

Soybean Yield Responds Minimally to Nitrogen Applications in Missouri

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Abstract

Interest among soybean (*Glycine max* Merr.) producers in using nitrogen (N) fertilizer for soybean production has been stimulated by recent reports of substantial yield responses to N. We conducted 48 experiments measuring soybean yield response to N over a broad range of soils, genetics, and weather. Nitrogen fertilizer was applied either preplant or at the beginning pod stage. Minimal soybean yield response to N was found. Small responses (approx. 1 bu/acre) to N applied at planting were observed in two groups of experiments: experiments with soil salt pH < 6.0 and experiments with soil nitrate-N < 50 lb/acre to a 2-foot depth. Of five experiments with yields > 60 bu/acre, two responded to N at planting. No yield response to N applied at the beginning pod stage was seen for any group of experiments sharing specific soil or crop factors.

Introduction

Soybeans contain high levels of protein, and therefore of nitrogen. A 50-bu/acre soybean crop contains as much N as a 225-bu/acre corn crop. Soybean plants fix atmospheric N₂, but fixation is minimal for the first month after planting even under conditions of low N availability. High soil N availability (as nitrate) can inhibit formation of nodules (5) and delay N fixation further or even suppress it through the whole season (4).

The lag in formation and activation of the N₂-fixing system suggests that soybean growth might sometimes be N-limited early in the growing season. During early growth, the plant relies on soil nitrate, along with the N stored in the seed. When soil nitrate is low, preplant application of N fertilizer could increase soybean growth and yield. This is exactly what was observed by Lamb et al. (6), who found large yield responses to N fertilizer (average about 5 bu/acre) when soil nitrate was below 75 lb/acre in the top two feet, and little response when soil nitrate was above this level.

However, when soil N availability is adequate, preplant N fertilizer applications might have a detrimental effect by suppressing nodulation. Nitrogen fertilizer applications later in the season may supplement N inputs from fixation while minimizing inhibitory effects on fixation (2). Wesley et al. (9) suggest that at high yield levels, maximum N₂ fixation rates may not be able to keep pace with seed demand for N. They found that irrigated soybean yields were increased by an average of 7 bu/acre (from 55 bu/acre to 62 bu/acre) when N fertilizer was applied at growth stage R3 (beginning pod development). This report has stimulated renewed interest in N fertilization among soybean producers in the midwestern U.S.

These are a few of the highlights of the considerable body of research that has been devoted to studying N fertilizer applications to soybean. Yield response and lack of yield response have both been frequently observed. Understanding the conditions that are conducive to yield response would aid in making the most profitable decision regarding N fertilization of soybean. We graphically combined results reported from 58 previous experiments measuring soybean yield response to N to look for factors favoring yield responses. This analysis suggested that yield increases are favored by:

- yield levels above 60 bu/acre
- application timing at the beginning pod stage
- 2-ft soil nitrate < 75 lb/acre
- soil pH > 7.5
- irrigation

Our objective was to estimate the frequency of soybean yield response to N in Missouri and to elucidate the effects of yield level, application timing, soil nitrate, and soil pH on this response.

Methods: 48 Experiments Across Six Years in Missouri

We conducted 48 experiments from 1996 to 2001 to measure the effects of N fertilizer application on soybean yield in Missouri. Twenty-eight of the experiments were in producer fields, and twenty were conducted at five research farms. Experimental locations are shown in Fig. 1. All major soybean-growing regions of Missouri are represented, along with a broad range of soils typically used for soybean production.

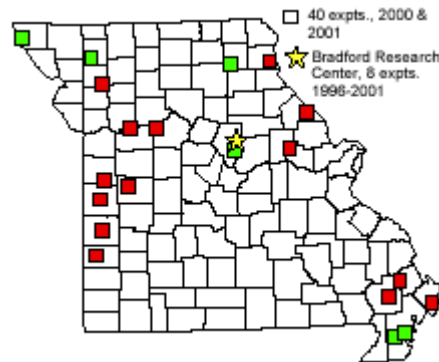


Fig. 1. Forty-eight experiments measuring soybean yield response to N fertilizer were spread widely around Missouri. Twenty farms (squares) had experiments in 2000 and 2001. Experiments in producer fields are shown in red; those at experiment stations are shown in green. Fields used in 2001 were different than fields used in 2000. The other eight experiments were conducted at the Bradford Research Center (star) from 1996 to 2001. A wide range of genetics, soils, production practices, and climate were represented.

One well-adapted cultivar was chosen for each of the 48 experiments. Cultivars used at more than one location included Asgrow 3701, Pioneer 93B82, Novartis S46-W8, Pioneer 9594, Asgrow 3302, Pioneer 94B01, Asgrow 4301, and Asgrow 4403. A seeding rate of 174,000 seeds per acre planted in 30-inch rows was used for all experiments. Average planting date was May 14, and ranged from May 1 to June 12. Some form of tillage was used in 38 of the 48 experiments, and 10 of 48 received sprinkler irrigation. The previous crop was corn in most experiments, with previous crops of soybean, rice, and cotton in a few locations.

For 40 experiments in 2000 and 2001 (including all 28 experiments in producer fields), there were three N application treatments: untreated control, N applied at planting, or N applied at growth stage R3 (beginning pod development). Nitrogen was hand-applied as ammonium nitrate at a rate of 25 lb of N per acre. This N rate was chosen because our literature survey revealed no significant effect of N rate on yield response to N (380 data points from 58 published experiments with N rates from 20 to 300 lb/acre were used for this analysis), and a low N rate would increase the likelihood of the treatment being economical for producers. A randomized complete block design with five replications was used, but two untreated control plots were included in each

replication. Plots were 25 ft long by 10 ft (four 30-inch rows) wide. At harvest, plots were trimmed to 20 ft in length, the center two rows of each plot were harvested with a plot combine, and yields were adjusted to 13% moisture. From each experimental area, 15 soil cores were taken to a 3-foot depth (depth increments of 0 to 6, 6 to 12, 12 to 24, and 24 to 36 inches) before planting, mixed, and analyzed for nitrate-N, ammonium-N, and salt pH (measured in a 1:1 paste of soil and 0.01 M calcium chloride) (this is the standard pH measurement for the University of Missouri Soil Testing Lab).

The other eight experiments were conducted on the Bradford Research Farm near Columbia, Missouri, and included additional treatments such as additional application timings or forms of N fertilizer. In this report, only results from ammonium nitrate applied at planting or at growth stage R3 are included in accordance with the other 40 experiments. Nitrogen rates ranged from 45 to 90 lb/acre in these experiments. When more than one N rate was used, yield results were combined across N rates. Details of planting, harvest, and experimental design were the same as the group of 40 experiments, except that only four replications were used, and only one untreated control was included in each replication. Soil samples (0- to 6-inch) were taken from two of these experiments and analyzed for nitrate-N.

Analysis of variance was used to determine whether a significant response to N fertilizer occurred at each experimental location. Linear regression was used to model the relationship between site variables (control yield, soil nitrate-N, soil ammonium-N, soil pH) and the apparent yield response to N (= yield with N - yield without N). A *t*-test was used to test whether yield response to N was different from zero over all experiments and for sub-groups with low soil nitrate-N and low soil pH.

Yield Levels

Average control yield over all 48 experiments was 47.5 bu/acre. This is a good yield for soybean in Missouri and indicates good production practices along with generally favorable growing conditions. The only experimental locations that experienced poor growing conditions were five experiments conducted in southwest Missouri in 2000, where drought stress limited yields to between 25 and 32 bu/acre.

Overall Response to N. Overall, minimal yield response to N applications was observed. Average yield response to N applied at planting was 0.5 bu/acre (a *t*-test indicates 90% probability that this was a true yield response) over the 48 experiments. Average yield response to N applied at the beginning pod stage was -0.01 bu/acre. Delaying N application timing until beginning pod clearly did not enhance soybean yield response to N in our experiments, as we had hypothesized based on our summary from a large group of experiments in the literature. However, the results of that summary were heavily weighted by the large yield increases from a single set of experiments (9) in which N was applied at the beginning pod stage.

It would not have been profitable to apply N (either timing) to the whole group of experiments. Recent results from twelve experiments in Minnesota (7) and three experiments in Virginia (3) also found that N applied to soybean at reproductive growth stages was not profitable.

We looked for site factors that would help identify and predict fields where soybean yield responded to N. We found evidence that yield response to N applied at planting was more likely where:

- soil pH was low (Fig. 2);
- soil nitrate was low (Fig. 3).

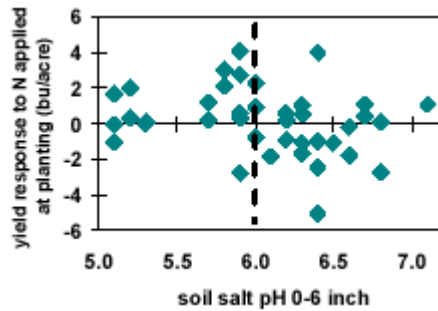


Fig. 2. At soil salt pH below 6.0, we observed an average yield response to N of 0.9 bu/acre ($P = 0.05$ by t -test). This may be related to negative effects of acidity on the nodulation process.

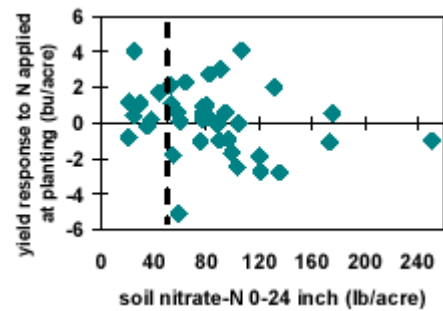


Fig. 3. At soil nitrate levels below 50 lb/acre, we observed an average yield response to preplant N of 1.0 bu/acre ($P = 0.11$ by t -test). Researchers in Minnesota have also observed that yield responds to preplant N mainly when soil nitrate is low (6), but their yield responses ranged up to 8 bu/acre.

However, even in these situations, yield response was small and we did not find any compelling economic benefits from N fertilizer applications to soybean in Missouri.

Response to N at Sites with Low Soil pH. Yield response to N applied at planting was greater at sites with lower soil pH (Fig. 2) with 85% probability based on regression analysis. Considering only the group of 16 experiments with salt pH less than 6.0 (water pH less than approximately 6.5), average yield response to N at planting was 0.9 bu/acre. A t -test indicates that there is a 95% probability that this was a true yield response. Sorensen and Penas (8) also found evidence that soybean yield response to N increased as soil pH decreased over a range of soil pH values from 6.9 to 5.7. This might be explained by inhibition of soybean nodulation at low pH (1). The soil pH values in our fields (salt pH from 5.1 to 7.1, roughly corresponding to water pH values from 5.6 to 7.6) were not low enough that they would be expected to severely inhibit nodulation. Based on this possible mechanism for soybean response to N, only small responses would be expected in our experiments.

Although small yield responses were measured for N applied at planting in fields with low soil pH, these fields did not respond to N applied at the beginning pod stage. If low pH reduces nodulation, it might be reasonable to expect a response at either stage. Low pH can also delay the onset of nodulation (1), so early N deficiency may explain why early N applications produced yield responses.

Several past studies have found large yield responses to N in experiments with soil pH above 7.5 (6,9). Only one of our experiments had pH that high. In that experiment, apparent yield response to N at planting was 1.1 bu/acre (not statistically significant).

Response to N at Sites with Low Soil Nitrate. We found evidence (89% confidence by t -test) of a small yield response (about 1 bu/acre) to N applied at planting when soil nitrate-N was below 50 lb/acre in the top 2 feet of soil (Fig. 3). Researchers in Minnesota observed larger yield responses, from 4 to 8 bu/acre, whenever soil nitrate-N in the top 2 feet was less than 75 lb/acre (6). One possible reason for larger yield responses to N in Minnesota than in Missouri when soil nitrate is low is that fast early-season growth may be more important in Minnesota where the growing season is shorter. There was no relationship between soybean yield response to N applied at the beginning pod stage and soil nitrate.

Response to N at High-Yielding Sites. Five experiments had control yields above 60 bu/acre, and 23 experiments had control yields above 50 bu/acre. We did not find any evidence of response to N applied at the beginning pod stage at our highest-yielding locations, our irrigated locations, our highest-yielding irrigated locations, or in any group of experiments. Thus, our results do not support the suggestion of Wesley et al. (9) that the N-fixation process may not be able to keep pace with demand for N during the grainfill period in high-yielding soybean crops. However, the amount of N contributed by soil during grainfill may vary over fields or regions, and so affect whether N demand can be met without N fertilizer.

Our results indicated that there were situations where yield responded to N at planting at our highest-yielding locations. Of the five locations with yields above 60 bu/acre, two had yield responses of approximately 4.0 bu/acre to N applied at planting ($P = 0.07$ and 0.11 by t -test), while the other three locations were not responsive. One of the responsive locations had very low soil nitrate-N at planting, 26 lb/acre to a 2-foot depth. One possible explanation is that early N application at this location speeded canopy development in a way that made higher yields possible. We do not have any canopy measurements that could be used to evaluate this idea. The yield difference between plots receiving N at planting and check plots was, on average, 1.6 bu/acre for the five locations with yield above 60 bu/acre (Fig. 4). This estimate cannot be considered a reliable average, but even if this estimate is accurate, it would indicate little or no economic benefit to applying fertilizer N to all high-yielding fields at planting.

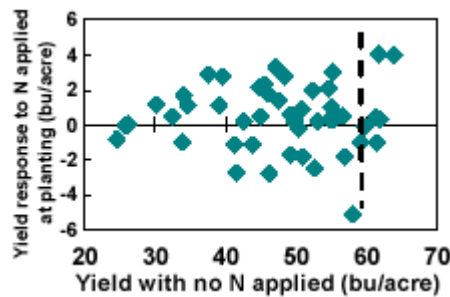


Fig. 4. The literature suggests that soybean yield response to N is more likely at yield levels above 60 bu/acre. Only five of our 48 experiments had yields above 60 bu/acre. None of the five had a significant yield response to N applied at beginning pod, but two of the five had a 4.0 bu/acre yield response to N applied at planting ($P = 0.07$ and 0.11 by t -test). No trend toward larger yield responses at higher yield levels was seen using regression analysis.

Summary

Forty-eight experiments were conducted measuring soybean response to N applications, including experiments in producer fields (28 experiments) and at experiment stations (20 experiments); across a wide range of genetics, soils, production practices, and weather; and with N applied either at planting or at the beginning pod stage. Yield responses to N fertilizer were minimal. Over all sites, response to N applied at planting was 0.5 bu/acre. A 1 bu/acre response to N applied at planting was seen for sites with soil salt pH less than 6.0, and for sites with soil nitrate less than 50 lb/acre in the top 2 feet. At two locations out of five with a control yield of above 60 bu/acre, response to N applied at planting was 4.0 bu/acre. No response to N applied at the beginning pod stage was observed over all sites or for any sub-group of sites sharing particular properties.

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