Soybean Root Nodulation and Nitrogen Fixation

KEY POINTS

- Between 50 to 70% of soybean nitrogen (N) requirements can be obtained from the air due to the action of N-fixing bacteria that form nodules on the roots.
- N-fixing bacteria must be available in the soil or applied to soybean seed for the nodulation process to occur.
- Soybean seed inoculants containing *B. japonicum* should be considered for fields if soybeans have not been grown for 3 to 5 years. Also, an inoculant should be added to fields that have a soil pH below 6.0, or sandy soils, or fields that have been flooded for several days.

Nodulation Development

Soybean can obtain between 50 to 70% of its nitrogen (N) requirements from the air when N-fixing bacteria have established functioning nodules on their roots (Figure 1).[1] However for this process to occur, adequate populations of N-fixing bacteria (*Bradyrhizobium japonicum*, in the genus Rhizobium), must be in the soil or applied to soybean seed.

Figure 1. Soybean nodules (red arrow) at

As a legume, soybean have the ability to live in a symbiotic (mutually beneficial) relationship with a specific bacteria. The rhizobia "fix" nitrogen from the air into ammonia, which can be used by the soybean plant. In return the soybean plant provide carbohydrates to the bacteria. *B. japonicum* is specific to soybean and will not fix nitrogen in other legume species. Likewise, the rhizobial species that fix nitrogen for alfalfa or other legumes will not nodulate and fix nitrogen on soybean.[2]

Shortly after emergence, nodule formation can be observed on the roots, but active nitrogen fixation does not begin until about the V2 (second-trifoliate) to V3 (third-trifoliate) growth stages. Prior to flowering, there should be 8 to 20 large (about 1/16th to 1/8th inch) and active nodules per plant. The number of nodules per healthy plant (several hundred) and the amount of N fixed is maximized around the R5.5 (beginning seed) growth stage.[1] New nodules are formed during most of the growing season, usually ending during the pod-filling growth stages. Active nodules have an internal pink color (Figure 2) and remain active for 6 to 7 weeks before they begin to break down. Nodules that have a black internal color are not functioning and are considered dead.

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

Soil Applied N Fertilizer

The application of N fertilizer to a soybean crop is not recommended as it generally does not increase yield potential.[4] The greater the supply of N in the soil, the less N fixation occurs by the plant. As the amount of soil applied N increases, the number of nodules decreases and the bacteria become less active. Interestingly, even though soybean plants remove a significant amount of N from the soil, yield does not increase proportionally with increasing N applications.[4] Soybean planted in fields with excessive residual

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nitrate should be closely monitored. If nodulation has been severely inhibited and N deficiency symptoms appear, additional N during pod fill may be helpful. Research has shown conflicting results regarding late-season N applications, with the greatest success occurring when N was applied via irrigation systems in high-yield situations.[5]

Are Seed Inoculants Needed?

Most universities guidelines suggest planting inoculated soybean seed in fields that have not grown soybean for the previous three to five years.[2,4,6]

The probability of a yield response to inoculated seed in fields with a recent history of soybean is extremely low. An eight-year study (2000-2008) testing 51 inoculant products in 73 experiments conducted in Wisconsin, Iowa, Indiana, Minnesota, and Nebraska resulted in an average yield response of 0 bu/acre. [5] Some highlights of the study are as follows:[7]

- 63 environments showed no significant yield response to inoculants.
- Four of the environments showed an average negative yield response of 6% to inoculants compared to the untreated seed.
- Six of the environments showed an average positive yield response of 12% to inoculants compared to untreated seed.

However, inoculated seed may improve yield potential compared to no inoculants for fields with the following soil or environmental conditions.

- No previous recent history of soybean production.
- Soil pH is below 6.0. Greater response from inoculants can be expected in fields with a pH below 6.0.
- Fields that have been flooded for several days since the previous soybean crop. Flooded fields can create anaerobic conditions for the existing rhizobia thus reducing their overall population in the soil.
- Fields with sandy soils and low organic matter (less than 1%) need to be inoculated every year. These soils generally have very low populations of rhizobia bacteria.

Nodulation Failure

The following conditions are most likely to cause poor nodulation in the field resulting in reduced N fixation:

- Fields with low soil rhizobia bacteria populations and/or fields with a high residual of soil N from a previous forage legume or due to manure application.
- Poor quality inoculants due to improper storage time and conditions. Follow the inoculant expiration date and proper storage conditions to preserve the inoculant's viability.
- Dry conditions, excessive moisture, or flooding for several days. Due to anaerobic conditions, nodules rot, turn brown, and die if soils are saturated for at least three days.
- Hail damage, root diseases, or iron deficiency chlorosis (IDC) symptoms early in the season.
- Soil pH levels below 6.0 or above 8.0.[8]
- 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.

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