

In-Season Fertilizer Nitrogen Applications for Soybean in Minnesota

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ABSTRACT

Predicted physiological factors and a limited number of field studies have resulted in debate regarding the recommendation of in-season fertilizer N for soybean [*Glycine max.* (L.) Merrill]. The objective of our research was to evaluate several in-season N fertilization strategies on soybean seed yield response as well as to measure the effect of fertilizer N additions on late-season plant N concentrations and accumulation, seed N removal, seed protein, and seed oil composition. The research was conducted at 12 sites in the southern soybean-growing region of Minnesota in 1998 and 1999. A combination of (i) application time (July vs. August), (ii) placement method (broadcast vs. knifed), and (iii) N source (urea vs. poly-coated urea) gave five N treatments plus a control at all sites. Seed yield did not respond to the fertilizer N treatments at any of the 12 sites; however, a combined analysis indicated a significant increase (generally less than 0.06 Mg ha⁻¹) from using polymer-coated urea or applying the urea in August. Herbage dry matter (DM) and herbage N concentrations at the R6 stage were not affected by any of the N fertilizer strategies. Although soybean seed protein was statistically different among the treatments, protein was only increased 0.4 g kg⁻¹. Soybean oil concentration was not affected by fertilizer treatments. In general, polymer-coated urea, knifed applications, and August applications increased soil NO₃-N in the 0- to 30-cm layer at R6 relative to standard urea, broadcast applications, and July applications. Even though in-season N fertilizer created greater levels of available soil N at all 12 sites during soybean pod filling, seed yield was not improved compared with unfertilized control plots at any site. As a result, the University of Minnesota does not recommend in-season N fertilizer applications for soybean production.

SOYBEAN PRODUCTION and its overall impact on farm profitability is of great importance to crop producers in the U.S. Midwest. Due to improved genetics and pest management options, soybean yields have increased steadily within the last 30 yr, giving rise to questions on the adequacy of biological N fixation to meet the N demand. At the same time, soybean products have experienced a global demand because of their nutritional and industrial properties. As a result, there is substantial incentive to increase soybean yield and a desire to grow soybean for specialty traits in order to enhance economic returns (Helms and Watt, 1991).

Preplant N application for soybean has given limited or inconsistent effects on seed yield. Sorensen and Penas (1978) reported seed yield increases with preplant N at 9 of 13 sites in a 3-yr Nebraska study. Yield increases were associated with more favorable yield environments as well as increased seed size. These researchers concluded that increased lodging and disease potential with preplant N application times limited positive yield in-

creases. A primary factor reported for predicting a yield response is soil inorganic N concentrations early in the growing season. Positive increases in soybean yields from supplemental N applications are a function of soil N concentrations (Stone et al., 1985). They concluded that fertilizer N increased soybean yields only if preplant soil NO₃-N concentrations were <190 kg ha⁻¹ in the top 180 cm. Al-Ithawi et al. (1980) measured significant seed yield increases at all three sites in one year and only at a moisture-limiting site in a second year. They attributed the yield response to inadequate residual soil NO₃-N at planting for the responding sites in Nebraska. In addition to soil N status, Lyons and Earley (1952) suggested that soybean response to either plowdown or topdressed N is dependent on rainfall and temperature during the growing season because these environmental factors influence sufficiency of symbiotically fixed N.

Seed yield increases were not obtained with N rates up to 448 kg ha⁻¹ in Illinois (Johnson et al., 1975). In Iowa, preplant N applications up to 270 kg ha⁻¹ did not affect seed yields (Bharati et al., 1986). Beard and Hoover (1971) also found no soybean seed yield response to a series of N rates under irrigation in California. No fertilizer N was recommended for dryland soybean on Coastal Plain soils near planting or at flowering, based on research in which only 1 of 10 sites responded to N applications (Reese and Buss, 1992). Deibert et al. (1979) also reported no statistical soybean seed yield increases from N management scenarios that included three N rates applied either near planting or at full bloom. Although seed yield increases due to N fertilization practices were measured at five of seven site-years in Alabama, the researchers concluded fertilizer N application to soybean is risky because yield responses were very inconsistent with regard to N rate and timing treatments (Wood et al., 1993).

Despite the lack of consistent positive yield responses, the concept of applying N to soybean late in the growing season has scientific merit. Shibles (1998) states that N₂-fixing capacity begins to decline rapidly after growth stage R5, which is approximately the same time as peak N demand for protein synthesis. Thus, adding fertilizer N to soybean later in the growing season can extend NO₃ reductase activity beyond R5 (Shibles, 1998). Afza et al. (1987) concluded that inadequate N supply during pod-filling limited soybean seed yields and that soil-applied fertilizer N judiciously applied during the late stages of growth can enhance seed yields. In a study evaluating time and methods of fertilizer N applications in Austria, Afza et al. (1987) reported that N applied during pod-fill resulted in a 37% increase in seed yield compared with the control, which had 20 kg N ha⁻¹ applied as a starter. Late-season N applications to soybean resulted in significantly increased yields at six of

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eight site-years in Kansas (Wesley et al., 1998). They concluded that yield response is positively correlated with higher yielding sites and that supplemental N should be considered at the R3 growth stage for irrigated soybean. Lawn and Brun (1974) measured positive responses to supplemental N applied at late-flowering, a time that nodule activity was previously found to decline. While only one of the two cultivars they grew produced a seed yield increase, seed protein content was measured in both.

Late season N application appears to negate some of the liabilities and uncertainties that early-season applications present. Wallace et al. (1990) concluded that late-season N applications are not easily achieved, yet potential seed yield increases may be more likely with determinate soybean because the N would not directly contribute to lodging and disease issues. The combination of lodging and disease issues are directly influenced by the stimulation of vegetative growth early in the growing season. By delaying N application until the latter stages of soybean growth, it is hypothesized that more of the N will contribute to pod-fill rather than vegetative growth (Afza et al., 1987).

The acceptance of refined, custom fertilizer application management strategies and the demonstrated potential for increasing soybean yield in certain environments encourages producers to question the decades-old debate on N fertilization of soybean. The objective of our research was to evaluate several in-season N fertilization strategies on the seed yield response of soybean. A secondary objective was to determine if fertilizer N additions significantly affect plant N accumulation, seed N removal, plant N concentration, soil NO₃-N concentrations, and seed protein and oil composition.

MATERIALS AND METHODS

The research was conducted at 12 sites in the southern soybean growing region of Minnesota in 1998 and 1999. Five site-years were located on University Research Centers or Fields and seven site-years were located on cooperators' fields. Criteria for field selection included: (i) plot areas within

one soil series; (ii) no manure applications for the previous 3 yr; (iii) soil test levels for P and K were optimum or greater for soybean production (Rehm et al., 1995); and (iv) corn (*Zea mays* L.) was grown the previous crop year. Soil series and taxonomic information, organic matter categories, basic soil test information, textural classes, and precipitation data for each site are listed in Table 1. All plot areas having somewhat poorly and poorly drained soils were tile drained. No plot areas were established in areas where other production-limiting issues (e.g., Fe chlorosis, salts, diseases) were a concern. Sites were selected with care to avoid confounding factors that would limit the scope of inference from this study.

Fertilizer N treatments consisted of a combination of the following factors: (i) application time, (ii) placement method, and (iii) N source. Application times were either the third week of July, immediately preceding canopy closure of the soybean rows and aligned with growth stage R2 (Ritchie et al., 1996), and the second week of August, during soybean growth stage R4 to R5. Application methods included over-the-canopy broadcast or subsurface banding, which placed the fertilizer in a zone 15 cm below the soil surface on 76-cm spacing. Nitrogen sources included standard granular urea and a polymer-coated urea, which was developed to delay available N release. From these three factors, five common treatments and an unfertilized control were used at all sites (Tables 2–4).

Fertilizer application was made using a plot-sized tractor and pneumatic, three-point hitch fertilizer spreader for all July treatments. August fertilizer N treatments were all hand-spread. No cultivation or tillage was used to incorporate broadcast urea applications. The N rate for all treatments was 84 kg ha⁻¹.

All soybean plots were seeded with high-yielding cultivars appropriate for the location and managed with optimum cultural practices (i.e., plant densities and planting dates). Row width at all locations was 76 cm. Weeds were controlled with labeled rates of herbicides at all sites. Seed yields were taken at physiological maturity by harvesting the center two rows, which were end-trimmed to 7.6 to 12.2 m, with a small-plot combine. Plot size was 3 m wide by 9.1 to 15.2 m long. Seed moisture content was determined, and yields were expressed on a dry matter basis. Seed samples from the harvest plots were analyzed for protein and oil content as whole seeds using a NIRS Systems (Silver Springs, MD) Model 6500. Values for protein and oil content are expressed on a 13% moisture basis.

Total aboveground plant samples were collected at the R6 stage during the first week of September (before leaf drop

Table 1. Soil series, textural class, taxonomy, soil properties (0–15 cm), and growing-season precipitation for each site-year.

Site-year	Soil series	Texture	Soil taxonomy	Organic matter†	pH‡	STP§	STK¶	Nitrate-N#	Precipitation††
								mg kg ⁻¹	mm
A	Webster	Clay loam	Fine loamy, mesic Typic Endoaquolls	High	7.3	59	217	11.1	165
B	Webster	Clay loam	Fine loamy, mesic Typic Endoaquolls	High	7.0	38	210	–	144
C	Canisteo– Glenco complex	Clay loam	Fine loamy, mesic Typic Endoaquolls	High	7.6	19	233	9.0	302
D	Port Byron	Silt loam	Fine silty, mesic Typic Hapludolls	Medium	6.3	82	245	6.5	424
E	Harps–Seaforth– Okoboji complex	Silty clay loam	Fine loamy, mesic Typic Calciquolls	High	7.0	50	257	13.5	243
F	Waukegon	Silt loam	Fine silty, mesic Typic Hapludolls	Medium	5.8	31	480	5.9	211
G	Waukegon	Silt loam	Fine silty, mesic Typic Hapludolls	Medium	5.8	31	480	5.9	356
H	Webster	Clay loam	Fine loamy, mesic Typic Endoaquolls	High	3.9	51	265	8.6	291
I	Harps	Clay loam	Fine loamy, mesic Typic Calciquolls	High	6.2	59	232	5.0	269
J	Webster	Clay loam	Fine loamy, mesic Typic Endoaquolls	High	6.8	41	213	6.4	189
K	Normania	Loam	Fine loamy, mesic Aquic Hapludolls	High	5.8	21	156	6.1	156
L	Everly	Clay loam	Fine loamy, mesic Typic Hapludolls	High	6.6	16	145	14.8	71

† Organic matter, which was measured using visual delineation, is categorized into medium (1–3%) and high (>3%) classes.

‡ Soil pH was measured using a distilled water extract.

§ Soil P was determined using Bray P₁ extractant except for Site-Year C, which used the Olsen bicarbonate extractant.

¶ Soil K was determined using an ammonium acetate extractant.

Nitrate N was measured from a 0- to 60-cm depth in May, after soybean emergence.

†† Season precipitation is calculated by summing precipitation events from 1 July through 15 September.

Table 2. Treatment means and associated statistical information for several dependent soybean and soil variables averaged across 12 site-years in Minnesota.

	Seed yield	Forage yield at R6	Nitrogen conc. at R6	Accumulation of N at R6	Seed protein	Seed oil	Seed N removal	Soil NO ₃ -N at R6
Treatment means								
	Mg ha ⁻¹		g kg ⁻¹	kg ha ⁻¹	g kg ⁻¹		kg ha ⁻¹	mg kg ⁻¹
Control	3.32	7.71	29.4	226	372	196	172	5.7
Broadcast urea (July)	3.38	7.48	30.3	228	370	196	174	7.3
Knifed urea (July)	3.38	7.63	29.5	226	374	196	176	10.5
Broadcast poly-coated urea (July)	3.43	7.67	29.8	226	374	195	178	9.1
Knifed poly-coated urea (July)	3.38	7.58	30.3	229	375	195	176	11.3
Broadcast urea (August)	3.38	7.55	29.8	224	376	195	177	14.0
Source of variation								
	<i>P</i> > <i>F</i>							
Location	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Treatment	0.10	0.78	0.57	0.86	<0.01	0.60	<0.01	<0.01
Control vs. others	0.10	0.52	0.37	0.77	0.04	0.40	0.04	<0.01
Broadcast vs. knifed	0.31	0.97	0.75	0.96	<0.01	0.93	0.07	<0.01
Poly-coated vs. standard urea	0.05	0.82	0.61	0.87	<0.01	0.12	0.01	<0.01
July vs. August application	0.07	0.84	0.35	0.26	<0.01	0.24	0.01	<0.01
Location × Treatment	0.29	0.14	0.91	0.53	0.24	0.17	0.23	<0.01
CV, %	6.1	9.8	9.7	13.5	1.3	2.1	6.2	31.7

began) to estimate maximum N and DM accumulation by the plants. Within each four-row plot, two 60-cm lengths of row were collected from the middle rows. These samples were weighed, dried, ground, digested, and then colorimetrically analyzed for total N (Bremner and Mulvaney, 1982). Soil samples were collected from the top 30 cm of soil at the same time as the plant samples. Eight cores were collected and composited from the area where the plant samples were removed in each plot. A systematic sampling scheme was used that consisted of selecting two random areas within the plot and collecting four vertical soil cores taken at 19-cm intervals on a transect perpendicular to the direction of the plant rows and possible fertilizer application bands. All soil samples were dried, ground to pass a 2-mm sieve, and analyzed for NO₃-N using colorimetric methods with Cd reduction.

Analysis of variance was conducted for experiments combined over locations for each of the dependent variables of seed yield, total DM yield at R6, plant N concentration at R6, N accumulation at R6, soil NO₃-N at R6, estimated seed N removal, seed protein, and seed oil content (SAS Institute, 1996). Single degree of freedom contrasts were used to compare the control with the fertilized treatments and the treat-

ment factors of application time, placement methods, and N source. In addition, correlation methods were used to evaluate the relationship between soil NO₃-N and seed yield. Individual site-year statistics are presented for seed yield and soil NO₃-N at R6, which was the only variable with a statistically significant location × treatment interaction.

RESULTS AND DISCUSSION

The location source of variation was significant for all dependent variables measured in this study (Table 2). This variation would be expected due to the physical, chemical, and biological soil properties, seasonal growing conditions including precipitation, cultivars grown, and cultural practices at each site-year location.

Seed Yield

Statistical probability for significance of 10% was chosen for the treatment source of variation when using the 12 site-year combined analysis of variance (Table

Table 3. Treatment means and associated statistical significance information for soybean seed yield from 12 site-years in Minnesota, 1998–1999.

	Site-year											
	A	B	C	D	E	F	G	H	I	J	K	L
Treatment means												
	Mg ha ⁻¹											
Control	2.78	3.74	3.91	2.46	3.53	3.15	3.00	3.56	3.58	3.71	3.59	2.92
Broadcast urea (July)	2.95	3.73	3.56	2.49	3.59	3.30	2.80	3.59	3.69	3.75	3.52	2.86
Knifed urea (July)	2.89	3.97	3.91	2.37	3.56	3.27	3.02	3.70	3.70	3.84	3.61	2.94
Broadcast poly-coated urea (July)	3.16	3.68	3.75	2.46	3.59	3.42	3.02	3.54	3.72	3.89	3.64	3.12
Knifed poly-coated urea (July)	3.35	3.58	3.86	2.44	3.65	3.14	2.96	3.68	3.72	3.83	3.58	3.04
Broadcast urea (August)	2.87	3.91	4.09	2.35	3.53	3.25	3.09	3.63	3.72	3.78	3.51	2.96
Source of variation												
	<i>P</i> > <i>F</i>											
Treatment	0.20	0.24	0.13	0.94	0.85	0.55	0.40	0.35	0.72	0.57	0.88	0.34
Control vs. others	0.13	0.77	0.46	0.89	0.50	0.36	0.72	0.31	0.12	0.18	0.91	0.84
Broadcast vs. knifed	0.68	0.55	0.11	0.50	0.76	0.19	0.34	0.05	0.98	0.84	0.87	0.99
Poly-coated vs. standard urea	0.07	0.08	0.34	0.96	0.61	0.99	0.36	0.58	0.76	0.41	0.59	0.04
July vs. August application	0.73	0.27	0.01	0.45	0.58	0.79	0.04	0.63	0.82	0.77	0.93	0.25
CV, %	9.9	6.0	6.4	9.3	3.8	6.9	7.8	3.2	3.7	3.9	4.9	7.3

Table 4. Treatment means and associated statistical significance information for late season soil NO₃-N from 12 site-years in Minnesota, 1998–1999.

	Site-year											
	A	B	C	D	E	F	G	H	I	J	K	L
	Treatment means mg kg ⁻¹											
Control	9.2	6.2	5.6	4.4	6.5	4.4	3.8	7.4	5.5	3.4	5.2	8.0
Broadcast urea (July)	12.6	6.5	8.1	4.6	7.4	5.0	4.7	8.2	6.0	3.9	7.3	14.3
Knifed urea (July)	12.8	15.0	13.0	5.6	10.0	8.3	5.3	15.3	6.7	11.2	11.5	13.2
Broadcast poly-coated urea (July)	16.4	10.2	8.5	4.3	8.8	6.7	6.3	12.4	7.1	5.6	10.2	14.5
Knifed poly-coated urea (July)	17.8	13.0	14.4	8.4	9.4	12.3	6.3	17.2	7.9	6.4	11.1	14.9
Broadcast urea (August)	14.9	22.6	18.3	14.1	9.0	16.0	13.2	23.9	9.0	9.0	7.5	12.7
	Source of variation P > F											
Treatment	0.03	<0.01	0.04	<0.01	0.17	<0.01	<0.00	<0.01	0.15	<0.01	0.09	0.56
Control vs. others	0.01	<0.01	0.04	0.01	0.04	0.01	0.03	<0.01	0.09	<0.01	0.03	0.08
Broadcast vs. knifed	0.76	<0.01	0.02	<0.01	0.12	<0.01	0.87	0.01	0.40	<0.01	0.14	0.90
Poly-coated vs. standard urea	0.02	0.45	0.64	0.08	0.70	0.03	0.27	0.14	0.25	0.11	0.46	0.75
July vs. August application	0.30	<0.01	<0.01	<0.01	0.28	<0.01	<0.01	<0.01	0.04	<0.01	0.94	0.70
CV, %	21.9	17.9	32.8	19.4	22.6	26.7	45.8	27.1	25.8	27.2	37.1	43.4

2). Treatment means ranged from 3.32 to 3.43 Mg ha⁻¹, a range of 3%. Using single degree contrasts to further compare treatment factors indicated the control treatment was different than the fertilized treatments at the 0.10 level, method of application was insignificant, and urea source and timing were significant at the 0.05 and 0.07 level, respectively. Because the statistical probabilities for seed yield are very close to the commonly accepted 0.10 significance level, individual site-year data and statistics were conducted for seed yield.

Whereas the treatment source of variation was statistically significant (0.10 probability) in the combined analysis, it was not statistically significant at any of the 12 site-years (Table 3). Although all site-year coefficients of variation were less than 10% for seed yield, combining the 12 site-years increased this level of precision, which decreased the treatment mean differential necessary for statistical significance at any given probability level. In the combined analysis, both the form of urea and the application timing were significant treatment variables at the 0.10 probability level, according to single degree-of-freedom contrasts (Table 2). Nonetheless, the combined mean for the standard urea was 3.38 Mg ha⁻¹ and the mean for the polymer-coated urea was 3.41 Mg ha⁻¹, an increase of less than 1%. Three of the 12 site-years had significant differences between the two urea sources, with poly-coated urea having greater yields at Sites A and L; whereas yields were greater with standard urea at Site B (Table 3). Application time differences were significantly significant at 2 of 12 site-years, with the overall treatment means being the same for the July and August application comparison (3.38 Mg ha⁻¹). Broadcast applications in August resulted in greater yields (0.29–0.53 Mg ha⁻¹) at Sites C and G compared with July applications.

Regardless of the mixed statistical interpretation with these results, the practical interpretation is that, for the majority of the trials, there is little to no impact of fertilizer N on seed yield. Any seed yield increases, whether from the overall analysis or an individual site-year, must be tempered by economic and logistical risk management. These results generally concur with those

of several others (Deibert et al., 1979; Reese and Buss, 1992), yet do not necessarily contradict other results that involve different conditions, primarily irrigated agriculture (Wesley et al., 1998; Beard and Hoover, 1971).

Forage Yield, Nitrogen Accumulation, and Seed Nitrogen Removal

Total DM yield at R6, the growth stage considered to represent maximum forage dry matter before leaf drop begins, was not affected by any of the N fertilizer treatments. Total N concentration in the forage at R6 ranged from 29.4 g kg⁻¹ (control treatment) to 30.3 g kg⁻¹ but was not affected by any of the treatments (Table 2). Total N accumulation at R6, calculated as the product of forage yield and forage N concentration, ranged from 224 to 229 kg ha⁻¹ and was not statistically significant. These findings directly contrasted those of Hanway and Weber (1971), who reported an increase in N accumulation with the addition of N fertilizer.

Seed N removal was significantly affected by all treatment factors (Table 2). Seed N removal was calculated by multiplying seed DM yield by seed N concentration, which was approximated by converting seed protein to N concentration. While seed N removal was significant in the combined analysis, the statistics of the variables comprising this data (seed yield and protein) should be interpreted independently. Nitrogen removal, which was very consistent among the treatments, ranged from 172 to 178 kg ha⁻¹. This result was similar to those reported by Varvel and Peterson (1992) who reported 150 to 200 kg ha⁻¹ N removed regardless of N fertilizer applications.

Seed Protein and Oil

Seed protein content was significantly affected by all treatment factors in this study (Table 2). Protein content averaged 372 g kg⁻¹ for the control compared with the maximum of 376 g kg⁻¹ for the August treatment (a 1.2% increase). The knifed treatments resulted in a 0.7% increase in protein compared with the broadcast treatment. The poly-coated urea also resulted in an ad-

ditional 0.7% increase compared with standard urea. Seed oil content ranged from 195.3 to 196.3 g kg⁻¹ and was not affected statistically by the treatments (Table 2). This research corroborates the conclusions of several researchers (Diebert et al., 1979; Wood et al., 1993; Weber, 1966)—additional fertilizer N does not affect oil content of normal nodulating soybean. It should be noted that both seed protein and oil data have very low coefficients of variation (1.3 and 2.1%, respectively) in this study.

Soil Nitrate-Nitrogen

Soil NO₃-N concentrations were initially measured in late May, after soybean emergence and uniform stands were established. Soil NO₃-N concentrations ranged from 5.0 to 14.8 mg kg⁻¹ (Table 1). Nitrate N concentrations are not normally measured for soybean crops; thus, these early season measurements cannot be categorized into formal sufficiency ranges. However, these concentrations are typical of soil NO₃-N concentrations measured from corn fields at the same time of year in Minnesota. Comparisons of early-season NO₃-N concentrations with late-season concentrations will not be made because the N mechanisms that both contribute and remove NO₃-N during the season were not measured in this study. Relative comparisons of the treated plots with the untreated control provide meaningful information on the impact of fertilizer N applications during late-season podfill.

Soil NO₃-N concentrations when the soybean plants were at the R6 stage were significantly affected by all treatment variables in this study (Table 2). Compared with the overall control treatment mean (5.7 mg kg⁻¹), the addition of 84 kg ha⁻¹ applied in-season almost doubled the amount of soil NO₃-N at R6 (10.5 mg kg⁻¹). Knife-injection of the fertilizer N increased soil NO₃-N by 33% compared with broadcast application. Polymer-coated urea resulted in 15% more NO₃-N compared with standard urea. This is expected, as the polymer coating is designed to delay hydrolysis of the urea, thus slowing N release and providing greater NO₃-N concentrations later in the season. Delaying fertilizer application from July (7.3 mg kg⁻¹) to August (14.0 mg kg⁻¹) significantly increased soil NO₃-N at R6. These combined data indicate that differences in soil NO₃-N concentrations were present during the pod-filling period as a result of the treatments selected.

The high coefficient of variation for soil NO₃-N (31.7%) illustrates the traditional variability in soil N measurements even though a systematic sampling scheme was used to account for band applications of fertilizer N. Also, there is much variation in the data, as indicated by the coefficients of variation at each location (Table 4). Evaluation of individual site-year data shows a range in absolute amounts of soil NO₃-N (Table 4). Averaged across all treatments, Site-Years A and H averaged 14 mg kg⁻¹ NO₃-N, whereas Site-Year J averaged only 6.6 mg kg⁻¹. Site-Years E and I only had a range of 3.5 mg kg⁻¹ NO₃-N between the control and the greatest treatment; whereas Site-Year H had a 16.5 mg kg⁻¹ difference.

At three of the individual site-years (E, I, and L), there were no statistical differences in soil NO₃-N concentrations (Table 4). At two of these site-years (E and I), very low soil NO₃-N concentrations were measured in all plots, including the control, most likely indicating loss of inorganic N was great. Except for these three nonsignificant site-years, application of fertilizer N consistently increased soil NO₃-N. At six of nine significant site-years, knife applications of N resulted in significantly greater soil NO₃-N. At only three site-years did the polymer-coated urea result in significant soil N differences, with the greatest effect at Site-Year F where a 44% increase was measured compared with standard urea. The other two sites had soil NO₃-N increases of 34 and 23%. At seven site-years, application of fertilizer N in August provided greater NO₃-N in early September than July application. Because the August applications of standard urea were topdress applied, volatilization may have occurred that would reduce soil NO₃-N concentrations.

SUMMARY

Despite potential theoretical advantages associated with late, in-season inorganic N additions for soybean, consistent agronomic yield responses were not found. Although greater lodging was sometimes observed for the N treatments, total DM and plant N concentrations at the R6 stage were not affected by the N treatments. Soybean seed protein was significantly affected by the treatments; however, the overall impact only affected protein quantities by a maximum of 1%. Soybean oil concentration was not affected. Soil NO₃-N concentrations were significantly affected by location and all of the treatment factors. In general, the use of polymer-coated urea, knifed applications, and August applications resulted in greater NO₃-N at R6 than standard urea, broadcast applications, and July applications. In-season fertilizer N treatments that did create differences in available soil N quantities during soybean pod filling did not result in seed yield differences compared with the unfertilized control plot. As a result, the University of Minnesota does not recommend in-season N fertilizer applications for soybean production.

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Approved by the ASA Board of Directors, 1 Nov. 1992