NITROGEN FERTILIZER ON SOYBEANS: ARE WE MAKING PROGRESS?

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INTRODUCTION

The recent drop in the price of soybeans has dampened enthusiasm for applying inputs of uncertain value to crops, but application of fertilizer N during the season is often reported by soybean yield contest winners as a way to increase yields, and some producers have adopted this as a practice.

As soybean yields have increased, the amount of N required by the crop has increased. Soybean seed with 36 percent protein is about 5.75% N, and a bushel of soybean grain contains about 3 lb. of N. The N harvest index (portion of total N uptake that is in the seed at maturity) is about 0.72, so the crop takes up about 4.2 lb. N for each bushel of soybean produced. A soybean crop yielding 60 bushels per acre takes up about 250 lb. of N per acre, and removes from the field about 180 lb. of N per acre. This N comes both from biological N_2 fixation (BNF) and from soil N supplied by mineralization and N fertilizer, usually that left over from the previous crop.

Soybean BNF rates vary widely depending on soil moisture, texture, and organic and inorganic N (Schipanski et al., 2010); BNF is generally estimated to provide 50 to 60% of the N that the soybean crop needs (Salvagiotti et al., 2008). Coarse-textured soils tend to be low in organic matter, and so soybeans grown in these soils may be more dependent on BNF than are soybeans grown in more productive soils. Two published experiments on coarse-textured soils with low organic matter showed that N fertilizer provided an economic yield increase (Wesley et al., 1998; Wood et al., 1993). In heavier soils, plant growth and BNF may be better-supported, but saturated soil may decrease the BNF rate more than dry matter accumulation (Bacanamwo and Purcell, 1999), and so assimilate supply may not always limit BNF.

Soil N mineralization rates also vary considerably within and among fields and among seasons. It is estimated that about 2% of soil organic N might become available in a typical year from mineralization, meaning that a soil with 3% organic matter in the top 7 inches might supply about 60 lb. of mineralized N (Fernandez et al., 2009). It is well-known that BNF rates are decreased in the presence of nitrate-N form fertilizer or mineralization. Still, when soil N supply or BNF rate is low, soybeans may not be able to take up enough N to meet the requirement for high yields. High soybean yields are, however, often achieved under conditions of temperature and soil moisture that are conducive to both soil N mineralization and BNF, which suggests that soybean yield level alone may be an inadequate basis on which to predict a response to supplemental N fertilizer for soybean.

Even though a high-yielding soybean crop requires uptake of a lot of N, crop responses to fertilizer N have been rare, and responses large enough to pay for this practice have been even rarer (Barker and Sawyer, 2005; Gan et al., 2003; Schmitt et al., 2001). One study conducted in the southern US showed that supplemental N fertilizer increased soybean yield by 12% compared to the control, but that yield levels, which ranged from 32 to 80 bushels per acre, had no effect on the response to N (Ray et al., 2005.) Salvagiotti et al. (2008) reviewed published soybean N experiments from around the world and found that of some 1,300 individual N trials, only 16% showed a yield response to N, with the average yield increase among responsive trials of about 7.7 bushels per acre. Most of the responsive trials were clustered in certain areas; for example, one report showed a response in 31 of 64 trials, while another showed no response in any of 54 trials. Responses were not closely tied to yield level among trials, either within or across regions.

We undertook a series of experiments to see if soybeans would respond to in-season fertilizer N and to see if responses were related to soybean yield level. We also, in 2015, undertook trials at several Illinois locations to see if N response might be greater in soils with lower organic matter, and to see whether N levels of plants and soils at different times during the season are affected by application of fertilizer N. Our primary goal was to find out if

MATERIALS AND METHODS

Between 2010 and 2014 we ran a series of trials in which fertilizer N, at rates ranging from 45 to 150 lb. of N per acre; forms including urea, ESN, and urea with Agrotain®; and applications times ranging from R1 to R4, with some split-applied, was applied to soybeans in small-plot trials over a range of Illinois sites. Sites were on University of Illinois Crop Sciences research centers, with soils textures ranging from silty clay loam with more than 3.5% organic matter to silt loam with less than 2% organic matter. Some of these trials included other variables in addition to N, in which case appropriate controls were used to compare to N-treated plots. Most trials had four replications. Yields were taken with a plot combine.

We conducted a more detailed study at four research center sites in 2015. Soils at these sites included a sandy loam with less than 1% organic matter at Chillicothe, which was also irrigated; silt loam with less than 2% OM at Brownstown; and silt loam soils with 3.5 to 4% OM at Monmouth and Urbana. Urea was applied at the rate of 100 lb. N per acre at planting, R1, R3, or R5; at both R3 and R5 (total of 200 lb. N/acre); and at all four timings (total of 400 lb. N/acre). A plot without soybean plants was included in order to monitor soil N in the absence of plant uptake. One-third of this fallow plot received no N, one-third got 100 lb. N at planting, and one-third had 100 lb. N applied at R3.

Soils in two of the four reps at each site were sampled at depths of 0 to 1 ft. and 1-2 ft. at planting, and at R1, R3, R5, R6, and at maturity, adding treatments after N had been applied. Soil samples were analyzed for both nitrate and ammonium by a commercial lab. Values in ppm were averaged over forms and depths and multiplied by 8 to give approximate lb. soil N per acre. At each sampling time beginning at R1, 8-plant samples were taken in each plot, dried, weighed, and analyzed for total N.

RESULTS AND DISCUSSION

Yield

Among 33 trials Illinois conducted between 2010 and 2014, we found a significant, positive response in two trials, and no significant effect of N fertilizer on yield in the other 31 trials (Figure 1). The only yield differences that were statistically significant were the two yield increases of about 6 bushels per acre. The average response over all of the trials was 0.5 bushels per acre. We find no indication that higher-yielding soybeans tended to respond more to N fertilizer; the overall regression is negative but weak ($r = -0.21$; $Pr>F = 0.24$), and the two significant yield increases occurred at one average- and one above-average-yielding site.

Yield responses to applied N at some sites were considerably larger in 2015 than we had seen in previous years (Table 1). This was not the case at Monmouth, where the only treatment that produced a higher yield than the check was application of 400 lb. of N per acre in four, 100-lb. increments. The ammonium sulfate treatment decreased yield at this site due to leaf damage following application of the material when the foliage was wet with dew. This occurred at Chillicothe as well, but at this site we saw a 22.4-bushel yield increase from application of N at planting time, and an additional 4.8 bushels when the planting-time application was followed by an additional three increments of N (at 100 lb. each) later in the season. Yields were not significantly higher than those of the check for the other in-season urea applications, but they averaged more than 7 bushels higher than the check, and if as a group they yielded significantly more than the check.

At Urbana, we found modest but significant yield increases of 5 bushels per acre for the 200- and 400-lb. treatments (N applied two or four times, respectively), but no effect of single N applications on yield (Table 1). Application of N at planting time decreased yield at this site, possibly due to a negative effect of N on nodule formation or activity. Adding 300 lb. N later in the season after 100 lb. N at planting appears to have overcome any negative effect of N at planting. At Brownstown, a site chosen in part because soybeans grown in lower-OM soil there might tend to show more response to fertilizer N, panting-time N tended to decrease yields, whether or not this was followed by three more increments of N later in the season. Applying 100 lb. N at R3 significantly increased yield at this site, but application at R1 or R5 did not affect yield.

Soil and plant nitrogen

Relatively little N was present at planting at Urbana, and with the soybean crop present but without fertilizer N, soil N changed little over the period of reproductive development (Figure 2). Soil N values of about 5 ppm (40 lb. N per acre) would be considered background in this soil. Adding 100 lb. N at planting raised soil N only slightly during the reproductive period except at R6, at which stage we recovered 176 lb. N. We have no good explanation for this spike; it may be that rainfall before this sampling time resulted in a flush of N. Without soybean plants present and with no added N, soil N levels rose gradually from stage R1 to stage R6, then dropped by maturity (R8). When 100 lb. N was added at planting to soil without the crop present, soil N levels were about 60 lb. per acre higher than without added N at R1, but diminished after that to levels similar to those without the crop present and no added N. Some N was likely lost under the wet conditions in June; by maturity the amount of soil N without a crop was about double that found where a crop was present, but was still only about 85 lb. N per acre.

In soybeans without fertilizer N at Urbana, plant N content rose rapidly during reproductive growth, from 39 lb. at R1 to 420 lb. N per acre at R6, before dropping to 314 lb. at R8 (Figure 3). Plant N at R6 was not increased by adding fertilizer N; in fact, plant N content was numerically (but not statistically) lower at both R6 and at R8 for all three fertilizer N treatments than without fertilizer N. Adding N fertilizer four times produced plants with only 361 and 227 lb. N per acre at R6 and R8, respectively, even though yield was higher (by 5 bushels per acre) in this treatment. Plant N across treatments averaged only about 275 lb. per acre at R8, close to the 3 lb. N per bushel we would expect to find in seed by itself. It’s not clear why this amount was low.

On the irrigated sandy loam soil at Chillicothe, soil N at planting was higher than at Urbana, (Figure 3), perhaps due to earlier soil warmup. The trend is soil N with soybean plants present was not unlike the trend at Urbana but without the spike at R6. Soil N levels remained low in plots with soybeans present whether or not fertilizer N was applied, indicating that the crop was taking up N as it became available. In plots without soybean plants and with fertilizer N at planting, soil N spiked at R5 and remained elevated up to crop maturity. It's possible that this spike came after rainfall, then levels remained elevated with drier weather late in the season.

At Chillicothe, where 100 lb. N at planting increased yield by more than 22 bushels per acre, we found that adding fertilizer N raised the amount of N in the plant at R6, from 264 lb. N per acre without N to 386 lb. N per acre with received fertilizer N (Figure 5). Treatments with 100 lb. N applied at R1 and applied four times had 319 and 321 lb. N per acre, respectively, in the plants at R6. This difference at R6 did not carry through to maturity; plants that did not receive N showed an increase in plant N content from R6 to R8, and had more N in the plants at R8 than did the treatments that received fertilizer N.

The larger amount of plant N at R6 is the major effect resulting from fertilizer N application that we found in this study, and it occurred at the site where N application produced a large yield increase. At this site, plants with N fertilizer applied at planting were noted to be greener and to grow more vigorously than those without fertilizer N, and it may be that these larger plants were simply better able to expand their root system or support nodules than were unfertilized plants. We did not do nodule counts, but there was a considerable amount of rainfall during the weeks following planting and N application, and it's likely that much of the applied N moved down in this well-drained soil and may have been too low to interfere with nodule formation and function.

While it's interesting that we found an instance in which N fertilizer applied to soybeans increased both yield and plant N at a specific stage, finding little or no response to N remains far more common than finding a response. We are a long way from learning when, on what soils, and at what application time or rate N fertilizer use on soybean might be consistently profitable.

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Table 1. Soybean yields following in-season applications of N at four sites in Illinois in 2015. With the exception of the last treatment (AMS = ammonium sulfate) all applications were done using broadcast urea, and 100 lb. was applied in each application. Yields followed by the same letter within each site were not statistically different at p=0.1.

Treatment	Monmouth		Chillicothe		Urbana		Brownstown	
	---------------------------bushels per acre-----------------------------							
No N applied	79.6	bc	63.9	bc	91.1	b	61.1	bc
At planting	79.9	b	86.3	a	85.8	c	56.6	c
R1	79.1	bc	71.8	b	92.0	ab	58.4	bc
R3	79.0	bc	71.6	b	92.5	ab	67.1	a
R5	77.8	bc	71.3	b	91.5	b	62.3	ab
R3+R5	76.9	c	71.3	b	96.1	a	62.2	ab
Pl+R1+R3+R5	83.1	a	91.1	a	96.1	a	56.2	c
AMS at R3	64.5	d	57.9	c	89.0	bc	61.4	bc

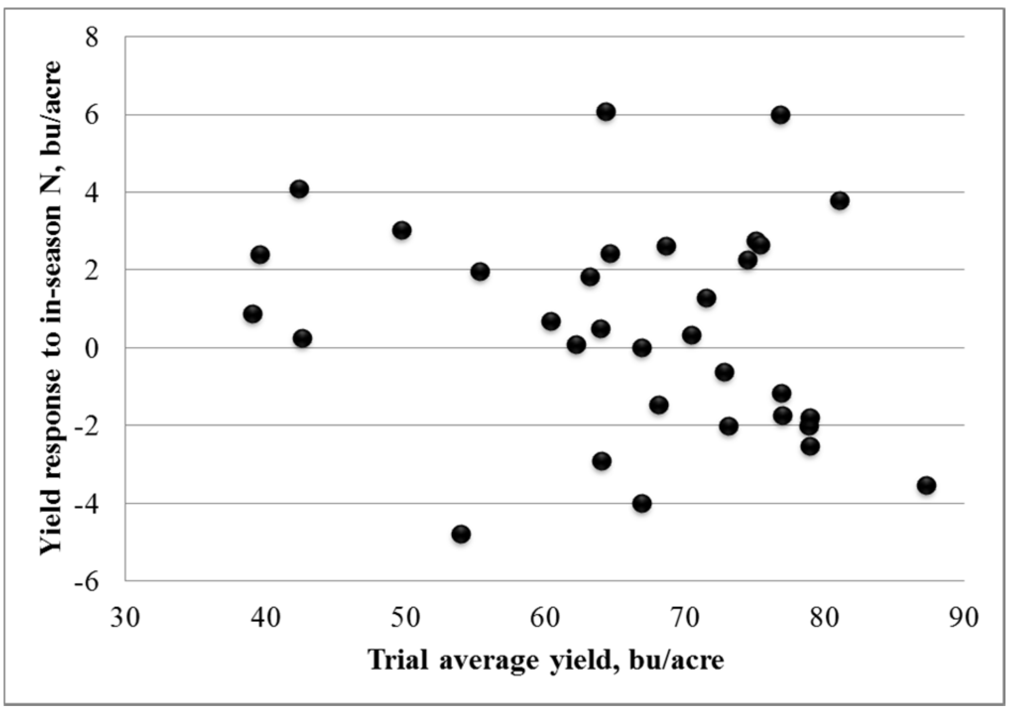

Figure 1. Response of soybean yield to in-season application of fertilizer N in 33 trials conducted between 2010 and 2014 in Illinois. The only statistically significant differences (at p=0.1) are the two differences of about +6 bushels per acre.

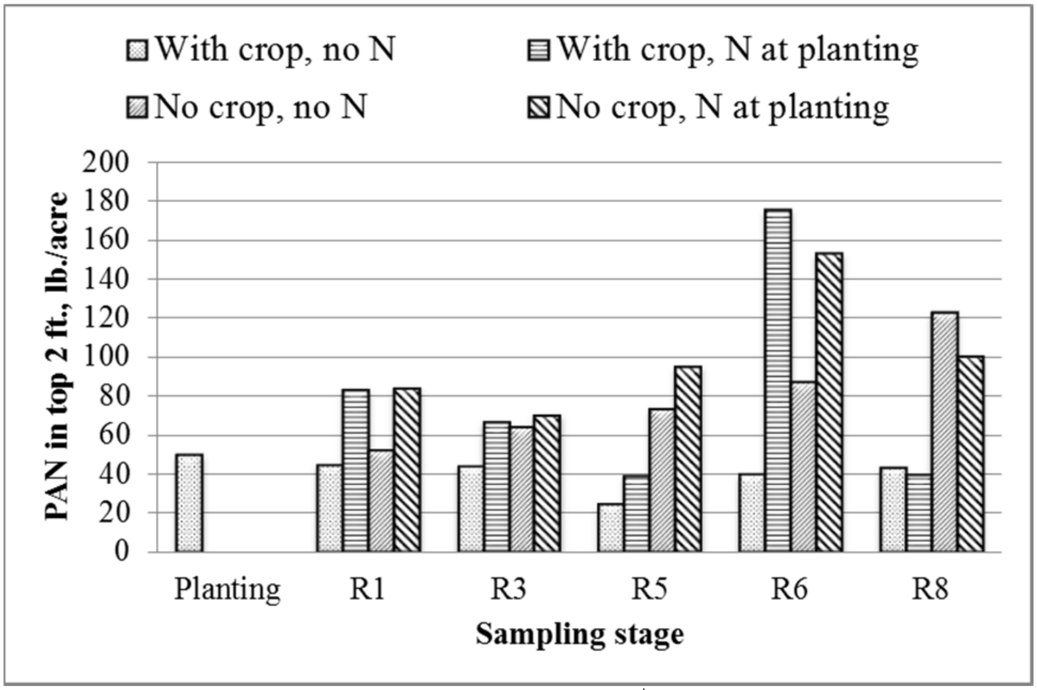

Figure 2. Plant-available N (PAN, extractable NO_3^-+ NH_4^+) in the top 2 ft. of soil with and without soybean plants and with and without 100 lb. N applied at planting in silt loam soil at Urbana in 2015.

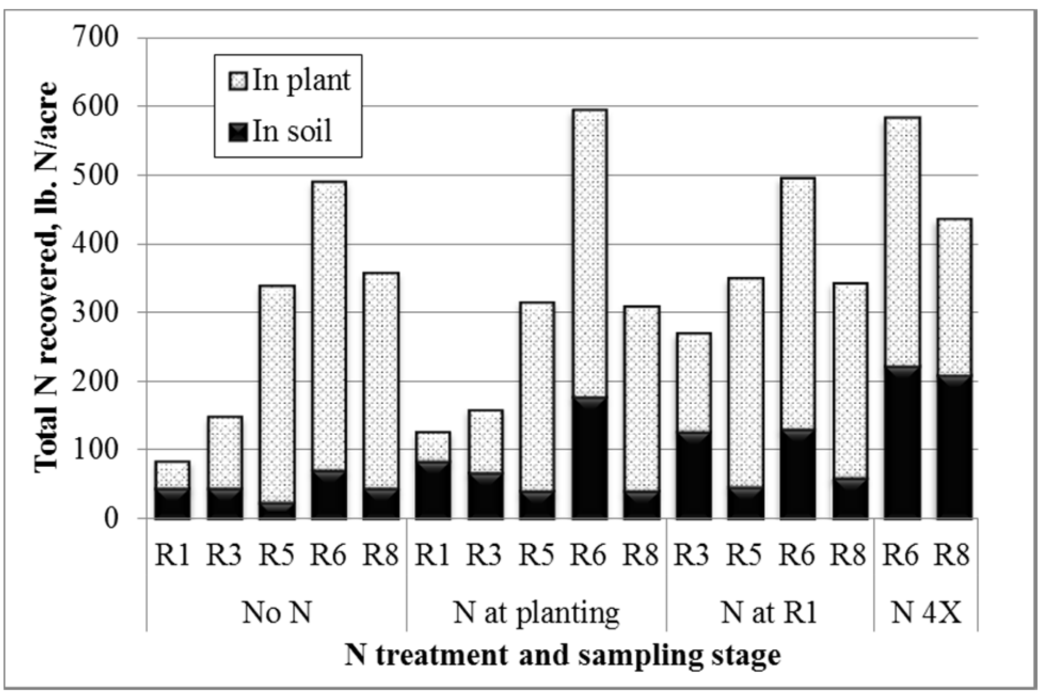

Figure 3. Nitrogen recovered from plants and soil sampled at reproductive stages of soybean with different fertilizer N treatments at Urbana, 2015.

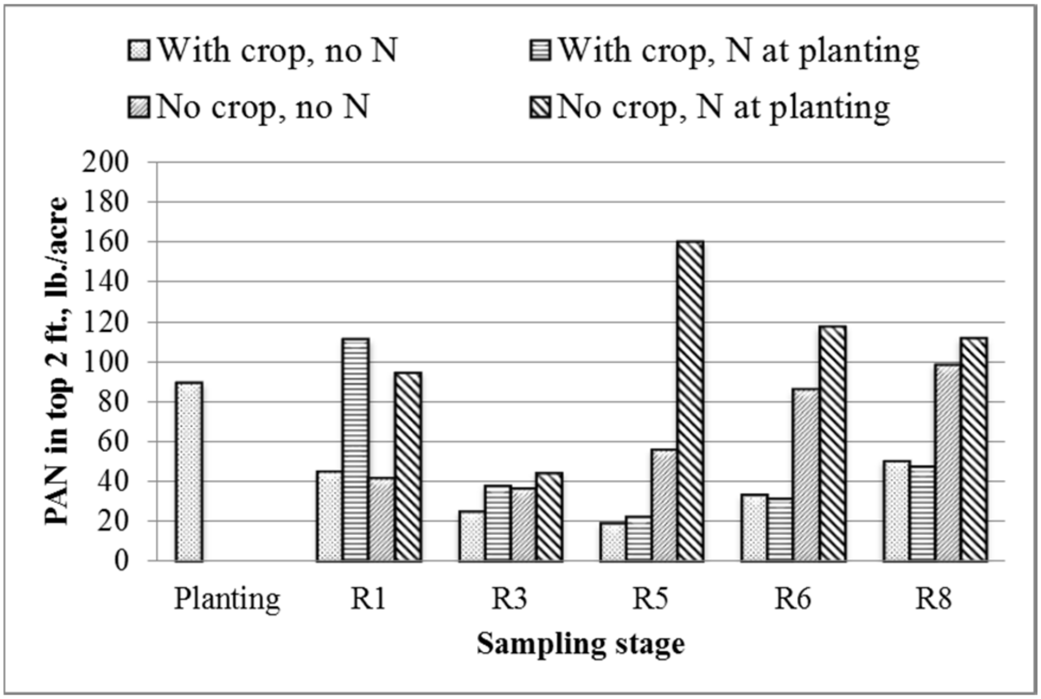

Figure 4. Plant-available N (PAN, extractable $NO_3^- + NH_4^+$) in the top 2 ft. of soil with and without soybean plants and with and without 100 lb. N applied at planting in irrigated sandy loam soil at Chillicothe in 2015.

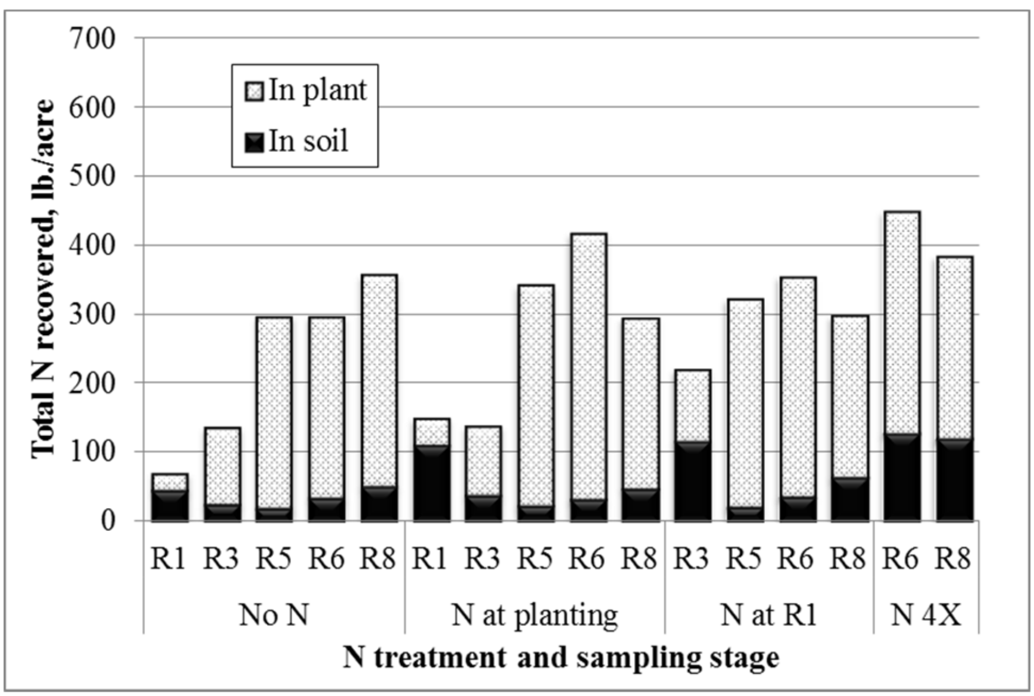

Figure 5. Nitrogen recovered from plants and soil sampled at reproductive stages of soybean with different fertilizer N treatments at Chillicothe, 2015.

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