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ABSTRACT

Grain yield in many soybean experiments fails to respond to fertilizer nitrogen (N). A few positive responses have been reported when soybean were grown in the southern U.S., when N was applied near flowering and when biosolids were added. In a previous study, low N concentrations of soybean forage in north Texas on a high pH calcareous soil were reported and thus, we suspected a N nutrition problem. Consequently, we initiated this study to determine whether selected preplant N sources broadcast and incorporated into a Houston Black clay (fine, smectitic, thermic Udic Haplusterts) might increase forage N concentration, forage yield, or soybean grain yield. In 2003, N was applied as ammonium nitrate (NH_4NO_3, AN) up to 112 kg N ha^{-1} and dairy manure compost (DMC) was applied at rates of 4.9, 9.9, 15.0, and 19.9 Mg ha^{-1}. The DMC contained 5.9, 2.6, and 6.7 g kg^{-1} of total N, P, and K, respectively; thus DMC added 29 to 116 kg N ha^{-1}. In 2004, AN was applied at rates of 112 and 224 kg N ha^{-1} and DMC was applied at 28 and 57 Mg ha^{-1}; thus, DMC added 168 to 335 kg N ha^{-1}. In another 2004 test, biosolids, a biosolids/municipal yard waste compost mixture (BYWC), and AN were compared. The biosolids contained 31, 18, and 2.9 g kg^{-1} total N, P, and K, respectively. The BYWC mixture contained 8.8, 6.1, and 3.4 g kg^{-1} of total N, P, and K, respectively. Biosolids were applied at 10 Mg ha^{-1} (310 kg N ha^{-1}), BYWC was applied at 58 Mg ha^{-1} (510 kg N ha^{-1}), and AN up to 224 kg N ha^{-1}. None of the soil treatments increased soybean grain yield or forage yield although AN slightly increased forage N concentration in 2003.

Keywords: forage soybean, manure, biosolids, nitrogen response, digestibility

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INTRODUCTION

Due to factors such as a warm and dry climate, soybean yield in the Southern Great Plains of the U.S. is almost always lower than yield in the Midwest. Other factors that appear to limit yield in this region include soil fertility. Although studies from the Midwest and Northern U.S. have shown that soybean grain yield does not respond to fertilizer N (Slater et al., 1991; Schmitt et al., 2001; Freeborn et al., 2001; Scharf and Wiebold, 2003), reports from the southern U.S. (Taylor et al., 2005) and other regions (Thies et al., 1995; Wesley et al., 1998) have shown positive responses. In some studies, the yield response to inorganic nitrogen (N) was greater under non-irrigated than under irrigated conditions (Purcell and King, 1996; Purcell et al., 2004; Ray et al., 2006). Other N sources may have a different response. In southern Minnesota, Schmidt et al. (2000) found liquid swine manure up to 500 kg N ha^{-1} did not affect soybean yield, but in a later study, lower rates had a positive effect (Schmidt et al., 2001). In north Texas, even though a soil test indicated that no fertilizer was recommended, it was found that seed yield of a vegetable soybean responded positively to soil-applied biosolids (Heitholt and Sloan, 2006) suggesting that N or other nutrients may be limiting in these highly calcareous clay soils.

Soybean utilization in the Southern Great Plains is not restricted to grain only. Cattle operators in this region often need an additional summertime source of forage protein, which soybean hay can provide (Heitholt et al., 2004; Rao et al., 2005). In previous research, forage from soybean grown in north Texas was relatively low in both yield and protein although it was very high in digestibility (Heitholt et al., 2004). This latter finding corroborates the earlier suggestion that more needs to be understood regarding N nutrition for soybean in this region. Therefore, the objectives of this research were to determine the effects of varying soil-applied N sources and rates on soybean forage yield, hay quality, and grain yield on a heavy clay calcareous soil.

MATERIALS AND METHODS

Soil Amendment and Soybean Culture

During a two-year period, three studies were conducted and are subsequently referred to as Studies A, B, and C. For Study A, a nine-treatment test with dairy manure compost (DMC) and ammonium nitrate (NH_4NO_3) (AN) was conducted in 2003 on a Houston Black clay (fine, smectitic, thermic Udic Haplusterts) in Dallas, Texas. The preplant soil test indicated the following traits: pH 8.3, 7 mg NO_3-N kg^{-1}, 66 mg phosphorus (P) kg^{-1}, 375 mg potassium (K) kg^{-1}, 150 g calcium (Ca) kg^{-1}, 604 mg magnesium (Mg) kg^{-1}, 0.31 mg zinc (Zn) kg^{-1}, 11.3 mg iron (Fe) kg^{-1}, 6.11 mg manganese (Mn) kg^{-1}, 0.53 mg copper (Cu) kg^{-1}, 356 mg sodium (Na) kg^{-1}, and 85 mg sulfur (S) kg^{-1}. Texture analysis indicated 16% sand, 38% silt, and 46% clay. Fertilizer N was surface applied as NH_4NO_3 with 3% S. Rates were 29, 57, 86, and 114 kg N ha^{-1}. The DMC (dry matter basis) was surface applied at 4.9, 9.9, 15.0, and 19.9 Mg ha^{-1}. Composition of DMC was 5.9, 2.6, and 6.7 g kg^{-1} N, P, and K, respectively; thus, DMC added 29 to 116 kg N ha^{-1}. For Study B, five treatments involving the same DMC and AN sources were compared in 2004 on a Houston Black clay at a new site 100 m from the 2003 site. Soil test results for this 2004 site are not available but were likely similar to those obtained for Study A. Fertilizer N rates were 112 and 224 kg N ha^{-1} and DMC (same composition as in 2003) was applied at 28.4 and 57.1 Mg ha^{-1}; thus, DMC added 168 to 335 kg N ha^{-1}. For both Studies A and B, amendments were incorporated (immediately after surface application) with a rotary tiller, which was also used on untreated plots. After tillage, seed of Deltapine 5110S (STS) soybean were sown on May 2, 2003 and May 20, 2004 in 76-cm rows at 375,000 seed ha^{-1}. In 2003, seed were inoculated prior to planting with Cell Tech 2000 (Nitragin, Inc., Milwaukee, WI) and in 2004 seed were inoculated by in-furrow application of Soil Implant (Nitragin, Inc.). Metolachlor was applied preemerge at 1.6 kg a.i. ha^{-1} immediately after planting in both years.

In Study C, an eight-treatment test was conducted on a Houston Black clay in 2004 at Prosper, TX. The soil test indicated the following; pH 8.1, 11 mg NO_3-N kg^{-1}, 32 mg P kg^{-1}, 249 mg K kg^{-1}, 156 g Ca kg^{-1}, K, 139 mg Mg kg^{-1}, 0.26 mg Zn kg^{-1}, 8.80 mg Fe kg^{-1}, 2.15 mg Mn kg^{1}, 0.45 mg Cu kg^{-1}, 495 mg Na kg^{-1}, 27 mg S kg^{-1}, and 2.67% organic matter. Pre-planted soil treatments included AN (two rates), biosolids, a biosolids/municipal yard waste compost mixture (BYWC), and three levels of Zn. Nitrogen (as AN) rates were 112 and 224 kg N ha^{-1}, biosolids were applied at 10 Mg per ha (dry matter basis), the BYWC mixture was applied at 58 Mg per ha^{-1} (dry matter basis), and zinc sulfate ($ZnSO_4$) was applied at 4.5, 9.0, and 13.4 kg Zn ha^{-1}. The biosolids contained 31, 18, and 2.9 g per kg total N, P, and K, respectively; thus biosolids added 310 kg N ha^{-1}. The BYWC mixture contained 8.8, 6.1, and 3.4 g per kg total N, P, and K, respectively; thus, BYWC added 510 kg N ha^{-1}. Seed of the cultivar Deltapine DP5414RR were sown on May 13, 2004 as described earlier and inoculated by in-furrow application of Soil Implant.

Forage Harvest, Forage Analysis, and Grain Yield

For Studies A and B at the Dallas location, plot size (four rows) was 3 m × 6 m and the center two rows were harvested on three (2003) or two (2004) separate dates for forage. Subsamples from each forage harvest were analyzed for N concentration, acid-detergent fiber (ADF), neutral-detergent fiber (NDF), and in vitro dry matter digestibility (IVDMD). Methods used for forage analysis were described previously (Heitholt et al., 2004). For Studies A, B, and C, grain yield was determined by harvesting the center two rows of each plot with a mechanical harvester after end-trimming.

EXPERIMENTAL DESIGN

For Studies A and B, plots for each treatment within a replicate were included four times (2003) and three times (2004) to accommodate the mid-season destructive forage harvests and a final grain yield harvest. Forage harvest dates were in 2003, were July 8, July 30, and August 28, and in 2004 were July 22 and August 18. Plots were arranged in randomized complete blocks with two replications in 2003 and 2004 at Dallas and three replications in 2004 at Prosper. For Study C, plots were arranged in randomized complete blocks with a factorial arrangement of soil amendment source-by-rate combinations. In the data analysis for all three Studies, sources of variation were replicate, source of amendment, and rate within source. Data from each forage harvest date were analyzed separately. Effects (treatment mean squares) were evaluated against the residual error mean square with SAS using PROC GLM.

RESULTS

In 2003, hay yields were not increased above that of the check treatment by DMC or by AN up to 114 kg ha^{-1} (Figure 1). For N concentration, the statistical analysis indicated non-significant treatment effects. However, there were significant regression trends for the fertilizer N from AN to increase the mean N concentration of the forage above that of DMC and the increase was proportional to the amount of N applied as AN (Figure 1). For example, the regression equation for July 8, 2003 was: Hay [N], mg/g = 25.6 + 0.0295 (N rate of AN) where the N rate is in kg N ha^{-1} ($P = 0.01$). The equation was Hay [N], mg/g = 23.5 + 0.0202 (N rate of AN) for 28 August 2003 ($P = 0.06$). In 2004, hay yields and quality traits were not consistently affected by the treatments (Table 1). In 2004, acid-detergent fiber averaged 330 and 350 g kg^{-1} on July 22 and August 18, 2004, respectively whereas neutral-detergent fiber averaged 48% and 51% on July 22 and August 18, 2004, respectively. The IVDMD of the forage averaged 720 g kg^{-1} and 680 g kg^{1} on July 22 and August 18, 2003, respectively. These three forage traits were relatively unaffected by either the source or level of soil amendment applied. In the two Dallas trials (with fertilizer N and DMC) and the 2004 Prosper trial (involving biosolids and Zn), grain yields were unaffected by AN, DMC, biosolids, BYWC, or Zn (Table 2).

DISCUSSION

In general, applications of N-containing fertilizers and soil amendments to the heavy clay calcareous soil used in this research had little effect on soybean forage yield, forage quality, or grain yield. At first glance, these results might be expected, because nodulated soybean has the capacity to fix atmospheric N_2

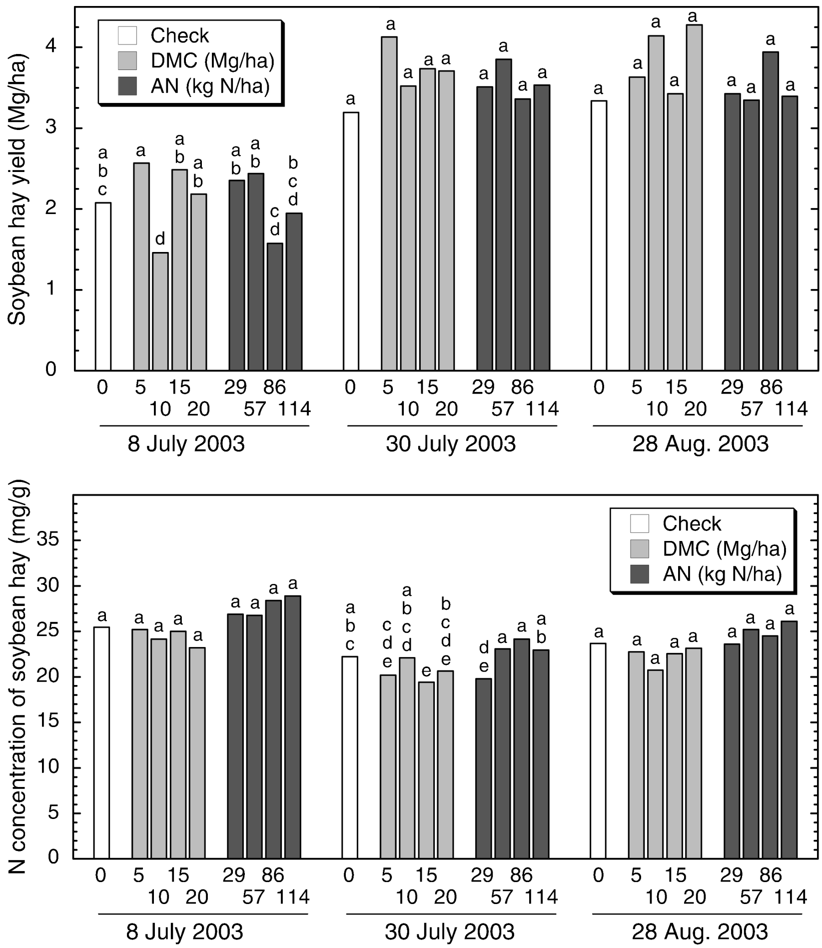

Figure 1. Effect of ammonium nitrate and dairy manure compost on forage yield and N concentration of DP 5110S soybean in 2003. Rates of DMC on x-axis are rounded to the nearest integer. Bars within a harvest date followed by the same letter are not significantly different according to LSD (0.05) test.

and many researchers have also reported that soybean is not greatly affected by N fertilizer, whether it is applied to the soil or foliage. Although our results and economic considerations might indicate that N nutrition adjustment for soybean in this region is unwarranted, there were responses that raised concerns regarding the sufficiency of N nutrition without amendments.

The first reason for us to suspect a N nutrition problem is that in a previous study (Heitholt and Sloan, 2006), we found a large soybean grain yield response to N-containing organic soil amendments. Since the same soil type

Table 1
Effect of preplant soil-applied NH_4NO_3 or dairy manure compost (DMC) on soybean forage (hay) yield and composition (quality) on 22 July and 18 August 2004

			Hay quality traits			
Treatment	Rate	Hay yield	N	NDF	ADF	IVDMD
		Mg ha^{-1}	g kg^{-1}			
		22 July 2004				
Check	na	2.4	21	479	327	731
NH_4NO_3	112 kg N ha^{-1}	3.1	23	493	341	700
NH_4NO_3	224 kg N ha^{-1}	3.2	25	473	324	715
DMC	24.8 Mg ha^{-1}	2.4	21	470	319	727
DMC	57.1 Mg ha^{-1}	2.9	25	465	328	718
	LSD (0.05)	0.6	ns	14	10	ns
		18 August 2004				
Check	na	5.3	22	519	355	676
NH_4NO_3	112 kg N ha^{-1}	5.5	20	534	372	663
NH_4NO_3	224 kg N ha^{-1}	5.8	22	491	332	703
DMC	24.8 Mg ha^{-1}	5.2	21	510	351	689
DMC	57.1 Mg ha^{-1}	5.0	22	506	352	683
	LSD (0.05)	ns	ns	ns	ns	ns

was involved in that study, we suggested that N, or some other mineral nutrient, limited soybean reproductive growth. The second reason to suspect a N nutrition problem was the low N concentration of the soybean forage reported in the present study (21–28 g kg^{-1}), which is substantially less than most reports, but was similar to the N concentration of forage found in a two-year study that immediately preceded the current study (Heitholt et al., 2004). Wood et al. (1993) reported forage soybean N concentrations of 26 to 39 g kg^{-1} in Alabama, Hintz et al. (1992) reported N concentrations of 29 to 32 g kg^{-1} in Wisconsin, and Sheaffer et al. (2001) reported concentrations of 32 to 54 g kg^{-1} in Minnesota. Soybean harvested for forage in El Reno, OK had 22, 30, and 34 g kg^{-1} in 2001, 2002, and 2003, respectively (MacKown et al., 2007). The causes of this low N concentration in our soybean forage for four seasons (2001-2004) compared to other regions remain unclear. However, the nearly linear response of the early-season and late-season forage N concentration to fertilizer AN in 2003 (Figure 1) suggests that N_2 fixation capability may indeed be limiting during mid-season in our region. Likewise, Sorensen and Penas (1978) reported that fertilizer N increased forage N concentration in seven of 13 Nebraska environments. In contrast to our 2003 results with AN and those of Sorensen and Penas (1978), Wood et al. (1993) showed a starter N-induced reduction of

Table 2
Effect of preplant soil-applied amendments on seed yield of soybean cv. 'DP 5110S' (Dallas) or 'DP 5414RR' (Prosper)

Year	Location	Treatment	Rate	Seed Yield $Mg\ ha^{-1}$
2003	Dallas	Check	na	1.09
		NH_4NO_3	29 $kg\ N\ ha^{-1}$	1.23
			57 $kg\ N\ ha^{-1}$	1.19
			86 $kg\ N\ ha^{-1}$	1.23
			114 $kg\ N\ ha^{-1}$	1.16
		DMC†	4.9 $Mg\ ha^{-1}$	1.22
			9.9 $Mg\ ha^{-1}$	1.16
			15.0 $Mg\ ha^{-1}$	1.09
			19.9 $Mg\ ha^{-1}$	1.24
2004	Dallas	Check	na	2.10
		NH_4NO_3	112 $kg\ N\ ha^{-1}$	1.50
		NH_4NO_3	224 $kg\ N\ ha^{-1}$	2.00
		DMC	24.8 $Mg\ ha^{-1}$	1.11
		DMC	57.1 $Mg\ ha^{-1}$	1.30
2004	Prosper	Check	na	1.93
		NH_4NO_3	112 $kg\ N\ ha^{-1}$	1.81
		NH_4NO_3	224 $kg\ N\ ha^{-1}$	1.73
		Biosolids	10 $Mg\ ha^{-1}$	1.74
		BYWC‡	58 $Mg\ ha^{-1}$	1.81
		Zn	4.5 $kg\ ha^{-1}$	2.00
			9.0 $kg\ ha^{-1}$	1.18
			13.4 $kg\ ha^{-1}$	2.39
			LSD(0.05)	ns§

†DMC, dairy manure compost.
‡BYWC, biosolids/municipal yard waste compost.
§ns indicates that yields were not significantly different among treatments within a year.

soybean forage N concentration at three locations, a N-induced increase at one location, and no effect at a fifth location.

Effects of N-containing soil amendments (such as those we imposed) on forage soybean yield might be expected, because abundant soil N is well known to stimulate vegetative growth. In Alabama, Wood et al. (1993) reported that a preplant soil-applied N (i.e., starter) application of 34 kg N ha^1 increased soybean forage yield (measured at R1) at three of seven locations and hay yields at R5 were increased in two of the seven locations.

Positive effects of soil-applied N on soybean grain yield have been reported in roughly the same proportion as its effects on tissue N concentration or vegetative growth (hay yield). Sorensen and Penas (1978) reported a grain yield increase with preplant N applications in nine of 13 Nebraska environments. Brevedan et al. (1978) reported a 27% yield increase in Kentucky when 168 kg N ha^{-1} was applied at R1 and again at R5, but applications at only one of the times did not significantly increase yield. Wood et al. (1993) also reported that either starter N or 56 kg N ha^{-1} applied at R1 increased grain yield in about 25% of the comparisons. Likewise, Gan et al. (2002) reported yield increases when 25 kg N ha^{-1} was applied at planting and followed by 50 kg N ha^{-1} applied at R1. Numerous researchers (Sorensen and Penas, 1978; Wood et al., 1993; Purcell and King, 1996; Ray et al., 2006) suggested that a positive soybean yield response to N fertilization was more likely in a stress/low yield environment, but that situation was also true for our study. The lack of hay and grain yield responses to various sources of N in our research indicated that any purported N limitation was ultimately overwhelmed by other factors. In our 2003 north Texas environment, water and heat stress were likely to be among these factors (Table 3). In 2004, rainfall was relatively abundant, but temperatures were again higher than optimal for soybean growth and yield. Other factors such as a high soil pH at our research sites might be a factor that causes an overall yield reduction across all treatments, masking the N effects.

The seemingly less sensitive response of forage N concentration to organic N as compared to AN-N raises a question regarding the availability of N supplied from the organic amendments. The subsequent plant response to organic N depends, in part, upon the mineralization rate of the amendment. The amount of N added at the highest rate of DMC was 335 kg N ha^{1}. The biosolids added 310 kg N ha^{-1},whereas the BYWC added 510 kg N ha^{-1}. Even with slow N mineralization, these quantities of available N are likely to have been similar to the lower amounts of N provided by AN. However, we did not measure the

Table 3
Average monthly temperatures and monthly rainfall totals from Dallas, Texas in 2003 and 2004

	Year			
	2003		2004	
Month	Temperature °C	Rain cm	Temperature °C	Rain cm
April	19.4	4.8	19.0	8.8
May	24.1	5.7	23.5	5.1
June	26.1	5.6	26.3	18.5
July	30.2	0.2	28.6	10.5
August	30.4	3.8	27.5	5.5
September	23.6	13.0	25.8	2.6

N availability and we suspect that a relatively high C:N ratio may have slowed N mineralization. Also, negative interactions between the organic soil amendments and soil mineral nutrients must be considered as a possible explanation for the lack of a N response.

In summary, soybean growth and grain yield responses to inorganic and organic N fertilizer sources were minimal in this north Texas study. Nevertheless, the low N concentration of the forage and its moderate response to AN is indirect evidence that soybean N nutrition is operating below capacity; consequently, more needs to be learned regarding the interaction of soil N fertility and subsequent soybean growth. Future studies need to involve the balance of N with other plant nutrients or testing in environments with less severe abiotic stress.

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