varieties.**



Foliar Feeding with K

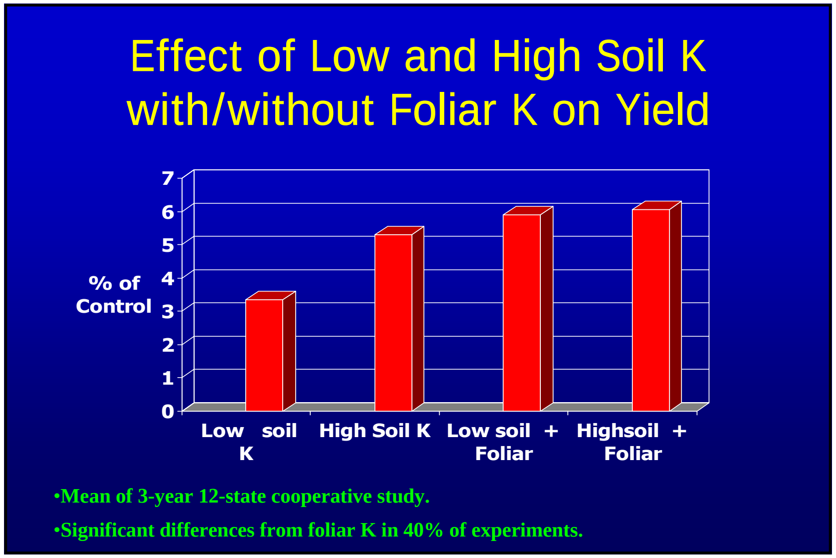
- Foliar K is a supplement to soil-applied K
- Timing: 4 weekly applications beginning at early flowering for maximum yield effect
- Rate: about 4 lb/acre per application

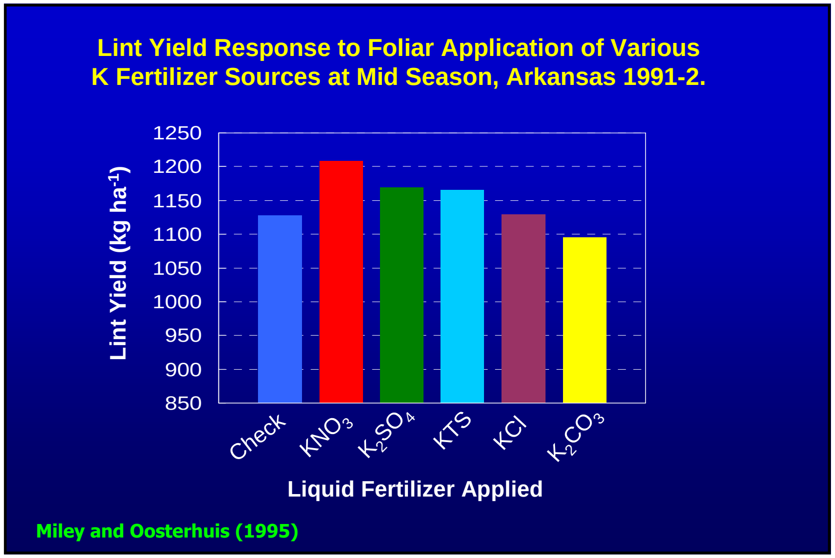
  Remember:
  - An average mature cotton crop requires about 100-220 kg K/ha
  - Required in large quantities by cotton up to 3-5 lb K/acre/day

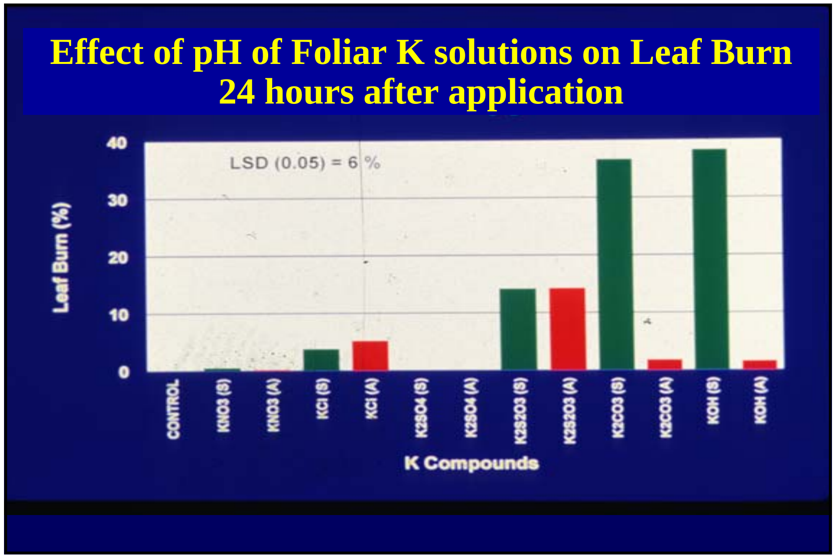
Effect of Foliar-Applied KNO_3 on Yield

Treatment	Seedcotton Yield kg/ha
Control	2,800
Foliar Urea	3,089
Foliar KNO3	3,150

Oosterhuis (1973)


Effect of Low and High Soil K with/without Foliar K on Yield
% of Control
0
1
2
3
4
5
6
7
Low soil K
High Soil K
Low soil + Foliar
Highsoil + Foliar
•Mean of 3-year 12-state cooperative study.
•Significant differences from foliar K in 40% of experiments.


Lint Yield Response to Foliar Application of Various K Fertilizer Sources at Mid Season, Arkansas 1991-2.
Lint Yield (kg ha-1)
850
900
950
1000
1050
1100
1150
1200
1250
Check
KNO3
K2SO4
KTS
KCl
K2CO3
Liquid Fertilizer Applied
Miley and Oosterhuis (1995)



Effect of Soil and Foliar K on Cotton Yield and Fiber Quality

Treatment	Lint Yield (kg/ha	Length Uniformity (%)
Control	606 c	85.4 b
Soil-applied K	619 bc	85.8 b
Foliar-applied K	631 ab	87.1 a
Soil + foliar K	649 a	86.0 ab

Similar letters within a column are not significantly different (p=0.05)

Oosterhuis and Wullschleger (1990)

Foliar Sprays and EDTA

Foliar Sprays and EDTA

Chelating agents are often recommended to complex Fe, Mn, Zn, and Cu in foliar sprays, at considerable expense to the farmer. However, the scientific literature contains very limited information on the use of chelates in foliar fertilizers. One recent study shows that chelates slow FE3+ absorption into leaves (Schonherr et al., 2005).

Remember that the leaf cuticle is a hydrophobic layer, comprised of high molecular weight biopolymers such as cutin and suberins, and hydrophobic C14-C27 epiculticular waxes (Holloway, 1993). Recent physiological studies have identified the polar aqueous pores which facilitate absorption of charged ions into the epidermal cells (Schonherr, 2000). Nutrient absorption via aqueous pores is a relatively slow process, however, as the cuticle still represents the primary barrier for foliar nutrient absorption.

We hypothesized that the negative charge of metal-EDTA complexes and their high molecular weight would reduce the rate of trace element absorption through leaf cuticles. The narrow size and negative charge of aqueous pores may hinder the diffusion of anionic, high molecular weight species such as EDTA

Sorption of Zn and Fe fertilizers by the Citrus leaf Cuticle

Procedure:

- Leaf discs were cut with a cork borer
- Cuticles were removed from the discs by pectinase solution
- Cuticles were rinsed in double de-ionized water
- Immersed in 1 mM $ZnSO_4$ and $FeSO_4$ solutions for 8 hours
  Either as the sulfate or as a chelate (1 mM EDTA)
- Removed, rinsed, , digested and analyzed for the metal

Absorption of Zn and Fe Fertilizers by enzymatically excised *Citrus sinensis* leaf cuticles

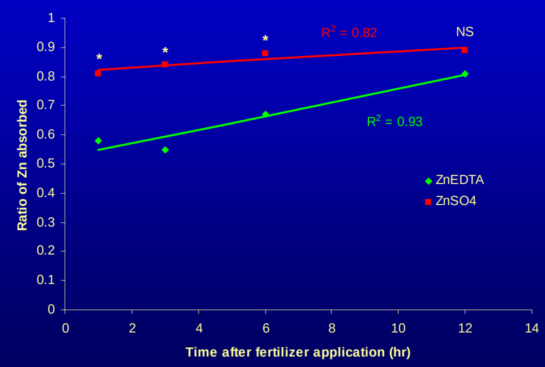
Fertilizer	Sorption of leaf cuticle (µg metal/mg cuticle)	
	Fe	Zn
Chelate free	10.72±1.47	2.87±0.11
Plus EDTA	0.45±0.57	0.48±0.05

Sorption of Zn and Fe fertilizers by Cotton Plants

Procedure:

- **Plants grown in pots until 5-weeks old**
- **Sprayed with 1 mM Zn fertilizer treatments:**
- **$ZnSO_4$ and ZNEDTA**
- **Simulated rain (12.5 mm/30min) after 1, 3, 6, and 12 hours**
- **Leaves harvested, dried, ground, digested in HNO3 and analyzed**

Absorption of Foliar-applied $ZnSO_4$ and ZnEDTA by Cotton Plants



* Significant at P=0.05

From Stacey and Oosterhuis 2006

Advantages of Foliar Fertilization

- Can react rapidly to symptoms or tissue analysis
- Rapid plant response for correcting deficiency
- Avoids soil problems
- Relatively low cost
- Only use small amounts of fertilizer
- No foliar burn (with KNO3 or K2SO4)
- Improved yield and fiber quality parameters

Disadvantages of Foliar Fertilization

- Only a limited amount of the nutrient can be applied at one time.
- Cost of multiple applications can be prohibitive.
- Possibility of foliar burn (with high concentrations).
- Low solubility of some fertilizers especially in cold water.
- Incompatibility with certain other agrochemicals.

Concluding statement...........

The complexity of crop growth, and sensitivity to the environment means that farmers need to:

- Understand the development of the crop.
- Know the specific requirements for each stage.
- Manage the crop according to requirements, environment and yield potential.
- Foliar fertilization provides a means of efficiently applying required mineral nutrients to a crop when tissue tests show a need (or visual deficiency symptoms appear)
- **However, foliar fertilization will only work if attention is applied to the basic practice as has been outlined in this presentation**