Soybean Soil Fertility

SF-1164, February 1999
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Soybeans need the 13 mineral nutrients, nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), zinc (Zn), manganese (Mn), copper (Cu), iron (Fe), boron (B), chloride (Cl) and molybdenum (Mo). Of these, North Dakota soils provide adequate amounts except for nitrogen, phosphorus, potassium, sulfur and iron. Rare instances of manganese and zinc deficiency have also been seen, but their occurrence is of only minor importance.

Nitrogen

Although the atmosphere is 78% nitrogen gas, plants cannot use it directly. Plants can use only ammonium-N, or nitrate-N. Soybean is a legume and should normally provide itself N through a symbiotic relationship with N-fixing bacteria of the species *Bradyrhizobium japonicum*. In this symbiotic relationship, carbohydrates and minerals are supplied to the bacteria by the plant , and the bacteria transform nitrogen gas from the atmosphere into ammonium-N for use by the plant.

The process of soybean infection by N-fixing bacteria and symbiotic N fixation is a complex process between the bacteria and the plant. The right species of N-fixing bacteria must be present in the soil, either through residual populations from inoculation of previous soybean crops or through inoculation of the seed or seed zone at planting.

N-fixing bacteria are attracted to the roots by chemical signals from the soybean root. Once in contact with the root hairs, a root compound binds the bacteria to the root hair cell wall. The bacteria releases a chemical that causes curling and cracking of the root hair, allowing the bacteria to invade the interior of the cells, and begins to change the plant cell structure to form nodules. The bacteria live in compartments, up to 10,000 in a nodule, called bacteroids. Each of the bacteroids are bathed in nutrients from the host plant, and the bacteroid takes N_2 gas from the soil air and converts it to ammonium-N using the enzyme nitrogenase, which consists of one Fe-Mo (iron-molybdenum) based protein and two Fe (iron)-based proteins. In this region, iron deficiencies can therefore interfere with nitrogen fixation. Molybdenum deficiencies can also stop N fixation but are not known to occur in North Dakota.

Figure 1. Nodules on soybean roots. (20KB color photo)

N-fixation by nitrogenase must take place in an environment without oxygen. However, bacteria and roots have to respire, which requires oxygen. To get around this problem, nodules use the same strategy humans do in oxygen transfer in the blood. The transfer compound is leghemoglobin (closely related to our hemoglobin). It results in a pink-red color of active nodule interiors. Soybean plants with an abundance of nodules with pink-red interiors are actively fixing N.

N-fixation is very energy intensive and does not come without cost to the soybean. Ten pounds of carbohydrate are needed for each pound of N produced.

Some researchers refer to carbohydrate movement in soybeans as the "source-sink" relationship. Early in the growing season, the source of carbohydrates is leaves and the main sink is the nodule, in addition to the growing points of the plant. After flowering, the activity of nodules decreases rapidly and eventually stops due to lack of nutrient supply. The plant changes the sink from the nodules to the seed production. Nodules disintegrate and bacteria are released once again into the soil.

There are environmental conditions that limit N-fixation.

- **Cold and heat.** A temperature of 60-80 degrees is ideal, while levels above or below this reduce bacterial activity and slow the establishment of the N-fixing relationship.
- **High soil N levels.** When soil N levels are too high, nodule number and activity decreases. Roots do not attract bacteria or allow infection, so N-fixation is limited or non-existent.
- **Drought.** Poor plant growth does not allow the plants to sustain nodules and plant growth. Nodule activity is

sacrificed.

- **Excessive wetness.** If soil pores are filled with water, not air, there is no N to fix.
- **Compaction.** Compaction has been shown to affect nodulating soybeans more than N fertilized legumes. If there is no air, there is no N to fix.

Using inoculants

N-fixing bacteria are fragile organisms. Inoculants need to be handled with care. Proper storage is critical. Make certain the inoculant is fresh and has been stored in a manner recommended by the manufacturer. Inoculation ahead of seeding is possible, but check with the manufacturer to see if the shelf life of the product will allow it. Some seed treatments are toxic to inoculum. Captan and PCNB are very toxic to inoculum. Vitavax is relatively safe up to 24 hours before seeding. Thiram produces effects in between these two groups. Planter box treatments using dry materials or auger treatments with liquids, fresh or frozen materials are both acceptable if they give good coverage of all seed. Granular treatments applied in-furrow at seeding have been shown to be more effective than seed treatments in some studies but are more expensive than planter box or transfer-auger treatments.

Competition is possible from native strains of Rhizobium bacteria which are less efficient than commercial inoculum. Nodules from initial inoculation tend to be located on the main top root near the surface, while native strains tend to grow on the branches away from the seed zone. Native strains also siphon off nutrients from the host, lowering the N-fixing ability of more efficient strains. Native strains are sometimes much better at infecting roots and can limit inoculation effectiveness. It is important to inoculate with the best strains whenever soybeans are planted, especially the first time, or in long rotations. However, because of competition from aggressive strains, the effectiveness of the inoculated strains will be reduced.

N recommendations for soybeans

In the central US soybean belt, it is uncommon for soybeans to respond to pre-plant fertilizer N applications. However, North Dakota soybeans are grown in a very different soil environment. Research at NDSU has shown that as soil salt and carbonate levels increase, nodule infection is reduced. Minnesota research at Crookston has demonstrated that a modest level of N supplied to soybeans before or at planting increases yields (Table 1), probably due to increased early season plant health which results in improved nodulation. South Dakota research on lower N sites supports the use of N fertilizer supplements on soybean (Table 2).

Table 1. Affect of N-rate and inoculation on soybean yields in the Red River Valley on a low N site, Crookston, MN, 1988.

N-rate	Yield, bu/acre	
lb/acre	Uninoculated	Inoculated
0	28.5	32.1
30	31.0	32.0
60	33.8	34.2
90	35.1	34.6
120	38.5	37.1

Differences between inoculation were not significant.
Differences between N rates were significant.

Table 2. Influence of N fertilizer on soybean yield, SD, 1993. Initial soil NO_3-N level at site 1 was 59 lb N/acre, at site 2, 35 lb N/acre.

N rate, lb/acre	Soybean yield, bu/acre Site 1	Site 2
0	40.5	31.4
40	41.4	32.3
80	43.8	35.9
120	43.5	45.8
LSD 5%	NS	11.3

If soil test N levels to 2 feet deep are less than 50-75 lb/acre, apply the difference up to the 75 lb/acre level to compensate for low early N-fixing activity, assuming that fertilizer/crop economics allow and yield potential is sufficiently high. Do not apply additional N if soil levels are over 75 lb/acre, as this will reduce the potential for any significant later season nodule activity. Since a 40 bushel soybean crop requires nearly 200 lb/acre of N to reach maturity, a large contribution by the nodules is necessary. Soybeans can be grown without nodules if N is supplied, but the fertilizer expenses are similar to those required by a corn crop. It is better to apply more modest levels of N and inoculate. If a field has a history of soybeans with good nodulation, supplemental N would probably not be required even if soil N levels were low.

Figure 2. N deficiency on soybeans. (57KB color photo)

There have been occasional references to soybean responses from late season N applications. Responses are most consistent in irrigated fields with spoon-fed applications up to 40-50 lb/acre N total. Dryland fields have only been occasionally responsive, and only when yields above 50 bu/acre are possible. Because of inconsistency of response and the cost of the practice, late-season N applications are not advised (Table 3).

Table 3. Affect of foliar treatment of soybeans at flowering and early pod-set. MN.

Treatment	Yield, bu/acre
Control	50
N-P-K, Iowa State*	48
10-34-0, 28%, + potassium sulfate	43

*Iowa State mix was a total of 96N-22P_2O_5-35K_2O-5S, from four applications of a 20 gal/acre spray solution containing a total of 20-5-7.5-1.5S total analysis. N from urea, K and S from potassium sulfate, and potassium polyphosphate. The 10-34-0, 28% and potassium sulfate treatment also tested at U of MN above was applied in four applications.

Phosphorus

Soybeans react to broadcast applications of P better than banded applications with or near the seed. Soybeans appear to prefer their entire rooting zone bathed in nutrients, rather than having nutrients concentrated in a small area of the root zone. Soybeans have a different, more tap-rooted habit than grassy plants like wheat and corn, which often respond more efficiently to banded fertilizer. Several recent studies confirm that broadcast application of P is better than banded P (Table 4).

Table 4. Affect of P placement on soybeans, NB, 1981. P test very low.

P rate P_2O_5/acre	Yield, bu/acre Starter	Yield, bu/acre Broadcast
0	34	34
23	35	42
46	36	42
69	37	43

If soil test levels are low to very low, then a separate application of broadcast P is justified. However, if soil test levels are medium or higher, the level of response of soybean to P fertilizer is small, not justifying a separate P application. Soybeans are excellent scavengers of P at medium or higher soil test levels. It would be better at medium or higher soil test levels to front-load the crop prior to soybeans or apply more to the crop following soybeans than to apply P to that soybean crop. The most common fertilizer practice in the central US soybean belt is applying extra P to the previous corn crop and allowing soybeans to utilize residual P from the soil. The practice has been successful for over 30 years.

Even though a broadcast application of P may result in several more bushels of soybeans than a banded application, some producers will elect to apply P with the seed. **NO** fertilizer of any kind is recommended with soybean seed in a 15 inch row or wider (Table 5), because soybean seed is more sensitive to salt than corn. However, using a double-disc drill with 6 inch spacings, up to 10 lb N/acre may be applied to soybeans as a P fertilizer (do not use urea). With air-seeders, risk to soybeans will be decreased with fertilizer spread across the seed zone. Even though it is possible to apply up to 10 lb N/acre with a 6-inch row spacing, dry weather at planting will increase the risk of injury. Sandier textures and low moisture soils may show more stand injury than other areas of the field. Again, the best recommendation for P application is to broadcast it (Table 6).

Table 5. Seed-placed fertilizer effects on soybean stand and yield, SD, 1993. Row width, 30 inches. Average of MAP and DAP treatments at two sites.

Rate, P_2O_5	Final stand,%	Yield, bu/acre
0	100	35
12.5	62	33.5
25	36	26.5
50	14	18

Table 6. Nutrient recommendations for soybean.

Yield goal	N		Soil test P, ppm VL	L	M	H	VH
		Bray	0-5	6-10	11-15	16-20	20+
		Olsen	0-3	4-7	8-11	12-15	16+
bu/a			lb P_2O_5/acre				
30	50-75*		35	20	10	0	0
40			50	30	10	0	0
50			60	35	10	0	0
60			70	40	10	0	0

Yield goal	N		Soil test K, ppm VL	L	M	H	VH
		Bray Olsen	0-40	41-80	81-120	121-160	160+
bu/a			lb K_2O/acre				
30			55	35	10	0	0
40			75	45	15	0	0
50			90	55	20	0	0
60			110	65	20	0	0

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Bray-P1 recommendation = (1.55-0.1 STP)YG
Olsen P recommendation = (1.55- 0.14 STP)YG
Potassium recommendations = (2.2-0.0183 STK)YG

The abbreviations used in the equations are as follows:
YG = yield goal
STP = soil test phosphorus
STK = soil test potassium

* Total of soil test N to 2 ft. and supplemental N. For fields growing soybeans for the first time and where nodulation is reduced by soil conditions. In fields with a history of good nodulation, no fertilizer N should be required.

Potassium

Most soils in North Dakota have high K levels. However, some sandier textured soils in the beach ridges west or east of the Red River Valley are lower in K. Sandier hilltops in the glacial till plain or in residual materials west of the Missouri River may also be lower in K. Some limited soil testing based on general landscape will show whether K is needed in these areas. When soils are dry, even high K testing soils can show K deficiencies. Ridge-till producers often include K in their 2 by 2 banded starter fertilizer applications to compensate for limited soil K availability in these dryland cropping systems. Potassium should be either broadcast or banded, with the seed and fertilizer separated. Do not apply potassium fertilizers with the seed (Table 6).

Figure 3. Potassium deficiency. (20KB color photo)

Sulfur

Although sulfur deficiency is possible, few reports of sulfur deficiencies exist. Deficiencies are most possible on sandy textured hilltops, beach ridges, and eroded areas with low organic matter.

Soil pH

Soybeans grow best around a pH of 6.5. Lowering pH is usually not an option because of the cost of amendments and the formation of salt if the application is successful. However, low pH levels have been found in North Dakota. Sampling by landscape position provides much better information regarding soil pH than composite testing. Application of limestone would be justified if soil pH is lower than 6.

Zinc

Soybeans are usually not sensitive to low soil zinc levels and grow well at zinc test levels much lower than sensitive crops like dry beans and corn. A recent North Dakota study with 10 locations and nine varieties with and without zinc revealed no significant differences even at soil test levels as low as 0.2 ppm. Although rare zinc deficiencies have been observed in North Dakota, it is not a problem most producers need consider. Zinc deficiency is expressed as a light green color developing in between the veins of younger leaves on sandy, low organic matter soils with very low (less than 0.2 ppm) zinc levels.

Iron

Soybeans are susceptible to low soil iron availability. Iron deficiency is expressed as yellowing in between veins on younger leaves. This yellowing is called "chlorosis." Iron chlorosis is not seen until the first trifoliar leaf emerges, since prior to this stage iron from the seed is translocated to new growth. At emergence of the first true leaves, iron becomes an immobile nutrient and the plant must rely on soil availability to supply iron needs.

Figure 4. Iron chlorosis (45KB color photo)

Iron chlorosis in this region is different than chlorosis reported in the central US soybean growing belt. High soil carbonates, increased solubility of bicarbonate caused by soil wetness, and the presence of elevated levels of soluble salts have been shown to influence the presence and severity of iron chlorosis in soybeans in North Dakota and northwestern Minnesota. Cold temperatures also aggravate the problem in some spring seasons.

Application of iron-EDDHA chelate appears to be most helpful in correcting chlorosis, but it is expensive at rates greater than 0.5-1 lb/acre. Research is under way to determine if a combination of chlorosis-tolerant varieties, low rates of iron-EDDHA (0.5-1 lb/acre) applied with the seed, and foliar application of a number of iron fertilizers may be effective in combating chlorosis. Many soybeans are also treated with post-emergence herbicides during expression of chlorosis. Research is now being conducted to determine if some herbicides are generally safer to use than others.

Figure 5. Herbicide phytotoxicity differences when applied during chlorosis. (62KB color photo)

There are genetic differences among soybean varieties for susceptibility to iron chlorosis. To combat chlorosis, plant the most iron chlorosis tolerant varieties available in a maturity range. If soybeans are seeded in rows (22 inches or wider), cultivation tends to dry the soil, reducing soluble bicarbonate levels and chlorosis.

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