**SOILS AND FERTILIZERS**
**MODULE 6B**
**REACTIONS OF SOIL NITROGEN AND NITROGEN FERTILIZERS**

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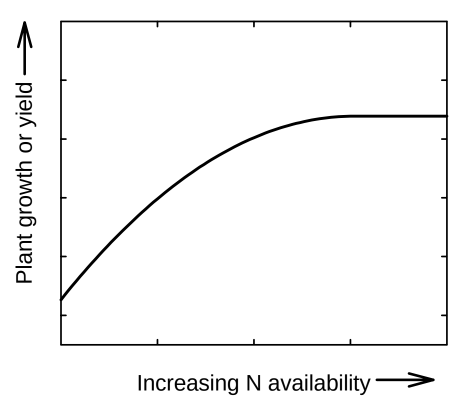
1. Nitrogen uptake by plants
   a. Plants will take up either $NH_4^+$ or $NO_3^-$ forms of N only; both the ammonium and nitrate forms are usable by plants.
   b. The majority of N taken up is usually in the $NO_3^-$ form, however, due to soil chemical and biological processes that make it the most prevalent form of soil N.
   c. A situation where $NH_4^+$ is the major N form taken up would be a crop grown under flooded soil, like rice; the soil is devoid of oxygen, biological <u>nitrification</u> is limited, and most N stays in $NH_4^+$ form.
   d. Under a flooded (oxygen-depleted) situation, $NO_3^-$ can be lost to the atmosphere through a process termed <u>denitrification</u>.
   e. Some plants like pine trees or blueberries grow better with $NH_4^+$; they generally grow in acidic soils, where conditions for nitrification are not favorable (high soil acidity limits action of the microbes that convert $NH_4^+$ to $NO_3^-$).
   f. Most solanaceous plants (e.g. tomatoes, potatoes, tobacco, squash, etc.) grow best if some nitrate is present; tomato plants grown entirely with $NO_3^-$ (in solution culture) produce more dry matter than when grown entirely with $NH_4^+$.
   g. $NO_3^-$ can be metabolized to organic N most anywhere in the plant; most $NH_4^+$ must be changed to $NO_3^-$ within the root tissue shortly after uptake; photosynthate must be transported to the roots to provide energy for this conversion.
   h. Citrus trees grow well with either $NH_4^+$ or $NO_3^-$ as the nitrogen source.

2. Plant use of nitrogen
   a. N is used in the synthesis of amino acids, proteins, and chlorophyll.
   b. The average plant tissue N content is about 2% for non-legumes and 4 to 6% for legumes.
   c. Nitrogen promotes <u>vegetative</u> growth of plants; too much N can delay flowering or fruit maturity; if too much N is applied it will not kill the plant, however, unless connected with another factor such as too much salt.
   d. General plant growth curve with increasing nitrogen:



3. Symbiotic N fixation
    a. Specific microorganisms (*Rhizobium* species) associated with the roots of legume plants (e.g. alfalfa, soybeans, clover, peanuts).
    b. *Rhizobium* bacteria inhabit nodules on plant roots; plant provides the bacteria with energy, and the bacteria in turn convert $N_2$ gas from the air to forms that are usable by the host plant.
    c. N fixation by this process can range between 50 and 200 lbs N per acre per year.
    d. Rhizobium strains are specific for each plant species, so often need to inoculate the plant seed with the proper strain.
    e. Environmental factors favoring symbiotic N fixation:
        i. Soil pH of 6.5 or higher.
        ii. Adquate soil moisture.
        iii. Supply of available calcium.
        iv. Warm temperatures.
        v. Low supply of available soil N.
4. Non-symbiotic N fixation
    a. Soil organisms that fix N without being associated with a leguminous plant.
        i. Blue-green algae
        ii. Certain free-living bacteria.
        iii. Results in about 10 to 30 lbs of N fixed per acre per year.
    b. N in rain water
        i. Lightning from thunderstorms will form mineral N from atmospheric N through the arc process; the amount of N deposited by thunderstorms in Florida is probably about 10 lbs N per acre each year.
        ii. N in rainwater is a partial reason why trees, grass and other plants in areas not touched by humans remain green.
5. Soil nitrogen and associated reactions
    a. Organic nitrogen
        i. Carbon/nitrogen ratio of soil organic matter is about 10:1; the nitrogen/sulfur and nitrogen/phosphorus ratios are about 10:1.
        ii. Soil organic matter is primarily <u>humic acid</u>, a slowly-degrading, stable compound; in Florida, most CEC is due to humus since little clay is present.
        iii. The average Florida sandy, well-aerated soil has about 1% organic matter; amount will vary with depth, landscape position, and type of vegetation.
    b. <u>Mineralization</u> is the term used to describe the process of conversion of N from organic forms to an inorganic form; it consists of three processes:
        i. Aminization: The breakdown of proteins into amino acids by bacteria or fungi.
        ii. Ammonification: The conversion of the amino acids produced in aminization to the ammoniacal compounds $NH_3$ and $NH_4^+$, also done by microorganisms (a very diverse population does this). The ammonium released may be converted to nitrate, absorbed by plants, utilized by microbes, fixed within the lattice of clay minerals (not in Florida), or released to the atmosphere.
        iii. Nitrification: Conversion of soil $NH_4^+$ to $NO_3^-$ by bacteria. Any source of ammonium is suitable for the nitrification process; aerobic conditions are required, i.e. molecular oxygen is needed for the reaction to proceed; the reaction produces $H^+$ ions and will increase the soil acidity.

c. Amount of N that might be released (through the aminization and ammonification processes) from organic matter over a period of years:
Example 1: Florida mineral soil, above-average OM concentration (2%); assume OM/N ratio is 20:1, the weight of an acre furrow slice is 2 million lbs, and the mineralization rate for the OM is 2% per year.

(2,000,000 lbs/acre 6-inch depth) x 0.02 = 40,000 lbs OM
40,000 lbs OM / 20 = 2000 lbs N in the soil
2000 lbs N x 2% = **40 lbs N/acre/year mineralized**
This is not a sufficient amount of N for agricultural crop production, so supplementation is needed through fertilization.

Example 2: Florida organic soil, 80% OM; the weight of an acre furrow slice is 800,000 lbs, all other constants the same as above.

(800,000 lbs/acre 6-inch depth) x 0.80 = 640,000 lbs OM
640,000 lbs OM / 20 = 32,000 lbs N in the soil
32,000 lbs N x 2% = **640 lbs N/acre/year mineralized**
This is definitely a sufficient amount of N for certain crops like sugarcane grown on organic soil, so N fertilization is not required. For other, shorter-season crops such as celery or radishes, the N may not be mineralized fast enough to meet the crop demand, and supplementary applications of fertilizer may be necessary.

Unless organic soils are flooded, most of the N in them mineralizes and becomes available for use by crops; the N that is not utilized by plants is leached away.

d. Mineralization of organic residues: The type of plant residue determines its rate of decomposition; more specifically, it is the C:N ratio.

| Material | C:N ratio |
|---|---|
| Soil humus | 10:1 |
| Clover (young) | 12:1 |
| Clover (mature) | 20:1 |
| Alfalfa (young) | 13:1 |
| Green rye | 36:1 |
| Corn stover | 60:1 |
| Sugarcane trash | 50:1 |
| Straw, small grain | 80:1 |
| Oak | 200:1 |
| Pine | 286:1 |
| Sawdust | 400:1 |

    i. In Florida, will get rapid decomposition of crop residue if the C:N ratio is favorable (i.e. less than about 20:1).
    ii. High N residues contain >1.6% N; if less than 1.6% N, nitrogen may be tied up for awhile, then will be slowly released; the initial tie-up can be eliminated with application of N fertilizer.
    iii. Legumes have 3 to 5% N in plant tissues, therefore release of N from their residues will be immediate; legumes decompose much more rapidly than non-legumes.

e. Reactions of $NH_4^+$ (ammonium) with the soil
    i. Because it is a cation, $NH_4^+$ can be adsorbed (held) by the soil cation exchange complex; the soil CEC determines the quantity of $NH_4^+$ which can be retained.
    ii. Banding ammonium can help retain it in sandy soils vs. broadcast application; leaching will occur from broadcast applications because of rapid nitrification and coarse soil texture (ease of water movement); banding is a good idea in Florida because the band slows the nitrifying bacteria, and all of the ammonium will not be leached away with the first heavy rain (some residual will be left).
    iii. Reaction of $NH_4^+$ with calcareous soils:

Ammonium nitrate + Calcium carbonate $\rightarrow$ Ammonium bicarbonate + Calcium nitrate

Ammonium bicarbonate $\rightarrow$ Ammonia gas + Carbon dioxide + Water

        (1) Calcareous soils contain free calcium carbonate dispersed in the soil; if any ammonium source (e.g. $NH_4NO_3$ or $(NH_4)_2SO_4$) is applied <u>to the surface</u> of a calcareous soil and comes into contact with solution $CaCO_3$ (via irrigation water or dew), ammonium bicarbonate ($NH_4HCO_3$) will be formed; this compound can then decompose to gaseous ammonia, and the N is lost to the atmosphere.
        (2) Do not surface-apply lime and ammonium fertilizer at the same time; nitrogen will be lost to the air; for protection, incorporate the materials or irrigate in at least 1 inch deep.
        (3) There are certain situations where the pH is high (e.g. a south Florida Spodosol that has been irrigated with high-pH irrigation water), but no free $CaCO_3$ exists on the soil surface; in this case, it would be acceptable to apply ammonium sulfate to the soil surface.
    iv. Ammonium can undergo nitrification.

f. Factors affecting nitrification
    i. Supply of $NH_4^+$ ion: $NH_4^+$ originates from the decomposition of organic matter or from nitrogen fertilizer; if C:N ratio of OM is too high, no $NH_4^+$ will be released unless fertilizer N is added for microbes to use.
    ii. Population of nitrifying organisms: The specific bacteria need to be present; injection of fumigants for disease/insect control will kill off these organisms.
    iii. Soil pH

(1) Active nitrification occurs in the pH range 5.0 to 8.5; nitrifying bacteria are inhibited below pH 4.6; thus, nitrification is a very active process within the normal agronomic pH range.
(2) Inhibition at low pH is generally due to aluminum solubility in mineral soils, which becomes toxic to the bacteria; organic soils may have very low pH, but nitrification proceeds because there is no aluminum present.

iv. Soil aeration
(1) Bacteria will not produce nitrates in the absence of oxygen in the soil; need a minimum of 2% oxygen in soil atmosphere to allow nitrification to proceed.
(2) Maximum nitrification occurs at soil atmosphere oxygen content of about 20%, which is about the same concentration of oxygen in the above-ground atmosphere.

v. Soil moisture: Nitrification proceeds most rapidly at soil moisture tensions near field capacity (a reading of 5 to10 on a tensiometer in a sandy Florida soil); too wet (near saturation) or too dry (near wilting point) of a condition will tend to decrease nitrification.

vi. Soil temperature
(1) Temperature is very influential in determining the nitrification rate, since it is a biological reaction.
(2) Over the range of 40 to 95 F, get a doubling of the nitrification rate for every 20 F increase; optimum temp is between 86 and 95 F.
(3) Below 40 F, nitrification almost stops because microbes shut down; need soil temperature to decrease below 40 F before nitrification will stop; soil temp at 6 inches below the soil surface almost never falls below 40 F in Florida, thus nitrification almost never stops.

g. Reactions of urea in soils
(1) When urea is applied to soil, it is acted on by the enzyme urease, which converts it to ammonium carbonate; this compound can then decompose to ammonium under conditions of high pH and high temperature:

Urea + Water + Urease $\rightarrow$ Ammonium carbonate

Ammonium carbonate $\rightarrow$ Ammonia gas + Carbon dioxide + Water

(2) Can lose up to 60 to 90% of the applied urea-N if it is surface-applied and not incorporated or irrigated into the soil.
(3) Factors influencing effectiveness of urea:
(a) Initial soil pH: Urea performance will be poor if initial pH is alkaline (will get volatilization of N); can still have volatilization in acid soils because microsite around a urea granule becomes alkaline due to formation of ammonium carbonate.
(b) CEC: Retention of ammonium is highest in soils with the highest CEC.
(c) Buffering capacity: Soils below pH 7 with the ability to resist changes in pH will hold more N from urea.
(d) Soil temperature: Urea hydrolysis is slow below 50 F.

(e) Soil moisture: Surface applications of urea are most efficient when soil moisture is near field capacity and the urea can be moved into the soil with water.

ii. Factors affecting leaching of N

(1) Amount and intensity of rainfall: Need to consider both together to determine partitioning of rainfall into infiltration and runoff (infiltration will definitely leach soluble fertilizers, runoff may or may not).

(2) Water content of soil at time of rain: The closer the soil is to saturation, the more runoff will occur.

(3) Conditions of soil surface: Mulches can eliminate infiltration almost totally, minimizing the leaching of fertilizers applied under them; BUT fluctuating water tables under the surface can leach out soluble nutrients from beneath plastic mulch; need to keep fluctuation to a minimum; also, mismanaged microirrigation systems can leach soluble nutrients.

(4) Profile permeability: Soils that are deep sands will move nitrogen through them rapidly with moving water; soils with clay deeper in the profile will leach less N even if the surface soil is sandy.

(5) Form of nitrogen

(a) Ammonium form will leach slower than nitrate form due to positive vs. negative charge.

(b) Urea will move with a water front because it has no charge.

(c) Most plant roots are in the top 6 to 8 inches of soil (especially in the south Florida flatwoods), thus it is important to try and keep the N from moving below this depth too quickly; there may be roots deeper in the profile, but they are often suberized and are not efficient at uptake of nutrients.

h. Denitrification

i. Loss of gaseous nitrogen to the atmosphere via a microbial respiration process; it involves the conversion of $NO_3^-$ to $N_2$ gas.

ii. Denitrifying bacteria are abundant in soil, but do not operate unless oxygen is **absent** in the soil.

iii. Factors influencing denitrification:

(a) Soil pH: Influences the form and rate of N loss; decreased denitrification below pH 5.

(b) Soil aeration: The soil oxygen supply is a major controlling factor in denitrification; if the soil atmosphere contains less than 2.0% $O_2$, or if the dissolved $O_2$ content of the soil water is less than 0.2 ppm, then denitrification takes place.

(c) Soil moisture: The soil water content has little direct effect on denitrification, but influences the oxygen diffusion rate in the soil ($O_2$ diffuses through water 10,000 times slower than through air); thus, increased soil water content decreases soil aeration, and denitrification will be favored at soil moisture levels near saturation.

(d) Denitrification usually occurs in water-logged soil; significant denitrification can occur in recently-saturated soil if anaerobic pockets develop, especially if the soil OM content is high.

(e) Can have denitrification at soil field capacity water content if there is high organic matter in or on the soil.

i. Methods of maximizing nitrogen use-efficiency of plants, or: How, considering all the ways that N can be lost from a Florida soil, can we get 70% or more of the applied N fertilizer into the plant?

   i. Can we use soil testing?

      (a) **Not** done **in Florida for nitrogen** because of its mobility; soil testing is best for <u>non-mobile</u> nutrients; high soil temperature, coarse-textured soil, lack of clay and OM, high rainfall, nitrification, leaching, denitrification all mean that N retention in low-organic matter sandy Florida soils is virtually zero.

      (b) Soil testing for N can be useful in those states with limited rainfall, e. g. in the western USA.

      (c) Best chance of finding some residual soil N in multiple cropping situations.

   ii. Use of slow-release fertilizers: Slow the rate of N release to the soil so the applied N cannot possibly move all at once.

   iii. Split applications of fertilizer ("spoon feeding"): N fertilizer applied in small doses prevents it all from leaching at one time.

   iv. Fertigation: A form of split application, but splits are much more frequent with smaller amounts of applied nutrients; e.g. for a newly-planted citrus grove, might split conventional dry fertilizer up into six applications, but fertilizer application with irrigation water may be split into 10 to 20 applications or more over the course of a year; research data has shown that for citrus, there is no advantage to doing this in terms of tree growth.

   v. Plastic mulch vegetable culture: A physical barrier that prevents almost all downward water movement from rainfall; fertilizer can still leach with a fluctuating water table or a mismanaged microirrigation system.

   vi. Timing of application. Examples:

      (1) Sugarcane at Belle Glade: Long term crop, grows relatively slowly except in summer; highly-organic soils supply enough N through mineralization such that no fertilizer N is needed.

      (2) Celery at Belle Glade: Much shorter-term crop than sugarcane; needs supplementary N fertilizer because mineralization rate is not high enough; (also needs high K application).

      (3) Field corn in Florida: Need to apply N before the crop reaches physiological stages when it needs it the most; the amount of N needed to produce 200 bu/acre is about 180 lbs/acre; corn at maturity has about 2 to 3% N in the plant tissue, and has taken up almost all N by the time tasseling occurs (65 to 80 days after emergence); if it does not have sufficient N in the tissues by this time, not enough grain will be produced to fill the ears; thus, need to apply N as a starter fertilizer, then the rest between 30 and 60 days after emergence; the root system is largest at tasseling, then declines.

      (4) Tomatoes in SW Florida: If using all dry fertilizer, do not have the opportunity to adjust timing schedule because all fertilizer must be put

under plastic mulch; however, if fertigating, can adjust schedule; plants do not grow at a constant rate throughout their life cycle, but grow faster earlier, then taper off; fertilizer application needs to follow this same pattern, and should probably be tapered off by 10 weeks after planting for a 14-week crop.

(5) Citrus in Florida: Need to apply N for vegetative growth and bloom in spring, and vegetative growth and fruit sizing in summer; can attempt to put on vegetative growth in late fall and winter with N application, but risk of freeze damage is always there (a dormant tree can withstand cold weather better than an actively-growing tree).