SF1164

Soybean Soil Fertility

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Soybeans need 14 mineral nutrients: nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), boron (B), chloride (Cl), molybdenum (Mo) and nickel (Ni).

Of these, North Dakota soils provide adequate amounts for soybean production of all of them except N, P, K, S and Fe.

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Nitrogen

Nodulation

Although the atmosphere is 78 percent nitrogen gas, plants cannot use it directly. Plants can use only ammonium-N or nitrate-N. Soybean is a legume and normally should 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.

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 through inoculation of the seed or the seed zone at planting.

N-fixing bacteria are attracted to soybean roots by chemical signals from the soybean root in the form of flavenoid compounds (1). 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 (2)(3) **(Figure 1)**.

The bacteria, up to 10,000 in each nodule, live in compartments called bacteroids **(Figure 2)**. Each bacteroid is bathed in nutrients from the host plant. The bacteroid takes nitrogen 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 North Dakota, northwestern Minnesota and northern South Dakota, iron deficiency chlorosis (IDC) may result in poor nodulation and may contribute to N deficiency as well as iron deficiency (4).

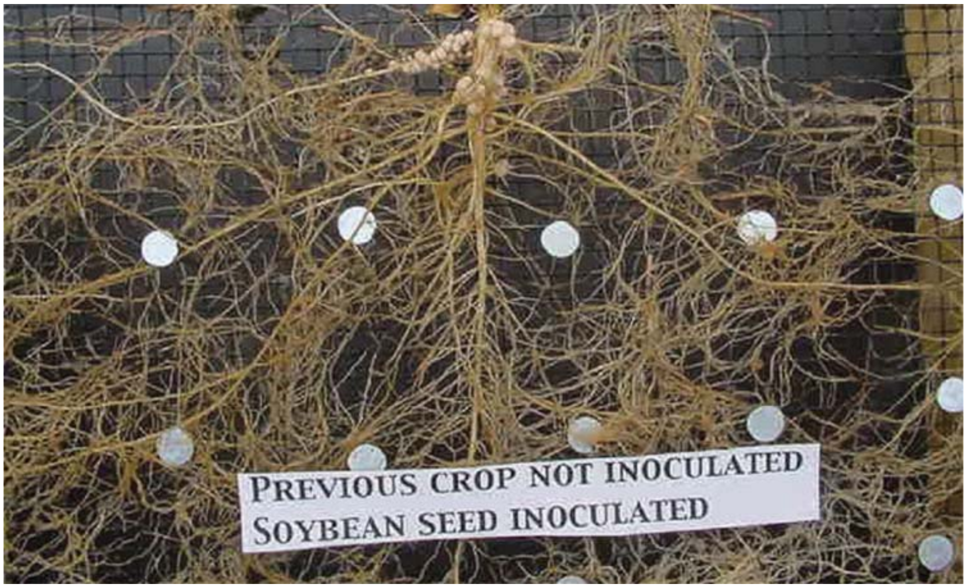

Figure 1. Nodules formed on soybean roots through infection by Bradyrhizobium japonicum inoculation in soils with no previous soybean inoculation history.

(R.J. Goos, NDSU)

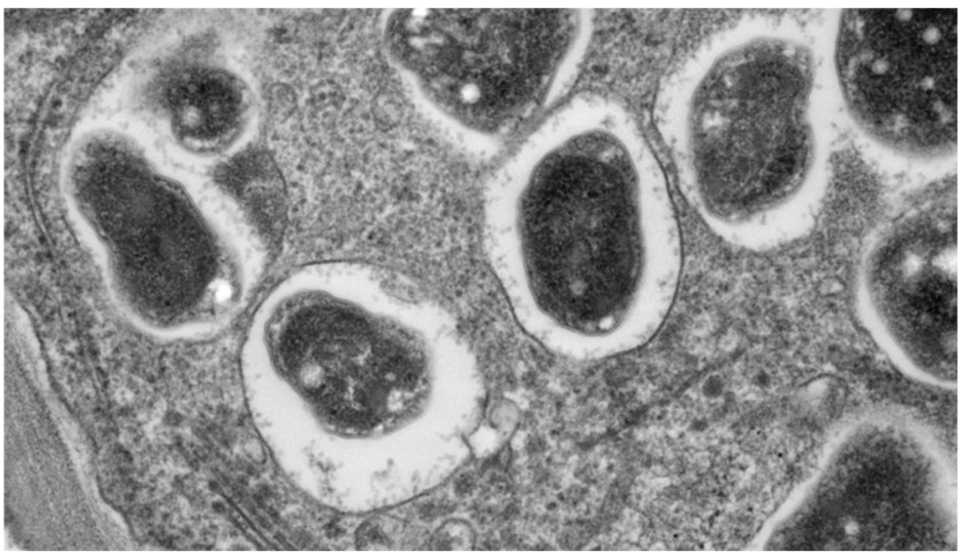

Figure 2. Soybean nodule cross section micrograph showing individual bacteroids.

(Courtesy of Louisa Howard, Dartmouth College)

Inoculation

If soybean will be planted in a field for the first time, the seed will need to be inoculated with Bradyrhizobium japonicum (soybean inoculum). Several inoculum types can be used. They can be peat-based, liquid-based or granular. Of the three, granular appears to be the most foolproof for a first inoculation. The other two also can be used, but the frequency of mistakes is much higher. No formulation is free of error.

For the peat-based and liquid-based treatments, all seed should have inoculum attached to it when it enters the soil. Peat-based inoculants can vibrate off the seed if they are not applied with adequate sticking agent. Liquid applications could be calibrated poorly and may not stick to all of the seeds if the application is not made carefully. Even granular formulations that are applied near the seed in-furrow will have problems in performing if the seeder is poorly calibrated.

With proper care in handling and application, the success rate of all inoculation is very high. In the rare event that nodulation does not take place, supplemental N will have to be applied to reach yield potential. In-season foliar N application is not recommended, and slow-release liquid N sources have no higher foliar N efficiency compared with UAN (urea-ammonium nitrate solutions).

If a field has been seeded to soybeans previously and nodulation was effective, inoculating again has only a small chance of being economically effective. Studies in North Dakota have compared many inoculum brands in fields where soybeans were grown previously and successfully inoculated. Only very small yield benefits have been seen; most often inoculation results in no yield benefit. The six-year mean was 1.7 bushel per acre higher with inoculation (45 bushels per acre) vs. without (43.3 bushels per acre) **(Table 1)**.

Nitrogen is not required by soybean if adequate inoculation is present. In the north-central U.S. region, soybeans grown in soils that usually do not exhibit iron deficiency chlorosis symptoms sometimes responded to higher soil nitrate levels (4). However, higher soil nitrate levels in soils increase the severity of IDC in soils where IDC-supporting conditions prevail (5).

In North Dakota experiments, nearly all responses to supplemental N have been to first-year soybeans where initial inoculation resulted in poor nodulation (6). A three-year study of supplemental N at soybean growth stages R1 to R3 with a slow-release N source at about 25 pounds of N per acre showed no yield response compared with untreated check.

Table 1. Frequency of soybean yield responses, grain yield and protein differences between experiments with or without a soybean history when seed is inoculated with *Bradyrhizobium japonicum* formulations at planting. (Carrington Research Extension Center, 2003-2007b and 2012; Oakes NDSU Experiment Farm, 2007a)

Site year*	Number of treatments	Soybean history	Number of treatments higher than check	Yield without inoculation	Mean yield with inoculation	Grain protein of the check	Mean grain protein inoculated
2003	38	No	38	32.8	38.8	31.5	35.0
2004	23	Yes	0	29.1	28.9	33.5	34.5 (NS)
2005	25	Yes	0	39.6	39.6	33.5	33.8 (NS)
2007a	7	Yes	0	55.9	55.9	35.1	35.1
2007b	11	No	11	46.1	50.7	32.0	34.1
2012	6	Yes	0	56.1	56.1	34.6	34.6

*All site years Carrington except 2007a treatment study at Oakes

Phosphorus

North Dakota soils are typically low in phosphorus (P). The soil test supported by NDSU recommendations is the Olsen sodium bicarbonate extraction method. The Olsen test best predicts crop response in the soils within state boundaries that range from below pH 5 to more than pH 8. More than one-half of soils in North Dakota have a pH higher than 7.

Soybeans have a great demand for P if soil tests are medium or below. Most soybean fields are seeded with grain drills and air-seeders to solid-seed soybeans. Historical use of these seeders for small-grain production has preconditioned most growers to apply their P with the seed.

Although up to 100 pounds/acre of 11-52-0 or equivalent P fertilizer can be applied with the seed row spacing through 12 inches in width, higher yields are achieved when the P is broadcast applied **(Table 2)**. Soybean, unlike small grain, canola, sugar beet and corn, usually does not benefit from banded P compared with broadcast P **(Table 2)**.

In some cases, phosphorus placed near the seed can reduce stand and yield **(Table 3)**. Experiments in Nebraska with broadcast compared with band resulted in almost a 5 bushel per acre advantage to broadcast. Similar experiments in Minnesota resulted in almost a 3 bushel advantage to broadcast vs. band.

In North Dakota, while seed-placed or near-seed-placed P application usually is profitable in small grains, canola, corn and sugar beet, profit is not assured in soybeans **(Table 3)**. No fertilizer P should be applied with the seed in 15-inch rows or wider because stand reduction can overwhelm any yield benefit of P application in wider rows **(Table 4)**.

In the central U.S. Corn Belt, P fertilizer commonly is applied to corn only in a corn-soybean rotation. This practice tends to provide good benefits to soybeans and corn because the soil P levels are most often in the "high" range. In North Dakota, the P test is

Table 2. Response of soybean to banded and broadcast fertilizer P, Nebraska, mean of three years. (G. Rehm).

	Placement Method	
	Broadcast	Band†
P_2O_5 lb/acre	Yield, bu/acre	
0	35.5	34.4
20	39.7	35.1
40	41.1	36.2
60	44.0	39.1
80	42.4	37.1

† Soil test P low. 2- by 2-inch band used.

Table 3. Seed-placed fertilizer effect on soybean stand, Carrington, three site-years, B. Schatz. Soybean seeded in 7-inch rows.

Rate of 11-52-0 with the seed	Final soybean stand	Yield bushels
lb/acre	plants per square foot	per acre
0	3.1	38.5
45	2.3	38.3
91	2.1	33.6
136	2.0	35.3

Table 4. Seed-placed 10-34-0 application to soybean stand and yield in 30-inch rows. Carrington, Endres and Hendrickson.

Application method	Stand	Yield
	1,000 plants/acre	bu/acre
Check	187.5	32.8
2 by 2, 4 gal/acre	188.6	33.5
In furrow 4 gal/acre	33.2	24.5
In furrow 8 gal/acre	20.6	18.9
LSD 5%	16.5	4.3

usually much lower, so P should be applied to soybean in a separate application. Fertilizing each crop is important until the field P test reaches the high availability range **(Table 5)**.

Phosphate "inoculants" sometimes are promoted to North Dakota soybean growers. The predominant inoculants are formulations of *Penicillium bilajii*, a fungus developed for commercial use in Canada about 20 years ago.

According to the developer, the fungus excretes acid from its hyphae. The acid can release trapped P from "occluded" P in the soil (P that is separated from the soil by a carbonate coating that can be present if the soils are high in free calcium carbonate). If, according to the developer, this P is present in soil, up to 10 pounds of P_2O_5 per acre may be made available during the course of the season with use of this inoculant.

The application of a P inoculant cannot be expected to act as a starter. The P inoculants will not release P in soil with a pH below 7 (7). Six site-years of work at Carrington found no significant soybean yield increase from the use of P inoculants (Endres, unpublished 2012). Recommendations for rates of P_2O_5 based on soil test can be found in **Table 7**.

Potassium

Potassium requirements for soybean are lower than they are for corn. However, in a corn and soybean rotation, fertilizing for higher nutrient levels is important.

Although the critical soil level for K using the 1-N ammonium acetate extraction method is only 100 ppm for soybean, the critical level for K in corn is closer to 200 ppm. Therefore, adding K to replace what the soybean crop may remove will make fertilizing corn less economically and logistically painful the next year corn is intended for the field.

In dry seasons, soybean has shown K deficiency symptoms even when soil test K is higher than 100 ppm. Recommendations for K fertilization of soybean based on soil test can be found in **Table 7**.

In-season Application of Foliar Sprays of N, P and K

Due to the observation of soybean plant physiologists that soybean nodule sustenance by the host plant is reduced soon after pod initiation, foliar fertilizer trials have been conducted in soybean-growing areas for the past 40 years.

Table 5. Effect of broadcast P application on low or very low soils in Minnesota (Rehm et al., 2001).

Application rate	Soybean yield
P_2O_5 lb/acre	bu/acre
0	23.0
23	37.0
46	39.5
69	41.3
92	40.2

Table 6. Soybean yield as affected by preplant N rate and seeding an oat cover crop at eight Minnesota IDC sites, 2006-2009. Lamb J., University of Minnesota (5).

N applied	Oats	C06	YM06	K07	YN07	C08	R08	C09	R09
lb/acre		bushels per acre							
0	No	42.1	52.0	3.7	51.7	34.3	30.4	51.0	42.0
100	No	28.6	32.2	0.3	46.5	—	—	—	—
200	No	25.3	19.1	0.1	40.2	—	—	—	—
0	Yes	42.5	52.4	40.2	50.7	41.7	28.1	50.0	44.0
100	Yes	20.5	42.6	24.5	43.4	—	—	—	—
200	Yes	18.9	25.9	7.2	33.7	—	—	—	—

Table 7. Phosphorus and potassium recommendation for soybeans based on soil test and yield potential.

			Soil Test Phosphorus, ppm					Soil Test Potassium, ppm				
Yield potential	Soil N plus fertilizer N required	Bray-1 Olsen	VL 0-5 0-3	L 6-10 4-7	M 11-15 8-11	H 16-20 12-15	VH 21+ 16+	VL 0-40	L 41-80	M 81-120	H 121-160	VH 161+
bu/a	lb/acre-2'		lb P_2O_5/acre					lb K_2O/acre				
30	0		40	23	10	0	0	55	33	11	0	0
40	0		54	31	10	0	0	73	44	15	0	0
50	0		67	39	11	0	0	92	55	19	0	0
60	0		80	47	13	0	0	110	66	22	0	0

Bray-I P recommendation = (1.55-0.10 STP)YP
Olsen P recommendation = (1.55-0.14 STP)YP
Potassium recommendation = (2.2000-0.0183 STK)YP

Yield responses to single nutrients or combinations of nutrients have not resulted in consistent yield responses to these applications (8)(9). Occasionally a yield response is recorded, but the great majority of experiments and on-farm trials have resulted in no yield increases and even yield decreases.

Some of the uncommon yield increases to foliar NPK applications have been related to low availability of soil nutrients. The rest of the yield increases are unexplained. The frequency of yield increases in all studies is so low and unpredictable that foliar application of NPK to soybean is not recommended.

Sulfur

Sulfur is as important to soybean as most other crops. The sulfur soil test poorly predicts the chance for S deficiency. Knowing the soils and considering the past precipitation is a better method of determining whether S is needed each season.

If the soils are loam or coarser in texture and the fall was wet, snowfall was normal to above normal and/or spring was wet prior to planting, the application of 10 pounds of S as a sulfate form (ammonium sulfate or gypsum) would be recommended.

Elemental sulfur of all formulations is not a recommended S source in North Dakota due to poor oxidation potential to sulfate.

Iron

North Dakota soils contain about 5 percent iron (Fe) by weight. However, only a tiny fraction ever is available to plants. Iron in well water is reduced iron (Fe++ or ferrous iron). Ferrous iron is very soluble in water.

The weight of a No. 2 carpenter nail can be dissolved in water if it were ferrous iron. Unfortunately, as soon as ferrous ion is exposed to oxygen, it oxidizes to oxidized Fe (Fe+++ or ferric iron). Ferric iron is a trillion times less soluble than ferrous iron. Plants, except for aquatic plants such as rice and pondweed, implement Fe uptake strategies to improve Fe nutrition and avoid deficiency.

In soybean, Fe is mobile in the plant from germination through the first monofoliate leaf. As the first trifoliate leaf emerges, Fe becomes immobile in the plant and must be taken up continually through the season to avoid deficiency.

The soybean strategy for Fe uptake begins by soybean roots acidifying the soil environment directly around the soybean root. The acidic soil environment is necessary for the activity of an Fe-reducing protein that is secreted by the soybean root (10). If the root rhizosphere remains acidic, the Fe-reducing protein contacts oxidized iron and reduces it to soluble ferrous iron, making it available to the plant.

Soybean plants exhibit iron deficiency as interveinal chlorosis **(Figure 3)**. In soils that are susceptible to iron deficiency chlorosis (IDC), the causal soil condition is the presence of carbonates (CO^{3--}) (11). As the soil becomes wetter, the solubility of carbonates increases, producing bicarbonate (HCO^{3-}) (12). Bicarbonate neutralizes the acidity around plant roots and makes the Fe-reducing protein secreted by the roots ineffective (13).

Iron foliar sprays generally are not effective in correcting a deficiency. The best application to reduce IDC is ortho-ortho-EDDHA Fe chelate applied

Figure 3. Soybean with IDC symptoms of interveinal chlorosis.

(D. Franzen, NDSU)

with water in-furrow at seeding. The ortho-ortho-EDDHA not only succeeds in delivering Fe to the plant root early in the season, but after conveying its original Fe, it has the ability to return to the soil solution, capture additional Fe and deliver it to the plant root with the soil water stream (Goos and Lovas, unpublished data, 2012).

The amount of ortho-ortho EDDHA **(Figure 4, left)** in relation to ortho-para EDDHA **(Figure 4, right)** is very important in an iron chelate product. Both forms can be in a product, although the form effective in reducing IDC is only the ortho-ortho-EDDHA. Recent research at NDSU has shown that the response of soybeans to EDDHA fertilizer is directly proportional to the percentage of ortho-ortho EDDHA Fe in the product **(Figure 5)**.

An effective IDC prevention strategy should not rely on the application of ortho-ortho-EDDHA alone, but on a comprehensive approach to the condition. An IDC-tolerant variety should be selected.

A recent four-state study led by NDSU found that highest yield for a soybean field on soils with and without susceptibility to soybean IDC would be best managed by seeding a high-yielding IDC-intolerant cultivar in non-IDC soils and an IDC-tolerant cultivar in the IDC-susceptible soils (14).

To reduce IDC pressure, the soybean should be seeded in wider than 15-inch rows. Although the exact mechanism for the IDC benefit of denser stands is not known, many growers have seen this effect when the planter stops within the field and leaves a high density strip of seed behind when it resumes planting. Soybeans in densely seeded areas are taller and have less IDC symptoms, compared with the normally seeded fields.

Similar reductions in IDC symptoms are seen as soybeans are seeded closer to each other in wider row spacings or higher seeding rates (15). The causes of the denser seeding reducing IDC could be related to reduced soil moisture under the row, higher root-zone acidity that would favor activity of the Fe-reducing substance secreted by the soybean root, or other unidentified mechanisms.

A three-state study several years ago found that seeding a cover crop of 1 bushel per acre of oats or other easily killed small-grain cover crop about the day of soybean planting can reduce excess water and take up some excess soil N **(Figure 6)**. Depending on soil moisture, the oats may be killed with herbicide early if conditions are dry, or up to the five-leaf stage of oats if the season is wet.

The use of an oat cover crop resulted in as high as 40 bushels per acre more soybean, compared with where they were not used at a Minnesota site in a wet season (5) **(Table 6)**.

Because soil salinity aggravates and increases the severity of IDC, a comprehensive, rotation-based strategy should be imposed to reduce soil salinity as much as possible. That strategy should include selection of better salinity-tolerant crops; the use of alfalfa strips to reduce roadside salinity; the use of alfalfa above saline seeps to reduce the severity of the seep; the use of cover crops when possible before, during or after cropping to reduce the field water table; and possibly tile drainage if practical and socially and/or regulation-permissible.

Other Nutrients

Deficiencies of zinc, manganese, boron, molybdenum, nickel, chloride or copper have not been recorded in North Dakota.

Field experiments have not revealed any supplemental requirement for these nutrients above what our soils provide.

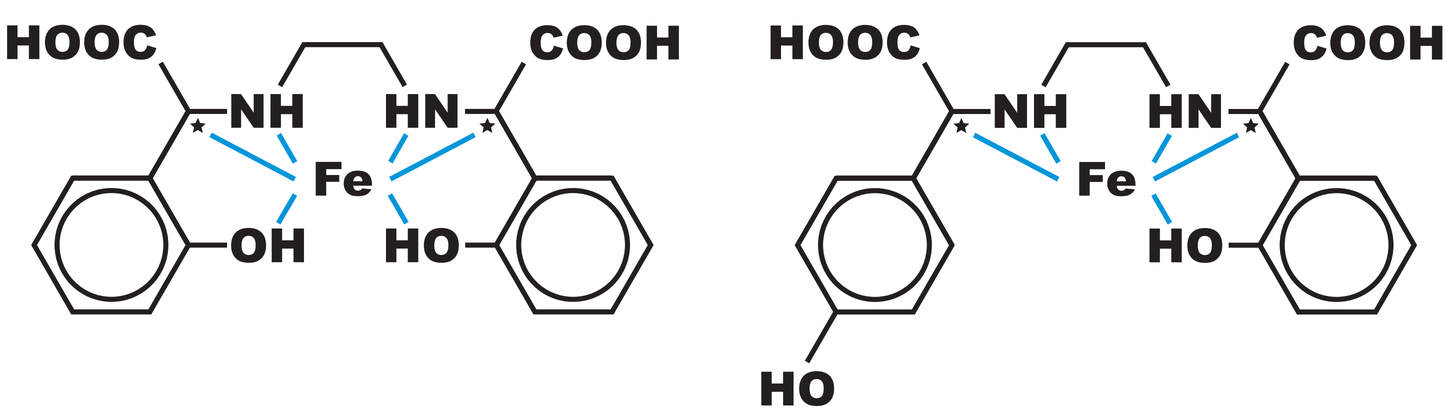

Figure 4. Ortho-ortho EDDHA (left); ortho-para EDDHA (right).

(Adapted by permission from Goos, 2012.)

Figure 5. Effect of a 1.5 percent Fe as ortho-ortho EDDHA added to soil at different rates (left) compared with a 5.5 percent Fe as ortho-ortho EDDHA applied at the same rates (right).

(Goos and Lovas, unpublished, 2012)

Figure 6a. One hundred pounds of N/acre with no oat cover crop (left), compared with 100 pounds of N/acre with oat cover crop (right).

(J. Lamb, University of Minnesota)

Figure 6b. No N applied and no oat cover crop (left). No N applied with oat cover crop (right).

(J. Lamb, University of Minnesota)

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