University of California

Nitrogen Management Training

for Certified Crop Advisers

MODULE 2

Nitrogen Forms, Transformations, Function, and Management in Agriculture

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Plant Nutrition

Nutrients are essential for productivity but result in environmental problems when managed poorly.

Sources of Nitrogen Contamination in Water

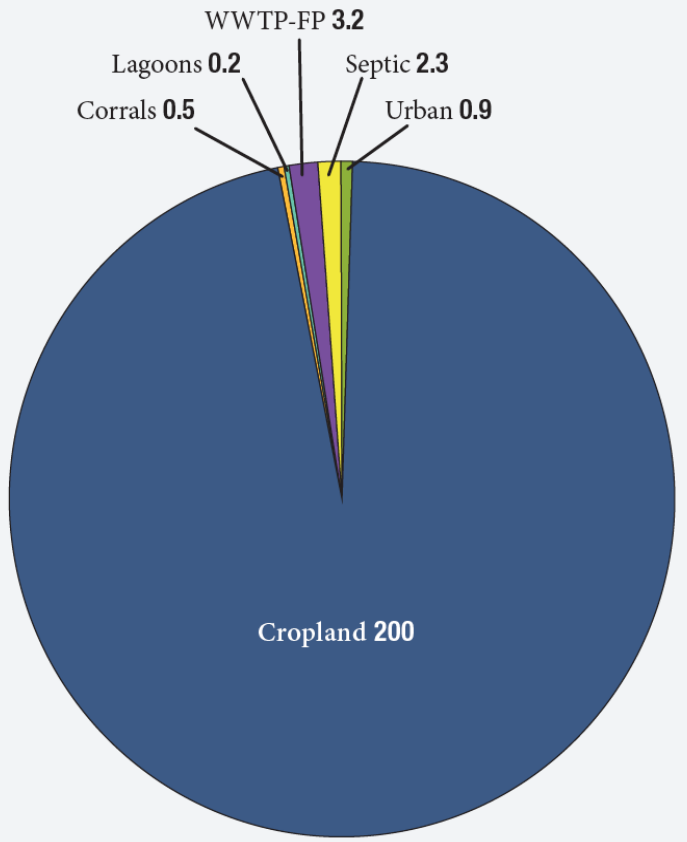
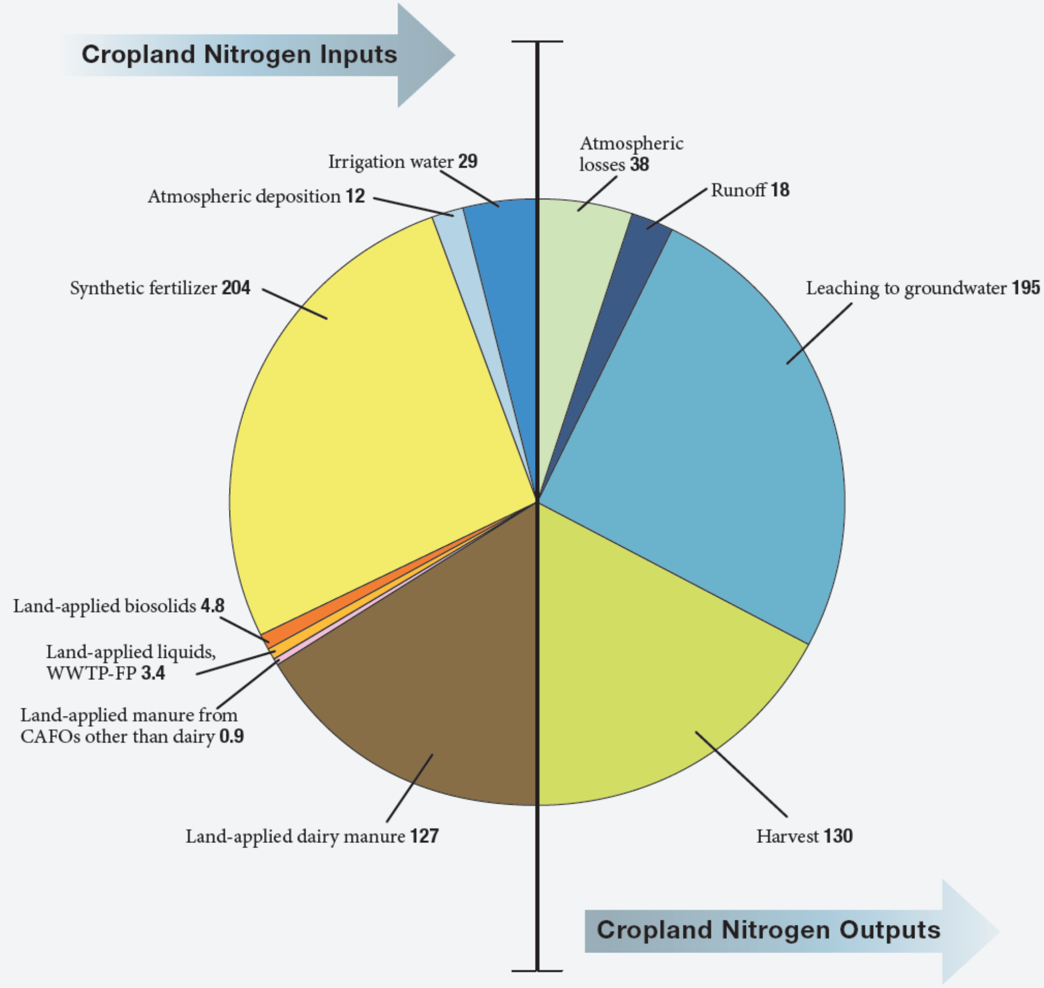


Figure ES-1. Estimated groundwater nitrate loading from major sources within the Tulare Lake Basin and Salinas Valley, in Gg nitrogen per year (1 Gg = 1,100 t).

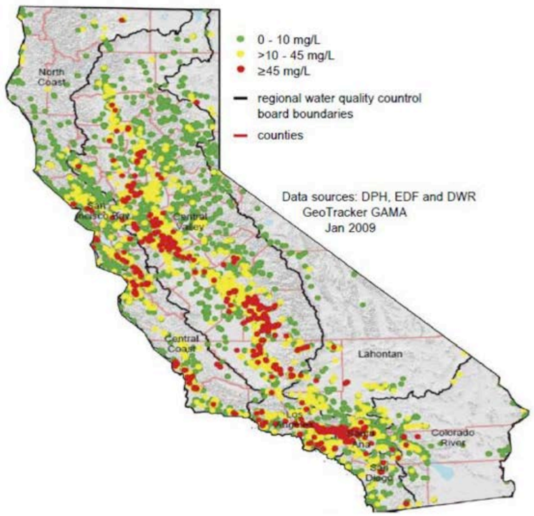


94% of nitrates due to Agriculture

N Application = >200% of Need

Sources of Nitrogen Contamination in Water

30 + % of wells exceed EPA drinking water levels (45 mg/L nitrate) and 250,000 people in SJV do not have access to 'safe' water.



(Ekdahl and others, 2009; Addressing Nitrates in California's Drinking Water, 2012)

Lakes, streams and estuaries suffer when nutrient and sediment load is too high.

Legislative Response: Mandated N Management Planning

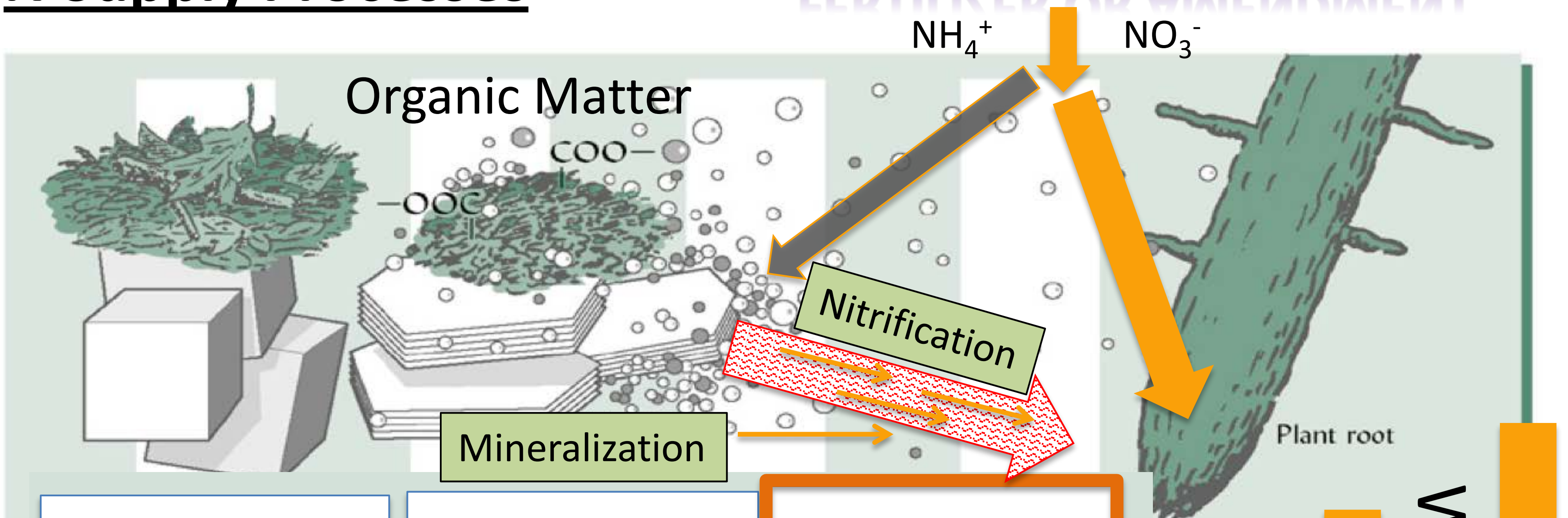
- Application rates will be based on field specific N budget estimates, accounting for all applied N x efficiency factor (60-80%).
- Trained Certified Crop Advisor sign-off required
- Post season verification and reporting, collated and managed by local water coalitions
- Self-reported, industry driven activity in the short term
  - However, if improvements in groundwater resources are not realized, a tightening of regulations can be expected.

Achieving optimal productivity with restricted nitrogen will REQUIRE enhanced efficiency of N use.

Nitrogen Cycle

N Supply Processes

FERTILIZER OR AMENDMENT



Mineral
Determined by source of soil minerals (volcanic, marine, alluvial etc) and age of soil.

Influences fertility but cannot be 'managed'.

Exchangeable
Fundamental determinant of native 'fertility'.

Cation and Anion Exchange Capacity

Influenced by pH, salinity, OM

Solution
Nitrate exists in the Soil Solution

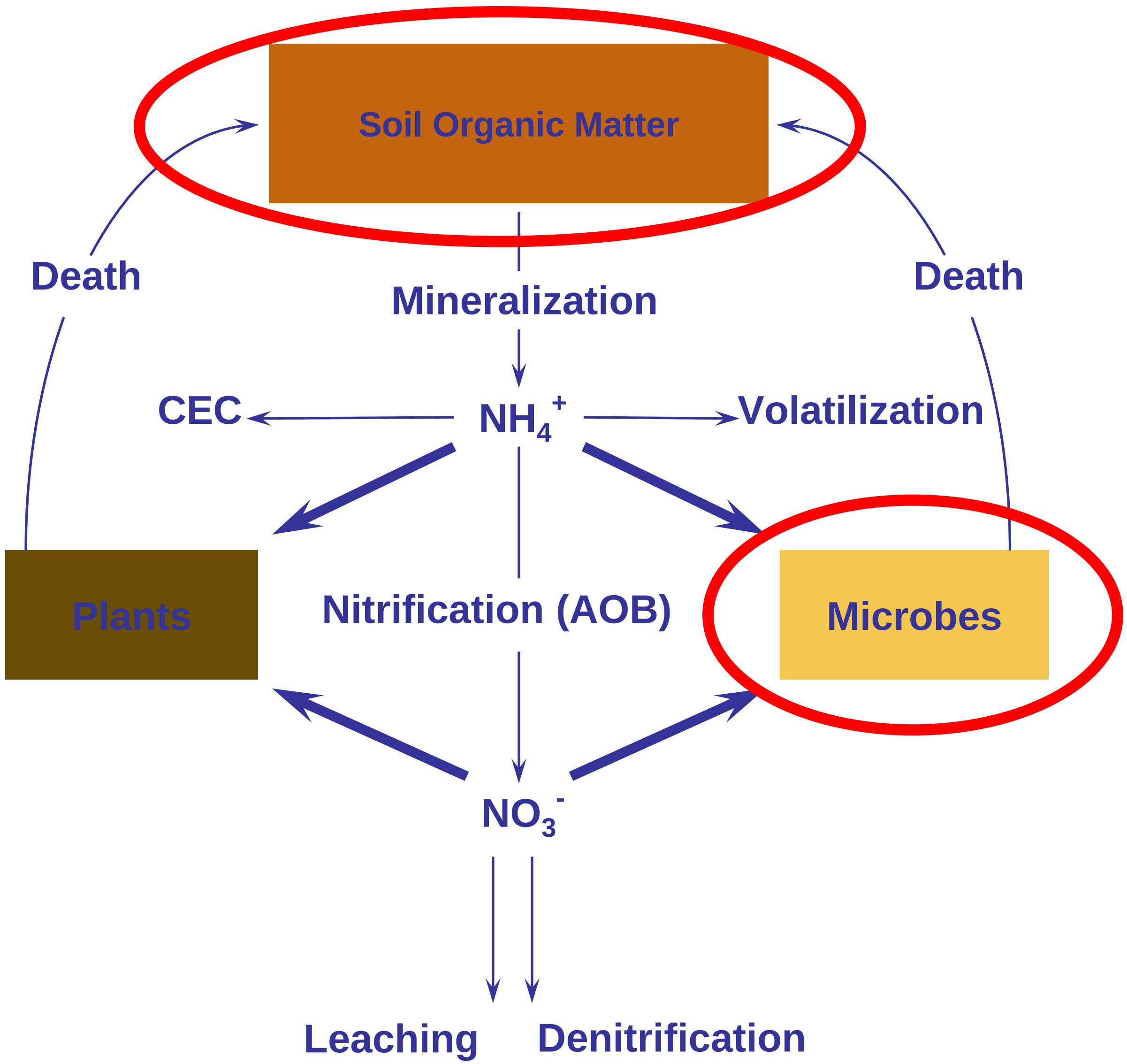
Uptake rate, exchange rate, leaching rate.

Root density and plant demand.

Nutrients that move below the root-zone will be lost.

(The Nature and Property of Soils: Brady and Weil, 2013)

Nitrogen Cycle Step by Step: Soil Organic Matter



The Process of Decomposition in Soils

- Composition of Plant Residues
  - Plant residues are the principal material undergoing decomposition in soils and, hence, are the primary source of soil organic matter.
  - Organic compounds can be listed in terms of ease of decomposition as follows:

Rapid decomposition

1. Sugars, Starches, and simple proteins
2. Crude proteins
3. Hemicellulose
4. Cellulose
5. Fats and waxes
6. Lignins and phenolic compounds

Very slow decomposition

(Elements of the Nature and Properties of Soils, 3/e by N. Brady and R. Weil)

Nitrogen in Organic Matter and Microbes

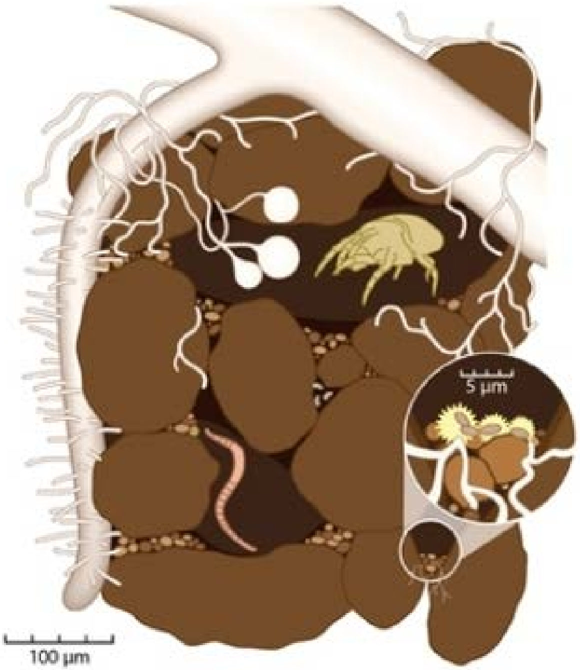
- SOM stores soil carbon and nutrients
  - Carbon acts as a food source for microbial populations
  - N is alternately taken up as microbes grow and released as they die
  - Most SOM does not fix N and is therefore recalcitrant and protected; the soluble organic matter is the portion that interacts with N cycling.

- The process of N release is driven by microbe populations
  - Release carbon and nutrients for their growth
  - Mineral N is produced

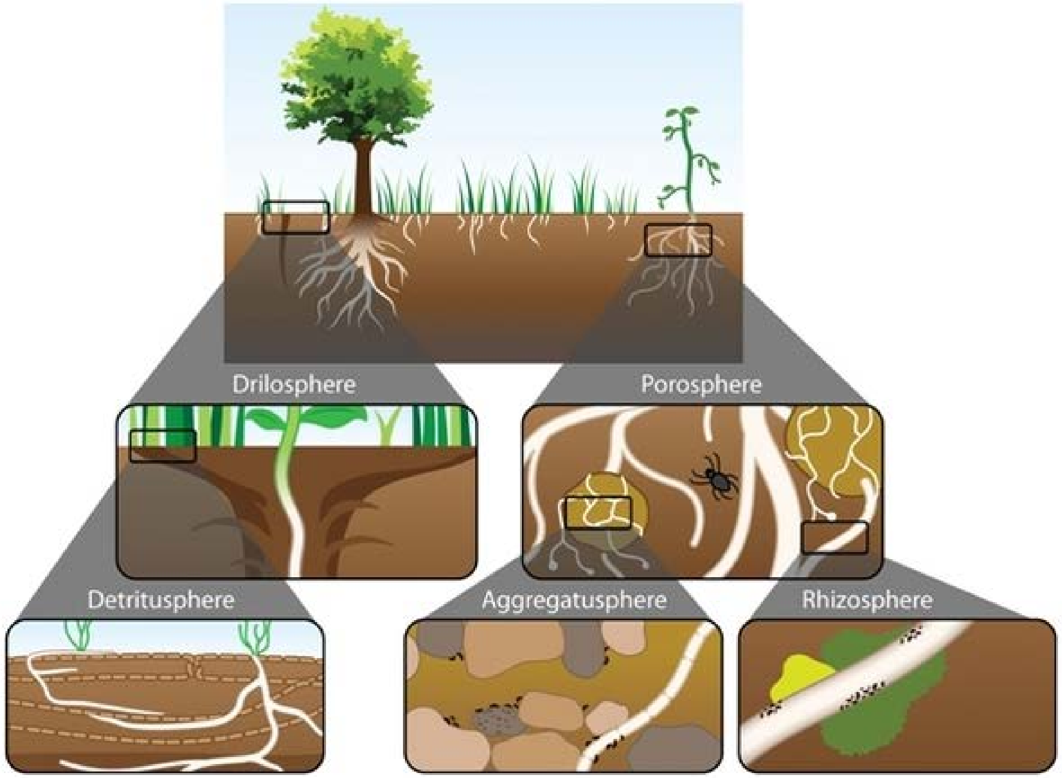
- Roots support microbes and increase the cycling of nutrients that otherwise would be lost by leaching and denitrification

- Gross N mineralization 10x higher in rhizosphere than bulk soil, e.g. wild oat (Herman *et al*. 2006)

Soil Microbe Function: The Soil is Alive!



Different aggregate sizes allow macro and micro pores, essential for aeration and water retention, respectively.



Soil zones. The rhizosphere is the most agriculturally significant zone, where the roots interact directly with the soil.

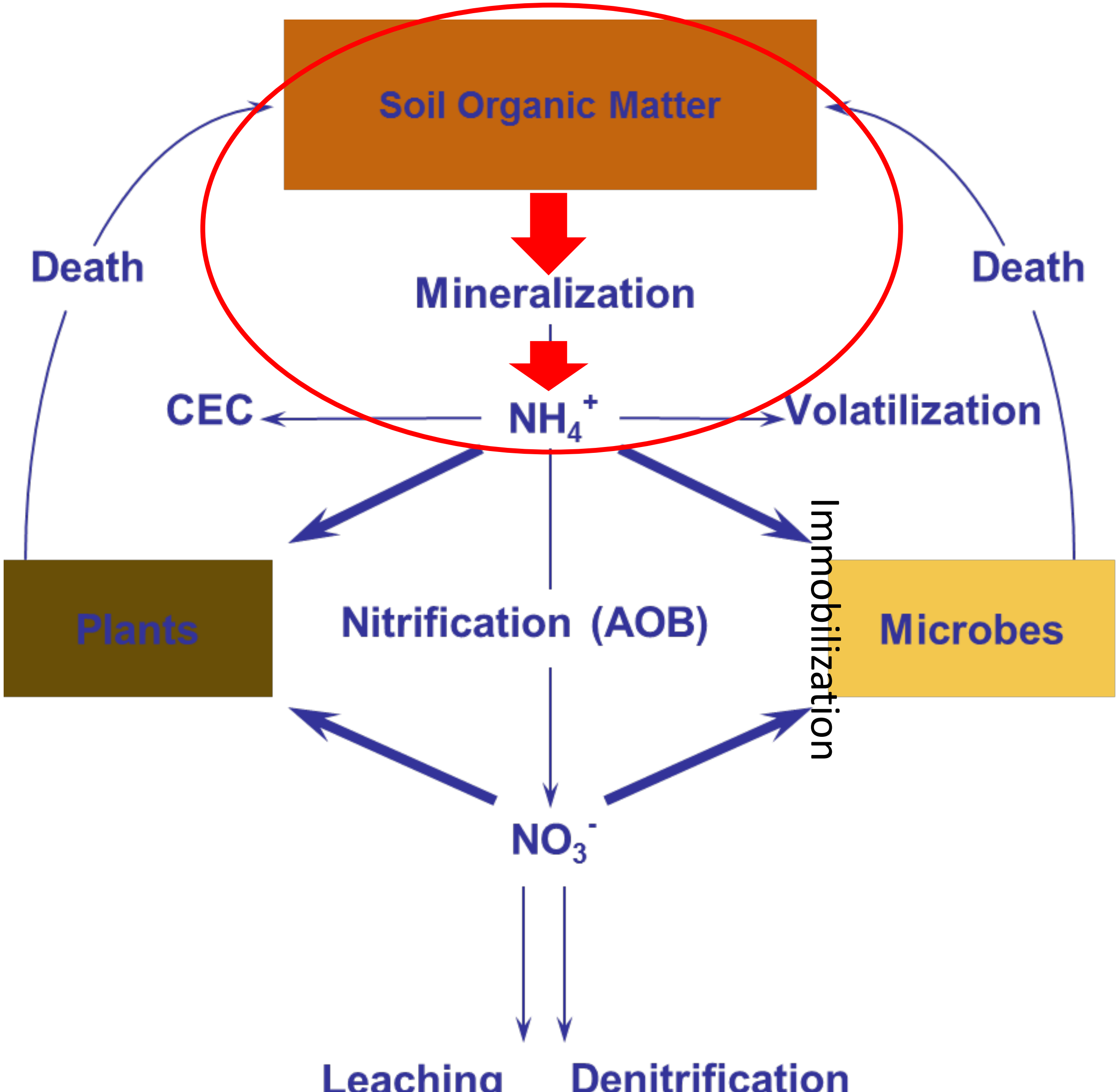
(Images from: http://www.nature.com/scitable/knowledge/library/the-soil-biota-84078125)

Influence of Soil Structure: Grassland Conversion to Intensive Vegetable Production Example

- Grassland→agriculture
  - Rapid decline in soil microbial biomass and SOM
  - Decreased respiration and potential N mineralization
  - Higher NO_3^-:NH_4^+ ratios
  - Higher NO_3^- pools and losses
  - Higher bulk density
  - Decreased water holding capacity

(Smith & Young 1975; Woods 1989; de Luca & Keeney 1994)

Nitrogen Cycle Step by Step: Mineralization



Immobilization ⟷ Mineralization Balance

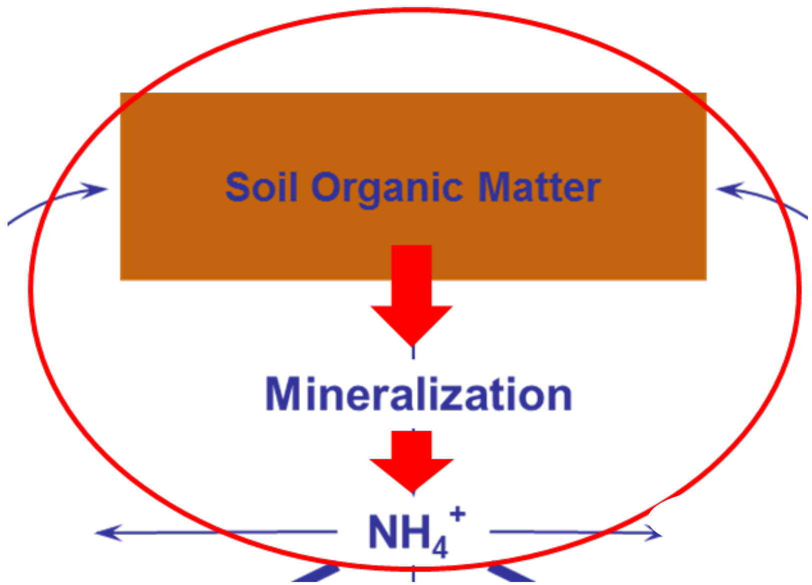
- **Mineralization** - process of conversion of organic N to plant available inorganic forms

- **Mineralization** - amine ($R\text{-}NH_2$) groups in SOM hydrolyzed to release ammonium (NH_4^+)
  - Heterotrophic microbial process
  - Rate depends on temperature and moisture
  - Most ammonium eventually oxidized to nitrate

- **Immobilization** - microbes incorporate mineral N from soil solution into organic compounds in cells
  - Reverse of mineralization

Balance of mineralization and immobilization determines the amount of available N in the soil at any given time

What do We Know about Mineralization Rates from Organic Matter?



What determines how quickly the mineralization process occurs?

Factors Controlling Mineralization and Decomposition Rates

- The time needed to complete the processes of decomposition and mineralization may range from days to years, depending mainly on two factors:
  - The environmental conditions in the soil
  - The quality of residues as a food source for soil organisms

- Therefore, the most important factor controlling these rates is the particular form of the organic matter or residue added to the soil, which dictates its C:N ratio.

(Elements of the Nature and Properties of Soils, 3/e by N. Brady and R. Weil)

Factors Controlling Decomposition and Mineralization Rates

- Physical Factors Influencing Residue Mineralization
- Carbon/Nitrogen Ratio of Organic Materials and Soils
- Soil Ecology (microbial activity)
- The Lignin and Polyphenol Content of Organic Materials

➔ Ideally, mineralization rates should be synchronized with plant N demand.

(Elements of the Nature and Properties of Soils, 3/e by N. Brady and R. Weil)

Factors Controlling Decomposition and Mineralization Rates

Table 11.2
TYPICAL CARBON AND NITROGEN CONTENTS AND C/N RATIOS OF SOME ORGANIC MATERIALS

Organic material	% C	% N	C/N
Spruce sawdust	50	0.05	600
Newspaper	39	0.3	120
Wheat straw	38	0.5	80
Corn stover	40	0.7	57
Maple leaf litter	48	1.4	34
Rotted barnyard manure	41	2.1	20
Bluegrass from fertilized lawn	42	2.2	20
Broccoli residues	35	1.9	18
Young alfalfa hay	40	3.0	13
Hairy vetch cover crop	40	3.5	11
Digested municipal sewage sludge	31	4.5	7
Soil microorganisms			
Bacteria	50	10.0	5
Fungi	50	5.0	10
Soil organic matter			
Average forest O horizons	50	1.3	45
Average forest A horizons	50	2.8	20
Mollisol Ap horizon	56	4.9	11
Average B horizon	46	5.1	9

(Elements of the Nature and Properties of Soils, 3/e by N. Brady and R. Weil)

Generally:

- A C:N ratio of 20:1 (2% N) is the dividing line between mineralization (immediate release) and immobilization (N binding and subsequent release).
- Most N in added materials will ultimately become available, though it may take several years.
- Anaerobic conditions will lead to no mineralization.

Nitrogen Release from Solid Organic Fertilizers

Breakdown rates of various dairy amendments are very well understood for forage and silage crops (see the articles linked below). Calculated rates are not immediately available for tree and vegetable crops, but this is the type of information needed for horticultural crops.

Manure Technical Guide Series
University of California Cooperative Extension

Dairy Manure Nutrient Content and Forms

http://manuremanagement.ucdavis.edu/files/134369.pdf

OPTIMIZATION OF ORGANIC FERTILIZER SCHEDULES

Project Leaders:
David M. Crohn and Marsha Campbell Mathews

USING DAIRY MANURE AS A NITROGEN FERTILIZER FOR FORAGE CROPS

Marsha Campbell Mathews[1]
David Crohn[2]

http://www.cdfa.ca.gov/is/docs/11-0456-SACrohn.pdf

http://alfalfa.ucdavis.edu/%2Bsymposium/proceedings/2008/08-159.pdf

Nitrogen Release from Solid Organic Fertilizers: Example

Dairy Manure Nutrient Content and Forms

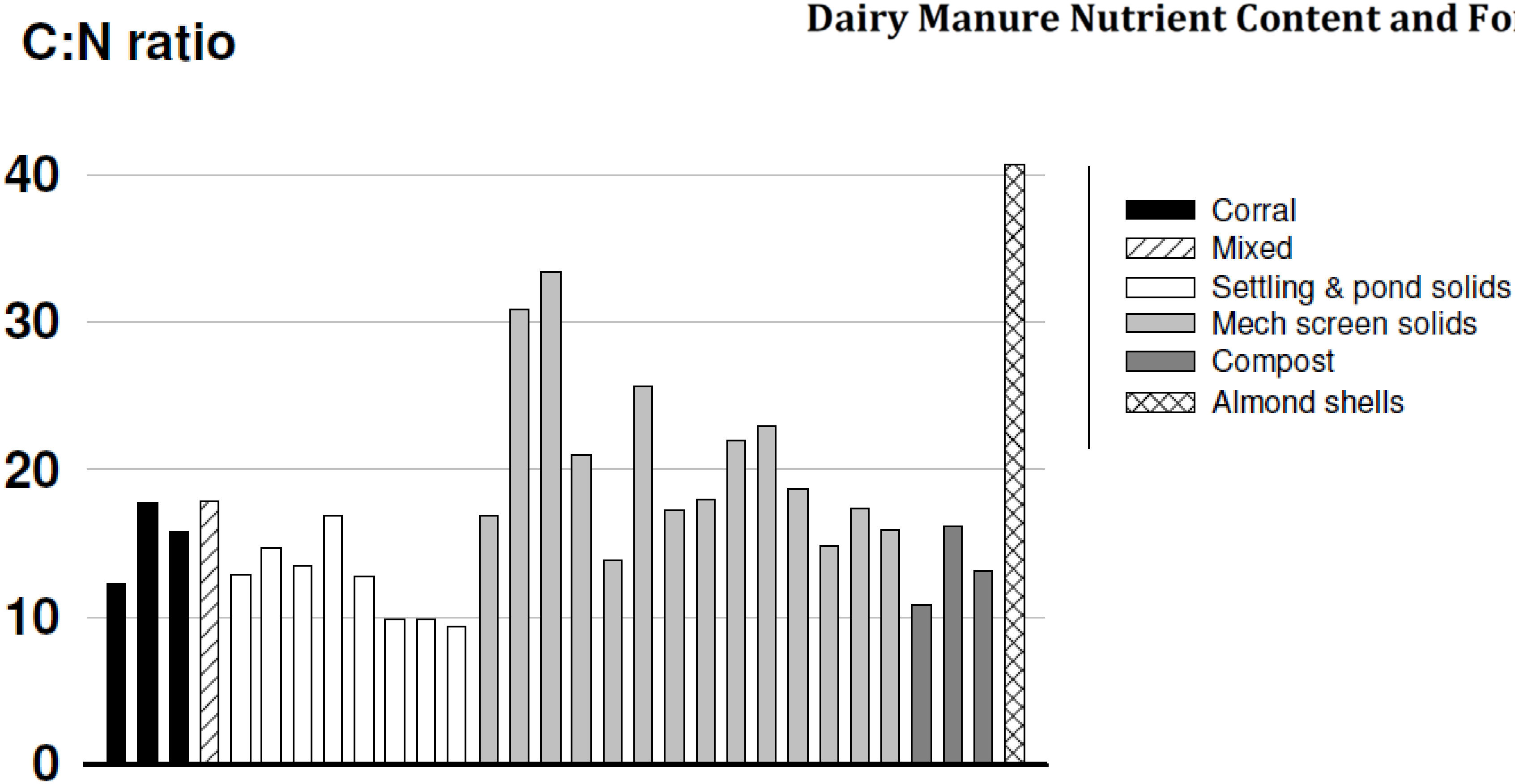
Material	pH	EC *dS/m*	DM *%*	VS *% of DM*	Total C *g C/kg DM*	Total C *g C/kg DM*
Fresh Manure	7.1c	3.2b	15b	83a	423a	507ab
Mechanical Screen Solids	8.3ab	2.1b	19b	88a	424ab	482b
Corral Scrapings	8.9a	7.6a	60a	46b	238c	527ab
Compost	8.2ab	3.0b	61a	57b	306bc	530ab
Anaerobic Dairy Lagoon Sludge	7.9b	2.4b	16b	51b	270c	540a

Material	Total N *g N/kg DM*	Inorg N *g N/kg DM*	Org N *g N/kg DM*	Org N *g N/kg VS*	C:N	C:Org N
Fresh Manure	25ab	2ab	23a	28c	17b	18b
Mechanical Screen Solids	17b	2ab	15a	18c	26a	30a
Corral Scrapings	19b	1b	18a	41b	12c	13cd
Compost	22ab	1b	22a	39b	14bc	14c
Anaerobic Dairy Lagoon Sludge	30a	5a	25a	50a	9d	11d

C:N Ratio of Solid Organic Fertilizers: Example

Manure Technical Guide Series
University of California Cooperative Extension

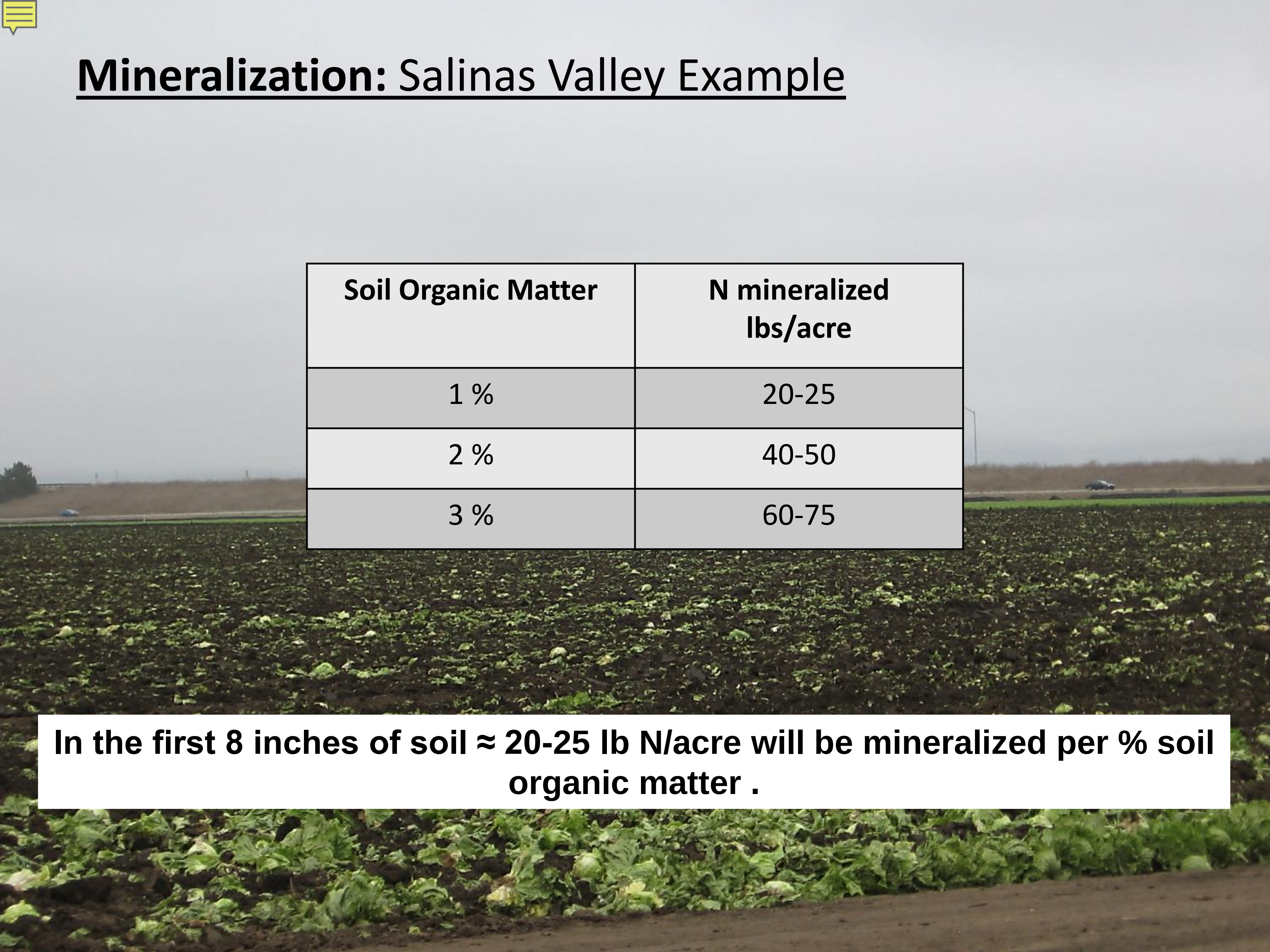
Dairy Manure Nutrient Content and Forms



Summary N Cycle: Mineralization

- SOM contains ~5% N
  – About 95% of N is in organic forms: stable OM fractions (‘recalcitrant’ humus) and clay-OM complexes
  – This portion is not directly available to plants
  – 1-2% of soil N is soluble, organic N

- Mineralization is the overall process of conversion of organic N to plant available inorganic forms.



Mineralization: Salinas Valley Example

Soil Organic Matter	N mineralized lbs/acre
1 %	20-25
2 %	40-50
3 %	60-75

In the first 8 inches of soil ≈ 20-25 lb N/acre will be mineralized per % soil organic matter .

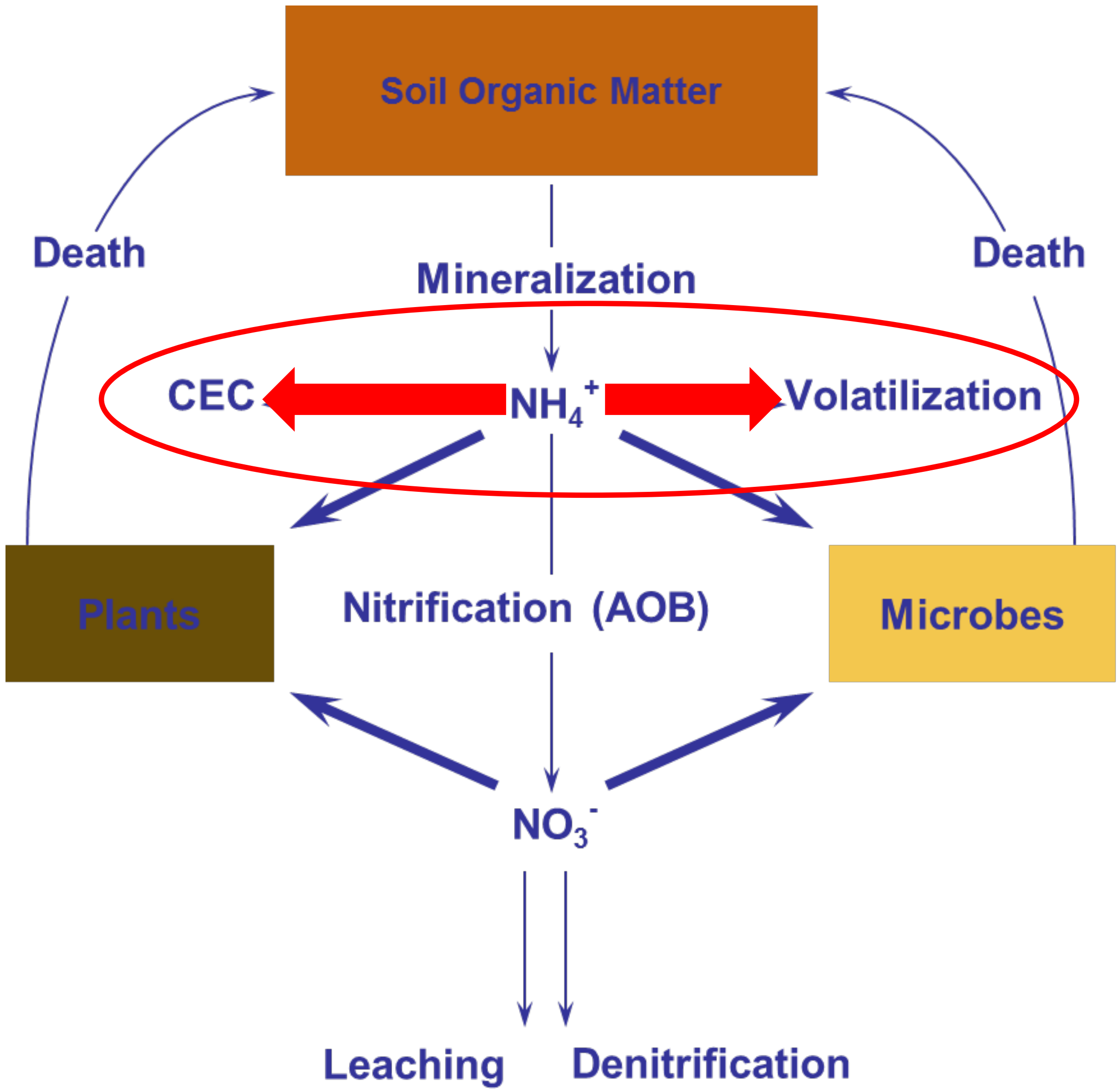
Summary N Cycle: Mineralization

- Carbon/Nitrogen ratio of organic materials is one of the main factors controlling mineralization rates.

- Environmental conditions, tillage and moisture strongly influence mineralization rates

- Chemical analysis of added organic matter is essential to determines the rate and timing of N release.

Nitrogen Cycle Step by Step: Fates of Ammonium After Mineralization



Fates of Ammonium After Mineralization

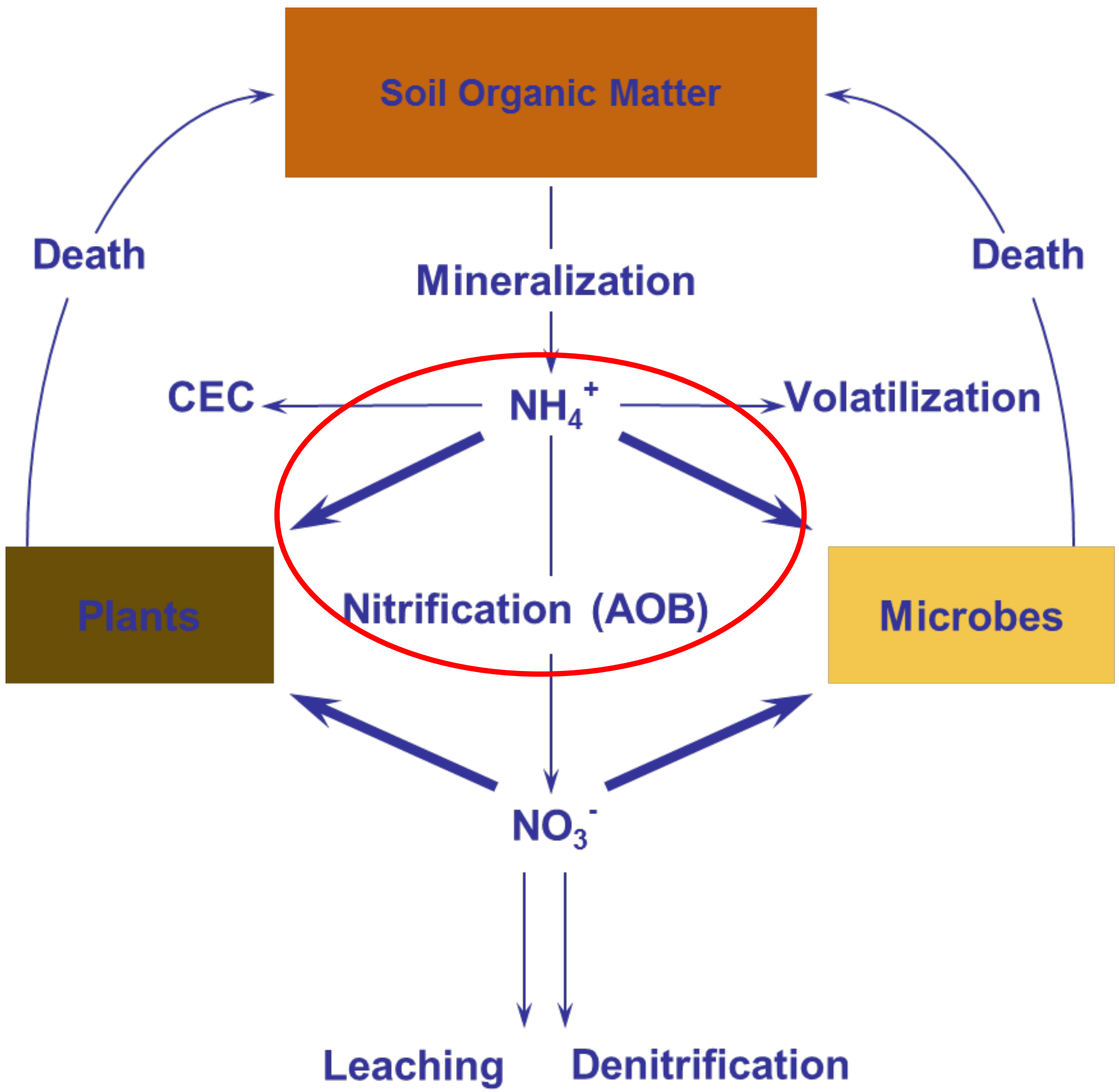
- Plant uptake
- NH_4^+ ions
  - Adsorbed on negatively charged clay surfaces
  - In 2:1, vermiculite clays, ammonium fixation can occur (very slow release)

- Ammonia volatilization

$$\underbrace{NH_4^+ + OH^-}_{\text{Dissolved ions}} \rightarrow \underbrace{\underline{NH}_3}_{\text{gas}} + H_2O$$

$$\underbrace{CO(NH_2)_2}_{\text{Urea}} + \underbrace{2H_2O}_{\text{Water}} \rightarrow \underbrace{(NH_4)_2CO_3}_{\text{Ammonium Carbonate}} \rightarrow \underbrace{\underline{2\,NH}_3}_{\text{Ammonia}} + \underbrace{2OH^-}_{\text{Hydroxide}} + \underbrace{CO_2}_{\text{Carbon Dioxide}}$$

Nitrogen Cycle Step by Step: Nitrification



Nitrification: $NH_4^+ \rightarrow NO_3^-$

Step 1: Ammonium to nitrite

$$NH_4^+ + 1\tfrac{1}{2}O_2 \xrightarrow{Nitrosomonas} NO_2^- + 2H^+ + H_2O + energy$$

Nitrite (NO_2^-)

- Toxic
- Doesn’t accumulate, rapid conversion to nitrate

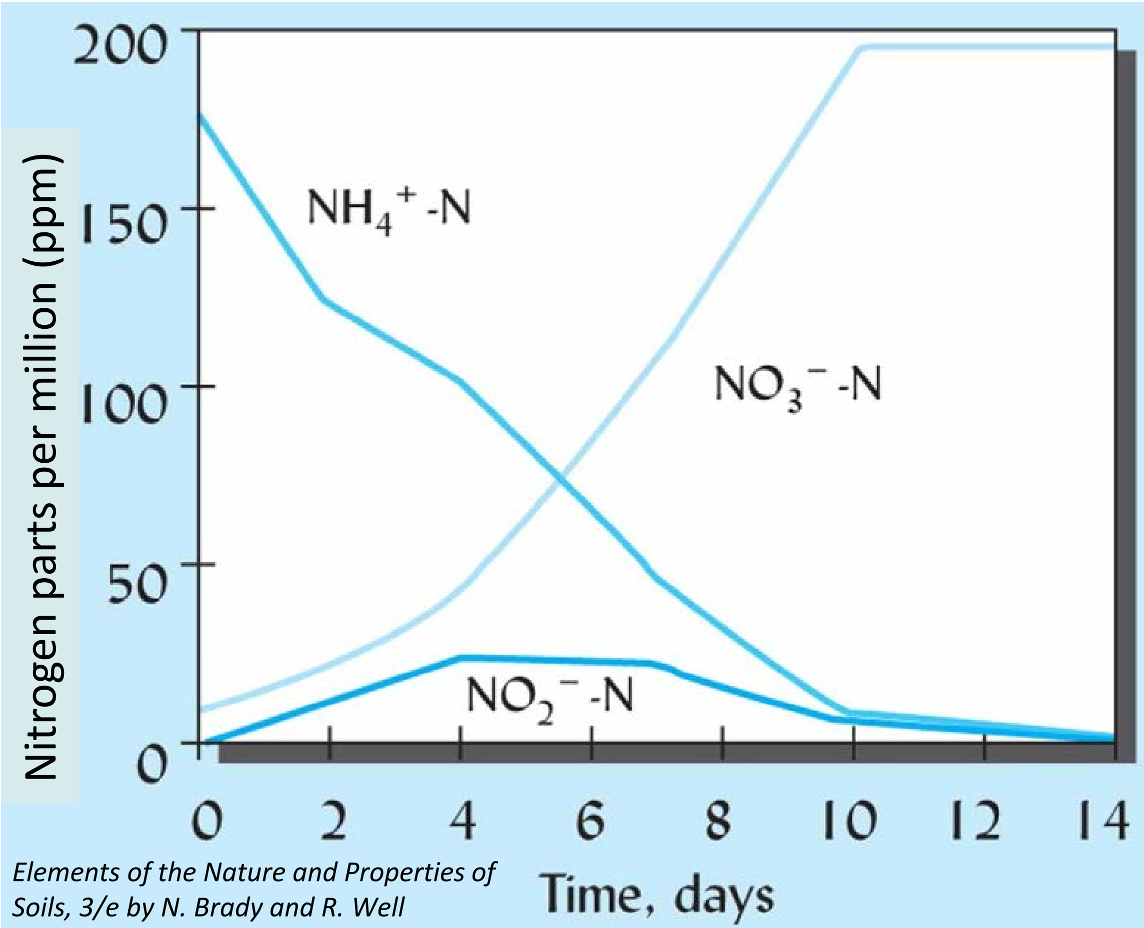
Step 2: Nitrite to nitrate

$$NO_2^- + \tfrac{1}{2}O_2 \xrightarrow{Nitrobacter} NO_3^- + energy$$

Nitrate (NO_3^-)

- Readily available for plant uptake
- Prone to loss by leaching (- charge) and denitrification

Nitrification: How Quickly Does it Occur?



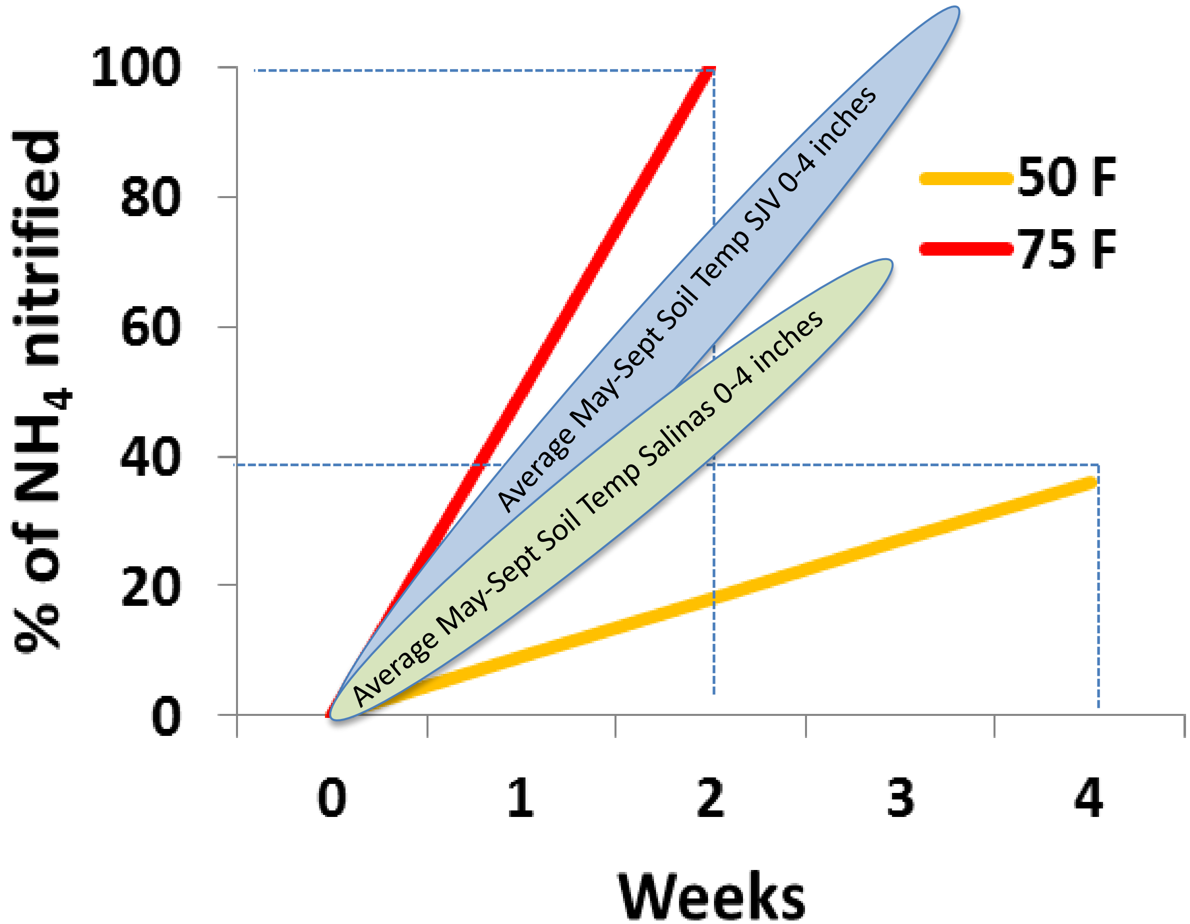
Elements of the Nature and Properties of Soils, 3/e by N. Brady and R. Well

1. Ammonium sulfate $(NH_4)_2SO_4$ added to silt loam soil at rate of 170 mg N/kg soil
2. Incubated/aerated 14 days
1. Analysis for different forms of N occurring every other day.

1. $$NH_4^+ + 1\tfrac{1}{2}O_2 \xrightarrow{Nitrosomonas} NO_2^- + 2H^+ + H_2O + energy$$
2. $$NO_2^- + \tfrac{1}{2}O_2 \xrightarrow{Nitrobacter} NO_3^- + energy$$

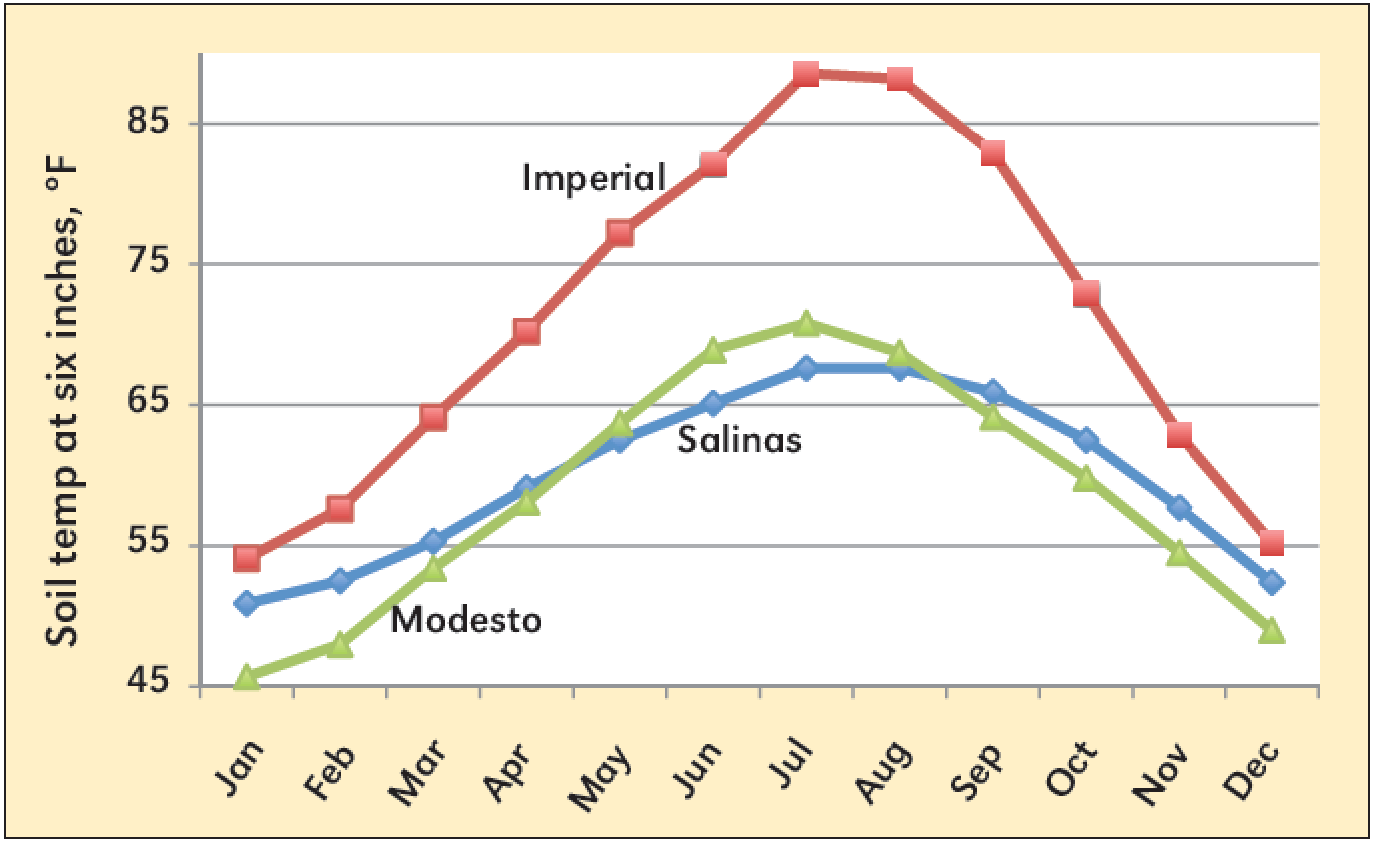
Nitrification: How Quickly Does it Occur?

Nitrification rate governed mostly by temperature:



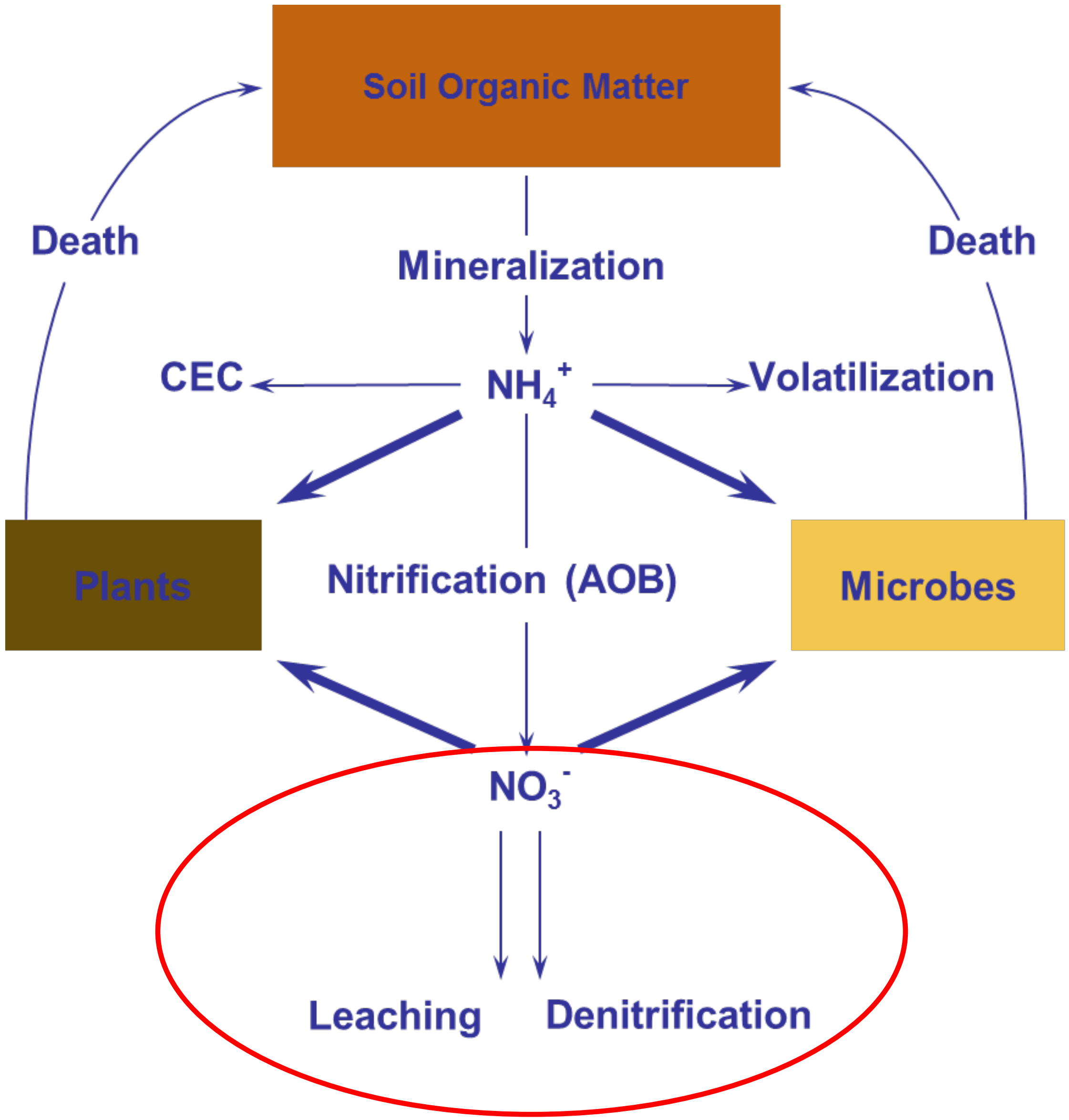
(Adapted from Western Fertilizer Handbook)

Nitrification: How Quickly Does it Occur? California Example



(IPNI, Nitrogen notes #4)

Nitrogen Cycle Step by Step: Nitrates



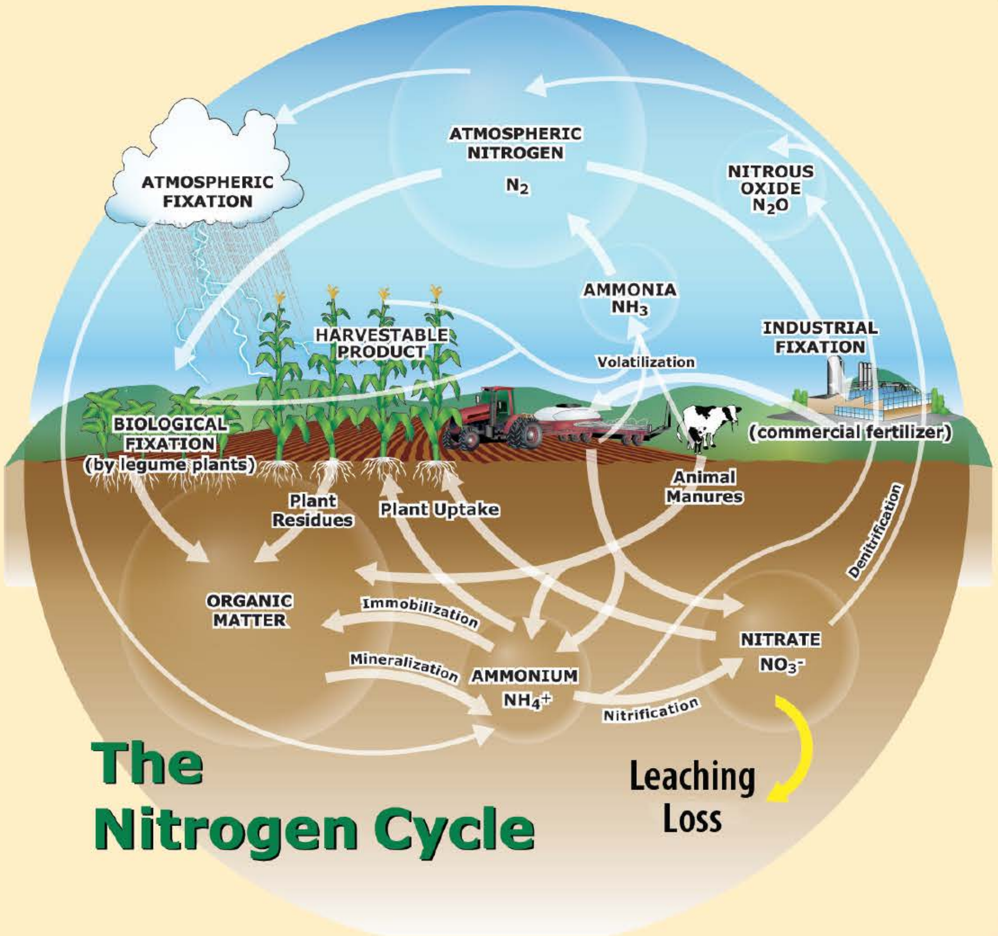
Why Does Nitrate Leach?

- Nitrate (NO_3^-) is negatively charged, so it is not held by the soil particles, also negatively charged.
- Because it is applied in excess
- Because water management is inadequate
- Because timing of application does not match crop demand

Nitrate Leaching Principles

NITRATE LEACHING

Nitrate is critical for supporting plant growth, but it is vulnerable to leaching through soil. For nitrate leaching to occur, (1) nitrate must be present in the soil, (2) the soil must be permeable for water movement, and (3) water must be moving through the soil.



(IPNI, Nitrogen Notes #3)

Nitrogen in Agricultural Systems

N in Plants

Irrigation Rapidly Moves N into Soil

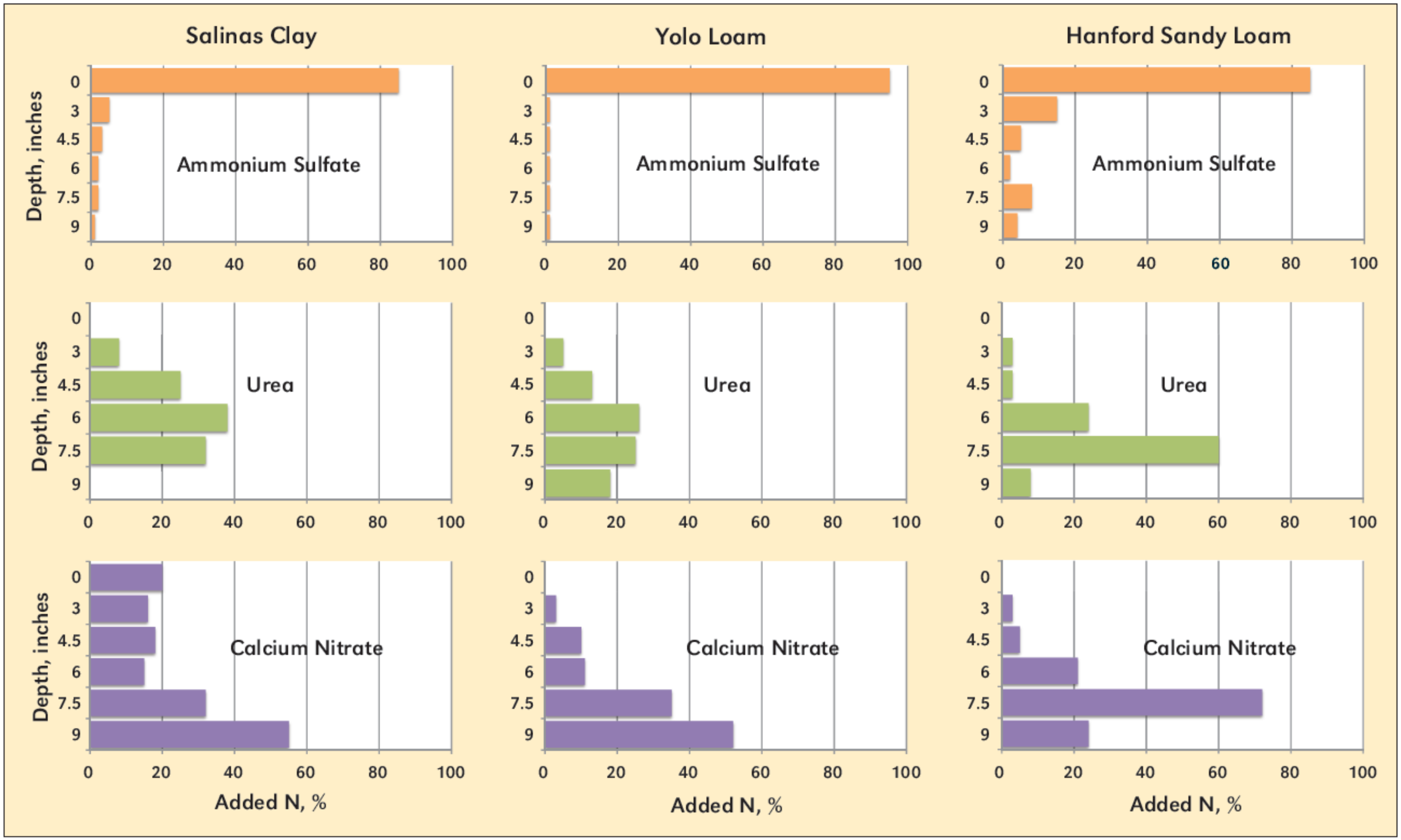


Figure 2. The movement of ammonium, urea, or nitrate in the surface 9 in. of three soils. The urea and calcium nitrate were applied to the soil surface and irrigated with a uniform amount of water. The ammonium sulfate was added as a solution. The soils were sampled 90 minutes after fertilizer and water application. (Broadbent et al., 1958).

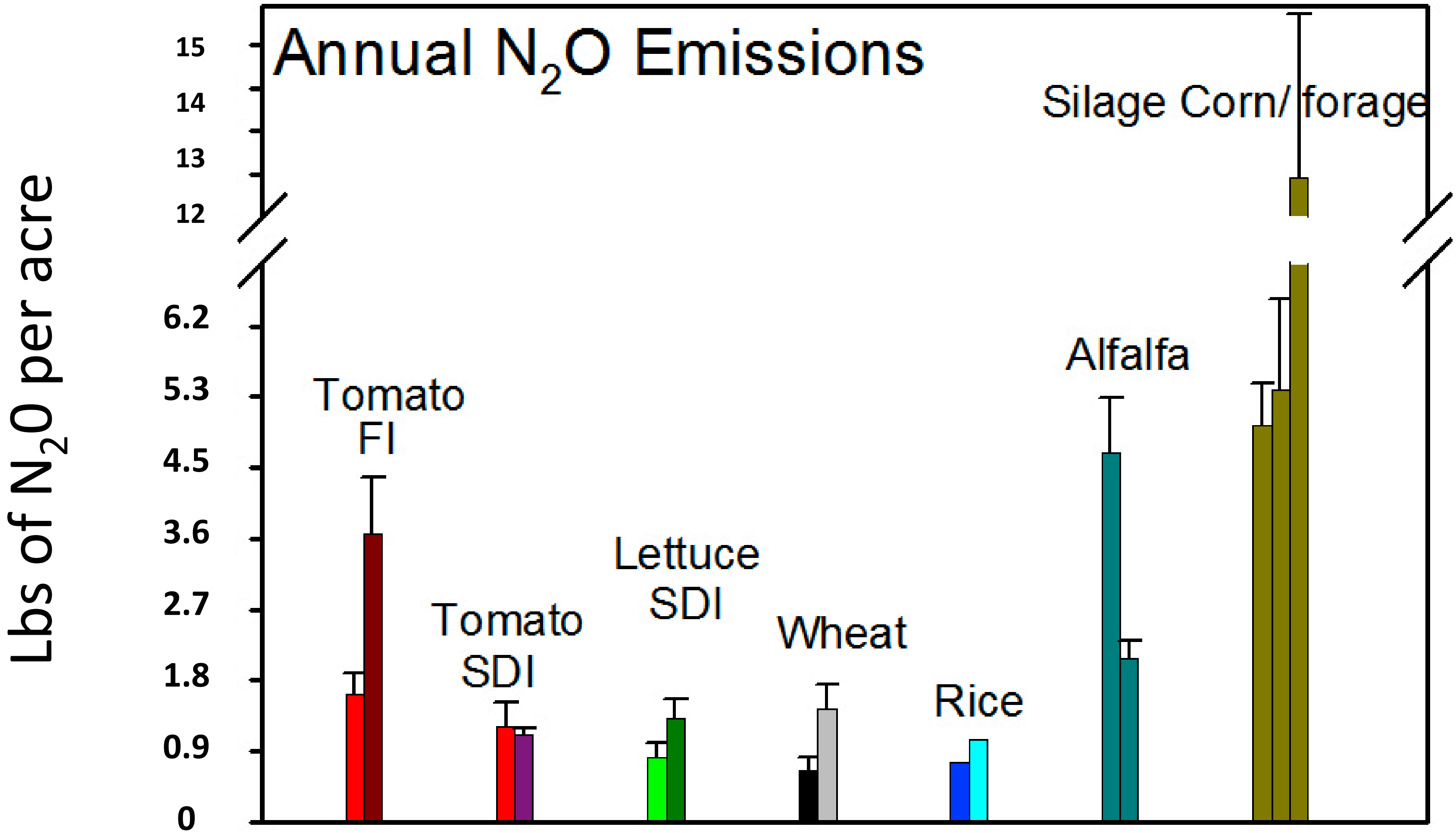
(Courtesy www.IPNI.org)

Denitrification

$$\underset{\substack{Nitrate\\(+5)}}{2NO_3^-} \xrightarrow{-2O} \underset{\substack{Nitrite\\(+3)}}{2NO_2^-} \xrightarrow{-2O} \underset{\substack{Nitric\ oxide,gas\\(+2)}}{2NO\uparrow} \xrightarrow{-O} \underset{\substack{Nitrous\ oxide,gas\\(+1)}}{N_2O\uparrow} \xrightarrow{-O} \underset{\substack{Dinitrogen\ gas\\(0)}}{N_2\uparrow}$$

- Occurs under warm, anaerobic conditions
- Global warming ➔ N_20 is 298x higher than same mass of CO_2
- Most significant in hydric soils (wetlands, rice paddies)
- Less significant in well-drained soils
- In irrigated agriculture, N_20 production is sporadic. Most N loss occurs during a brief period when the soil is warm, wet, and high in nitrate (i.e. fertigation).

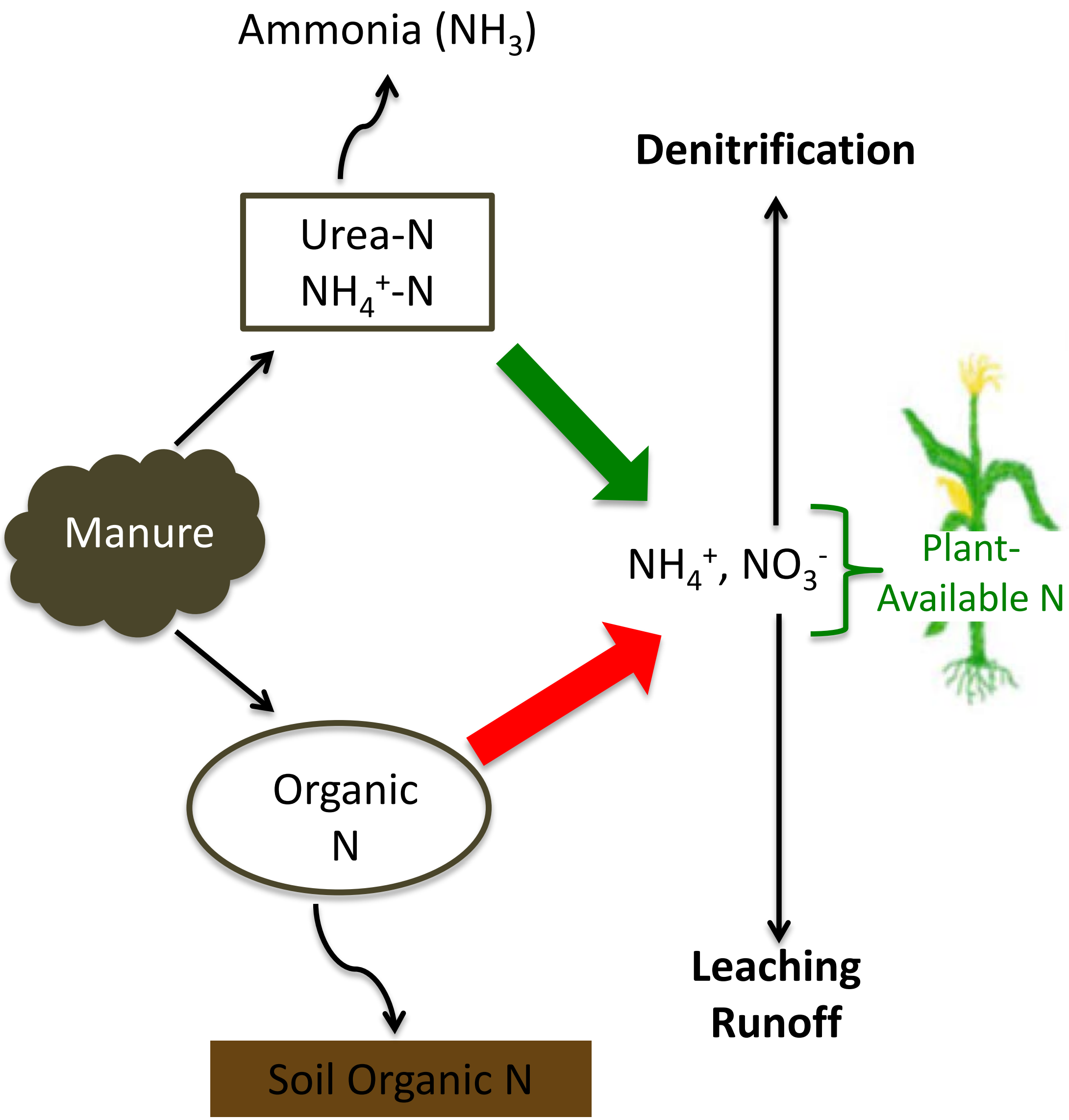
Denitrification: Rates Vary with Cropping System



SDI = Subsurface drip irrigation
FI = Furrow irrigation

Almond: 0.25 – 0.94 kg N_2O-N ha^{-1} (Schellenberg *et al.*, 2012)
Vineyard: 0.13 -.22 kg N_2O-N ha^{-1} (Garland *et al.*, 2011)

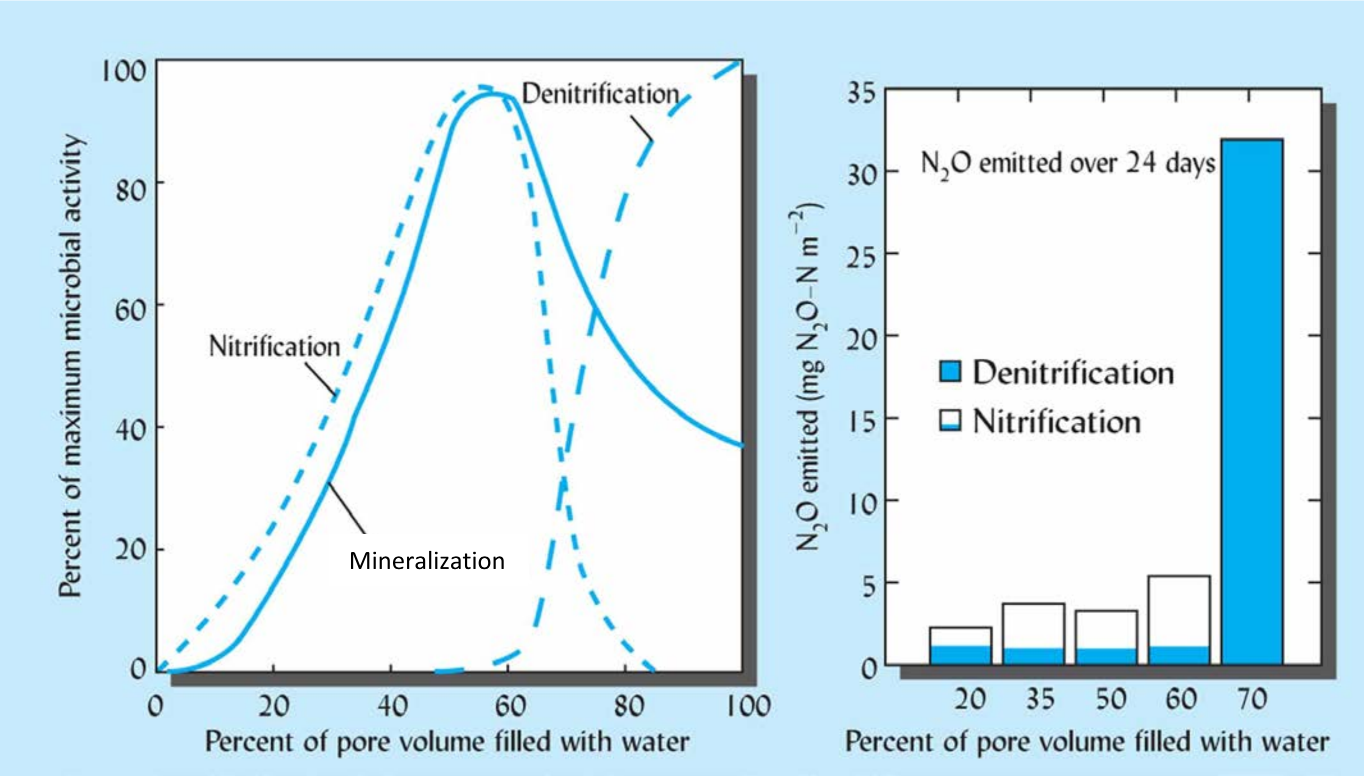
Summary N Cycle: Conceptual Points Covered So Far



- Inorganic fraction of N (Urea-N, Ammonium-N) moves into plant rapidly.
- Organic fraction of N moves into plant much more slowly, and the rate is much more dependent on the specific form of the nitrogen.

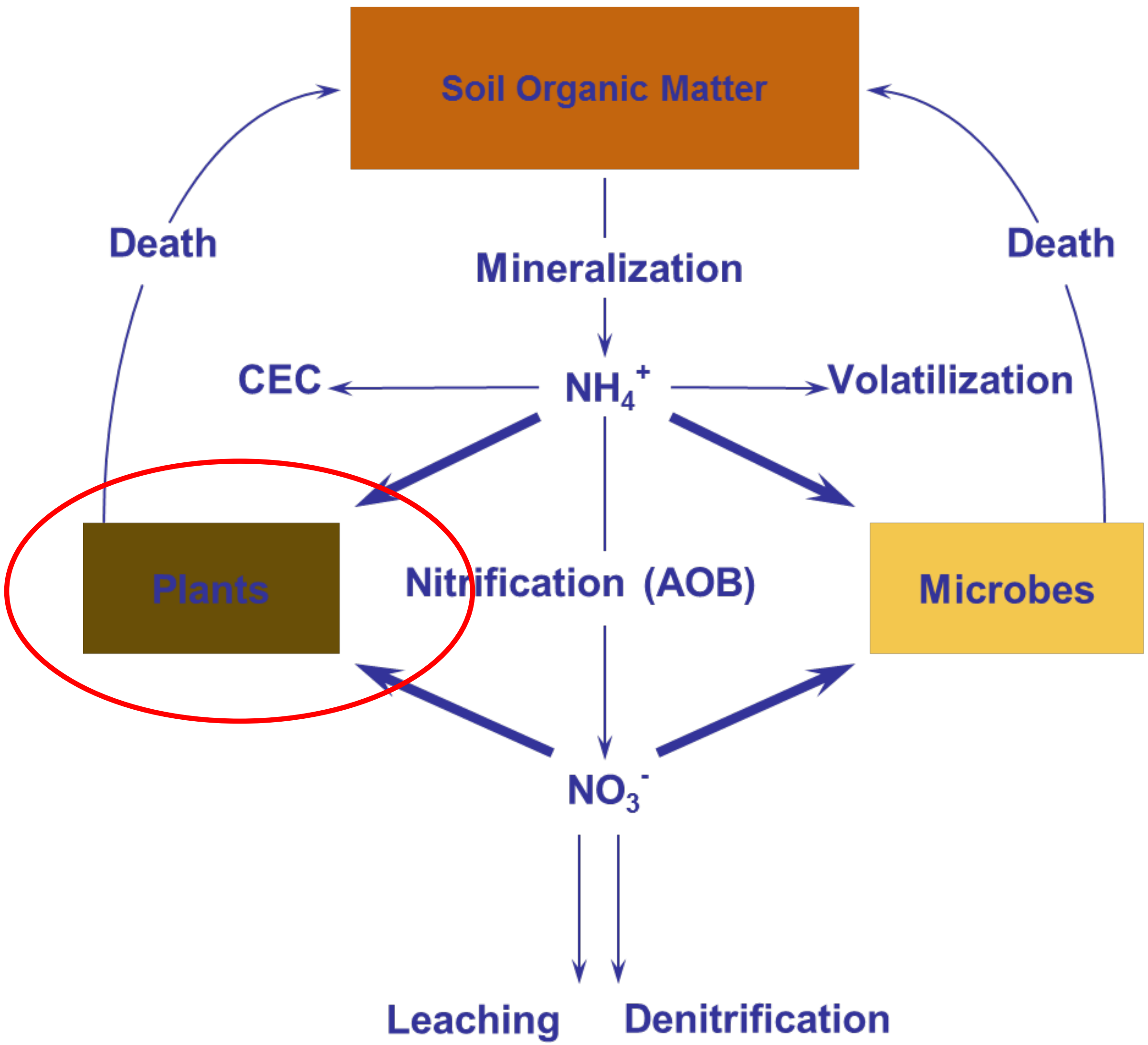
Image adapted from *http://extension.umass.edu/cdle/sites/extension.umass.edu.cdle/files/fact-sheets/images/ConservingAmmoniainManure-2.gif*

Summary N Cycle: Nitrification, Mineralization, and Denitrification Rates



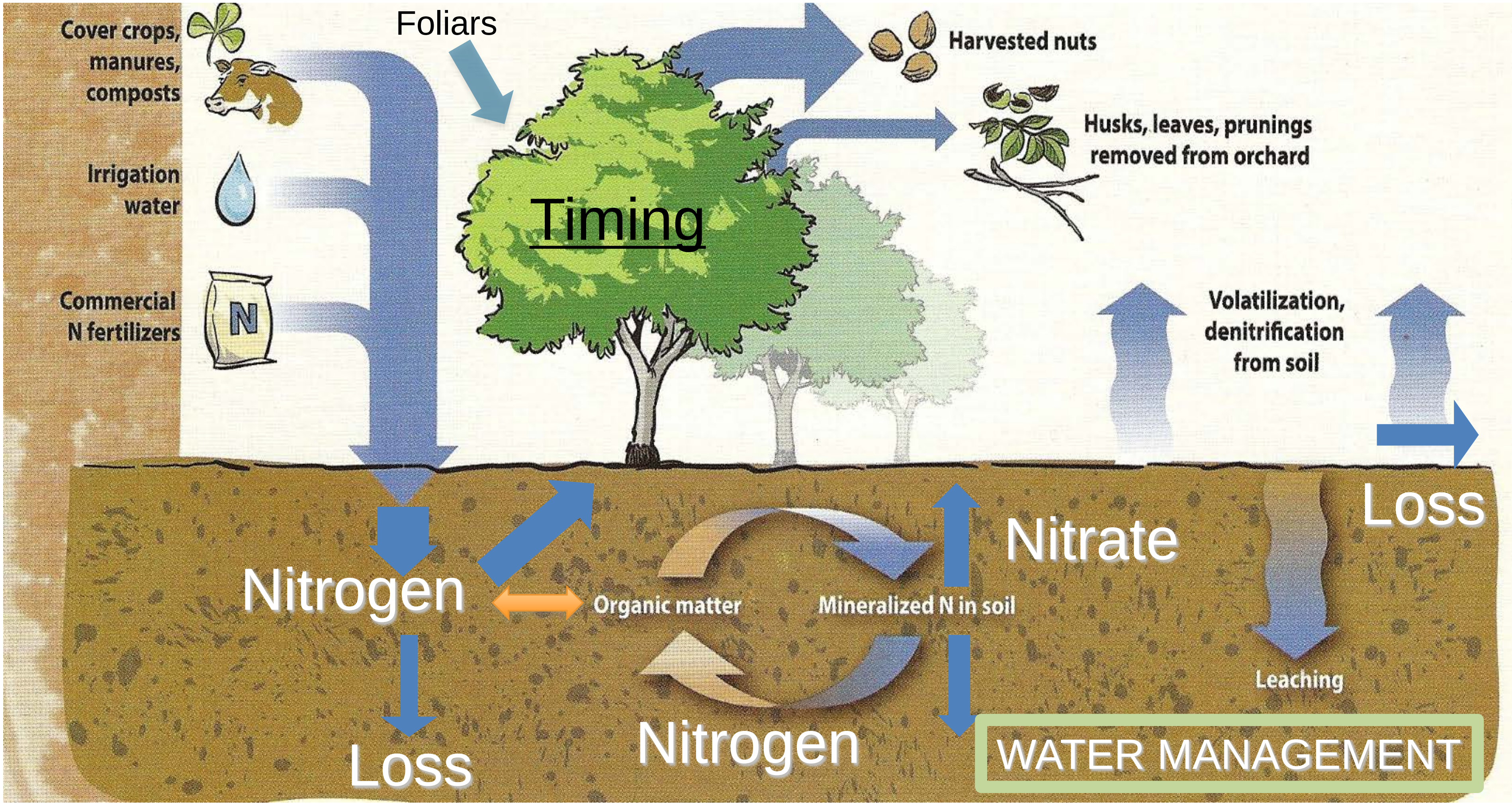
(Elements of the Nature and Properties of Soils, 3/e by N. Brady and R. Weil)

Nitrogen Cycle Step by Step: N in Plants



Nitrogen Cycle: A Balancing Act

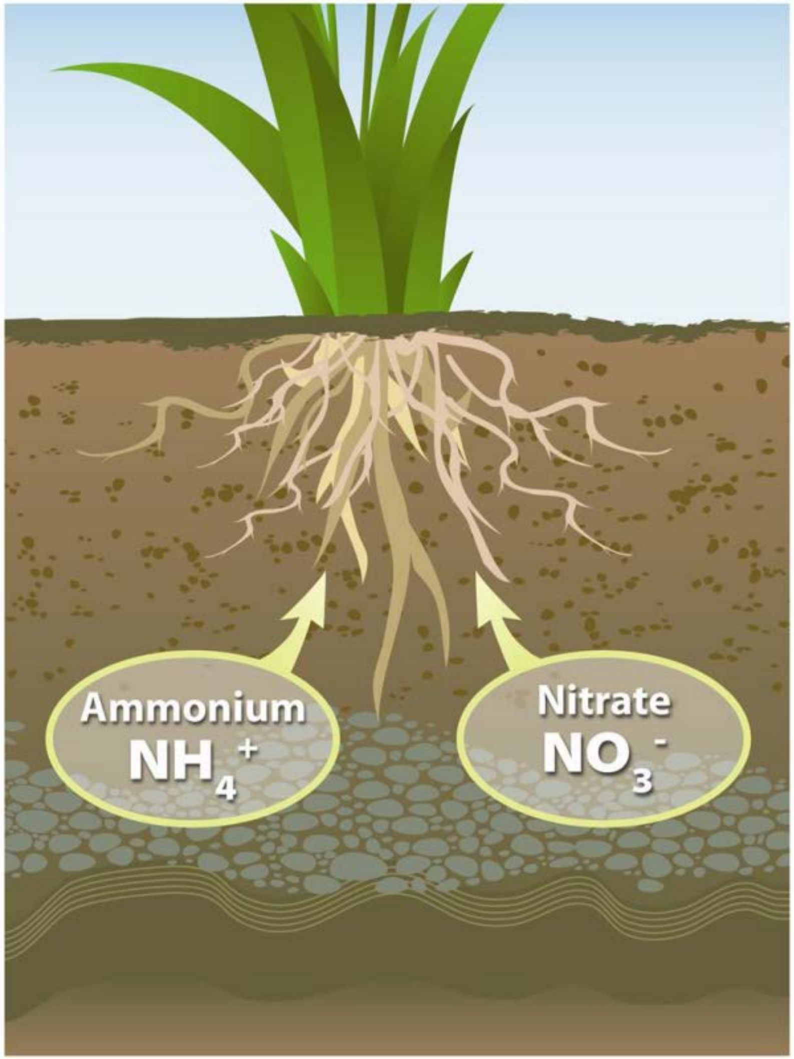
Supply: Demand:



(Kathy Kelley-Anderson et al: ANR Pub # 21623)

Nitrogen in Plants

Plants take up N in the form of ammonium (NH_4^+) and Nitrate (NO_3^-).



(Image from http://www.nitrogenfree.com/problem/nitrogen_cycle.php.html)

Nitrogen in Plants

- Most abundant mineral element in plants (2-4% Dwt)
  - Amino acids, proteins, nucleic acids
  - Most common limiting element in natural and man-made environments.

- Uptake as nitrate and ammonium (also limited uptake of organic N sources)
  - Species have distinct preferences (Nitrate is significantly more ‘expensive’ to assimilate than ammonium)
  - Nitrate dominates in warm, neutral-alkaline soils
  - Ammonium dominates in cool, wet, and acid soils
  - Uptake and assimilation are highly regulated

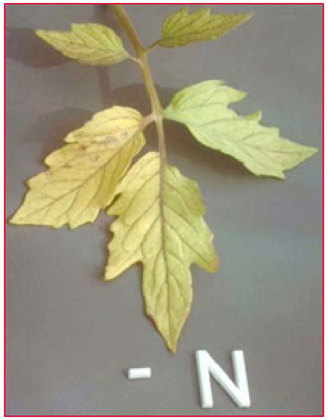
Nitrogen in Plants: Chlorosis

Growth and symptoms

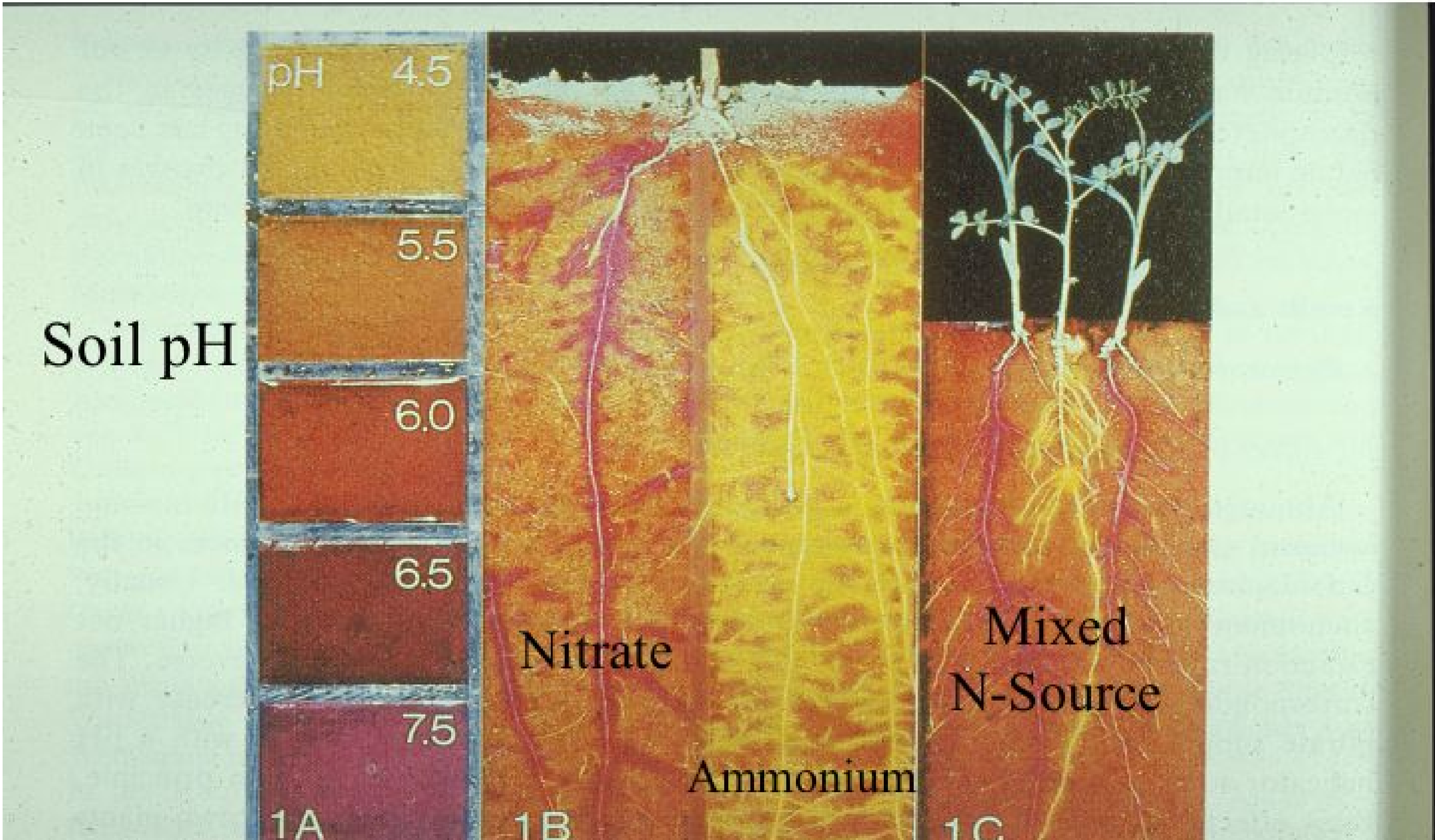
- N availability alters root allocation (root weight ratio) and shoot branching.

- High N enhances vegetative growth (‘lushness’), delays senescence, increases disease susceptibility (chemical and phenological causes).

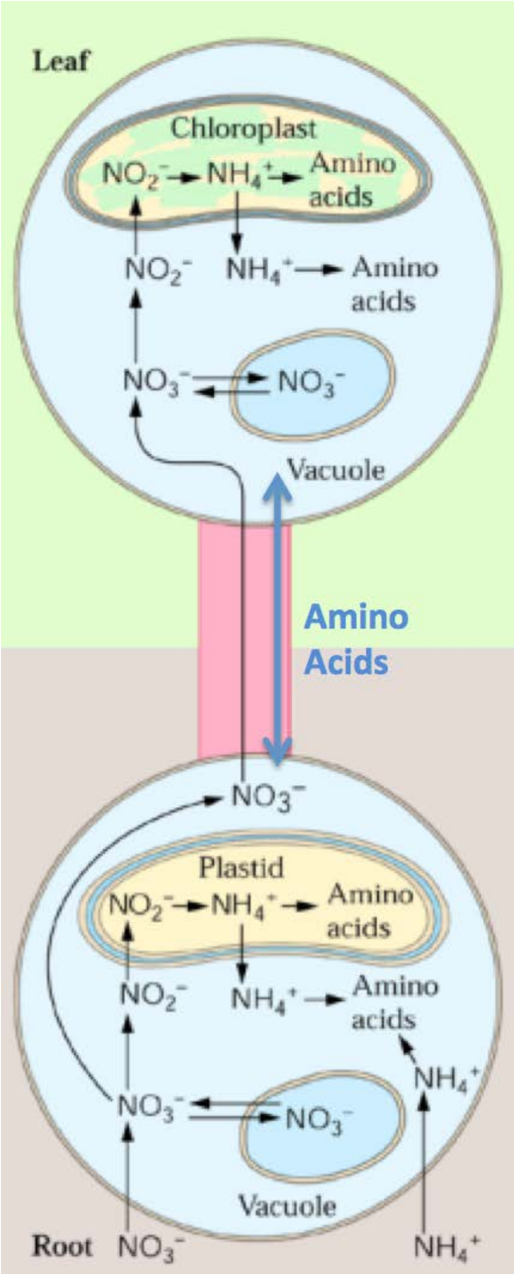
- Deficiency symptoms: growth inhibition/chlorosis appearing on older leaves; progresses to young leaves if severe.



Nitrogen in Plants: N Uptake and Rhizosphere Changes



Nitrogen in Plants: Biology of Nitrate Uptake



Some species transport nitrate to the **shoot** prior to reduction to ammonium and assimilation into amino acids. In these species petiole nitrate levels are high (1,000's ppm Nitrate).

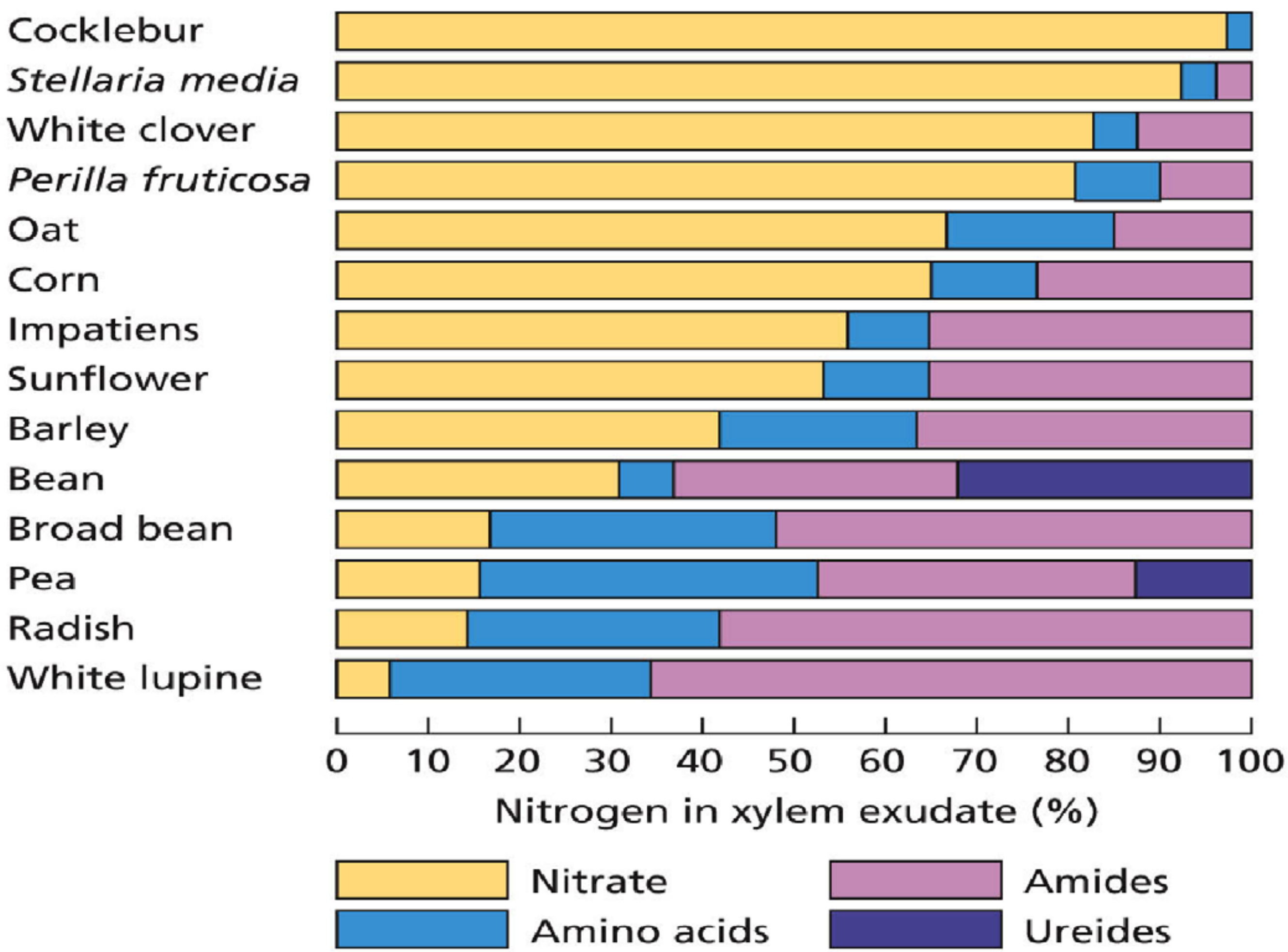
Other species reduce nitrate in the **root**, and petiole nitrate remains low (10's ppm Nitrate).

In all species nitrate uptake is a regulated process determined by internal nitrate concentrations and concentrations of amino acids transported from the shoot to root. The concentrations of nitrate and amino acids are determined by the rate at which protein synthesis is occurring in the plant and hence is strictly tied to growth rates.

(Plant Physiology, 4th Ed 2006 Sinnauer)

Nitrogen in Plants: N Concentration in Sap

Concentration of nitrate in sap differs between species. In most tree species, nitrate in sap is too low to detect reliably.

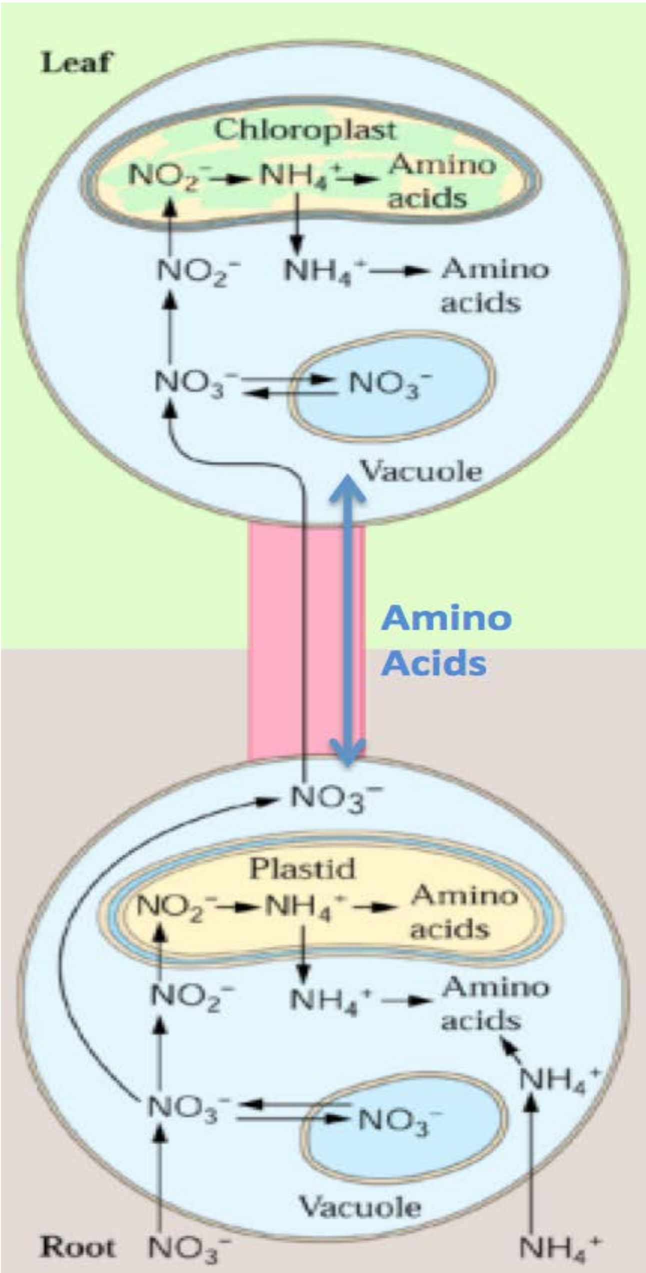


Many vegetables

Grape

Almond, walnut, pistachio, apple, peach.

Nitrogen in Plants: Biology of Ammonium Uptake



Ammonium uptake and assimilation is tightly regulated:

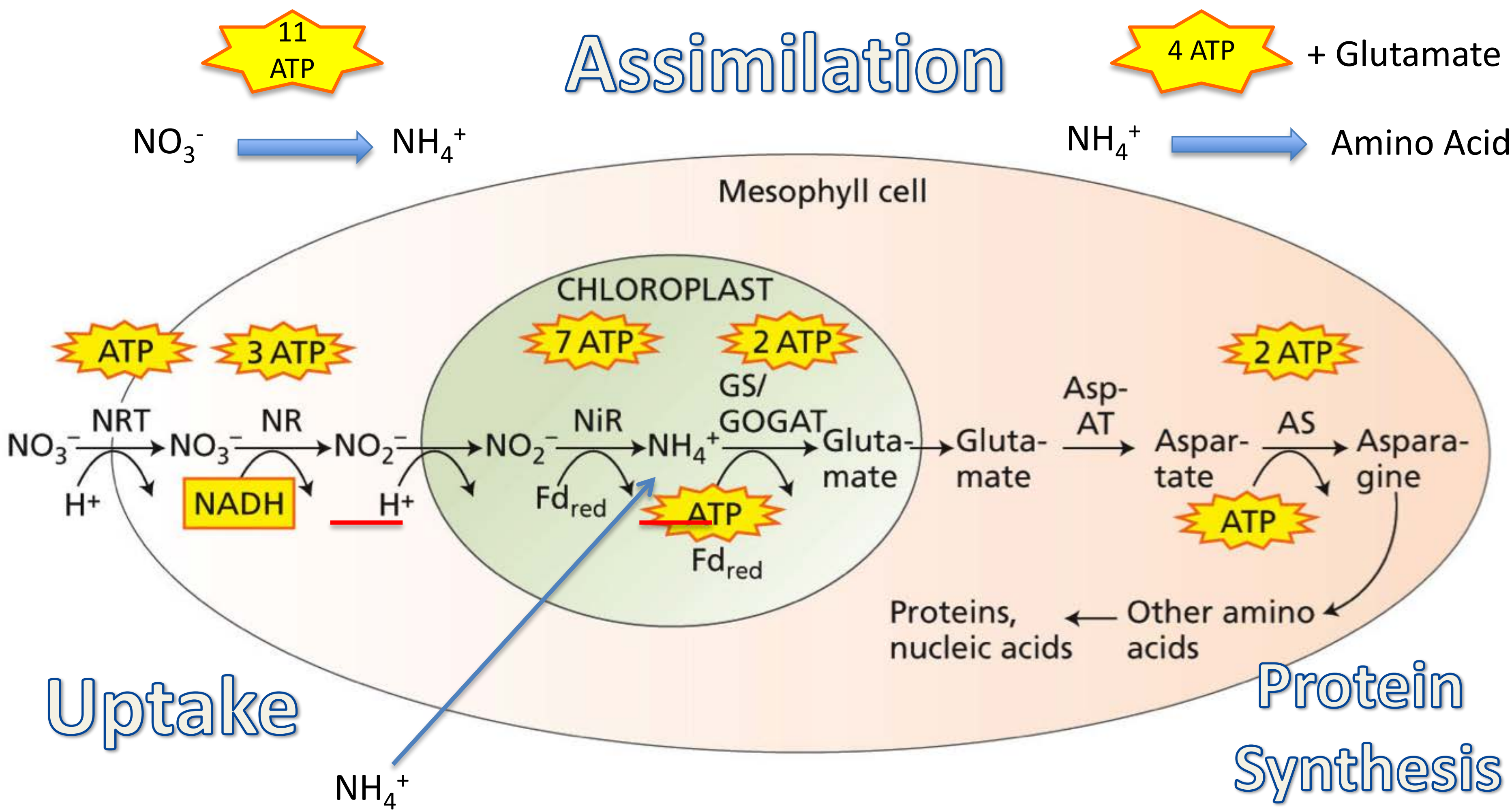
•NH_4^+ is toxic and hence is rapidly assimilated into amino acids and amides and is not transported.

•NH_4^+ assimilation (from NH_4^+ uptake) occurs almost exclusively in the roots, requiring a large transport of energy and carbon to the root.

•Uptake rate is feedback regulated by concentration of amino acids and protein in plant AND by availability of energy and carbohydrates.

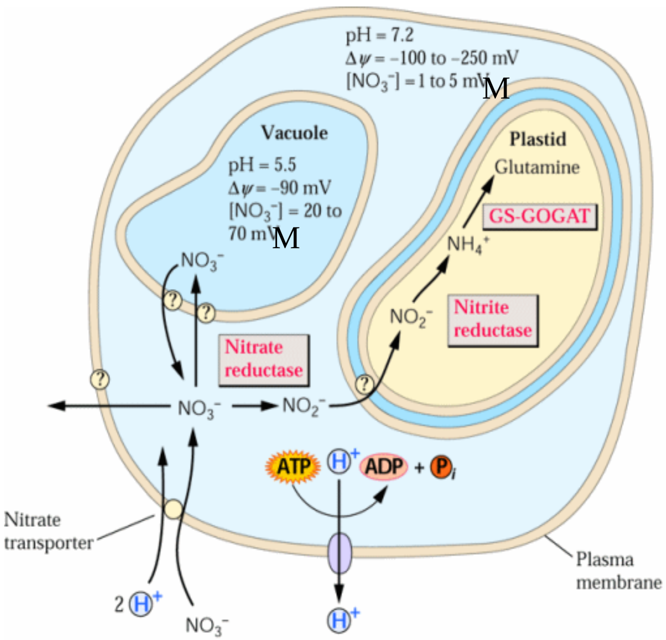
(Plant Physiology, 4th Ed 2006 Sinnauer)

Nitrogen in Plants: Energy Cost of Uptake and Assimilation



(Plant Physiology, 4th Ed 2006 Sinnauer)

Nitrogen in Plants: Nitrate Uptake and Assimilation



(Plant Physiology, 4th Ed 2006 Sinnauer)

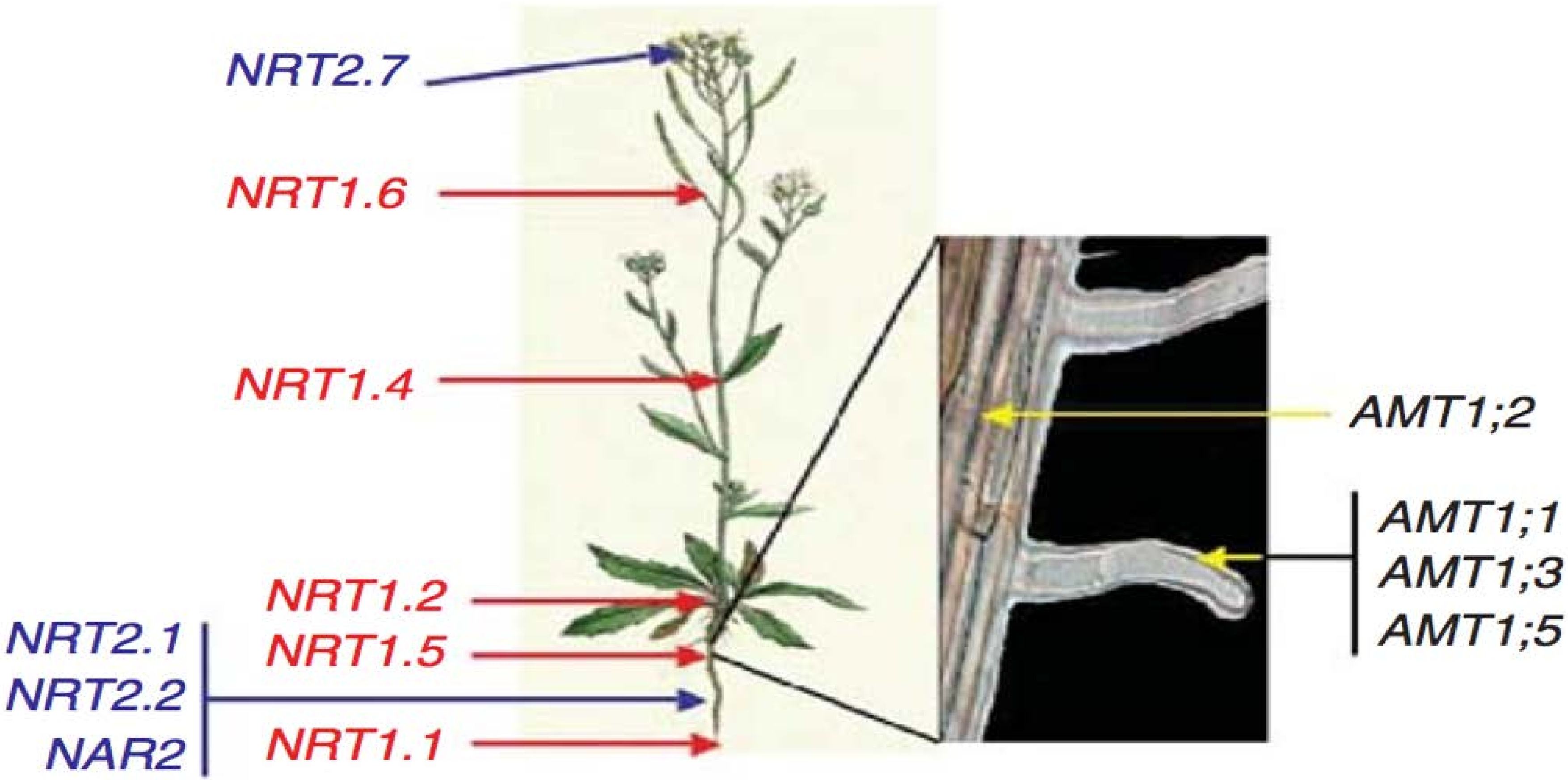
- Nitrate uptake, reduction, and assimilation are intricately integrated with photosynthesis and C availability.

- If N demand or rate of photosynthesis is limited, uptake is reduced.

- Nitrate/nitrogen availability is a primary determinant of growth rate, root allocation, root architecture, flowering time, and fruit quality.

- Excess N in any form will result in 'excess' tissue N with no growth benefit and possible negative effects.

Nitrogen in Plants: Uptake Transporters

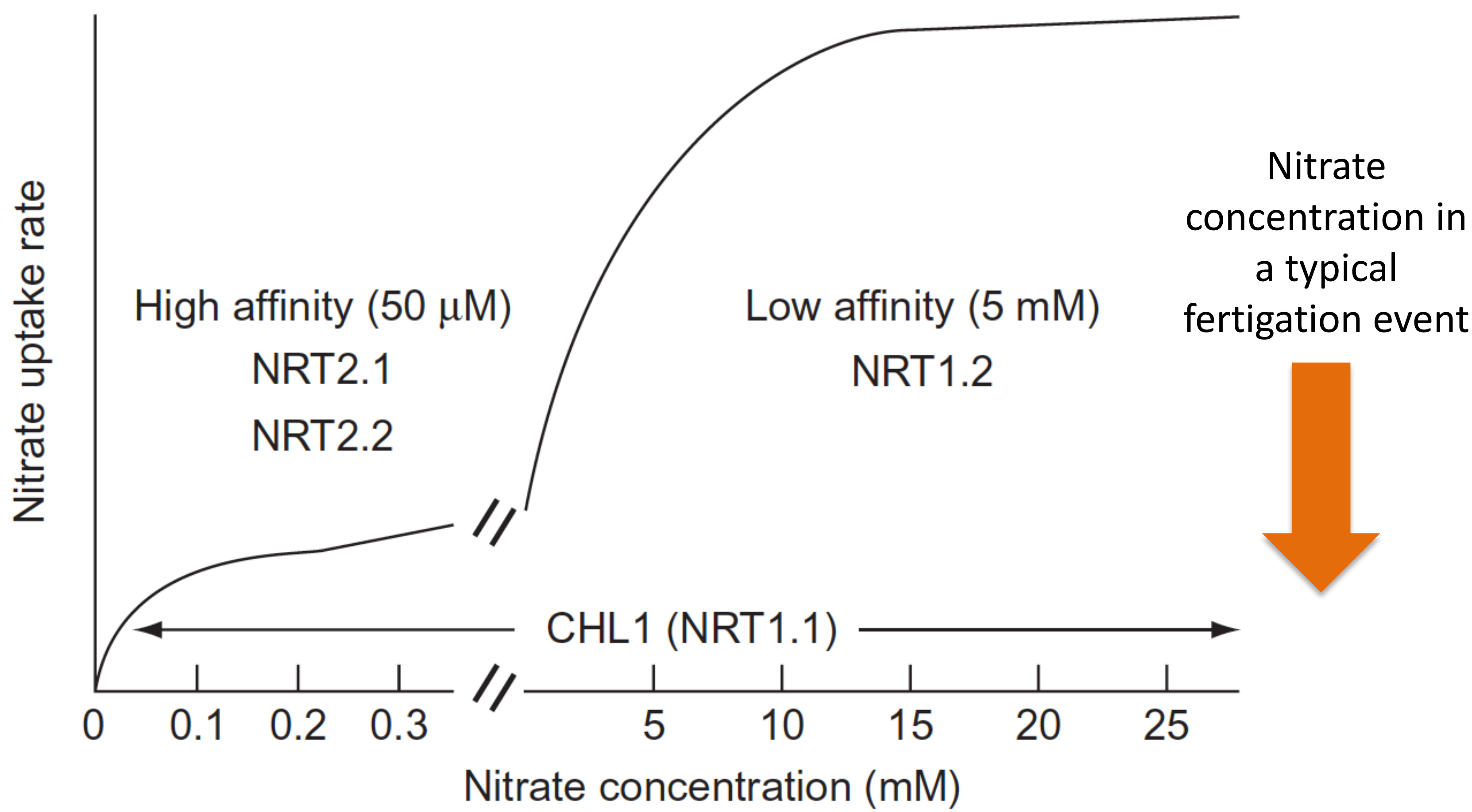


Hundreds of genes coding for dozens of nitrogen and ammonium uptake transporters (e.g. NRT2.7), located in many different organs have been identified. All are carefully regulated by demand, supply, environment and phenology.

Masclaux-Daubresse et al. — *Nitrogen in agricultural plants* *Annals of Botany* **105**: 1141–1157, 2010

Nitrogen in Plants: Nitrate Uptake Rate

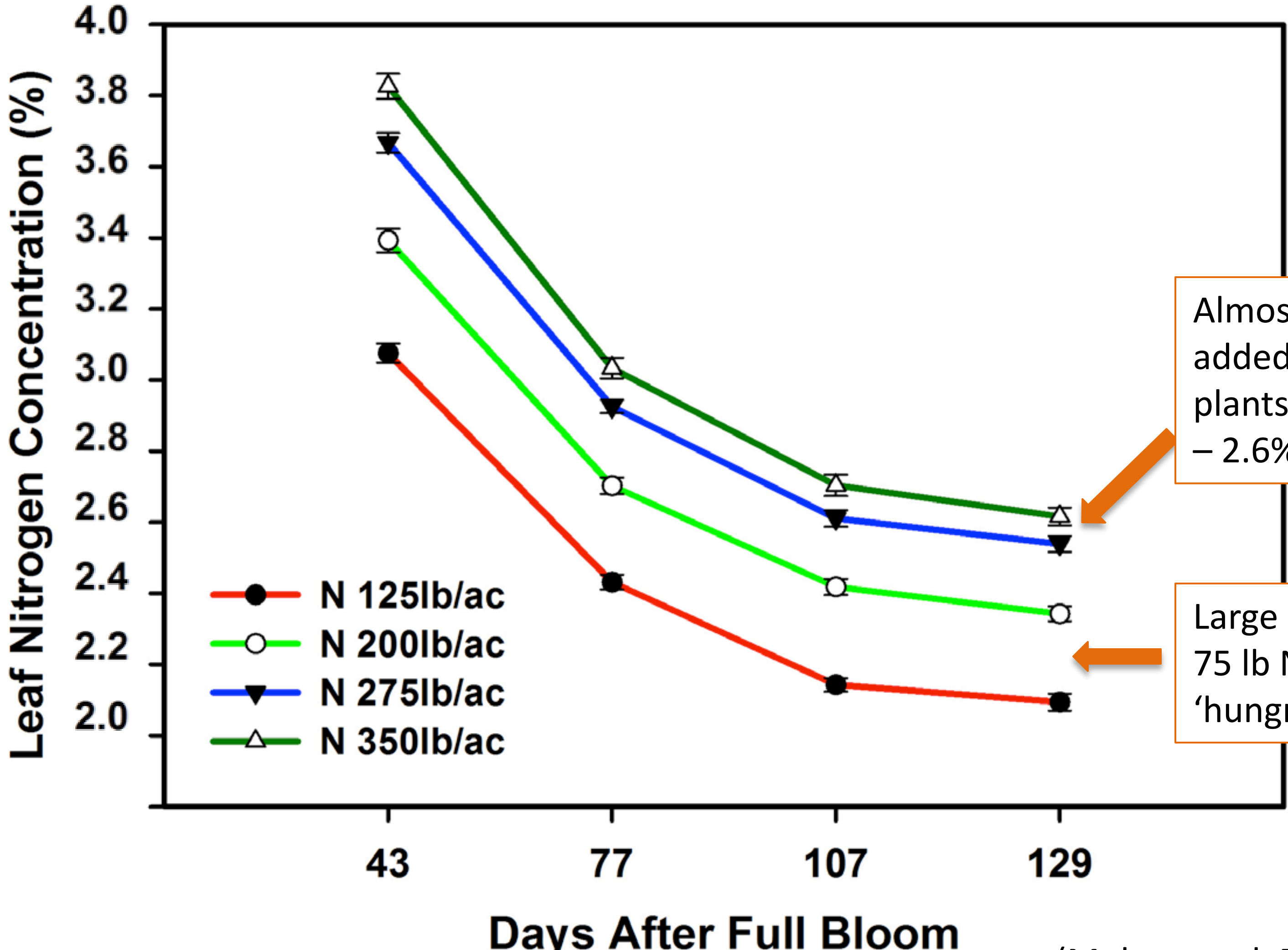
Nitrate uptake rate varies with nitrate concentration but is saturated at common fertigation concentrations.



(Marschner, P. (2012). Mineral Nutrition of Higher Plants. Academic Press. Waltham, MA, USA.)

Nitrogen in Plants: N in Excess of Demand is Inefficiently Used

Effect of nitrogen rate on leaf N in almond:



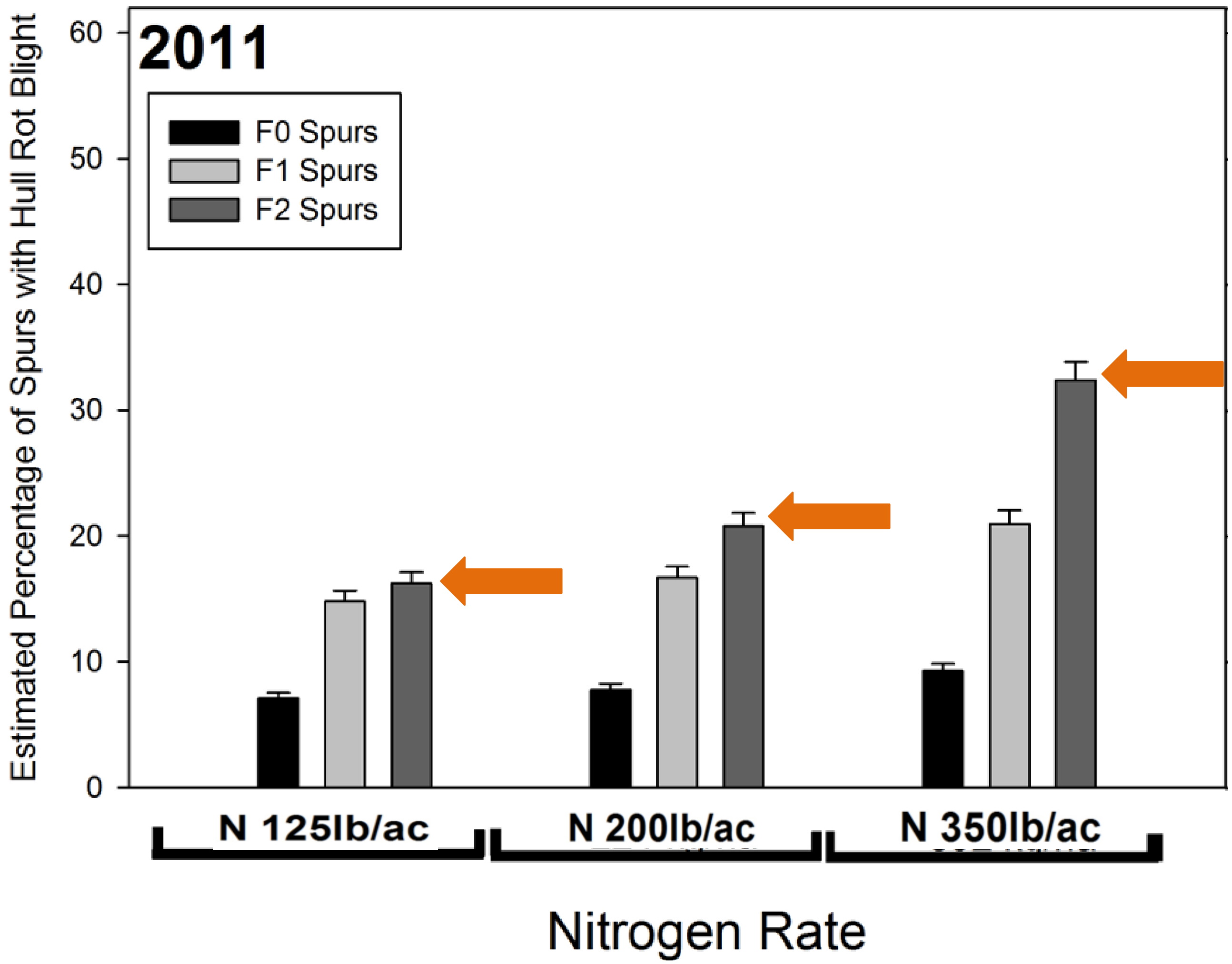
Almost no response to added 75 lb N when plants are 'satisfied'. (2.55 – 2.6%)

Large response to added 75 lb N when plants are 'hungry'. (2.0 – 2.4%)

(Muhammad, PhD Dissertation. 2013)

Nitrogen in Plants: Excess N Example

Almond hull rot incidence increased as N increased:



F0, F1, F2 = Zero, Single, and Double Fruited Spurs.

(Elana Peach-Fine, MSc. 2013)

Summary N Cycle: Plant

- Most abundant mineral element in plants (2-4% dry weight)
- Uptake as nitrate and ammonium (also limited uptake of organic N sources)
- Nitrate uptake efficiency diminishes with exposure to increasing N and is regulated by demand (growth).
- N in excess of demand is inefficiently used.

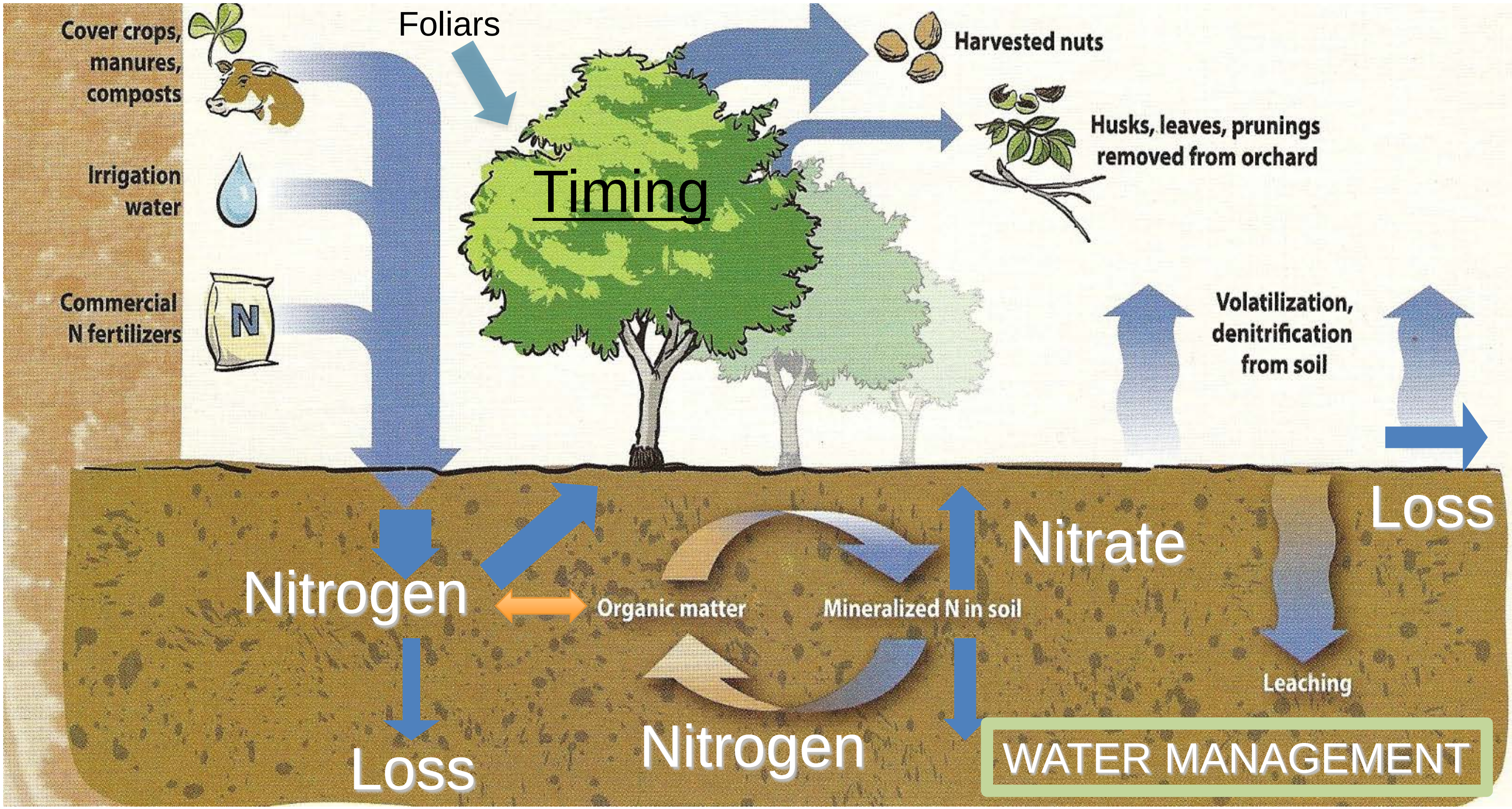
Nitrogen in Agricultural Systems

Integration of N Cycling with Cultural Management

Reduce Leaching and Costs, Increase Efficiency

N Cycle and Management

Supply: Demand:



(Kathy Kelley-Anderson et al: ANR Pub # 21623)

Efficient N Mangement: Applying the 4 Rs Principle

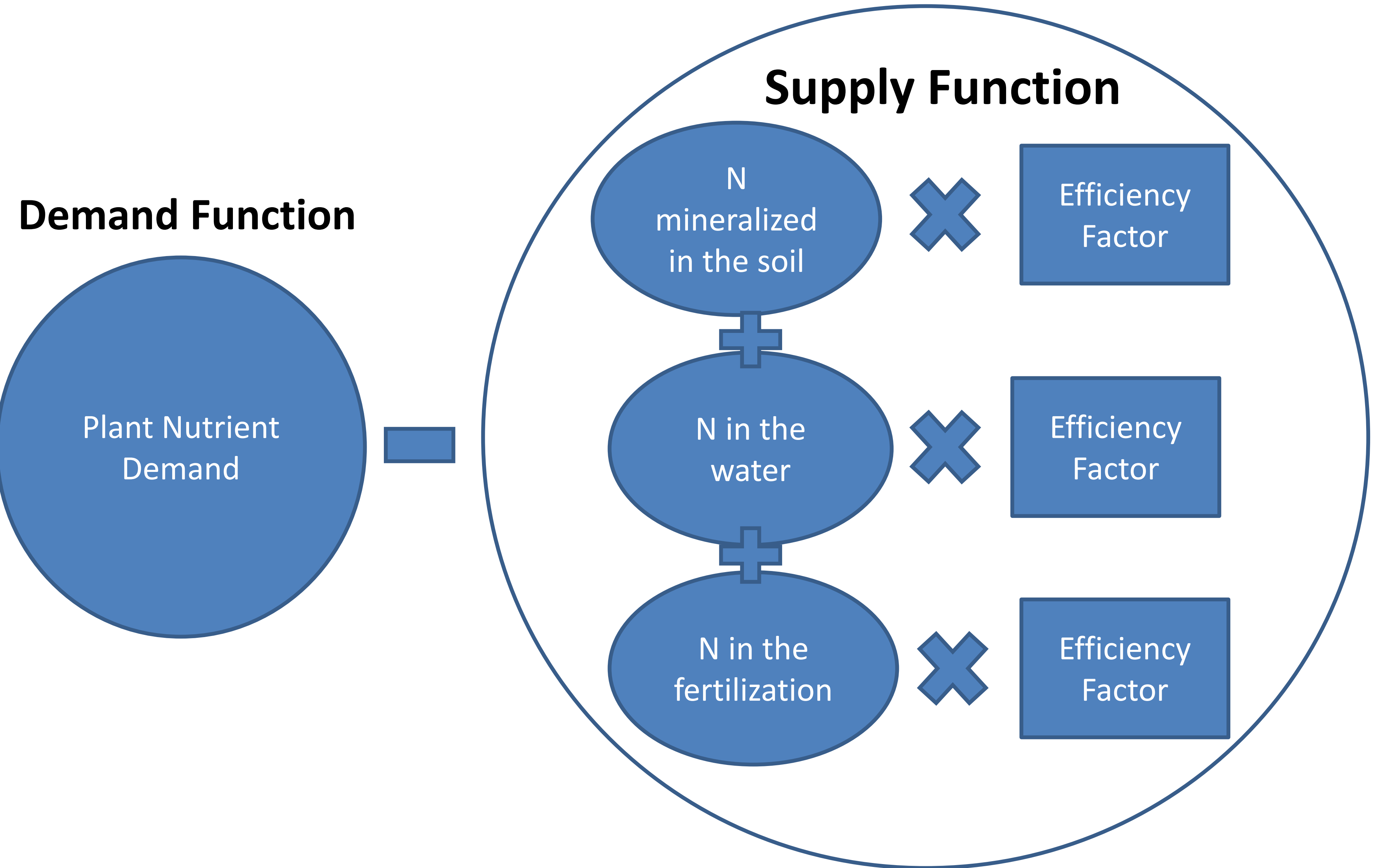
- Apply the Right Rate
  - Match supply with crop demand (all inputs- fertilizer, organic N, water, soil).
- Apply at the Right Time
  - Apply coincident with crop demand and root uptake.
- Apply In the Right Place
  - Ensure delivery to the active roots.
  - Minimize movement below root zone
- Use the Right Source

The 4 Rs are specific to every individual orchard/field and every year.

Calculating the Right Rate

1. Know crop N based on predicted yield
2. Calculate all N credits
3. Calculate amount of nitrogen needed
4. Incorporate the fertilization efficiency

The Right Rate Equation



Right Rate: Nutrient Demand in Harvested Crop

Nutrient removal in harvested portion of crop	Unit	Removal, lb/unit			
		N	P_2O_5	K_2O	S
Alfalfa	ton	51	12	49	5.4
Tomato	ton	2.5	0.92	5.7	
Barley grain	bu	0.99	0.4	0.32	0.09
Rice grain	bu	0.57	0.3	0.16	
Wheat grain (winter)	bu	1.16	0.48	0.29	0.1
Potato tuber	cwt	0.32	0.12	0.55	0.03

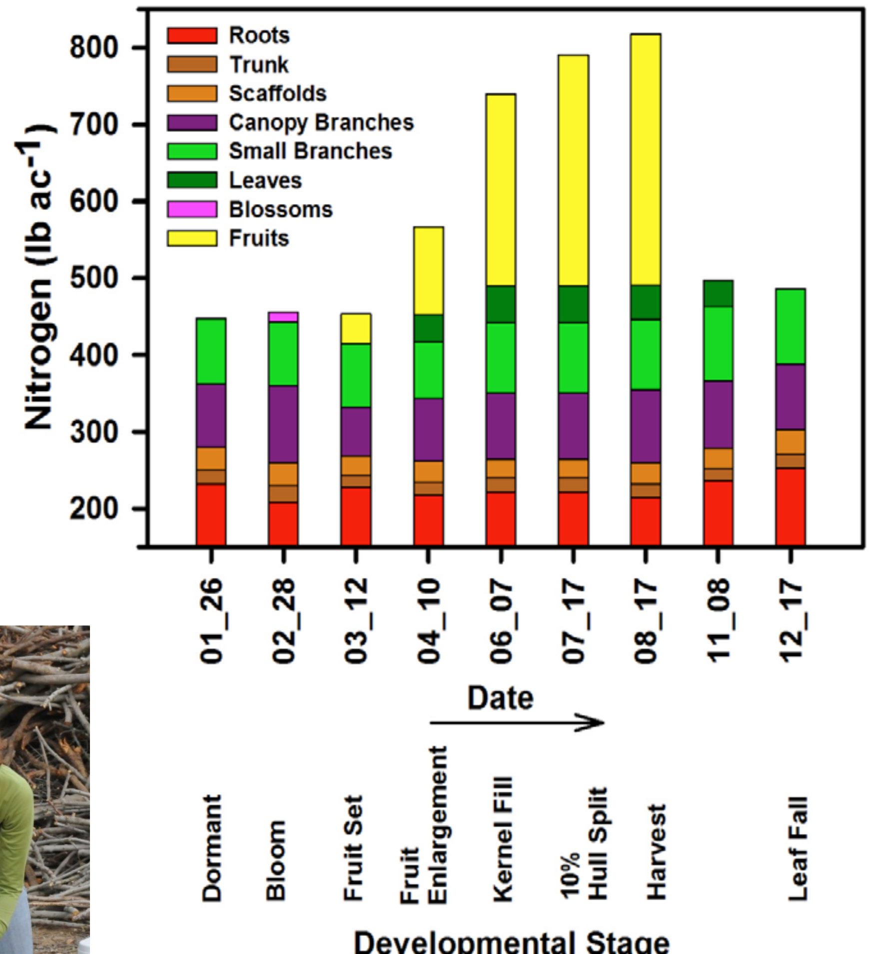
(Modified from: 4R Plant Nutrition: A Manual for Improving the Management of Plant Nutrition, 2012 IPNI)

Right Rate: Nutrient Demand in Harvested Crop Example

Fertilization rates often exceed N demand:

	Typical range (lb N / acre)		
	seasonal N application	**Total crop N uptake**	**N removal in harvest**
Lettuce	**120-200**	**110-140**	**60-80**
Broccoli	**150-250**	**200-300**	**60-90**
Celery	**200-300**	**180-240**	**120-160**
Spinach	**120-180**	**80-110**	**60-80**
Strawberry	**160-260**	**180-200**	**70-100**

Right Rate: Nutrient Demand Almond Example



(Muhammad, PhD Dissertation. 2013)

Right Rate: Nutrient Demand Examples

ALMOND

Nutrient removal per 1000 lb kernels

Nonpareil

- N removal 68 lb per 1000

Monterey

- N removal 65 lb per 1000

Growth Requirement

- Yield 2,000-4,000 = 0 lb N
- Yield 1,000-2,000 = 20 lb N
- Yield <1,000 = 30 lb N

PISTACHIO

Kerman:

- N removal 28 lb per 1000

Growth Requirement:

- On-year: 25 lb N
- Off-year=25-40 lb N

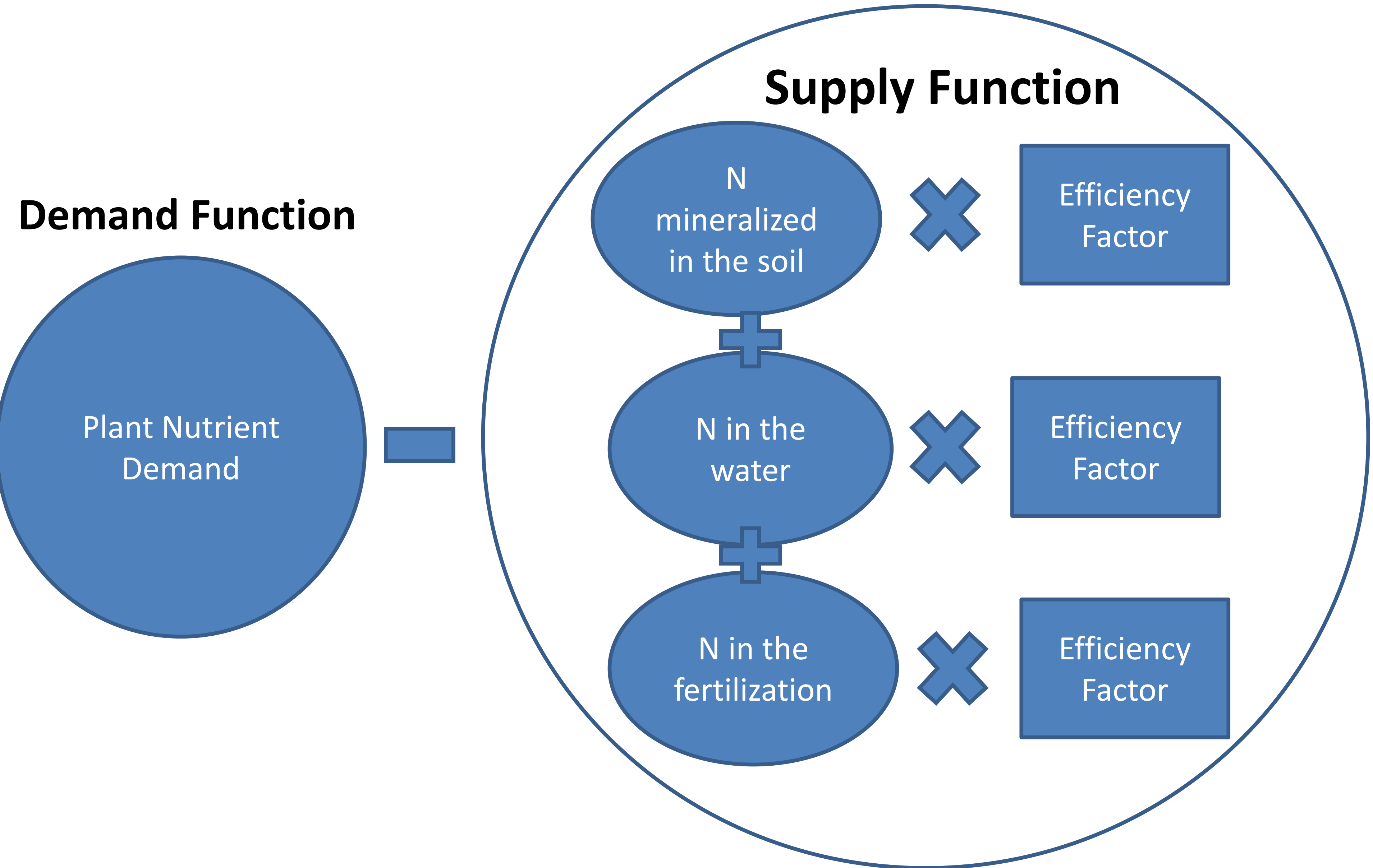
Right Rate: Methods for Setting Realistic Yield Goals

- Use experience of the potential of a particular field, and then consider environmental conditions.
  - For annuals, weather at planting can have a major effect.
  - For perennials, the past year's yield plus winter and spring weather can be critical.

- Use 80% of maximum potential yield as determined by crop yield models.
  - Good models exist for Midwest corn and soybean, but there are relatively few models for California.

- Set target of 10% above the field's 3-5 year average, excluding years with unusual negative conditions (pests/disease/drought, etc).

The Right Rate Equation: Supply Function



Right Rate 'Supply': Nutrients in Manures and Composts

Type of Livestock	Waste Handling System	Dry Matter, %	Nutrient, lbs/ton			
			N		P_2O_5	K_2O
			Available*	Total†		
Solid Handling Systems						
Swine	Without bedding	18	6	10	9	8
	With bedding	18	5	8	7	7
Beef cattle	Without bedding	15	4	11	7	10
	With bedding	50	8	21	18	26
Dairy cattle	Without bedding	18	4	9	4	10
	With bedding	21	5	9	4	10
Poultry	Without litter	45	26	33	46	34
	With litter	75	36	56	45	34
	Deep pit (compost)	76	44	68	64	45
Liquid Handling Systems						
Swine	Liquid pit	4	20	36	27	19
	Oxidation ditch	2.5	12	24	27	19
	Lagoon	1	3	4	2	0.4
Beef cattle	Liquid pit	11	24	40	27	34
	Oxidation ditch	3	16	28	18	29
Dairy cattle	Lagoon	1	2	4	9	5
	Liquid pit	8	12	24	18	29
Poultry	Lagoon	1	2.5	4	4	5
	Liquid pit	13	64	80	36	96

*Primarily NH_4^+-N, which is plant available during the growing season. † - NH_4^+-N plus organic N, which is slow releasing.
Application conversion factors: 1,000 gal = about 4 tons; 27,154 gal = 1 acre-inch
Source: Sutton et al., 1985, Univ. of Minn. Ext. Bull. AG-FO-2613

(IPNI, Four R's. 2012)

Right Rate 'Supply': N in the Soil

- Especially important for annual crops
- Soil Nitrate Testing at planting or before side-dress is a valuable tool.
- The specifics of this for individual crops will be discussed in future modules.

Factors Controlling Rates of Decomposition and Mineralization

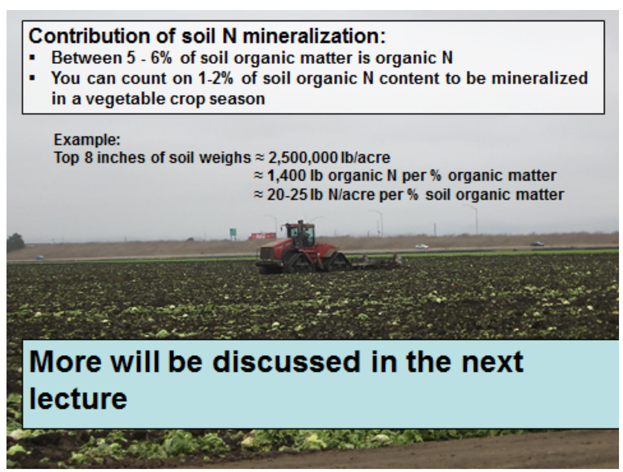
Table 11.2
Typical Carbon and Nitrogen Contents and C/N Ratios of Some Organic Materials

Organic material	% C	% N	C/N
Spruce sawdust	50	0.05	600
Newspaper	39	0.3	120
Wheat straw	38	0.5	80
Corn stover	40	0.7	57
Maple leaf litter	48	1.4	34
Rotted barnyard manure	41	2.1	20
Bluegrass from fertilized lawn	42	2.2	20
Broccoli residues	35	1.9	18
Young alfalfa hay	40	3.0	13
Hairy vetch cover crop	40	3.5	11
Digested municipal sewage sludge	31	4.5	7
Soil microorganisms			
Bacteria	50	10.0	5
Fungi	50	5.0	10
Soil organic matter			
Average forest O horizons	50	1.3	45
Average forest A horizons	50	2.8	20
Mollisol Ap horizon	56	4.9	11
Average B horizon	46	5.1	9

As a rule of thumb:

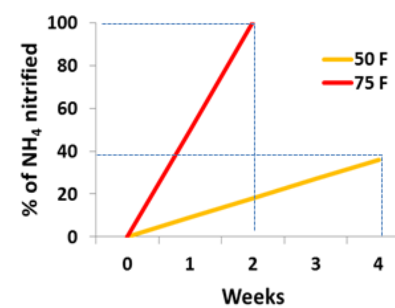
- A C:N ratio of 20:1 is the dividing line between immobilization and mineralization
- Generally, N mineralization occurs with residue N >2% under aerobic conditions
- Anaerobic = no mineralization

Elements of the Nature and Properties of Soils, 3/e by N. Brady and R. Weil



How quickly does nitrification occur?

- **Nitrification rate governed mostly by temperature**



Source: Adapted from Western Fertilizer Handbook

Right Rate 'Supply': N in the Water

- Formula for Nitrate:

  Nitrate concentration (ppm) x inches irrigation applied x 0.052

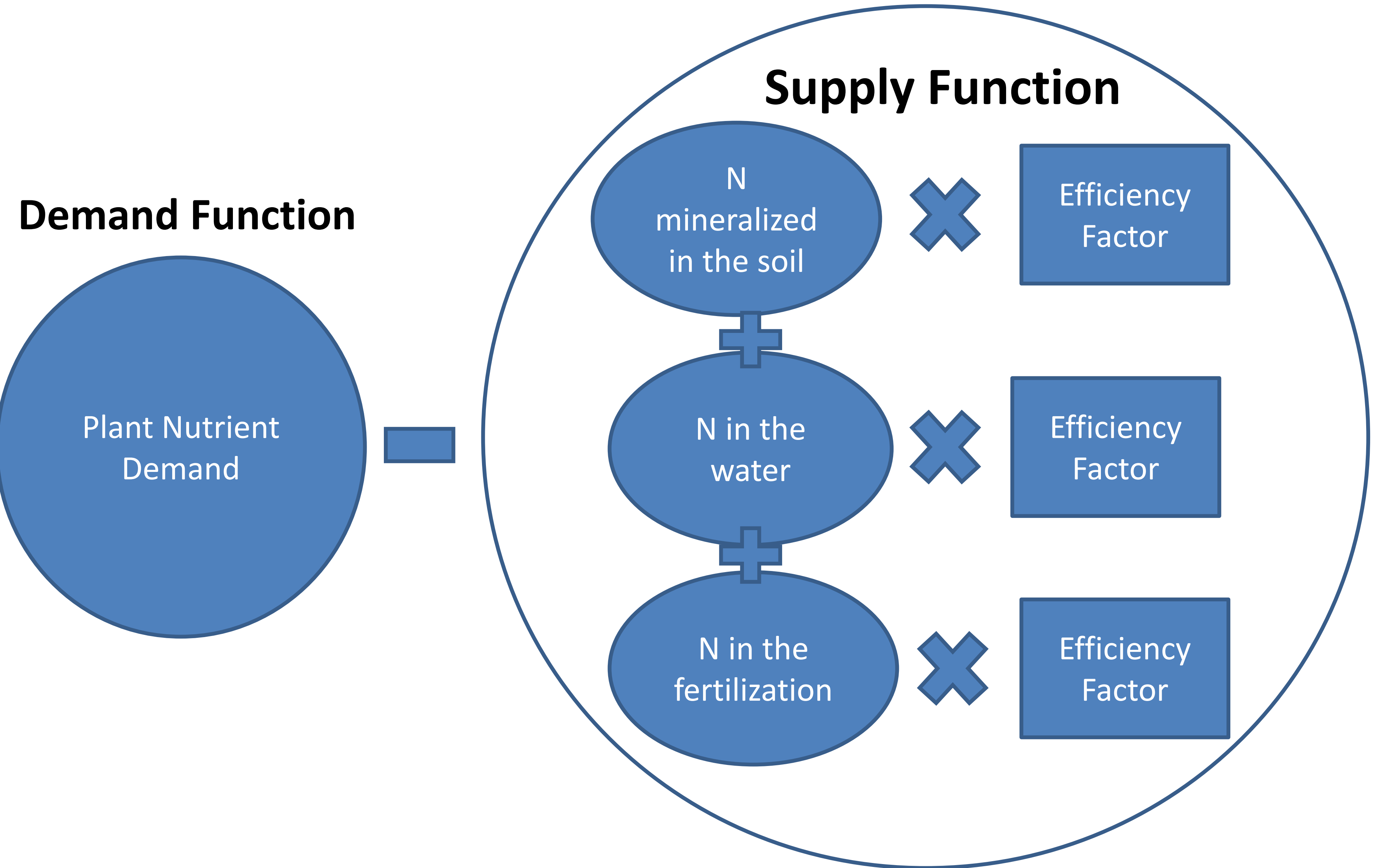
- Formula for Nitrate-N:

  Nitrate-N concentration (ppm) x inches irrigation applied x 0.23

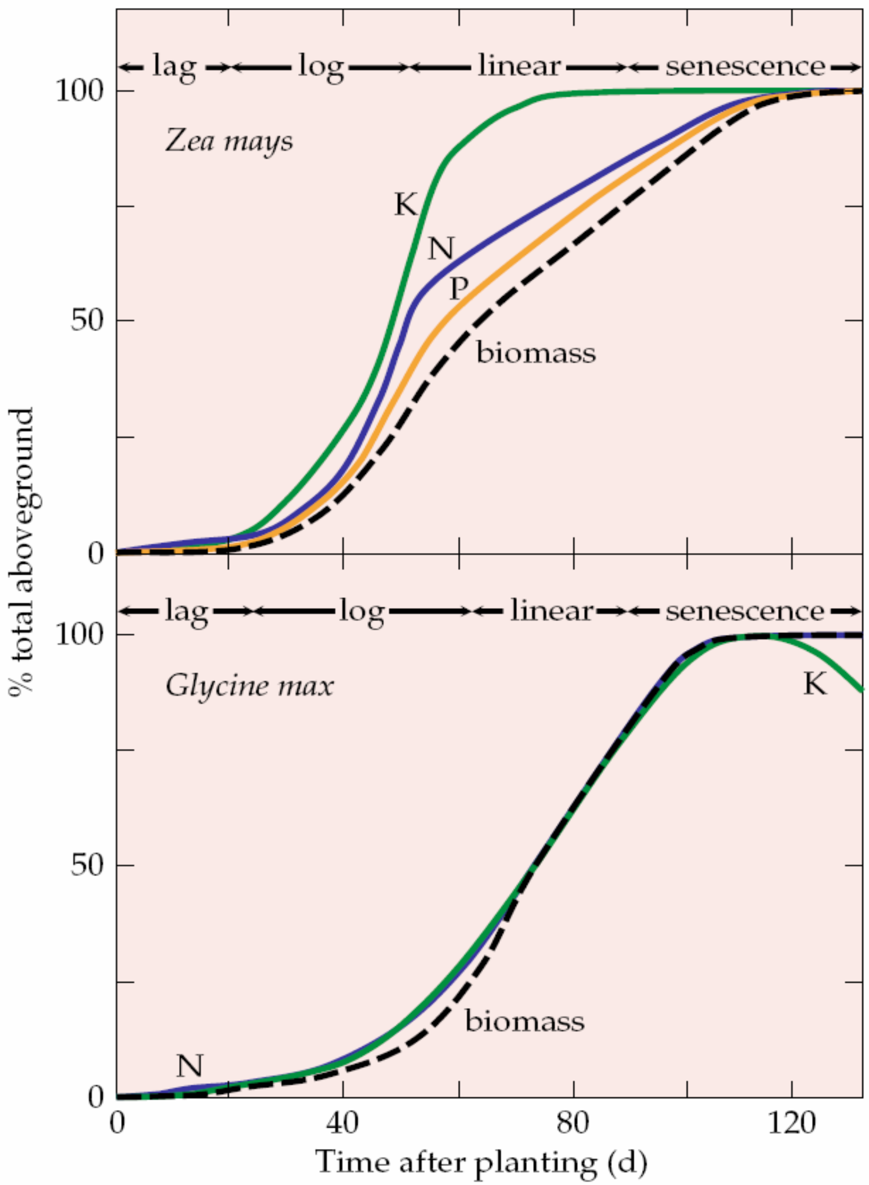
Example: Lab reports 10 ppm Nitrate or 2.27 ppm Nitrate-N and you apply 48 inches of water

Answer = 25lb

The Right Rate Equation: Demand Function



Right Rate and Timing 'Demand': Plant Nutrient Demand



Demand for N is largely driven by biomass accumulation.

Nutrient demand per time is related to growth rate; fast growth requires a high rate of N uptake and assimilation.

(Fernandez et al., Foliar Fertilization, Scientific Principles and Field Practices, 2013)

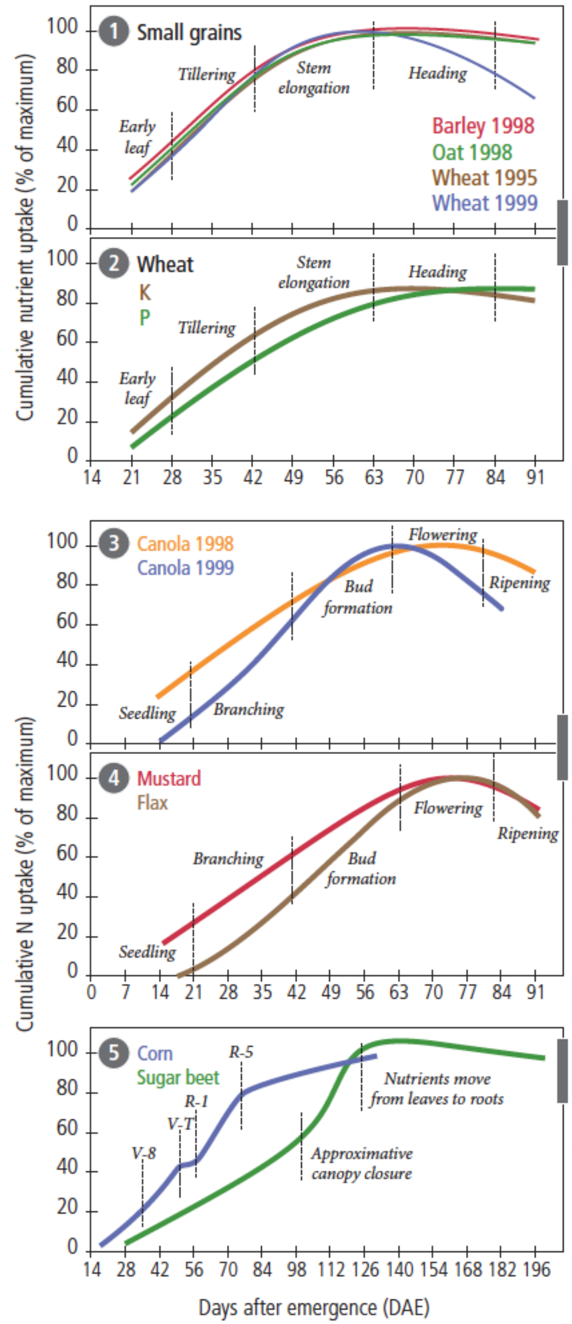
Right Rate and Timing ‘Demand’:
Plant Nutrient Demand

Knowledge of Nutrient Accumulation Patterns

Consideration of all N Sources

- irrigation
- residual N
- manures

Realistic yield estimation and in-season adjustments for seasonal conditions.



Cumulative nutrient uptake as a percent of maximum accumulation by dryland spring grains over time in Saskatchewan; ❶ wheat, oat, and barley N in 1998, and wheat N in 1999, ❷ wheat P and K in 1998.

Cumulative N uptake as a percent of maximum accumulation by ❸ canola in 1998 and 1999, ❹ mustard and flax in 1998 in Saskatchewan.

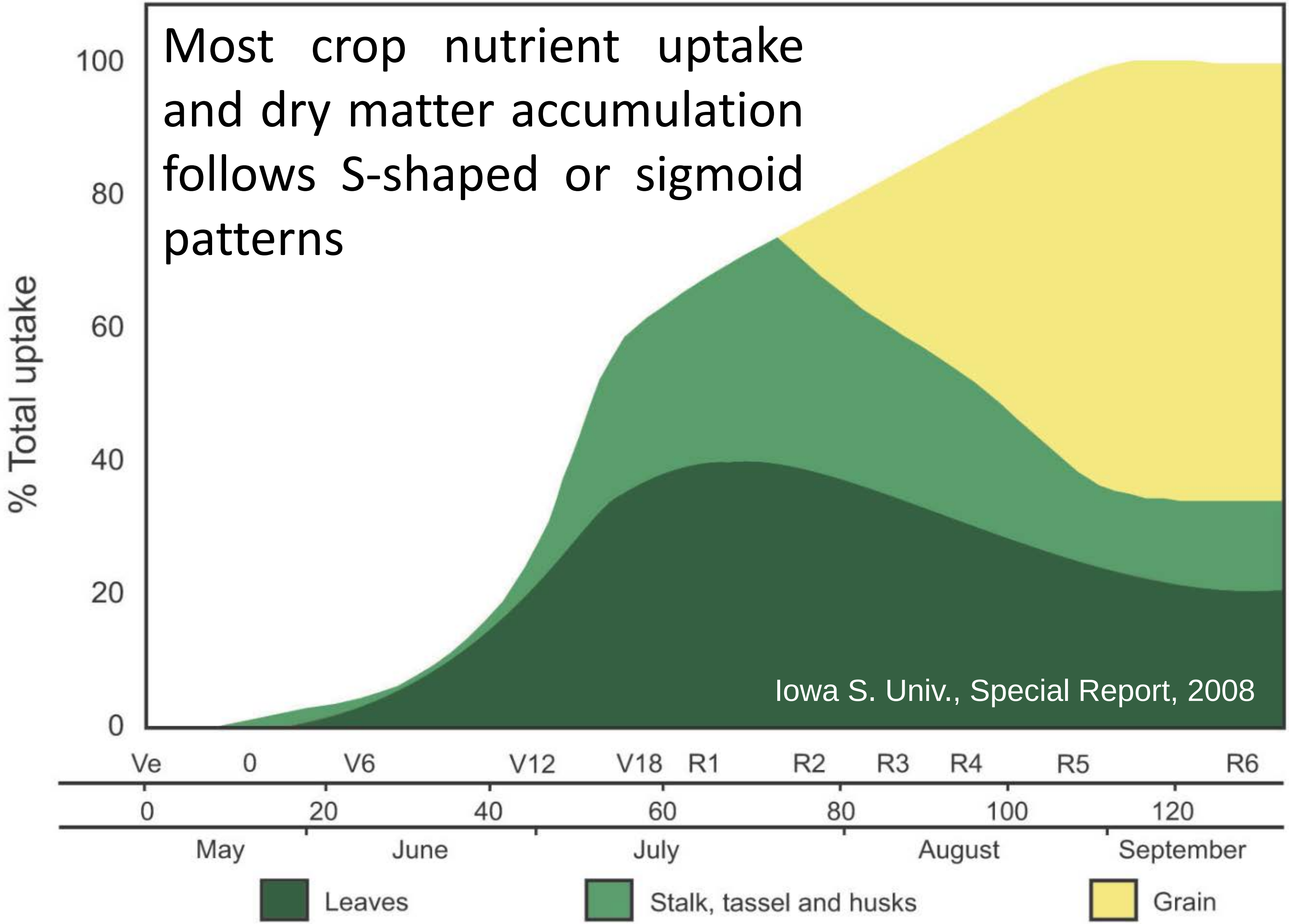
Cumulative N uptake as a percent of maximum accumulation by corn in Manitoba (V-8 = 8 leaf, V-T = tassel emergence, R-1 = silking, R-5 = dent) and sugar beet in France.

Figure 5.2. Patterns of nutrient accumulation as a percentage of total seasonal accumulation over the growing season for six field crops (Adapted from Jones *et al.*, 2009).

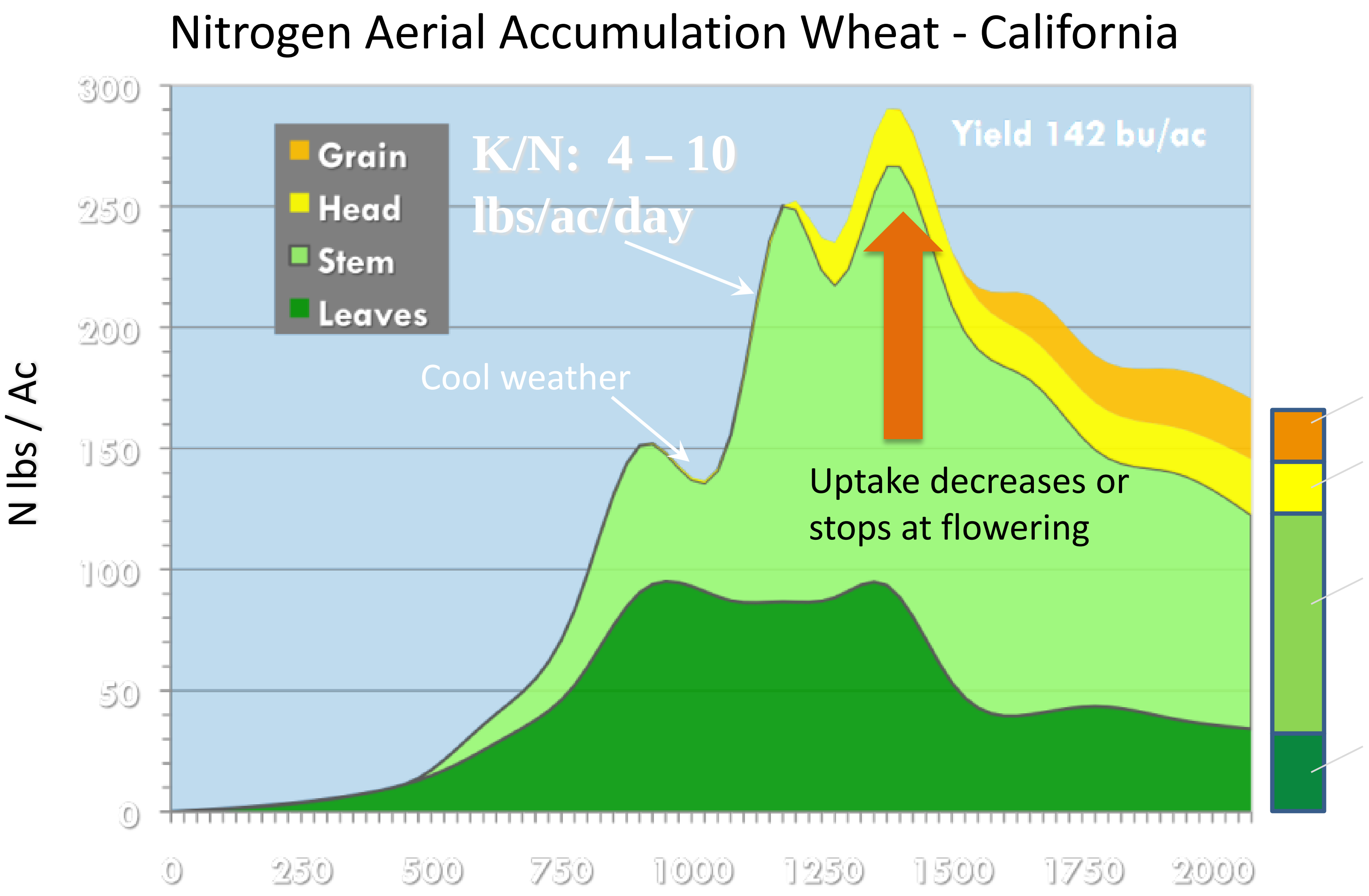
(Fernandez et al., Foliar Fertilization, Scientific Principles and Field Practices, 2013)

Right Rate and Timing ‘Demand’: Corn Example

Most crop nutrient uptake and dry matter accumulation follows S-shaped or sigmoid patterns

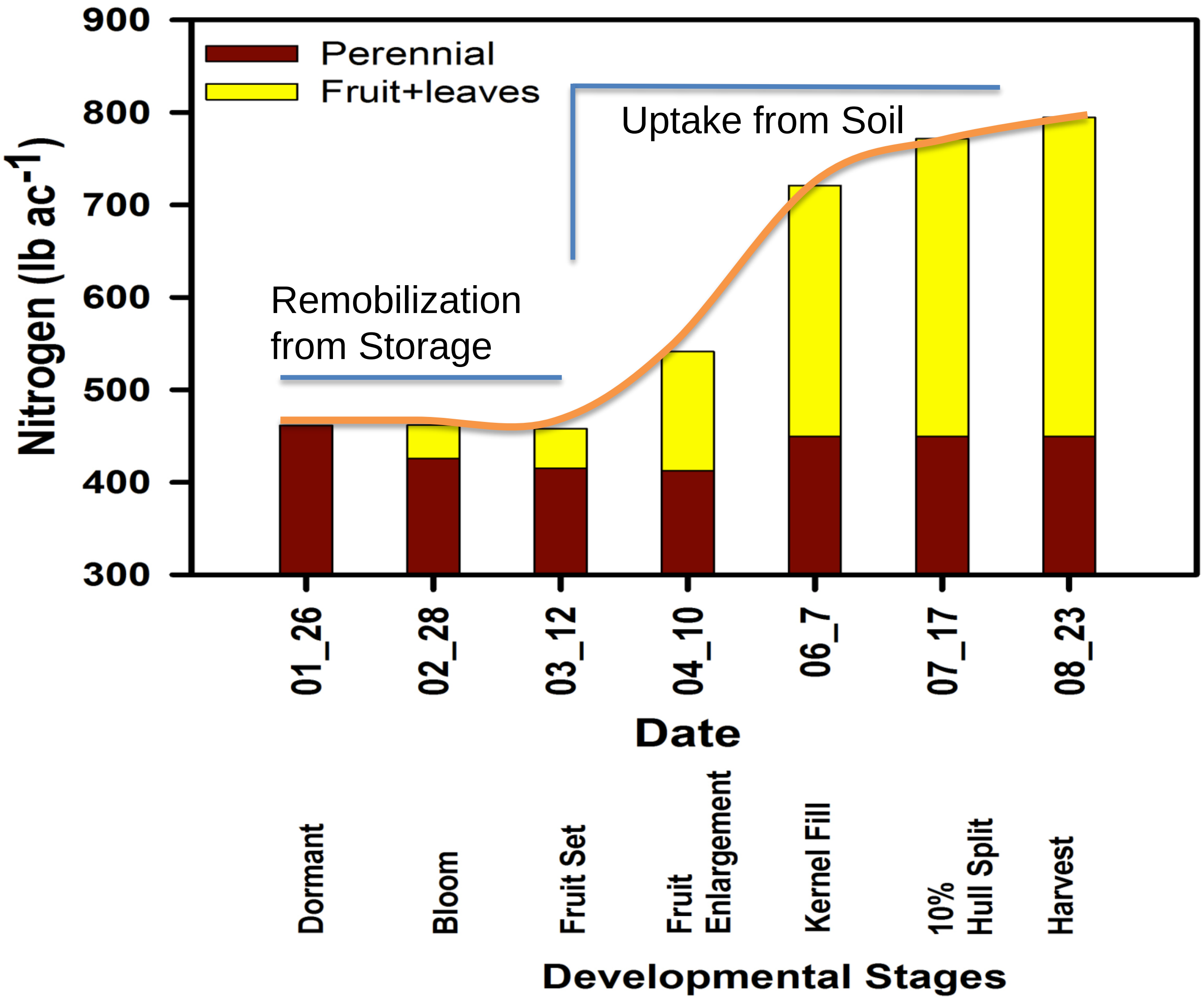


Right Rate and Timing 'Demand': Wheat Example



(Miller, 1990)

Right Rate and Timing 'Demand': Almond Example



From dormancy to mid-March there is very little N uptake.

Uptake commences at mid-leaf out and is essentially complete by hull split.

Recommended N Split:

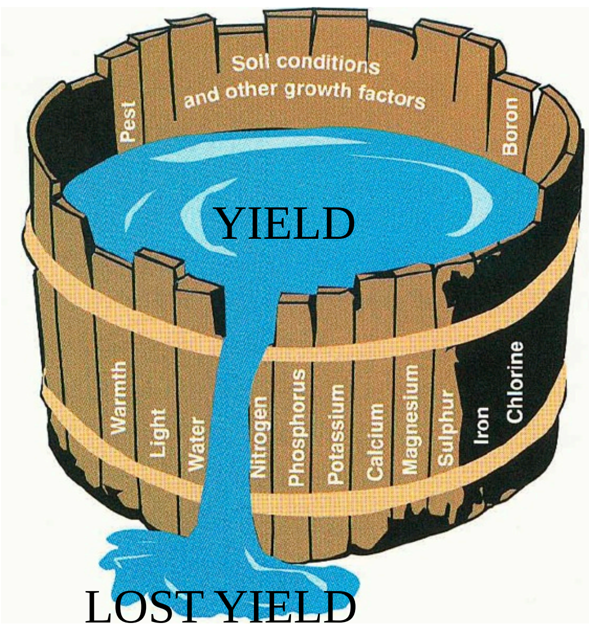
20% Leaf Out-Fruit Enlargement

30% Fruit Enlargement
30% Kernel Fill

20% Hull-split through early Post-Harvest

Right Source: Nutrient Balance

The efficiency of nitrogen will always depend upon the adequacy of all other essential elements and growth conditions.

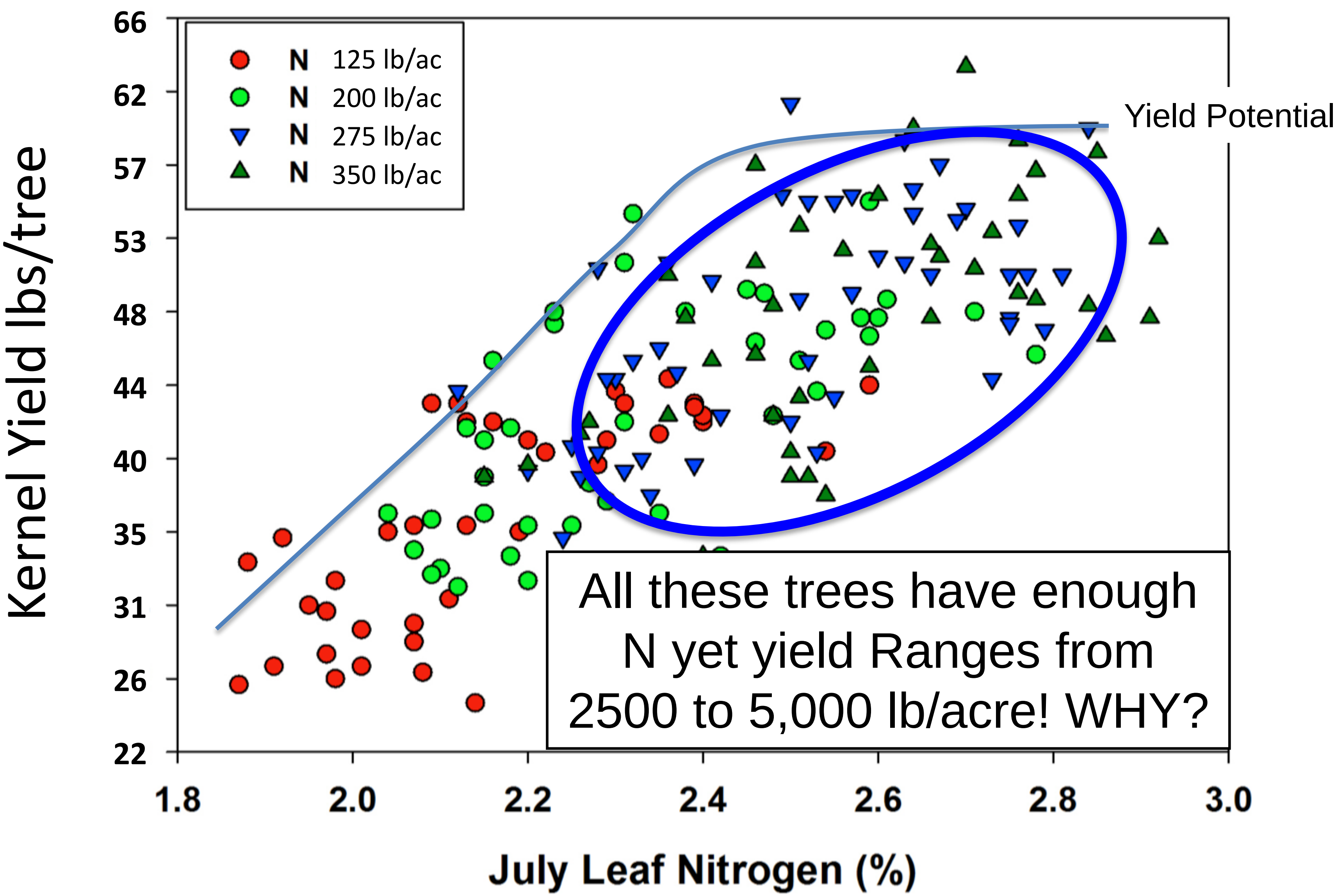


The Law of Minimum
Justus Von Leibig, 1863

If any nutrient is inadequate - Yield is lost AND a response to other elements cannot occur.

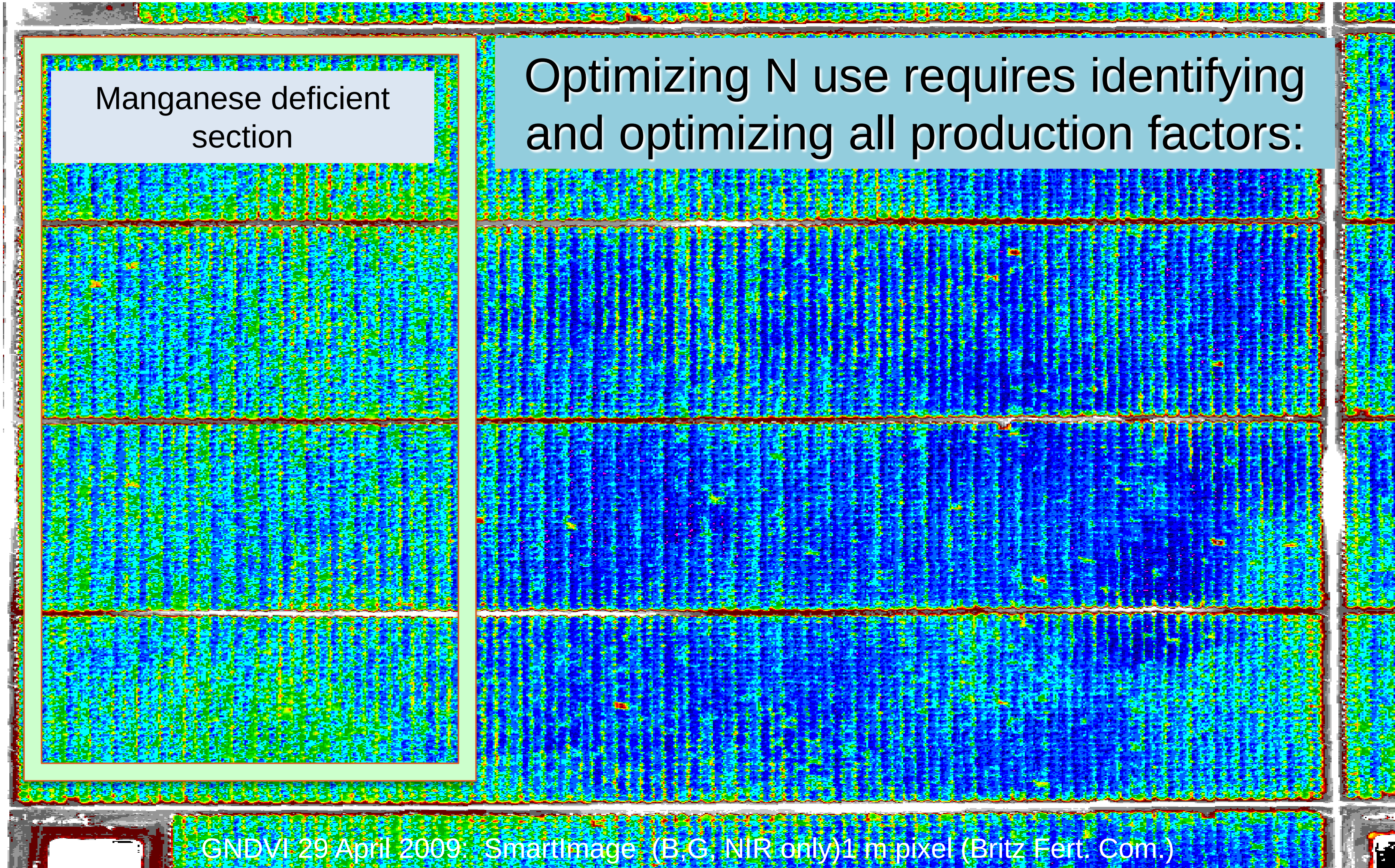
If any nutrient is oversupplied - Money is wasted

Right Source: N Management Alone is Not Enough



Right Source: N Management Alone is Not Enough Example

Manganese deficiency can limit crop response to N:



Right Place: Where are the Roots?

How to manage 200 to 300 lb N/acre

for a crop with a 6-inch rooting depth?

How to manage 200 to 300 lb N/acre

for a crop with a 4-foot rooting depth?

(Photo's Courtesy Tim Hartz and IPNI)

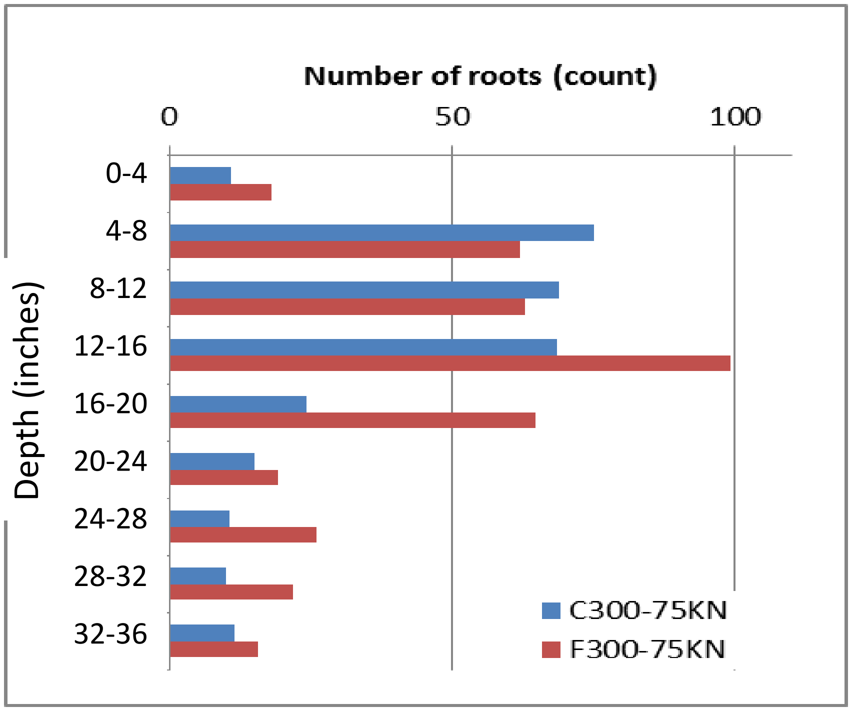
Right Place: Where Does N Uptake Occur?

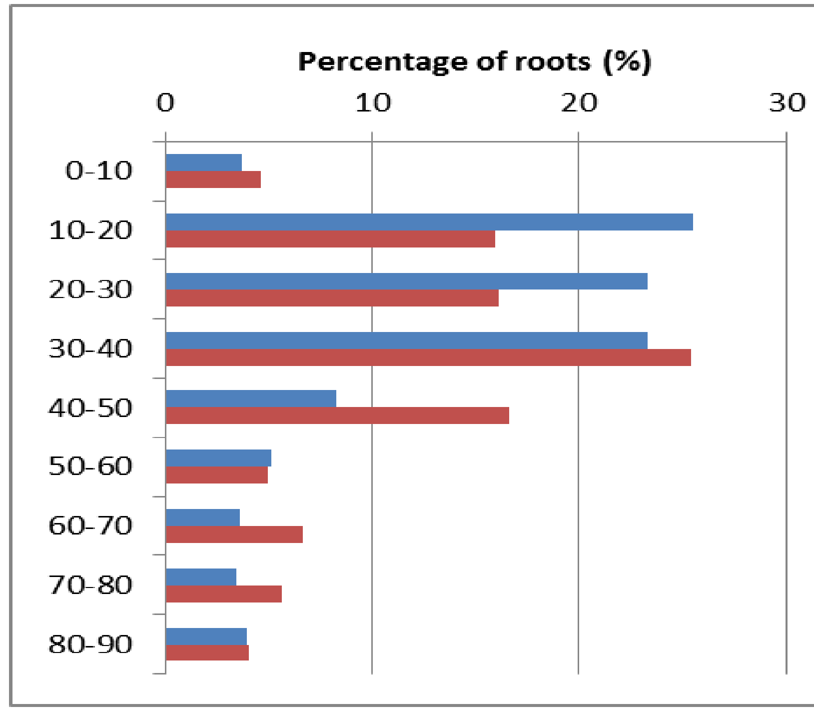
Soil and irrigation practices will influence this greatly:

Specie	Depth of Main Root Zone (inches)	Reference
Almond	8-23	Dziljanov and Penkov 1964b
Apricot	8-16	Ghena and Tercel 1962
Cherry	4-16	Tamasi 1975
Peach	0-32	Dziljanov and Penkov 1964b
Plum	10-24	Tamasi 1973
Walnut	0-16	Kairov et al. 1977

(Adapted from: Atkinson, 1980. The Distribution and Effectiveness of the Roots of Tree Crops. Horticultural Reviews.)

Right Place: Where Does N Uptake Occur? Almond Example



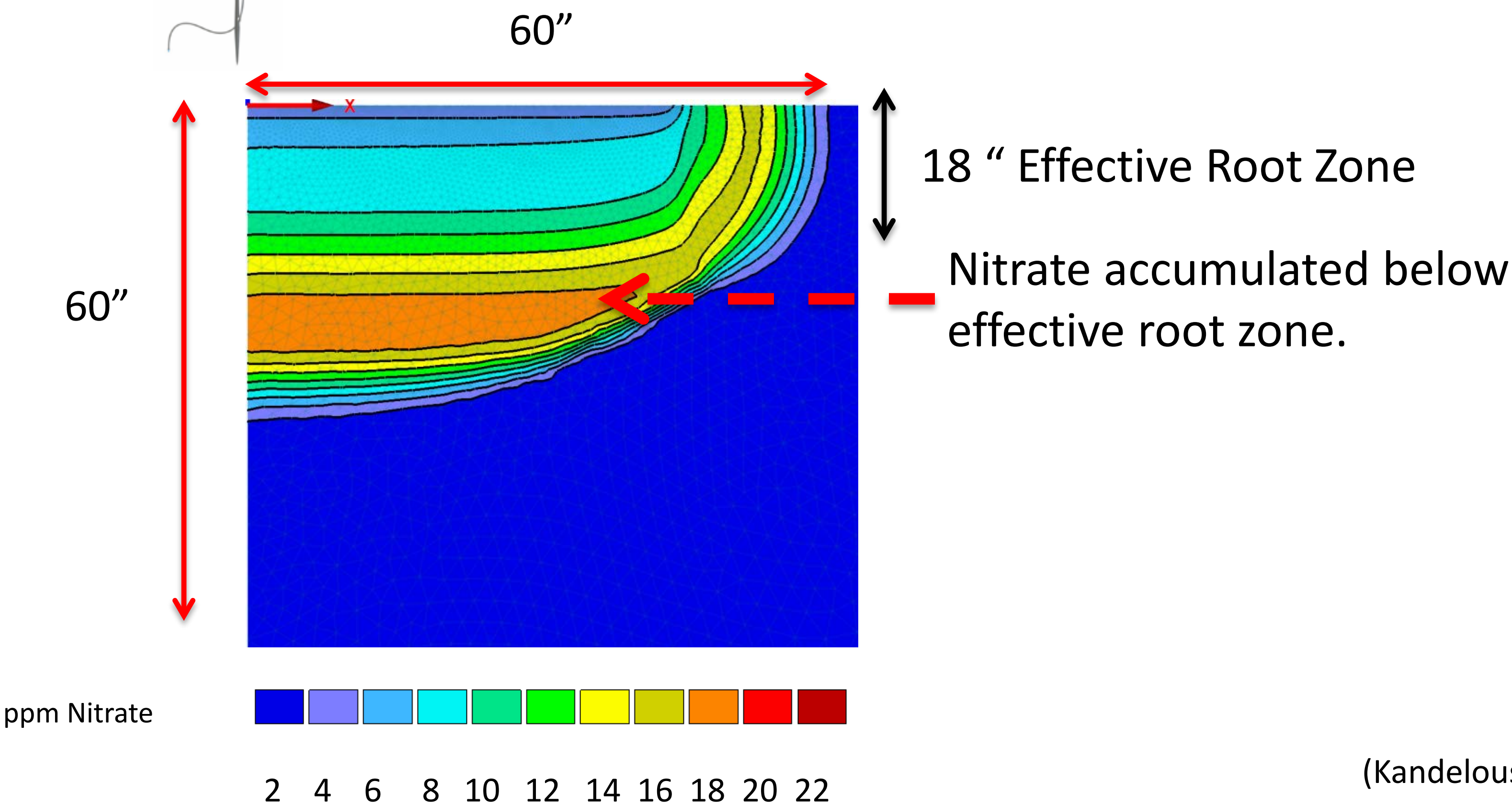


→ In almonds, the majority of roots are in the top 18 inches of soil.

(Olivos, Unpublished)

Right Place: Impact of Fertigation Timing on Nitrate Uptake

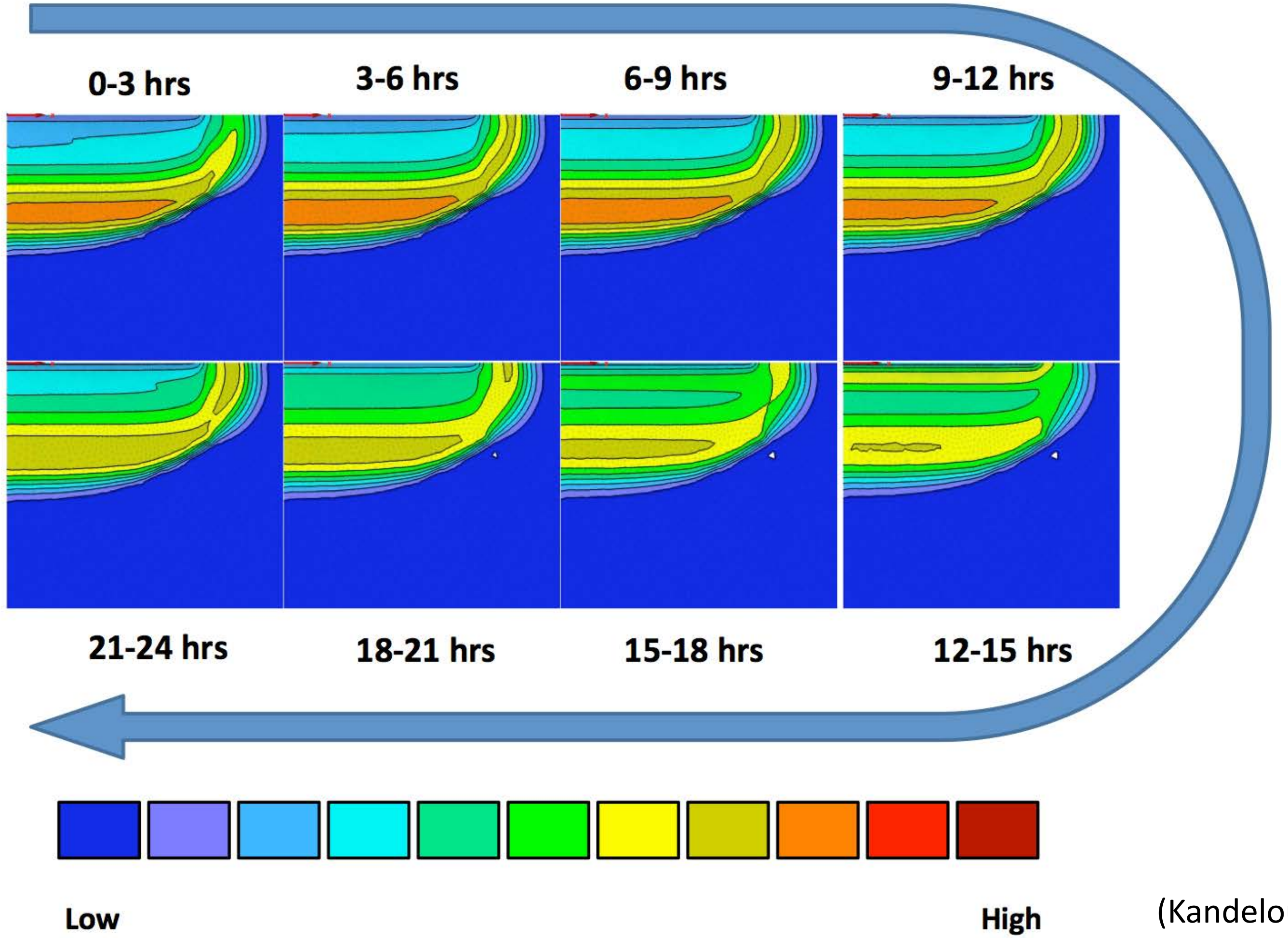
At what point during an irrigation event should nitrogen be applied?



(Kandelous, Unpublished)

Right Place: Impact of Fertigation Timing on Nitrate Uptake

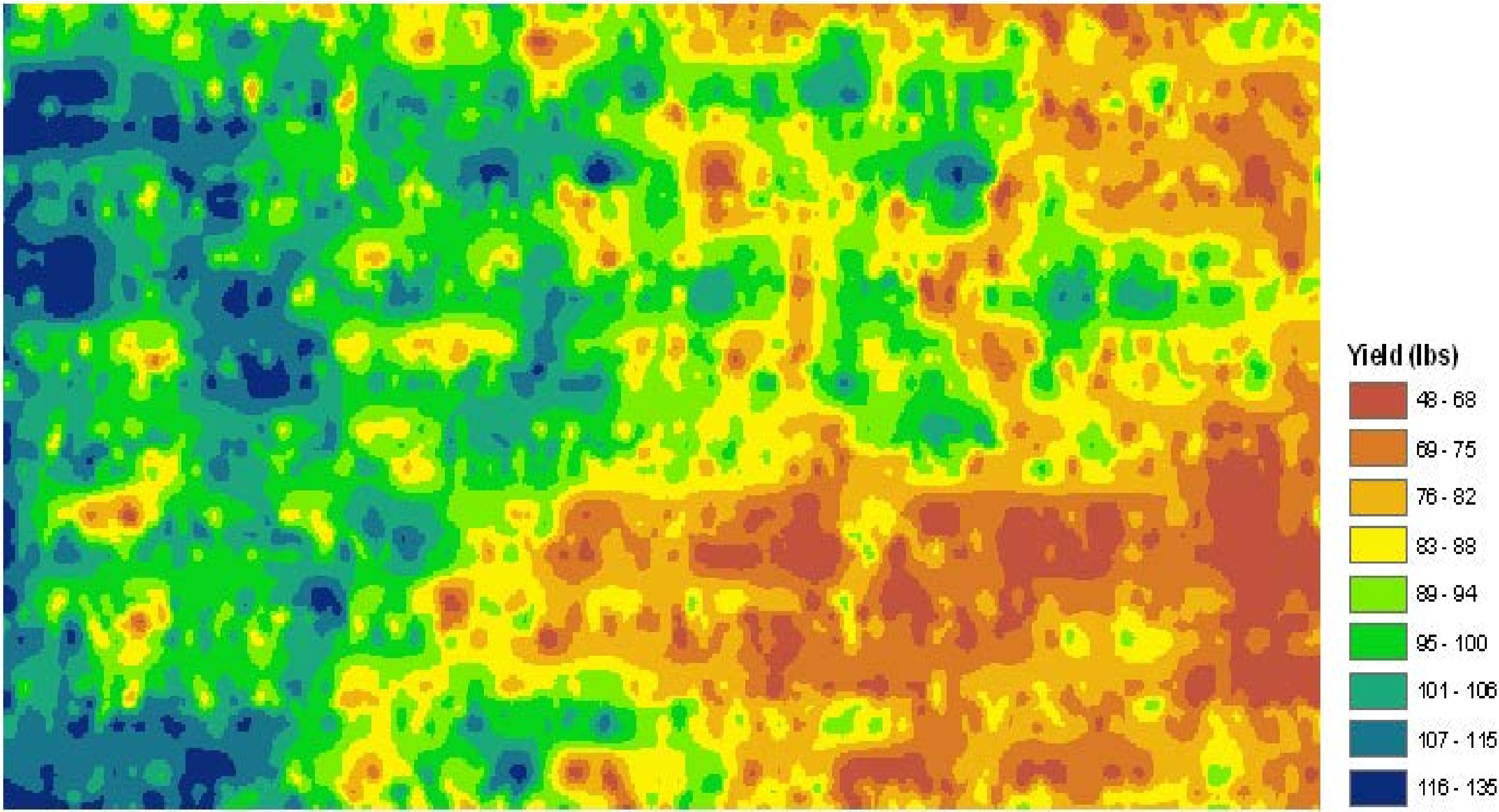
Each of these 8 images represents a 3-hour fertilizer injection event (day 0) that occurred during a 24 hour 1.5” irrigation event. This was followed by two additional irrigation only events on days 7 and 14 for 4.5” total. The images show nitrate in the profile at 21 days after the fertigation, prior to the subsequent fertigation.



(Kandelous, Unpublished)

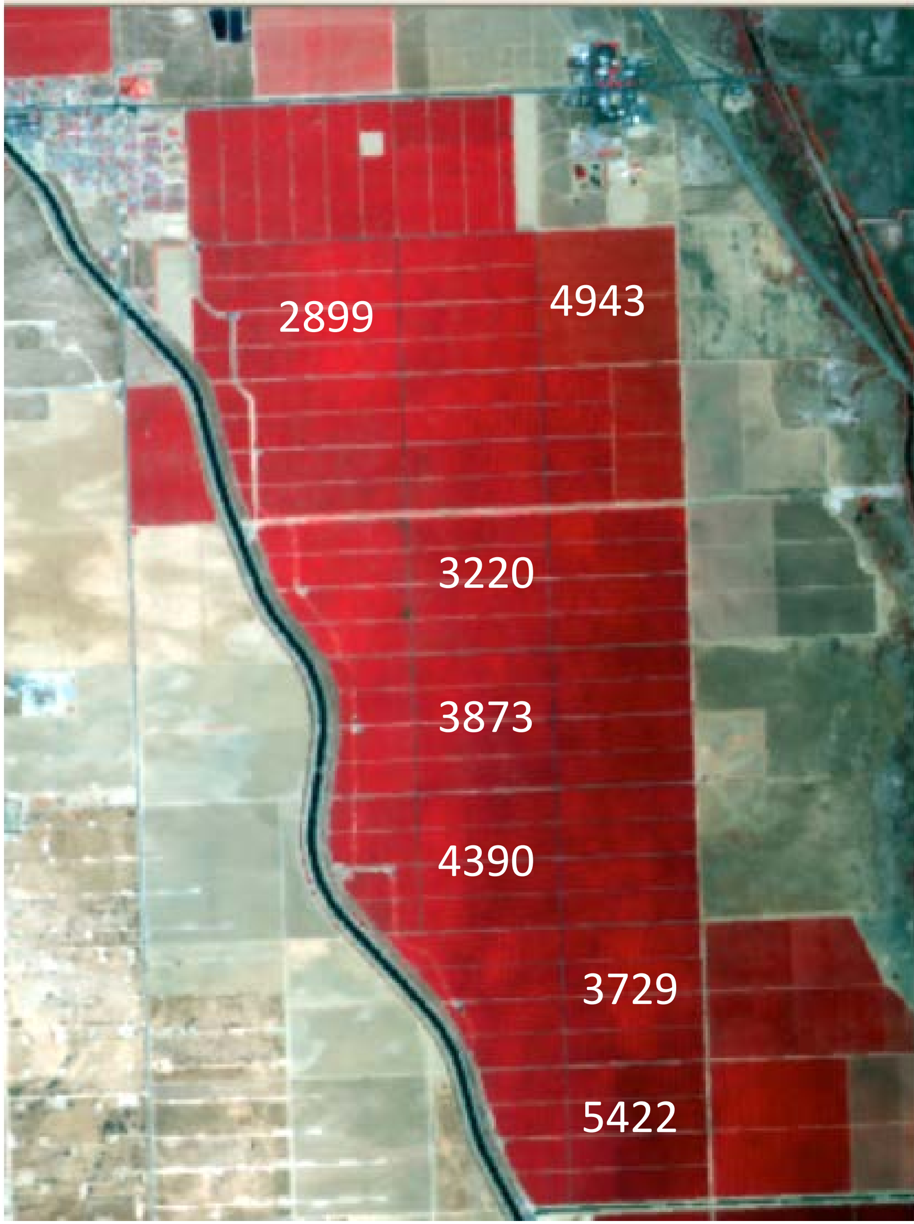
Right Place: Non-uniform Yield

Varying yields across 80 acres of Pistachio trees:

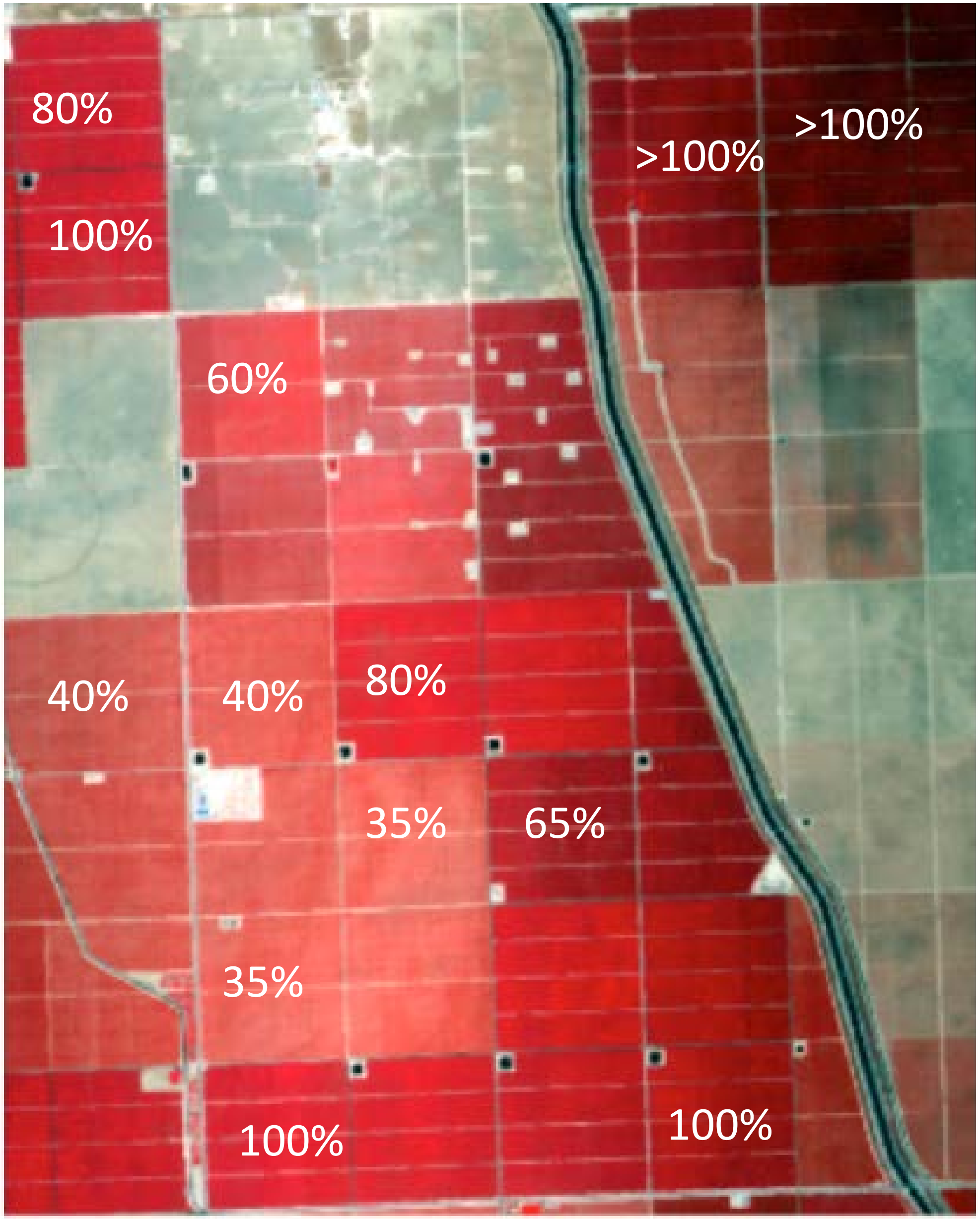


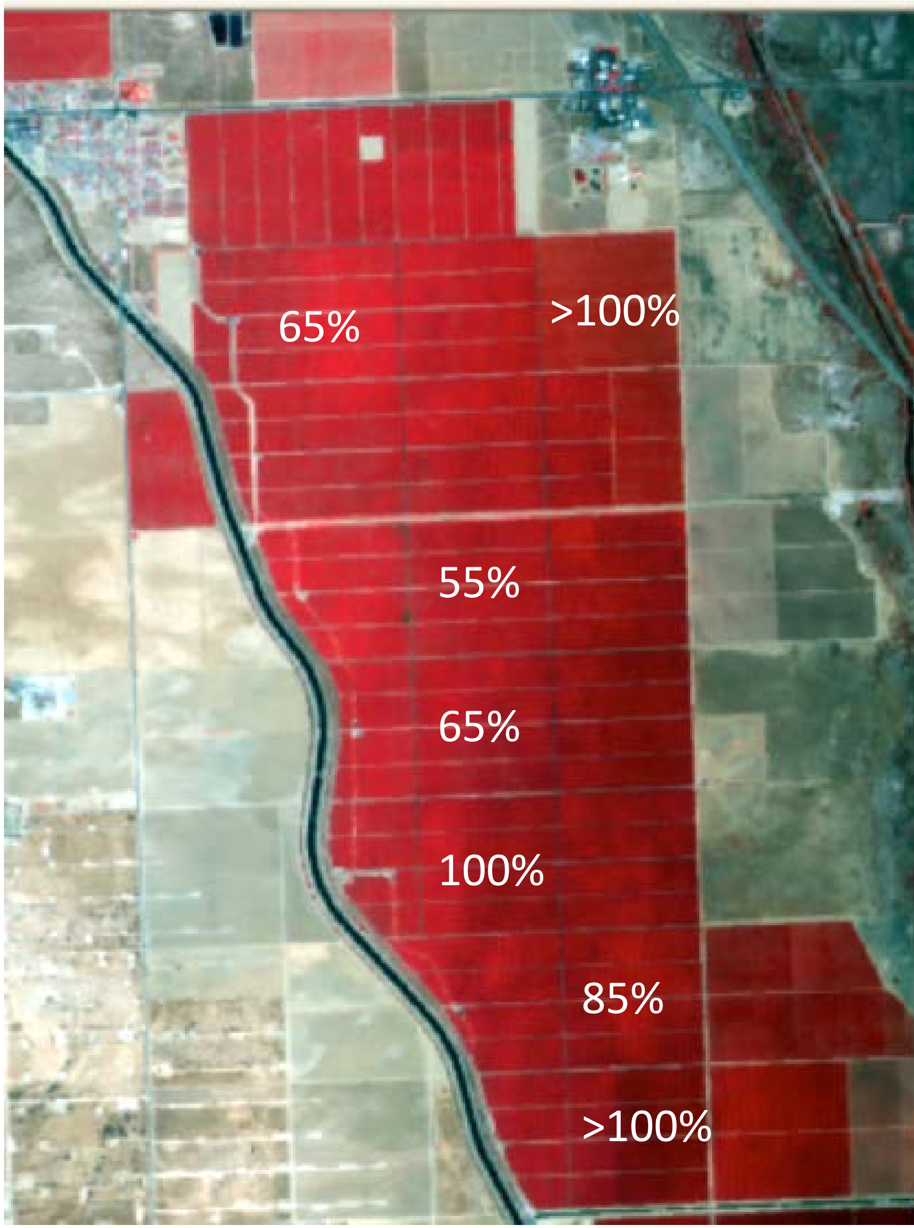
Managed as a single plot, large fields will always be non-uniform and less nutrient-efficient than smaller fields.

Right Place: Non-uniform Yield Example



Right Place: Non-uniform Yield Example cont'd.





Summary: Nitrogen Use Efficiency (NUE)

- The highest efficiency is achieved by the best combination of right rate, right time, right place and right source.
  - This requires understanding the dynamics of nitrogen in the soil and the plant

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Nitrogen Management Training

for Certified Crop Advisers

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ciwr.ucanr.edu/NitrogenManagement

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