Soybean Nodulation Process

Nitrogen (N) fixation begins in soybean root nodules between the V2 and V3 growth stages, and inoculation can help increase root nodulation in fields newly seeded to soybean.

Nodule Formation

Adequate populations of N-fixing bacteria (*Bradyrhizobia japonicum*) are necessary for successful atmospheric N fixation to occur. These bacteria should either be available in the soil or applied to soybean seed to help nodules form on the roots.

The first nodules are formed and become large enough to become visible shortly after seedlings emerge. Here are the steps to development of root nodules:

1) Successful penetration of the bacteria into the root hair of a soybean seedling and the formation of an infection thread.
2) Thread forms and grows to the base of the root hair.
3) Swelling develops near the tip of the infection thread.
4) Multiple or double infections from a single thread may result in a root nodule.

Around the V2 to V3 stage, the N fixation process begins in the nodule.[1] First, rhizobium bacteria convert atmospheric N to ammonium (NH_4), the plant-available form of N. In turn, plants provide carbohydrates to the bacteria to survive. The number of nodules per healthy plant (several hundred) and the amount of N fixed is maximized around the R5.5 stage.[2]

Figure 1. Comparison between a well-nodulated plant (left) and a poorly nodulated plant (right). Photo courtesy of Stu Duncan, Kansas State University.

Nitrogen Fertilization

Nitrogen fertilizer applications are not recommended in soybean crops as they typically do not increase yield potential. As amounts of applied N increase, the number of nodules decreases, and the bacteria become less active.[3] Soybean planted in fields with excessive residual nitrate should be closely monitored. If nodulation has been severely inhibited and N deficiency symptoms appear (Figure 1), additional N during pod fill may be helpful. Although research has inconsistent results, the greatest success seems to occur when N was applied via irrigation system in high-yield situations.[4]

Nodule Viability Assessment

After the second or third trifoliate has emerged, nodules should be large and active. Nodule viability can be assessed by following these steps -

1) Dig up at least 10 soybean plants without pulling to avoid stripping nodules off the roots.[5]

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2) Soak plants in a bucket of water to loosen soil without removing too many nodules.

3) If there are less than five nodules per plant, resample the same field one week later.

4) Prior to flowering, there should be 8 to 20 large (2 to 4 mm) and active nodules per plant.[5]

5) Pink to reddish coloring of internal tissues indicates the nodule is active and N fixation is occurring (Figure 2).

Pink to red discoloration does not indicate efficiency of nodules. Some nodules are pink to red but are not very effective at producing ammonium. A mushy nodule and those with green or brown coloration are not fixing N. Immature nodules are small white, and have yet to fix N. New nodules are formed until pod-filling stage.

When Inoculants Are Most Important

Rhizobium can be added as liquids, granular peat inoculants, or as peat-based powder if soils do not contain high populations. Seed– or in-furrow applications can have a positive effect in many growing situations including the following-

- Field has no previous history of soybean production, or soybean has not been grown in the field in the last 3 to 5 years (Figure 3).[1]
- Soil pH is below 6.0.[1] Greater response from inoculants can be expected in fields with a pH below 6.0.
- Fields that have been flooded for several days can create anaerobic conditions for rhizobia.
- Compaction and cool soil temperatures, due to no-till practices can reduce nodulation.

Fields with sandy soils and low organic matter (less than 1%) need to be inoculated each year.[4] These soils generally have very low populations of rhizobia bacteria.

Unsuccessful Nodulation

The following conditions are most likely to cause poor nodulation and reduce N fixation:

- Fields with low soil rhizobia bacteria populations and/ or fields with a high residual of soil N.
- Fields new to soybean should be double inoculated with application to both the seed and soil.
- Poor quality inoculants due to improper storage time and conditions. Follow expiration date and storage guidelines; avoid heat and direct sunlight.

Figure 2. Cross-section of a healthy soybean nodule.

- Dry conditions, excessive moisture, or flooding for several days. Nodules rot, turn brown, and die in soils saturated for three days.
- Hail damage, root diseases, or iron deficiency chlorosis symptoms early in season.
- Soil pH levels below 6.0 or above 8.0.[6]
- Soil compaction can limit rooting and the development of root hairs that are hosts for rhizobia to colonize and develop root nodules.
- Symptoms of inadequate nodulation include yellowing and stunting of soybean plants.[6]

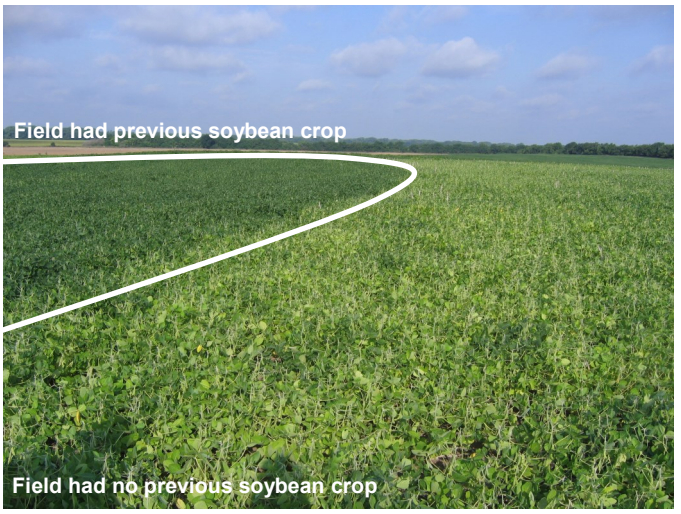

Figure 3. Photo courtesy of Stu Duncan, Kansas State University.

Sources
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