AGRONOMIC Spotlight
Technology Development & Agronomy by MONSANTO

Soybean Nodulation: Process and Failure

- Nitrogen (N) fixation is a symbiotic process, between soybean plants and rhizobia soil bacteria, where atmospheric N is converted to a form that is available to the plants.
- Nitrogen fixation occurs in soybean root nodules and begins when the plant is between the V2 and V3 growth stages and reaches maximum level when the plant is about R5.5 stage.
- Understanding the factors that lead to nodulation failure can help avoid N deficiency and potential yield reduction in soybean.

As soybean planting season approaches, farmers may be thinking of planting a field that is new to a soybean crop or has been out of soybean production for several years. These situations may cause concerns in achieving enough root nodulation for an adequate N fixation throughout the growing season, which may reduce yield potential.

How Nodules Are Formed?

For successful atmospheric N fixation to occur, adequate populations of soil N-fixing bacteria (*Bradyrhizobia 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.

About 10 to 14 days later, or until the V2 to V3 stage, the N fixation process occurs in the nodule.[1] Rhizobium bacteria convert atmospheric N to ammonium (NH_4), which is a form of N 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 N fixed is maximized around the R5.5 (midway between R5 and R6) stage, subsequently they begin to turn a dark black color and die.[1, 2]

Nitrogen Fertilization

The application of N fertilizer to soybean crop is not recommended, as it generally does not increase yield potential;[1] The greater the supply of N in the soil, the less N fixation occurs. As the amounts of applied N increase, the number of nodules decreases and the bacteria become less active[2]; however, 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 is recommended.[5] Research has shown conflicting results regarding late-season N applications, except when N was applied via irrigation system produced more than 60 bushels per acre.[5]

Figure 1. Yellow leaves due to temporary N deficiency caused by wet soil and lack of nodulation.

Nodule Viability Assessment

Dig up a few (at least 10) soybean plants, without pulling to avoid nodules stripping off the roots, after the second or third trifoliate has emerged. 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 2). Nodules found on the tap roots are probably the result of the current season's inoculation, while nodules developed on the lateral roots are from rhizobium bacteria existing in the soil. New nodules are formed during much of the life of the plant, ending during pod-filling.

If the internal tissue of a dissected nodule is pink to red in color, the nodule is active and N fixation is occurring. Nodules that are green, brown, or musty are not fixing N, while immature nodules are small, white, and have yet to fix N.

Figure 2. Comparison between (L) a well nodulated plant and (R) a poorly nodulated plant. Photo courtesy of Stu Duncan, Kansas State University.

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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.

When Inoculants Are Needed?

There is no need for re-inoculation if soybean seed is going to be planted into fields that recently had a soybean crop and the plants were well nodulated. Research on soybean seed inoculants shows a 2.1 bushel per acre and a 0.9% protein advantage with inoculation compared to non-inoculated;[4] Therefore, inoculants are necessary and can have a positive impact in the following situations:

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

- Field has no previous history of soybean production (Figure 3).
- Soil pH is below 6.0. Greater response from inoculants can be expected in fields with a pH below 6.0.
- Field that has been flooded for several days can create anaerobic conditions for the rhizobia.
- Compaction and cool soil temperatures, due to no-till practice, can reduce nodulations.
- Fields with sandy soils, low organic matter (less than 1%), need to be inoculated every year.[2] 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 from a previous forage legume, such as alfalfa and clover, or due to manure application.

  Applying inoculants to the seed and soil can potentially increase nodulation in a first-year soybean crop. Also, in fields without a long history of soybean production, consider planting a soybean crop for two consecutive years and inoculating both times.[3]
- Poor quality inoculants due to improper storage time and conditions.

  Follow the inoculum expiration date and proper storage conditions to preserve the inoculant's viability. Additionally, avoid exposing inoculum to direct sunlight or excessive heat.
- 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 chlorosis deficiency (ICD) symptoms early in the season (Figure 4).
- Soil pH levels below 6.0 or above 8.0.[3]
- Soil compaction can limit rooting and the development of root hairs that are hosts for rhizobia to colonize and develop root nodules.


Figure 4. Iron deficiency symptoms in susceptible soybean products.

Symptoms of inadequate nodulation include yellowing and stunting of soybean plants. Timely application of between 60 to 70 pounds of actual N per acre can correct the deficiency and may provide an economic return of up to 10 bushels per acre.[3] Supplemental N should be applied when 50% of the plants are between R1 and R2 stage or when there is one open flower on one of the upper two nodes of the main stem.

Because urea-ammonium nitrate (UAN) solutions can damage the foliage, they should be applied to the soil. If leaves are dry urea can be applied by broadcast without causing injury to the leaves. It is recommended to add a urease inhibitor to urea and 28% UAN to reduce volatilization losses.[3]

Summary

- The symbiotic relationship of a soybean plant with soil rhizobia bacteria converts atmospheric N into usable ammonia (NH_4) within plant root nodules that grow on the root system.
- Between 50 to 75% of the soybean total N requirement is obtained through the N fixation process.
- Provided adequate nodulation and N fixation, soybean plants can grow well in low N soils.
- Generally, there might be no need to inoculate soybean seed if a well-nodulated soybean crop was recently grown.
- Healthy and active dissected nodules are pink to red in color.
- Timely and the method of applications can correct N deficiency.

Sources: [1] Pedersen, P. 2004. When do we need to inoculate our soybean seeds? Integrated Crop Management. Iowa State University, http://www.ipm.iastate.edu (verified 2/20/14); [2] Pedersen, P. 2003. Soybean seed inoculation. Integrated Crop Management. Iowa State University, http://www.ipm.iastate.edu (verified 2/20/14); [3] Staton, M. 2014. Identifying and responding to soybean inoculation failures. Michigan State University, http://msue.anr.msu.edu (verified 2/20/14); [4]Kandel, H. 2012. Soybean nodulation. Crop and Pest Report. North Dakota State University, http://www.ag.ndsu.edu (verified 2/20/14); [5]Larson, K. et al. Successful soybean nodulation without rhizobia. 2012. 344 Agronomy e-Updates, Kansas State University Extension; We would like to thank Dr. Stu Duncan, Kansas State University, for granting permission for the reprint of soybean images.
Other source used: Evaluating soybean nodulation. 2011. Michigan State University Extension, http://msue.anr.msu.edu, (verified 2/20/14).

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