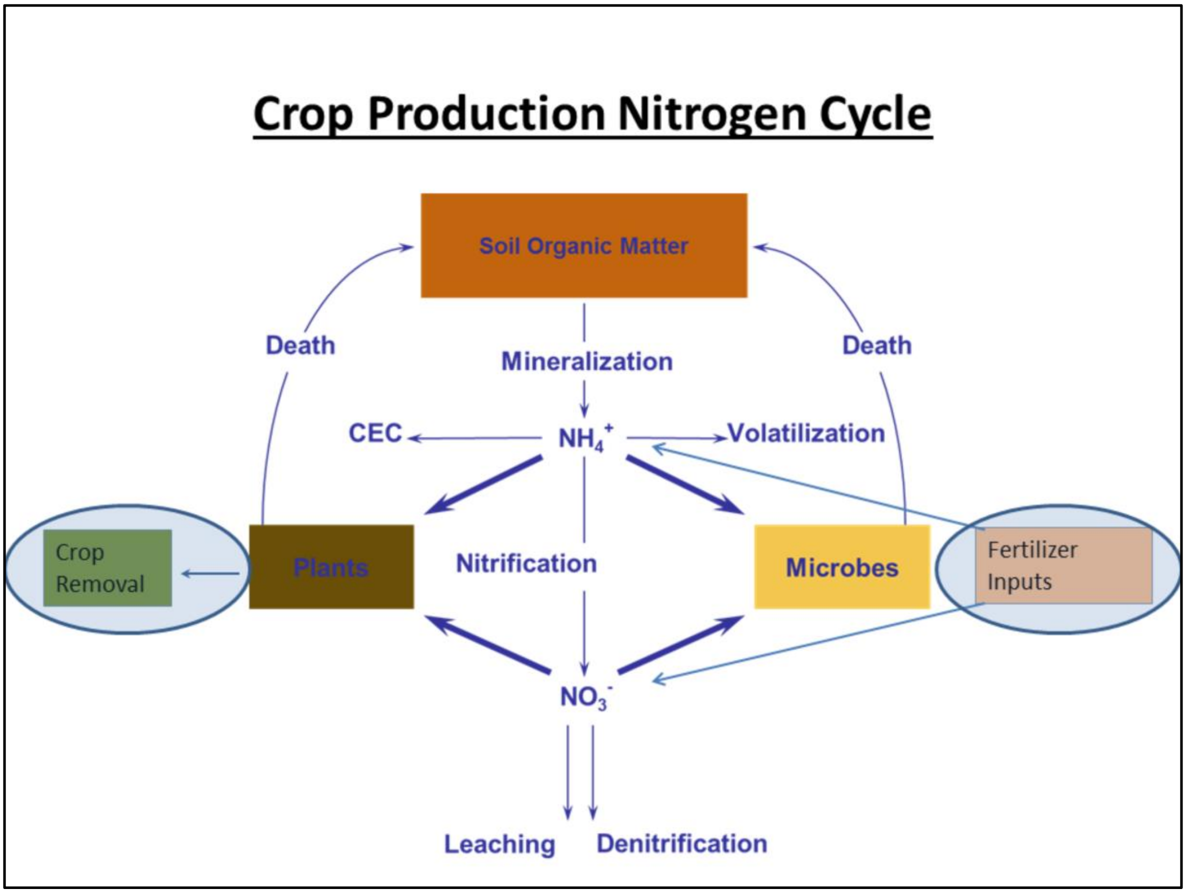
# Nitrogen in Crop Production Systems

## The Nitrogen Cycle

***Section 2***




This is a crop production nitrogen cycle of soil organic matter decomposition, fertilizer inputs and harvest removal on nitrogen.
Emphases on the cycle OM
1 – mineralization to microbes then back to OM
2 – mineralization to plants and back to OM
3 – the escapes from the cycle volatilization, crop removal, denitrification, and leaching

## Nitrogen in Soil Organic Matter (SOM) and Microbes

- SOM stores soil carbon and nutrients
- The process of N release is driven by microbe populations
  - Carbon and nutrients are taken up as microbes grow then released as mineral N upon death(mineralization).
- Microbes increase the cycling of nutrients that otherwise would be lost by leaching and denitrification

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

The majority of soil organic matter is recalcitrant and does not interact with N. It is the small fraction of organic matter that is soluble that can interact with N and is hence most important.

The process of N release is driven by microbe populations

Release carbon and nutrients for their growth

Mineral N is produced

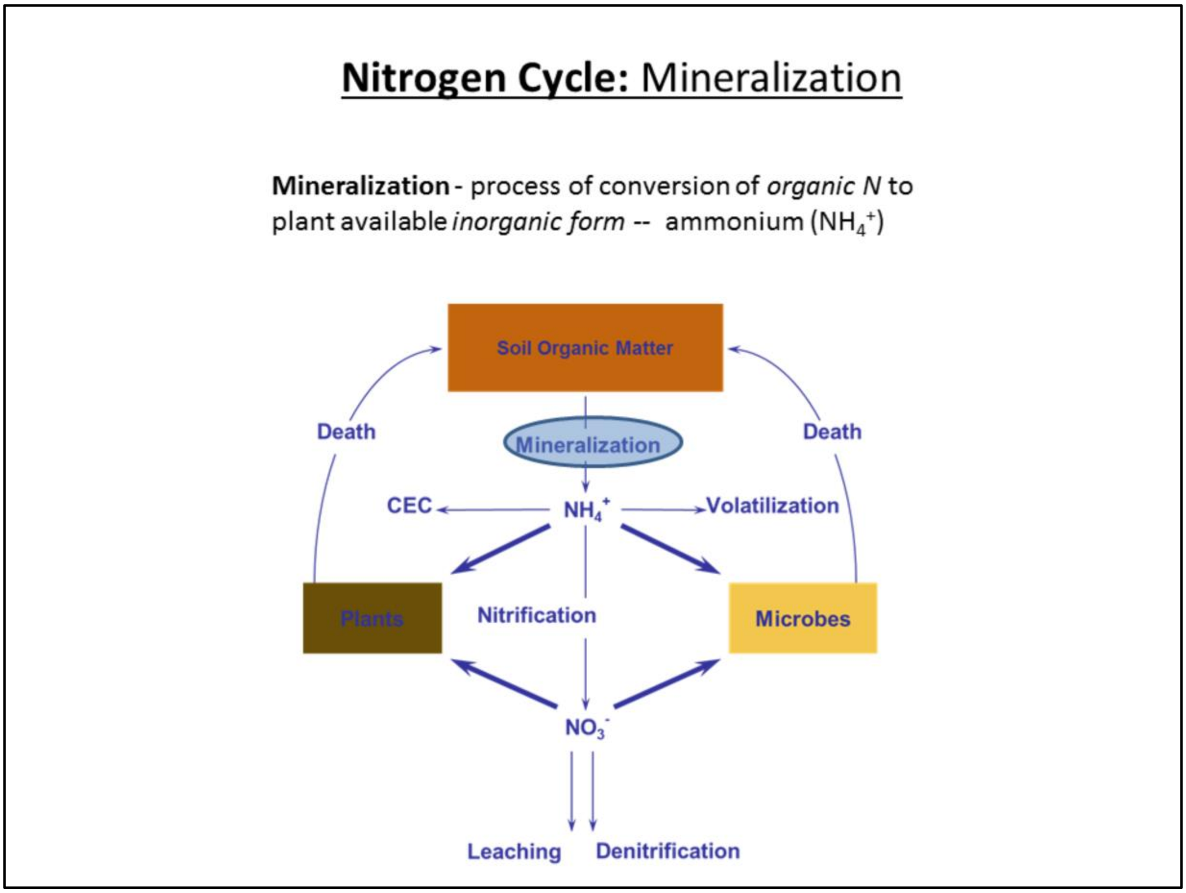



*Figure*: Mineralization is the conversion of Soil Organic Matter (SOM) to plant-available ammonium.
The **mineralization** process and its inverse, **immobilization**.

Mineralization is the conversion of Soil Organic Matter (SOM) to plant-available Ammonium.

Microbes derive energy from organic matter
Rate depends on temperature and moisture
Most ammonium eventually oxidized to nitrate

Emphasize the two cycles: SOM to microbes and back to SOM and SOM to plants and back to SOM and relate to plant availability

## The Process of Decomposition in Soils

- **Composition** of Plant Residues
  - Crop and plant residues (cover crop, compost and animal manure) 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:

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

Rapid decomposition

Very slow decomposition

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

- Organic matter added to the soil decomposes, releasing N as it does.
- Rate of decomposition depends on the composition of the organic matter. The boxed portion of the slide shows the relative rates of decomposition of different forms of organic matter.
- Faster decomposition means faster release of N.

## 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)*

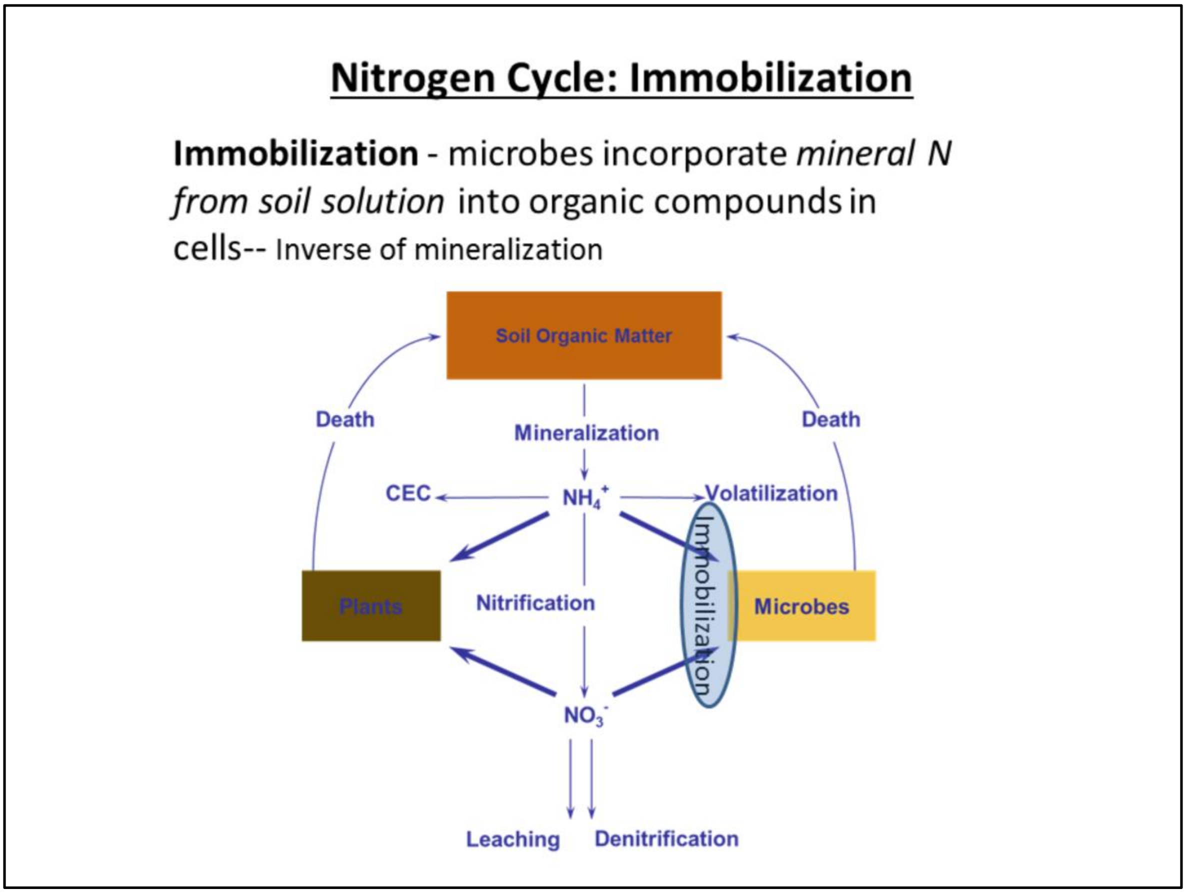
Generally:

- **A C:N ratio** of 20:1 (2% N) is the dividing line between mineralization (immediate release) and immobilization (N binding and subsequent release).
- The higher the C:N ratio the slower decomposition and mineralization occur
- Most N in added materials will ultimately become available, though it may take several years.
- Anaerobic conditions will lead to very slow mineralization.

With a large C:N ratio Microbes take N for growth holding N unavailable

As decomposition continues the C:N ratio narrows

At about 20:1 N becomes available for plant use

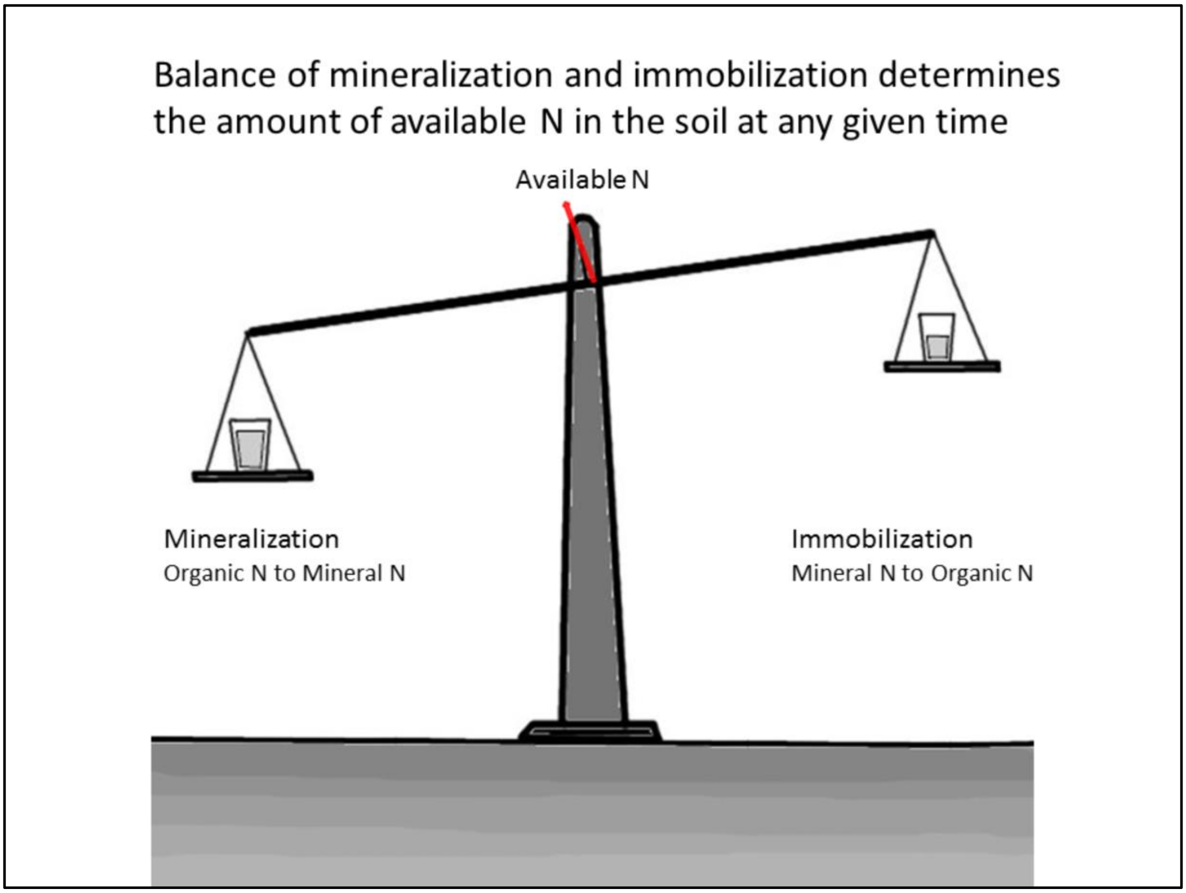



Microbes hold N as they decompose SOM then release mineral N as they die as the carbon source is mineralized.

When adding an organic source to the soil that has high carbon and low nitrogen, available mineral N is taken up by the microbes reducing soil available mineral N.

Begin cycle at organic matter
Mineralization by microbes to ammonium

At that point ammonium can be immobilized by the microbe population – incorporated into their bodies OR
Taken up by the plant
OR
Nitrified to nitrate
Then
Taken up by the plant
OR
immobilized by microbes
OR
Denitrified
OR
Leached




*Note*: This balance depends on the activity level of soil microbes. Microbial population growth is influenced by temperature and moisture, but is mostly limited by amount of carbon in soil. When carbon is added to soil, microbes are able to take up more N to make proteins, increasing immobilization and decreasing mineralization.

**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

## Mineralization

- **Carbon/Nitrogen ratio** of organic materials is one of the main factors controlling mineralization rates.
- Environmental conditions, **tillage**, **temperature**, and **moisture** strongly positively influence mineralization rates.
- Chemical analysis of added organic matter is essential to determine the rate and timing of N release.

*Note*: Mineralization is a particularly relevant component of the N cycle when a grower has or adds large amounts of SOM.

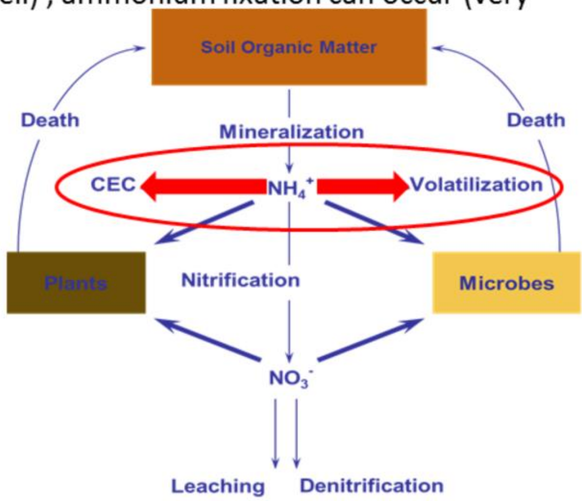
## Immobilization

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

- If C:N ratio is high microbes have priority in using available mineral N until decomposition of SOM declines to about 20:1 C:N

## Fates of Ammonium After Mineralization

- Plant uptake
- Incorporated into Microbes
- $NH_4^+$ ions
  - Adsorbed on negatively charged clay surfaces
  - In 2:1, vermiculite clays (shrink swell) , ammonium fixation can occur (very slow release)
- Ammonia volatilization
- Converted to nitrate (nitrification)




Vermiculite clays expand when wet and contract when they dry trapping $NH_4^+$ ions between the clay plates.
The release back to the soil solution is very slow.

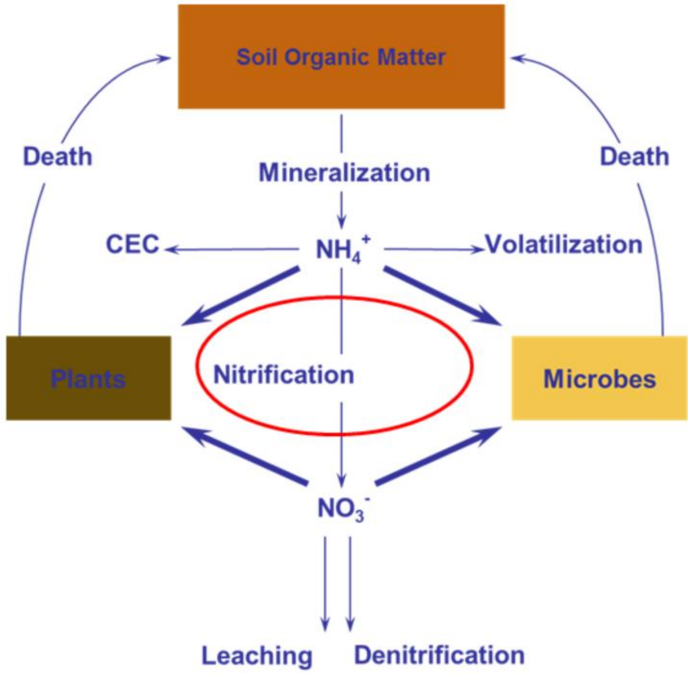
Ammonium produced by mineralization or added directly to the soil has one of several fates, including binding directly to soil at **cation exchange sites (CEC)** or being lost to **volatilization**.

## Ammonia Volatilization

- **The loss of gaseous $NH_3$ to the atmosphere**
  - Conditions that favor volatilization with:
    - Fresh manures
    - Ammonia injections
    - Urea
    - UAN
      - Lack of incorproation
      - Dry soil
      - Coarse-textured soils (sandy)
      - High pH soils/water

*Note about volatilization*: Ammonia gas (NH3) can be present in fresh manures and anhydrous ammonia injections, and is also a breakdown product of urea and UAN. In gas form, it is easily lost to volatilization. Typically, soil moisture is adequate to rapidly convert NH3 (ammonia), to $NH4^+$ (ammonium), preventing volatilization. However, in dry soil, especially when coarse-textured and high pH, NH3 volatilization can be significant (up to 30%).

# Nitrogen Cycle : Nitrification




This is the most relevant component of the soil N cycle for California agriculture

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

Ammonium is oxidized to Nitrate by bacteria in two steps for the purpose of the microbes obtaining energy

Nitrate ($NO_3^-$)

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

Nitrification is the biochemical oxidation of ammonium to nitrate that occurs in warm, moist, well aerated soils

The first equation shows how ammonium is converted to nitrite. Nitrosomonas is a heterotrophic bacterium that converts ammonium to nitrite.

The second equation shows the second step of the process, with nitrite being converted to nitrate. Nitrobacter is an autotrophic bacterium that oxidizes nitrite to nitrate. The final product is nitrate, which is readily available for plant uptake.

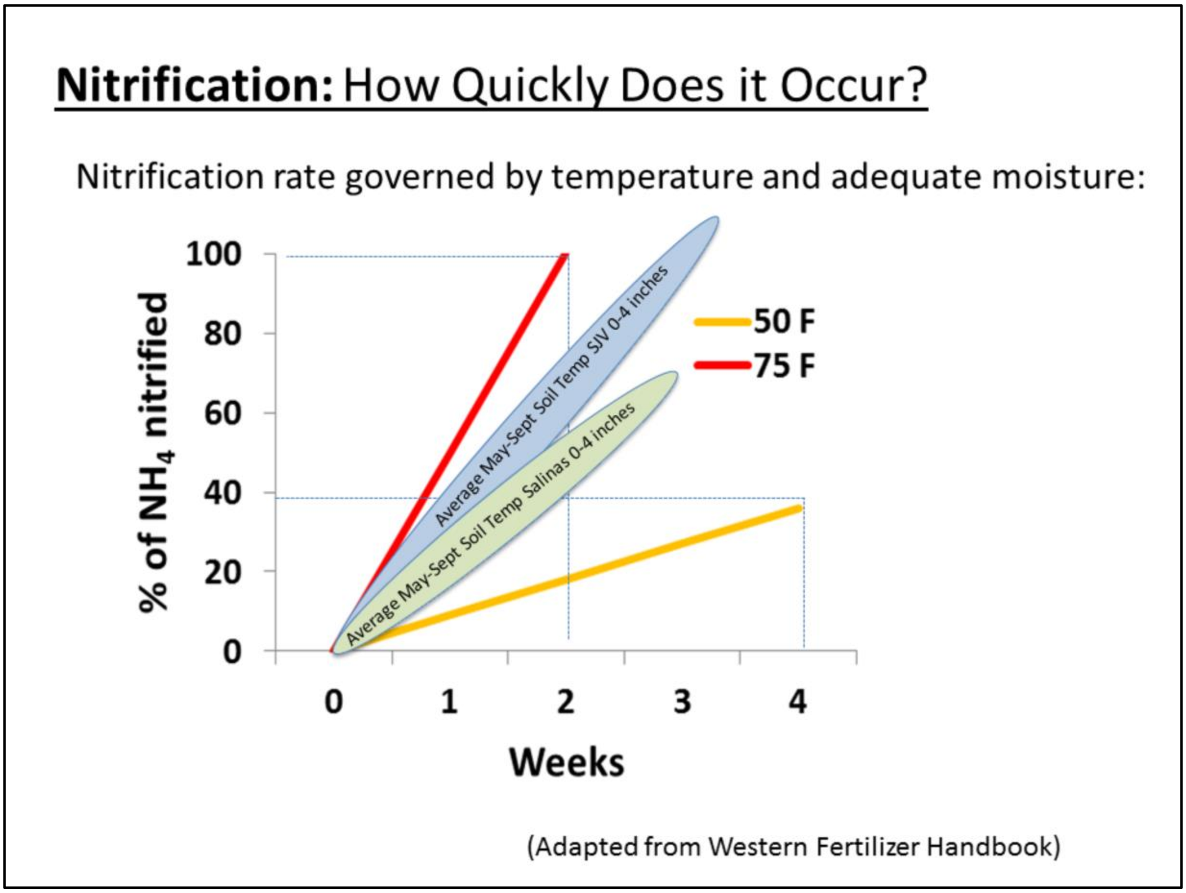
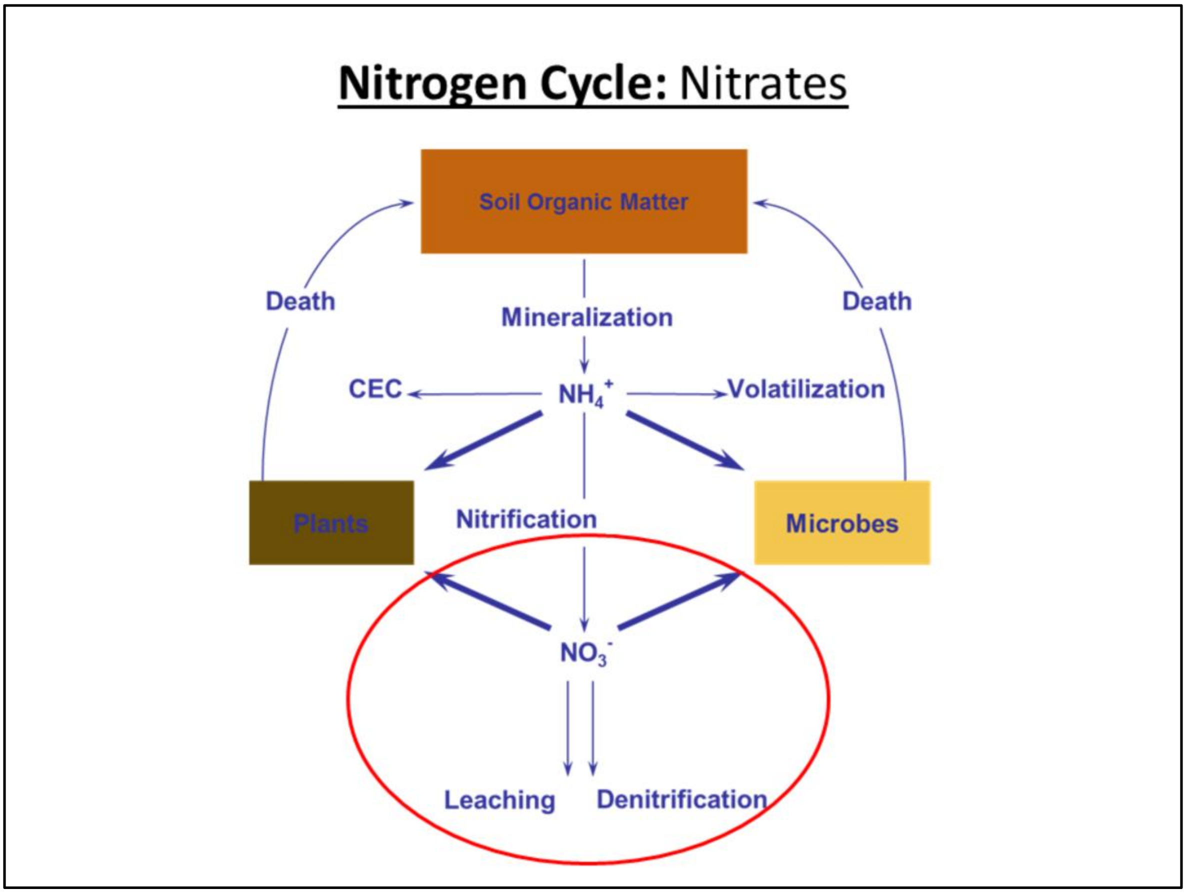



*Figure*: Estimate of nitrification rates in California soils (San Joaquin and Salinas Valleys), depending on soil temperature.
Mention average of 50% in 1-2 weeks




This is the most difficult component of the cycle to manage because it has the highest potential for loss through **leaching** and **denitrification**.

Point out that NO3 can be used by plants and microbes or be lost to denitrification or leaching

## Why Does Nitrate Leach?

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

Water management inadequate = excess irrigation
Timing does not match crop leaves excess N available for leaching

# Nitrate Leaching Principles

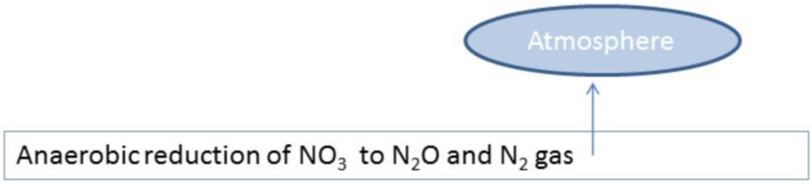
**For nitrate leaching to occur:**

Nitrate must be present in the soil

Soil must be permeable for water movement

Water must be moving through the soil

## Denitrification: Loss of N to atmosphere




- Occurs under warm, anaerobic conditions
- Most significant in wetlands and rice paddies
- Less significant in well-drained soils
- In irrigated agriculture, $N_20$ production is sporadic.

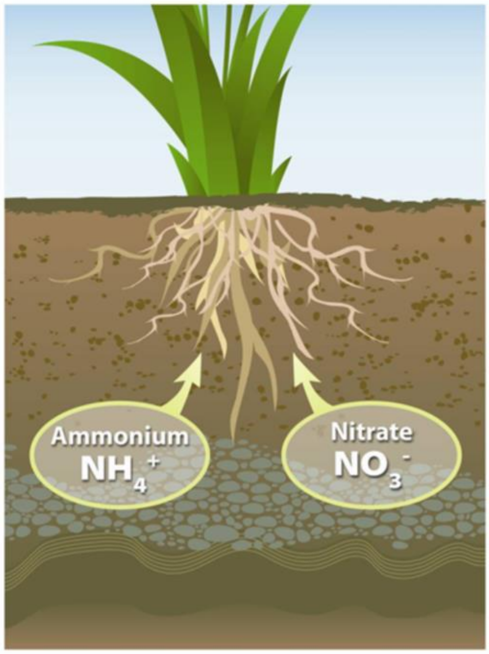
  **Most N loss occurs during a brief period when the soil is warm, wet, and high in nitrate (i.e. fertigation).**

The chemical formula shows denitrification, the reduction of nitrate to nitric and nitrous oxide gasses, and dinitrogen gas, all of which can volatilize off the field. This conversion occurs in the presence of an available C source for anaerobic, heterotrophic bacteria that use the N in nitrate as an electron acceptor.(for energy)

# **Nitrogen Cycle:** N in Plants

## 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 Assimilation

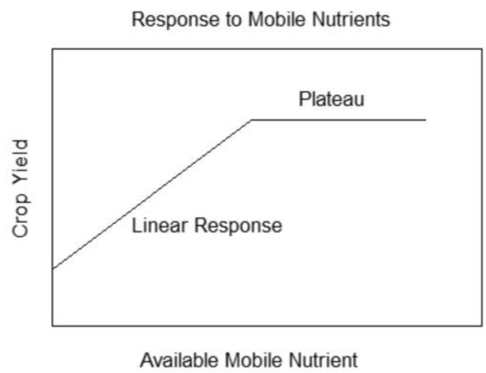
- All N sources must be first converted to Amino Acids which is an energy expensive process

Therefore:

Plant only assimilate the needed amount plus a small amount of “luxury consumption”.

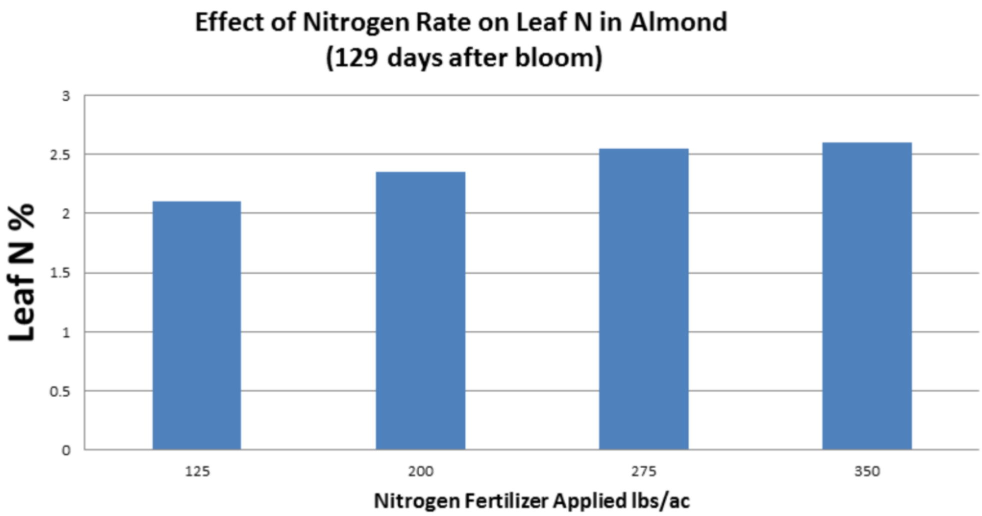
# Nitrogen

- Plants require greater amounts of nitrogen than any other mineral nutrient.
- Nitrogen availability generally limits crop productivity until adequacy is reached where productivity does not further increase.




Fertilization past a level of adequacy does not increase productivity.
The goal is to consider all sources of nitrogen (soil residual, irrigation water, and applied fertilizers) at appropriate times and rates to maximize nitrogen use efficiency and reduce the leaching potential.

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




From Muhammad, 2013

*Figure*: This example from a high-yield almond orchard illustrates the phenomenon described in the previous slide. At the highest level of N applied, no significant additional N was taken up by the plant compared to the second-highest application level. This treatment level is considered excessive, as we can be sure that N remains in the soil.

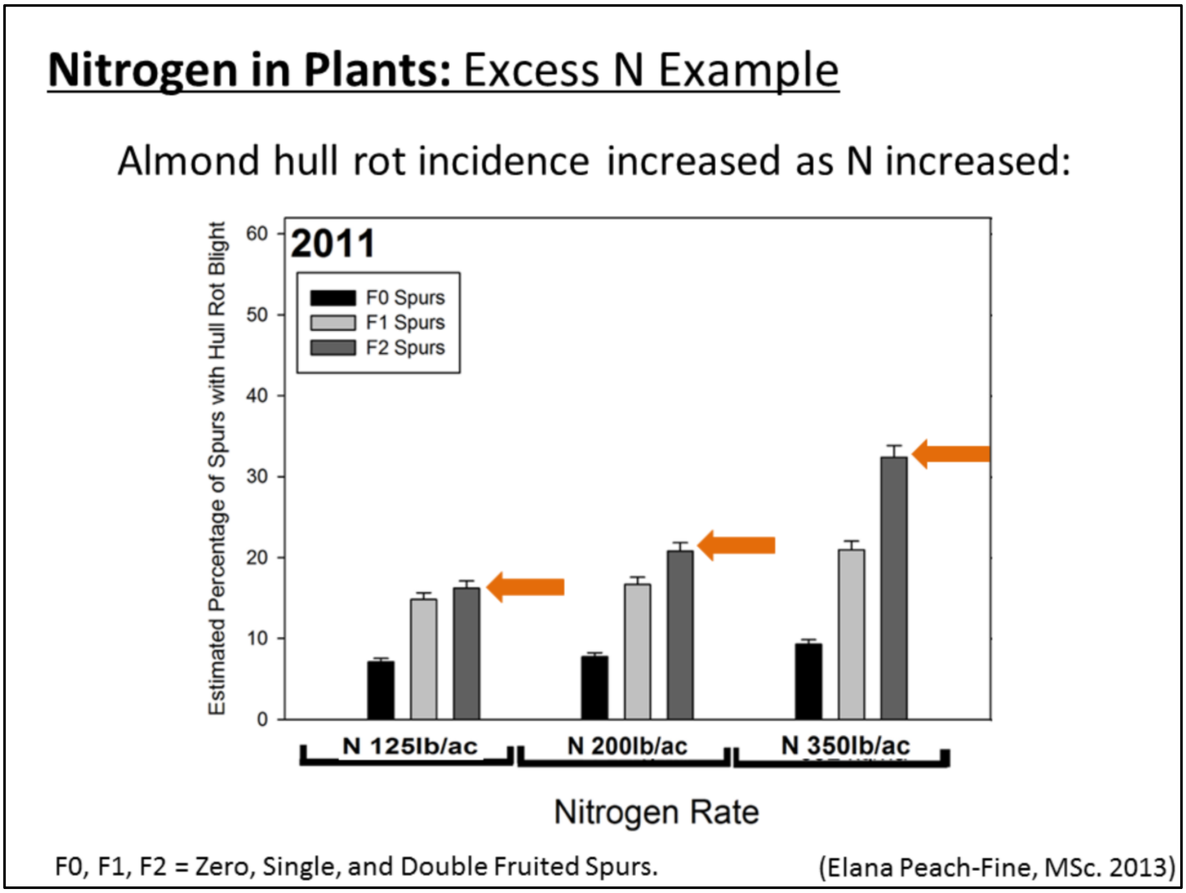
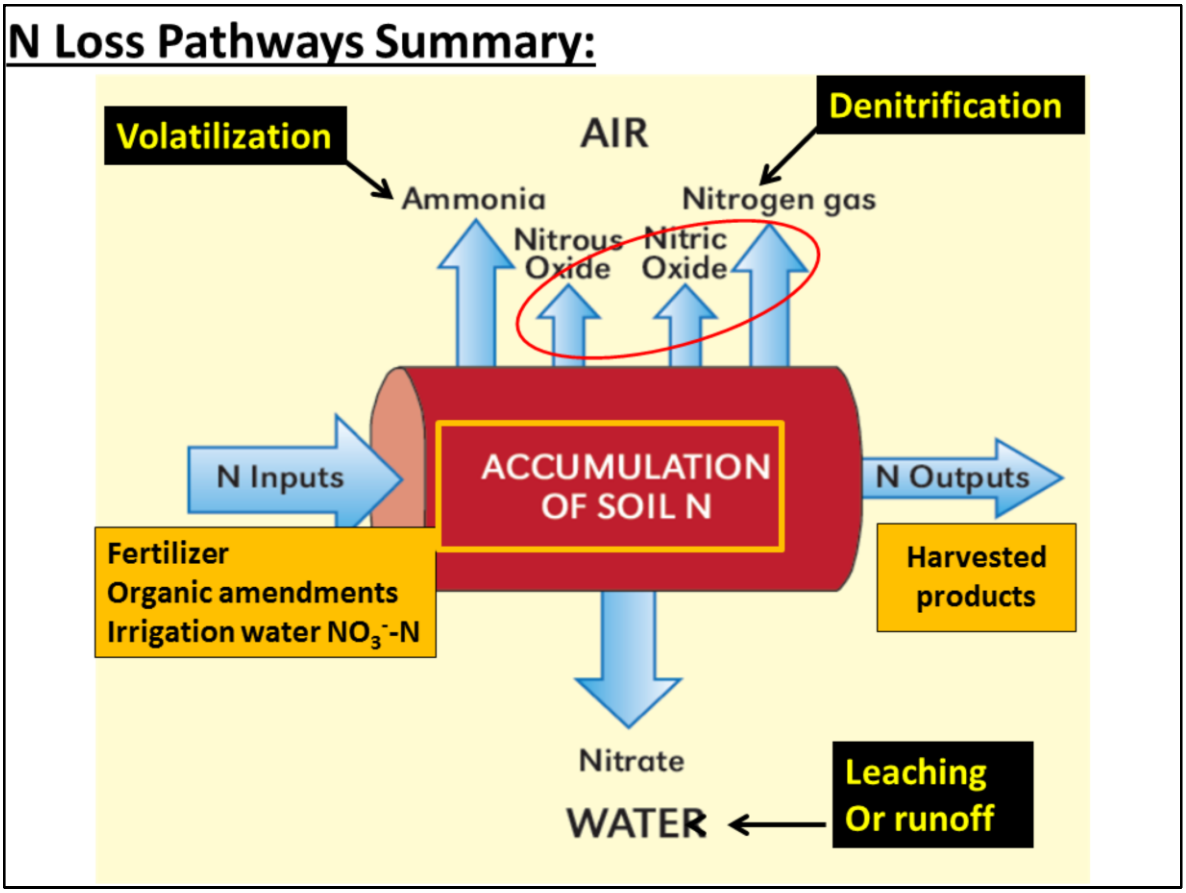



*Figure*: Excess N can have negative consequences for plants. Here excess N resulted in increased incidence of hull rot. The exact mechanism is unknown, but rot may be related to N-induced changes in plant defense against fungal invasion.




Which N loss pathways are most significant in fruiting crop systems?

- Volatilization: This is a very minor component for coastal row crop production but can be a problem for Central Valley cereal crops
- Denitrification: This is a minor consideration for Central Valley conditions. However, for growers applying dairy waste products or furrow irrigating, denitrification can be significant.
- Leaching/Runoff: Will depend on the magnitude of N accumulation in soil, which varies based on use or absence of tillage. Many tile-drainage tests indicate that N leaching is significant.

Note that mineral nitrogen carried forward from one crop to another leads only to short-term N buildup in soil. It is not equivalent to long-term accumulation of organic form N bound up in soil. Because of the reliance upon tillage in these systems, there is not likely very much accumulation of organic form N in soil.