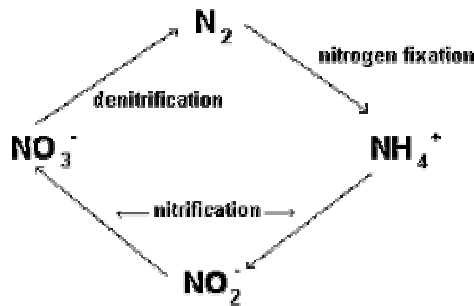


Biological Nitrogen Management

The Simple Nitrogen Cycle



The denitrification reaction is non-reversible
 The nitrification reactions are reversible
 The nitrogen fixation reaction is non-reversible

In soils, nitrogen forms important to agriculture are:

- N₂ – Atmospheric (unavailable) N
- NH₄ – Ammonia N
- NO₃ – Nitrate N
- NO₂ – Nitrite N
- Protein N
- Amide N

Soil microbiology regulates nitrogen in many ways, simple and complex. Biological nitrogen management is an important agricultural tool.

FOUR Major Processes

The major processes involved in biological nitrogen management are:

1. **Denitrification** - conversion of fixed nitrogen to dinitrogen gas or nitrous oxide.
2. **Nitrification** - conversion of ammonium ions to nitrite and nitrate
3. **Ammonification** – release of ammonium from organic compounds (mineralization).
4. **Biological Nitrogen Fixation** - conversion of dinitrogen gas to ammonium ions or fixed forms of nitrogen.

Nitrification & denitrification are very important concepts to have a general understanding of. We hope to more clearly explain the following summary:

NITRIFICATION	DENITRIFICATION
Obligate Aerobic	Facultative anaerobic
Chemoautotrophic	Heterotrophic
Requires CO ₂ for C source	Requires organic carbon for carbon source
Gain energy from inorganic reactions	Use organic carbon for energy source
"Inhibited" by excess carbon	Requires organic carbon source
Well defined taxonomic group	Variable group - many members from many different genera.
Reversible	Not reversible

Denitrification

Denitrification is one of the major sources of loss of N from soils. Without having a background in chemistry, the negative result is simple. Plant available nitrogen (N) in its most predominate uptake form, Nitrate (NO_3) is converted to atmospheric N (N_2) which is unavailable.

Available Nitrogen	NON-Available Nitrogen
Nitrate – NO_3	Atmospheric N – N_2
Best form for plant uptake. Only loss in low oxygen, anaerobic soils.	Already present above each acre of soil in huge volumes – 80% of atmosphere. No agricultural value!

In order for nitrogen to be lost by denitrification, two ingredients are needed;

- 1) *Anaerobic conditions* – tight, waterlogged soils, which causes a lack of oxygen. Excess moisture (rain & over irrigation) and lack of soil structure (low calcium) are often the cause.
- 2) *Decomposable Organic Matter & Nitrate* – Always present in soils, especially in commercial agriculture. Organic matter comes from the addition of manure & last years crop residues. Denitrification is increased in the presence of high amounts of nitrate-N, especially from commercial fertilizer sources.

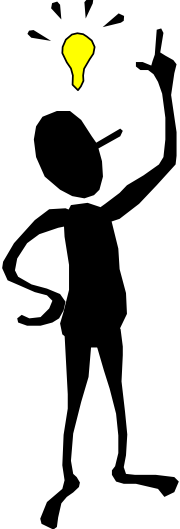
Soil microbes that are facultative anaerobes cause denitrification. These are microbes that can live (reproduce – grow) in both the presence and absence of OXYGEN. When oxygen is sufficient, these microbes will not “reduce” nitrate nitrogen, however, when soils become waterlogged or compacted, they use alternate sources of oxygen. Sources of “alternate oxygen” as follows and are also utilized in this order depending on the volume of each and length of the anaerobic conditions.

Nitrates – NO_3^{2-}
Manganic – MnO_2
Ferric compounds – $\text{Fe}(\text{OH})_3$
Sulfates – SO_4^{2-}
Sulfides – $\text{S}_2\text{O}_3^{2-}$

Many different kinds of facultative anaerobic bacteria can carry out this process; the most common are *Pseudomonas sp.*, *Achromobacter sp.*, *Paracoccus sp.*, *Moraxella sp.*, *Bacillus sp.*, *Alcaligenes sp.*, and *Gluconobacter sp.* **All are relatively common soil bacteria.** Therefore eliminating the problem by killing denitrifying bacteria is not a viable option.

These microbes are “heterotrophic” which means that they require organic compounds (sugars, amino acids, etc) for an energy source. These compounds come from the organic residues of crops, soil organic matter, microbial sources and also

COMPOST. Therefore, applying organic matter (compost) in large amounts *during anaerobic conditions* can have a negative effect on the availability of nitrogen.

	<p>Positive Action Management – Denitrification</p> <p>Spoon Feed N – Excess amounts of applied nitrate forms of nitrogen increase the possibility of nitrogen loss due to denitrification. This reaction is non-reversible, once it occurs it cannot be changed back, easily.</p> <p>Calcium – In soils with a CEC of 7.0 & higher, make sure the % of calcium on the colloid is a minimum of 65%. Low calcium causes poor soil structure, which results in low soil oxygen conditions for prolonged periods of time. Excess moisture (rain) is an uncontrollable factor, however, its negative impact can be reduced by good soil structure.</p>
---	---

Nitrification

The term *nitrification* refers to the conversion of ammonium to nitrate. Most soil-applied forms of ammonia are converted to nitrate before plant uptake. Ammonia can be also converted to organic N (amino acids) before plants take it up. Free ammonia-N will burn plant roots and leaves. **Therefore, nitrification is an important biological function in utilizing commercial fertilizers.**

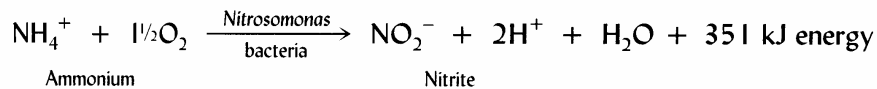
Simply put: NH₄ (ammonia) to NO₂ (nitrite) to NO₃ (nitrate)

This reaction is only possible by soil microbes! There are two major types of bacteria involved in this process; one for NH₄ to NO₂ and another for NO₂ to NO₃.

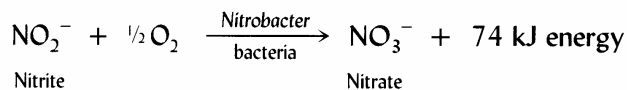
Ammonium (NH₄) oxidizer			
Nitrosomonas	Single straight rods, motile one or two sub-polar flagella or non-motile	Best Conditions for growth; 5 - 30C, pH 5.8 - 9.5	Found in; Soil, marine, freshwater
Nitrite (NO₂) oxidizer			
Nitrobacter	Short rods, motile with a single polar flagellum or non-motile	Best Conditions for growth: 5 - 40C, pH 5.7 - 10.2	Found in: Soil, marine, freshwater

These nitrifying bacteria obtain their energy from ammonium oxidation rather than from organic matter, as in denitrification. The formulas below illustrate the components of the nitrification process.

Step 1

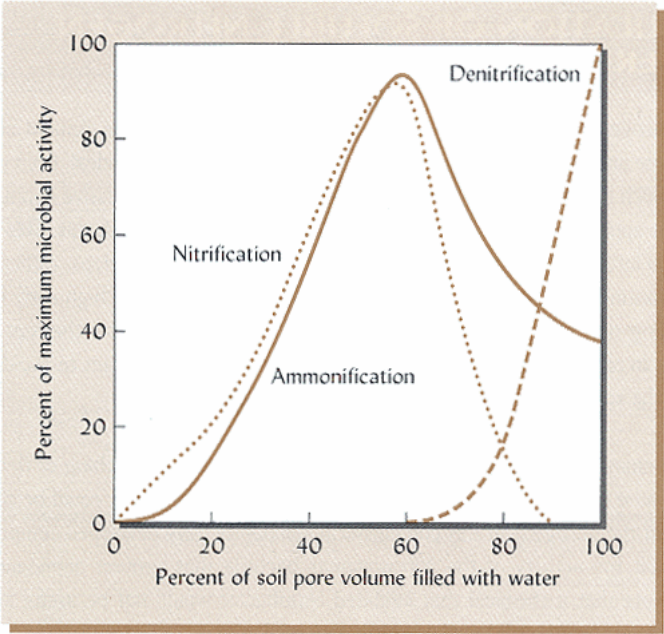




Step 2



Ammonium fertilizer by these formulas gives energy for microbial growth and increases soil acidity. Notice, however, that each reaction requires O₂, oxygen; therefore nitrification can only take place in aerobic soil conditions.

These nitrifying bacteria (Nitrosomonas & Nitrobacter) are much more sensitive to environmental conditions than the broad groups of microbes responsible for the release of ammonia from organic nitrogen sources. As follows are some important factors in the soil's ability to convert ammonia-N to nitrate-N;

Effect of Water	
	<p>“The Nature & Properties of Soils”, 11th Ed., Brady & Weil, pg 409</p>
Ammonia Level NH₄	Nitrification can only take place if ammonia is present. Factors such as a high C/N ratio of plant residues or added organic matter

	<p>will tie up NH_4 and prevent nitrification.</p> <p>High concentrations of urea or anhydrous ammonia, especially in alkaline soils, may result in too much free ammonia that suppresses <i>Nitrobacter</i> only (step 2 of nitrification). This results in the accumulation of nitrite (NO_2) N, which is toxic to many plants.</p>
<p>Aeration</p> 	<p>As stated, these nitrifying organisms are aerobic bacteria that require oxygen. If oxygen is too low, other bacteria cause denitrification. Good soil aeration and drainage is required.</p> <p>In minimum tillage operations, nitrification is lower due to less aeration, especially in the first few years of a minimum tillage program. Therefore, it is advisable to use more nitrate fertilizer under these conditions.</p>
<p>Carbon - Food</p> 	<p>These microbes (nitrifiers) use CO_2 and bicarbonate ions (hard water) as sources of carbon to build their cellular components. Being autotrophs, they do not require organic matter as either a carbon source or an energy source.</p> <p>Therefore, nitrifying bacteria are effective even in low organic matter soils.</p>
<p>Cations & pH</p>	<p>Nitrification proceeds most rapidly when there is an abundance of exchangeable cations (CEC – Ca, Mg, K). In low mineral, acid soils, nitrification is much slower. Nitrifying microbes are also somewhat sensitive to low pH, but lower pH soils with adequate minerals still have reasonable nitrification action.</p> <p>Nitrate Fertilizers on low pH, low CEC soils are likely most effective; whereas urea or ammonium based fertilizers will take longer to become nitrates. In acid soils NO_3 comes more rapidly from organic N than from chemical fertilizer NH_4. This is because the increase in pH during the decomposition of organic materials due to the formation of ammonia (ammonification) allows microsites of higher pH to form and with higher nitrification activity in the acid soils with organic amendments.</p>

Ammonification – Organic-N

At any time, most of soil nitrogen (95% +) is contained in soil organic matter, which protects it from loss, but leaves it readily unavailable to plants. With increasing environmental pressures on nitrogen applications and the growing interest in “organic” fertilizers, a general understanding of how organic-N is converted to plant food is necessary.

Organic-N in soil organic matter is present as amine groups ($R+NH_2$), largely in proteins or humic acids. Protein forms of nitrogen are first broken down by soil microbes into simpler amino acid compounds, then the amine groups are hydrolyzed and the nitrogen is released as ammonia-N (NH_4).

The conversion of organic-N to inorganic forms (NH_4 & NO_3) is called mineralization or ammonification.

Not only is organic-N found in soil organic matter but also from decaying plant and animal residues (proteins, nucleic acids, amino sugars, urea) that is converted to ammonia (NH_3) and ammonium (NH_4^+). The resultant ammonia can be converted back to organic N (immobilization) where it is taken up by microbes and plants (assimilated), or nitrified to nitrate (NO_3).

Urea

The application of urea utilizes the biological function of mineralization to convert urea to ammonia to nitrate. More technically, the reaction consists of several steps as follows:

- $CO(NH_2)_2 + HOH + UREASE \longrightarrow$
(Urea + water + urease enzyme)
- $H_2NCOOHNH_4 \longrightarrow 2NH_3 + CO_2$
(Ammonium carbamate to ammonia & carbon dioxide)
- $2NH_3 + HOH \longrightarrow 2NH_4OH$
(Ammonia + water = Ammonium Fertilizer)

Mineralization of N, a viable source?

Many studies have shown that 1.5% to 3.5% of the organic nitrogen of soil is mineralized (converted to ammonia-N) each year. (5% of a soil tests OM reading is considered as potential N.) The rate of mineralization depends on temperature, moisture and aeration status of the soil. In low organic matter soils, 3.5% of a little is still not an effective amount of nitrogen from today's agricultural needs. For example,

1% organic matter = 15 to 35 units of N
2% organic matter = 30 to 70 units of N
4% organic matter = 60 to 140 units of N

However, in high organic matter soils, organic N is a viable source of nitrogen. Ironically, **even when high amounts of fertilizer are used in high organic matter soils, most of the nitrogen taken up by plants comes from the nitrogen reserve in organic matter.** This is due to the fact that more applied nitrogen is immobilized (opposite of mineralized) in the soil organic matter.

Ammonia-N

Ammonia is the first product of organic matter breakdown, urea breakdown and is a common form in most fertilizers. Therefore it is important to understand the five possible “fates” of ammonia-N.

- Immobilization by microorganisms (C:N ratios)
- Removal by plant uptake
- Fixed in clay (CEC)
- Volatilized – converted to ammonia gas
- Nitrified – converted to nitrate

Carbon : Nitrogen Ratio

The C/N ratio and biological nitrogen management is an important aspect to understand in the overall management of nitrogen; **especially in organic farming practices.**

The carbon : nitrogen ratio (C:N) of the added organic matter (nitrogen source) is used as an indicator of which step in the nitrogen cycle occurs next.

C/N ratio of <20:1	C/N ratio of 20-30:1	C/N ratio >30:1
Net gain of NH_4^+ and NO_3^-	Neither gain nor loss of N	Net uptake of NH_4^+ and NO_3^-
Ratios less than 20:1 mean that excess N is present in the organic matter and nitrification proceeds (with a net gain of N).	With ratios between 20:1 and 30:1, nitrification and immobilization rates are in equilibrium (equal) and there is no net gain or loss of N.	With a ratio greater than 30, N is limited and net immobilization occurs with uptake (or loss) of N from the active N cycle.

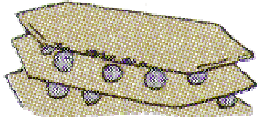
When N is limited at high C:N ratios, nitrogen-fixation by free-living nitrogen fixers is stimulated. This shows the need for **balance!** Applied fall residues should be higher than a C/N ratio of 30:1; this will result in 2 positives factors, (1) free nitrogen is “tied up” (not leached) and (2) biological nitrogen fixation is stimulated for a further increase in N. On the other hand, applications of organic matter before planting should have a C/N ratio of 20:1 or less. The lower, the better.

The following table illustrates C/N ratios of common materials. This is the most important information to have when putting on any form of organic matter.

Material	C:N Ratio	Material	C:N Ratio
Microbial tissues	6-12	Wheat Straw	80
Sewage sludge	5-14	Corn Stover	57
Soil humus	10-12	Rye Cover (seed stage)	37
Mature Alfalfa Hay	25	Forest wastes	150-500
Young Alfalfa Hay	13	Hardwood Sawdust	400
Barnyard manure (rotted)	20	Spruce Sawdust	600

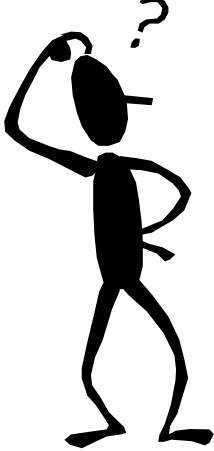
The Clay Concept

Ammonia-N (NH_4) is about the same “size” as potassium ions (K). Therefore, ammonia can be trapped in certain clays and not be available to most plants. **Understanding a little of clay type is important, especially when rotating from a crop with a high CEC root system like alfalfa to a crop with less CEC like potatoes.**

 <p>Fixed in 2:1 clays.</p>	<p>Vermiculite has the greatest capacity to fix both ammonium and potassium ions in an unavailable state. Fine-grained micas and some smectites also have this ability.</p> <p>This concept becomes more important in organic fertilizing practices.</p>
---	--

Biological Nitrogen Fixation

This is possibly the most important biochemical reaction for life on earth. Through this process certain organisms convert inert gas (N₂) to nitrogen-containing compounds that become available through the nitrogen cycle.

Is the amount of Nitrogen “fixed” by Biology (life-forms) Significant?		
		Metric Tonnes/year
	Legume Crops	35,000,000
	Non-legume Crops	9,000,000
	Meadows & Grassland	45,000,000
	Forest & Woodland	40,000,000
	Other Vegetated Land	10,000,000
	Total Land	139,000,000
	Sea	36,000,000
	Total Biological	175,000,000
	Lightening	8,000,000
	Fertilizer Industry	77,000,000
Grand Total	260,000,000	

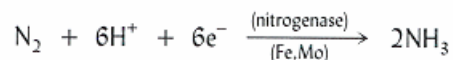
There are four methods by which microorganisms can fix nitrogen from the air and process it into a plant available form.

- **Symbiotic Nitrogen Fixation with Legumes**
- **Symbiotic Nitrogen Fixation with NON-Legumes**
- **Symbiotic Nitrogen Fixation without Nodules**
- **NON-Symbiotic Nitrogen Fixation**

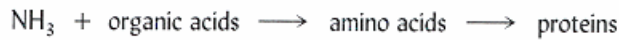
Three of the four ways are “Symbiotic”, which means “mutually beneficial relationship”.

These are also the highest producers of free nitrogen. Why? The reduction of atmospheric N (N₂), requires a great deal of energy to break the chemical bonds that hold N₂ together. Therefore, the process is **greatly enhanced by the energy received from plants**, which is derived from photosynthesis.

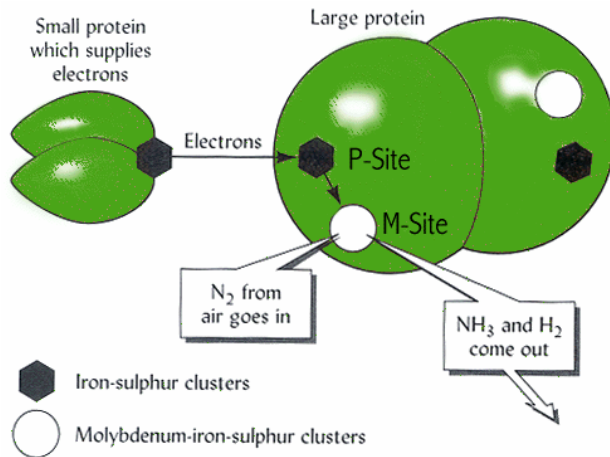
Regardless of the type of nitrogen fixation, the key in this activity is the enzyme, nitrogenase. This enzyme plays the important role of “splitting” gaseous nitrogen (dinitrogen or N₂) to ammonia gas as follows:



The ammonia is then combined with organic acids to form amino acids, which are the base of protein that is the form of natural nitrogen storage. In nature, this “natural N” then goes through the cycle of “ammonification” as explained earlier to become available to plants.



Nitrogenase is worthy of further examination to better understand its role in the nitrogen cycle and its great importance to mankind.



The Nitrogenase enzyme complex consists of 2 proteins. The smaller protein supplies the electrons, while the larger actually converts the nitrogen.

Notice the importance of Mo, S, and Fe in this reaction.

No matter what form of biological N fixation, this enzyme starts the reaction by converting the unavailable, inert N gas in the atmosphere to viable N forms for plants!

Why are nodules supposed to be pink?

The enzyme, nitrogenase, is destroyed by free oxygen (O₂), so the organisms that fix nitrogen must protect the enzyme from exposure to oxygen. In legumes, one means of protecting the enzyme is by the formation of *leghemoglobin*. This molecule is virtually that same as the *hemoglobin* that gives human blood its red color when oxygenated. This *leghemoglobin* binds with the oxygen (turns red) and protects the nitrogenase. The oxygen is available for respiration in other parts of the nodule tissue.

Why doesn't a legume fix so much N that it becomes toxic?

This reaction, like so many in nature, is “end-product inhibited”. The end products of biological N fixation, NH₄ & NO₃, will inhibit and shutdown the process. Applications of ammonia or nitrate fertilizers are known to suppress nitrogen fixation in legumes.

What nutrients are important in “feeding” this system?

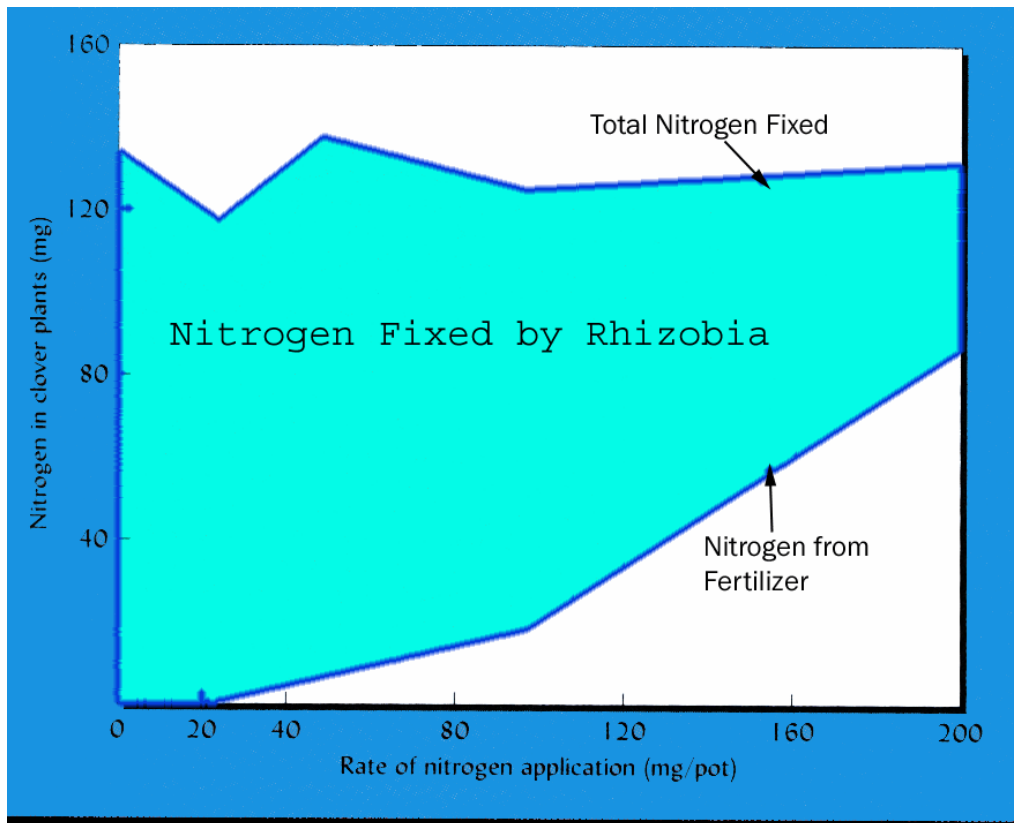
As stated above, feeding biological N fixation microbes with nitrogen is not good. However, the system has a high requirement for molybdenum (Mo), iron (Fe), phosphorus (P) and sulfur (S). Of these elements, it is likely that Mo is likely the most overlooked in most soils.

Symbiotic N Fixation with Legumes

This process results from a mutually beneficial relationship of plants and bacteria. The major types of bacteria are:

- | Rhizobium | Bradyrhizobium |
|---|--|
| <ul style="list-style-type: none">• Fast Growing• “Acid” forming• Does not do well in low pH soils | <ul style="list-style-type: none">• Slower growth• Non-Acid Forming• Does better in low pH soils |

With increasing costs of energy, planting rotational crops for increasing soil nitrogen reserves is a cost effective alternative. Unfortunately, a general mismanagement and misunderstanding of soil microbiology leads a lack of fixed nitrogen. Like many other biological systems in the soil, N-fixation only occurs when there is a lack of nitrogen in the soil.



Notice that the higher the amount of nitrogen added, the lower the amount is fixed by the rhizobium bacteria. Total N is about the same, because the microorganisms responsible for the fixing of N are like many other biological systems, controlled by the end product; in this case nitrogen.



Did you know?

It should also be pointed out that many high protein crops (alfalfa, beans, peas, etc.) are legumes in the first place, because they need high amounts of nitrogen for seed development. Therefore, allowing seed development (and harvesting the seed) in a bean or pea crop does not necessarily lead to an increase in soil N, because the crop utilizes the N. Therefore, when using an N-fixing crop for soil N building, it should be worked into the soil at bloom.

Another very important (and overlooked) impact on the net amount of nitrogen fixed is that **increased photosynthates (sugars) from the plant result in high amounts of fixed nitrogen**. It is common to consider a legume rotation as a “low input” crop and very little nutritional emphasis is put in growing it. Like any other plant, a low net photosynthesis results in low “extra – energy” for extra root development and feeding of beneficial organisms for N-fixation.

Fate of Legume-Fixed Nitrogen

The nitrogen fixed in the root nodules is distributed into the soil environment in three ways, all of which are important to understand and incorporate into a complete fertilizer program, especially in low-N input situations such as organics.

N-Fate #1 – The nodule fixed nitrogen is of course used by the host plant, as stated most legume crops are high protein crops, therefore the need for additional nitrogen availability. However, remember that unless the high protein portion of the plant is returned to the soil, the legume rotation will not supply as much N as anticipated.

N-Fate #2 – Some of the fixed nitrogen becomes available to non-fixing plants grown in association with the legume. This is an overlooked concept of crop management, especially considering that growing compatible crops could not only result in N-fixation, but also other important root exudes; such a plant growth factors, disease suppression and even weed suppression via competition of the secondary crop.

In some cases, direct transfer of the nitrogen from the legume to the non-fixing plant occurs via the mycorrhizal hyphae connecting the two plants, however most of the nitrogen transfer is thought to occur from “leaching” root exudes, sloughed off root cells and nodule tissues.

N-Fate #3 – The third distinct and important pathway for legume fixed nitrogen is immobilization by soil microorganisms and eventual incorporation into soil organic matter. This is covered in a following section, but it should be pointed

out that soil organic matter (SOM) cannot be built and increased without some type of legume rotation.

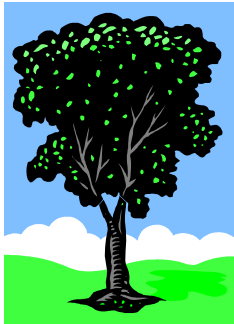
Symbiotic Nitrogen Fixation *with* Nodules

Many species of nitrogen fixing NON-Legumes are known to develop nodules and accommodate some fixation of nitrogen. In a good bio-fertilizer program, nodules are often seen forming on potatoes, which is uncommon enough to result in great unbelief even in circles of potato “experts”.

The nodules form when the root hairs of these plants are “invaded” by the soil actinomycetes, *Frankia* species.

These associations are found in several important groups of angiosperms (flowering plants). In North America, these include Betulaceae (alder species), Rhamnaceae (buckthorn species) and Elaeagnaceae (olive family).

Although many of these species are not used by commercial agriculture, their nitrogen fixing capability in pounds per year on a worldwide basis is considered HIGHER than agricultural legume fixation. This concept of high nitrogen fixing plants in forest systems is important for those who work in commercial agriculture, especially in regards to the ground water nitrogen issues.



In Mount Vernon, Washington, nitrate levels in rivers and streams were considered too high and of course the farmer was immediately implicated. However, as the nitrogen levels in the water were monitored further up stream, it was noted that levels of nitrogen in the water was HIGHER above the agricultural ground. The nitrate levels in the water actually DROPPED going through the farmed fields. The source of N – Alder growing in up stream natural forests!

N-fixation in forest systems is critical for reforestation, in that various nodule-forming non-legumes fix needed nitrogen in low fertility soil. This nitrogen is incorporated back into the system and over years a new forest flourishes.

Symbiotic Nitrogen Fixation *without* Nodules

The most significant non-nodule nitrogen fixing plant/microbe systems are those involving blue-green algae (cyanobacteria). However, if you observe blue-green algae in nature, you will find it growing on surfaces and areas that are constantly wet. Therefore, in agricultural situations (especially arid areas and under drip), there is not the surface moisture to sustain this organism. Cyanobacteria grow on surfaces because they use the sun's energy for growth, therefore “green” caused by photosynthesis.

The agricultural situations in which cyanobacteria can become a major contributor for nitrogen supply is in rice paddies, especially those in tropical and semitropical areas. The azolla/anabaena complex is thought to contribute 150 to 300 lbs/acre of nitrogen each year.

The symbiotic nitrogen fixation system commonly referred to as beneficial for commercial agriculture is quite common, but low in nitrogen fixing capability (5 to 30 lbs/acre per year). This nitrogen-fixing phenomenon IS important and found in the rhizosphere of many grasses and other non-legume plants.

The bacteria that are commonly promoted in agricultural circles and literature for this symbiotic non-nodule nitrogen fixation are *Azospirillum* and *Azotobacter*. Volumes of literature are published on these organisms, especially in Russia and India where these products are commonly used, even today. There are two important facts to know about these organisms in order to apply them in a practical agricultural system.

Growth Factors or Nitrogen?

The earlier literature promotes the use of these bacteria as a source of nitrogen fixation only. It is true that they fix reasonable amounts of nitrogen in a very efficient area of the plant (rhizosphere). There is also no doubt that in low input and low production areas, 30 units of nitrogen per acre can contribute to yield. However, in many demonstrations the effect of the application of these organisms FAR outweighed the effect of nitrogen only.

Why do Azo-inoculated Plants Grow so Well?

In recent years, it has been shown that numerous species of *Azospirillum* and *Azotobacter* are effective producers of Plant Growth Hormones. These include auxins, gibberellins and cytokine, all beneficial rooting and plant growth promoting compounds. In another publication dealing with biologically produced plant growth hormones, we will deal with this subject in greater detail.

Conclusion – *Azospirillum* and *Azotobacter* products are somewhat, but limited, producers of nitrogen, but effective promoters of overall plant growth, root growth and increased nutrient uptake ability due to the production of plant growth substances.

Non-Symbiotic Nitrogen Fixation

If you have read this carefully, you will remember that biological nitrogen fixation from atmospheric N is a process that requires a lot of ENERGY. Therefore, the most effective nitrogen fixing combinations are a plant and a group of specific microorganisms. These microorganisms get their ENERGY from the plant and then supply nitrogen (and many other valuable compounds) back to the plant. Therefore, this relationship is term “SYMBIOTIC.”

There are, however, certain microorganisms in the soil environment that can fix nitrogen without a plant; they are non-symbiotic or “free-living” nitrogen fixers. However, nothing is free, so an energy source is required. This comes in two forms:

- Fixation by Heterotrophs
- Fixation by Autotrophs

Heterotrophs – Microorganisms that get energy from a carbon source

Autotrophs - Microorganisms that get energy from an external source (sunlight)

The Heterotrophs found in soils depends on soil type. *Azotobacters* are commonly found in temperate zone soils, although they need a lot of organic matter to function properly. *Beijerinckia* species are found in tropical soils. Certain anaerobic bacteria of the genus *Clostridium* are also able to fix nitrogen.

These microbes will fix nitrogen in soils where “pockets” of low oxygen exist when the soils are “in good tilth”. Aerobic and anaerobic bacteria work side by side in many well-drained soils, producing nitrogen from the “trapped air”.

The amount of nitrogen fixed by Heterotrophs varies greatly depending on pH, soil N levels and the sources of organic matter that is available. Because of their limited energy, the amount of actual nitrogen though to be fixed by these organisms is only from 5-20 lbs/acre per year.

The Autotrophs on the other hand, derive energy from the sun, certain photosynthetic bacteria and cyanobacteria. In the presence of light these types of bacteria are able to fix carbon dioxide and nitrogen simultaneously. HOWEVER, these microbes need a high surface moisture level to survive, therefore are once again difficult to utilize in high production commercial agriculture, especially in arid climates.

The cyanobacteria do fix significant quantities of nitrogen in wetland areas and in certain rice paddies. Some nitrogen fixation in soils is found, but is limited.

Nitrogen Fixation Amounts

Crop or Plant	Associated Organism	Typical Levels of N-Fixation in POUNDS/Acre/year
Symbiotic		
Legumes (Nodulated)		
Ipil Ipil Tree		100-500
Locust Tree		75-200
Alfalfa		150-250
Clover	Bacteria (<i>Rhizobium</i>)	100-150
Lupine		50-100
Vetch		50-150
Bean		30-50
Cowpea		50-100
Peanut		40-80
Soybean	Bacteria (<i>Bradyrhizobium</i>)	50-150
Pigeon Pea		150-280
Kudzu		100-140
Non-legumes (Nodulated)		
Alder Trees	Actinomycetes (<i>Frankia</i> sp)	50-150
Species of Gunnera	Cyanobacteria (<i>Nostoc</i>)	10-20
NON-legumes (non-nodulated)		
Pangola grass	Bacteria (<i>Azospirillum</i>)	5-30
Bahia grass	Bacteria (<i>Azotobacter</i>)	5-30
Azolla	Cyanobacteria (<i>Anabena</i>)	150-300
NON-Symbiotic		
	Bacteria (<i>Azotobacter</i> & <i>Clostridium</i> species)	5-20
	Cyanobacteria (blue-green algae)	10-50

Data derived from *The Nature & Properties of Soils*, Brady & Weil, 1996

Practical Application – Notice the various types of nodulated legumes and their associated type of Rhizobium, which cover crop should you use in which soil?