Plant Nutrition Basics: Understanding the Principles to Optimize the Practices.

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Mike Mason's Challenge: How Should I Fertigate?

- What tools (leaf, soil, water) should I be using?
  - All of them (if done right), plus a little bit of plant nutrition understanding, and:
  - Adjust fertilizer rates annually according to recent and likely yield
- Are university guidelines for critical values still viable?
  - Yes, but proper sampling is really difficult and you cannot manage on sampling alone
- Is there any basis to foliar fertilizers and 'specialty products' and what questions should I ask before I give it a try?
  - Foliars = Yes and 'Specialties' = maybe!
  - 1) what is the biology and 2) can an improvement be measured and 3) is it economic?

Ideal Nutrient Management Approach
-the 4 R's-

- Applying the Right Rate
  - Match demand with supply (all inputs- fertilizer, organic N, water, soil).
- At Right Time
  - Maximize uptake minimize loss potential.
- In the Right Place
  - Ensure delivery to the active roots.
- Using the Right Source
  - Maximize uptake minimize loss potential.

How, Why, When, Where and What of Tree Nutrition

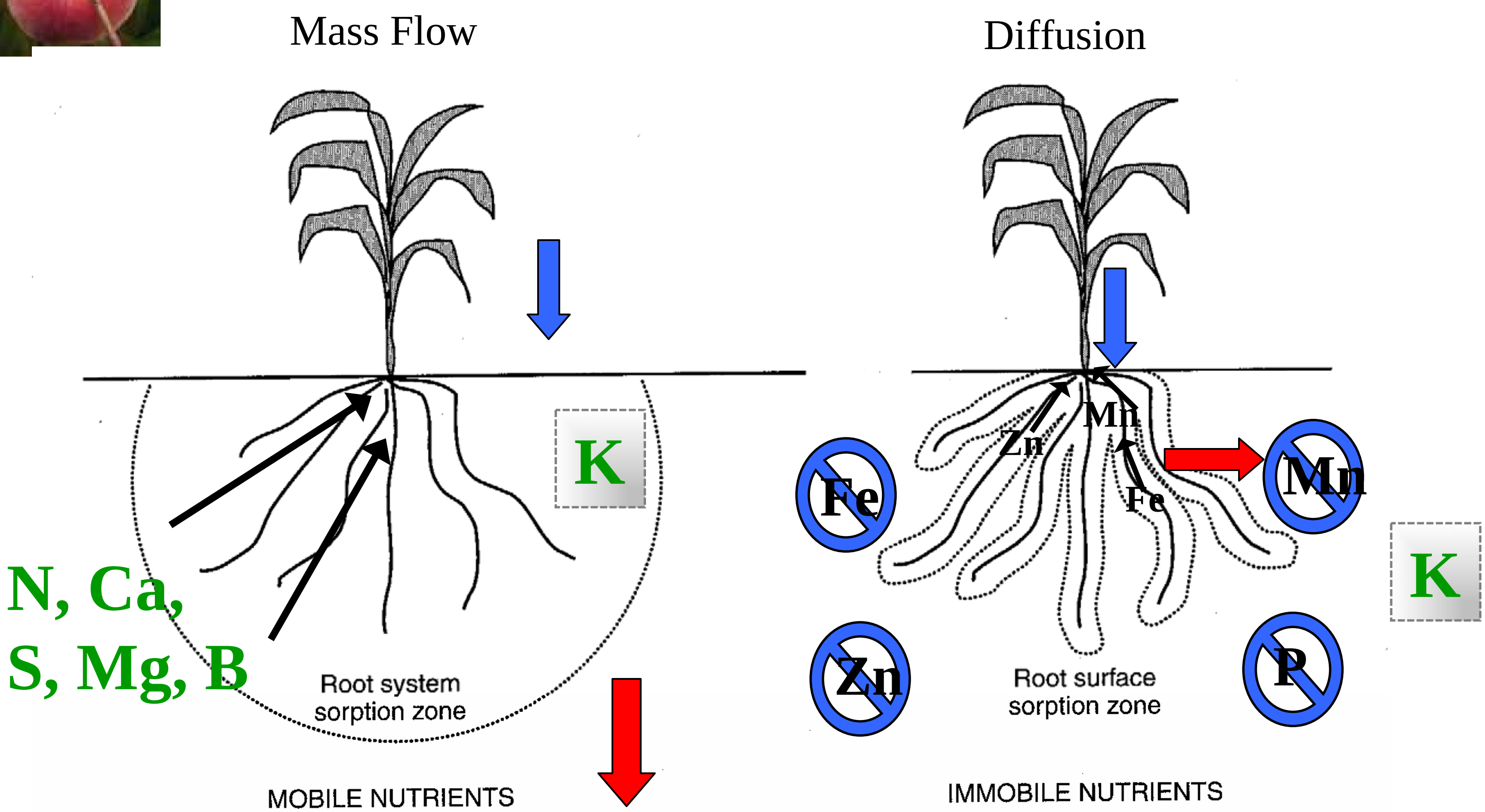
Principles:

- How are nutrients acquired by plants
- Why are they needed, what is their function and how do they move in the plant.
- How much, when and where are they required.

Soil Supply Processes

- Nutrients move to the root in soil moisture
- Nutrient supply from a soil depends on:
  - The size of the nutrient ‘pool’ (your bank balance),
  - The ‘solubility’ of nutrients in the ‘pool’ (your ATM limit)
- Solubility is determined by soil minerals, pH, CEC, lime, organic matter content.
  - Optimized soil management, N source, fertilizer source
- Soils must allow root penetration, provide adequate water and oxygen for root growth.
  - Manage soil structure and irrigation.

Mass Flow versus Diffusion



Nitrogen, Ca, B, S, B and Cl are generally mobile in the soil while P, Mn, Zn, Fe are immobile and can only be obtained from soil in close proximity to the root surface. K is variable depending on soil type.

The uptake of immobile-nutrients (P, Zn, Fe, Mn) depends greatly on root ‘health’.

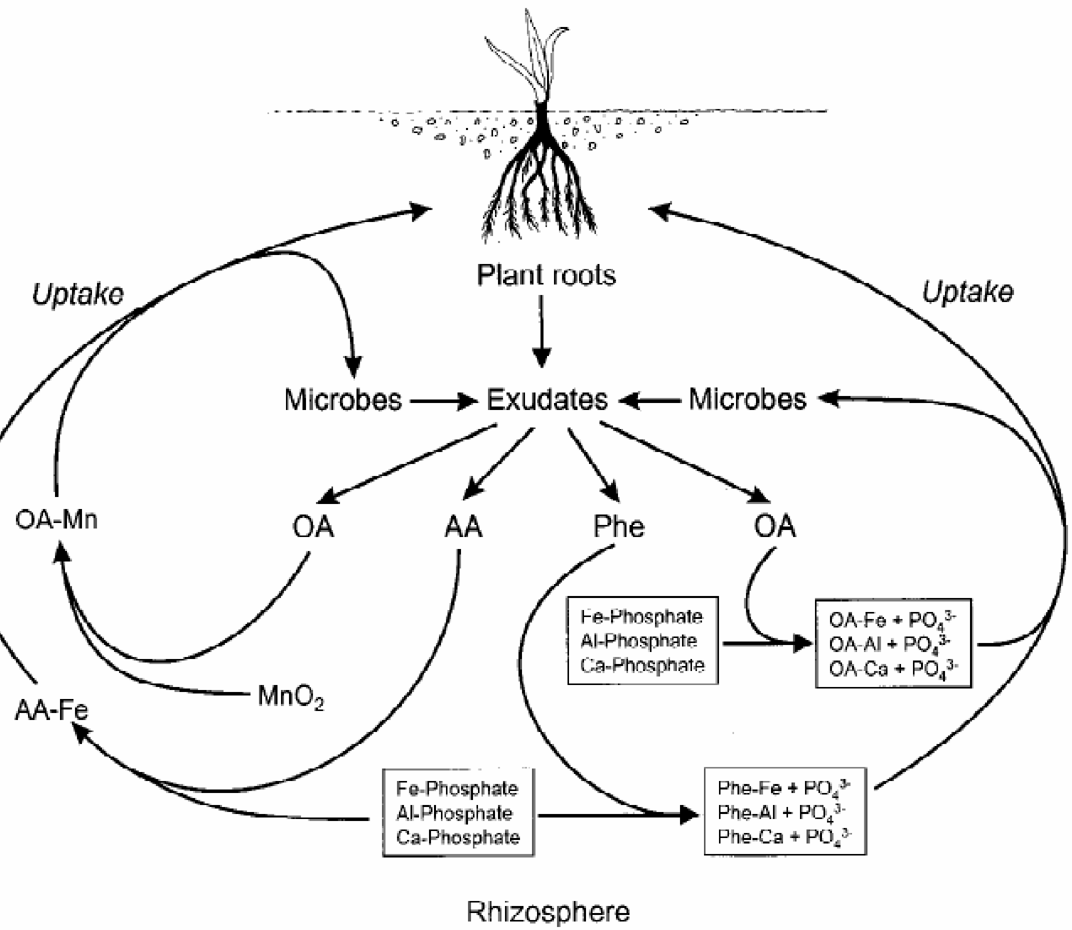
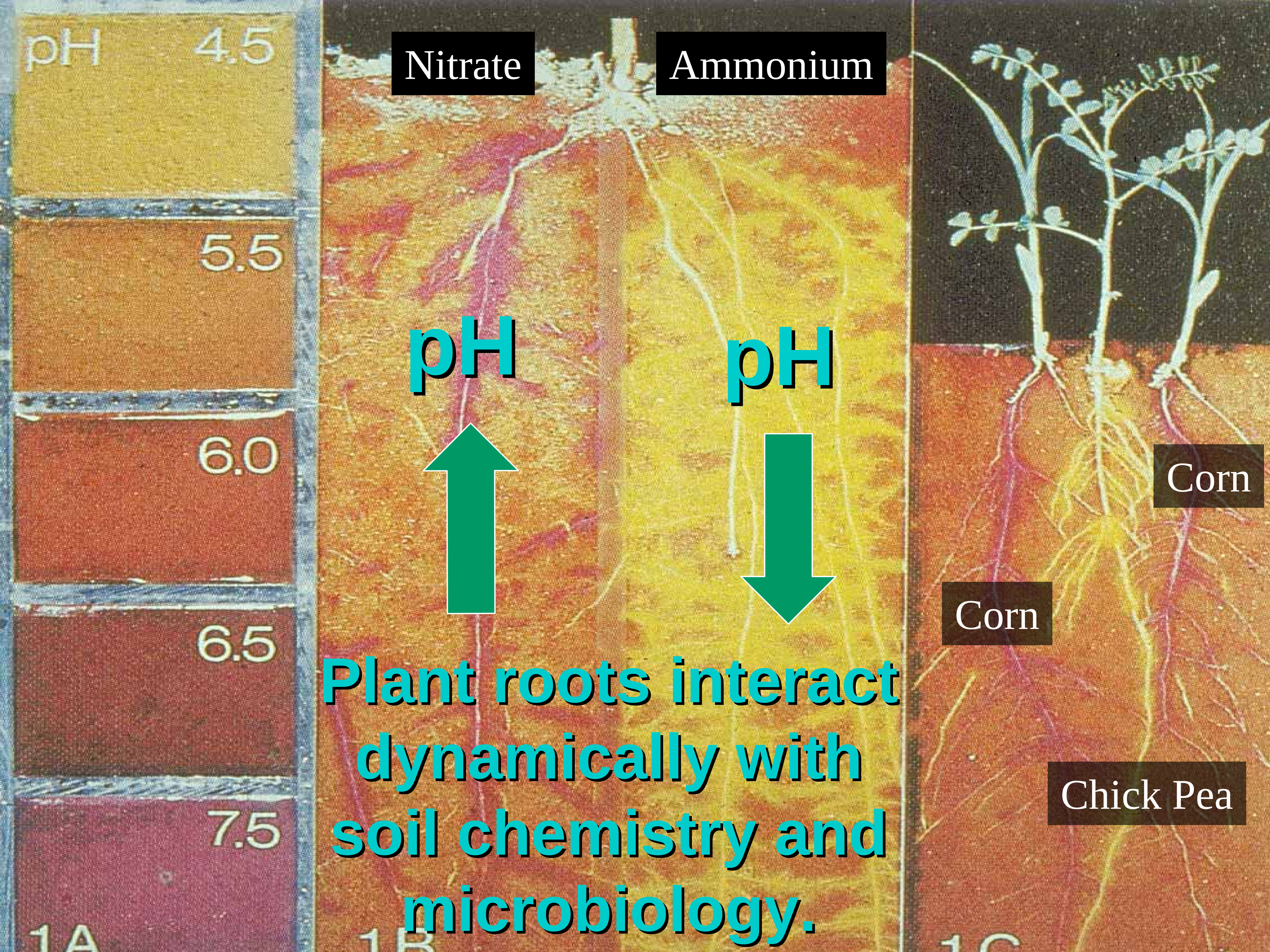


Figure 1. Effects of root exudate components on nutrient availability and uptake by plants and rhizosphere microbes. OA = organic acids; AA = amino acids including phytosiderophores, Phe = phenolic compounds.

Up to 50% of all photosynthesis is ‘exuded’ into root zone to access Zn, Fe, P.

In soils that ‘fix’ these elements root ‘health’, soil amendments or choice of fertilizer sources may be more important than amount of fertilizer.



Plant roots interact dynamically with soil chemistry and microbiology.

Quick Review

Soil Supply Processes

- Nutrients are taken up in water only by active roots.
  - Active root growth is required.
  - Water and oxygen are required for uptake
  - Leaves are required for nutrient uptake by roots
- Knowledge of the solubility of critical nutrients in your soil is essential
- N, S, Mg, Ca, B are mobile and soluble in most soils
  - Water movement delivers these nutrients to roots
  - Nutrients can be leached or displaced.
- Mn, Zn, Cu, Fe, P have restricted solubility and movement in soils, hence:
  - Root exploration and ‘soil health’ is critical
  - Nutrients and roots must be in the same place
  - Soils that limit root growth can cause Zn, Fe, Cu deficiencies
- K is mobile/available in some soils but not others
  - Soil tests to determine K-fixation are essential to K management.

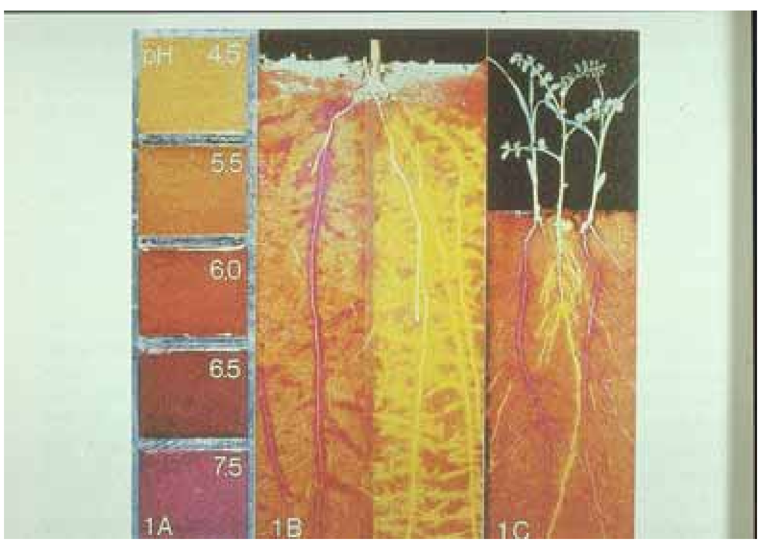
Soil Sampling and Analyses Challenges:

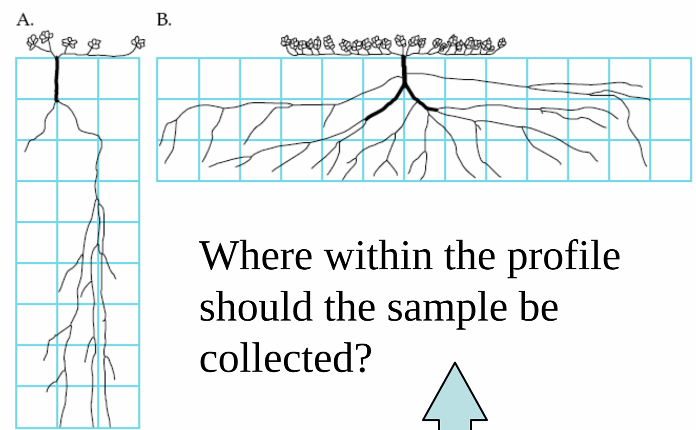
Challenges:

Where are the active roots?
What is the true solubility?
How healthy are the roots?
How does my irrigation interact?

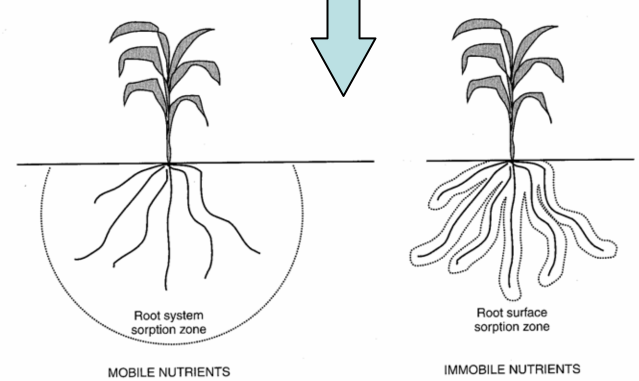
Plants Can Alter Their Rooting Environment

-Altered soil pH influences micronutrient uptake
-Species vary in their capacity to affect soil pH
-Fe deficiency and Nitrogen source can alter soil pH





Where within the profile should the sample be collected?



Micronutrients (excluding B and Cl) are immobile in the soil
and can only be obtained from soil in close proximity to the root surface.
Root growth and root patterns (fineness, depth etc) influence uptake.

Soil Testing (How and Why)

How:

- Collect soil samples that reflect where roots will be growing
- Collect samples from all parts of the orchard and build a ‘map’ of the whole property. Do it once, do it right and map the results – they don’t change.

What:

- Determine K, P fixation characteristics, residual N (?).
    - For micronutrients (with the exception of B), soil analyses of nutrient availability are of limited value.
- Soil tests that provide background information on general soil physical and chemical characteristics are essential for all orchards.
    - pH, Lime/Bicarbonate - as an index of potential solubility of natural and applied nutrients
    - CEC, OM as a measure of buffering capacity
    - Salinity, Toxic Elements, gross imbalances.
    - Soil physical characteristics (water movement and root development)

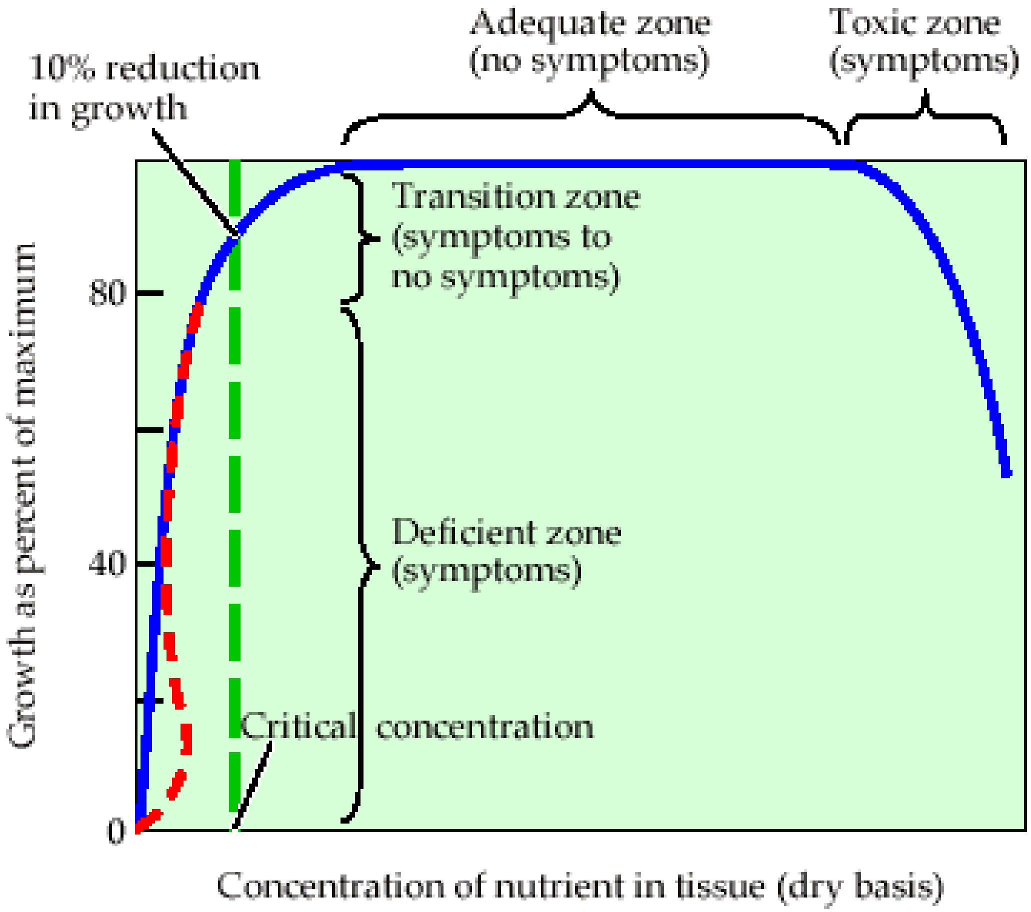
Leaf Sampling and Critical Values

Still valid after all these years??

What do we know and how do we manage?

Leaf Sampling and Critical Value Analysis in Orchard crops

(based on Ulrich @ U Calif in 1950-70's)



*Critical values for boron deficiency and toxicity are currently being revised. Hull boron >300 ppm is excessive. Leaf sampling is not effective to determine excess boron.

ງ the right leaf is difficult, sampling the
rly is very hard

y valid for July/August

/'s are not yield based

əld trials (N, K, B)

af symptoms (P, S, Mg, Ca, Mn, Zn,
Cu)

known (Ni, Cl, Mo)

ı of results (NO R'S!)

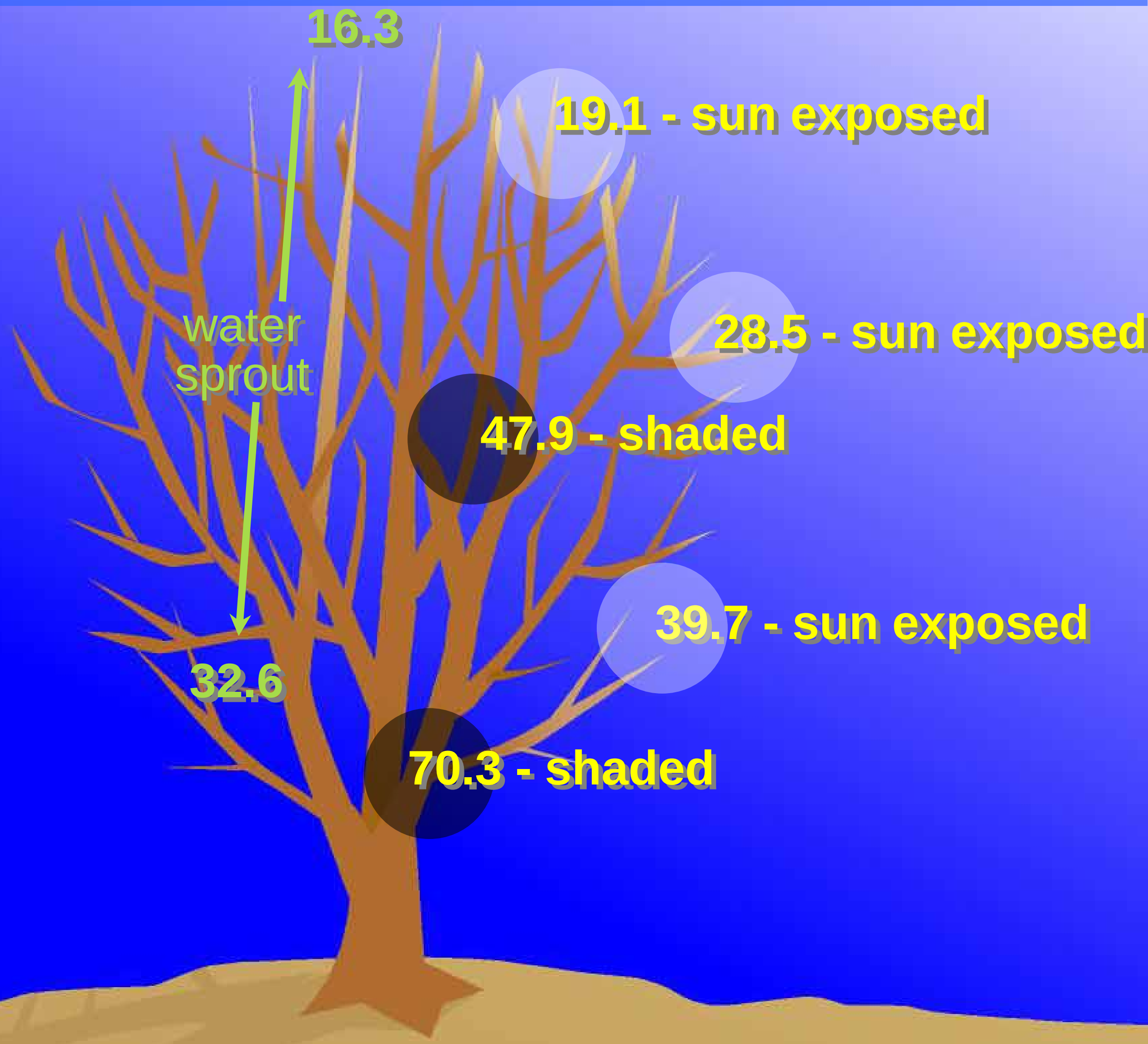
lysis can indicate a shortage but
ine how to respond.

nation on cause of deficiency

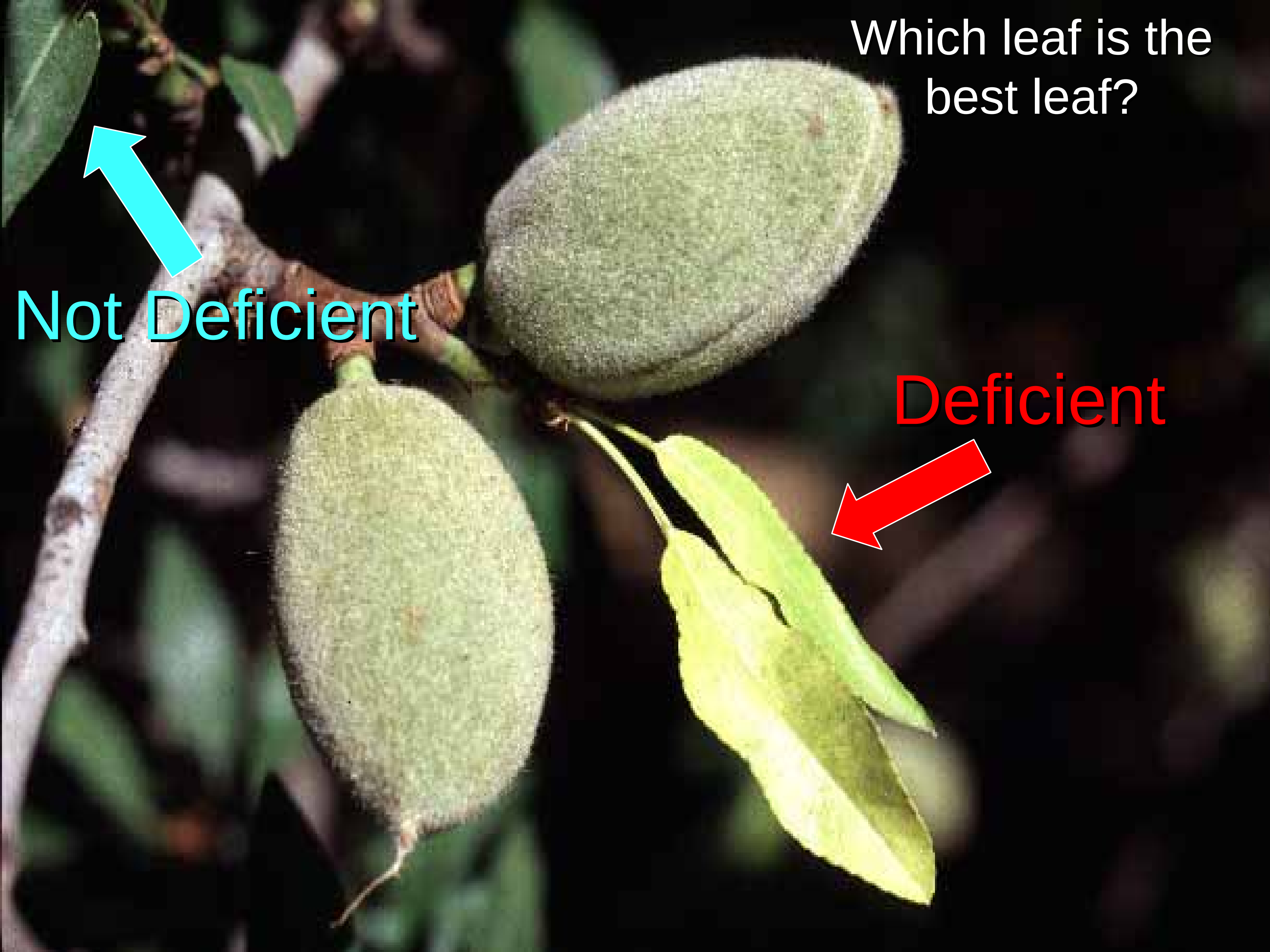
ınce on Rate, Timing, Placement or

Problem with leaf sampling: Sampling challenges.

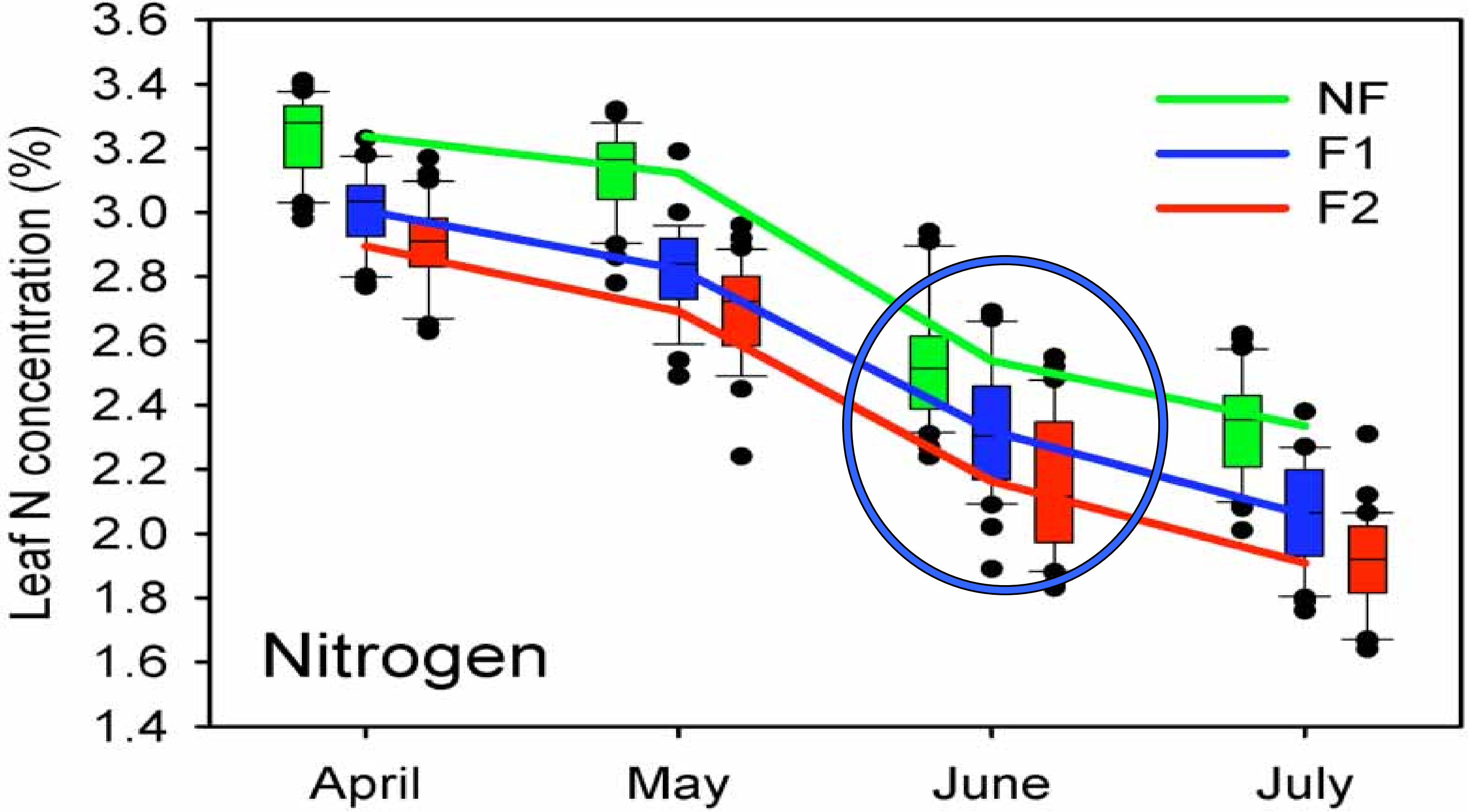
Shoot Zn Distribution Through A Dormant Peach Tree (ppm)



Standard Sample: Fully Exposed non-fruiting leaves in late summer


Which leaf is the best leaf?
Not Deficient
Deficient

Critical Values are based on July/August sample. Early season CV's have not been validated.



Current Practice: Late summer sample. Too late for current season response. Too early for next season planning (yield potential is defined by winter and spring weather)

Challenge: Develop early season sampling and interpretation methodologies.

Challenges of Sampling: Field Variability

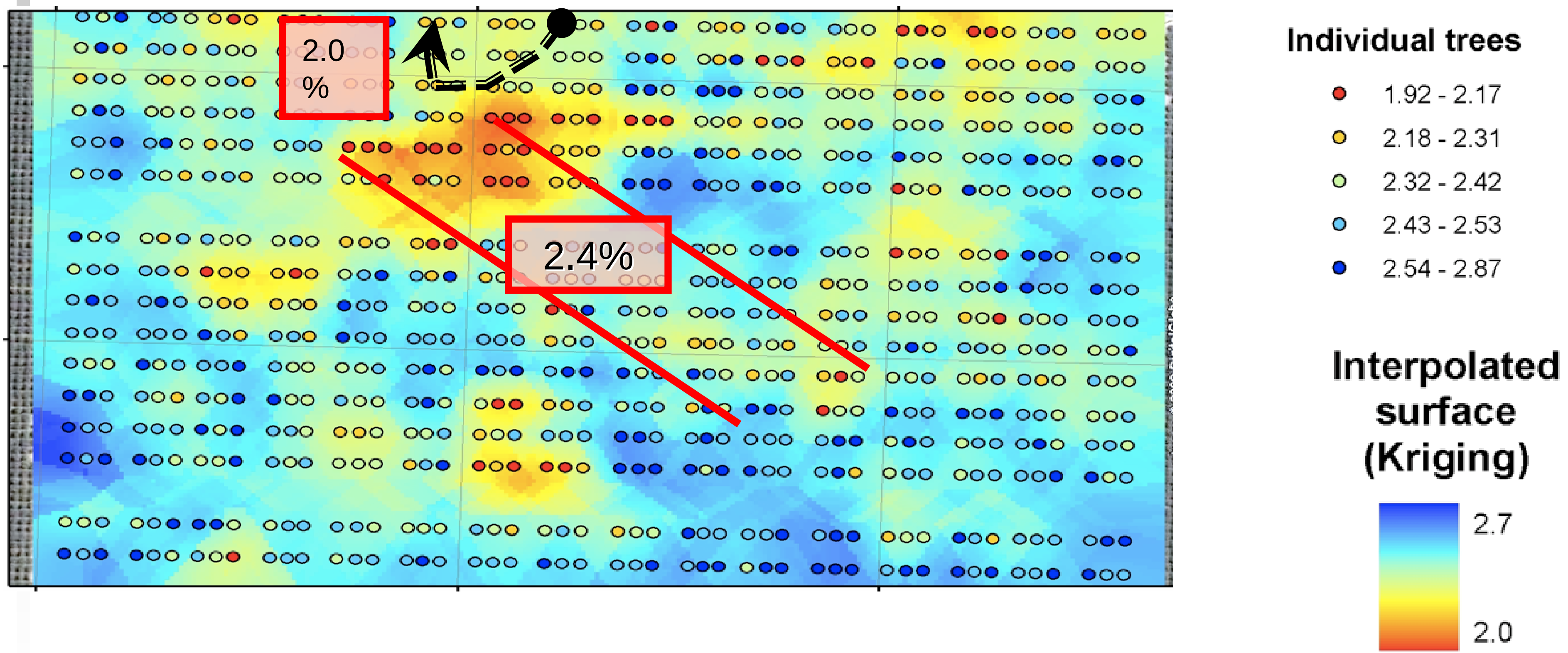
(768 individual tree samples. High producing ‘uniform’ orchard)

Typical Sampling: 1 pooled sample per management unit

(Hypothetical) Field Mean 2.4% N (June): Critical Value 2.4% = OK?

***No!**: Full productivity can only be achieved when all individuals are above 2.4%*

What is the right target mean? (variability:response:cost:returns:yield)



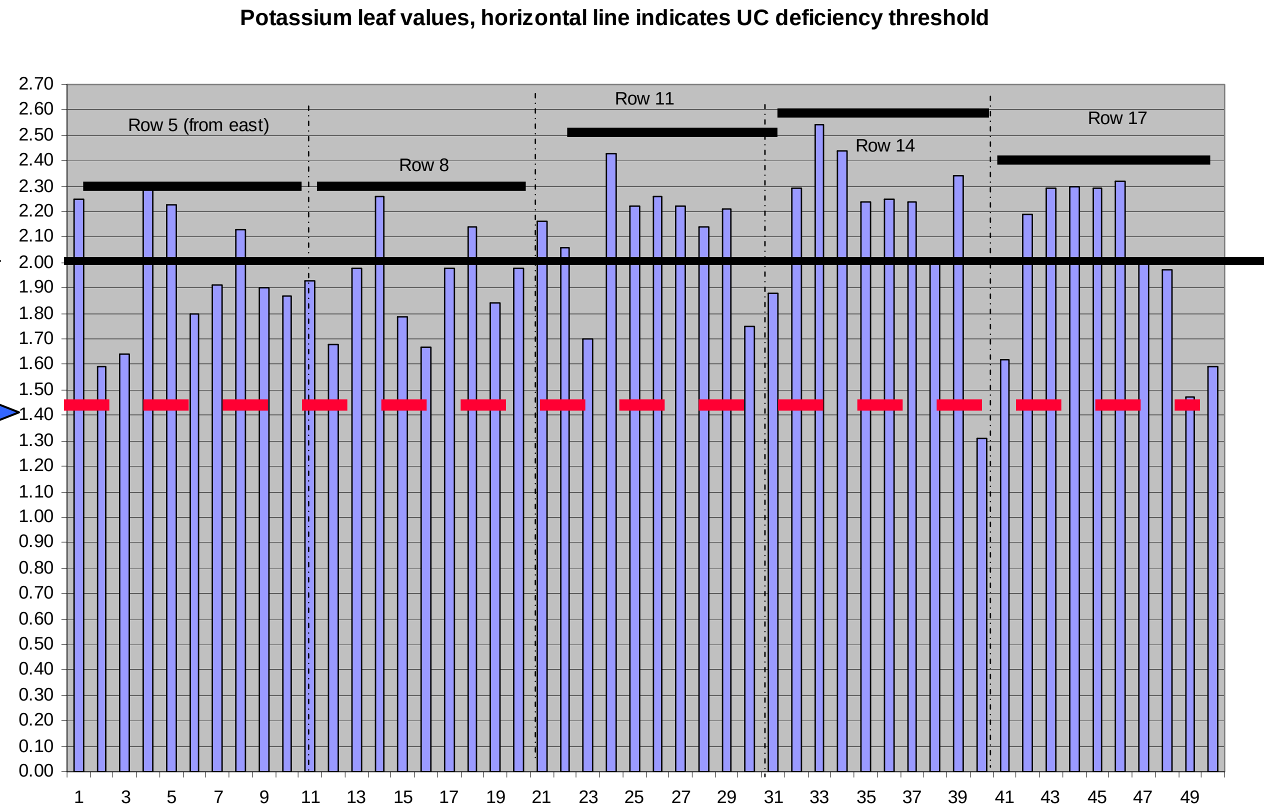
Challenge: Develop sampling protocols that incorporate variability, have a clear cost:return basis, while remaining cost effective.

Why are grower/industry CV's higher than UC recommends?

(Individual sample collected from each of 50 rows and analyzed separately)

Grower target CV = 2.0% K
(95% of trees are above 1.4%K)

University of California recommended CV = 1.4% K)



Summary: Tissue Testing for Almonds

- **Challenges**.
  - Difficult to sample properly and hard to interpret. Sampling in the way most people currently do it, is a waste of money.
  - Does not inform management practice
  - UC critical values are probably correct at a tree level but a single ‘pooled’ sample does not provide enough information at an orchard level
- **How to use it correctly**
  - Sample more and keep good records (location and year to year)
  - Follow trends over time, relate to yield
  - Develop improved lower cost (remote sensing, hand held meters etc).
  - Integrate sampling with a nutrient budget approach and an understanding of the processes.

Alternatives?

Alternate Approaches to Nutrient Management

Nutrient Budgeting

Replacing nutrients removed from the field

Essential Components and Challenges:

- Estimate demand (Last years yield, this years estimated yield, tree age, common sense)
  - Improved techniques are under development (remote sensing, modeling etc)
  - Yield monitoring
- Measure and control inputs and losses (soil, fertilizer, irrigation, leaching, volatilization)
- Manage efficiencies and interactions
  - Synchronization and location of nutrient applications
  - Monitoring crop response

How?

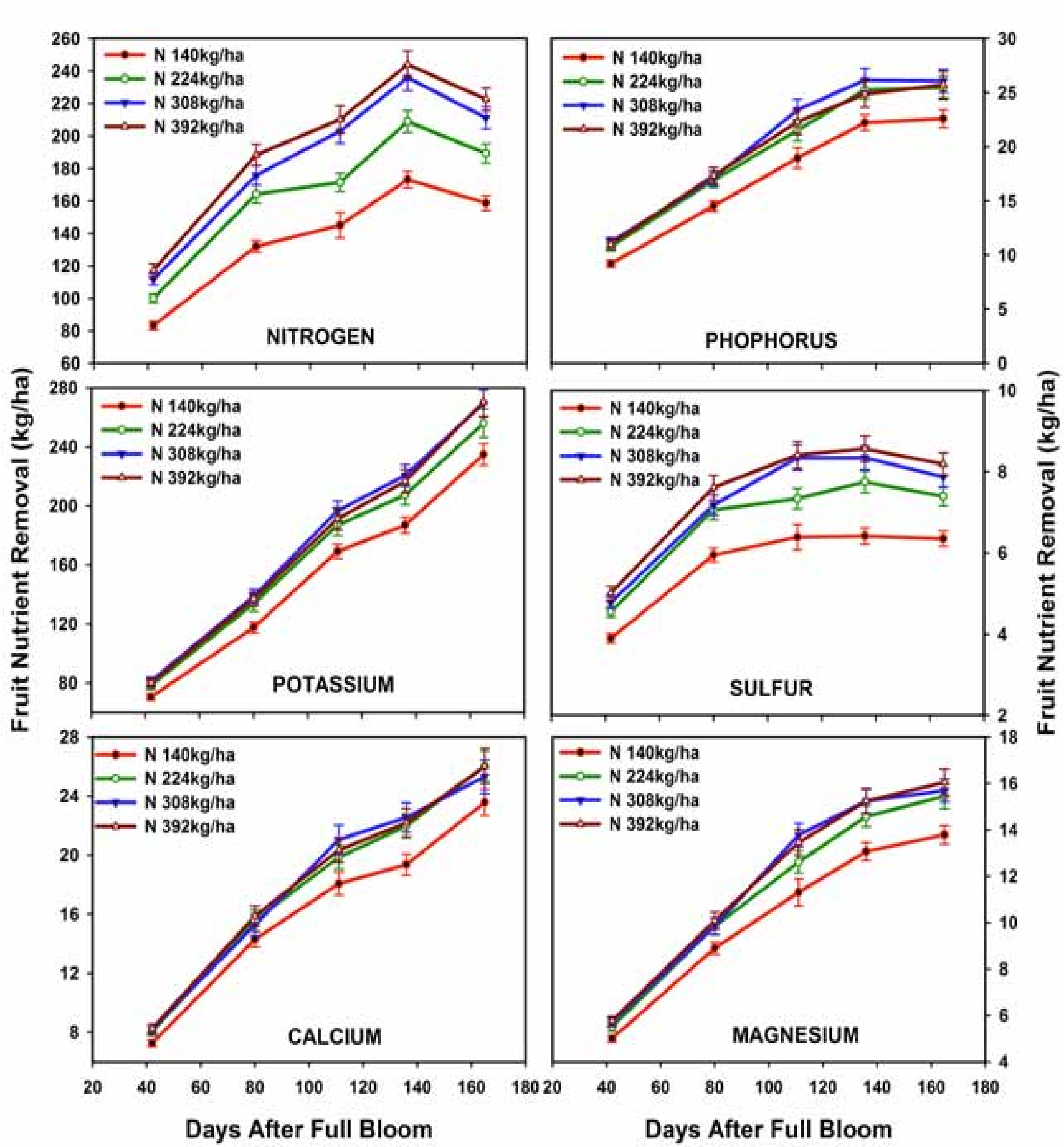
Estimating Nutrient Demand: Whole tree Harvesting:
5 mature trees x 5 times in a year

DEVELOP YIELD BASED FERTILIZATION GUIDELINES
768 individual tree analyses
2008, 2009, 2010

Optimized with local refinements:
- Site (Soil, environment, cultivar)
- Year and history
- Yield Potential
- Management practices and constraints

Nutrient	Nutrient Removal (lbs / 3560 kernel lb)	Nutrient Removal (lbs / 1000 kernel lb)
N	204	58
P	24	7
K	180	51

2009



Almond

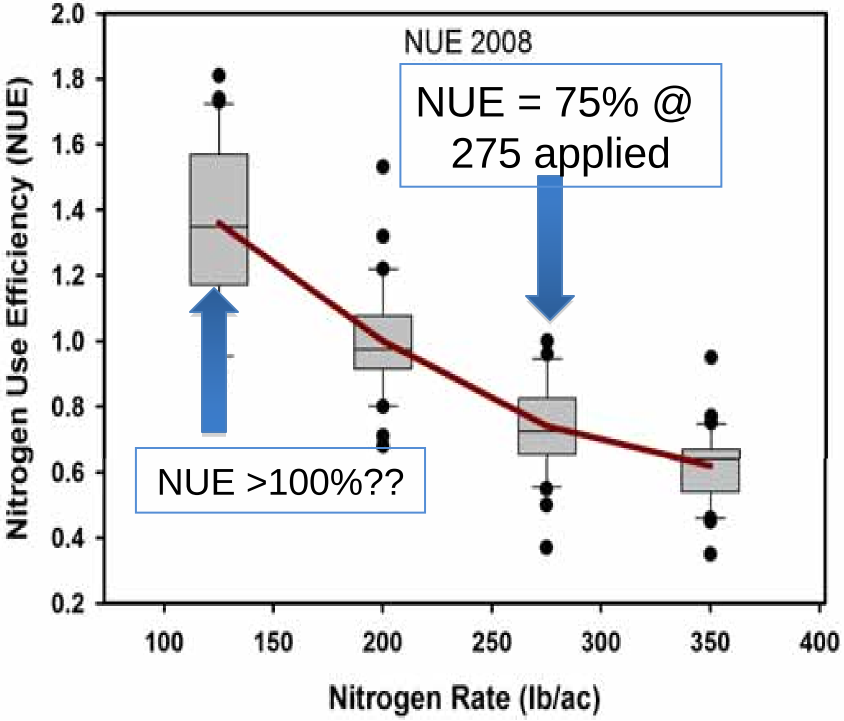
NITROGEN USE EFFICIENCY

(N removed in harvested fruit / N applied 758 trees measured in 2008)

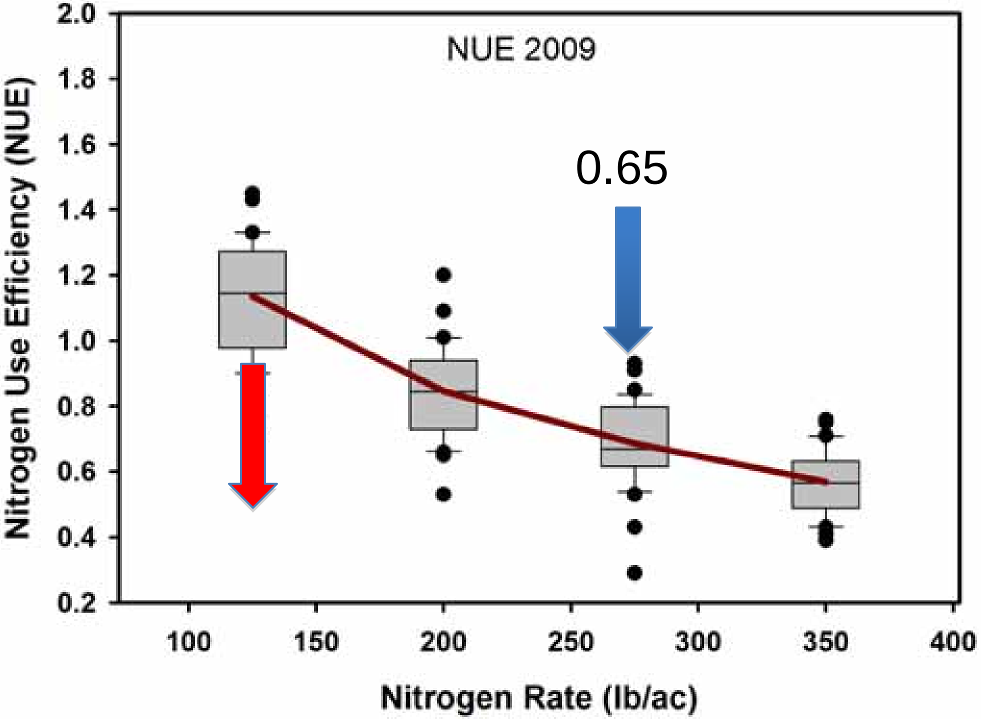
Fertigated: 4 times in-season timed with tree demand

Low rainfall, no leaching, low OM, neutral pH soils.

3700 lbs yield /210 lbs N



3300 lbs yield /180 lbs N



An NUE of 65-75% is among the highest ever measured in agriculture

Almond

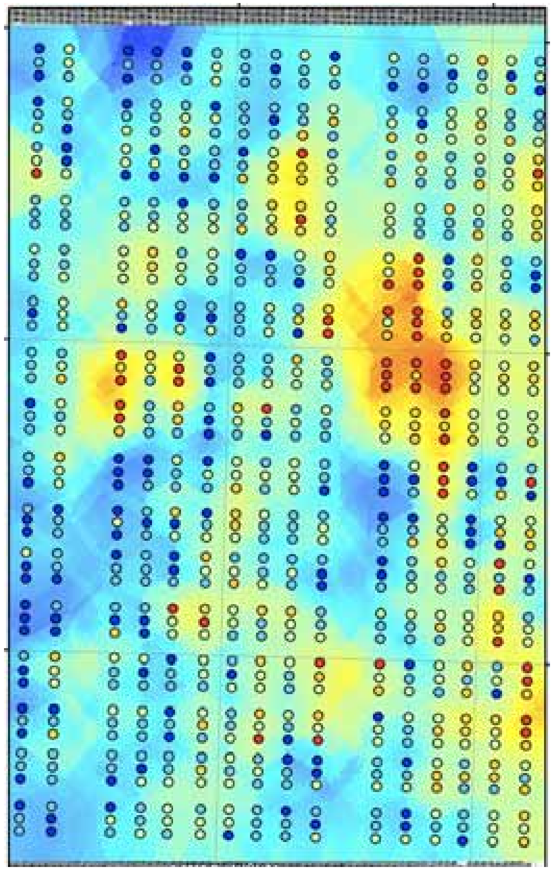
NITROGEN USE EFFICIENCY

An NUE of 65-75% is among the highest ever measured in agriculture – is that good enough?

70% efficiency = 50 lbs N/acre/yr (x $500,000^{+}$ acres)

= 25,000,000 lbs N/yr (current best case scenario)

- However small changes make a big impact.
    - A 25 lb reduction in N application or 15% increase in efficiency HALVES this N loss



<u>Challenges</u>:

Adapt fertilization to real yield potential

Apply N coincident with tree demand

Keep fertilizer N in the root zone

Manage variability

Monitor for soil and plant accumulation

What about the micronutrients?

Nutrient Function and Mobility in Plants

Function and mobility determine how, when and how much to fertilize.

Table 6.1: Mobility of mineral elements in the phloem.

Mobile	Low or No Mobility	
Potassium	Sodium	Calcium
Rubidium	Iron	Strontium
Nitrogen	Manganese	Barium
Magnesium	Zinc	Lithium
Phosphorus	Copper	
Sulfur	Molybdenum	
Chlorine		

Boron

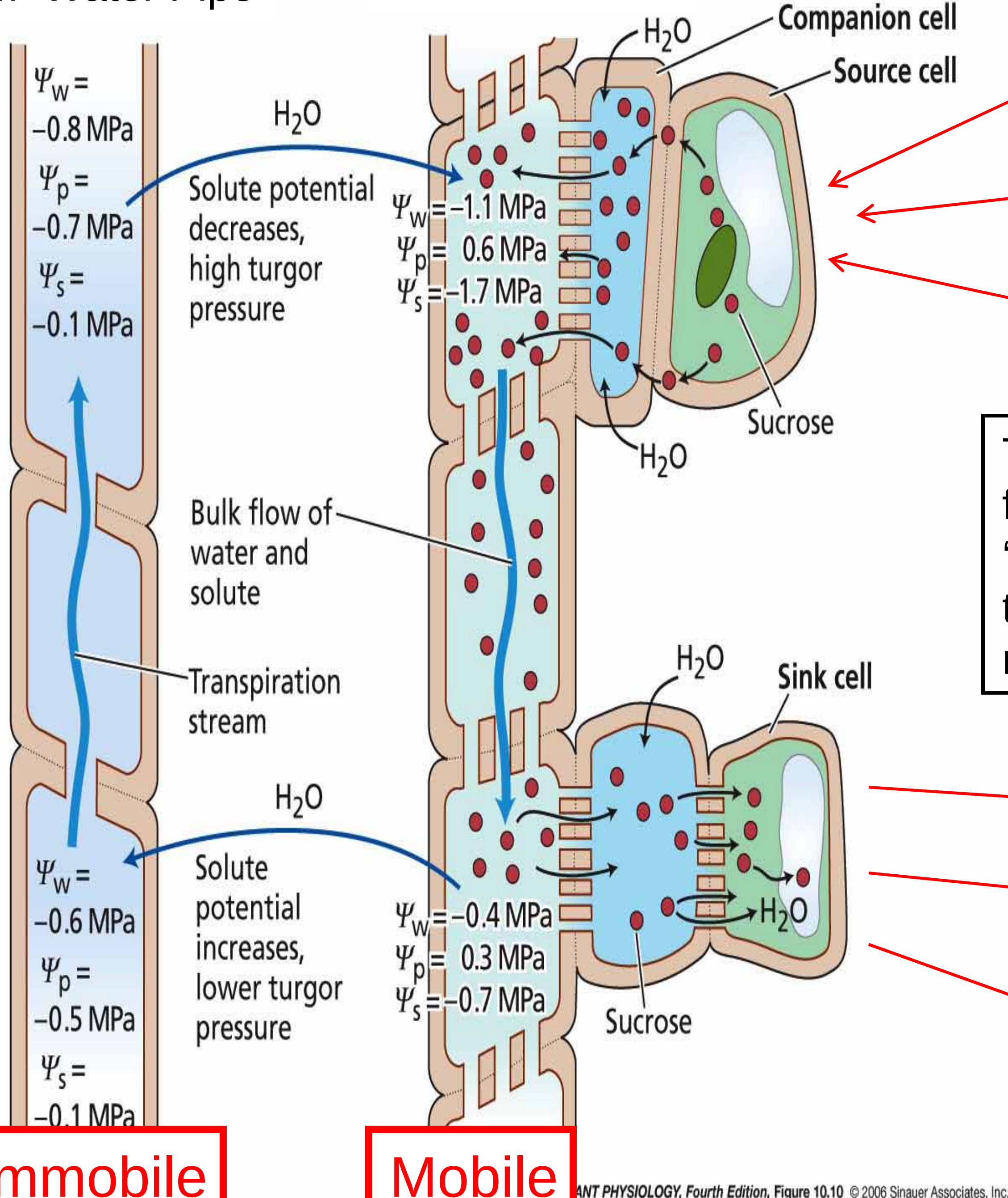
Boron is mobile in Almond, Avocado, Apple, Olive

Mobility = Once in the plant the nutrient can move around freely to satisfy new demand.

Importance: Influences fertilizer strategy and deficiency symptoms

Xylem=Water Pipe

Phloem =UPS



Photosynthesis

Photosynthesis

Photosynthesis

The movement of sugar from 'source' leaves to 'sink' leaves, determines the direction of movement of nutrients.

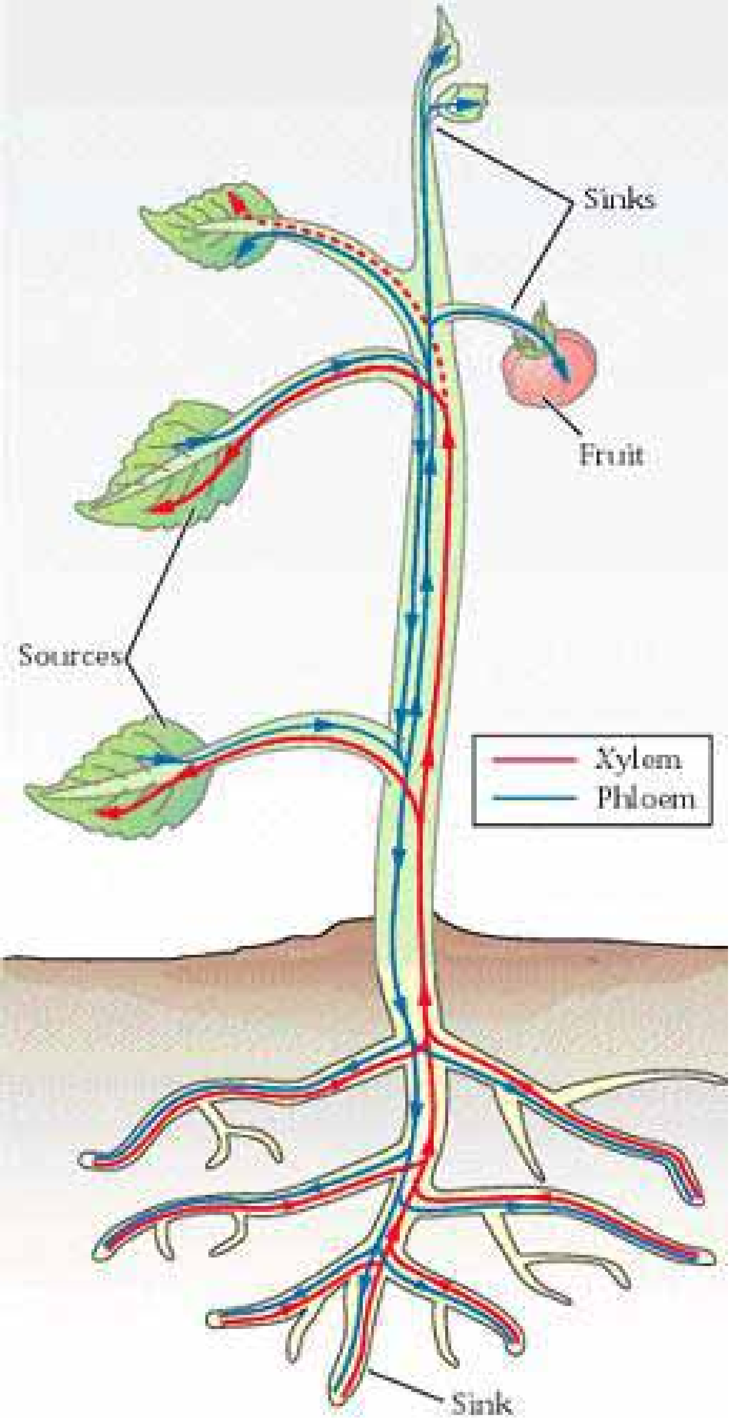
Growth

Growth

Growth

Immobile

Mobile



Immobile Elements (Ca, Zn, Mn, Fe) are immobile once in the plant.

Nutrients move with water movement ONLY:

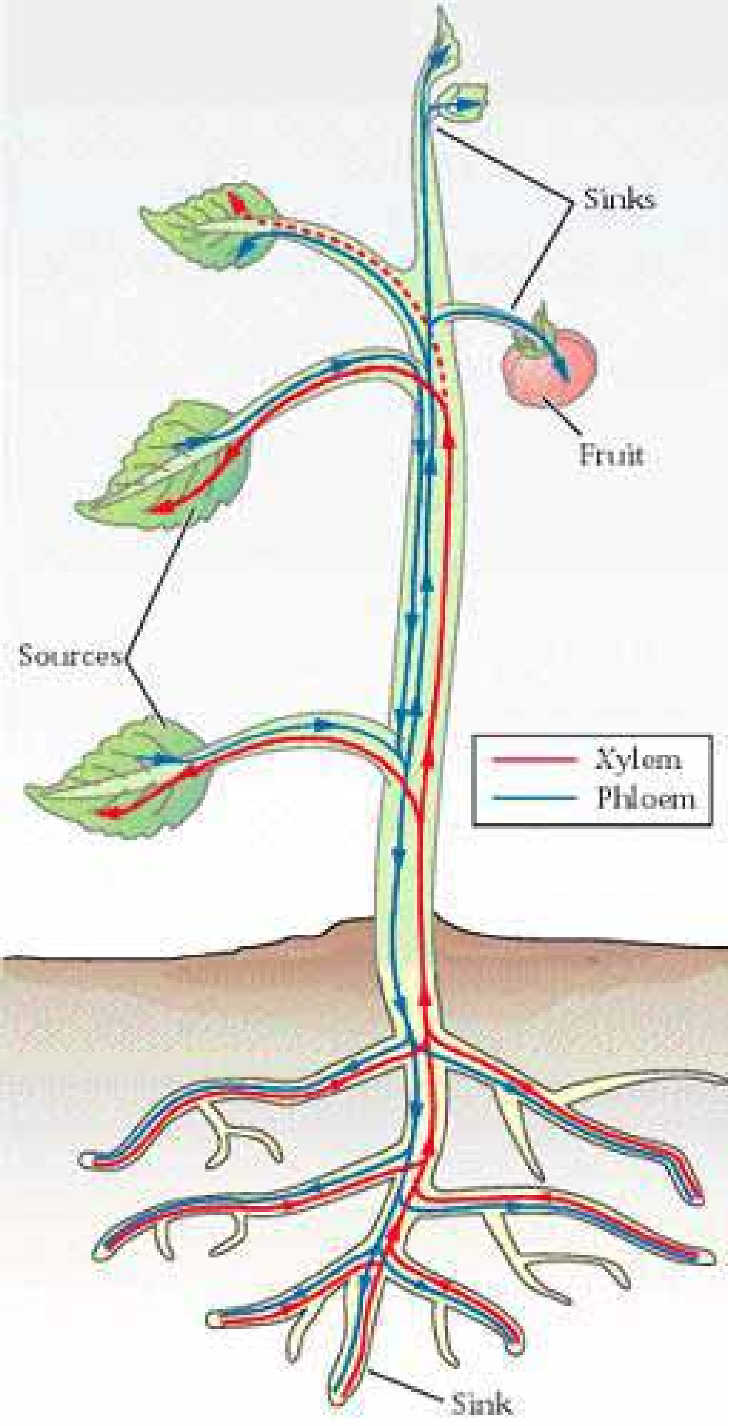
- Drought or low water movement can cause deficiencies
- Tissues that don’t lose water are sensitive.

Management Implications:

- Supply required throughout all stages of growth and reproduction.
- Fertilizers have limited long term effectiveness.
- Foliar fertilizers benefit only the tissues sprayed and cannot benefit tissues developed after application.

Nutrients cannot be ‘stored’ for later use.

Young tissues show deficiencies, old tissues show toxicity.



Mobile Elements (N, P, K, Mg, S, B) move in both the Xylem (one way) and Phloem (two way).

Photosynthesis and growth drives movement.

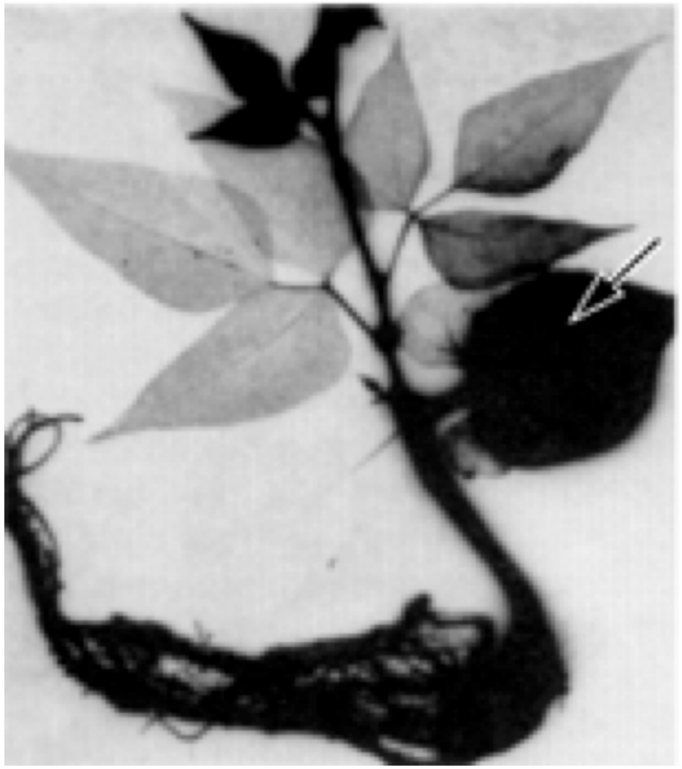
Fertilization can have longer term benefits and nutrients can be stored.

Foliar fertilizers can effectively supply current and developing tissues.

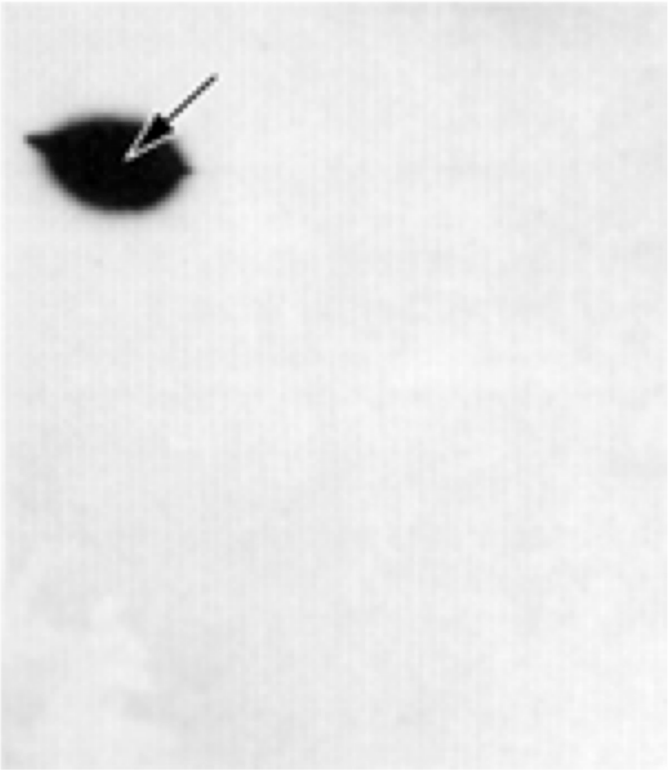
Older plant parts develop deficiencies first.

Phloem mobility determines longevity and efficacy of foliar fertilizers.

Mobile



Immobile



Application of mobile element (N, K, P, S, Mg, B) will supply roots, fruits and shoot tips.

Application of immobile element (Zn, Mn, Fe, Cu, Ca) will supply only the sprayed leaf.

Nitrogen, Potassium, Sulfur, Phosphorus, Magnesium
Uptake, Function, Mobility, Management

Uptake and Soil Reactions

- N, S, Mg are generally soluble and mobile in the soil (N can be leached)
- K and P mobility is highly soil specific (knowledge of your soil is critical)
- Uptake timing and demand are driven by growth and yield.

Function

- N, K, S, P, Mg are structural and metabolic elements required at all stages of growth.

Mobility

- N, K, S, P, Mg are mobile in plants and hence can be stored.

Management

- Efficient replacement of exported nutrient (amount and timing) is the goal
- N can be lost from soil so integration with irrigation is essential
- Foliar fertilizers can be effective and may have some longevity but total supply may be limited.
- Leaf and Soil analysis alone is not an adequate management practice.

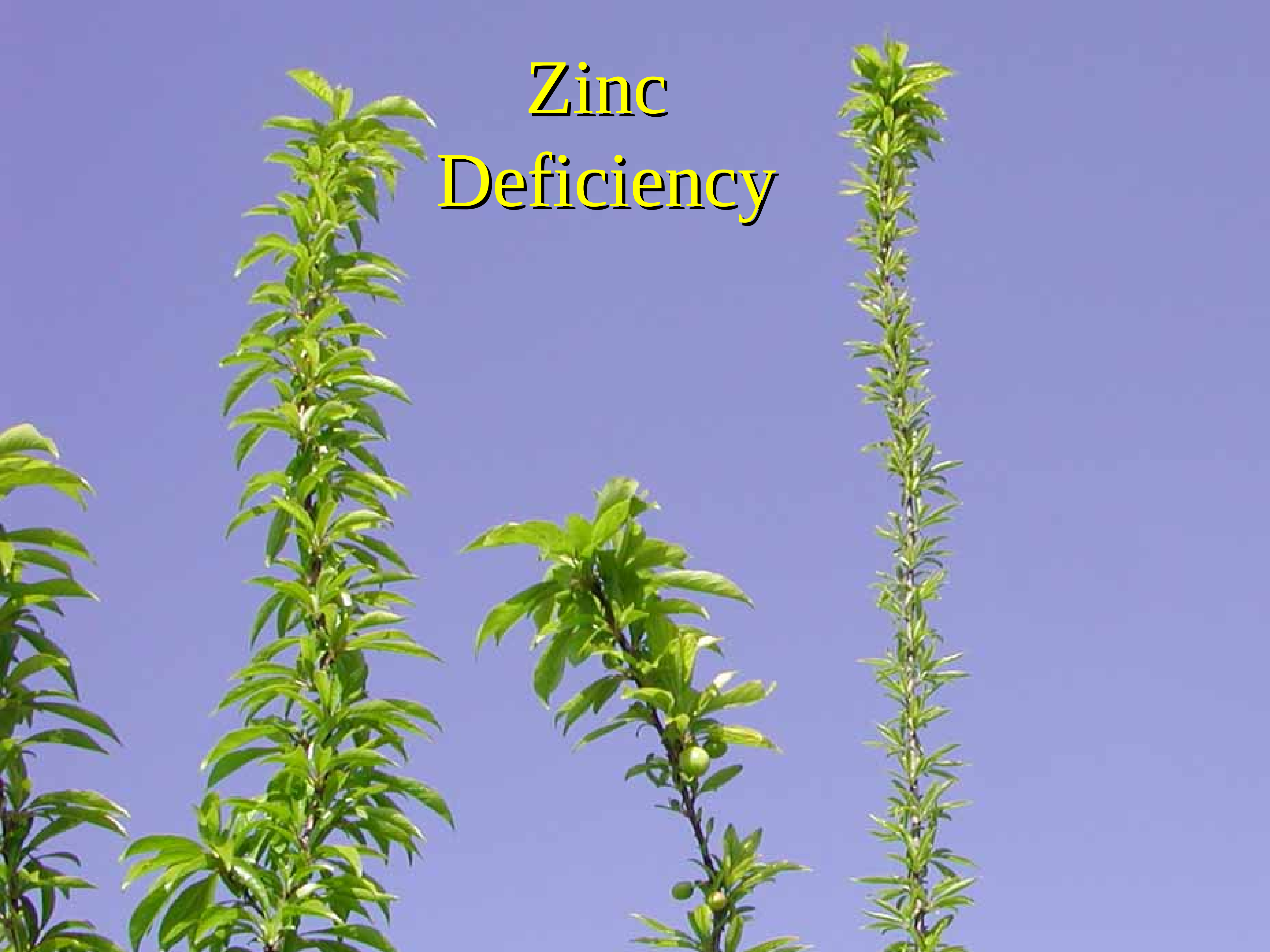
Micronutrients

Copper, Zinc, Boron, Iron, Manganese, Chlorine, Nickel, Molybdenum

Micronutrient Management Challenges

- The micronutrients Zn, Cu, Mn, Fe are immobile in soils and plants
- Micronutrients are far more specific in function, required for short periods of time and more localized in occurrence
- Total crop demand is much lower, more variable and more difficult to measure.
- Therefore - Nutrient budget approach does not work and leaf and soil sampling is much more difficult

Examples: Zn and Boron


Zinc
Deficiency

February 22, 2005

Zn Deficient

Zn Sufficient

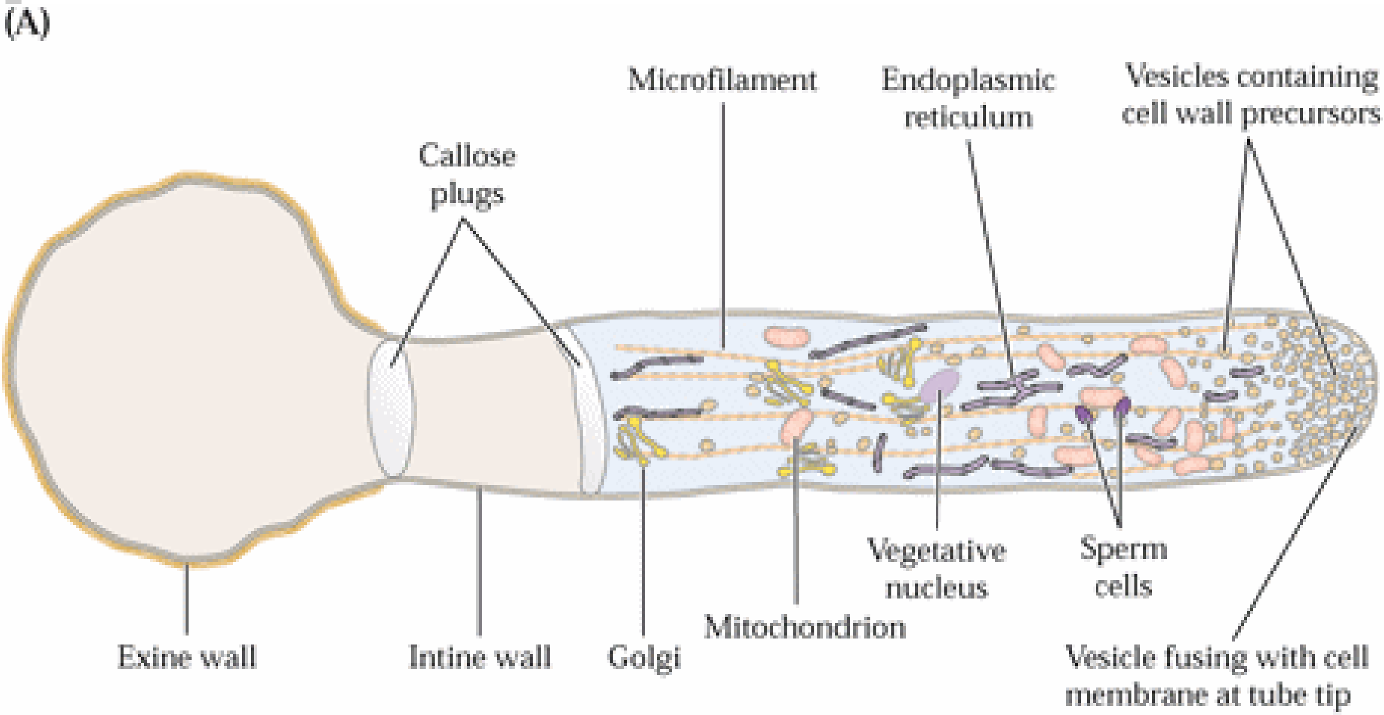
Zinc

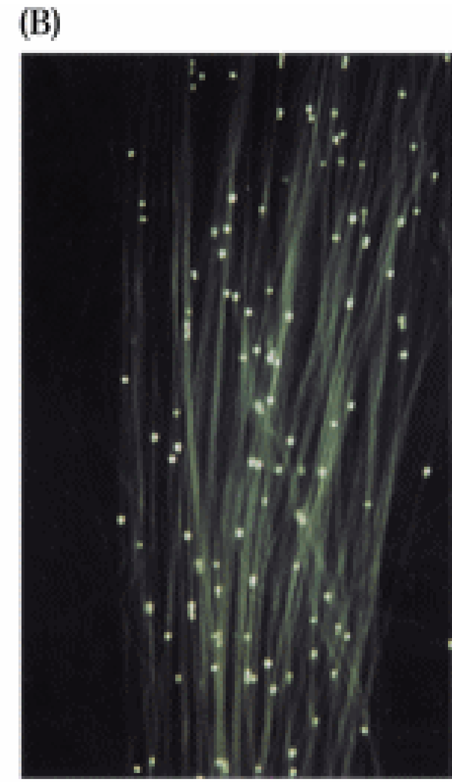
- Uptake and Soil Reactions
  - Immobile and prone to complexation.
  - Knowledge of soil characteristics (pH, fixation, solubility) is essential
  - Highly dependent on root exploration and soil ‘health’.
- Function
  - The key role of Zn is for spring shoot and reproductive growth.
- Mobility
  - Generally immobile or slightly mobile in plants in the spring but otherwise very immobile and not easily absorbed by leaves.
  - Efficacy of foliar fertilizers is short lived.
- Soil and plant analysis are very difficult to interpret
  - Easily contaminated, highly variable, short lived but important.
- Fertilization Strategy
  - Ensuring spring and reproductive adequacy is key
  - Maintaining soil solubility of fertilizers is key (formulation/application/amendment)
  - Foliar fertilizers are inefficient but can work (young tissues, frequent low rates). Fall sprays can work but are very, very inefficient!

Boron Deficiency primarily affects growth and reproduction

Boron deficiency induced flower abortion in Pistachio

Boron strongly influences pollen tube germination, growth and reproduction.





Title:

The gene responsible for borate cross-linking of pectin RG-II is required for plant reproductive tissue development and fertilization

Authors and affiliations:

Hiroaki Iwai*, Akiko Hokura†, Masahiro Oishi§, Hiroshi Chida*, Tadashi Ishii‡, Shingo Sakai* & Shinobu Satoh*

Boron

Managing Fertilization

- Nutrient Uptake and Assimilation
  - Uncharged and mobile in soil, therefore fertilization and fertigation are generally effective and formulation does not make a big difference (providing it is soluble)

- Function and Mobility
  - Critical and specific role in growth (vegetative and reproductive)
  - Highly mobile in Almond.

- Fertilization Strategy
  - Ensure you satisfy the B requirement in flowering
  - High yields can deplete tree B reserves
  - Foliar fertilizers and soil fertilizers can be effective
  - Soil and plant (hull) analysis is effective for toxicity but cannot reliably detect deficiency

Plant Nutrient Uptake and Response to Fertilizer

Diffusion versus Mass Flow

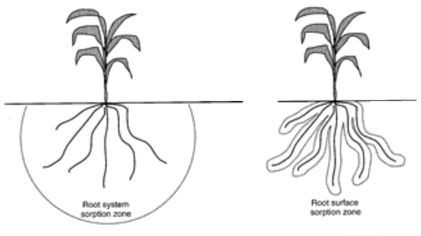


FIGURE 9.44 Difference in nutrient extraction zones between mobile and immobile nutrients in the soil. For mobile nutrients, the soil test must estimate the total nutrient available in the root zone. For immobile nutrients, the soil test is an index of the quantity available to the plant. *Courtesy B. Raun and G. Johnson, Oklahoma State Univ.*

Soil pH and Minerology determines Nutrient Solubility

(knowledge of solubility characteristics of your soils is important.)

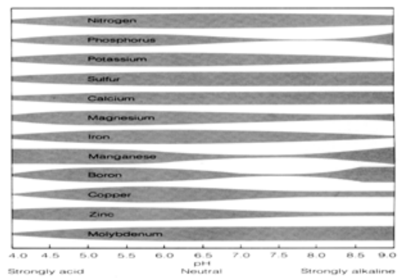


FIGURE 5.6. Influence of soil pH on the availability of nutrient elements in organic soils. The width of the shaded areas indicates the degree of nutrient availability to the plant root. (From Lucas and Davis, 1961.)

Nutrient Mobility Defines Symptoms And Response

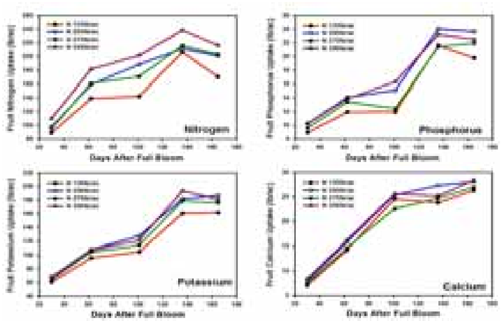
Table 6.1: Mobility of mineral elements in the phloem.

Mobile	Intermediate	Immobile
Potassium	Sodium	Calcium
Rubidium	Iron	Strontium
Nitrogen	Manganese	Barium
Magnesium	Zinc	Lithium
Phosphorus	Copper	Boron
Sulfur	Molybdenum	Silicon
Chlorine		

- Roots, water and growth are required for nutrient uptake.
- Nutrient Mobility/Solubility in Soil
  - N, Mg, Ca, S, B are soluble and mobile in most soils
    - Generally predictable response to fertilization, formulations are less relevant
  - Mn, Zn, Cu, Fe, P are not soluble and mobile in many soils.
    - Less predictable response, greater dependence on source.
- Nutrient Mobility in Plant
  - Mobility influences symptoms.
  - N, P, K, S, Mg, Cl, B are mobile and have more predictable and long lasting response to soil and foliar fertilization
  - Zn, Mn, Fe, Cu are immobile, nutrients cannot be stored and fertilizer response is shorter and less predictable.

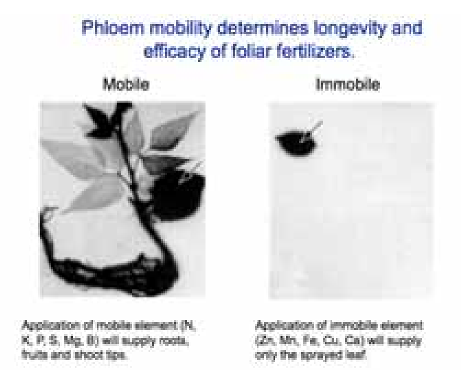
Mike Mason's Challenge: How Should I Fertigate?

Macronutrient Demand and Timing is Driven by Growth and Yield



Micronutrient Demand is Phenology Specific

Mobility Determines Efficacy of Foliars



Micronutrient Deficiencies are Highly Variable in Occurrence

- Demand for N, P, K, S, Mg is directly determined by growth and yield.
  - Replace what will be removed
  - Balance applications
  - Time applications to match demand.
- Demand for B, Zn, Cu (Fe, Mn) varies with phenology and environment.
  - Difficult to predict, more variable and difficult to correct.
  - Prevention is better than cure
  - More research on Zn formulations/fertigation is needed

Thank You

Questions?

Almond

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= 25,000,000 lbs N/yr (current best case scenario)

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