Nutrient Management for Apple Trees on Dwarfing Rootstocks

Lailiang Cheng

Department of Horticulture

Cornell University

Outline

- Nutrient requirements
- Nutrient supply sources
- Tree nutrient status
- Management strategies

Trees on dwarfing rootstocks

Compared with trees on seedlings:

- **Have a smaller and shallower root system**
- **Crop earlier and have higher yield**

Nutrient requirements

- Essential nutrients
  - Macronutrients: N, P, K, Ca, Mg, S
  - Micronutrients: B, Zn, Cu, Mn, Fe, Mo, Cl, Ni.
- Seasonal patterns and magnitude

Determining nutrient requirements

- **Six-year-old Gala/M.26 were grown in sand culture at 1.07 X 3.35m spacing (186 trees/mu).**
- **Each tree received 30 g N in Hoagland's solution during the entire growing season.**
- **Cropload was adjusted to 8.2 fruit/cm^2 TCA at 10 mm king fruit (~104 fruit/tree).**
- **Four trees were destructively sampled for analysis at each key developmental stages.**

Leaf and fruit nutrient status

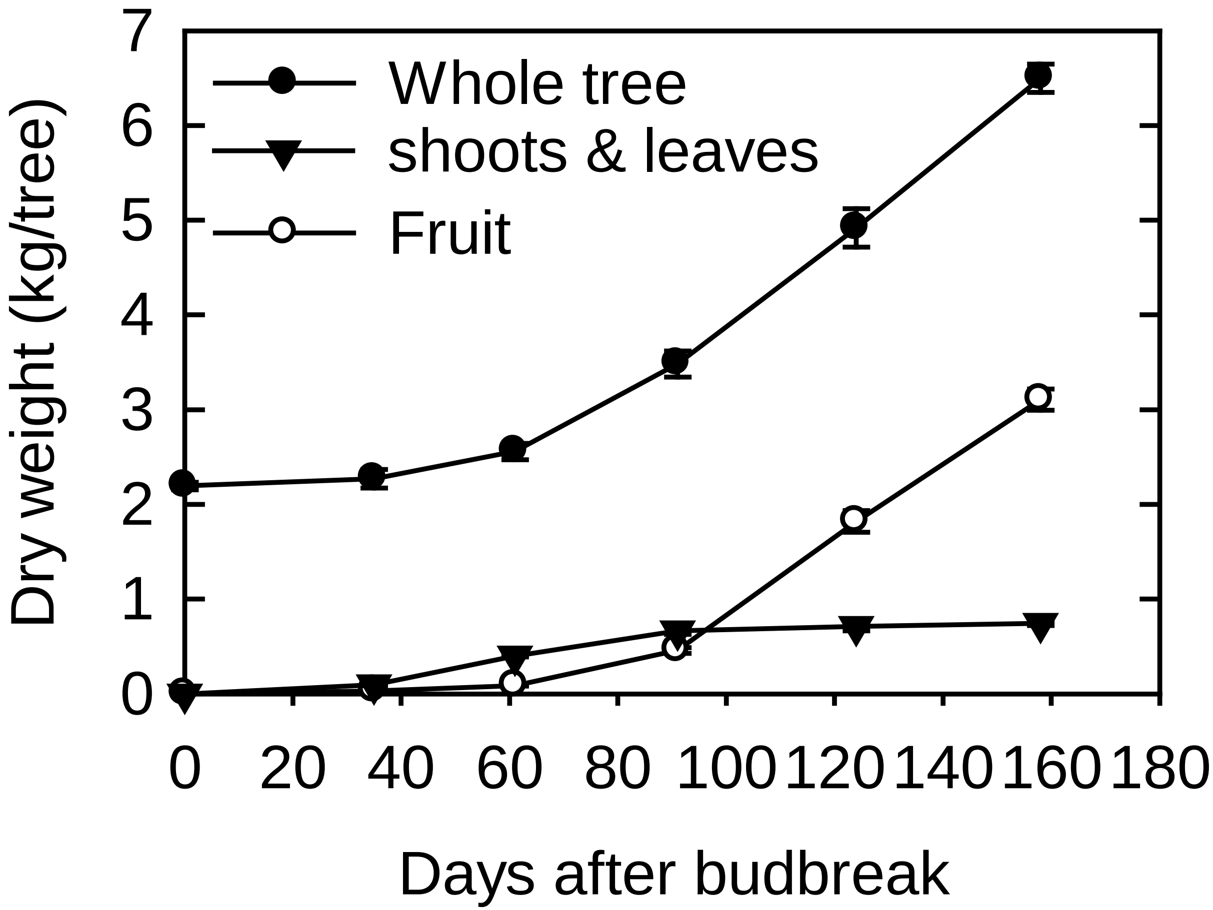
Macronutrients (%)

Tissue	*N*	*P*	*K*	*Ca*	*Mg*
Leaf	**2.00**	**0.18**	**1.61**	**1.10**	**0.39**
Fruit	**0.25**	**0.06**	**0.80**	**0.05**	**0.04**

Micronutrients (ppm)

Tissue	*B*	*Zn*	*Cu*	*Mn*	*Fe*
Leaf	**27.3**	**27.3**	**8.3**	**143.8**	**83.5**
Fruit	**21.8**	**3.5**	**3.8**	**7.8**	**25.3**

Dry matter accumulation of 6-yr-old Gala/M.26



Cropload: 8.2 frt/cm^{2}TCA

Fruit#/tree: 104

Yield:18.8Kg/tree

Leaf area/fruit: 550 cm^2/frt

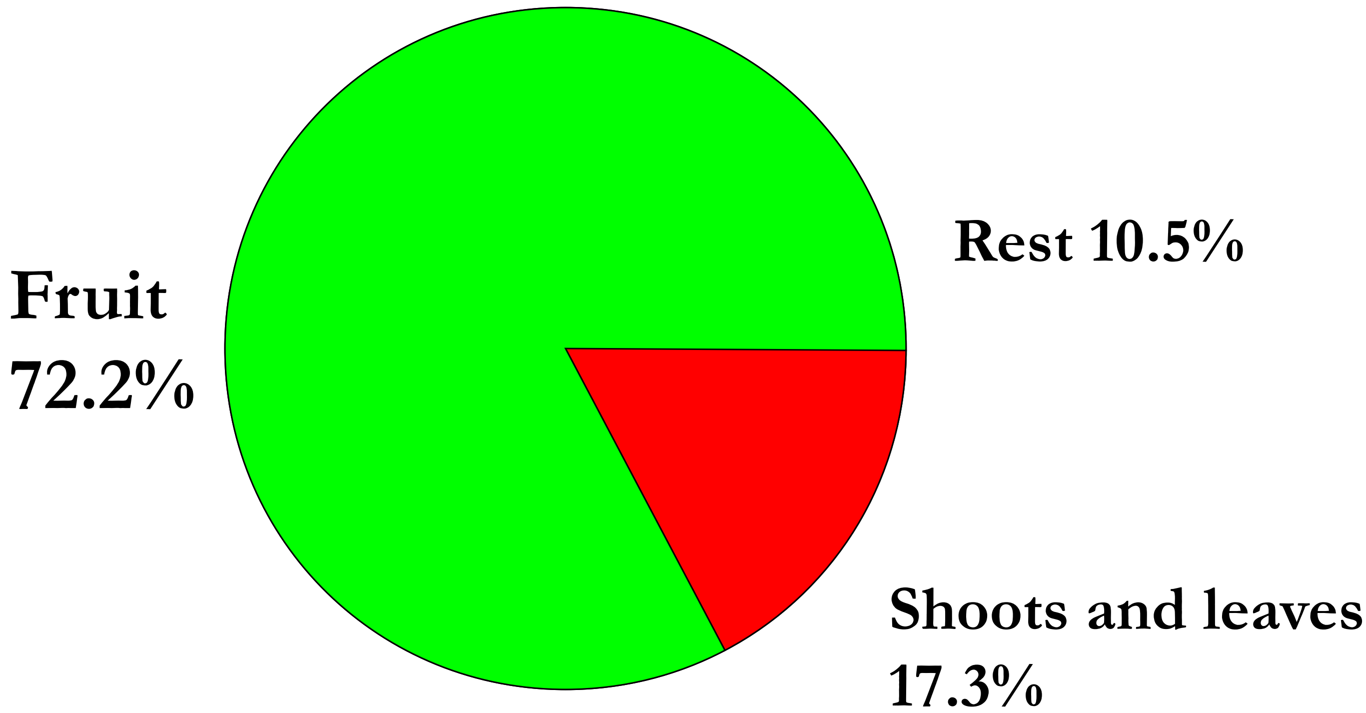
Fruit size: 181 g/fruit

Fruit firmness: 16.8 lbs

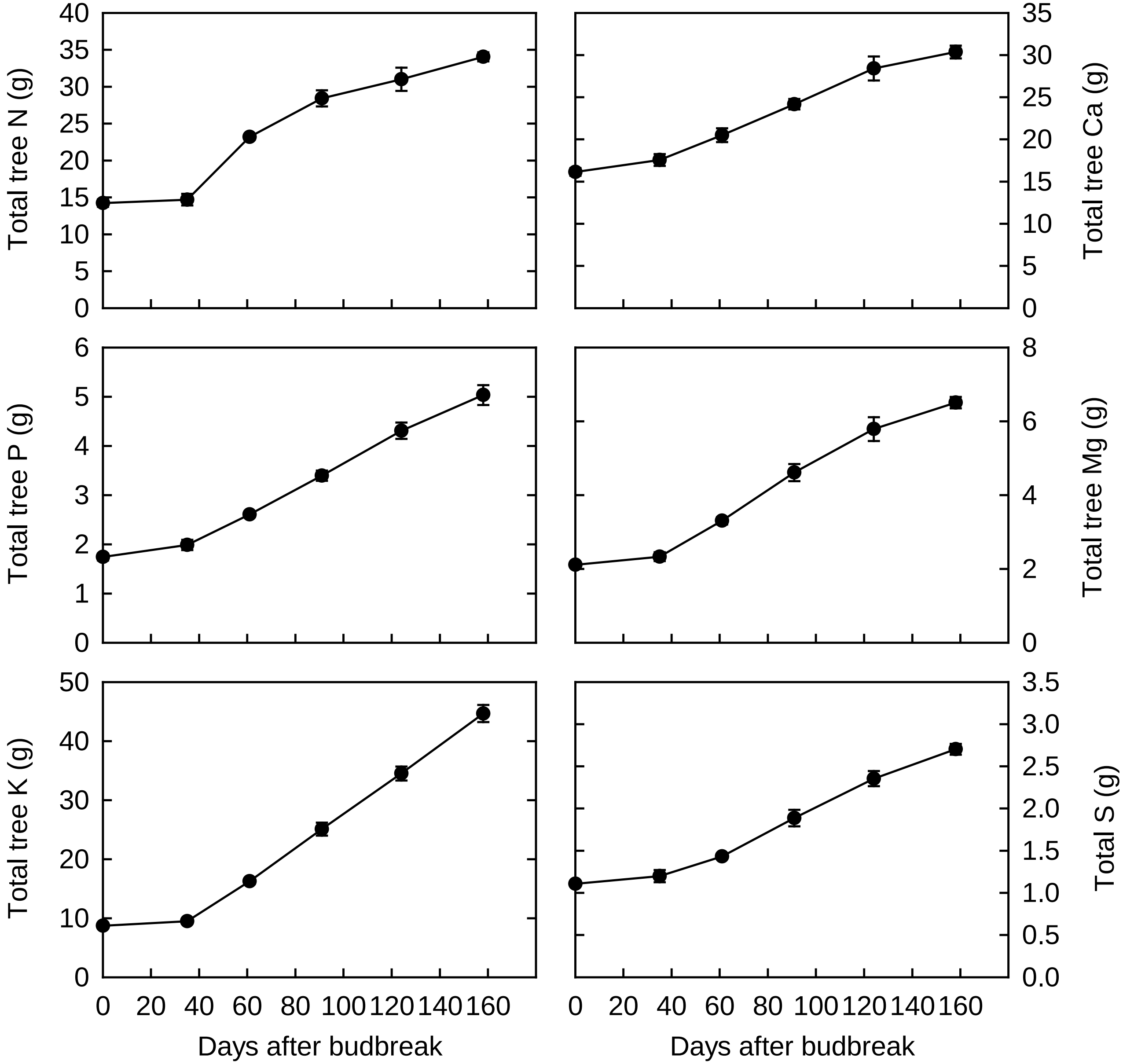
Soluble solids: 14.5%

Net dry matter gain and its partitioning

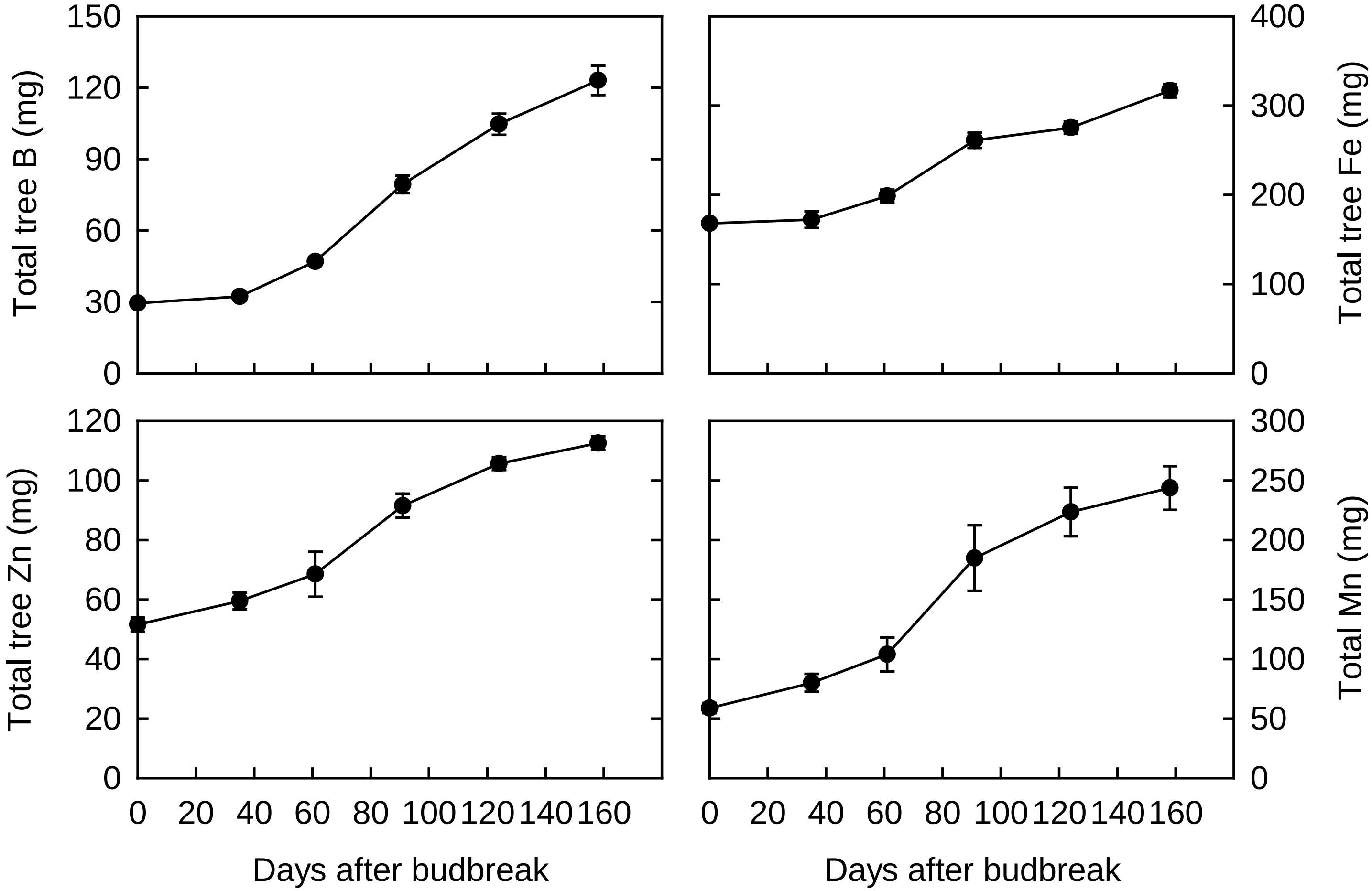
(Net DW gain: 4.3 kg)



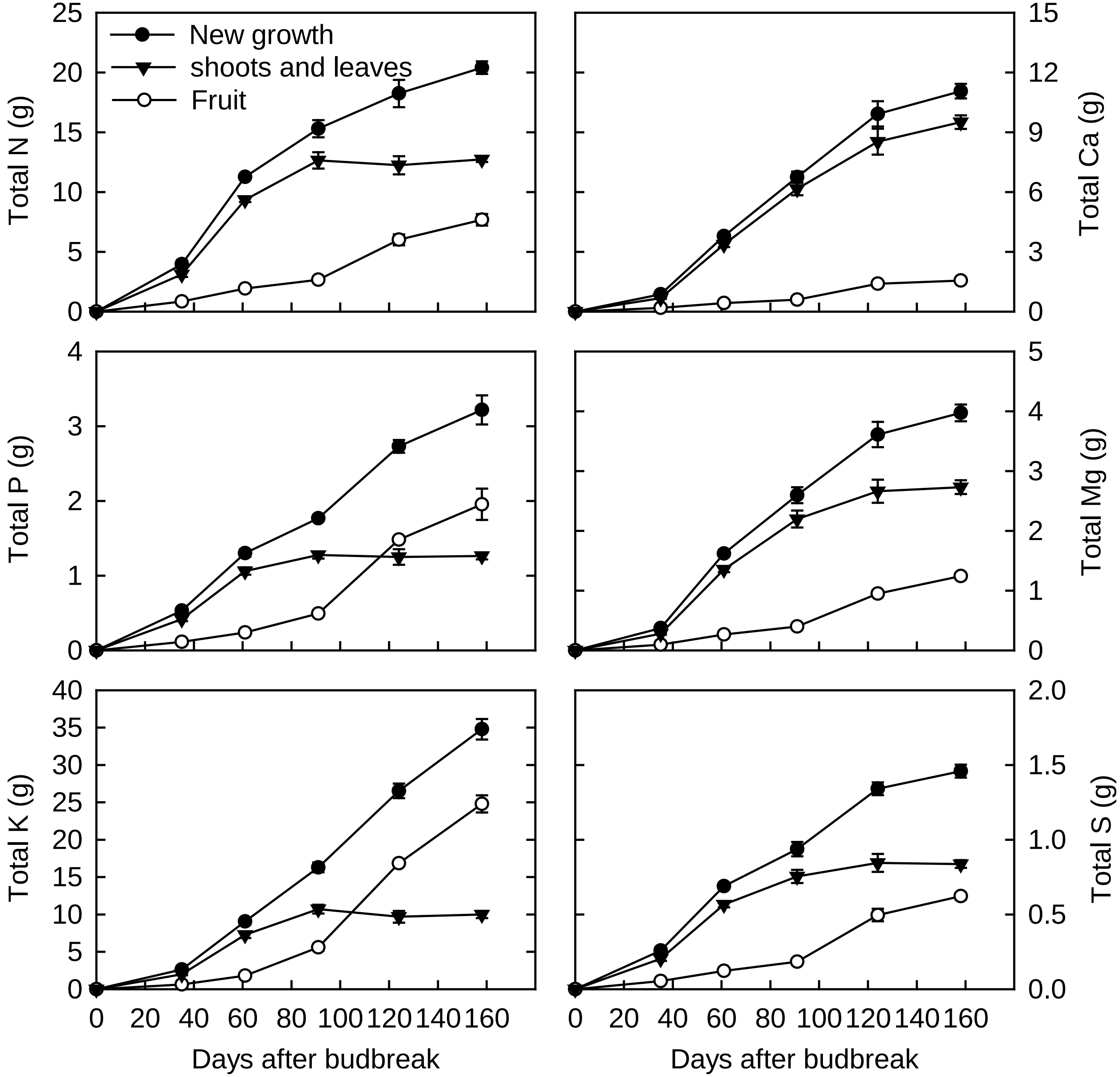
Macronutrient accumulation patterns of whole tree



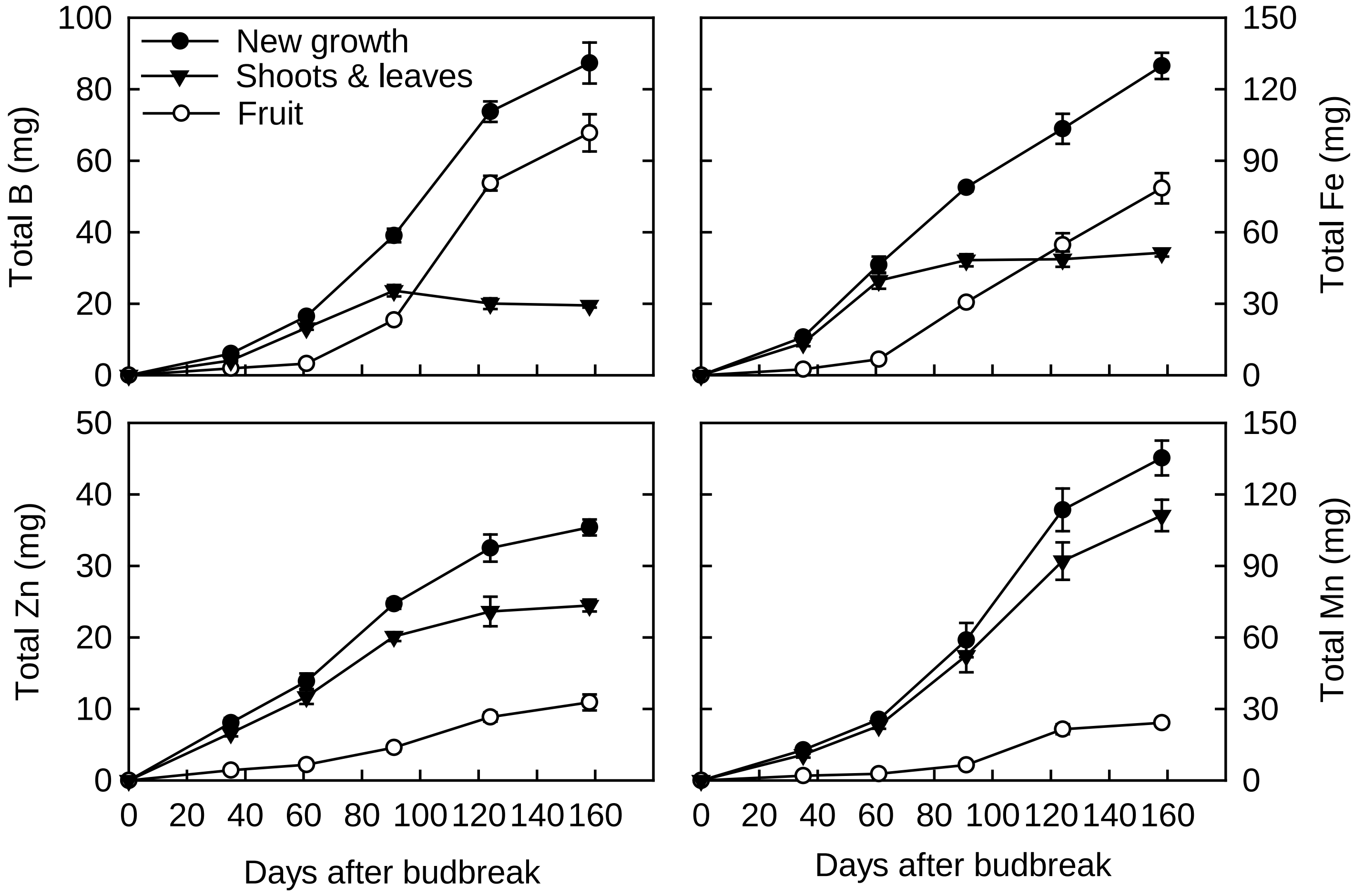
Micronutrient accumulation patterns of whole tree



Macronutrient accumulation patterns in new growth



Micronutrient accumulation patterns in new growth



Gala/M.26 nutrient requirements

(52.5 t/ha or 3.5t/mu)

Macronutrients (kg/mu)

	N	*P*	*K*	*Ca*	*Mg*
Net gain	**3.78**	**0.62**	**6.76**	**2.68**	**0.82**
New growth	**3.84**	**0.61**	**6.55**	**2.08**	**0.75**

Micronutrients (g/mu)

	B	*Zn*	*Cu*	*Mn*	*Fe*
Net gain	**17.40**	**11.35**	**9.08**	**34.81**	**28.00**
New growth	**16.65**	**6.81**	**3.78**	**25.73**	**24.21**

Nutrient requirements in relation to yield

Macronutrients (kg/mu)

Yield (kg/mu)	*N*	*P*	*K*	*Ca*	*Mg*	*S*
1000	**1.05**	**0.17**	**1.91**	**0.76**	**0.23**	**0.08**
2000	**2.11**	**0.35**	**3.82**	**1.51**	**0.47**	**0.17**
3000	**3.16**	**0.52**	**5.73**	**2.27**	**0.70**	**0.25**
4000	**4.21**	**0.70**	**7.65**	**3.02**	**0.93**	**0.34**
5000	**5.26**	**0.87**	**9.56**	**3.78**	**1.17**	**0.42**
6000	**6.32**	**1.05**	**11.47**	**4.53**	**1.40**	**0.51**

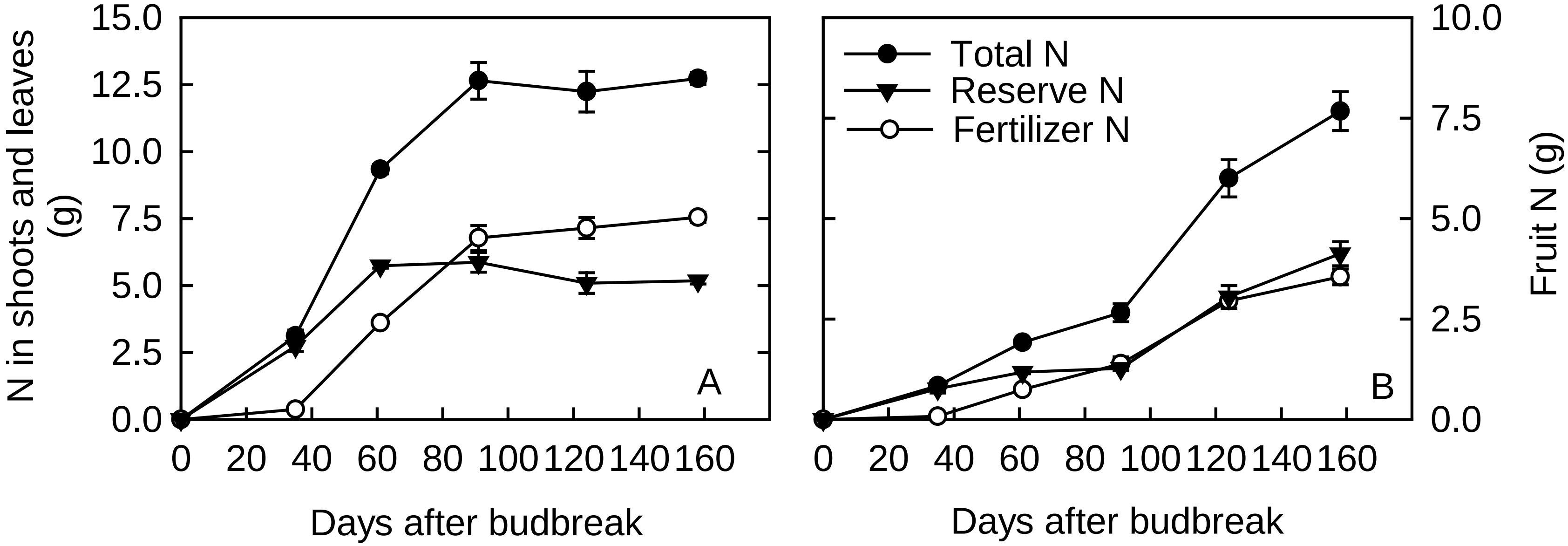
Summary

- **Nutrient requirements: N: 3.68, P: 0.61, K: 6.69, Ca: 2.64, Mg: 0.82, and S: 0.30 kg/mu, and B: 17.4, Zn: 11.3, Cu: 8.6, Mn: 34.4, and Fe: 27.7g/mu at a yield of 3.5ton/mu.**
- **Highest N demand occurs from bloom to the end of shoot growth, followed by a lower but steady demand; many other nutrients shows relatively constant demand from bloom to harvest.**
- **Differential requirements by fruit and leaves**
  - **Timing: bloom to end of shoot growth for leaves; end of shoot growth to fruit harvest for fruit;**
  - **Amount: fruit needs more P, K, B, and Fe than leaves.**

Nutrient Supply Sources

- Tree nutrient reserves
  - Important for phloem-mobile nutrients
- Soil
- Fertilizers applied to soil or foliage

Contribution of reserve N to new growth



Soil analysis

- Soil analysis provides pH and mineral nutrient availability for preplant preparation and for proper diagnosis of tree nutrient status. However, only the optimal ranges for Ca, Mg, K, P, B, and Al have been developed.

- Soil sampling
  - Late summer or in the fall after harvest
  - Separate topsoil (0 to 25cm) from subsoil (25-50cm)
  - Thorough sampling (10 to 20 sub samples per sample for a 10-acre orchard)

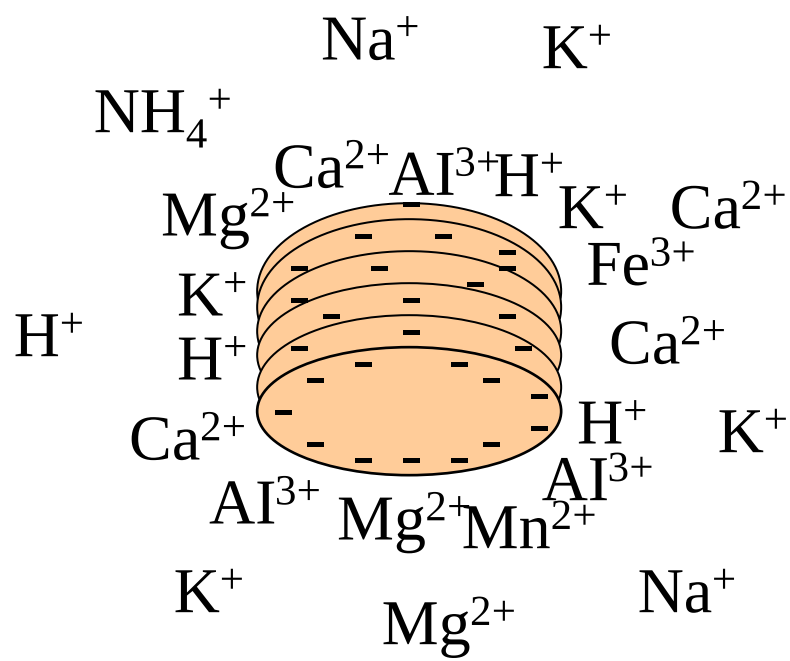
Soil pH

$$\text{Colloid-H}^+ \rightleftharpoons H^+ \text{ (Solution)}$$

$$pH = -\log[H^+]$$

- **Optimal soil pH for apple: 6.0 to 6.5.**

Adsorption of cations by soil colloids



Acid-forming cations: H^{+}, Al^{3+}, Fe^{3+}, Mn^{2+}

Base cations: Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}

CEC and approximate needs for Ca, Mg and K

Soil texture	*CEC (meq/100g)*		*Ca (lbs/acre)*		*Mg (lbs/acre)*		*K (lbs/acre)*	
	0-8”	8-16”	0-8”	8-16”	0-8”	8-16”	0-8”	8-16”
Sand, gravel	5	3	1,500	800	185	100	150	100
Sandy loam	12	8	3,600	2,100	440	260	350	220
Loam, silty loam	18	12	5,500	3,200	660	385	525	335
Silty clay loam	20	14	6,100	3,700	740	450	580	370
Clay loam, clay	25	18	7,600	4,800	900	580	730	465

Soil test P values and rates of P_2O_5 application

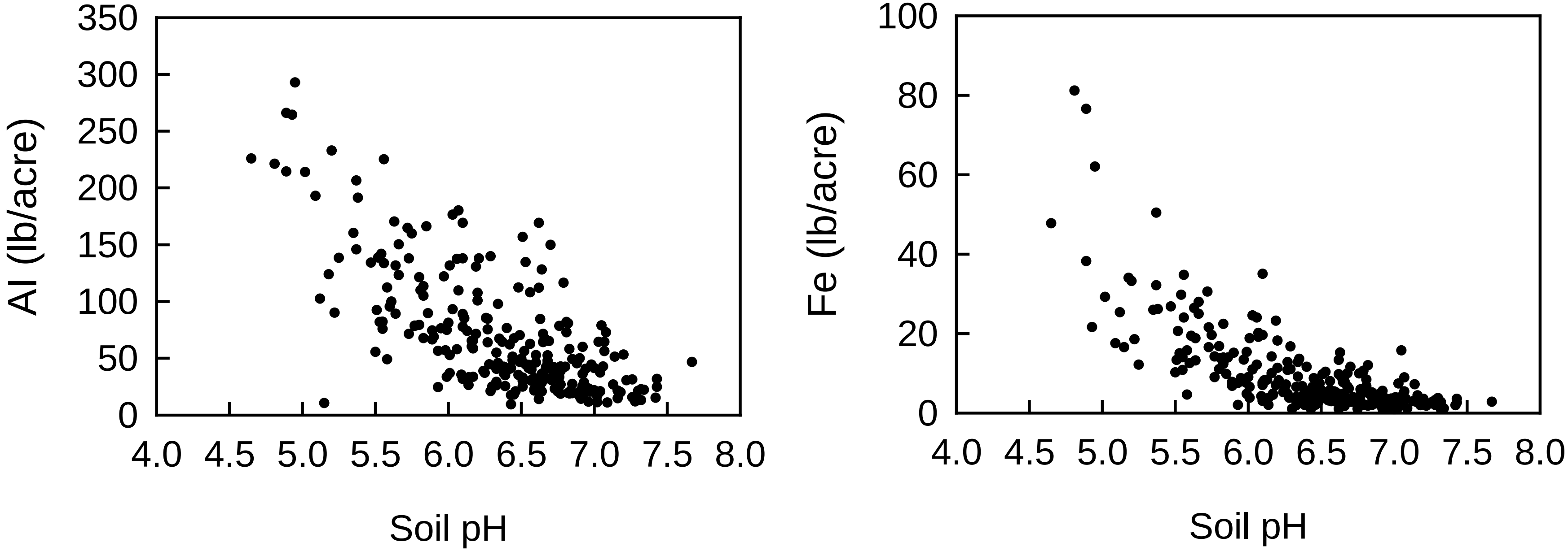
Soil test value (lb P/acre)	*Pre-plant P_2O_5 lb/acre*	*Established orchard P_2O_5 lb/acre*
<1	120	60
1-3	100	60
4-8	60	30
9+	40	0

Preplant P_2O_5rate (lb/acre): (9-P) X 10 + 40
Established orchard P_2O_5 rate: (9-P) X 5 + 20

Soil test B levels and rates of B application

Relative level	*Loam, silt loam B (lb/acre)*	*Sandy loam B (lb/acre)*	*Loamy sand B (lb/acre)*	*B(lb/acre) to apply*
Very high	**>2.4**	**>1.8**	**>1.2**	**0**
High	**1.6-2.4**	**1.2-1.8**	**0.7-1.2**	**1**
Medium	**0.8-1.6**	**0.6-1.2**	**0.4-0.7**	**2**
Low	**<0.8**	**<0.6**	**<0.4**	**3**

Al, Fe and Mn in relation to pH



200 lbs of Al or a combination of Al, Fe and Mn indicates a problem

Soil Zn and Cu

- **Availability decreases as pH increases.**
- **Negatively affected by high soil phosphates.**
- **High organic matter may also decrease the availability.**
- **Optimum range has not been established.**

Benefits of liming

- **Increase the availability of Ca, Mg, and P.**
- **Decrease Al, Fe, and Mn levels to avoid toxicity problems.**
- **Promote microbial activity and improve soil structure.**
- **Improve root growth and fertilizer use efficiency.**

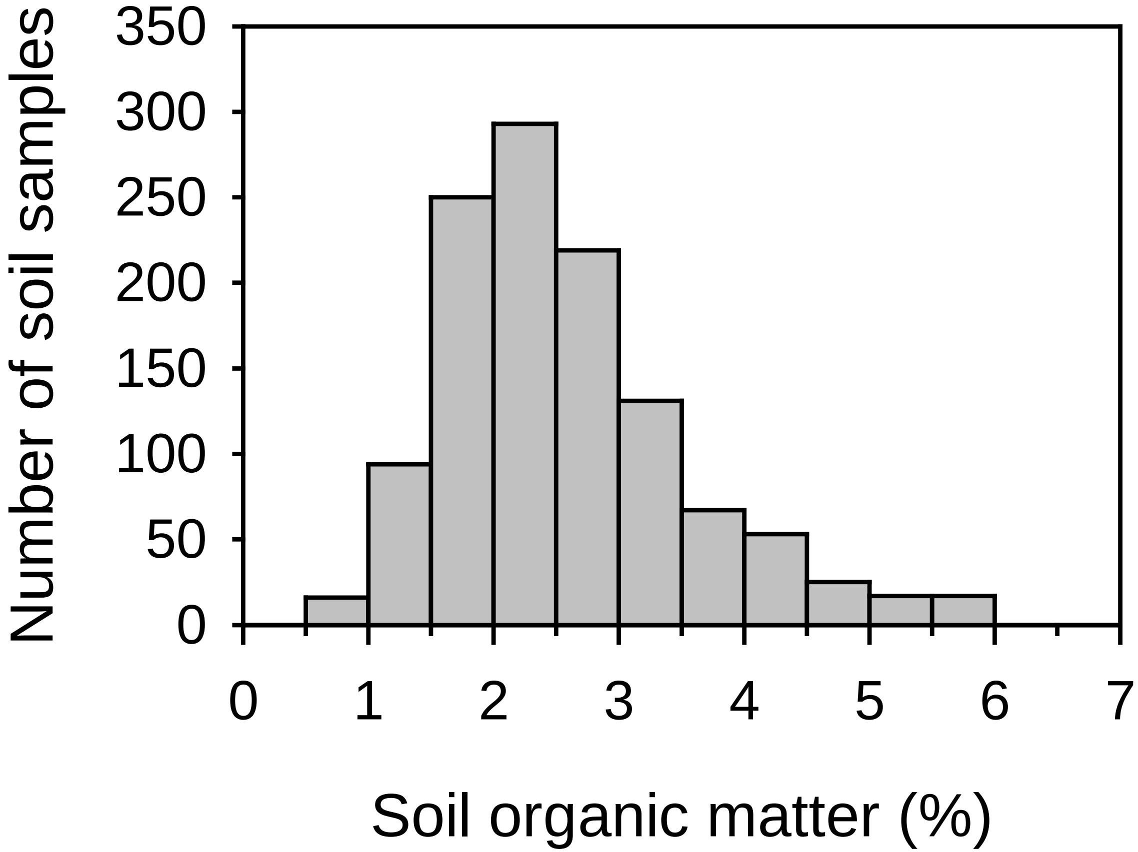
Lime requirement

- **Preplant**
  - **Target pH: top soil 7.0; subsoil 6.5**
  - **Based on CEC, base saturation at target pH and Ca/Mg of 5 to 1.**
- **Maintenance**
  - **Target pH: 6.0 to 6.5.**
  - **2 tons of lime per acre every 2 years based on soil and leaf analysis.**

Soil Organic Matter (SOM)

- **Provides N, K, P, and many other nutrients**
- **Increases CEC, water-stable aggregates and water holding capacity**
- **Supports diverse microbial community**
- **Reduces nutrient leaching.**

Organic matter content in NY orchard soils

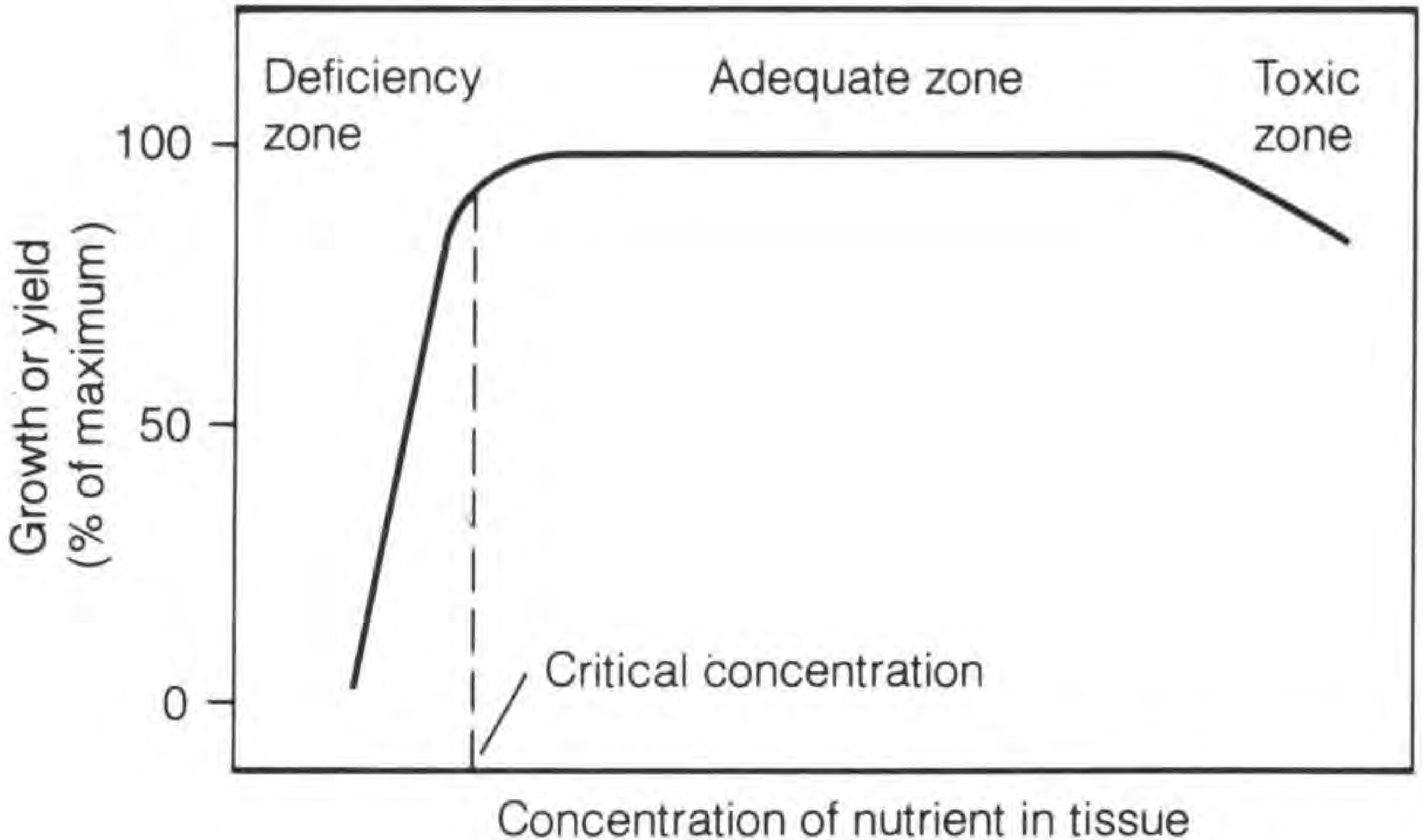


Diagnosis of Tree nutrients status via tissue analysis

- **Tissue analysis provides the actual concentration sof nutrients in plants, which reflects demand-supply relationship**

- **However, tissue nutrient concentrations are affected by tree vigor and cropload, and therefore tissue analysis alone is not enough for developing an effective fertilization program**

Tissue nutrient concentrations and tree growth and yield



Leaf sampling

- 60 to 80 days after petal fall (early August).
- 100 leaves with petiole from trees of a single cultivar representative of a block (<10 acres).
- Leaves free of insect and disease damage.
- Taking notes on
  - Shoot length and thickness
  - Relative size and appearance of leaves
  - Incidence of insect and disease damage
  - Visual deficiency symptoms
  - Crop load
  - Pruning severity
  - Effectiveness of weed control

Sample preparation

- Gently wash in mild detergent. Rinse 3 times with distilled water.
- Blot dry, dry on paper towels.
- Place loosely in paper bag for air drying.
- Store in a warm dry place until processing.

Interpretation of leaf analyses

- Compare analysis results with standards.
- Look at the balances between nutrients as well as actual content.
- Take tree growth, cropload, soil nutrient availability and other factors into consideration.

Apple Leaf Nitrogen

Tree type	*Leaf N (%)*
Young non-bearing apples	2.4 – 2.6
Young bearing apples	2.2 – 2.4
Mature soft varieties	1.8 – 2.2
Mature hard varieties	2.2 – 2.4

- **Shoot growth: 10 to 16 inches (25 to 40 cm)**
- **Cropload: leaf N is higher on heavy cropped trees;**
- **Drought/weed competition decreases leaf N;**
- **More prone to biennial bearing when leaf N<2.2.**

Other Nutrients

Nutrients	*Desired level*
Phosphorus	**0.13-0.33%**
Potassium	**1.35-1.85%**
Calcium	**1.3-2.0%**
Magnesium	**0.35-0.5%**
Boron	**25-50 ppm**
Zinc	**25-50 ppm**
Copper	**7-12 ppm**
Manganese	**50-150 ppm**
Iron	**50+ ppm**

Leaf Phosphorus

- Optimum range: 0.13 to 0.33%.
- Low P often indicates low soil pH.
- High P often results from concentrating effects of limited leaf expansion by Zn deficiency.

Leaf Potassium

- Optimum range: 1.35 to 1.85%.
- N/K ratio: 1.00 ~ 1.25 for McIntosh and 1.25 ~ 1.5 for Delicious.
- Drought decreases leaf K.
- Inverse relationship with cropload.

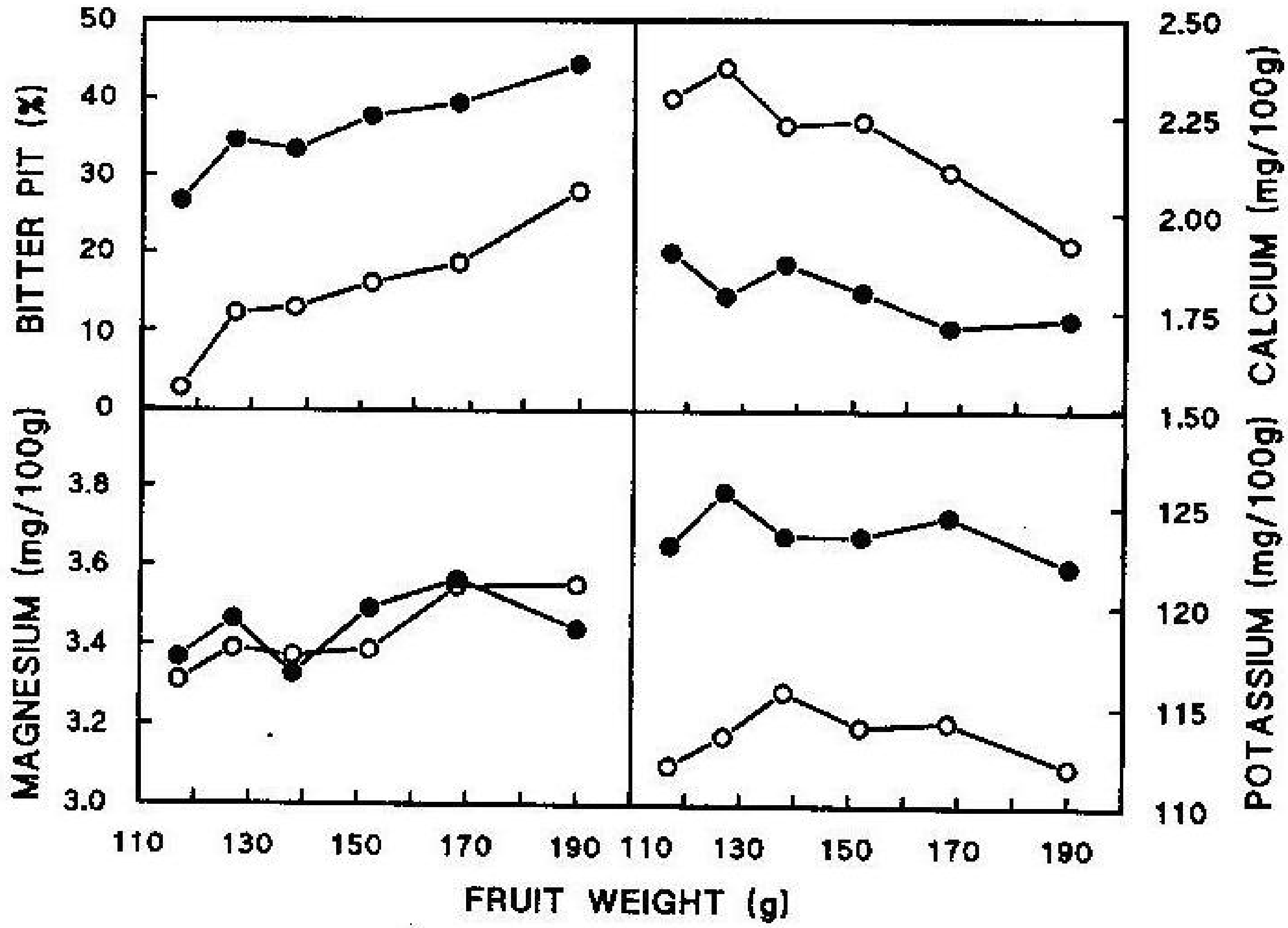


Fig. 1. Bitter pit incidence and Ca, Mg, and K concentrations of fruit from heavy-(○) and light-(●) cropping trees. Data are the means from four orchards for each fruit weight. SEDs and *P* values for the mean data are given in Table 1.

From: Ferguson &Watkins 1992 JASHS 117:373

Leaf Calcium

- Optimum range: 1.3 to 2.0%.
- Low leaf Ca results from low soil pH, B or Zn deficiency.
- High leaf Ca does not necessarily translate into good fruit Ca status due to its transpiration-driven distribution and low phloem mobility.

Leaf Magnesium

- **Optimum range: 0.35 to 0.50%.**
- **K/Mg should be 4 or less.**
- **Low leaf Mg may result from low soil pH or high K.**
- **Dolomitic lime, Sulpomag, and foliar application of $MgSO_4 \cdot 7H2O$.**

Leaf Boron

- **Optimum range: 25 to 50 ppm.**
- **Soil moisture affects B availability.**
- **When deficient, both soil and foliar applications are essential.**
- **If soil test unavailable, soil application of 2 lbs B/acre is suggested when leaf B<25ppm.**

Leaf Zinc

- **Optimum range: 25 to 50 ppm.**
- **P/Zn ration should be 100 or less.**
- **High pH, high phosphates, high organic matter and low temperature.**
- **When deficient, foliar application of Zn chelate is most effective.**

Leaf Copper

- **Optimum range: 7 to 12 ppm.**
- **High pH, high phosphates, and high organic matter decrease Cu availability.**
- **Copper fungicides at green tip is most effective. Copper sprays after flower cluster opening can cause severe russeting of fruit.**

Leaf Manganese

- **Optimum range: 50 to 150 ppm.**
- **High soil pH (>6.3) leads to deficiency whereas low pH (<5.6) leads to excess.**
- **When deficient, a single application of manganese sulfate (4 lbs/100 gal) at first cover is sufficient.**

Fruit Analysis

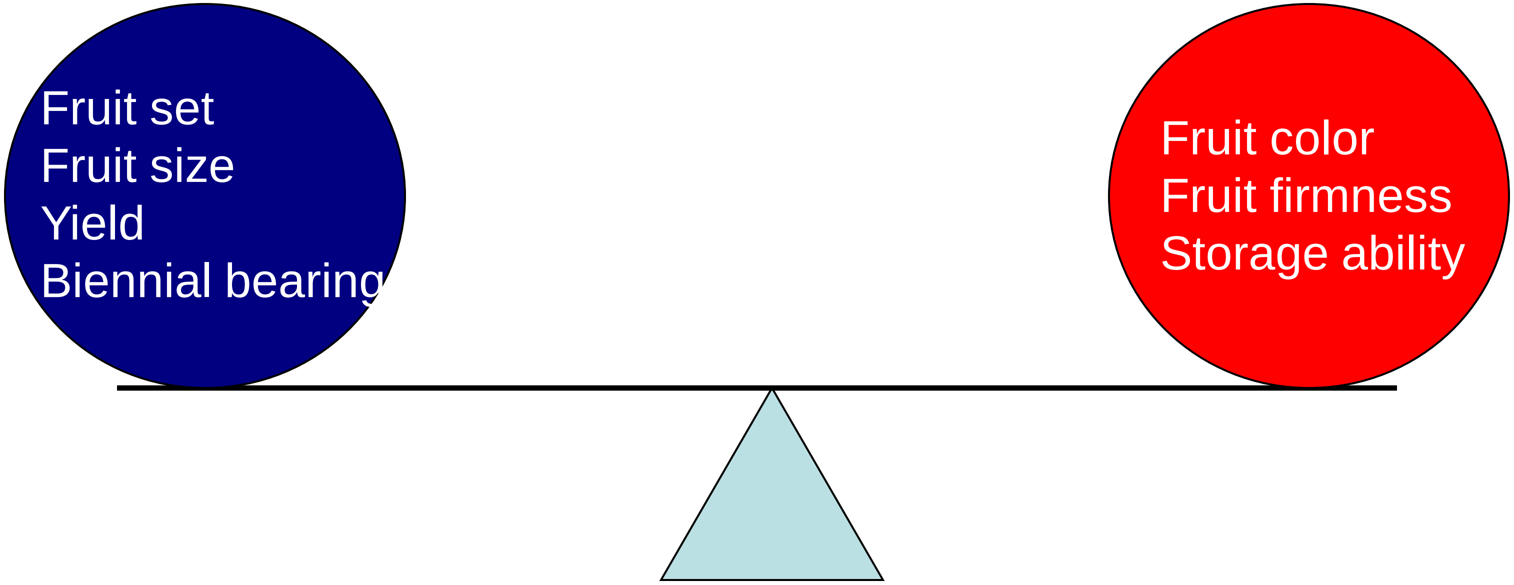
- Two types: fruitlet in July or fruit at harvest.
- Purpose: diagnosis and/or prediction.
- Standards for Cox and Bramley fruit at harvest (mg/100 g fresh fruit) for long term storage.

Variety	*N*	*P*	*K*	*Mg*	*Ca*
Cox	50 - 70	11 (min)	130 - 170	5.0	5.0
Bramley	60 (max)	9 (min)	105 -115	5.0	5.0

Nutrient management strategies

- Conventional methods: timing and rate
- Fertigation (Fertilization + irrigation)
- Controlled release fertilizers
- Build up soil organic matter

Nitrogen management



Nitrogen supply

22 **66** **131** **262 lbsN/A**

Return Bloom of Gala/M.26 Trees in Response to N Supply

2007

2008

Ideal Pattern of Tree N Status

- Trees have relatively high N status early in the season to promote rapid canopy development and early fruit growth.
- As the season progresses, N status declines gradually to guarantee fruit quality development and wood maturity.

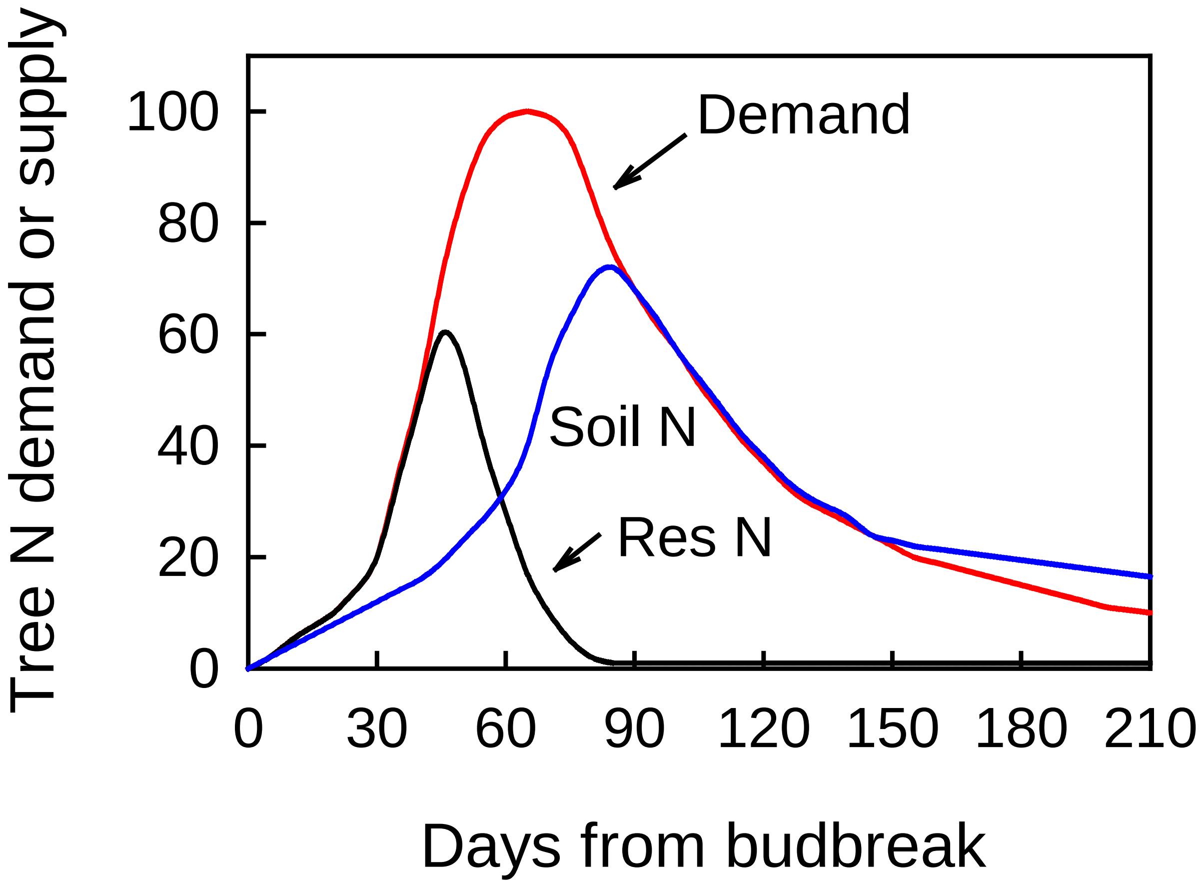
Apple leaf analysis standards for N

Tree type	*Leaf N (%)*
Young non-bearing apples	**2.4 – 2.6**
Young bearing apples	**2.2 – 2.4**
Mature soft varieties	**1.8 – 2.2**
Mature hard/processing varieties	**2.2 – 2.4**

Soft varieties: Cortland, Empress, Goldens, Honeycrisp, Mac, Jersermac, Jonagold, Jonamac, Jonathan, Macoun, Mutsu, Paulared, Spartan and other early ripening varieties

Hard varieties: Delicious, Empire, Gala, Idared, Liberty, Melrose, Rome, Stayman, York Imperial, and processing varieties

Tree N Demand-Supply



Timing of N application

- **Both early season (budbreak to petal fall) and late N applications fit the patterns of tree N demand.**

- **For soils with low fertility or varieties not very sensitive to N, multiple split applications during spring-summer period may be appropriate.**

Amount of N application

- Tree nitrogen requirement
- Natural supply of nitrogen from soil
- Uptake efficiency of applied fertilizers

Natural supply of N from soil

- Every 1% organic matter releases about 20 lb. N/acre per year
- N uptake efficiency is about 60%
- Every 1% organic matter contributes about 12 lb N/acre to apple trees.

Amount of N to be applied

- The difference between N demand and the supply from soil, with uptake efficiency factored in.
- Site-specific
- As a rule of thumb, every 10% increase in fertilizer results in 0.1% in leaf N

Estimating N Use Efficiency in Shandong Orchards

- **According to a survey by Dr. Jiang, the average N rate used in Qixia in 2012 was 540kg/acre（198 ~ 2556 kg/acre）**
- **At a yield of 30 tons/acre，N requirement is 30~36 kg/acre**
- **Assuming soil natural N supply contributed to 20% of the requirement, the N fertilizer use efficiency would be only 36 * (100 – 20)/540 ≈ 5%**

It's unlikely that N use efficiency is only 5%!

- Lon-term over-fertilization led to acidification of orchard soil (Average pH5.5 in Qixia), and low retention of fertilizers

- Very vigorous tree growth indicates N supply exceeds tree needs

- At a N fertilizer use efficiency of 25%, N fertilizer rate can be reduced to ¼ to 1/5 of the current rate

Foliar N application

- Foliar N application can help to meet the tree N demand early in the season or to increase tree N reserves in the fall.
- Early in the season: 0.4 to 0.6% urea. In the fall: 3% urea.

Summary on N application

- **Both early season (budbreak to petal fall) and late N applications fit the patterns of tree N demand.**
- **The amount N you need to apply depends on tree N status and natural N supply from soil.**
- **Foliar N application can help to meet the tree N demand early in the season or to increase tree N reserves in the fall.**

Potassium Application

- Fall application
- Maintenance (80 to 100 lbs/acre) vs correction (150 to 200 lb K_2O /acre).

K removal in relation to Gala yield

Yield (bushels/acre)	K (lbs/acre)	*K_2O (lbs/acre)*
500	27.7	33.3
1000	55.3	66.6
1500	83.0	100.0
2000	110.7	133.3

From: Cheng and Raba, 2009

Calcium management

- **Adjust soil pH for adequate Ca supply from soil**
- **Promote and maintain root growth, and uptake (B, Zn, water availability)**
- **Balance with N and K is important.**
- **Control tree vigor to mitigate competition with fruit for Ca.**
- **Avoid low cropload situation**

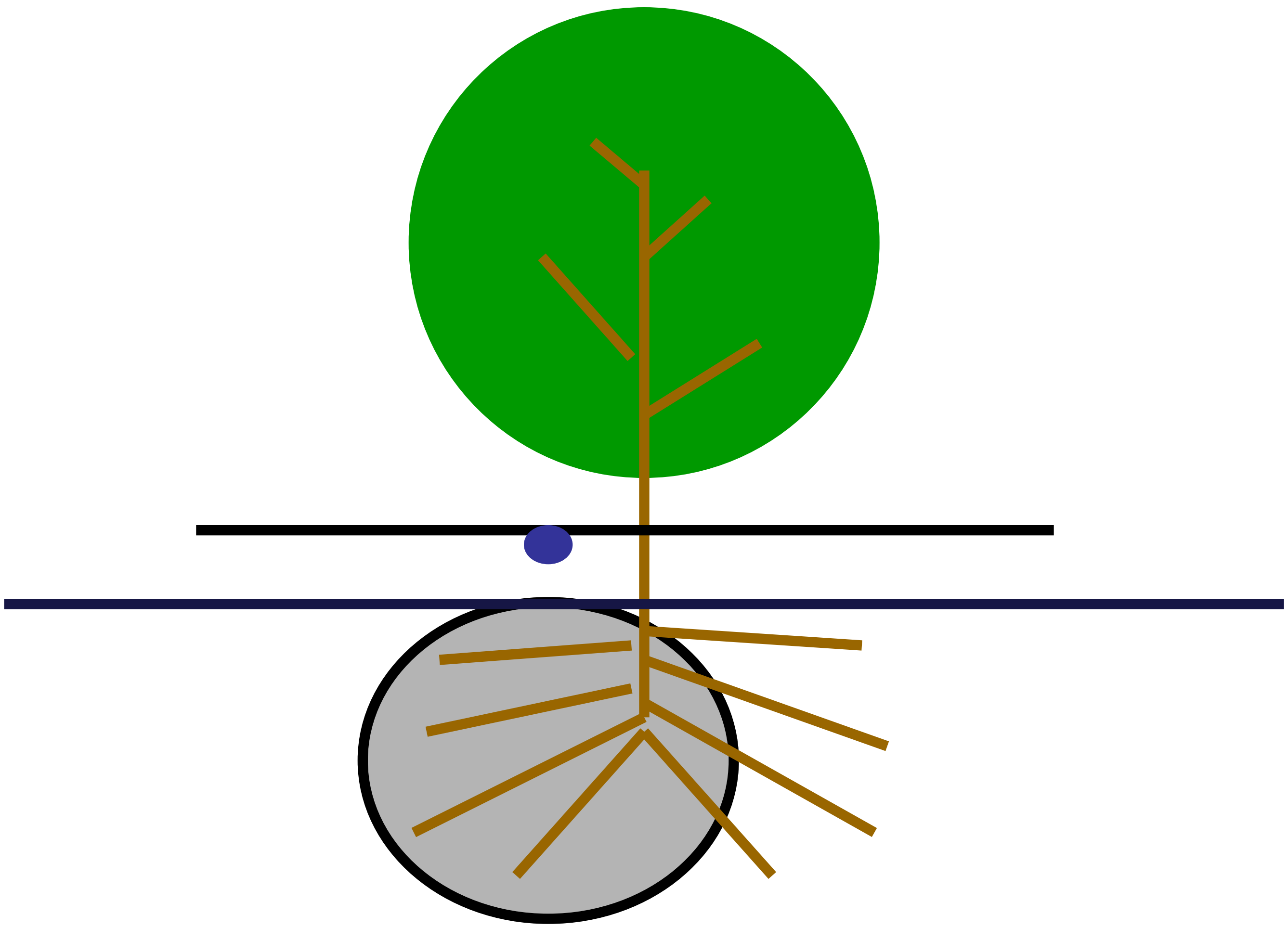
Calcium Sprays

- 3 to 4 sprays of 1 to 2 lbs of $CaCl_2$ (78%) or its equivalent per 100 gallons (dilute basis) at 14 day intervals beginning 7 to 10 days after petal fall.
- 2 additional sprays of 3 to 4 lb per 100 gallons at 4 and 2 weeks prior to harvest.

This program provides 7.5-13.4 lbs of actual Ca per acre

Fertigation: Potential Advantages

1. Delivers nutrients to the root zone at the right time
2. Reduces leaching and runoff of nutrients



Potential Application Problems

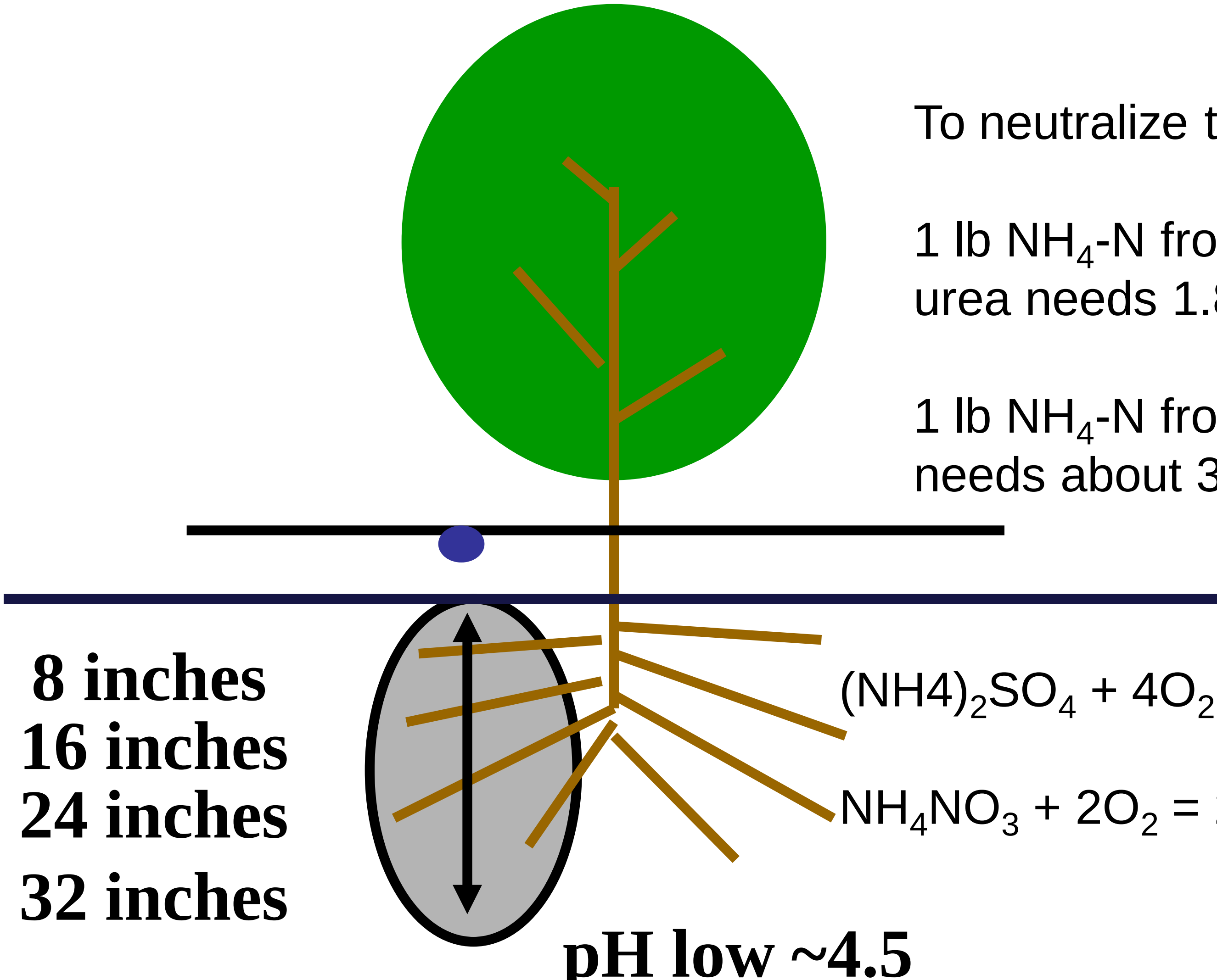
- Incompatibility of chemicals resulting in precipitates.
  - Ca, Mg, Fe, Zn and Cu should not be mixed with phosphates or sulfates.
  - High Fe content in the water can cause precipitate problems.
- Solubility of Materials.
  - Potassium fertilizers generally have low solubility.
  - Heating water will increase solubility but be careful of "salt out"
- Acidifying of the Soil.
  - Soil under the emitters can become very acid if acidifying nitrogen fertilizers are used.
  - Banded lime applications along the trickle line are required

pH Under Trickle Emitters After 6 Years

To neutralize the acidity:

1 lb NH_4-N from NH_4NO_3 and urea needs 1.8 lbs $CaCO_3$

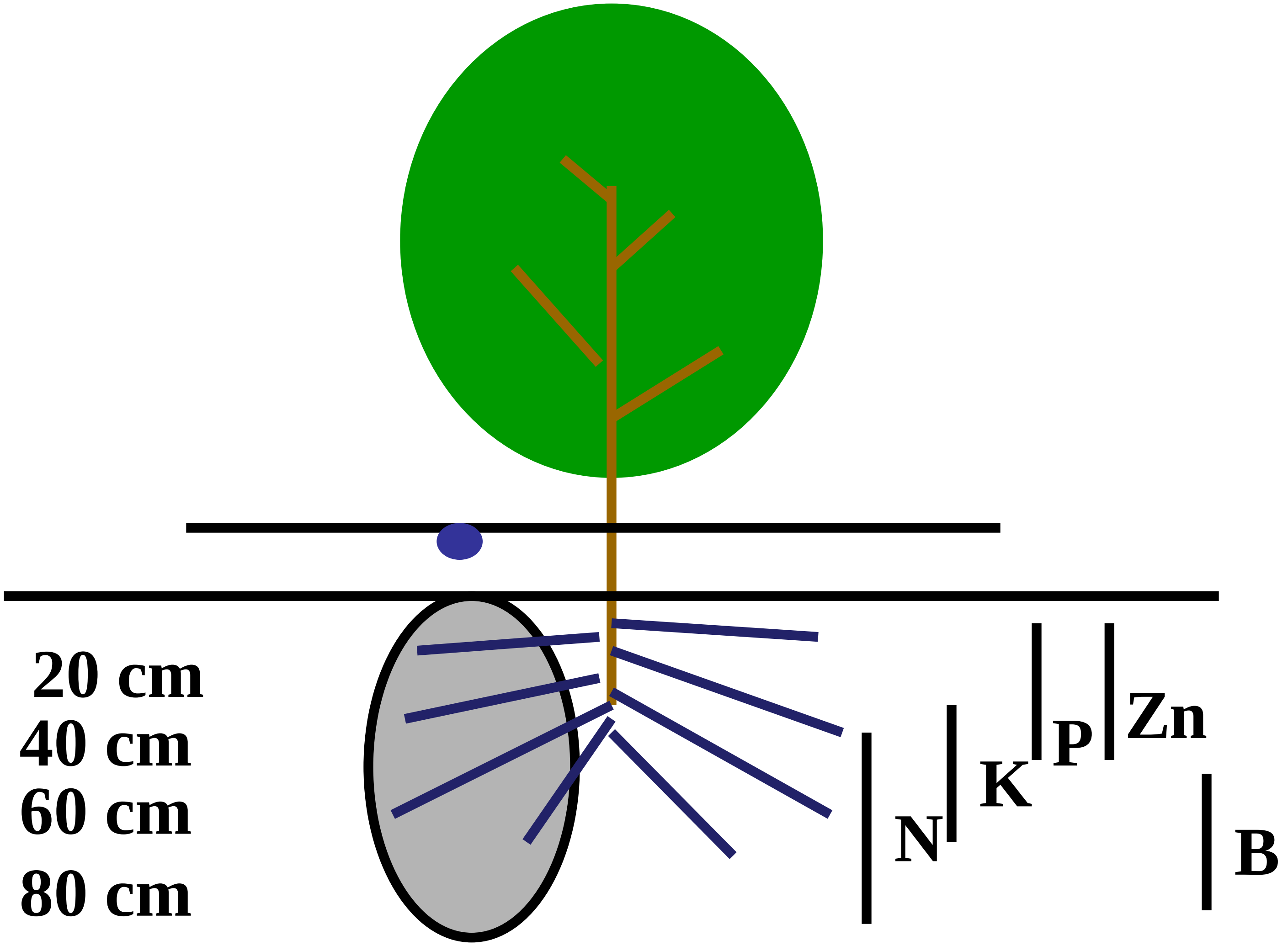
1 lb NH_4-N from $(NH_4)_2SO_4$ needs about 3.6 lbs of $CaCO_3$



$(NH4)_2SO_4 + 4O_2 = 2NO_3^- + 4H^+ + 2H_2O$

$NH_4NO_3 + 2O_2 = 2NO_3^- + 2H^+ + H_2O$

Distribution of Nutrients in the Soil



N and K Fertilizers Applied by Fertigation:

- **Nitrogen**
  - NH_4NO_3 (acidifying)
  - $(NH4)_2S_2O_3$ (liquid)
  - KNO_3 (low solubility)
  - Urea (not readily available)
  - Ca $(NO_3)_2$ (incompatibility with phosphates)
  - Urea/Ammonium Nitrate combinations (URAN) (liquid)
- **Potassium**
  - KCl (Moderate Solubility)
  - KNO_3(Low Solubility but good source of Nitrogen)
  - K_2SO_4 (Low Solubility)
  - Liquid Potassium fertilizers have low concentrations of potash

Other Fertilizers Applied by Fertigation:

- **Phosphorus**
  - $NH_4H_2PO_4$ (MAP) (low solubility)
  - $(NH_4PO_3)_n$ (APP) (liquid)
  - Phosphorus is best applied preplant with apples.
- **Calcium**
  - $Ca(NO_3)_2$ (incompatibility with phosphates)(Ca content too low)
- **Magnesium**
  - $MgSO_4 \cdot 7H2O$ (highly soluble but incompatible with phosphates)
- **Boron**
  - Solubor (highly soluble and accurately applied by trickle)
- **Zinc**
  - Zinc Chelates (effective but rates required are not economical)

Application Strategies :

1. **Constant concentration of nutrients in all irrigation water.**
   - **With light textured soils**
     - **N=100ppm on young trees and 50ppm on mature trees**
     - **K=10ppm on young trees and 50ppm on mature trees**
   - **With heavier textured soils**
     - **N=50ppm on young trees and 30ppm on mature trees**
     - **K=10ppm on young trees and 50ppm on mature trees.**
   - **Advantages with this strategy**
     - **Tree roots are exposed to a constant concentration of fertilizer in the soil solution.**
   - **Problems with this strategy**
     - **Dependence of amount of fertilizer on water demand.**
     - **In wet years less fertilizer is applied.**
     - **In dry years more fertilizer is applied**

NY Application Strategy

2. **Weekly Dose of Fertilizer (NY strategy)**
   - **Total amount of fertilizer to be applied per year is divided by number of weeks over which fertilizer is to be applied. (e.g. 10 weeks)**
   - **The weekly dose is applied in one irrigation cycle on one day of the week.**
   - **If additional water is needed it is applied without dissolved fertilizers.**
   - **Advantages with this strategy**
     - **Amount of fertilizer applied is independent of amount of irrigation water used**
   - **Disadvantages with this strategy**
     - **The concentration of fertilizer in the soil solution declines when non fertilized water is applied.**

Weekly Dose Strategy

- **With light textured soils**
  - **Young trees**
    - **N=60-100 lb/acre/year over 10 weeks (6-10 lb/acre/week)**
    - **K_2O=60 lb/acre/year over 15 weeks (4 lb/acre/week)**
  - **Mature trees**
    - **N=40-60 lb/acre/year over 10 weeks (4-6 lb/acre/week)**
    - **K_2O=100 lb/acre/year over 15 weeks (7 lb/acre/week)**
- **With heavier textured soils**
  - **Young trees**
    - **N=40-60 lb/acre/year over 10 weeks (4-6 lb/acre/week)**
    - **K_2O=60 lb/acre/year over 15 weeks (4 lb/acre/week)**
  - **Mature trees**
    - **N=20-40 lb/acre/year over 10 weeks (2-4 lb/acre/week)**
    - **K_2O=80 lb/acre/year over 15 weeks (5 lb/acre/week)**

Fertigation Strategy First 3 Years:

- **Liquid Nitrogen**
  - **CAN 17 (liquid)**
  - **N=60-100 lb/acre/year over 10 weeks or 6-10 lb/acre/week**
- **Potassium beginning in year 2**
  - **K_2O=60 lb/acre/year over 15 weeks or 4 lb/acre/week**
- **Small amounts of water applied twice weekly.**
  - **5 gallons per tree per week in year 1**
  - **10 gallons per tree per week in year 2**

Effect of Fertigation on Growth and Yield of Empire, Mutsu and Delicious Trees

Treatment	Shoot Growth yr. 1-3 (m)	Shoot Growth yrs4-5 (m)	Yield/ tree yr. 2-4 (kg)	Yield/ tree yr. 5-6 (kg)	Av. Fruit Size (g)
		(% of Control)			
Unirrigated	100 b	100 b	100 b	100 b	100 b
Trickle Irrigation	160 a	139 a	145 a	160 a	107 a
Fertigation	153 a	134 a	140 a	135 a	108 a

Conclusions on Fertigation

- **Fertigation is an efficient way to deliver Nitrogen and Potassium fertilizers to apple.**

- **Fertigation improves early tree growth and early yield.**

- **Fertigation can in some cases give larger fruit size and greater yield of mature trees.**

Controlled Release Fertilizers (CRFs)

Controlled release fertilizers with different proportions of N-P_2O_5-K_2O have been tested in apple orchards in Shandong by Drs Zhang Min, Jiang Yuanmao and others. These CRFs provide an effective way to match nutrient supply with tree nutrient demand, improve fertilizer use efficiency, and reduce leaching of nutrients

Build up soil organic matter

- **Manure and compost applications**
- **Straw-mulching in the row, and growing grasses between rows**
- **Cover crops, such as legumes**