Nitrogen Fertilizer Carriers and Their Placement for Minimum Till Corn Under Sprinkler Irrigation

W. R. Raun, D. H. Sander,* and R. A. Olson

ABSTRACT

Nitrogen fertilizer efficiency is influenced by source of N and how sources interact with different methods of application. This study was initiated to evaluate various N sources and placement methods for sprinkler irrigated corn (*Zea mays* L.) grown under minimum tillage on a Sharpsburg silty clay loam (fine, Montmorillonitic, mesic Typic Argiudoll) in 1983 to 1985. In general, no differences were found for the yield parameters measured in this study for any of the N methods or N source combinations at 180 kg N ha^{-1}. At the 90 N kg ha^{-1} grain yields were equal when N was applied broadcast preplant (using urea-ammonium nitrate, urea, or urea-ureaphosphate as sources) and when anhydrous ammonia was applied (preplant and sidedressed at the eight-leaf stage). Both the broadcast preplant and anhydrous ammonia treatments were found to maximize grain yield at the low N rate. Broadcast preplant and anhydrous ammonia treatments provided superior grain yields, fertilizer N uptake in the grain, fraction of N translocated to the grain, and values for harvest index compared with the banding methods employed (dribble surface and band to the side of the seed) at the low N rate. Marked differences were observed in N utilization efficiency as only the banding methods showed fertilizer response above 90 kg N ha^{-1} while having no advantages over the other methods at 180 kg ha^{-1}. There were generally small differences among N sources although urea-ureaphosphate did appear to maximize total dry matter yields versus sulfur-coated urea, urea, and urea-ammonium nitrate over the 3-yr period. Measurements made for ear leaf N did not consistently show high positive correlation with grain yield, therefore limiting the use of such a variable for identifying season N deficiencies.

REDUCED-TILLAGE corn production under sprinkler irrigation has increased dramatically in the last two decades because of increased emphasis on control of soil erosion. Methods of N application in minimum tillage systems have been given considerable attention with particular concern for applications of urea (Fox and Hoffman, 1981; Fox et al,. 1986; Mengel et al., 1982; Mengel, 1985; Touchton and Hargrove, 1982). Because of the rapid hydrolysis of urea to ammonium carbonate and the subsequent potential for ammonia volatilization, various authors have stressed the importance of banding this source below the surface of the soil (Fenn and Kissel, 1973; Fox and Hoffman, 1981; Mengel, 1985). However, rainfall following surface applied urea has been shown to reduce ammonia losses (Fox and Hoffman, 1981). Ammonia losses are also generally smaller for high cation exchange soils than low cation exchange soils (Fenn and Kissel, 1976). Effectiveness of surface applied N sources has been shown to decrease with increasing crop residues on the soil surface (Mengel, 1985).

W.R. Raun, CIMMYT Apdo, Postal 6-641, Mexico D.F. 06600; D.H. Sander and R.A. Olson, (Deceased), Dep. of Agronomy, Univ. of Nebraska, Lincoln, NE 68583. This research was supported in part by the Tennessee Valley Authority. Contribution from Nebr. Agric. Exp. Stn., Lincoln, NE as paper No. 8722. Received 3 June 1988. *Corresponding author.

Published in Agron. J. 81:280–285 (1989).

Studies evaluating N sources in minimum tillage corn have shown that anhydrous ammonia and urea-ammonium nitrate injected into the soil resulted in higher yields than did urea, urea-ammonium nitrate, or ammonium nitrate broadcast on the surface of no-till soils (Mengel et al., 1982). Similar work in a study conducted in Nebraska showed the long-term benefits of knifing anhydrous ammonia preplant versus urea-ammonium nitrate sidedressed or banded preplant in conventional tillage (Olson et al., 1986). Advantages of urea-phosphate have been attributed to the acidifying effect of the phosphoric acid component in this source. The phosphoric acid maintains a lower soil pH following the enzymatic hydrolysis of urea by soil urease, lowering gaseous N losses as ammonia (Bremner and Douglas, 1971; Urban et al., 1987). This acidity also neutralizes the products of urea hydrolysis (ammonium carbonate/bicarbonate), while reducing the concentration of free ammonia near the germinating seeds (Tennessee Valley Authority, 1983). Work by Urban et al. (1987) suggested that urea-ureaphosphate is an affective source for surface application to non-calcareous soils under no-tillage management.

Ammonia losses have been reduced considerably with sulfur-coated urea on acid and calcareous soils as compared with urea and ammonium sulfate (Matocha, 1976). Sulfur-coated urea has also been found to reduce the amount of NO_3^--N movement below the root zone while achieving nearly maximum yields (Sander and Moline, 1980). It is expected that the slow release of urea from sulfur-coated urea within a band would keep the salt levels and free ammonia within non-toxic ranges for germinating seeds (Tennessee Valley Authority, 1983). As a slow N release source, sulfur-coated urea is generally considered to be an alternative to split N applications (Tennessee Valley Authority, 1983).

Although minimum/no-tillage systems have shown definite advantages over that of conventional tillage in having decreased erosion losses (Mengel, 1985), increased soil moisture (Legg et al., 1979; Mengel, 1985; Moschler et al., 1973), higher residual soil mineral N levels (Moschler et al., 1973), and increased microbial biomass (Doran, 1980) there are some possible disadvantages of minimum tillage. These include increased acidity in the soil surface horizon (Blevins et al., 1977, 1978), higher potentials for denitrification and immobilization (Doran, 1980; Fredrickson et al., 1982), increased N requirements (Legg et al., 1979; Rice and Smith, 1984), and greater NO_3^--N leaching losses (Mengel, 1985).

A 3-yr minimum tillage corn experiment under sprinkler irrigation was initiated in 1983 with the objective of comparing several methods of nitrogen fertilizer placement using anhydrous ammonia, urea-ureaphosphate, urea, urea-ammonium nitrate, and sulfur-coated urea.

MATERIALS AND METHODS

A field study was conducted in 1983, 1984, and 1985 at the Mead Field Laboratory, Mead, NE on Sharpsburg silty clay loam. The experimental design was an incomplete factorial randomized complete block with three replications. No tillage operations were made other than ridge planting with an adapted Buffalo Till All-Flex planter (Fleischer Mfg., Inc., Columbus, NE). Weeds were controlled by annual broadcast applications of atrazine [2-chloro-4 ethylamino-6-isopropylamino-1,3,5 triazine] at 2.8 kg a.i. ha^{-1}, alachor [2-chloro-2'-6'-diethyl)-N-(methoxymethyl)-acetanalide] at 3.8 kg a.i. ha^{-1}, and 2,4-D (2,4-dichlorophenoxyacetic acid) at 0.6 kg a.i. ha^{-1} immediately following planting. Corn hybrids Pioneer 3720 and Pioneer 3377 (Pioneer Hi-Bred Int., Inc., Lincoln, NE) were planted in 1983 and 1984, 1985 respectively, at populations of 69 000 seed ha^{-1}. An early maturity variety was used in 1983 due to an 8 June planting. Corn was planted on 1 June and 21 May in 1984 and 1985, respectively. Methods of N placement were; band to the side of the seed at planting (6 cm to the side, 6 cm below the soil surface) (BA), dribble surface band at planting (6 cm to the side of the seed) (DS), broadcast preplant (BRP), anhydrous ammonia preplant (15 cm deep, 38 cm knife spacing (AA-PP), and anhydrous ammonia sidedress (15 cm deep, 76 cm spacing) at the 8-leaf stage (AA-SD). Nitrogen rates were 90 and 180 kg N ha^{-1} with two check plots (No N) per block. Sources of N were urea-ureaphosphate (UUP), 38-6-0 (N-P-K); sulfur-coated urea (SCU), 39-0-0-14 (29% 7-d dissolution rate); urea (U), 45-0-0; urea-ammonium nitrate (UAN), 32-0-0; and anhydrous ammonia (AA), 82-0-0. All methods of application, N sources, and N rates were included in a complete randomized block design with a factorial treatment arrangement, except the anhydrous ammonia and check treatments, which were outside the factorial. All plots were adjusted by rate for the carrier phosphorus and sulfur in the urea-ureaphosphate and sulfur-coated urea sources with concentrated superphosphate, 0-20-0; and elemental sulfur, 0-0-0-92S; respectively. Experimental units consisted of 4-row plots (76 cm × 10 m).

Grain was hand harvested from 3 m of the center two rows, weighed, shelled, and subsampled for moisture and total N determinations. Ear-leaf samples were taken from each plot at early silking. Hand-harvested stalks were cut, weighed, subsampled, ground, and analyzed for total N. Stover and ear leaf samples were dried in a forced-air oven at 70 °C and ground to pass a 2.0 mm screen. Total N in the ground grain, stover, and ear-leaf tissue samples were determined using the macro-Kjeldahl procedure. A composite soil sample for the entire experimental area was taken, prior to treatment application in 1983, for soil analysis and site characterization (Table 1). Corn was grown on this site without N fertilization in 1982. Water was applied via a sprinkler irrigation system all 3 yr.

Total dry matter was determined by the sum of grain yield and stover yield. Harvest index (HI) was calculated by dividing grain yield by the total dry matter. Fertilizer N uptake in the grain (FNUG) was determined by subtracting the total N in the grain of check plots (by replication) from total N in the grain of each experimental unit. The fraction of total N translocated to the grain (Ng/Nt) was determined by the method of Moll et al. (1982) where total N in the grain is divided by the total N in the plant (grain + stover).

Complete factorial treatments were analyzed separately due to the incomplete factorial design employed. Analysis of variance of the entire experiment including the anhydrous ammonia treatments were performed on the 3-yr means since interests were in the long-term effects of N treatments. All contrasts were non-orthogonal. Error variances from the replication, treatment, and complete factorial models were found to be equal, thus making simultaneous factorial and non-factorial treatment comparisons possible.

Table 1. Initial soil characteristics, Mead, NE, 1983.

Depth	NO_3^--N†	NH_4^+-N‡	P§	K¶	pH#	CEC††
	μg g^{-1}	μg g^{-1}	μg g^{-1}	μg g^{-1}		cmol kg^{-1}
0 to 30 cm	4.1	4.3	8.8	298	6.6	20.1
30 to 60 cm	4.1	5.0	4.3	163	6.5	20.6
60 to 90 cm	3.0	4.3	8.1	160	6.3	20.4
90 to 120 cm	3.6	3.5	9.5	184	6.4	19.7
120 to 150 cm	5.2	3.9	16.0	190	6.6	21.1
150 to 180 cm	7.3	3.6	25.0	216	6.7	22.0

† NO_3^--N = phenoldisulfonic acid procedure
‡ NH_4^+-N = steam distillation
§ P = Bray & Kurtz P-1
¶ K^+ = 1N NH_4 Ac extraction
# pH = 1:1 soil:water
†† CEC = Rhoades, 1982

RESULTS AND DISCUSSION

Grain yields reached a maximum with 90 kg N ha^{-1} for the broadcast preplant N application, while N response above 90 kg N ha^{-1} was still evident for banding methods of application (dribble surface and band to the side) as shown by the significant contrast within the method by rate interaction (Table 2 and 3). Differences between methods of N application with 180 kg N ha^{-1} were for the most part non-significant, resulting in a method × source × rate interaction, which restricts interpretation of the method of rate interaction. This three-way interaction occurred because at 90 kg N ha^{-1} urea-ammonium nitrate broadcast yield was 1.9 Mg higher than urea-ammonium nitrate banded, compared with only a 0.9 Mg yield increase for the other sources, while no differences in grain yield at 180 kg N ha^{-1} were observed. This was generally found to be the case for the other dependant variables. Therefore, the major focus of this paper concentrates on the treatment effects obtained at the lower N rate where differences in N use efficiency were evident. Because the main interests were in the long-term effects of method of N application and N sources, statistical analysis of the 3-yr means was used.

Applying N broadcast preplant maximized grain yields and dry matter production versus band to the side of the seed and dribble surface band methods at 90 kg N ha^{-1} (Table 2 and 3). In addition, broadcast N resulted in more fertilizer N and a greater amount of the total N appearing in the grain compared with either banding treatments. This is in contrast to previous research. Several investigators have demonstrated the superiority of banding or subsurface applications compared with surface broadcast N in minimum/no tillage corn production systems (Fredrickson et al., 1982; Mengel et al., 1982; Mengel, 1985; Touchton and Hargrove, 1982). However, much of the superiority of banding, and especially subsurface applications in these studies, may have been the result of volatilization losses soon after application. Relatively low volatilization losses were expected from N applications in this study since either adequate rainfall was received or water was applied via a sprinkler irrigation system each year immediately following fertilizer application. Low ambient and soil temperatures also aided in lowering the potential for volatilization losses at the time fertilizers were applied. This is probably also the reason that no differences were observed between surface and subsurface banding.

Harvest index values were also found to be greater for broadcast versus banding methods, which indicates that early growth was not a factor in terms of stover production (Table 2 and 4). In fact, stover production was not affected by N application methods or interactions affecting N sources, rates, or methods. Since methods of N application influenced grain, but not stover production, it appears that the effect of methods of N application on N availability may have occurred late in the growing season. Previous research by Gass et al. (1971) indicated that N uptake late in the season is more efficiently channeled to the grain than N uptake in early growth, which appeared to be immobilized in vegetative parts.

The superiority of broadcast N may suggest immobilization of broadcast applied N (Rice and Smith, 1984). The immobilized N could have provided an inorganic N pool that became available later in the growing season. It is also possible that broadcast N stimulated residue decomposition releasing added N later in the growing season. In any event, as summer soil temperatures increased mineralization would proceed more rapidly, thus continually providing a new source of NH_4^+-N and NO_3^--N. The advantage of having an NH_4^+-N supply later in the life cycle of corn as compared with NO_3^--N has been demonstrated by others (Below et al., 1981; Mills and McClhannon, 1982; Olsen, 1986). Rapid mineralization rates should have been present during the growing season since sprinkler irrigation provided optimum moisture conditions.

It is interesting to note that yield levels expressed as a relative percent increase or decrease as compared to the environment mean (average of all plots each year at 90 kg N ha^{-1}) were found to decrease year to year for banding methods (−6, −8, −13% for 1983,

Table 2. Analysis of variance for the complete factorial arranged treatments on the 3-yr means. Mead, NE, 1983 to 1985.

Source of variation	df	Grain yield	Total dry	Stover yield	FNUG‡	Harvest index	Ng/Nt§
		Mg ha^{-1}			kg ha^{-1}		
Rep	2	**	**	**	†	**	†
Method	2	*	NS	NS	*	**	*
BRPvsBA, DS¶		**	NS	NS	*	**	**
BAvsDS		NS	NS	NS	†	NS	NS
Source	3	NS	NS	*	NS	NS	NS
UUPvsSCU,UAN, U		NS	*	**	NS	NS	*
UANvsSCU,UUP,U		NS	NS	*	†	*	†
SCUvsUAN		NS	NS	NS	NS	NS	NS
Rate (RT)	1	**	**	†	**	†	*
Method × Source	6	NS	NS	NS	NS	NS	NS
Method × Rate	2	*	NS	NS	*	*	†
BRPvsBA,DS×RT		*	†	NS	**	**	*
BAvsDS×RT		NS	NS	NS	NS	NS	NS
Source × Rate	3	NS	NS	NS	NS	NS	NS
Method × Source × Rate	6	†	NS	NS	**	NS	NS
BRPvsBA,DS×UANvsSCU,U,UUP×RT		*	*	NS	**	†	NS
Error	46						
Coefficient of variation, %		11	11	14	20	5	6
Standard error of a treatment mean		0.489	0.767	0.408	5.205	0.018	0.022

†,*,**, Significant at 0.10, 0.05, and 0.01 probability levels, respectively. NS = not significant.
‡, FNUG = Fertilizer N uptake in grain.
§, Ng/Nt = Fraction of total N translocated to the grain.
¶ BRP = broadcast preplant, BA = band to the side, DS = dribble surface band, UUP = urea-ureaphosphate, SCU = sulfur-coated urea, UAN = urea-ammonium nitrate, U = urea, and RT = rate.

Table 3. Treatment means (3-yr) for grain yield, total dry matter, and stover yield, Mead, NE. 1983 to 1985.

N source	Broadcast preplant			Band to the side			Dribble surface band			Mean		
	Grain yield	Total dry matter	Stover yield	Grain yield	Total dry matter	Stover yield	Grain yield	Total dry matter	Stover yield	Grain yield	Total dry matter	Stover yield
	Mg ha^{-1}											
	90 kg N ha^{-1}											
Sulfur-Coated Urea	7.47	11.82	4.35	7.02	12.14	5.12	6.53	11.39	4.86	7.00	11.78	4.78
Urea-Ammonium Nitrate	7.98	12.77	4.79	5.53	10.14	4.61	6.68	11.41	4.73	6.73	11.44	4.71
Urea	7.80	13.22	5.42	6.39	11.58	5.19	6.32	11.40	5.09	6.84	12.07	5.23
Urea-Ureaphosphate	7.84	12.90	5.06	7.22	13.28	6.05	7.07	12.60	5.53	7.38	12.92	5.55
Mean	7.77	12.68	4.91	6.54	11.79	5.24	6.65	11.70	5.05			
	180 kg N ha^{-1}											
Sulfur-Coated Urea	7.98	13.30	5.32	6.97	12.17	5.20	8.14	13.74	5.60	7.70	13.07	5.37
Urea-Ammonium Nitrate	7.53	12.22	4.69	8.50	13.78	5.28	8.09	13.33	5.25	8.04	13.11	5.07
Urea	7.69	13.05	5.35	8.01	13.80	5.79	7.54	12.22	4.68	7.75	13.02	5.27
Urea-Ureaphosphate	8.23	13.48	5.25	7.62	13.96	6.34	7.32	13.07	5.75	7.72	13.50	5.78
Mean	7.86	13.01	5.15	7.78	13.43	5.65	7.77	13.09	5.32			

1984, and 1985, respectively). Comparatively, broadcast preplant showed relative increases with time with respect to the environmental mean over the 3-yr period (+1, +7, and +17%, respectively). It seems that corn grain yield was tending to decrease over the 3 yr of the experiment when N was banded compared with an increasing trend when N was broadcast. How or if these trends are related to any accumulative effect over time is not known. Recent research reported by Rice et al. (1986) has shown that the lower N availability reported initially in no-till systems compared with conventional tillage (Blevins et al., 1977) may be a transient effect, and that this difference becomes zero over longer term.

Ammonia Treatment Comparisons

Grain and stover yields for preplant anhydrous ammonia and side-dressed anhydrous ammonia (eight-leaf stage) were maximized at the low N rate. There were few significant differences between these two methods for any of the response variables measured (Table 5 and 6). The exception was for lower stover yield and a higher harvest index where ammonia was sidedressed compared with ammonia preplant. In general, the ammonia treatments provided increased grain and total dry matter yields compared with all other N method or source combinations, excluding N applied broadcast preplant at the low N rate (Table 3, 4, 5, and 6). Results from an experiment conducted by Mengel et al. (1982) sharply contrasts this finding. However, the immediate watering following broadcast applications in this experiment probably reduced volatilization losses to a minimum. Immediate watering could take place under field conditions where center pivot irrigation systems are used. Although grain and stover yields were not different for broadcast preplant compared with ammonia (preplant and sidedress), total dry matter and fertilizer N uptake in the grain was found to be greater for the ammonia treatments. While not included in the tables, protein contents in the grain

Table 4. Treatment means (3 yr) for fertilizer N uptake in the grain, harvest index, and fraction of N translocated to the grain, Mead, NE, 1983 to 1985.

	Broadcast preplant			Band to the side			Dribble surface band			Mean		
N source	FNUG†	Harvest index‡	Ng/Nt§	FNUG	Harvest index	Ng/Nt	FNUG	Harvest index	Ng/Nt	FNUG	Harvest index	Ng/Nt
	kg ha^{-1}			kg ha^{-1}			kg ha^{-1}			kg ha^{-1}		
					90 kg N ha^{-1}							
Sulfur-Coated Urea	41.1	0.62	0.72	38.9	0.56	0.68	27.8	0.56	0.67	36.0	0.58	0.69
Urea-Ammonium Nitrate	45.6	0.62	0.74	19.4	0.54	0.66	28.5	0.58	0.68	31.2	0.58	0.69
Urea	43.1	0.58	0.71	37.4	0.55	0.66	30.0	0.55	0.67	36.8	0.56	0.68
Urea-Ureaphosphate	41.8	0.60	0.69	41.1	0.54	0.65	35.4	0.55	0.65	39.5	0.57	0.67
Mean	42.9	0.61	0.72	34.2	0.55	0.66	30.4	0.56	0.67			
					180 kg N ha^{-1}							
Sulfur-Coated Urea	55.8	0.58	0.67	46.4	0.57	0.65	56.1	0.58	0.66	52.8	0.58	0.66
Urea-Ammonium Nitrate	42.7	0.58	0.66	60.5	0.61	0.69	52.4	0.60	0.69	50.9	0.60	0.68
Urea	52.9	0.57	0.64	64.4	0.57	0.64	49.4	0.61	0.70	55.6	0.59	0.66
Urea-Ureaphosphate	56.9	0.60	0.69	51.9	0.55	0.63	46.6	0.55	0.63	51.8	0.57	0.65
Mean	52.1	0.58	0.67	55.8	0.58	0.65	51.1	0.59	0.67			

† FNUG = Fertilizer N uptake in grain (kg ha^{-1}).
‡ Harvest index = Grain weight/total dry matter.
§ Ng/Nt = Fraction of total N translocated to the grain.

Table 5. Analysis of variance and single degree of freedom contrasts comparing ammonia preplant and sidedress with other N application methods and sources. Mead, NE, 1983–1985.

Source of variation	df	Grain yield	Stover dry matter	Stover yield	FNUG‡	Harvest index	Ng/Nt§
		Mg ha^{-1}			kg ha^{-1}		
Total	89						
REP	2	**	**	**	*	**	*
TRT	29	**	**	**	**	**	*
Check vs Rest	1	**	**	**	NT	**	NS
AA-PP 90 vs SD 90¶	1	NS	NS	*	NS	†	NS
AA-PP & SD 90 vs BRP 90	1	NS	†	NS	**	NS	NS
AA-PP & SD 90 vs BA 90	1	**	**	NS	**	**	†
AA-PP & SD 90 vs DS 90	1	**	**	NS	**	*	†
AA-PP & SD 90 vs UUP 90	1	*	NS	NS	**	†	†
AA-PP & SD 90 vs U 90	1	**	**	NS	**	*	NS
AA-PP & SD 90 vs UAN 90	1	**	**	*	**	NS	NS
AA-PP & SD vs SCU 90	1	**	**	†	**	NS	NS
AA-PP & SD 90 vs BRP-SCU 90	1	†	*	*	*	NS	NS
AA-PP & SD 90 vs BA, DS-UUP 90	1	†	NS	NS	**	NS	NS
AA-PP & SD 90 vs BRP-UUP 90	1	NS	NS	NS	*	NS	NS
Error	58						
Coefficient of variation, %		12	11	14	20	5	5
Standard error of a treatment	mean	0.492	0.769	0.405	5.030	0.018	0.020

†,*,** Significant at 0.10, 0.05, and 0.01 probability levels, respectively. NS = not significant, NT = not a testable effect.
‡ FNUG = Fertilizer N uptake in grain.
§ Ng/Nt = Fraction of total N translocated to the grain.
¶ AA-PP = Anhydrous ammonia preplant, SD = sidedress, BRP = broadcast preplant, BA = band to the side, DS = dribble surface band, UUP = urea-ureaphosphate, U = urea, UAN = urea ammonium nitrate SCU = sulfur-coated urea.

Table 6. Anhydrous ammonia treatment means (3-yr) for grain yield, total dry matter, stover yield, fertilizer N uptake in the grain, harvest index, and fraction of N translocated to the grain, Mead, NE. 1983 to 1985.

N rate	Method	Grain yield	Total dry matter	Stover yield	FNUG†	Harvest index	Ng/Nt
$kg\ ha^{-1}$		Mg ha^{-1}			$kg\ hg^{-1}$		
90	AA-PP‡	8.62	14.66	6.04	56.9	0.58	0.68
90	AA-SD§	8.29	13.23	4.94	55.5	0.62	0.72
Mean		8.46	13.95	5.49	56.2	0.60	0.70
180	AA-PP	8.30	13.81	5.51	59.7	0.59	0.66
180	AA-SD	8.21	12.71	4.49	58.6	0.64	0.70
Mean		8.26	13.26	4.96	59.2	0.62	0.68
0	Check	4.11	7.89	3.78	—	0.52	—

† FNUG = Fertilizer N uptake in grain
‡ AA-PP = Anhydrous ammonia preplant
§ AA-SD = Anhydrous ammonia sidedress

were also greater for the ammonia treatments as compared with all other N method-source combinations at the low N rate.

The only broadcast preplant treatment found to be lower yielding compared with the ammonia methods was when sulfur-coated urea was used as the N source. Since all plots were adjusted for the S in the sulfur-coated urea, S was not believed to be the limiting factor. The dissolution rate of this source was probably too slow causing insufficient N to be available during the reproductive stage of growth.

N Source Differences

Differences in response to N sources were generally small. However, total dry matter and stover yields were found to be greater for urea-ureaphosphate compared with sulfur-coated urea, urea, and urea ammonium nitrate (Table 2 and 3). In a similar study, Urban et al. (1987) attributed the favorable response of urea-ureaphosphate to decreased ammonia losses because of pH buffering by the phosphoric acid component in this source. At 90 kg N ha^{-1} urea-ammonium nitrate banded to the side of the seed performed poorly in terms of grain yield. Although this is consistent with previous results obtained at this location the cause of this effect is not understood (Olson et al., 1986).

Ear-Leaf Tissue Sampling

Ear-leaf samples at early silking were taken in an attempt to establish critical N levels for future N fertilization recommendations. Various response equations (by method, source, year, across years, and various combinations of these three variables) of ear leaf N versus grain yield were tested. However, no significant relationships were obtained to either predict yield or determine critical N levels needed for maximum grain yield.

CONCLUSIONS

Grain yields were maximized with broadcast preplant applications of N as compared with band to the side and dribble surface band methods in an irrigated minimum tillage corn production system. This may have been due to the low volatilization losses expected since sufficient water was applied immediately following application. Broadcast preplant applications of N were no better than anhydrous ammonia preplant and/or sidedress methods in terms of grain yield, but were lower in total dry matter produced. Grain yields expressed as a function of the environmental means were found to decrease with time for the banding methods while increases were observed when N was applied broadcast. Ear leaf N was not found to be a good predictor variable for grain yield, thus restricting its use for identifying critical N levels, which could indicate the need for further in-season fertilization.

REFERENCES

Below, F.E., L.E. Christensen, A.J. Reed, and R.H. Hageman. 1981. Availability of reduced N and carbohydrates for ear development of maize. Plant Physiol. 68:1186–1190.
Blevins, R.L., L.W. Murdock, and G.W. Thomas. 1978. Effect of lime application of no-tillage and conventionally tilled corn. Agron. J. 70:322–326.
———, G.W. Thomas, and P.L. Cornelius. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after 5 years of continuous corn. Agron. J. 69:383–386.
Bremner, J.M., and L.A. Douglas. 1971. Decomposition of urea phosphate in soils. Soil Sci. Soc. Am. Proc. 35:575–578.
Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. Am. J. 44:765–771.
Fenn, L.B., and D.E. Kissel. 1973. Ammonia volatilization from surface applications of ammonia compounds on calcareous soils. I. General theory. Soil Sci. Soc. Am. Proc. 37:855–859.
———, and ———. 1976. The influence of cation exchange capacity and depth of incorporation on ammonia volatilization from ammonia compounds applied to calcareous soils. Soil Sci. Soc. Am. Proc. 40:394–398.
Fox, R.H., and L.D. Hoffman. 1981. The effect of N fertilizer source on grain yield, N uptake, soil pH, and lime requirement in no-till corn. Agron. J. 73:891–895.
———, J.M. Kern, and W.P. Piekielek. 1986. Nitrogen fertilizer source, and method and time of application effects on no-till corn yields and nitrogen uptakes. Agron. J. 78:741–746.
Fredrickson, J.K., F.E. Koehler, and H.H. Cheng. 1982. Availability of ^{15}N-labeled nitrogen in fertilizer and in wheat straw to wheat in tilled and no-till soil. Soil Sci. Soc. Am. J. 46:1218–1222.
Gass, W.B., G.A. Peterson, R.D. Rauck, and R.A. Olson. 1971. Recovery of residual nitrogen by corn (*Zea mays* L.) from various soil depths as measured by ^{15} tracer techniques. Soil Sci. Soc. Am. Proc. 35:290–294.
Legg, J.O., G. Stanford, and O.L. Bennett. 1979. Utilization of labeled-N fertilizer by silage corn under conventional and no-till culture. Agron. J. 71:1009–1015.
Matocha, J.E. 1976. Ammonia volatilization and nitrogen utilization from sulfur-coated ureas and conventional nitrogen fertilizers. Soil Sci. Soc. Am. J. 40:597–601.
Mengel, D.B., D.W. Nelson, and D.M. Huber. 1982. Placement of nitrogen fertilizers for no-till and conventional till corn. Agron. J. 74:515–518.
———. 1985. Curbing N loss in reduced till. Solutions 29(2):60–64.
Mills, H.A., and McClhannon. 1982. Nitrogen uptake by sweet corn. Hortic. Sci. 17:743–744.
Moll, R.H., E.J. Kamprath, and W.A. Jackson. 1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agron. J. 74:562–564.
Moschler, W.W., D.C. Martens, C.I. Rich, and G.M. Shear. 1973.

Comparative lime effects on continuous no-tillage and conventionally tilled corn. Agron. J. 65:781–783.
Olsen, S.R. 1986. The role of ammonium nutrition in higher yields. p. 6–14. *In* J. Havlin (ed.) Proc. of the great plains soil fertility workshop. Denver, CO. 4–5 March 1986. Kansas State Univ., Manhattan, KS.
Olson, R.A., W.R. Raun, Yang Shou Chun, and J. Skopp. 1986. Nitrogen management and interseeding effects on irrigated corn and sorghum and on soil strength. Agron. J. 78:856–862.
Rhoades, J.D. 1982. Cation exchange capacity. *In* A.L. Page (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:149–157.
Rice, C.W., M.S. Smith, and R.L. Blevins. 1986. Soil nitrogen availability after long-term continuous no-tillage and conventional tillage corn production. Soil Sci. Soc. Am. J. 50:1206–1210.
———, and ———. 1984. Short-term immobilization of fertilizer nitrogen at the surface of no-till and plowed soil. Soil Sci. Soc. Am. J. 48:295–297.
Sander, D.H., and W.J. Moline. 1980. Sulfur-coated urea and urea compared as nitrogen sources for irrigated corn. Soil Sci. Soc. Am. J. 44:777–782.
Tennessee Valley Authority. 1983. New developments in fertilizer technology. Natl. Fertilizer Develop. Ctr. Bulletin Y-181.
Touchton, J.T., and W.L. Hargrove. 1982. Nitrogen sources and methods of application for no-tillage corn production. Agron. J. 74:823–826.
Urban, W.J., W.L. Hargrove, B.R. Bock, and R.A. Raunikar. 1987. Evaluation of urea-ureaphosphate as a nitrogen source for no-tillage production. Soil Sci. Soc. Am. J. 51:242–246.