Nitrogen Fixation

Nitrogen (N) is not a scarce element on earth but the most abundant forms (N_2 gas in the atmosphere and N fixed in the earth's crust and sediments) are not directly available for plants. As a result, N is often a limiting factor in agricultural production, especially for corn and hay crops that take up large amounts of N. The N_2 in the atmosphere can become plant available through symbiosis (a mutually beneficial relationship) of microorganisms and legumes. In this fact sheet, we discuss the basic principles of N fixation and management options for enhancing N fixation.

Nitrogen Fixation

Nitrogen fixation refers to the conversion of atmospheric N_2 to ammonia and then to N-containing organic compounds that can become available to all forms of life. Nitrogen can be fixed by non-biological processes, such as lightning or the Haber-Bosch process used to produce fertilizer products such as urea. However, biological N fixation is the most common N fixation process. Globally, an estimated 193 x 10^6 tons of N is fixed through biological N fixation each year (Table 1).

Table 1: Estimated amounts of nitrogen fixed annually from different biological and non-biological sources (Data source: The Nature and Properties of Soils, 2002).

Source of N fixation	Nitrogen fixed (10^6 tons per year)
Land	153
Legume	39
Non-legume	10
Others	104
Sea	40
Total biological	193
Lightning	9
Industry	85
Total non-biological	94

Biological N Fixation

Nitrogenase is an essential enzyme for biological N fixation. This N fixation process requires a lot of energy (adenosine triphosphate or ATP) to break the triple bond that exists between N atoms in N_2:

$$N_2 + 8H^+ + 16\ Mg\ ATP \rightarrow (nitrogenase)$$
$$\rightarrow 2NH_3 + 2H^+ + 16\ Mg\ ADP + 16\ Pi$$

As mentioned, large amounts of N can be fixed through symbiosis of microorganisms and legumes. In this process, the plants generate the energy (through photosynthesis) and the microorganisms utilize this energy to fix N_2.

Biological N fixation is carried out by a range of bacteria that are either free living, or in loose associations with plants, or in symbiotic associations with plants (*Rhizobium* and *Actinomycetes*). In our climate, legume-bacteria symbiosis is the major form of N fixation that provides N to agricultural crops.

The Legume-Bacteria Symbiosis

Rhizobium and *Bradyrhizobium bacteria* are involved in the symbiotic fixation with legumes. They infect root hairs and cortical cells and ultimately form root nodules that are sites of N fixation (Figure 1). A nodule that is pink or reddish in color is actively fixing N.

Once root nodules are established, bacteria start the N fixation process and excrete ammonia to plant cells. The N fixed in root nodules can be (1) used directly by the host plants, (2) become available to other non-N-fixing plants, or (3) become immobilized or leach from the root zone.

Figure 1: *Rhizobium* inoculated seedlings of birdsfoot trefoil show effective nodules for N fixation (Picture courtesy of Ken Evans, Iowa State Press, Ames, IA, 2003).

Estimated N Fixation by Field Crops

The amount of N fixed by legumes can vary greatly. Typical ranges are given in Table 2.

Table 2: Typical levels of N fixation (Data source: The Nature and Properties of Soils, 2002).

	N fixation
	Lbs per acre per year
Alfalfa	130-220
Clover	90-130
Vetch	45-130
Dry beans	25-45
Soybean	45-130

Management decisions related to inoculation of seeds, soil fertility management, and crop rotation can greatly impact the actual amount of N fixed.

Inoculating Legume Seeds

Where a certain legume has been grown for several years, the appropriate species of bacteria might already be present. However, the natural bacteria population in most soils might not be sufficient and it is generally recommended to use inoculated seed for improved N fixation. Solid, powder type inoculants can be applied to legume seeds or directly to the soil.

Each bacterial species infects only certain species of legumes, so it is important to select the proper species of bacteria. For example, *Rhizobium trifoli* infects most clovers but not sweet clover. Read the package label carefully to select the proper inoculant.

Legumes in Crop Rotations

Legumes are often grown in rotation with corn or as cover crops because of their ability to fix N. Legume sods will supply large amounts of N to the following corn crop (first year corn) eliminating the need for additional N for corn following alfalfa. However, grass sods also can supply enough N for first year corn (see Agronomy Fact Sheet #21). Medium red clover is the more common legume cover crop in New York. If overseeded in the previous summer (until June), it can provide up to 70-100 lbs N/acre N to a following crop. However, if seeded after corn harvest, N supply will be much lower.

Management Factors Impacting N Fixation

The following conditions will affect the amount of N fixed by legume-bacteria symbiosis:

- Manure or fertilizer N application; because N fixation requires a lot of energy, the amount of N fixed through biological N fixation will be much less when the soil contains inorganic N from other sources.
- Low soil fertility status; deficiencies in especially Mo, Fe, P, Mg, and S will result in reduced N fixation as these elements are part of the nitrogenase complex that allows for N fixation to take place.
- Low pH; a pH of lower than 6.7 will greatly reduce N fixation.
- Soil temperature; soil temperature from 75 to 86ºF is optimum for most legumes and rhizobia. Effective N fixation will be inhibited below 50ºF.

Good management skills are required to grow healthy legume and bacteria communities and to maximize the rate of N fixation. Especially optimal pH management (desired pH for alfalfa is 7.0) is important to ensure N fixation. But, if soil conditions are optimal, legumes can supply a large portion of their N needs through N fixation, eliminating the need for fertilizer N.

Additional Resources

- Cornell University Agronomy Fact Sheet #2 (Nitrogen Basics – The Nitrogen Cycle), #11 (Nitrogen Leaching Index), and #21 (Nitrogen Needs of 1st Year Corn) http://msp.css.cornell.edu/publications/factsheets.asp.
- Legume Seed Inoculants webpage: http://www.ext.colostate.edu/Pubs/crops/00305.html.
- NEON Crop rotation manual + spreadsheets webpage: http://www.neon.cornell.edu/croprotation/.

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For more information

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Chie Miyamoto, Quirine Ketterings, Jerry Cherney, Tom Kilcer

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