Soybean Root Nodulation and Nitrogen Fixation

- Soybean contains more than 35% protein, which equates to three to five pounds of nitrogen (N) required by the plant to produce one bushel of soybeans.
- About 70% of the total nitrogen requirement for soybean is obtained from the nitrogen-fixation symbiotic process that occurs in root nodules between soybean plants and soil N-fixing bacteria.
- The nitrogen fixation process begins in the nodule around the V2 to V3 growth stages. Nodulation failure can result in nitrogen deficiency and a significant reduction in yield potential may occur.

Nodulation Development

For successful atmospheric nitrogen fixation to occur, adequate populations of nitrogen-fixing bacteria (Bradyrhizobium japonicum, in the genus Rhizobium) should either be available in the soil or applied to soybean seed so nodules can form on the roots. Shortly after seedlings emerge, the first nodules are formed and become visible as they increase in size. The initial step in nodulation is a successful penetration of the bacteria into the root hair of a soybean seedling and the formation of an infection thread. The thread forms and grows to the base of the root hair. Root nodules may result from multiple infection threads or double infections from a single thread. Swelling develops near the tip of the infection thread.

Around the V2 to V3 stage, the nitrogen fixation process begins in the nodule. Rhizobium bacteria convert atmospheric nitrogen to ammonium (NH₄), which is a form of nitrogen available to the plant, and in turn, the plant provides carbohydrates to the bacteria to survive. A successful nodulation by the V3 to V4 growth stage should produce 8 to 10 healthy nodules per plant. The number of nodules per healthy plant (several hundred) and the amount of nitrogen fixed is maximized around the R5.5 stage.

Soil Applied N Fertilizer

The application of nitrogen fertilizer to a soybean crop is not recommended as it generally does not increase yield potential. The greater the supply of nitrogen in the soil, the less nitrogen fixation by the plant occurs. As the amounts of applied nitrogen increase, the number of nodules decreases and the bacteria become less active. Interestingly, even though soybean plants remove a significant amount of nitrogen from the soil, yield does not increase proportionally with increasing nitrogen applications. Soybean planted in fields with excessive residual nitrate should be closely monitored. If nodulation has been severely inhibited and nitrogen deficiency symptoms appear, additional nitrogen during pod fill may be helpful. Research has shown conflicting results regarding late-season nitrogen applications, with the greatest success occurring when nitrogen was applied via irrigation system in high-yield situations.

Evaluate Nodule Viability

Dig up a few (at least 10) soybean plants in each field after the second or third trifoliate has emerged to assess viability of the root nodules. After digging, soak plants in a bucket of water to loosen the soil so that you don’t remove too many nodules. If present, nodules should be large and active. If there are less than five nodules per plant, resample the same field one week later. Just prior to flowering there should be 8 to 20 large (2 to 4 mm) and active nodules per plant (Figure 1). Nodules found on the tap roots are probably the result of the current season’s inoculation. Nodules developed on the lateral roots may be from existing rhizobium bacteria, depending on the bacteria's movement through the soil or if soil-applied inoculants were used. New nodules are formed during much of the life of the plant, ending during seed filling.

If the internal tissue of a dissected nodule is pink to red in color, the nodule is active and nitrogen fixation is occurring. However, this is not a measure of the efficiency of the nodule. Some nodules are pink to red but are not very effective at producing ammonium. Nodules that are green, brown, or mushy are not fixing nitrogen, while immature nodules are small, white, and have yet to fix nitrogen.

Rhizobium can be added as a liquid, as granular peat inoculants, or as a peat-based powder if soils do not contain high populations. They can be seed-applied or used in-furrow.

Situations When Inoculants are Most Important

Inoculants can have a positive impact in many growing situations including the following:
- Field has no previous history of soybean production.
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- 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 can create anaerobic conditions for the 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 every year. These soils generally have very low populations of rhizobia bacteria.

Nodulation Failure
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 from a previous forage legume, such as alfalfa, clover, or other crop, or due to manure application.
- Fields new to soybean should always be double inoculated with one application preferably to the soil. Applying inoculants to both seed and soil can potentially increase nodulation.
- 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. Additionally, avoid exposing inoculant to direct sunlight or excessive heat.
- Dry conditions, excessive moisture, or flooding for several days (Figure 2). 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.

Summary

- Much of the soybean N requirement is supplied through the N fixation process, which is a result of a beneficial relationship between the plant and soil rhizobia bacteria.
- Lack of N fixing bacteria in a field can be overcome by inoculating the seed with the rhizobia bacteria.
- Unsuccessful inoculations can result in soybean plants showing N-deficiency symptoms.
- The inside of healthy and active nodules are pink to red in color.
- When soybean plants are short and light green late in the season, this may be an indication of poor nodulation.

Sources:

For additional agronomic information, please contact your local seed representative.

Individual results may vary, and performance may vary from location to location and from year to year. This result may not be an indicator of results you may obtain as local growing, soil and weather conditions may vary. Growers should evaluate data from multiple locations and years whenever possible. ALWAYS READ AND FOLLOW PESTICIDE LABEL DIRECTIONS. Agrow and the A Design®, Agrow® and DEKALB® are registered trademarks of Monsanto Technology LLC. Leaf Design® is a registered trademark of Monsanto Company. All other trademarks are the property of their respective owners. ©2015 Monsanto Company. 140304006139 040915JMG