Effects of Phosphorus on Nitrogen Fixation

Phosphorus is an essential ingredient for *Rhizobium* bacteria to convert atmospheric N (N_2) into an ammonium (NH_4) form useable by plants. *Rhizobium* are able to synthesize the enzyme nitrogenase which catalyzes the conversion of N_2 to two molecules of ammonia (NH_3). The pink color, typical of healthy and effective nodules, is due to the presence of a protein called leghemoglobin. This special protein contains both iron (Fe) and molybedenum (Mo) and is responsible for binding oxygen. This creates a low oxygen environment within the nodule which allows *Rhizobium* bacteria to live and to fix N_2. Phosphorus becomes involved as an energy source when 16 molecules of adenosine triphosphate (ATP) are converted to adenosine diphosphate (ADP) as each molecule of N_2 is reduced to NH_3. The ATP is generated during the process of photosynthesis, when light energy is transformed and stored in the form of ATP for later use by the plant.

Phosphorus (P) enhances the symbiotic nitrogen (N) fixation process in legume crops. Generally, legumes require more P than grasses for root development and energy driven processes.

Phosphorus influences nodule development through its basic functions in plants as an energy source. Inadequate P restricts root growth, the process of photosynthesis, translocation of sugars, and other such functions which directly or indirectly influence N fixation by legume plants. The fundamental practice of liming acid soils to the pH range of 6.5 to 7.0 is significant to the relationship between P and the symbiotic N fixation process. It improves the availability of soil P for plant absorption and creates a soil environment more favorable for beneficial bacteria such as the different strains of *Rhizobium*.

Research documents the influence of P on nodule development and the N fixation process by legumes. For example, when P was applied to alfalfa, nodules developed earlier. On high P soils, nodules were first noted on alfalfa roots 11 days after seeding. Nodules developed about three days later on low P soils. As shown in **Table 1**, nodule number, volume, and dry weight can be increased by treating P deficient soils with fertilizer P. The nodules became pink earlier, developed more quickly, and became active sooner in response to P fertilization.

Phosphorus Increases Yield and Nitrogen Content in Legumes

Other studies reveal that P applied to low P soils can increase the percent N in legumes and result in greater dry matter yields (**Table 2**). This is believed to be one of the reasons why legumes, dependent on symbiotic N, have a higher P requirement than grasses which depend on fertilizer N.

Facts Related to Phosphorus and Nitrogen Fixation

- Nodules develop when a root hair (growing out from active roots) is infected by Rhizobium bacteria. Plant tissue develops around the infected area, forming the nodule and site of bacterial growth and the fixation of elemental N from the soil

TABLE 1. Effect of P on nodule development of alfalfa 26 days after seeding.

P_2O_5 rate, lb/A	Measurements of nodule development		
	Dry weight	Weight/nodule	N content
	mg		
0	0.13	13	0.01
125	1.06	28	0.07
255	3.31	60	0.15

atmosphere. Any restriction to root development, a shortage of essential nutrients such as P or Mo, an excessively acid soil, or a decline in photosynthesis can restrict nodulation and N fixation.

TABLE 2. Effect of P fertilization on the yield and N content of legumes.

Crop	Yield, lb/A		Tissue N, %	
	No P	P	No P	P
Sub. clover	2,400	3,400	2.5	2.8
Alfalfa	4,980	10,710	3.8	4.3

- The N fixation process requires a readily available source of energy for bacterial growth and the transformation of N_2 into NH_3. Photosynthesis generates the high energy sugars. Phosphorus provides the mechanism for energy storage in the form of ATP and the transfer of that energy source to fuel vital plant functions such as N fixation.
- The translocation of photosynthate from leaves to roots and the movement of N-containing compounds from nodules to other plant parts are vital to an efficient symbiotic system. Phosphorus is an integral part of the compounds needed to drive the system.
- The concentration of P in the tissue of healthy, active nodules is often two to three times higher than in the roots on which they are formed. Legumes need a readily available supply of P from the soil. It serves during critical growth periods such as seedling root development and over a more prolonged period for optimum photosynthesis.

Summary

Phosphorus plays a key role in the symbiotic N fixation process by:

- Increasing top and root growth (restricted root development reduces the ability of that plant to fix N)
- Decreasing the time needed for developing nodules to become active and of benefit to the host legume
- Increasing the number and size of nodules and the amount of N assimilated per unit weight of nodules
- Increasing the percent and total amount of N in the harvested portion of the host legume
- Improving the density of *Rhizobia* bacteria in the soil surrounding the root BC

Phosphorus encourages root growth and N fixation in legumes. These soybean root nodules contain N-fixing bacteria.