SOIL FERTILITY

Nitrogen Application to Soybean at Early Reproductive Development

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ABSTRACT

Nitrogen application during soybean [*Glycine max* (L.) Merrill] reproductive stages has the potential to increase soybean productivity. The objective of this study was to determine the impact of N fertilizer applied to the soil at the beginning pod growth stage on soybean yield and grain quality. Additional objectives were to study alternative N fertilizer and application practices that might enhance soybean use of applied N. A field study was conducted at five locations in Iowa during 1999 and 2000. Nitrogen treatments were urea and polymer-coated urea broadcast and subsurface band placed between the rows at 45 and 90 kg N ha^{-1} and a no-N control. The study showed few, small, and inconsistent effects of N material, placement, and rate on grain yield and quality components at individual sites or when combined across individual sites. There were no significant effects on grain yield, with only a 39 kg ha^{-1} increase from applied N. Grain protein, oil, and fiber concentrations were the same with or without N application. Aboveground plant dry matter (DM) at the R6 growth stage was greater with the higher N rate, but plant DM with N application was lower than the no-N control. Nitrogen concentration in plant DM was significantly increased with applied N. In conclusion, N application increased N concentration in R6 soybean plants, but N rate and alternative application practices had no positive effect on plant DM, grain N concentration and removal, grain yield, or grain quality components. It was concluded that growers should not consider fertilizer N applied to soil during early reproductive stages as a method to increase soybean yield or grain quality.

Interest in N fertilization of soybean has grown in the U.S. Midwest during recent years. Demand for high grain quality, recognition of large N requirement for seed fill, and new varieties with high yield potential are renewing interest in this nontraditional management practice. Soybean uses biological N_2 fixation to produce approximately half of its total N requirement (Harper, 1987). The remaining N is derived from soil inorganic N, mineralized organic matter, or residual N from the previous crop. Soil nitrate is the main N source utilized up to the beginning pod growth stage (R3) (Pedersen, 2004), with crop use depleting soil inorganic N. Nitrate utilization and reductase activity drops rapidly at this time (Shibles, 1998). Soil nitrate availability is therefore related to the length of the inorganic N utilization period. Significant N use does not occur from N_2 fixation until approximately beginning bloom (R1), increases in the late full-bloom stage (R2) and R3 stages, and continues slightly beyond the beginning seed stage (R5) (Harper and Hageman, 1972). It has been shown that high soil nitrate levels delay *Bradyrhizobia* spp. infection and nodulation, thus reducing N_2 fixation capacity (Shibles, 1998). Application of N before planting or during the early growth stages can suppress the N_2 fixation process. Fertilizer N applied during soybean reproductive stages (R1 to R5) might increase the capacity and duration of the inorganic N utilization period while maintaining N_2 fixation.

A study conducted in Kansas with irrigated soybean found significant soybean yield response when N was applied between the R3 and full pod stage (R4) (Wesley et al., 1998). Their work showed an average yield increase of 464 kg ha^{-1} at six of eight sites. The two nonresponsive sites had low yield, below 3360 kg ha^{-1}. Nitrogen application did not enhance grain protein and oil. This study suggests that in soybean with high yield potential (3700 kg ha^{-1} or greater), 22 kg N ha^{-1} would produced a positive yield response. Gascho (1993) in Georgia studied a variety of N application treatments on irrigated soybean with high yield potential (3360–3695 kg ha^{-1}) at the R3 to R5 growth stages. Nitrogen increased yields by more than 340 kg ha^{-1} on sandy soils and up to 340 kg ha^{-1} on loamy soils over a period of 5 yr. Afza et al. (1987) conducted a study with N application during the R4 growth stage. The plants translocated 40 to 67% of applied N into the pods and resulted in a significant seed yield increase. Results also showed that lower N rates (less than 40 kg N ha^{-1}) did not inhibit N_2 fixation. Studies showing positive response to N application have suggested that yield increases are limited to irrigated systems with high yield potential.

Swine manure applied as an N source during soybean reproductive stages has also produced positive yield increases. Anderson (1998) applied fertilizer N at the R1 growth stage and liquid swine manure in three weekly to 16-d intervals at R1 and middle reproductive stages. Grain yield increases of 8% occurred with the manure treatments but not the fertilizer N application. Furthermore, manure inhibited nodulation less than the fertilizer N treatment. An explanation proposed by Anderson (1998) for this result was that the swine manure provided a slow continuous release of N during seed filling, and soybean absorbed manure ammonium before nitrification.

Schmitt et al. (2001) evaluated in-season N applications on soybean in Minnesota. Treatments of urea and polycoated urea applied broadcast and in subsurface bands increased soil nitrate (0- to 30-cm depth) at the full seed stage (R6). Nitrogen did not increase grain yields but slightly increased seed N removal and grain protein. The overall conclusion was that N applied during the soybean reproductive stages would not increase yield and was not a recommended practice. Research

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Abbreviations: DM, dry matter.

in Virginia on irrigated soybean revealed a consistent lack of response to N applications during reproductive stages (Freeborn et al., 2001). They reported no significant effect with yields ranging from 2400 to 5300 kg ha^{-1}. Beard and Hoover (1971) also concluded no benefit to N application during the R2 stage on irrigated soybean. This contradicts some studies that have achieved yield responses in irrigated systems. Other studies throughout the U.S. Midwest have found increased soybean yield through in-season N applications, but the response has been small, inconsistent, and not always economical (Welch et al., 1973; Oplinger and Bundy, 1998; Randall and Schmitt, 1998). Research with double-crop soybean systems in Kentucky and Virginia found variable and infrequent yield responses and concluded in-season N application is not economical due to small yield increases (Reese and Buss, 1992; Judy and Murdock, 1998).

Previous research has shown the potential exists under some conditions to increase soybean grain yield with in-season N application. The main objective of this study was to determine the effect of N fertilizer applied to the soil at the beginning R3 growth stage on soybean grain yield and grain quality components. Additional objectives were to study N rate, slow-release N, and concentrated fertilizer placement practices that might enhance soybean use of applied fertilizer N.

MATERIALS AND METHODS

A field study was conducted at five Iowa State University Research and Demonstration Farms in 1999 and 2000. The sites represent predominant soils and soybean production areas of Iowa (Table 1). Sites were in a corn (*Zea mays* L.)–soybean rotation, with corn grown the previous year. Tillage practices were predominantly fall chisel plow, spring disc, and field cultivation before planting. Research at Lewis, however, was managed with no-tillage (Table 1). Plot areas were selected where recommended N rates were applied to corn in prior years and with no manure history. Plot size was six or eight 76-cm rows by 15 m in length. All experiments were planted with varieties chosen by the farm manager and adapted for the geographic area. Cultural practices were typical of the region.

Fertilizer N treatments included a no-N control and a combination of two materials, two placements, and two rates applied approximately at the end of the R2 and beginning R3 growth stages (usually the last week in July). Treatments were a complete factorial arrangement with four replications in a randomized complete-block design. Urea and polymer-coated urea (PCU) were applied broadcast and in subsurface bands at 45 and 90 kg N ha^{-1}. Purcell Technologies, Inc. supplied the PCU material. According to the company, the polyurethane polymer coating was designed to provide N release duration of 8 wk at 20°C and 4 wk at 30°C. Placement of fertilizer was broadcast-applied by hand over the plant canopy and subsurface band applied by digging a narrow trench of soil (5 cm wide by 5 cm deep) with a roto-tiller midway between every other soybean row, dribbling fertilizer in the trench, and covering the fertilizer with soil.

Soil samples were collected randomly in the control plots at 0- to 30- and 30- to 60-cm depths before N application to assess soil organic matter and nitrate levels (Table 1). Soil organic matter was estimated from organic C determined by dry combustion (Nelson and Sommers, 1996). Nitrate N was determined using the colorimetric cadmium reduction method (Gelderman and Beegle, 1998). Weather data were collected from the Iowa Environmental Mesonet Network for each research farm (Arritt and Herzmann, 2004). Aboveground plant biomass (plant DM) was collected at the R6 growth stage. Whole soybean plants were cut at the soil surface from three random 30-cm sections of row per plot. Plants were weighed immediately after collection. Subsamples of five plants were dried at 60°C for 3 d in an air-forced oven to determine moisture content. Dried plants were ground to pass through a 2-mm sieve. Ground soybean plant and grain material was digested using wet acid digestion and total N determined using microdiffusion methods (Mills and Jones, 1996; Stevens et al., 2000) or dry combustion (Jones and Case, 1990). Plant DM and N concentrations are reported on a dry weight basis. Plant N and grain N removal were calculated from the N concentration and amount of plant or grain material.

Soybean grain yield was determined by harvesting two or three rows 15 m in length from each plot with small-plot combines. Reported grain yields were corrected to 130 g kg^{-1} moisture. Grain protein, oil, and fiber concentration were determined using near-infrared spectroscopy by the Iowa State University Grain Quality Laboratory (Rippke et al., 1995). Concentrations of protein, oil, and fiber are interpreted by

Table 1. Site characteristics, soybean varieties, and precipitation after N application.

Site-year	Soil series	Soil classification	Variety†	Maturity group	Organic matter	Soil NO_3–N‡		Precipitation		
						0–30 cm	30–60 cm	Days to ≥ 13 mm§	Initial 7 d¶	Total#
					g kg^{-1}	mg kg^{-1}		d	mm	
Crawfordsville-99	Kalona silty clay loam	Fine, smectitic, mesic Vertic Endoaquoll	Stine 3398-8	III	54	2.3	1.4	9	3	154
Crawfordsville-00					53	3.0	2.8	4	16	61
Kanawha-99	Canisteo clay loam	Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquoll	Midwest G1912	I	61	1.9	1.0	24	0	31
Kanawha-00					60	1.3	1.8	11	4	105
Lewis-99	Marshall silty clay loam	Fine-silty, mixed, superactive, Typic Hapludoll	Pioneer P93B01 RR	III	39	2.8	1.4	11	4	130
Lewis-00					40	2.3	2.3	13	8	40
Nashua-99	Kenyon loam	Fine-loamy, mixed, superactive, mesic Typic Hapludoll	Asgrow 1980-4 RR	I	35	4.9	1.1	3	34	123
Nashua-00					38	1.0	1.3	20	0	88
Sutherland-99	Galva silty clay loam	Fine-silty, mixed, superactive, mesic Typic Hapludoll	Kruger K2343+	II	41	8.6	4.1	29	1	15
Sutherland-00					41	6.8	5.8	6	23	118

† RR indicates glyphosate-resistant variety.
‡ Soil collected in no-N control at time of N application.
§ The number of days after N fertilizer application to a precipitation event of 13 mm or greater.
¶ Precipitation during the initial 7 d after N application.
# Total precipitation between N fertilizer application and R6 growth stage plant collection.

Rippke et al. (1995) as follows: grain protein < 330 g kg^{-1} (low), 330 to 370 g kg^{-1} (medium), and > 370 g kg^{-1} (high); grain oil < 165 g kg^{-1} (low), 165 to 198 g kg^{-1} (medium), and > 195 g kg^{-1} (high); and grain fiber < 40 g kg^{-1} (low), 40 to 55 g kg^{-1} (medium), and > 55 g kg^{-1} (high).

Analysis of variance was conducted for each site-year using the General Linear Models procedure of SAS (SAS Inst., 2001), with treatment differences considered significant at $P \leq 0.05$. The no-N control was compared in a single degree-of-freedom contrast to the N application mean. Individual site-year statistical analyses showed few, inconsistent, and small significant treatment effects. Therefore, a combined analysis was also performed across all site-years using appropriate expected mean squares and *F* ratios for a factorial treatment design in a randomized complete-block with treatments fixed and environments random in the model (McIntosh, 1983; Carmer et al., 1989).

RESULTS

When averaged across site-years, there was no significant effect of N treatments on soybean grain yield, with an increase of only 39 kg ha^{-1} compared with the no-N control (Table 2). Plants at Lewis in 2000 were damaged by hail in July and produced low yield (2286 kg ha^{-1}). However, N application did result in a small (6%) but statistically significant yield increase at that site (data not shown). Nitrogen application did not improve yield at any other site-year. The grain yield of individual site-years ranged from 2286 to 4095 kg ha^{-1}.

Grain protein concentration at Kanawha in 1999 was unusually low (310 g kg^{-1}). Nashua in 1999 and Sutherland in 2000 had significantly reduced grain protein from N application when compared with the no-N control, but the difference was small. Grain protein concentration was the same with or without N application when averaged across site-years. Grain oil and fiber concentrations were consistent across site-years with no significant treatment effect (Table 2).

Plant DM was reduced by 960 kg ha^{-1} at Kanawha in 1999 with N fertilizer application. This site-year also had little rainfall between the R3 and R6 growth stages (Table 1) and the lowest grain protein. Across all site-years, plant DM was not responsive to N rate or application practices (Table 3). Plant N concentration and plant N were significantly increased from applied N. A 5 kg ha^{-1} increase in plant N occurred when 90 kg N ha^{-1} was applied. This is in contrast to the plant DM response. Grain N concentration and N removal were not increased by N rate or application practices (Table 3). The average grain N concentration was 51.5 g N kg^{-1} in harvested seed (130 g kg^{-1} moisture equivalent). This value is lower than often reported for soybean grain N removal (Hoeft et al., 2000).

DISCUSSION

Lack of positive response to in-season N application in this research is consistent with several studies throughout the U.S. Midwest (Welch et al., 1973; Oplinger and Bundy, 1998; Randall and Schmitt, 1998; Schmitt et al., 2001). Nitrogen fertilization also had no positive effect on grain quality components. Application of slow-release N or concentrating N into bands between alternating rows did not increase responses. The no-N control resulted in the same productivity and grain N as any one of the treatments or mean of the treatments.

Application of N to the soil appears ineffective due to a number of contributing factors. Despite adequate rain to move N into the active root zone at some site-years, others had low and variable rain after application (Table 1). This variability could have an influence on N fertilizer effectiveness between the late R2 and R6 growth stages. Also, the amount of rainfall in the week after N application (Table 1) shows 6 out of 10 site-years may have experienced N loss with broadcast treatments through NH_3 volatilization. Past studies have reported urea applied to the soil receiving no rainfall 6 d after application resulted in 30% or greater NH_3 loss (Fenn and Hossner, 1985).

Table 2. Effect of early reproductive stage N fertilizer application on soybean grain yield and quality components for the 10 site-years.

		Fertilizer rate (kg N ha^{-1})							
		Yield		Protein†		Oil†		Fiber†	
N material	**Placement**	**45**	**90**	**45**	**90**	**45**	**90**	**45**	**90**
		kg ha^{-1}		g kg^{-1}					
Urea	**broadcast**	**3483**	**3502**	**353**	**353**	**184**	**184**	**51.0**	**51.2**
	band	**3460**	**3505**	**352**	**353**	**184**	**183**	**51.1**	**51.1**
PCU‡	**broadcast**	**3465**	**3466**	**354**	**355**	**183**	**183**	**51.2**	**50.7**
	band	**3432**	**3442**	**354**	**354**	**183**	**183**	**51.1**	**51.0**
N rate mean		**3460**	**3479**	**353**	**354**	**183**	**183**	**51.1**	**51.0**
N fertilizer mean		**3469**		**354**		**183**		**51.0**	
Control mean		**3430**		**354**		**184**		**50.8**	
		Statistics							
		P > *F*							
N rate (NR)		**0.350**		**0.641**		**0.767**		**0.360**	
Material (M)		**0.087**		**0.053**		**0.212**		**0.433**	
Placement (P)		**0.244**		**0.840**		**0.766**		**0.343**	
NR × M		**0.561**		**0.829**		**0.710**		**0.228**	
NR × P		**0.622**		**0.674**		**0.982**		**0.837**	
M × P		**0.607**		**0.880**		**0.344**		**0.533**	
NR × M × P		**0.780**		**0.174**		**0.984**		**0.402**	
Control vs. N		**0.159**		**0.516**		**0.812**		**0.135**	

† Concentrations on a 130 g kg^{-1} moisture basis.
‡ PCU, polymer-coated urea.

Table 3. Effect of early reproductive stage N fertilizer application on soybean plant and grain for the 10 site-years.

		Fertilizer rate (kg N ha^{-1})									
		Plant N conc.†		Grain N conc.‡		Plant DM§		Plant N		Grain N	
N material	Placement	45	90	45	90	45	90	45	90	45	90
		g kg^{-1}				kg ha^{-1}					
Urea	broadcast	31.4	31.3	59.4	58.0	6839	7030	216	221	180	177
	band	30.9	30.7	59.1	59.5	7073	7290	220	224	178	182
PCU¶	broadcast	31.2	31.5	59.1	59.0	6993	6979	220	220	179	178
	band	31.1	31.6	59.7	59.4	6820	7115	214	227	179	178
N rate mean		31.2	31.3	59.4	59.0	6931	7104	217	223	179	179
N fertilizer mean		31.2		59.1		7017		220		179	
Control mean		30.1		59.5		7230		218		178	
						Statistics					
		$P > F$									
N Rate (NR)		0.736		0.056		0.053		0.042		0.945	
Material (M)		0.476		0.127		0.263		0.981		0.534	
Placement (P)		0.247		0.134		0.232		0.419		0.545	
NR × M		0.228		0.691		0.799		0.831		0.754	
NR × P		0.899		0.096		0.206		0.125		0.142	
M × P		0.300		0.822		0.161		0.675		0.482	
NR × M × P		0.618		0.007		0.406		0.327		0.137	
Control vs. N		0.011		0.276		0.102		0.711		0.631	

† Total N concentration in soybean plants collected at the R6 growth stage, dry weight basis.
‡ Total N concentration in harvested grain, dry weight basis.
§ DM, dry matter.
¶ PCU, polymer-coated urea.

The soils at each site were high in organic matter. Mineralization of organic matter could be adequate to supply needed inorganic N from the soil to soybean plants. Also, several sites had low soil nitrate N concentrations in the top 60 cm at N application, but other sites were relatively high for nonfertilized soil and in-season sampling (Table 1). Studies successful in showing positive response to in-season applied N in Kansas and Georgia were on well-drained soils with medium to low organic matter content (Gascho, 1993; Wesley et al., 1998). Closed-canopy soybean fields during middle to late summer in Iowa make application of granular N difficult. Direct sunlight, high relative humidity, and warm daytime temperatures caused some broadcast urea at 5 out of 10 site-years to quickly solublize on top of the canopy (this did not cause visible leaf damage).

CONCLUSIONS

Nitrogen applications increased plant N concentration and plant N at R6 but did not increase plant DM, grain N concentration and removal, grain yield, or grain quality components. Nitrogen, as urea, was not an effective soybean fertilization practice when applied at the beginning pod stage across Iowa's predominant soybean production areas and typical midsummer environmental conditions. Use of slow-release coated urea and concentrating N into bands between alternate rows did not enhance response to N application. Results from this study lead to the conclusion that growers should not consider fertilizer N applied to soil during early reproductive stages as a method to increase soybean grain yield and quality.

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