Table 2. Effect of previous crop, dairy manure, and urea-N on corn yield and N uptake at Waseca, MN in 1990.

Previous crop	N source	Rate	Grain Yield	Grain N uptake	Silage Yield	Silage N uptake
			bu/A	lb/A	T DM/A	lb/A
Alfalfa	Urea	0 lb/A	154	102	6.84	129
		30	177	124	7.77	156
		60	172	118	7.94	155
		100	159	113	7.12	149
		140	159	115	7.24	150
	Manure	3000 gal/A	170	117	7.45	148
		5000	174	120	7.69	157
		7000	177	117	8.00	152
P>F			0.07	0.12	0.07	0.16
CV(%)			7.2	8.0	13.1	10.5
Corn	Urea	0 lb/A	136	78	5.71	98
		60	146	89	6.50	116
		100	145	92	6.43	120
		140	146	95	6.50	121
		180	167	112	7.19	141
	Manure	3000 gal/A	132	79	5.61	98
		7000	145	93	6.22	121
		11000	150	98	6.59	132
P>F			0.01	0.05	0.01	0.01
CV (%)			7.2	7.5	7.3	7.7

Table 3. Estimated N availability and N credits for dairy manure applied to continuous corn at Rosemount and Waseca, MN.

Location	Manure rate	Estimated N-availability[1]	N-credit[2]
Waseca	3000	55	0
	7000	130	75
	11000	203	110
Rosemount	3000	32	47
	7000	74	78
	11000	116	90

[1] Estimated N availability is based on 25% of the organic N being available the year of application

[2] N credit was determined by comparing continuous corn grain yield after application of manure with fertilizer-N response of continuous corn

CORN AND SOYBEAN PRODUCTION AS INFLUENCED BY BRIGHT SUN[1]

1990

G. W. Randall and B. W. Anderson[2]

ABSTRACT: This one-year study was conducted to determine if foliar applications of Bright Sun, a foliar plant food, would enhance corn or soybean production. Factorial studies with Bright Sun and N applied to corn and Bright Sun and P & K applied to soybeans were conducted on Nicollet and Webster soils at Waseca. Corn production was improved by N application but unaffected by Bright Sun. Soybean production was not improved by either the application of P & K or by Bright Sun. Based on this test, Bright Sun is not recommended for corn or soybeans at this time.

Foliar application of nutrients to corn and soybeans has shown very limited success in numerous trials throughout the Corn Belt. The purpose of this study was to evaluate the efficacy of Bright Sun, a molasses containing foliar plant food, on corn and soybean production in south-central Minnesota.

Experimental Procedures - CORN

A factorial design consisting of three preplant N rates (0, 75 and 150 lb N/A) and two Bright Sun treatments (none and a complete foliar program) was replicated four times on a Nicollet clay loam (Aquic Hapludoll). This previous crop was corn that had been moldboard plowed in October, 1989. Anhydrous ammonia was preplant-applied on May 4 just prior to field cultivation. Corn (Pioneer 3737) was planted on May 8 at 28,420 plants/A. Lasso (3.5 lb/A) plus Bladex (3.0 lb/A) was applied preemergence on May 11. All plots were cultivated once in mid-June. Weed control was excellent. Each plot was 10' wide (4-30" rows) x 55' long.

Bright Sun was applied three times at a rate of 3 gal/A each time using 40+ psi and a total application volume of 18 gal/A. Water was the carrier. The first application was made with a bicycle sprayer on June 21 when the corn was in the V5 stage (12" tall). The second application was made with a Spirit motorized sprayer on July 13 (V11 stage with 0-lb N rate and V12-13 with 75- and 150-lb N rates). A Hy-Boy sprayer was used on July 31 to make the third application (R1 to R2 stage). All applications were made before 9:30 AM or after 5:00 PM without using a surfactant.

Plant population was determined by counting the total number of plants in the two center rows each 55' long. Plant height after tasseling was taken on August 9 by measuring to the top of the tassel on 10 random plants/plot. Silage yields were taken by hand-harvesting 15' of row on September 27. Grain yield and moisture were obtained on October 6 by combine harvesting the center two rows of each 4-row plot with a JD 3300 plot combine. Ear length was determined from a random sample of 10 ears per plot. Kernel weight was determined by weighing 100 kernels that had been oven-dried to remove water.

Grain N concentration was determined by the University's Research Analytical Laboratory using a total Kjeldahl N procedure. Fodder samples taken at physiological maturity were ground and submitted to the University's NIRS Forage Research Laboratory for crude protein, ADF, NDF, and elemental analyses.

Experimental Procedures - SOYBEANS

A factorial design consisting of three preplant phosphate (P) and potash (K) applications (0, 25 lb P_2O_5/A + 40 lb K_2O/A, and 50 lb P_2O_5 + 80 lb K_2O/A) and two Bright Sun treatments (none and a complete foliar program) was replicated four times. The experimental site was a Nicollet clay loam (Aquic Hapludoll) - Webster clay loam (Typic Haplaquoll) complex that was tile drained. The previous crop was corn that had been moldboard plowed in October, 1989. The P and K treatments were broadcast applied on June 6 and immediately incorporated with a field cultivator. Soil tests for the area prior to fertilization averaged: pH = 6.4, Bray P_1 = 21 ppm (VH), and exchangeable K = 156 ppm (VH).

Hardin soybeans were planted in 30-inch rows at a rate of 10 beans/foot of row on June 6. Each plot was 10' wide (4 - 30" rows) x 55' long. Lasso (3.5 lb/A) and Amiben (2.5 lb/A) were applied on June 7. All plots were cultivated on July 16. Weed control was perfect. Pictures were taken on July 13 and 31.

Bright Sun was applied four times at a rate of 3 gal/A each time using the same procedures as for corn. The first and second applications were made on July 13 (V5 stage) and July 31 (R2 stage), respectively, using a Spirit motorized sprayer. The third application was made with a bicycle sprayer on August 28 (R4 stage). The fourth application was made by hand on September 5 (R5 stage) using a backpack sprayer and a boom.

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[1] Partial support for this project was provided by Cargill.

[2] Professor and assistant scientist, Southern Experiment Station, Waseca, MN

Plant height was determined on October 6 by measuring 10 random plants per plot. All plants from a 3-foot section of row in each plot were cut at the soil surface on October 8. The plants were separated into the bottom 12" versus the rest and pod counts were made on each plant portion. Soybean seed yields and moisture were obtained on October 11 by harvesting the center two rows of each plot with a specialized ALMACO SPC-40 plot combine.

Seed weight was determined on 100 random seeds. Protein and oil content based on 13% moisture were determined by Dr. J. Orf's soybean research project.

Results and Discussion - CORN

Corn grain yield, grain N concentration, ear length, plant height, kernel weight, fodder yield and silage yield were all increased over the control by the 75- and 150-lb preplant N treatments (Table 1). Grain and silage yield, grain N concentration and plant height were significantly higher for the 150-lb N rate compared to the 75-lb rate. Grain moisture was reduced with increasing N rate. Plant population was not influenced by N rate.

The application of Bright Sun did not have any effect on grain moisture, grain yield, N concentration, plant population, plant height, kernel weight, ear length, fodder yield, and silage yield (Table 1). Moreover, there was no interaction between N rate and Bright Sun application. This indicates that Bright Sun did not influence corn production even when N was limiting.

Table 1. Grain yield, moisture, plant height, kernel weight and dry matter yield as influenced by N rate and Bright Sun in 1990.

N rate	Bright Sun	Grain H_2O	Grain Yield	Grain N	Plant Popl'n	Plant Height	Kernel Weight	Ear Length	Fodder Yield	Silage Yield
lb/A		%	bu/A	%	ppA x 10^3	cm	g/100	in/ear	--- TDM/A	----
0	No	24.0	85.4	1.12	28.0	230	17.7	6.12	2.14	4.96
0	Yes	24.6	82.8	1.12	27.8	226	18.2	5.88	1.96	4.67
75	No	19.7	128.1	1.18	28.1	251	19.0	7.42	2.82	7.25
75	Yes	20.2	131.1	1.17	27.9	243	18.6	7.35	3.03	7.29
150	No	19.2	148.5	1.27	28.1	254	19.6	7.55	3.16	7.98
150	Yes	18.8	149.4	1.29	28.1	254	19.3	7.48	2.91	7.74
N rate										
0		24.3	84.1	1.12	27.9	227	17.9	6.00	2.05	4.81
75		20.0	129.6	1.17	28.0	247	18.8	7.39	2.93	7.27
150		19.0	149.0	1.28	28.1	254	19.4	7.51	3.04	7.86
Signif. Level (%):		99	99	99	69	99	96	99	99	99
BLSD (.05) :		1.0	6.3	0.05	-	7	1.2	.19	0.20	0.26
Bright Sun										
No		21.0	120.6	1.19	28.1	245	18.8	7.03	2.70	6.73
Yes		21.2	121.1	1.29	28.0	240	18.7	6.90	2.64	6.56
Signif. Level (%):		34	12	14	79	83	13	88	56	85
N rate x Bright Sun Interaction										
Signif. Level (%):		40	31	22	37	46	27	40	91	56
CV (%) :		5.0	5.4	3.9	0.8	2.9	5.8	2.8	7.8	4.1

NIRS analyses of the fodder (not ensiled) indicated that crude protein, acid detergent fiber (a measure of non-digestible fiber), neutral digestible fiber, (more easily digestible cell walls) K and Ca were all increased by the preplant N rates over the control (Table 2). The highest N rate resulted in the highest protein levels and K concentrations. Phosphorus and Mg concentrations were not influenced by the N rates.

Bright Sun increased crude protein of the fodder by 10% and resulted in a slight increase in K concentration (Table 2). Some of this protein increase could have been due to the liquid fertilizer adsorbed onto the fodder tissue rather than absorbed into the cell tissue. There were no interactions between N rates and Bright Sun applications.

Results and Discussion - SOYBEANS

Soybean seed yield, moisture, protein and oil content were not influenced by P and K application rates (Table 3). Bright Sun significantly reduced soybean seed yield but did not affect seed moisture, protein or oil content. Because no phytotoxicity symptoms were observed and visual observations did not reveal height differences, one can suspect that physical disturbance caused by walking through the bushy and somewhat lodged soybeans to apply the last two treatments may have caused this yield depression. Application of foliar materials by ground driven means was impossible because severe traffic damage would have resulted. There was no interaction between P & K rate and Bright Sun application.

Table 2. Nutrient concentrations in the fodder at physiological maturity as influenced by N rate and Bright Sun in 1990.

N rate	Bright Sun	Crude Protein	ADF	NDF	P	K	Ca	Mg
lb/A		%						
0	No	3.25	41.5	63.4	0.22	1.15	0.17	0.15
0	Yes	3.79	42.1	63.5	0.22	1.20	0.17	0.14
75	No	3.93	44.1	67.6	0.22	1.26	0.20	0.15
75	Yes	4.16	43.9	66.8	0.22	1.27	0.21	0.15
150	No	4.70	44.2	66.9	0.22	1.29	0.22	0.15
150	Yes	5.13	44.5	66.8	0.22	1.31	0.23	0.15
N rate								
0		3.52	41.8	63.4	0.22	1.18	0.17	0.14
75		4.05	44.0	67.2	0.22	1.26	0.21	0.15
150		4.91	44.3	66.9	0.22	1.30	0.22	0.15
Signif. Level (%):	99	99	99	22	99	99	78	
BLSD (.05) :		.30	0.8	1.5	-	.03	.02	-
Bright Sun								
No		3.96	43.2	66.0	0.22	1.23	0.22	0.15
Yes		4.36	43.5	65.7	0.22	1.26	0.20	0.15
Signif. Level (%):	99	54	35	54	95	61	46	
N rate x Bright Sun Interaction								
Signif. Level (%):	41	32	16	4	61	18	32	
CV (%) :	7.4	1.9	2.3	4.9	2.4	11.	6.6	

Table 3. Soybean seed yield, protein and oil content as influenced by three levels of phosphorus and potassium fertilizer and Bright Sun.

P_2O_5 rate	K_2O rate	Bright Sun	Seed H_2O	Yield	Protein	Oil
------ lb/A ------			%	bu/A	%	%
0	0	No	12.1	50.2	35.6	17.0
0	0	Yes	12.0	45.9	35.6	16.8
25	40	No	12.2	51.8	35.8	16.8
25	40	Yes	12.1	46.4	35.9	16.8
50	80	No	12.2	52.2	36.1	16.6
50	80	Yes	12.1	45.7	35.9	16.8
Rate of P_2O_5+K_2O ----- lb/A ----						
0	0		12.0	48.0	35.6	16.9
25	40		12.1	49.1	35.9	16.8
50	80		12.2	49.0	36.0	16.7
Signif. Level (%):			29	47	90	85
Bright Sun						
No			12.2	51.4	35.8	16.8
Yes			12.0	46.0	35.8	16.8
Signif. Level (%):			62	99	18	<1
P_2O_5+K_2O x Bright Sun Interaction						
Signif. Level (%):			5	48	36	41
CV (%) :			2.2	4.1	1.0	1.1

Soybean yield components (plant height, seed weight, and pod count) were also not influenced significantly (P = 95% level) by the P & K rates (Table 4). Bright Sun did significantly reduce the number of pods on the lower portion of each plant but did not influence the other yield components. Again, interactions between Bright Sun and P & K applications were not evident.

Table 4. Plant height, seed weight and pod distribution on plant as influenced by three levels of phosphorus and potassium fertilizer and Bright Sun.

P_2O_5 rate	K_2O rate	Bright Sun	Plant Height	Seed Weight	Pod Distribution Bottom 1'	Above 1'	Total
lb/A			in.	g/100 seeds	No. pods/plant		
0	0	No	35.5	18.6	18.5	23.0	41.5
0	0	Yes	35.2	18.5	14.0	19.8	33.8
25	40	No	36.2	19.0	17.7	21.2	39.0
25	40	Yes	36.0	18.8	15.5	22.2	37.8
50	80	No	36.8	18.7	13.5	21.0	34.5
50	80	Yes	36.0	18.9	13.0	20.5	33.5
Rate of P_2O_5+K_2O lb/A							
0	0		35.4	18.6	16.2	21.4	37.6
25	40		36.1	18.9	16.6	21.8	38.4
50	80		36.4	18.8	13.2	20.8	34.0
Signif. Level (%):			88	78	94	31	87
Bright Sun							
No			36.2	18.8	16.6	21.8	38.3
Yes			35.8	18.7	14.2	20.8	35.0
Signif. Level (%):			70	30	95	66	92
P_2O_5+K_2O x Bright Sun Interaction							
Signif. Level (%):			17	45	62	79	76
CV (%) :			2.6	1.9	18.	11.	12.

Conclusions

Foliar applications of Bright Sun to corn and soybeans did not result in yield or quality improvement under the soil and climatic conditions of this study.

DECLINE RATES OF SOIL TEST P AND K IN A CORN-SOYBEAN ROTATION[1]

1990

G. W. Randall and S. D. Evans[2]

ABSTRACT: Decline rates of soil test P and K are being measured following 12 years of various application rates of P and K at two locations. Soil test P declined by about 13% at Waseca. Soil test K also decreased from 15 to 30% at Waseca. Even though soil test differences occurred among the treatments at Morris, the high variability made interpretation very difficult. Soybean yields were increased about 13% over the long-term control plots at the two sites when soil test Bray P_1 was greater than 30 lb/A. Reducing soil test K from about 250 lb/A to 175 lb/A resulted in a 7 to 8 bu/A soybean yield reduction at Waseca.

With good fertilization practices over the last 20 to 30 years, many farmers throughout the Cornbelt have built their P and K soil tests to high and very high levels. Studies conducted over the last 12 years have not shown corn and soybean yield increases from additional broadcast P and K at these high to very high test levels. Consequently, a number of farmers have curtailed P and K fertilization on these high testing soils. Two commonly asked questions in this scenario are: (1) How fast will my soil test drop if I don't continue to add fertilizer P and K? and (2) At what test level should I begin to add P and K to maintain fertility at an optimum level for efficient and economical production? The purposes of this study are to determine (1) the decline rates of soil test P and K and (2) the optimum soil test level which should be maintained for economical corn and soybean production.

EXPERIMENTAL PROCEDURES

High rates of P and K were applied over a 12-year period (1973-84) in studies at the Southern Experiment Station at Waseca (Table 2) and the West Central Experiment Station at Morris (Table 3). These rates created a wide range of soil test values upon which we can evaluate the decline rates of soil test P and K when no additional fertilizer is added. Treatments 2, 3, and 4 have not received additional P since 1984 while treatments 6 and 7 at Waseca have not received K. The K treatments were not included at Morris because of very high native soil test K levels. Treatment 5, which had a moderately high level of fertilization prior to 1985, continues to receive P and K, and thus, serves as the high fertility control.

Table 1. Experimental procedures for soybeans on the high P and K rate study at the two branch stations in 1990.

Variable	Location	
	Morris	Waseca
Planting date	5/21	6/1
Row spacing	30"	30"
Planting rate (plants/A)	9-10 seeds/ft	10-11 seeds/ft
Variety	Evans	Hardin
Herbicide	3# Lasso/A (Bdct)	3.5# Lasso + 3# Amiben/A (Bdct)
Harvest date	9/24	10/11
Soil type	Aastad clay loam	Webster clay loam

The P and K materials (0-46-0 and 0-0-60) were broadcast on the soil surface and incorporated by chisel plowing the corn residue in the fall of 1989. Specific experimental procedures used for corn at the two locations are presented in Table 1. Management practices providing for optimum yields were employed at each location. Starter fertilizer was not used.

RESULTS AND DISCUSSION

Total phosphate (P_2O_5) and potash (K_2O) applied over the 12-year period ranged from 0 to 1200 lb/A (Tables 2 and 3). These application rates plus the 1985-89 rates resulted in highly significant differences in soil test P and soil test K at Waseca. At Waseca soil test P ranged from 10 to 99 lb/A (Table 2). Soil test P declined about 13% compared to 1989. Soil test K declined by about 15% since 1989 where the 100-lb rate was applied but by over 25% where no K was applied. Soybean yields were increased significantly by P but plateaued at soil P levels higher than 30 lb/A. Yields were also decreased significantly on those plots that did not receive K and had soil test K values of 170 to 175 lb/A.

[1] Funding provided by the TVA-National Fertilizer Development Center.

[2] Soil scientists and professors at the Southern Experiment Station (Waseca) and West Central Experiment Station (Morris), respectively.

At Morris, Bray P_1 ranged from 13 to 35 lb/A while Olsen's $NaHCO_3$ test ranged from 12 to 29 lb P/A (Table 3). Due to extremely high variability, these differences were not statistically significant at the P = 90% level. Considering this variability, both soil test P and K declined at this site in 1990.

Table 2. Soil test values, seed moisture, and seed yield as influenced by 17 years' application of P and K at Waseca.

	P and K Treatments						Soil Test[2]			Soybean	
	Total										
No.	1973-84			1985-89[1]			pH	P	K	Moisture	Yield
	------ lb P_2O_5 + K_2O/A ------							--- lb/A ---		%	bu/A
2	0	+	1200	0	+	100	6.7	10	278	12.5	42.6
3	600	+	1200	0	+	100	6.6	30	239	12.8	55.5
4	1200	+	1200	0	+	100	6.8	67	251	12.7	53.6
5	600	+	1200	100	+	100	6.7	71	254	12.8	54.5
6	1200	+	0	100	+	0	6.8	99	171	12.1	47.5
7	1200	+	600	100	+	0	6.7	91	175	12.1	47.0
Signif. Level (%):							32	99	99	91	99
BLSD (.05) :							-	15	48	-	5.9
CV (%) :							2.7	15.0	12.	2.7	6.4

[1] Treatments applied each fall. P was discontinued for treatments 6 & 7 in 1988.
[2] Samples were taken in October before 1990 treatments were applied.

Table 3. Soil test values, seed moisture, and seed yield as influenced by 17 years' application of P and K at Morris.

	P and K Treatments						Soil Test[2]				Soybean	
	Total											
No.	1973-84			1985-89[1]			pH	P_1	P_2	K	Moisture	Yield
	------ lb P_2O_5 + K_2O/A ------							------- lb/A -------			%	bu/A
2	0	+	1200	0	+	100	7.9	13	12	424	13.2	26.2
3	600	+	1200	0	+	100	7.9	30	27	344	13.0	30.6
4	1200	+	1200	0	+	100	7.9	35	29	366	13.3	35.4
5	600	+	1200	100	+	100	7.9	27	24	388	13.3	34.1
Signif. Level (%):							13	50	50	60	98	95
BLSD (.05) :							-	-	-	-	0.2	7.4
CV (%) :							0.8	78.	71.	17.	1.0	13.

[1] Treatments applied each fall.
[2] Samples were taken in October before 1990 treatments were applied.

CONCLUSIONS

Long term (12-yr) additions to these two soils created a wide range in soil test P levels. Soybean yields were optimized over the no P treatments at soil test P levels of 30 lb/A at Waseca. Yields were reduced when soil test K dropped to <175 lb/A at Waseca. At Morris, soybean yields were significantly improved with the higher soil test P levels. Soil test P declined by about 13% at Waseca. Soil test K was reduced by 15% when K was added and by over 25% when no K was added at Waseca. Additional years will be needed to more accurately determine the decline rates.

CONSERVATION TILLAGE FOR CORN AND SOYBEAN PRODUCTION[1]

Waseca, 1990

G. W. Randall and J. B. Swan[2]

ABSTRACT: This was the 16th and final year of a study to evaluate five primary tillage systems for corn and soybean production on a Nicollet-Webster soil complex. Surface residue amounts ranged from 4% with MP tillage to 97% with NT. Corn yields were reduced by about 80 bu/A with NT due primarily to very aggressive foxtail growth. Yields were not different among the MP, CP, RP and SD systems but were enhanced 7 bu/A by the former starter fertilizer applications with all tillage systems. Intensive soil sampling showed marked decreases in soil pH in the top two inches with NT and in the surface of the RP ridge. Soil test P and K were highly stratified in the CP, RP, SD and NT systems. Starter fertilizer applied for 10 of 16 years greatly increased soil test P and K in the top 6" of all tillage systems.

With increasing emphasis on controlling erosion and minimizing energy requirements (time, labor, and fuel), tillage practices have changed markedly over the last decade. Many tillage practices have come to be known as "conservation tillage". To fit this definition, a tillage practice must leave 30% of the soil surface covered with residue after planting.

EXPERIMENTAL PROCEDURES

To evaluate some of these conservation tillage practices an experiment was started in 1975 with continuous corn grown on a Webster clay loam and Nicollet clay loam at the Southern Experiment Station. Five tillage treatments [no tillage (NT), fall moldboard plow (MP), fall chisel plow (CP), ridge-plant (RP) and till-plant (flat)] were replicated four times. Each plot was 20' wide by 125' long. Tile lines spaced 75' apart run perpendicular to the rows in all plots. Beginning in 1979 all plots were split into two, 4-row plots -- one with starter fertilizer and the other without.

After 8 years of continuous corn, soybeans were planted in 1983 to begin a long-term corn-soybean rotation. Tillage and starter fertilizer treatments remained the same except the till-plant (flat) treatment was changed to a spring-disk (SD) (20" disk blade) treatment (Table 1).

Ridges for the RP treatment in 1990 were built in June, 1989. The MP and CP treatments were performed on Nov. 3. On May 2 all plots received 150 lbs N/A as ammonium nitrate broadcast on the surface. On May 4 the MP and CP treatments were field cultivated once with the chiseled plots receiving a prior disking. The SD treatment was disked twice.

Corn (Pioneer 3578) was planted in 30" rows at a rate of 29,900 plants/A on May 18 with a John Deere 7100 planter. B&H ridge cleaners were attached for the RP treatment. No starter fertilizer was used. Broadcast P and K were not applied for the 1990 crop because of very high soil tests. Soil tests from moldboard plow plots averaged: pH = 6.9, $Bray_1$ extractable P = 66 lb/A and exchangeable K = 370 lb/A. Lasso (3.5 qts/A) + Bladex (3 lb/A) were applied broadcast to all plots on May 30. All plots except NT were cultivated with a Hiniker 5000 cultivator on June 15. As a result of the herbicides plus cultivation, weed control was excellent on all plots except no tillage.

Surface residue coverage was measured by the line-transect method on April 2 prior to spring tillage. Soil samples were taken in 2- and 3-inch increments from all plots on July 18. Yields were taken by combine harvesting the center two rows from each plot where starter and no starter fertilizer had been applied previously.

RESULTS

Surface residue amounts prior to planting were highly related to tillage system with the following ranking NT>SD=RP>CP>MP (Table 1).

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[1] Funding provided by the Southern Experiment Station, Waseca.

[2] Professors, Southern Experiment Station, Univ. of Minnesota and The Leopold Center, Iowa State U., respectively.

Table 1. Influence of tillage methods for corn after soybeans on surface residue before spring tillage at Waseca in 1990.

Treatment	Surface Residue Coverage
	%
No tillage (NT)	97
Fall plow (MP)	4
Fall chisel (CP)	13
Ridge plant (RP)	60
Spring disk (2x) (SD)	62
Significance Level (%):	99
BLSD (.05) :	7
CV (%) :	10.

Corn yields were significantly affected by both tillage system and the previous starter fertilizer treatments (applied from 1979-1988) (Table 2). No tillage resulted in significantly reduced yield compared to all other tillage systems with no difference among the MP, CP, RP and SD systems. The primary reason for the very low NT yield was poor weed control. Over 6" of rain in May prevented herbicide application until 12 days after planting. By this time corn emergence curtailed application of Roundup to the carpet of foxtail that did not appear to be affected by the Lasso and Bladex application. Weed control was excellent in the other tillage systems due to secondary tillage and cultivation in conjunction with the herbicides. The residual effects of the previous starter fertilizer treatments increased corn yield by 7.0 bu/A regardless of tillage system. Grain moisture at harvest was slightly higher for the NT system.

Table 2. Influence of tillage method and residual starter fertilizer on corn production at Waseca in 1990.

Tillage	Starter Fertilizer	Moisture	Yield
		%	bu/A
No tillage	Yes	22.9	67.4
	No	23.6	60.2
Fall plow	Yes	21.9	151.3
	No	22.2	142.4
Fall chisel	Yes	20.3	147.2
	No	22.1	139.9
Ridge plant	Yes	21.2	146.7
	No	22.2	142.1
Spring disk (2x)	Yes	20.8	147.5
	No	20.0	140.3
MAIN EFFECTS			
Tillage System			
No tillage		23.3	63.8
Fall plow		22.1	146.8
Fall chisel		21.2	143.6
Ridge plant		21.7	144.4
Spring disk (2x)		20.4	143.9
Signif. Level (%):[1]		94	99
BLSD (.05) :		-	10.2
Starter Fertilizer			
Starter		21.4	132.0
No starter		22.0	125.0
Signif. Level (%):[1]		71	95
INTERACTION			
Tillage x Starter			
Signif. Level (%):[1]		39	1
CV (%) :		7.6	8.2

[1] Probability level of significant difference between means.

Soil samples taken on July 18 from all plots show a substantial effect of tillage over this 16-year period on soil pH (Table 3), soil P (Table 4), and soil K (Table 5). Soil pH was depressed by about 1.0 unit in the surface 0 - 2" layer of the NT system and in the ridge area of the RP system. Individual plots in the NT system were as low as 4.9 and may explain the foxtail growth and very poor weed control. Differences in soil pH did not appear between the no starter and starter fertilizer systems.

Extractable soil P and exchangeable K were greatly influenced by both tillage system and starter fertilizer history. Both P and K were very uniformly distributed throughout the 0 - 6" layer with MP tillage. On the other hand substantial stratification occurred throughout the 0 - 12" layer with the NT, CP, RP and SD systems. Greatest stratification occurred in the ridge of the RP system. Soil test P and K within the top 6" were considerably higher in the plots that had received 10 years of starter fertilizer regardless of tillage system. This may have led to the higher yields shown in Table 2. Stratification of P & K was greater were starter fertilizer had been applied.

Table 3. Soil pH after 16 years of continuous tillage.

Depth	Starter[1] fert.	Tillage System[2] NT	MP	CP	RP-R	RP-V	SD
inches							
0-2	No	5.4	6.6	6.2	5.6	6.1	6.6
2-4	No	6.0	6.9	6.5	6.0	6.6	6.8
4-6	No	6.4	7.0	6.8	6.5	6.8	7.1
6-9	No	6.6	7.0	7.1	6.7	6.8	7.2
9-12	No	6.7	7.3	7.1	6.8	6.8	7.2
0-2	Yes	5.5	6.6	6.4	5.8	6.2	6.3
2-4	Yes	5.9	6.8	6.7	6.1	6.6	6.4
4-6	Yes	6.5	6.9	6.9	6.6	6.8	6.8
6-9	Yes	6.6	6.9	7.1	6.7	6.8	7.0
9-12	Yes	6.7	7.1	7.2	6.7	6.8	7.0

[1] Starter fertilizer was applied for 10 years (1979-1988).
[2] RP-R = Ridge plant - ridge, RP-V = Ridge plant - valley.

Table 4. Extractable soil P (Bray 1) after 16 years of continuous tillage.

Depth	Starter[1] fert.	Tillage System[2] NT	MP	CP	RP-R	RP-V	SD
inches		ppm					
0-2	No	38	22	29	44	30	32
2-4	No	27	22	22	24	19	19
4-6	No	15	22	15	13	11	11
6-9	No	12	13	8	10	8	8
9-12	No	6	6	5	9	5	6
0-2	Yes	50	37	32	65	54	45
2-4	Yes	30	39	20	46	23	25
4-6	Yes	18	32	11	22	14	13
6-9	Yes	14	17	6	17	9	11
9-12	Yes	10	9	4	16	7	7

[1] Starter fertilizer was applied for 10 years (1979-1988).

Table 5. Exchangeable soil K after 16 years of continuous tillage.

Depth	Starter[1] fert.	Tillage System[2] NT	MP	CP	RP-R	RP-V	SD
inches		ppm					
0-2	No	216	179	201	244	207	227
2-4	No	185	193	168	177	145	157
4-6	No	142	187	140	134	117	129
6-9	No	122	141	108	118	93	102
9-12	No	99	107	95	104	97	94
0-2	Yes	265	201	187	283	244	258
2-4	Yes	186	216	149	177	165	160
4-6	Yes	136	201	122	134	123	127
6-9	Yes	118	145	99	124	96	113
9-12	Yes	101	110	89	109	102	93

[1] Starter fertilizer was applied for 10 years (1979-1988).

SUMMARY - 1990

This was the fourth crop of corn grown following soybeans in this long-term study with continuous corn from 1975 through 1982 and soybeans in 1983, 1985, 1987, and 1989. Surface residues prior to planting were greater than 50% with NT, RP, and SD tillage. Due primarily to poor weed control, corn grain yields with NT were about 80 bu/A less than with MP, CP, RP and SD tillage. Residual effects of starter fertilizer increased corn yields by 7 bu/A regardless of tillage systems. Grain moisture was slightly higher with NT but was unaffected by starter fertilizer.

SIXTEEN-YEAR YIELD SUMMARY (Not including 1989)

Grain yields from the five tillage systems where starter fertilizer was used from 1975-1982 are shown in Table 6. The 8-year average yield shows a 5.3 bu/A yield advantage for the moldboard plow over the ridge-plant system. Some of this difference can be attributed to the 17 bushel advantage in 1980 for moldboard plowing. The chisel plow and till-plant (flat) systems showed intermediate yields while lowest yields were obtained with no tillage. Weed control was excellent in all treatments except no tillage. Postemergence herbicides were applied to no tillage in 1979 and 1980 and did provide better weed control.

Four-year data (1979-82) indicate some advantage for the use of starter fertilizer with the chisel plow (6 bu/A), ridge-plant (5 bu/A) and no tillage systems (5 bu/A). No reason can be given for the obvious difference in response to starter fertilizer between the no tillage and till-plant (flat) systems when both treatments represent the most severely reduced tillage systems.

Yields with no tillage continue to be significantly below the other tillage systems since converting to a corn/soybean sequence (Table 6.) Moldboard plow tillage in this sequence has resulted in corn yields being about 5% higher (7 bu/A) than for CP, RP and SD tillage on the starter fertilizer plots. When no starter was used this difference increased to 7% (10 bu/A). Soybean yields in this sequence averaged about 6% higher with the moldboard plow system compared to the CP, RP or SD systems with virtually no difference among the latter three systems.

Table 6. Influence of tillage methods and starter fertilizer on long-term corn and soybean yields at Waseca.

Treatment		Cont. Corn Yield		Soybeans	Corn
Tillage	Starter	1975-82	1979-82	1983,85,87 & 89	1984, 86, 88 & 90
		bu/A			
No tillage	Yes	129.2	140.6	34.5	100.4
"	No		136.0	34.3	89.2
Fall plow	Yes	154.5	170.9	51.0	147.0
"	No		170.8	50.2	141.5
Fall chisel	Yes	144.4	161.8	47.7	138.8
"	No		155.5	45.5	128.4
Ridge plant	Yes	149.2	161.5	46.9	139.8
"	No		156.4	47.2	132.6
Till plant (flat)[1]	Yes	144.9	154.8	46.8	141.7
"	No		157.4	47.1	134.2

[1] This treatment was converted to a spring disk (2x) beginning with the 1983 crop.

EVALUATION OF THE EFFECT OF POTASH FERTILIZER APPLIED IN RIDGES ON THE EARLY GROWTH AND YIELD OF CORN

George Rehm, Andy Scobbie, and Dan Schmitz[1/]

ABSTRACT: The rate of K_2O that can be applied in a band without causing emergence and early growth problems is a major concern for ridge-tillers. This study was conducted to evaluate the fall application of 0, 20, 40, 80, 160 lb. K_2O/acre in a band. This banded K_2O was applied in the center of the ridge in the fall at a depth of 3.0 to 3.5 inches. The rate of K_2O applied in this way had no significant effect on corn emergence, early growth and yield in each of the 3 years of study.

Introduction:

Many farmers who have switched to ridge-till planting systems have complained about problems associated with using starter fertilizers. They seek an alternative. There is equipment available which allows for placement of either liquid or dry fertilizer in a band in existing ridges. This equipment can be used to apply needed phosphate and potash in the ridge in late fall. There is reason to believe that the use of this practice could substitute for the use of a starter fertilizer at planting.

There is also concern that high rates of potash fertilizer applied in the fall might cause problems with emergence and early growth. This concern is valid and field trials were needed to evaluate the impact of banded potash applied in the center of the ridge on early growth of corn and subsequent yield.

Experimental Procedures:

This study was initiated in the fall of 1987 at the Southern Experiment Station at Waseca and continued through the 1989 growing season. The plots used for the trial in 1988 were used again in 1990. Treatments in 1990 were reapplied to the plots used in 1988. A separate site was used for the trial in 1989. Soil samples were collected in the fall of 1987 and 1988 for use in 1988 and 1989, respectively. The results of the analysis are summarized in Table 1. All treatments were applied to existing ridges. Soybeans were the previous crop in all years.

Table 1. Relevant soil properties for the experimental sites.

Soil Property	Year 1988, 1990	1989
pH	7.9	6.1
phosphorus (Bray), ppm	-	28.0
phosphorus (Olsen), ppm	13.5	-
potassium (1N $NH_4C_2H_3O_2$), ppm	120	117

Five rates of K_2O (0, 20, 40, 80, 160 lb./acre) were knifed into the center of existing ridges in late October in 1987, 1988, and 1989. The bands, using 0-0-60 as the source of K_2O, were placed at a depth of 3.0 to 3.5 inches below the soil surface. Adequate N as 82-0-0 was applied to all treatments each fall.

Corn was planted in either late April or early May. Recommended practices were used throughout the growing season to assure optimum corn yields.

Whole plant samples were collected from each plot at approximately 4 weeks after emergence. These plants were dried and weighed. Stand counts were also taken at this time. Grain yields were measured in mid-October and corrected to 15.5% moisture.

Results and Discussion:

Grain yields are summarized in Table 2. The rate of applied K_2O had no significant impact on yield. The soil test levels for K are considered to be in the medium range. The soil, however, was able to supply adequate K for corn production under these growing conditions. As would be expected, year-to-year yields varied with rainfall.

[1/] Extension Specialist; Assistant Scientist and Junior Scientist, respectively.

Table 2. The effect of rate of potash fertilizer applied in the center of existing ridges on the yield of corn at Waseca.

K_2O Applied	1988	Year 1989	1990
lb./acre	- - - - - - -	bu./acre	- - - - - -
0	84.4	160.1	147.1
20	81.7	166.9	148.5
40	78.4	161.8	149.4
80	86.3	161.6	147.5
160	83.6	162.3	151.7

Stand counts are summarized in Table 3. The emergence was not affected by the rate of K_2O applied in the band. Emergence was also uniform over the three years of the study.

Table 3. The effect of rate of potash fertilizer applied in the center of existing ridges on corn stand measured at 4 weeks after emergence at Waseca.

K_2O Applied	1988	Year 1989	1990
lb./acre	- - - - -	plants/20 ft	- - - - - -
0	33	34	34
20	33	34	34
40	33	34	33
80	34	35	33
160	34	34	33

These data indicate that relatively high rates of K_2O can be safely applied in the center of existing ridges in the fall and not have a negative effect on corn emergence.

The rate of K_2O applied in the band had no significant effect on early growth of corn (Table 4). These results are consistent with emergence and yield measurements.

Table 4. The effect of rate of potash fertilizer applied in the center of existing ridges on weight of young corn plants at 4 weeks after emergence at Waseca.

K_2O Applied	1988	Year 1989	1990
lb./acre	- - - - -	gm/6 plants	- - - - - -
0	29	27	49
20	31	31	46
40	29	30	48
80	35	29	51
160	31	30	50

Summary:

Banded application of phosphate and potash fertilizers can be very effective alternatives to broadcast usage in ridge-till planting systems. The results of this study indicate that relatively high rates of K_2O can be applied in a band in the center of the ridge in the fall. No emergence, early growth, and yield reductions were measured with this practice.

EFFECTS OF NUTRIENT SOURCES, APPLICATION TIMING AND RATE ON ALFALFA PRODUCTION[1/]

M.A. Schmitt, C.C. Sheaffer and G.W. Randall[2/]

Farmers often have questions regarding the effect of manure application on alfalfa. Although alfalfa is grown on fewer acres than corn in Minnesota, alfalfa removes more nutrients on a per acre basis. However, since alfalfa can produce its own nitrogen (N), many livestock producers are reluctant to apply manure to alfalfa fields.

The primary goal of this project is to evaluate the feasibility of using livestock manures as a fertilizer material on alfalfa fields such that the immediate nutrient demands of the alfalfa are met and the residual nitrogen (N) fertility from the manure and the alfalfa meet subsequent corn crop requirements.

Materials and Methods

A long-term project was started to examine the effects of manure fertilization on alfalfa. Trials were established at University of Minnesota Agricultural Experiment stations at Rosemount and Waseca. At Rosemount, hog manure was used on a shallow Waukegon silt loam soil lying on outwash gravel subsoil. At Waseca, dairy manure was used on a Nicollet clay loam soil.

Three rates of manure (3000, 6000, and 12000 gallons per acre) were broadcast and incorporated immediately prior to establishment of the alfalfa. Three inorganic commercial fertilizer treatments were also used--applied to give equivalent P and K application rates as contained in the three rates of manure.

Topdress application methods were also included. The two higher rates of manure were also applied as annual applications (applied at one-half rates) after first cutting. A topdressed inorganic fertilizer treatment was also applied.

Along with measures of overall dry matter yield at each harvest, plant samples were collected at each harvest for total nutrient analysis. After the second year, before the alfalfa was plowed, subplots were undercut and crown counts, crown and taproot dry matter yields and N contents measured. Soil samples were collected to a depth of two feet in one-foot increments during the growing season and analyzed for nitrate-N and ammonium-N. In this paper, only the production variables will be addressed along with the soil N concentrations.

Results

First Cutting Yields in Establishment Year

The most visual treatment differences in this study were observed during the establishment period. The alfalfa growth in the manured plots was always taller and darker green than the nonmanured plots--this most likely due to the increased N levels in the soil at a time when symbiotic N fixation is not at maximum production. Even though the stray weeds are obvious, the estimated weed contributions in the initial cuttings of all of the stands was statistically insignificant. Weeds were not a factor in any of the plots after the first cutting at all locations.

The effect of the three rates of preplant inorganic fertilizer and manure treatments on forage dry matter production at Rosemount in 1989 is listed in Table 1. The first cutting yields increased with the manure treatments up until the highest manure rate, at which the alfalfa was noticeably lodged. Since the soil tests at Rosemount were categorically "high" (Bray P at 35 ppm and K at 200 ppm), it is conceivable that the response of the alfalfa was most likely due to factors other than just the P and K.

The plots established at Rosemount in the spring of 1990 had similar results as those plots established in 1989. The manure additions increased yields compared to the control up to the highest rate of manure (Table 1). The added inorganic fertilizer increased first cutting production only with the highest rate treatment.

[1/] This project was supported, in part, by the Potash and Phosphate Institute

[2/] Extension Soil Scientist, Department of Soil Science, Agronomist, Department of Agronomy and Plant Genetics, and Soil Scientist, Southern Experiment Station, respectively.

The increasing rates of manure resulted in lower yields of alfalfa at the Waseca plot site (Table 1)--which tested "low" for both P (8.5 ppm) and K (94 ppm). However, the forage yields increased significantly as the rate of inorganic fertilizer increased, as would be predicted by the soil test levels. The decrease in alfalfa production with increasing manure rates can be primarily attributed to a major stand problem. The combination of manure additions and large-scale application equipment created a severe compaction problem, resulting in almost no stand in the wheel tracks. This problem was corrected during the 1989 growing season.

Production Year Yields

Despite slight yield increases with the inorganic fertilizer rates at Rosemount, there was no statistically significant difference between the control treatment and the inorganic fertilizer treatment means (Table 2). As previously mentioned, the relatively high soil test values for P and K would give credence to current University of Minnesota soil test recommendations and interpretations.

The application of manure did significantly increase alfalfa dry matter yields at Rosemount compared to the unfertilized control treatment (Table 2). The lowest manure rate increased alfalfa yields more than the highest rate of inorganic fertilizer, suggesting that the yield increase was not due to the manure's added P and K. There was a significant yield response up to the 6000 gallons per acre rate of manure. Above this rate, similar yields were measured.

At Waseca, the yield response to both commercial fertilizer and manure was statistically significant (Table 2). While the lowest rate of inorganic fertilizer did not result in a significant increase in alfalfa yield, the low rate of fertilizer produced 0.44 tons of dry matter more than the control. The middle and high fertilizer rate each produced a significant increase in dry matter production. The increase in tonnage was almost a direct linear correlation with the rate of fertilizer application. With the low soil test levels for P and K at this site, the increase in yield was predictable.

Soil Nitrate Levels

Nitrate-N concentrations measured in the soil provide an indicator as to the amount of N that can potentially be lost by leaching, denitrification and/or plant uptake. Since a properly nodulated alfalfa plant symbiotically fixes atmospheric nitrogen for plant use, nitrate-N quantities in manure-treated plots above the quantities in the control plots represent the nitrate contributions from the manure. Throughout the 1989 growing season, there were statistically significant differences in soil nitrate-N due to manure rate differences--these differences being somewhat related to the relative application rates of the manure. In July and thereafter, the low manure rate nitrate-N concentrations were not different from the control and after August, the medium manure rate was not different from the control.

At Waseca, fewer samplings were taken, yet the same results were observed. In 1989, there was a significant effect of the manure rate on soil nitrate-N. The first sampling in 1990 showed significant nitrate-N differences in the medium and high manure rates, but subsequent samplings resulted in no statistical differences among treatments.

The soil nitrate-N results are of importance due to the concern for groundwater quality. If significant amounts of nitrate-N were present in the soil while a crop was not growing, the nitrate-N could be subject to downward movement. Thus, the elevated levels measured in 1989 could pose a potential risk, especially if alfalfa growth were limited. However, since alfalfa is a deep-rooted perennial and requires substantial amounts of N, nitrate-N available in the soil system is likely to be used by the growing alfalfa. Thus the diminishing quantities of soil nitrate-N are likely due to plant uptake.

Summary

Manure applications generally have a positive significant effect on alfalfa dry matter production. This response can be measured with the first cutting of the newly established alfalfa as well as with full production year values. The response to manure is probably due to more than just P and K since a yield response occured even when soil tests for P and K would not have indicated a yield response.

Inorganic fertilizer applications resulted in yield increases when the soil tests for P and K were low and no yield increases when the soil tests were high. Topdressing either manure or commercial fertilizer did not result in consistent, explainable results.

Although the manure brings certain weed concerns to the stands, these did not persist past the first cutting. While manure adds substantial amounts of N to the soil, the nitrate-N concentrations from the manure treatments were not statistically different from each other or the control 17 months after application.

Table 1. Dry matter production from first cuttings in the establishment year of alfalfa as effected by preplant incorporated nutrients.

Treatments	Rosemount 1989 DM Yield	Rosemount 1990 DM Yield	Waseca 1989 DM Yield
	T/A	T/A	T/A
Control	1.55	1.15	1.37
Manure 3000 GPA	1.79	1.58	1.45
6000 GPA	1.96	1.89	1.16
12000 GPA	1.62	2.05	1.30
Fertilizer, Low*	1.60	1.22	1.48
Medium*	1.70	1.36	1.51
High*	1.76	1.59	1.58
Pr.>F	0.0004	0.0001	0.003
LSD(.10)	0.149	0.272	0.148

* - The inorganic fertilizer rates were calculated based on the manure rates and the estimated P and K quantities contained within (see Table 2 for rates).

Table 2. Alfalfa dry matter yield means for the first full year of production as influenced by nutrient management in 1990.

Nutrient Source	Time of Application	Application Rate Rosemount	Application Rate Waseca	DM Yields Rosemount	DM Yields Waseca
				- - - - T/A	- - - -
None	-	-	-	3.81	2.84
Manure	Preplant	3000 gpa	3000 gpa	4.31	3.40
Manure	Preplant	6000 gpa	6000 gpa	4.60	4.12
Manure	Preplant	12000 gpa	12000 gpa	4.55	4.49
Fertilizer[1]	Preplant	0+90+69	0+33+69	3.87	3.28
Fertilizer	Preplant	0+180+138	0+66+138	3.97	3.71
Fertilizer	Preplant	0+360+276	0+132+276	4.17	4.57
Manure	Topdress[2]	6000 gpa	6000 gpa	4.47	2.93
Manure	Topdress[2]	12000 gpa	12000 gpa	4.98	2.82
Fertilizer[1]	Topdress[2]	0+180+138	0+66+138	4.21	2.97
Pr.>F				0.0001	0.0001
LSD(.10)				0.36	0.45

[1] - Expressed as lbs of $N+P_2O_5+K_2O$.

[2] - Topdress treatments were applied by two annual applications after first cutting in 1989 and 1990.

Table 3. Two-foot soil nitrate-N concentrations from plots receiving preplant incorporated manure applications in 1989.

		Manure Rate (GPA)					
Location	Date	Control	3000	6000	12000	Pr.>F	LSD(.10)
		- - - - - pp2m NO_3-N - - - - - -					
	1989						
Rosemount	May 1	14.2	17.6	16.9	17.8	0.47	-
	May 31	16.9	41.4	79.5	106.2	<0.01	31.5
	June 22	17.2	42.5	68.8	103.3	<0.01	17.2
	July 11	4.8	14.0	34.6	70.8	<0.01	20.8
	Aug. 3	3.5	4.3	14.1	38.4	<0.01	3.9
	Aug. 28	3.7	3.6	12.1	32.9	<0.01	10.1
	Nov. 1	1.6	1.7	2.1	15.4	<0.01	4.8
	1990						
	April 12	15.6	14.2	27.3	39.1	0.27	-
	May 3	12.7	14.9	18.1	40.7	0.03	15.0
	May 31	9.8	9.9	15.3	19.6	0.13	-
	June 25	11.1	10.6	14.4	15.6	0.44	-
	July 18	11.8	9.7	8.6	13.7	0.37	-
	Aug. 20	5.9	7.1	7.1	7.3	0.37	-
	1989						
Waseca	July 5	18.1	25.2	38.1	48.1	<0.01	5.7
	July 27	17.1	24.6	36.1	55.0	<0.01	7.3
	Sept. 11	7.3	15.7	32.8	47.4	<0.01	12.5
	1990						
	April 27	14.5	14.0	21.8	28.9	<0.01	4.3
	May 23	10.2	11.2	16.0	17.7	0.21	-
	June 22	6.9	7.9	7.2	10.0	0.41	-
	July 23	3.9	2.8	4.1	5.0	0.17	-

WATER QUALITY RESEARCH WITH NITROGEN AT THE HERMAN ROSHOLT WATER QUALITY RESEARCH FARM, WESTPORT, MN 1990 [1]

Large and Small plot phases

G.L. Malzer, T.J. Graff, J. Neiber, and D. Steele [2]

Abstract: The objective of the **small plot** water quality research phase is to evaluate and quantify the impact of a variety of agricultural practices on crop nitrogen utilization efficiency and the potential impact on water quality. Currently agricultural practices such as crop rotation, tillage, and fertilizer N management including, rates, sources, time of application, methods of application and use of nitrification inhibitors are being evaluated. There was no significant difference in corn grain or soybeans yields utilizing a traditional chisel-plow tillage systems than ridge-till systems. Corn grain yields when no fertilizer N was applied were 20-40 bu/A higher when the previous crop was soybeans rather than corn. Nitrogen fertilizer significantly increased corn grain yield when 160 lbs N/A was applied with continuous corn and 215 lbs/A corn-soybean sequences. The small yield increases obtained with rates over 105 lbs N/A under continuous corn and 50 lbs N/A under corn soybean sequence would be difficult to justify environmentally. Early sidedress applications tended to be inferior in yield, to late applications, especially at the lower rates of N application. High amounts of precipitation during 1990 apparently leached some of the fertilizer N which had been applied early. Nitrification inhibitors increased yield when used at the lower rates of fertilizer N. Rates of fertilizer N in excess of plant need resulted in higher concentrations of nitrate-N in the percolate water.

The objective of the **large plot** groundwater phase is to monitor the movement of nitrate-N through the soil profile into the underlying aquifer and to quantify subsequent impact on groundwater quality. Experimentation utilizes several sampling devices, including suction lysimeters, glass blocks, sheet metal (pan) containers, wick samplers, and wells established at three different levels in the aquifer. Three treatments replicated twice were established in 1987. Each plot area is in excess of one acre and the treatments include continuous corn at a moderate (160 # N/A) and high (215 # N/A) rate of N, and a corn-soybean rotation at the moderate N rate. Corn grain yields were not increased by the high N rate in 1987,1988, 1989 and 1990. Concentration of nitrate-N in the percolate water increased as the rate of fertilizer N increased. Method of water collection influenced the actual concentration measured.

In 1987 three phases of nitrogen (N) research were started at the Herman Rosholt Water Quality Research Farm at Westport, MN. The three phases of research included a lysimeter phase, a large plot groundwater phase and a small plot N management/crop production phase. The large and small plot phases are reported here, the lysimeter phase will be reported separately.

The soil at the Rosholt farm is an Estherville sandy loam with 15-30 inches of sandy loam soil overlying glacial outwash composed mainly of coarse sand and gravel. Because of the coarse nature of these soils and the low water holding capacity, they are frequently irrigated to attain high yields. The higher yield potential along with higher fertilizer inputs, low water holding capacity, and shallow underlying aquifer create conditions which could result in groundwater contamination with nitrate N. Improper fertilizer N management can result in reduced yields, reduced fertilizer use efficiency, decreased profits, and increased groundwater contamination. The purpose of these phases of research was to determine the impacts of different N and crop management practices on crop yield, N utilization and their resulting impacts on groundwater quality.

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2. Professor and Asst. Scientist respectively, Dept. of Soil Science, and Associate Professor and Research Asst. respectively, Dept. Agricultural Engineering, University of MN.

Experimental Procedures

Small Plot N Management/Crop Production Phase: consisted of 25 N treatments randomized within a split-split plot design with three replications. The main plot consisted of two cropping sequences (continuous corn and corn following soybeans) with the sub-plots being tillage (ridge till and chisel plow). Ridges were constructed in 1987. In 1990 the entire experiment was planted to corn. The 25 N treatments within each sub-plot consisted of a control (zero N) plus four N rates (60, 120, 180, and 240 kg N/ha -- these will be reported as 50, 105 160, and 215 # N/A), two nitrification inhibitors (none and N-Serve) and three times/methods of application (all N early-4 leaf growth stage, all N late-8 leaf growth stage, and split with 2/3 N early and 1/3 late). All fertilizer N treatments were applied as anhydrous ammonia. The nitrification inhibitor N-Serve was applied with an in-line injection pump which inserted the chemical in front of a bidirectional flow integrator and the manifold. N-Serve was applied at a rate of 0.5 #/A active ingredient.

Soil samples were taken from 0-1 and 1-2 ft depth from 13 of the 25 treatments on April 19th before planting and on October 29th after harvest. The soil samples were analyzed for ammonium and nitrate concentration and the data is reported in tables 4 and 5. Spring samples were taken on corn following corn and only the check plots of the corn following soybeans. Fall samples were taken from both studies.

Corn (Pioneer 3790 - 95 day R.M.) was planted on May 11 in 30 inch rows at a population of 29,900 seeds/A using a four-row Buffalo planter. Starter fertilizer was applied to the corn plots at the rate of 10 gal/A of 7-21-7 as a band below the seed and Counter was banded in the row at planting. Dual(1.75 #/A) and Bladex (1.75 #/A) was applied on May 16th for weed control in the corn. For additional weed control the corn was cultivated twice. The first cultivation was on June 21th, and second on July 3rd, ridges were also built on July 3rd. Nitrogen treatments were applied on June 20th (early-4 leaf) and on July 2nd (late-8 leaf). The irrigation program (traveling boom) was started on July 10th and continued through August 15th with 5 inches of water being applied through irrigation. An additional 21.32 inches of water was obtained during the growing season as rainfall.

Large Plot Groundwater Phase:

In 1987 six large plots (approximately one acre) were established at the Rosholt farm. The experiment area consisted of three treatments with two replications. Two treatments are continuous corn with N rates of 160 and 215 lbs N/A. The third treatment is in a corn following soybeans rotation with 160 lbs N/a applied during the corn year. In 1987 all treatments were planted to corn. In 1988 soybeans were planted into the corn-soybean rotation treatment, and in 1989 all treatments were planted to corn. In 1990 soybeans were planted in the corn-soybean rotation treatments. Nitrogen was applied as anhydrous ammonia in split application of two-thirds of the N rate with a nitrification inhibitor (N-Serve) at an early growth stage 4-leaf (June 20, and one-third at the 8-leaf growth stage (July 2). N-Serve was applied only at the 4-leaf stage utilizing an in-line injection pump which inserted the chemical in front of a bidirectional flow integrator and the manifold. N-Serve was applied at a rate of 0.5 #/A a.i.
Corn (Pioneer 3790 - 95 day R.M.) was planted on May 11 in 30 inch rows at a population of 29,900 seeds/A using a four-row Buffalo planter. Starter fertilizer was applied at the rate of 10 gal/A of 7-21-7 as a band below the seed. Counter was banded in the row at planting. Lasso (3.0 #/A) and AAtrex 90 DF (1#/A) were sprayed on May 14th for weed control.
Soybeans were planted on May 22nd at the rate of 63 #/A. Lasso at 3#/A was used for weed control on May 25th.
The irrigation program (traveling boom) was started on July 10th and continued through August 15th with 5.0 inches of water being applied through irrigation and an additional 21.32 inches of water coming through rainfall during the growing season.
Grain yields were obtained on October 24th by hand harvesting 800 ft^2 of plot area. Corn grain yields were adjusted to 15.5% moisture. Grain yields results are presented in table 6.

Chemical movement through soils to groundwater

To follow the movement of nitrate-N through soils to the groundwater several types of soil water sampling devices have been installed. These include suction lysimeters, glass blocks, pan sheet metal, wick samplers, and wells. The wells were installed by the United States Geological Survey. Data from the wells and suction lysimeters will not be presented at this time. The glass blocks did not collect enough water in 1990 to present the data in tabular form.

Glass block samplers are made from glass building blocks,(12" X 12"X 4" - L X W X D). Holes were drilled into the blocks to allow water to enter and permit access for removing the water collected.

Three glass blocks were installed in plots at a soil depth of 18-24 inches (depth where soil becomes very coarse). Three blocks were installed side by side, one directly under a crop row and one on either side.

Suction lysimeters were installed at depths of 4 and 7 feet during 1987. The ceramic cup of the suction sampler was cast into a silica slurry which hardens in the soil to insure continuous contact between the soil and the ceramic cup. Outflow tubes were run to the soil surface for sampling. This type of sampler allows for the collection of soil water samples at the aforementioned depths.

Pan sheet metal samplers consist of 18-gauge sheet metal, cut, bent, and spot welded into a trough-like collection box. The samplers are 30" long 12" wide and 3" deep and made watertight by soldering along seams. Holes were drilled into the top of the sampler to allow entry of water. Access tubes were installed to the soil surface to facilitate extraction of the water collected.

Wick samplers are a one-half inch glass plate, 12 inches X 30 inches. A hole was drilled in the center of the glass plate and a 2 inch length of PVC pipe was attached to it. A braided glass rope was inserted through the PVC pipe and onto the glass plate. The strands of glass rope were unraveled over the surface of the glass plate and epoxied to the edges of the plate, forming a spider web-like pattern. The glass rope thus acted as a wicking device to draw water from the surface of the plate into a one gallon collection jar. These also have outflow tubes going to the surface. The pan sheet metal and wick samplers were installed at approximately the same depth as the glass blocks.

General Results

Small Plot N Management/Crop Production Phase:

When no fertilizer N was applied corn yields were 20-40 bu/A higher when the previous crop was soybeans. Across the entire experiment corn grain yields were essentially the same utilizing a chisel system of tillage or the ridge tillage. Yield increases were obtained with fertilizer N up to rates of 215 lbs/A for corn following soybeans and 160 lbs/A following corn. However, most of the yield increase from fertilizer N was associated with rates of 105 lbs/A for continuous corn and 50 lbs/A for corn following soybeans. Early sidedress applications tended to be inferior in yield, to late applications, especially at the lower rates of N application. High amounts of precipitation during 1990 apparently leached some of the fertilizer N which had been applied early. Nitrification inhibitors increased yield when used at the lower rates of fertilizer N. Rates of fertilizer N in excess of plant need resulted in higher concentrations of nitrate-N in the percolate water.

The soil nitrate-N concentration following harvest were generally lower than that found before planting. This reduced concentration of nitrate-N may be due to either efficient utilization of the N by the plant or the movement of the N below the 0-2 ft sampling region. Since yields were not high , and 1990 growing season precipitation was high it would seem feasible that at least a major portion of the nitrate moved deeper into the soil profile during the growing season. The highest rate of fertilizer N tended to have higher concentrations of nitrate-N in the soil profile. The NO_3-N concentration of water collected in the pan lysimeters tended to be higher in the continuous corn plots than in the corn following soybeans plots (table 6). Water samples collected by the wick lysimeters had higher NO_3-N concentrations than the water collected in the pan lysimeters.

Large Plot Groundwater Phase:

Results displayed in table 7 suggest that there was no yield advantage to the application of fertilizer N over 160 lbs/A in 1990 which corresponded to the results that were obtained in 1987, 1988, and 1989. Higher rates of fertilizer N resulted in higher concentrations of NO_3-N in the water samples collected in the pan and wick samplers (table 8). Concentration of NO_3-N was higher in the corn-corn rotation than the respective soybean-corn rotation. The pan samplers provided lower estimates of the concentration of the NO_3-N in the soil water than the wick samplers.

Table 1. Influence of N-rate, nitrification inhibitors, method of application and tillage on **continuous corn** grain yields, N-concentration, and N removal. Westport, MN. 1990

Total N-Rate	Early N	Inh.	Late N	Tillage	Yield	Corn Grain N-content	N-removal
#/A	#/A		#/A		Bu/A	%	#/A
Control	----	--	----	C	71.8	1.13	38.1
50	50	--	----	C	97.6	1.12	51.7
50	----	--	50	C	114.9	1.28	69.6
50	35	--	15	C	107.4	1.19	60.5
50	50	NS	----	C	108.3	1.14	58.5
50	----	NS	50	C	124.9	1.40	82.8
50	35	NS	15	C	116.8	1.29	71.4
105	105	--	----	C	125.6	1.36	80.9
105	----	--	105	C	129.3	1.34	81.5
105	70	--	35	C	128.8	1.43	87.1
105	105	NS	----	C	125.7	1.44	85.8
105	----	NS	105	C	126.8	1.44	86.4
105	70	NS	35	C	124.4	1.38	81.4
160	160	--	----	C	134.2	1.50	95.1
160	----	--	160	C	131.4	1.32	82.0
160	105	--	55	C	127.4	1.41	84.7
160	160	NS	----	C	127.6	1.52	91.7
160	----	NS	160	C	134.4	1.42	90.5
160	105	NS	55	C	124.3	1.40	82.5
215	215	--	----	C	130.7	1.35	83.8
215	----	--	215	C	124.3	1.30	76.4
215	145	--	70	C	126.7	1.49	89.0
215	215	NS	----	C	131.9	1.50	93.8
215	----	NS	215	C	130.5	1.53	94.4
215	145	NS	70	C	126.2	1.49	88.8
Control	----	--	----	R	62.4	1.08	31.8
50	50	--	----	R	102.4	1.13	54.7
50	----	--	50	R	121.2	1.26	72.5
50	35	--	15	R	102.2	1.15	55.1
50	50	NS	----	R	105.8	1.27	63.3
50	----	NS	50	R	119.6	1.29	72.5
50	35	NS	15	R	114.9	1.28	69.8
105	105	--	----	R	139.4	1.46	96.0
105	----	--	105	R	128.0	1.43	86.4
105	70	--	35	R	111.3	1.42	75.0
105	105	NS	----	R	127.4	1.30	78.4
105	----	NS	105	R	127.6	1.41	84.8
105	70	NS	35	R	122.8	1.39	80.2
160	160	--	----	R	135.2	1.40	89.6
160	----	--	160	R	125.6	1.38	82.1
160	105	--	55	R	125.2	1.41	83.1
160	106	NS	----	R	134.5	1.50	95.4
160	----	NS	160	R	126.3	1.39	82.7
160	105	NS	55	R	131.8	1.36	84.9
215	215	--	----	R	140.3	1.48	98.0
215	----	--	215	R	127.2	1.51	90.4
215	145	--	70	R	125.3	1.44	85.4
215	215	NS	----	R	124.9	1.51	88.8
215	----	NS	215	R	135.5	1.47	94.3
215	145	NS	70	R	128.8	1.43	86.9

Table 1. continued. Continuous Corn Split Plot Statistical Analysis

	Corn Grain		
	Yield	N-Content	N-Removal
	Bu/A	%	#/A
Tillage			
Chisel	124.5	1.37	81.2
Ridge Till	124.2	1.37	81.3
P-Value	8	15	1
N-Rate X Method X Inhibitor			
N-Rate #/A			
50	111.3	1.23	65.2
105	126.4	1.39	83.7
160	129.8	1.41	87.0
215	129.3	1.45	89.1
P-Value	99	99	99
BLSD (.05)	2.8	0.03	2.3
Method			
1. 4 leaf	124.4	1.37	81.6
2. 8 leaf	126.7	1.38	83.1
3. Split 2/3 1/3	121.5	1.37	79.1
P-Value	96	34	99
BLSD (.05)	2.7		2.2
Inhibitor			
None	123.3	1.35	79.6
N-Serve	125.0	1.39	82.9
P-Value	86	99	99
N-Rate X Method	99	99	99
N-Rate X Inhibitor	97	98	99
Method X Inhibitor	96	82	92
N-Rate X Method X Inhibitor	52	55	75
N-Rate X Method X Inhibitor X Tillage			
N-Rate X Tillage	17	48	66
Method X Tillage	91	66	96
Inhibitor X Tillage	21	99	98
N-Rate X Method X Tillage	88	92	76
N-Rate X Inhibitor X Tillage	59	92	87
Method X Inhibitor X Tillage	99	95	99
N-Rate X Method X Inhibitor X Tillage	48	75	96

Table 2. Influence of N-rate, nitrification inhibitors, method of application and tillage on corn grain yields, N-concentration, and N removal following soybeans. Westport, MN. 1990

Total N-Rate	Early N	Inh.	Late N	Tillage	Yield	Corn Grain N-content	N-removal
#/A	#/A		#/A		Bu/A	%	#/A
Control	----	--	----	C	96.5	1.01	45.8
50	50	--	----	C	117.1	1.33	73.5
50	----	--	50	C	131.8	1.37	85.5
50	35	--	15	C	117.8	1.18	66.2
50	50	NS	----	C	112.8	1.18	62.6
50	----	NS	50	C	123.7	1.26	73.8
50	35	NS	15	C	130.9	1.36	84.0
105	105	--	----	C	119.0	1.33	74.5
105	----	--	105	C	133.8	1.36	86.0
105	70	--	35	C	123.1	1.37	79.6
105	105	NS	----	C	126.9	1.31	78.9
105	----	NS	105	C	111.9	1.30	68.9
105	70	NS	35	C	133.0	1.39	87.8
160	160	--	----	C	126.0	1.43	85.4
160	----	--	160	C	131.9	1.44	89.7
160	105	--	55	C	141.8	1.42	95.4
160	160	NS	----	C	123.4	1.54	89.7
160	----	NS	160	C	115.8	1.38	75.7
160	105	NS	55	C	131.1	1.44	89.2
215	215	--	----	C	130.8	1.39	86.2
215	----	--	215	C	133.3	1.49	94.3
215	145	--	70	C	134.2	1.42	90.1
215	215	NS	----	C	129.1	1.39	85.0
215	----	NS	215	C	129.3	1.22	74.5
215	145	NS	70	C	134.3	1.44	91.3
Control	----	--	----	R	102.3	1.11	53.6
50	50	--	----	R	120.2	1.19	67.6
50	----	--	50	R	123.1	1.39	80.9
50	35	--	15	R	129.9	1.26	77.3
50	50	NS	----	R	120.1	1.27	72.1
50	----	NS	50	R	124.5	1.33	78.2
50	35	NS	15	R	119.4	1.16	65.3
105	105	--	----	R	135.4	1.51	96.8
105	----	--	105	R	131.0	1.42	88.0
105	70	--	35	R	111.6	1.29	68.0
105	105	NS	----	R	127.0	1.44	86.4
105	----	NS	105	R	131.7	1.21	74.8
105	70	NS	35	R	125.3	1.36	80.8
160	160	--	----	R	136.6	1.44	92.8
160	----	--	160	R	112.0	1.44	76.4
160	105	--	55	R	124.7	1.37	80.6
160	106	NS	----	R	135.7	1.43	91.7
160	----	NS	160	R	133.6	1.39	87.9
160	105	NS	55	R	130.8	1.32	82.0
215	215	--	----	R	125.4	1.55	91.7
215	----	--	215	R	135.4	1.43	91.4
215	145	--	70	R	132.6	1.47	92.0
215	215	NS	----	R	145.8	1.41	97.4
215	----	NS	215	R	138.8	1.44	94.2
215	145	NS	70	R	135.6	1.42	91.1

Table 2. continued. Corn Soybean Rotation Split Plot Statistical Analysis

	Corn Grain		
	Yield	N-Content	N-Removal
	Bu/A	%	#/A
Tillage			
Chisel	126.7	1.36	82.0
Ridge Till	128.5	1.37	83.5
P-Value	73	47	95
N-Rate X Method X Inhibitor			
N-Rate #/A			
50	122.6	1.27	73.9
105	125.8	1.35	80.9
160	128.6	1.42	86.4
215	133.7	1.42	89.9
P-Value	99	99	99
BLSD (.05)	2.8	0.03	2.4
Method			
1. 4 leaf	126.9	1.38	83.3
2. 8 leaf	127.6	1.36	82.5
3. Split 2/3 1/3	128.5	1.35	82.5
P-Value	49	84	23
BLSD (.05)			
Inhibitor			
None	127.4	1.38	83.7
N-Serve	127.9	1.34	81.8
P-Value	35	99	95
N-Rate X Method	99	99	99
N-Rate X Inhibitor	56	72	11
Method X Inhibitor	92	99	99
N-Rate X Method X Inhibitor	99	41	99
N-Rate X Method X Inhibitor X Tillage			
N-Rate X Tillage	33	98	99
Method X Tillage	99	99	99
Inhibitor X Tillage	99	61	94
N-Rate X Method X Tillage	95	88	84
N-Rate X Inhibitor X Tillage	99	47	95
Method X Inhibitor X Tillage	99	90	99
N-Rate X Method X Inhibitor X Tillage	99	99	99

Table 3. Continuous Corn And Corn Soybean Combine Split Plot Statistical Analysis
Westport, MN 1990

	Corn Grain		
	Yield	N-Content	N-Removal
	Bu/A	%	#/A
Previous Crop			
Corn	124.2	1.37	81.3
Soybeans	127.6	1.36	82.8
P-Value	99	24	60
N-Rate X Method X Inhibitor X Tillage			
N-Rate #/A			
50	116.9	1.25	69.6
105	126.1	1.37	82.3
160	129.2	1.41	86.7
215	131.5	1.44	89.5
P-Value	99	99	99
BLSD (.05)	1.9	0.02	1.6
Method			
1. 4 leaf	125.7	1.37	82.4
2. 8 leaf	127.1	1.37	82.8
3. Split 2/3 1/3	125.0	1.36	80.8
P-Value	93	64	94
BLSD (.05)			
Inhibitor			
None	125.4	1.37	81.7
N-Serve	126.5	1.37	82.4
P-Value	84	20	69
Tillage			
Chisel	125.4	1.37	81.6
Ridge Till	126.4	1.37	82.4
P-Value	77	29	75
N-Rate X Method	99	99	99
N-Rate X Inhibitor	67	87	95
N-Ratr X Tillage	44	99	99
Method X Inhibitor	95	72	96
Method X Tillage	99	99	99
Inhibitor X Tillage	97	99	22
N-Rate X Method X Inhibitor	93	63	98
N-Rate X Method X Tillage	98	90	87
N-Rate X Inhibitor X Tillage	99	74	93
Method X Inhibitor X Tillage	98	12	81
N-Rate X Method X Inhibitor X Tillage	93	99	99
N-Rate X Method X Inh. X Tillage X Provious Crop			
N-Rate X P-Crop	99	99	99
Method X P-Crop	99	71	95
Inhibitor X P-Crop	55	99	99
Tillage X P-Crop	5	23	75
N-Rate X Method X P-Crop	76	68	56
N-Rate X Inh. X P-Crop	96	95	97
N-Rate X Tillage X P-Crop	5	33	39
Method X Inh. X P-Crop	95	99	99
Method X Tillage X P-Crop	76	54	93
Inhibitor X Tillage X P-Crop	99	88	99
N-Rate X Method X Inh. P-Crop	89	31	91
N-Rate X Method X Tillage X P-Crop	75	98	83
N-Rate X Inh. X Tillage X P-Crop	74	82	93
Method X Inh. X Tillage P-Crop	99	99	99
N-Rate X Method X Inh. X Tillage X P-Crop	99	99	99

Table 4. Influence of N-rates, nitrification inhibitors, method of application and tillage in **continuous corn** on soil ammonium and soil nitrate from spring and fall soil samples depth 1 (0-1 ft) and depth 2 (1-2 ft) Westport, MN 1990.

Total N-Rate	Early N	Inh.	Late N	Tillage	Depth	Ammonium Spring	Ammonium Fall	Nitrate Spring	Nitrate Fall
#/A	#/A		#/A			-----ppm-----		-----ppm------	
Control	---	---	---	C	1	3.2	1.8	5.5	4.0
					2	2.4	1.4	1.8	4.4
50	50	---	---	C	1	3.5	2.2	8.3	10.0
					2	2.8	1.6	4.0	5.7
50	---	---	50	C	1	3.2	2.1	5.2	6.2
					2	2.3	1.2	3.1	5.3
105	105	---	---	C	1	2.8	2.1	7.5	5.4
					2	2.6	1.8	6.7	44.3
105	---	---	105	C	1	2.9	1.9	7.4	11.5
					2	2.4	1.7	3.8	13.9
160	160	---	---	C	1	3.5	4.1	8.1	2.1
					2	2.2	1.5	9.5	3.2
160	---	---	160	C	1	3.1	2.6	8.4	4.6
					2	2.4	1.7	5.5	12.6
160	105	---	50	C	1	3.6	2.5	6.6	4.6
					2	2.2	1.6	3.1	10.4
160	160	NS	---	C	1	3.2	2.2	15.2	5.7
					2	2.7	1.6	11.4	5.2
160	---	NS	160	C	1	6.9	3.0	10.1	6.2
					2	3.8	1.8	10.2	5.3
160	105	NS	50	C	1	3.1	4.8	11.3	10.7
					2	2.5	1.5	6.2	8.2
215	215	---	---	C	1	5.8	5.8	13.3	4.5
					2	3.5	3.0	16.2	4.2
215	---	---	215	C	1	9.9	16.1	17.8	3.1
					2	3.4	4.0	19.0	4.2
Control	---	---	---	R	1	2.9	2.0	6.8	11.4
					2	3.3	1.5	2.3	6.9
50	50	---	---	R	1	3.3	1.9	9.7	12.7
					2	1.9	1.6	4.3	3.3
50	---	---	50	R	1	3.1	1.9	7.5	7.5
					2	2.8	1.7	2.5	2.8
105	105	---	---	R	1	3.6	2.1	12.0	5.8
					2	3.6	1.8	8.8	3.6
105	---	---	105	R	1	3.6	2.5	18.7	2.9
					2	5.0	2.0	3.6	3.3
160	160	---	---	R	1	3.3	2.6	14.2	6.9
					2	3.0	1.8	6.5	2.8
160	---	---	160	R	1	4.8	2.4	16.5	12.9
					2	2.9	1.9	10.7	5.1
160	105	---	50	R	1	3.0	2.2	11.8	10.8
					2	2.7	1.4	5.8	7.5
160	160	NS	---	R	1	3.1	2.4	13.3	17.5
					2	2.7	2.0	9.4	5.7
160	---	NS	160	R	1	3.3	10.5	13.1	4.4
					2	3.1	4.7	10.0	5.8
160	105	NS	50	R	1	3.5	2.3	10.6	6.8
					2	2.8	1.5	3.6	5.2
215	215	---	---	R	1	4.4	2.0	17.2	3.9
					2	3.0	1.6	9.6	3.3
215	---	---	215	R	1	3.2	4.0	11.2	7.5
					2	3.1	1.9	9.2	3.4

Table 5. Influence of N-rate, nitrification inhibitors, methods of application and tillage in **corn following soybeans** on soil ammonium and soil nitrate from spring and fall soil samples depth 1 (0-1 ft) and depth 2 (1-2 ft) Westport, MN 1990.

Total N-Rate	Early N	Inh.	Late N	Tillage	Depth	Ammonium Fall	Ammonium Spring	Nitrate Fall	Nitrate Spring
#/A	#/A		#/A			-----ppm-----		-----ppm------	
Control	---	---	---	C	1	1.4	2.7	4.2	7.4
					2	1.3	2.2	2.0	4.6
50	50	---	---	C	1	2.3		3.6	
					2	1.7		2.2	
50	---	---	50	C	1	1.6		3.2	
					2	1.3		1.8	
105	105	---	---	C	1	2.4		3.2	
					2	1.3		2.5	
105	---	---	105	C	1	2.5		8.1	
					2	1.3		5.0	
160	160	---	---	C	1	2.7		9.6	
					2	1.7		7.1	
160	---	---	160	C	1	2.8		8.4	
					2	1.8		10.4	
160	105	---	50	C	1	3.5		5.1	
					2	1.8		5.6	
160	160	NS	---	C	1	2.6		5.7	
					2	1.6		4.6	
160	---	NS	160	C	1	7.1		10.5	
					2	2.1		8.3	
160	105	NS	50	C	1	3.2		8.0	
					2	1.6		4.6	
215	215	---	---	C	1	2.5		11.0	
					2	1.6		6.5	
215	---	---	215	C	1	5.0		20.6	
					2	1.8		13.5	
Control	---	---	---	R	1	1.8	2.5	2.9	4.9
					2	1.6	2.4	1.5	2.3
50	50	---	---	R	1	1.5		4.1	
					2	1.3		2.8	
50	---	---	50	R	1	2.0		6.1	
					2	1.8		3.7	
105	105	---	---	R	1	2.0		4.7	
					2	1.4		2.6	
105	---	---	105	R	1	3.2		8.5	
					2	1.5		6.9	
160	160	---	---	R	1	2.7		6.0	
					2	1.9		5.7	
160	---	---	160	R	1	3.3		6.5	
					2	2.2		6.6	
160	105	---	50	R	1	2.1		7.7	
					2	1.5		5.0	
160	160	NS	---	R	1	6.3		8.9	
					2	4.9		6.7	
160	---	NS	160	R	1	2.9		10.7	
					2	1.6		7.2	
160	105	NS	50	R	1	2.3		3.7	
					2	1.5		4.6	
215	215	---	---	R	1	1.7		6.2	
					2	1.1		4.5	
215	---	---	215	R	1	2.0		8.0	
					2	1.7		5.9	

Table 6. Nitrate-N concentration of water collected in pan and wick lysimeters in the small plot area, Westport, MN 1990.

N rate		Pan corn-corn	Pan corn-beans	Wick corn-corn	Wick corn-beans
#/A		ppm NO_3-N			
0		8.7	1.7	-	8.4
105	early	1.3	1.8	-	25.9
105	late	21.4	6.0	30.8	-
215	early	31.6	5.3	-	22.3
215	late	1.7	1.0	-	21.0

Table 7. Corn grain yields from large plot area Westport, MN 1990.

Total N-Rate	Early N	Late N	Crop Rotation	Grain Yield	Grain N-Content	Grain N-Removal
#/A	#/A	#/A		Bu/A	%	#/A
160	105	55	Corn-Corn	126.9	1.37	82.2
215	140	75	Corn-Corn	122.0	1.36	78.4
160	105	55	Soybeans-Corn	50.1		

Table 8. Nitrate-N concentration of water collected from the pan and wick lysimeters in large plot area, Westport, MN 1990.

N rate	Rotation	NO_3-N
Pan		
lb N/A		ppm
160	corn-corn	9.2
215	corn-corn	38.8
160	soybeans-corn	No samples
Wick		
160	corn-corn	48.9
215	corn-corn	79.0
160	soybeans-corn	19.9

RESIDUAL EFFECTS OF NITROGEN FERTILIZER TREATMENTS AND TILLAGE ON GRAIN YIELD, UPTAKE AND NO_3^- LEACHING IN IRRIGATED CORN[1]

Manjula Vivekanandan, G.L. Malzer and J.L. Anderson[2]

Abstract

Irrigation of coarse textured soils increase the leaching potential of applied nitrogen. This study was initiated in 1987 to study the effects of tillage, Nitrification inhibitor (DCD), and N rates (fertilizer treatments given in 1987 and 1988 only) on crop yields, water percolation and NO_3-N leached in a corn-corn-soybean rotation in central Minnesota. During the first two years of the study (I) N rate increased corn yield and concentration of NO_3 in the percolating water, and (II) urea treated with DCD reduced the NO_3 concentration in the percolating water. In the third year of the study (1989), tillage or fertilizer treatments applied during the first two years of the study did not have any effects on soybean yields or, water and NO_3 movement. However, in the fourth year of the study (1990), tillage treatments did influence the corn grain yields. No-till systems had significantly lower yields than roto-till systems. There was no evidence for residual fertilizer effects on grain yield or N uptake. Tillage treatments didn't have any influence on the amount of water percolated or total amount of N leached. However, NO_3-N concentration in roto-till treatments were significantly higher than no-till treatments. Residual effects of prior fertilizer treatments were reflected in the total amount of NO_3 leached during the early season leaching events. However, these differences didn't exist in late season leaching events. Nitrate leached through the profile was directly related to the amount of water percolated.

Introduction

Irrigation of coarse textured soils in central Minnesota increases the leaching potential of applied nitrogen. Nitrate leaching in these soils can be reduced by adopting efficient fertilizer management practices. The objective of this study was to evaluate the influence of tillage, residual effects of nitrification inhibitor treated fertilizer and N rates on crop yields, water percolation and NO_3-N leached in a corn-corn-soybean rotation in central Minnesota.

Experimental Procedures

In 1975, 30 non-weighing lysimeters were installed on the Rosholt farm at Westport, Minnesota. Each lysimeter was 5.75 ft in diameter, and 4 ft deep and constructed of 12-gauge galvanized steel coated with coal tar epoxy enamel. At the bottom of each lysimeter a sintered stainless steel filter candle was installed and connected to the soil surface by polyethylene tubing. Soil at the experimental site was a Estherville sandy loam (Typic Hapludoll) and was used to fill the lysimeters by depth.

Prior to the initiation of this experiment the site had been cropped with dryland no-till soybeans for 2 years (1985 and 1986). Selected chemical and physical characteristics are shown in Table 1. Irrigation was provided to all plots through a drip-type irrigation system. Drippers were 30 inches apart on a 0.5 inch plastic irrigation line. An irrigation line was placed along each row of corn. Water was pumped through the irrigation system at 13.8 kPa

Table 1. Some chemical and physical properties of the Estherville sandy loam.

Soil depth	Gravel	Sand	Silt	Clay	Organic Matter	pH
in	%					
0-6	0.8	57.9	23.8	18.3	4.8	5.7
6-15	8.0	69.0	16.8	14.1	1.1	5.8
15-30	5.4	66.8	16.1	17.1	0.7	6.2

[1] Funding provided by the Center for the Impact of Agricultural Practices on Water Quality.
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pressure. The emission rate for each dripper was 0.35 gal/h. Each lysimeter contained 4 drippers. Irrigation water was applied when less than 2 inches of water were available in the soil profile. Irrigation water was metered through 3 main irrigation lines.

Corn (Pioneer 3790) was planted in the spring of 1990 at seed density of 28,000 seeds/A. The crop rotation was corn-corn-soybeans-corn. Soil temperature, wind speed, air temperature, and rainfall were measured at regular intervals during the four growing seasons. The fourth year research data will be reported here.

Treatments consisted of a factorial arrangement of 2 tillage treatments (roto-tillage and no-tillage), 3 N rates (0, 70, and 140 lbs N/A) applied in 1987 and 1988, and 3 blocks. Dicyandiamide (DCD) was an additional treatment in 1987 and 1988, and was applied at rates of 0 or 10% of the applied N in the 140 lbs N/A treatments.

Corn was harvested from a four ft. row at the 12 leaf and silking stage for dry matter production and N uptake (data not presented). Grain and stover yields were obtained by harvesting two 20 ft. rows at black layer stage. Subsamples from stover, cob and grain components were analyzed for total Kjeldahl N. Corn grain yields were reported at 15.5% moisture.

Soil water percolate was collected throughout the growing season from the bottom of the lysimeters following rainfall events. The amount percolated and the NO_3-N in the leachate was measured to quantitate concentration, flow rate and total N lost by leaching.

1990 was a wet year compared to the prior three years of the study. Monthly precipitation was 2.1, 7.3, 3.1, 2.4, 2.5 and 4.0 inches for May, June, July, August, September and October respectively. Four inches of supplemental irrigation water was applied between the 9th of July and 7th of August.

Results and Discussion

Corn grain yields averaged 103 bu/A even though there was no fertilizer applied. Yields from no-till treatments were 5 bu/A lower than roto-till treatments (Table 2). Nitrogen removal with the grain was not influenced by tillage. Prior fertilizer treatments (applied in 1987 and 1988) did not influence grain yield or N uptake (Table 2).

Table 2. Influence of tillage, residual fertilizer N on grain yield and N uptake of corn, 1990.

Tillage	N rate*	Grain yield	Grain N uptake
	lb N/A	bu/A	lb/A
Roto-till	0	105	52
	70	105	51
	140	106	52
	140 + DCD	108	56
No-till	0	101	46
	70	99	48
	140	103	54
	140 + DCD	100	48
LSD(0.05)		NS	NS
Tillage			
Roto-till		106	53
No-till		101	50
LSD(0.05)		4.7	NS
N rate			
	0	103	49
	70	102	50
	140	105	53
	140 + DCD	104	52
LSD(0.05)		NS	NS

* Nitrogen fertilizer treatments were given in 1987 and 1988 only.

Soil inorganic N (NO_3+NH_4-N) in surface 12" before planting (spring, 1990) ranged from 37 to 65 lb N/A. Relatively higher levels of inorganic N levels in the control plots when compared to 1989 (52 lb N/A in 1990; and 26 lb N/A in 1989) may have resulted from previous year of soybeans. There were no significant differences due to tillage treatments or prior N fertilizer treatments. At the end of the season (Fall, 1990) soil inorganic N levels ranged from 12 to 15 lb N/A.

Water leachate was collected from the lysimeters 10 times during 1990. The leaching events were grouped into 3 phases considering the growth stage and water use pattern of corn (Table 3). Total amount of water percolated throughout the season amounted to 9.3 inches; this compares with 0, 2.4, and 7.7 inches for 1987, 1988, and 1989, respectively. Tillage treatments did not influence the amount of water percolated or the amount of N leached. However, the NO_3-N concentration from the roto-till plots were significantly higher than in no-till plots throughout the growing season (Table 3). Residual effects of prior fertilizer treatments were reflected in the total amount of NO_3 leached during planting to silking stage but not with the later time intervals. However, these differences were not evident during silking to black layer and post harvest stage leaching events.

Table 3. Tillage and residual effects of N fertilizer and DCD on water percolation and NO_3-N concentration in the leachate.

Tillage	Planting-Silking			Silking-Blacklayer			Post harvest		
	H_2O in	N lb/A	NO_3-N ppm	H_2O in	N lb/A	NO_3-N ppm	H_2O in	N lb/A	NO_3-N ppm
Roto-till	5.1	16	15	1.2	13	60	2.0	4	11
No-till	6.7	13	10	1.2	7	34	2.4	4	7
LSD(0.05)	NS	NS	4	NS	NS	21	NS	NS	3
N rate* lb/A									
0	5.5	11	11	1.6	12	46	2.4	4	8
70	6.3	14	12	1.6	11	44	2.4	4	8
140	5.9	15	13	0.8	8	49	2.0	4	11
140 + DCD	6.3	19	15	1.2	10	52	2.0	4	9
LSD(0.05)	NS	4.5	NS	NS	NS	NS	NS	NS	NS

* Nitrogen fertilizer treatments were given in 1987 and 1988 only.

Concentrations of NO_3-N in the leachates were higher during silking to black layer stage than the planting to silking and post harvest stages. Intensive rainfall events which occurred prior to this leaching interval perhaps resulted in dilution effects in the early season leaching events. The minimal percolation during silking to black layer period probably resulted in higher concentration of NO_3-N during this period.

Nitrate movement through the soil profile was correlated to the amount of percolated water (Fig. 1). As the amount of water percolated increased, the NO_3-N concentration decreased (Table 3), and the total amount of NO_3-N leached increased in both tillage treatments (Fig. 1).

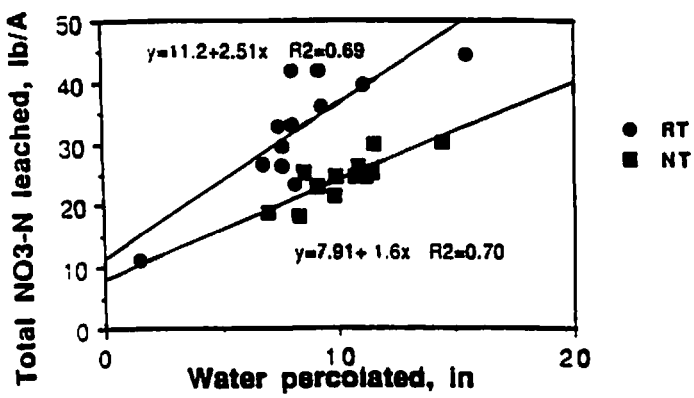

Fig 1. Relationship between water percolated and total N leached throughout the season, 1990.

LAND TREATMENT OF SEWAGE SLUDGE INCINERATOR ASH[1]

Carl Rosen, Dave Birong, and Louise America[2]

ABSTRACT: The fourth year of an ongoing experiment was conducted at the Rosholt Research farm in Westport, MN to evaluate the use of sewage sludge incinerator ash as a phosphorus source for corn production. The evaluation this year was done on sweet corn. Three rates of phosphate fertilizer (70, 140, and 280 lb P_2O_5/A) were compared with equivalent rates of P supplied by ash based on the citrate soluble P test. Early plant (8-12 leaf) dry weight and final grain yield significantly increased with both ash and fertilizer compared to the control. There was a slight but significant increase in yield of fertilizer grown plants compared to ash grown plants. The Olsen P soil test seemed to predict response to the ash amended soils better than the Bray P1 or Nitric acid extractants. There was slight, but significant increase in nitric acid extractable Cd and Cr at 6-12" soil depths when ash was applied compared to control an fertilized plots. Other heavy metals did not appear to move out of the top 6" of soil. Tissue analysis revealed that both P sources increased P levels in the plant; however, at equivalent P rates, stover P concentrations were greater with the fertilizer source compared to the ash source. There were no differences in P concentrations in cob and kernel tissue due to P source. Tissue concentrations of Zn and Cu were higher with ash applications compared to fertilizer applications. Tissue levels of Cd increased slightly with ash applications. Other heavy metals such as Pb, Ni, and Cr did not accumulate in the kernels, husk, stover, or cob.

Incineration of sewage sludge is a common means of reducing the volume of municipal waste material. As landfill usage is being reduced, disposal of the resulting ash is becoming more of a problem. Finding an environmentally acceptable disposal method for incinerator ash is important as increasing quantities of sewage sludge wastes are burned. Sewage sludge incinerator ash contains many elements that are essential for plant growth. In particular, high concentrations of phosphorus, calcium and magnesium have been reported in previous studies. However, this ash also contains heavy metals such as cadmium, lead, zinc, copper, and others which can pose problems to plants and animals in high concentrations. When properly managed, recycling incinerator ash nutrients by land spreading may provide a disposal method that is beneficial to both incinerator operators and crop producers. The purpose of this study was to determine whether sewage sludge ash can be used as a soil amendment/fertilizer without lowering crop quality or polluting the environment. Results reported here are from the fourth year of an ongoing study.

MATERIALS AND METHODS

A field experiment was initiated in May 1987 at the Rosholt Research Farm in Westport, MN. This site was selected because irrigation was available and soil test P was at a level where a response to applied phosphorus might be expected. The soil is an Estherville sandy loam with an initial pH of 5.7 and Bray P1 of 17 ppm.

Ash was collected from the Metropolitan Waste Water Treatment Plant in St. Paul in April 1987 and stored in 5 gallon covered plastic containers. A complete elemental analysis of the material was presented in detail three years ago (see 1988 Bluebook). Briefly, the ash is 8.8% P_2O_5 based on the citrate acid soluble P test and has a calcium carbonate equivalent of 13.7%. Particle size analysis revealed that 99% passed through a 60 mesh screen and 88% passed through a 100 mesh screen.

Treatments consisted of a control, three rates of phosphate fertilizer (0-46-0: 70, 140 and 280 lb P_2O_5/A) and three equivalent rates of sewage sludge incinerator ash based on available phosphate. Treatments were applied to the same plots at the same rates as in 1989. Loading rates of Cd, Ni, Cr, and Pb based on the digest analysis and application rates were less than the annual maximum application rates set by the Minnesota Pollution Control Agency. A Gandy fertilizer spreader was used to broadcast applications of 0-0-60 (200 lbs/A) and 45-0-0 (195 lbs/A). Sludge ash and phosphate fertilizer were applied by hand. The entire plot area was disked to a depth of 4-6". A randomized complete block design with four replications was used. Field corn (Funks G-4100 hybrid) was planted on May 10, 1990 at a population of 32,000 plants/A in 30" rows along with a furrow application of Counter insecticide. The stand was very poor due to cool wet conditions and was therefore plowed up on June 14. Sweet corn (Jubilee) was planted on June 18 at a population of 25,000 plants/A in 30" rows. Each plot consisted of four 30' rows. Irrigation supplemented rainfall to provide approximately 1" of water per week. Suction cup lysimeters were installed in all treatments in reps 1 and 3 on May 14 at a depth of 18". Water samples were collected on September 4 and 13 and October 11, approximately 3 or 4 days after at least 1" of rainfall or irrigation was supplied. On August 3, 4 whole

[1] Funding for this project was provided by the Metropolitan Waste Control Commission.

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plants were sampled from each plot at the ends of the two middle rows. At this sampling, plant development corresponded to the 8-12 leaf stage. The entire plot was sidedressed with 70 lb N/A as ammonium nitrate on July 2 and 140 lb N/A as ammonium nitrate on July 19. Ear leaf samples were collected from each plot at the mid-silking stage (August 20). Plots (20' from the middle two rows) were harvested for unhusked, husked, and stover yields on September 13. Subsamples of stover, husk, and kernel plus cob were collected for moisture determinations, shelling percentages, and elemental analyses. All plant samples were ground in a Wiley mill to pass through a 30 mesh screen. Multiple element analysis using ICP procedures were performed on ashed samples dissolved in 1 N HCl. Following Kjeldahl digestion, total nitrogen in plant tissues was determined using conductimetric procedures.

Soil samples were collected on September 4 at 3 depths: 0-6", 6-12", and 12-24". Samples were air dried, ground using a rolling pin and extracted with 1 N nitric acid. Multiple elements were determined using ICP procedures. Available nutrients were determined using the following extractants: Bray P1 extractant, Olsen P, ammonium acetate, and DTPA. Soil pH and soluble salts were determined on a 1:1 soil - water mixture.

RESULTS

Soil and Water Samples. Elemental analyses of the water collected in the suction cup lysimeters are presented in Table 1. Concentrations of Cd, Pb, Ni, and Cr were generally below detection limits of the ICP spectrophotometer. Phosphorus concentrations did not show any consistent trend due to treatment. Other elements such as Cu, Zn and B were at background levels. None of the other elements determined exhibited trends with increasing ash or fertilizer treatments.

As expected, extractable P increased with increasing ash and fertilizer rate in the 0-6" depth (Tables 2a and 2b). Nitric acid and the Bray P1 extractant extracted more P from the soil amended with ash than with fertilizer. In contrast, Olsen P extractant extracted more P from soil amended with fertilizer than with ash. Soil pH linearly increased with ash application, but was not affected by P fertilizer application. Soluble salts were not affected by treatment. Ammonium acetate and nitric acid extractable Na increased slightly with increasing ash rates. All nitric acid extractable elements except K and Co increased with ash applications. Of particular interest is the DTPA or 'plant available' metals. Ash amendments significantly increased DTPA extractable Zn, Cu, Pb, and Cd and decreased extractable Mn in the top 6".

In the 6 - 12" depth, Bray and Olsen extractable P increased with both amendments (Table 3a). In contrast, there was no difference in nitric acid extractable P (Table 3b). Soil pH and soluble salts were not affected by treatment. DTPA and nitric acid extractable Cu tended to increase with ash application. Nitric acid extractable Na, Fe, Cr increased with ash application. Concentrations of nitric acid extractable Cd and Cr were higher with ash application compared to fertilizer application.

In the 12 - 24" depth, Bray and Olsen extractable P tended to increase with both amendments (Table 4a) with no differences in nitric acid extractable P (Table 4b). Nitric acid extractable Cd tended to increase with increasing ash rates.

Yield Data. Both triple superphosphate fertilizer and ash significantly increased early plant dry weight compared to plants growing in the check plot (Table 5). This early plant response to P fertilizer is common in corn grown in low P soils. Unhusked (green) and husked yield increased with ash and fertilizer application compared to the check. Yields were higher in phosphate fertilized plots compared to ash amended plots. Reasons for the differences in yield between the ash and fertilizer plots are not precisely known. Toxicity due to trace metals or high soluble salts does not appear to be involved. Stover yield increased with ash and fertilizer application compared to the control plot. There was no difference in stover yield between fertilizer and ash amended plots. These results clearly indicate that application of ash can increase yield, but the magnitude may not be the same as with fertilizer.

Tissue Analyses. Fertilizer and ash treatments increased tissue P concentrations in corn sampled at the 6 - 8 leaf stage (Table 6). Even though rates of ash were adjusted to equivalent rates of available P in fertilizer using the citrate acid test, corn grown in plots supplied with fertilizer source was superior to the ash source in supplying P. Both Cu and Zn concentrations tended to increase with ash applications; however, both of these nutrients are essential for plant growth and levels reported are well below those considered toxic to plants or animals. Although generally low, concentrations of Cd increased with ash application. The other heavy metals, Pb, Ni, and Cr were generally at background levels or at levels below the detection limit of the ICP. Ear leaves sampled at silking increased in P with fertilizer and ash applications (Table 7). As in whole plant samples, the increase was greater in the 0-46-0 plots than with the ash plots. Phosphate fertilizer increased tissue Mn and Cr, but decreased Cu and Zn concentrations compared to the ash treatments. Concentrations of Cd increased in ear leaf tissue with both fertilizer and ash applications.

Concentrations of P increased in stover to a greater extent in plants supplied with 0-46-0 than in plants supplied with ash (Table 8). Stover K and Mg decreased and Ca increased when fertilizer was applied. Levels of Zn and Cu in stover were greater with ash application compared to P fertilizer application. Concentrations of Cd increased with increasing ash rate. Concentrations of P in the cob were not consistently affected by treatment (Table 9). Cob Zn significantly decreased when P fertilizer was applied. Levels of P in kernels increased with fertilizer and ash treatments compared to those in the control plots (Table 10). Kernel Zn, Cu, B, and Mn decreased with increasing ash and fertilizer application. Concentrations of Pb, Ni, Cr, and Cd in kernels were either at background levels or below detection limits of the ICP. Husk P increased with increasing ash and fertilizer application. Husk Zn increased with increasing ash application, but decreased with increasing fertilizer application. Concentrations of Cd in husk tissue increased with both ash and fertilizer application

GENERAL DISCUSSION

The positive yield response from both ash and fertilizer application indicate that the ash can serve as a source of P for plant growth. From tissue analysis results, phosphate availability at equivalent rates does not appear to be as good from the ash source as from the fertilizer source. This may be due to lower P solubility in the ash compared to the fertilizer which may not be readily detected by the available (citrate soluble) P test. The Olsen P soil test seemed to predict response to the ash amended soils better than the Bray P1 or Nitric acid extractants. Ash appears to be a good source of Zn, a nutrient which can be limiting when high rates of P fertilizer are used. For the first time in four years, there appeared to be some uptake of Cd by the plant. Concentrations of Cd were well below those considered toxic for plants or animals. Further experimentation at this same site is required to evaluate longer term effects of incinerator ash on element movement in the soil and uptake by the plant.

Table 1. Elemental composition of lysimeter water as affected by fertilizer or ash treatment at three sampling dates.

Treatment lb P_2O_5/A	P Source	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
Sept 4		ppm														
control	--	0.07	1.9	198	52	<0.33	0.05	9	0.03	0.17	<0.03	0.04	<0.66	<0.02	<0.02	<0.01
70	Fert.	0.11	2.7	300	78	<0.20	0.04	9	0.02	0.10	<0.03	0.05	<0.45	<0.03	<0.02	<0.01
140	Fert.	0.08	2.9	158	44	<0.20	0.04	10	0.05	0.05	<0.03	0.04	<0.50	<0.02	<0.02	<0.01
280	Fert.	0.08	4.3	335	87	<0.21	0.05	28	0.13	0.12	<0.03	0.05	<0.62	0.04	<0.02	<0.01
70	Ash	0.07	1.8	186	47	<0.20	0.04	14	0.03	0.04	<0.03	0.05	<0.37	<0.02	<0.02	<0.01
140	Ash	0.08	2.2	266	67	<0.39	0.16	11	0.08	0.11	<0.04	0.05	<1.30	<0.04	<0.02	<0.01
280	Ash	0.09	2.3	237	63	<0.20	0.04	11	<0.00	0.06	<0.03	0.05	<0.47	<0.02	<0.02	<0.01
Sept 13																
control	--	0.06	1.5	139	37	<0.20	<0.02	7	0.02	<0.04	<0.03	0.03	<1.90	<0.02	<0.02	<0.01
70	Fert.	0.10	2.1	246	63	<0.20	0.03	8	0.02	0.04	<0.03	0.04	<1.20	<0.03	<0.02	<0.01
140	Fert.	0.07	2.9	138	38	<0.20	<0.04	10	<0.05	<0.05	<0.03	0.04	<0.94	<0.03	<0.02	<0.01
280	Fert.	0.09	3.8	283	74	<0.20	0.03	21	0.09	0.06	<0.04	0.05	<3.91	0.03	0.02	0.01
70	Ash	0.05	1.2	122	31	<0.20	<0.02	7	0.01	<0.01	<0.03	0.04	<3.05	<0.02	<0.02	<0.01
140	Ash	0.08	1.8	187	47	<0.21	0.05	7	0.06	<0.06	<0.03	0.04	<1.62	<0.03	<0.02	<0.01
280	Ash	0.07	1.7	166	44	<0.20	0.03	8	<0.00	<0.01	<0.03	0.04	<1.63	<0.02	<0.02	<0.01
Oct 11																
control	--	0.05	2.0	201	53	<0.20	0.03	9	0.02	1.13	<0.03	0.03	<0.82	<0.03	<0.02	<0.01
70	Fert.	0.10	2.4	321	84	<0.20	0.04	10	0.02	0.47	<0.03	0.04	<0.56	<0.02	<0.02	<0.01
140	Fert.	0.08	2.5	153	43	<0.20	0.03	11	0.03	0.28	<0.03	0.04	<1.01	<0.02	<0.02	<0.01
280	Fert.	0.08	4.0	349	92	0.52	0.06	26	0.11	0.22	<0.06	0.04	<1.05	0.04	0.02	<0.01
70	Ash	<0.10	1.7	196	51	<0.20	0.04	14	0.02	0.17	<0.03	0.04	<0.48	<0.03	<0.02	<0.01
140	Ash	0.09	2.1	307	77	<0.47	0.12	12	0.10	<0.95	<0.04	0.05	<1.10	<0.05	<0.02	<0.01
280	Ash	0.09	2.3	225	61	<0.20	0.03	11	<0.00	<0.25	<0.03	0.04	<0.85	<0.02	<0.02	<0.01

Table 2a. Effect of sludge ash and phosphate fertilizer on soil pH, Bray P1, Olsen P, Ammonium Acetate extractable cations, and DTPA extractable micro elements (0-6" depth).

Treatment	P Source	pH	Soluble Salts	BrayP1	OlsenP	NH_4OAc Extractable				DTPA Extractable							
						K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Pb	Ni	Cr	Cd
lb P_2O_5/A			mmhos/cm	ppm													
Control	-	4.9	0.65	21.0	12.8	160	1749	254	8.0	96.7	67.5	1.4	1.01	1.39	3.02	0.07	0.12
70	Fert.	4.8	0.63	58.3	32.8	143	1777	246	8.3	103.1	72.6	1.4	0.97	1.55	3.50	<0.09	0.26
140	Fert.	4.8	0.60	118.5	63.8	161	1670	235	8.2	101.4	75.5	1.5	0.98	1.55	3.28	0.09	0.12
280	Fert.	4.9	0.63	208.0	108.8	141	1694	233	8.6	98.1	67.1	1.6	1.02	1.35	3.22	<0.09	0.12
70	Ash	4.8	0.65	82.0	40.5	165	1716	242	7.4	102.7	70.2	2.8	2.76	1.87	3.44	0.14	0.22
140	Ash	5.2	0.55	154.5	59.0	152	1848	291	10.3	88.7	44.8	4.5	4.86	2.32	3.33	<0.06	0.38
280	Ash	5.2	0.65	240.5	75.0	158	1882	312	11.9	86.0	31.5	7.3	8.07	2.24	3.21	0.07	0.55
Significance		*	NS	**	**	NS	NS	**	*	*	**	**	**	**	NS	-	**
BLSD(0.05)		0.4	-	22.4	10.3	-	-	36	3.1	14	26.2	0.7	0.78	0.35	-	-	0.16
Contrasts																	
Ctrl vs Rest		NS	NS	**	**	NS	NS	NS	NS	NS	NS	**	**	**	NS	-	*
Fert vs Ash		**	NS	**	**	NS	*	**	*	**	**	**	**	**	NS	-	**
Linear Fert.		NS	NS	**	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
Quad Fert.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
Linear Ash		**	NS	**	**	NS	*	**	**	**	**	**	**	**	NS	-	**
Quad Ash		NS	NS	*	**	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	-	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 2b. Effect of sludge ash and phosphate fertilizer on 1N nitric acid extractable elements (0-6" depth).

Treatment	P Source	1 N Nitric Acid Extractable																			
		P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	As	Ba	Co	Mo	S
lb P_2O_5/A		ppm																			
Control	-	75	179	2730	420	1645	185	9	146	5.1	3.5	1.3	5.47	5.00	0.79	0.31	1.48	93	0.93	0.53	16.2
70	Fert	118	163	2883	440	1786	214	10	170	5.5	3.6	1.3	6.31	5.80	0.92	0.40	1.69	102	1.03	0.57	18.0
140	Fert	203	187	2704	405	1750	220	8	177	5.2	3.5	1.2	5.92	5.39	0.91	0.33	1.66	94	1.08	0.57	18.0
280	Fert	326	172	2863	421	1881	260	11	184	5.8	3.7	1.3	6.37	5.28	1.05	0.36	1.70	97	1.10	0.61	19.4
70	Ash	189	188	2782	414	1768	214	10	166	8.0	7.6	1.3	6.62	5.42	1.28	0.54	1.64	96	1.01	0.63	18.7
140	Ash	392	180	3366	549	1942	249	15	170	13.4	14.7	1.4	8.27	5.84	2.28	0.88	1.75	102	1.02	0.62	19.4
280	Ash	675	195	3745	598	2181	300	20	179	20.7	24.7	1.6	10.55	6.08	3.67	1.37	2.08	114	1.10	0.73	20.9
Significance		**	NS	**	*	**	**	**	*	**	**	**	**	**	**	**	**	**	**	**	*
BLSD (0.05)		58	-	421	138	125	24	1.9	26	1.8	2.2	0.1	0.70	0.63	0.30	0.14	0.17	8.8	0.1	0.06	3
Contrasts																					
Ctrl. vs Rest		**	NS	*	NS	**	**	**	**	**	**	*	**	**	**	**	**	**	**	**	**
Fert. vs Ash		**	NS	**	**	**	**	**	NS	**	**	**	**	NS	**	**	**	**	NS	**	NS
Linear Fert.		**	NS	NS	NS	**	**	NS	**	NS	NS	NS	*	NS	NS	NS	*	NS	**	**	*
Quad Fert.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Linear Ash		**	NS	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	NS	**	**
Quad Ash		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 3a. Effect of sludge ash and phosphate fertilizer on soil pH, Bray P1, Olsen P, Ammonium Acetate extractable cations, and DTPA extractable microelements (6-12" depth).

Treatment	P Source	pH	Soluble Salts	BrayP1	OlsenP	NH_4OAc Extractable				DTPA Extractable							
						K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Pb	Ni	Cr	Cd
lb P_2O_5/A			mmhos/cm	ppm													
Control	-	6.1	0.33	3.8	2.3	62	1617	261	8.9	28.2	9.6	0.2	0.55	<0.31	1.24	<0.03	<0.03
70	Fert.	5.9	0.35	5.0	2.8	67	1628	251	8.5	29.4	9.3	0.3	0.56	<0.30	1.74	<0.08	<0.03
140	Fert.	6.0	0.30	5.3	3.3	68	1621	255	8.8	29.4	9.3	0.3	0.60	<0.31	1.43	<0.02	<0.04
280	Fert.	6.0	0.40	9.0	6.0	87	1933	311	12.7	28.4	10.5	0.3	0.57	<0.34	1.64	<0.06	<0.03
70	Ash	6.1	0.40	4.8	2.8	71	1793	284	11.1	29.7	12.1	0.3	0.61	<0.31	1.64	<0.02	<0.04
140	Ash	6.2	0.38	5.5	3.0	66	1680	269	10.2	26.1	9.9	0.5	0.64	<0.42	1.36	<0.02	<0.04
280	Ash	6.1	0.33	6.5	4.0	71	1786	291	11.9	27.2	9.7	0.3	0.73	<0.37	1.44	<0.02	<0.06
Significance		NS	NS	**	**	NS	NS	NS	*	NS	NS	NS	NS	-	NS	-	-
BLSD (0.05)		-	-	2.6	2.0	-	-	-	3.3	-	-	-	-	-	-	-	-
Contrasts																	
Ctrl vs Rest		NS	NS	*	*	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	-	-
Fert vs Ash		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	-	NS	-	-
Linear Fert.		NS	NS	**	**	*	NS	NS	**	NS	NS	NS	NS	-	NS	-	-
Quad Fert.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	-	-
Linear Ash		NS	NS	*	*	NS	NS	NS	NS	NS	NS	NS	**	-	NS	-	-
Quad Ash		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	-	NS	-	-

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 3b. Effect of sludge ash and phosphate fertilizer on 1 N nitric acid extractable elements (6-12" depth).

Treatment	Source	1 N Nitric Acid Extractable																			
		P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	As	Ba	Co	Mo	S
lb. P_2O_5/A		ppm																			
Control	-	47	41	2289	572	1545	306	11	48	3.9	2.4	0.8	4.74	3.37	1.15	0.22	1.5	64	0.69	0.55	8.1
70	Fert.	34	44	2316	565	1572	297	12	46	4.1	2.6	0.9	4.66	4.40	1.15	0.23	1.5	71	0.67	0.54	9.2
140	Fert.	43	43	2344	565	1523	288	12	46	4.0	2.7	0.8	4.72	3.69	1.12	0.22	1.5	66	0.68	0.55	10.2
280	Fert.	51	44	2275	569	1506	305	13	52	4.1	2.7	0.8	4.61	4.17	1.14	0.23	1.5	65	0.66	0.55	10.4
70	Ash	43	44	2633	642	1621	323	13	54	4.5	2.9	0.9	4.89	4.57	1.26	0.27	1.6	72	0.75	0.57	9.6
140	Ash	59	42	2370	617	1561	327	13	55	4.1	2.7	0.9	4.68	3.66	1.29	0.28	1.6	68	0.69	0.57	10.0
280	Ash	42	41	2408	661	1663	377	14	49	4.9	3.1	0.9	5.04	3.99	1.38	0.26	1.7	75	0.73	0.59	10.9
Significance		NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD (0.05)		-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Contrasts																					
Ctrl vs Rest		NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fert. vs Ash		NS	NS	NS	*	NS	**	**	NS	NS	NS	NS	NS	NS	**	*	NS	NS	NS	NS	NS
Linear Fert.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quad Fert.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear Ash		NS	NS	NS	NS	NS	*	**	NS	NS	*	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
Quad Ash		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 4a. Effect of sludge ash and phosphate fertilizer on soil pH, Bray P1, Olsen P, Ammonium Acetate extractable cations, and DTPA extractable micro elements (12-24" depth).

Treatment	P Source	pH	Soluble Salts	Bray P1	Olsen P	NH_4OAc Extractable				DTPA Extractable							
						K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Pb	Ni	Cr	Cd
lb. P_2O_5/A			mmhos/cm	ppm													
Control	-	7.2	0.25	3.5	2.0	57	1511	205	6.1	15.3	10.8	0.2	0.62	<0.33	0.72	<0.06	<0.05
70	Fert.	6.9	0.23	4.0	2.8	65	1134	182	6.7	16.4	10.7	0.3	0.50	<0.42	1.10	<0.08	<0.04
140	Fert.	7.2	0.25	4.5	2.8	57	1333	181	4.3	14.3	10.2	0.2	0.54	<0.30	0.55	<0.09	<0.05
280	Fert	7.2	0.23	6.3	4.3	59	1470	173	6.2	15.4	12.1	0.2	0.58	<0.39	0.81	<0.06	<0.05
70	Ash	7.3	0.23	3.5	2.3	62	1329	190	6.0	14.7	14.1	0.2	0.60	<0.27	0.85	<0.07	<0.04
140	Ash	7.4	0.25	5.8	3.8	49	1953	193	5.6	14.3	10.1	0.3	0.66	<0.30	0.76	<0.04	<0.07
280	Ash	7.3	0.25	8.3	4.3	60	1527	180	6.3	17.4	13.2	0.3	0.72	<0.41	1.17	<0.07	<0.03
Significance		NS	NS	*	*	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	-	-
BLSD (0.05)		-	-	3.5	2.0	-	-	-	-	-	-	-	-	-	-	-	-
Contrasts																	
Ctrl vs Rest		NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	-	-
Fert. vs Ash		**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	-	-
Linear Fert.		NS	NS	*	**	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	-	-
Quad Fert.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	-	-
Linear Ash		NS	NS	**	**	NS	NS	NS	NS	*	NS	NS	NS	-	NS	-	-
Quad Ash		NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	-	NS	-	-

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 4b. Effect of sludge ash and phosphate fertilizer on 1 nitric acid extractable elements (12-24" depth).

Treatment	P Source	1 N Nitric Acid Extractable																			
		P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	As	Ba	Co	Mo	S
lb. P_2O_5/A		ppm																			
Control	-	118	38	3019	2062	992	378	11	77	3.0	2.3	1.0	3.09	3.67	1.01	0.21	1.5	40	0.65	0.36	11.9
70	Fert.	98	41	3390	1230	951	344	9	63	2.7	1.9	0.8	2.96	5.07	0.98	0.20	1.3	37	0.54	0.34	8.2
140	Fert.	109	41	7208	1957	849	340	11	71	2.6	2.0	1.0	2.72	3.14	0.94	0.20	1.4	38	0.60	0.31	12.5
280	Fert.	125	45	8399	2971	891	374	12	87	2.8	2.5	1.6	3.00	4.83	0.97	0.23	1.6	41	0.67	0.32	15.8
70	Ash	112	39	5381	2132	860	361	10	80	2.8	2.2	1.0	2.79	9.51	0.93	0.22	1.4	42	0.63	0.32	10.0
140	Ash	147	38	6177	4572	918	453	15	106	3.5	2.9	1.5	3.23	4.64	1.20	0.26	1.8	39	0.83	0.37	22.7
280	Ash	133	40	6317	2355	958	394	13	89	3.3	2.8	1.1	3.24	5.80	1.06	0.27	1.5	47	0.65	0.36	11.5
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD (0.05)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Contrasts																					
Crtl vs Rest		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fert. vs Ash		*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
Linear Fert.		**	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quad Fert.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear Ash		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
Quad Ash		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 5. Effect of sludge ash and phosphate fertilizer on whole plant dry weight at the 8-12 leaf stage, green yield and husked yield and dry yield for ears, husks and stover.

Treatment	P Source	Early plant yield 8-12 leaf	Green yield	Husked Ears >5.5"	Husked Ears <5.5"	Husked Ears Unuseable	Husked Ears Total	Dry Matter Ears	Dry Matter Husks	Dry Matter Stover	% Moisture in kernals
lb P_2O_5/A		g dw	T/A	T/A	T/A	T/A	T/A	Lbs/A	Lbs/A	Lbs/A	
Control	-	114.0	4.62	1.62	1.88	0.12	3.62	1550	345	4070	76.8
70	Fert.	168.3	5.89	3.20	1.25	0.10	4.56	2106	423	4785	74.5
140	Fert.	176.5	6.30	2.95	1.52	0.11	4.59	2128	545	5129	75.0
280	Fert.	188.3	6.16	3.33	1.18	0.12	4.63	2240	496	5112	75.8
70	Ash	146.5	5.64	2.21	1.93	0.13	4.27	1917	441	4525	74.5
140	Ash	164.8	5.84	2.22	1.81	0.09	4.12	1936	571	4903	73.8
280	Ash	182.8	5.62	2.46	1.68	0.15	4.28	2002	455	4642	74.5
Significance		**	**	**	NS	NS	**	**	*	*	**
BLSD (0.05)		22.2	0.42	0.63	-	-	0.30	186	141	651	0.01
Contrasts											
Control vs Rest		**	**	**	NS	NS	**	**	**	**	**
Fert. vs Ash		*	**	**	**	NS	**	**	NS	NS	*
Linear Fert.		**	**	**	NS	NS	**	**	*	**	NS
Quad. Fert.		**	**	**	NS	NS	**	**	*	*	**
Linear Ash		**	**	*	NS	NS	**	**	NS	NS	**
Quad. Ash		*	**	NS	NS	NS	*	**	**	*	**

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 6. Effect of sludge ash and phosphate fertilizer on elemental composition of whole plants sampled at the 8-12 leaf stage.

Treatment	P Source	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
lb. P_2O_5		%					ppm										
Control	-	2.92	0.25	4.86	0.45	0.35	63	139	28	48	46	6.7	6.4	3.0	1.50	1.0	0.38
70	Fert.	2.82	0.30	4.40	0.45	0.30	53	126	26	51	35	4.8	6.3	3.0	1.54	1.0	0.34
140	Fert.	2.76	0.33	4.22	0.43	0.30	50	120	22	47	28	3.4	5.8	1.7	1.08	1.5	0.40
280	Fert.	2.76	0.43	3.93	0.47	0.32	54	129	25	48	24	3.0	5.6	<1.5	0.99	0.8	0.29
70	Ash	2.90	0.28	4.66	0.46	0.32	53	127	27	50	46	6.0	6.0	1.8	1.17	0.8	0.54
140	Ash	2.92	0.31	4.60	0.47	0.32	52	129	26	45	49	6.2	6.1	3.0	1.43	0.9	0.49
280	Ash	2.78	0.33	4.36	0.47	0.34	47	117	24	38	52	6.1	6.1	3.3	1.51	1.0	0.65
Significance		NS	**	**	NS	NS	*	*	NS	**	**	**	*	-	NS	NS	NS
BLSD (0.05)		-	0.02	0.40	-	-	11	16	-	5	7	0.8	0.6	-	-	-	-
Contrasts																	
Ctrl vs Rest		NS	**	**	NS	*	**	**	NS	NS	*	**	*	-	NS	NS	NS
Fert vs Ash		NS	**	**	NS	NS	NS	NS	NS	**	**	**	NS	-	NS	NS	**
Linear Fert.		NS	**	**	NS	NS	NS	NS	NS	NS	**	**	**	-	*	NS	NS
Quad Fert.		NS	NS	NS	NS	*	**	**	NS	NS	*	**	NS	-	NS	NS	NS
Linear Ash		NS	**	**	NS	NS	**	**	NS	**	NS	NS	NS	-	NS	NS	NS
Quad Ash		NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	-	NS	NS	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 7. Effect of sludge ash and phosphate fertilizer on the elemental composition of ear leaf sampled during initial silking.

Treatment	P Source	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
lb. P_2O_5/A		%					ppm										
Control	-	3.24	0.30	2.60	0.77	0.44	42	337	48	81	27	10.1	4.9	4.6	1.7	1.0	0.44
70	Fert.	3.22	0.33	2.67	0.83	0.43	38	309	52	86	23	8.4	5.2	4.6	1.7	1.0	0.47
140	Fert.	3.15	0.35	2.74	0.87	0.44	40	314	51	95	20	6.7	5.2	4.9	1.7	1.1	0.51
280	Fert.	3.19	0.48	2.61	0.97	0.48	39	319	55	98	19	5.8	5.7	4.9	1.7	1.7	0.53
70	Ash	3.09	0.31	2.62	0.81	0.42	38	299	47	84	32	9.3	4.8	4.5	1.6	1.0	0.47
140	Ash	3.33	0.34	2.45	0.94	0.48	39	324	50	74	38	9.8	5.0	4.6	1.7	1.0	0.52
280	Ash	3.31	0.36	2.45	0.97	0.50	39	322	52	67	40	9.9	5.1	4.5	1.6	1.0	0.61
Significance		**	**	*	**	**	NS	NS	NS	*	**	**	NS	NS	NS	NS	*
BLSD (0.05)		0.13	0.02	0.23	0.06	0.05	-	-	-	20	4	0.7	-	-	-	-	0.1
Contrasts																	
Ctrl vs Rest		NS	**	NS	**	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	*
Fert. vs Ash		NS	**	**	NS	NS	NS	NS	NS	**	**	**	*	NS	NS	NS	NS
Linear Fert.		NS	**	NS	**	*	NS	NS	NS	*	**	**	*	NS	NS	*	*
Quad Fert.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS
Linear Ash		*	**	NS	**	**	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	**
Quad Ash		NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 8. Effect of sludge ash and phosphate fertilizer on elemental composition of stover at harvest.

Treatment	P Source	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
lb. P_2O_5/A		%					ppm										
Control	-	1.72	0.16	2.45	0.39	0.30	45	127	29	47	29	6.5	6.3	1.9	0.8	0.7	0.28
70	Fert.	1.52	0.16	2.33	0.36	0.24	45	118	24	41	17	4.2	5.4	<1.3	0.7	1.1	0.20
140	Fert.	1.62	0.20	2.31	0.42	0.27	40	122	27	47	15	3.4	5.7	<1.5	0.7	0.6	0.23
280	Fert.	1.61	0.30	2.22	0.46	0.28	44	122	30	50	12	2.6	6.0	1.5	0.7	0.6	0.27
70	Ash	1.60	0.17	2.30	0.39	0.27	46	124	31	42	27	6.0	6.0	<2.0	0.8	0.7	0.30
140	Ash	1.57	0.19	2.41	0.43	0.28	45	121	32	37	33	5.8	6.1	2.0	0.9	0.7	0.36
280	Ash	1.55	0.20	2.39	0.41	0.26	48	117	25	31	31	5.1	5.5	<1.5	0.7	0.6	0.43
Significance		*	**	NS	**	NS	NS	NS	NS	**	**	**	**	-	NS	NS	NS
BLSD (0.05)		0.1	0.23	-	-	-	-	-	-	6	5	0.6	0.5	-	-	-	-
Contrasts																	
Ctrl vs Rest		**	**	NS	NS	*	NS	NS	NS	*	**	**	**	-	NS	NS	NS
Fert vs Ash		NS	**	NS	NS	NS	NS	NS	NS	**	**	**	NS	-	NS	NS	**
Linear Fert.		NS	**	*	**	NS	NS	NS	NS	NS	**	**	NS	-	NS	NS	NS
Quad Fert.		*	**	NS	NS	*	NS	NS	NS	NS	**	**	**	-	NS	NS	NS
Linear Ash		**	**	NS	NS	NS	NS	NS	NS	**	NS	**	**	-	NS	NS	**
Quad Ash		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	NS	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 9. Effect of sludge ash and phosphate fertilizer on the elemental composition of cob at harvest.

Treatment	P Source	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
lb. P_2O_5/A		%			ppm												
Control	-	0.81	0.11	0.79	310	663	<2.9	14	12	10	37	5.1	3.1	<0.84	0.40	0.42	<0.10
70	Fert.	0.71	0.10	0.67	264	498	<2.6	13	12	8	26	3.6	2.5	<0.84	0.42	0.41	<0.11
140	Fert.	0.77	0.11	0.68	283	507	<2.0	14	9	7	19	2.5	2.5	<0.84	0.38	0.43	<0.08
280	Fert.	0.73	0.13	0.68	300	483	<2.2	15	11	7	15	1.7	2.3	<0.84	0.42	0.50	<0.14
70	Ash	0.80	0.12	0.75	329	603	<2.2	14	12	10	38	4.8	2.9	<0.84	0.46	0.48	<0.10
140	Ash	0.77	0.11	0.77	303	540	<2.2	14	11	8	37	4.3	2.7	<0.84	0.42	0.45	<0.13
280	Ash	0.76	0.13	0.77	322	558	<2.4	14	15	7	43	4.1	2.8	<0.84	0.49	0.48	<0.20
Significance		*	**	NS	NS	**	NS	NS	NS	**	**	**	*	-	NS	NS	-
BLSD (0.05)		0.08	0.02	-	-	93	-	-	-	2.2	6	0.4	0.5	-	-	-	-
Contrasts																	
Ctrl vs Rest		*	NS	NS	NS	**	-	NS	NS	**	**	**	**	-	NS	NS	-
Fert. vs Ash		*	NS	**	**	**	-	NS	NS	NS	**	**	**	-	NS	NS	-
Linear Fert.		NS	**	NS	NS	**	-	NS	NS	**	**	**	**	-	NS	NS	-
Quad Fert.		NS	*	NS	NS	**	-	NS	NS	*	**	**	NS	-	NS	NS	-
Linear Ash		NS	*	NS	NS	*	-	NS	NS	**	*	**	NS	-	NS	NS	-
Quad Ash		NS	NS	NS	NS	NS	-	NS	NS	NS	NS	NS	NS	-	NS	NS	-

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 10. Effect of sludge ash and phosphate fertilizer on the elemental composition of kernel at harvest.

Treatment	Source	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
lb. P_2O_5/A		%			ppm												
Control	-	2.54	0.47	1.43	292	2221	5.3	34	12	20	38	6.1	5.0	<1.0	0.7	0.50	0.10
70	Fert.	2.38	0.49	1.37	247	2157	5.1	33	9	18	35	4.8	4.4	1.0	0.7	0.54	0.11
140	Fert.	2.37	0.53	1.42	261	2309	4.9	35	9	17	35	3.7	4.6	<1.1	0.6	1.06	0.09
280	Fert.	2.33	0.59	1.42	243	2373	4.6	36	7	18	35	2.2	4.1	1.2	0.6	0.57	0.11
70	Ash	2.42	0.53	1.46	279	2314	4.7	37	9	19	40	5.5	4.9	<0.9	0.7	0.85	0.18
140	Ash	2.34	0.54	1.42	250	2338	4.9	38	8	17	41	4.7	4.4	<1.1	0.7	0.55	0.11
280	Ash	2.40	0.62	1.49	277	2582	4.5	40	10	16	46	4.9	4.6	<1.0	0.7	0.55	0.15
Significance		NS	**	NS	**	*	NS	*	NS	*	**	**	**	-	NS	NS	NS
BLSD (0.05)		-	0.45	-	31	280	-	5.5	-	2.7	2.1	0.7	0.4	-	-	-	-
Contrasts																	
Ctrl vs Rest		**	**	NS	**	NS	NS	NS	NS	**	NS	**	**	-	NS	NS	NS
Fert. vs Ash		NS	NS	NS	*	NS	NS	**	NS	NS	**	**	*	-	NS	NS	NS
Linear Fert.		**	**	NS	**	NS	NS	NS	NS	NS	**	**	NS	-	NS	NS	NS
Quad Fert.		NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	-	NS	NS	NS
Linear Ash		NS	**	NS	NS	**	NS	*	NS	**	**	**	**	-	NS	NS	NS
Quad Ash		*	NS	NS	*	NS	NS	NS	NS	NS	NS	*	*	-	NS	NS	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 11. Effect of sludge ash and phosphate fertilizer on the elemental composition of husks at harvest.

Treatment	Source	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
lb. P_2O_5/A		%			ppm												
Control	-	0.74	0.09	0.51	737	1161	14	19	16	16	24	2.2	3.4	<1.1	<0.4	0.38	0.10
70	Fert.	0.88	0.12	0.62	836	1271	14	21	15	16	21	2.4	3.8	<1.2	<0.4	0.40	0.13
140	Fert.	0.87	0.13	0.64	831	1219	14	22	14	16	17	1.9	3.8	<1.2	0.4	0.43	0.13
280	Fert.	0.84	0.16	0.56	819	1207	12	20	11	16	14	1.0	3.4	<1.2	<0.4	0.37	0.14
70	Ash	0.72	0.10	0.49	734	1138	13	18	13	14	23	1.7	3.3	<1.2	<0.3	0.36	0.10
140	Ash	0.85	0.13	0.63	915	1273	15	23	13	14	30	2.6	3.8	<1.1	<0.4	0.41	0.21
280	Ash	0.74	0.12	0.52	885	1219	13	19	14	12	28	1.6	3.6	<1.1	<0.4	0.42	0.17
Significance		NS	**	NS	*	NS	NS	NS	NS	*	**	**	NS	-	-	NS	**
BLSD (0.05)		-	0.02	-	125	-	-	-	-	3.3	3	0.8	-	-	-	-	0.05
Contrasts																	
Ctrl vs Rest		NS	**	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	-	-	NS	*
Fert. vs Ash		*	**	NS	NS	NS	NS	NS	NS	*	**	NS	NS	-	-	NS	NS
Linear Fert.		NS	**	NS	NS	NS	NS	NS	*	NS	**	**	NS	-	-	NS	NS
Quad Fert.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	-	-	*	NS
Linear Ash		NS	**	NS	**	NS	NS	NS	NS	**	**	NS	**	-	-	NS	**
Quad Ash		NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-	-	NS	*

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

UREA APPLICATION STRATEGIES ON CORN GRAIN YIELDS AND STALK NITRATE-N CONCENTRATIONS

M.A. Schmitt[1/]

ABSTRACT: Urea applications are attractive to corn producers due to their application accuracy, speed and safety. However, volatilization concerns are present when topdress application are made and not incorporated. The urease inhibitor NBPT (N-(n-butyl) thiophosphoric triamide) was evaluated, along with nitrogen rates, times of application and methods of application, on grain yields and postharvest stalk nitrate-N concentrations of corn at two sites in east-central Minnesota. At one of the sites, there was not a grain yield response to N fertilizer, thus there was no effect of the inhibitor. At the N responsive site, the inhibitor was successful in increasing yields compared to the broadcast treatments without an inhibitor when there were conditions present for urea volatilization after application. Nitrate-N concentrations were measured in stalk samples as an indicator of N excess or deficiency during the season. At both sites, relative nitrate-N concentrations were significantly affected by the urea treatments, even when there was not a yield response.

Introduction

The use of urea as a primary N fertilizer product is increasing due to its ease of handling, cost competitiveness and its application options. The primary agronomic liability of urea is its volatilization potential. While incorporation with tillage and injection application systems minimize this volitilization potential, many farmers would like to reduce the necessity of this tillage operation. A urease inhibitor (N-(n-butyl) thiophosphoric triamide) also minimizes volatilization potential by chemically inhibiting the bacteria necessary for the volatilization process to occur. While the inhibitor has been shown to work well in the laboratory, more research is needed from field studies to evaluate its niche in nitrogen (N) management and application strategies.

The objective of this trial is to measure the effect of a urease inhibitor on corn grain yields when urea is the N source. This will be accomplished by evaluating several rates of N to determine overall N response at each site and with different application methods.

Material and Methods

Experimental sites were established on two farmer-cooperator farms in 1990. One was on a Waukegon/Dakota loam soil in Dakota county. Soybeans had been the previous crop and the field has a history of conservation tillage. The second site was in Isanti county on a Alstad fine sandy loam soil. Continuous corn with conservation tillage practices were part of the field history.

All crop management decisions and operations--with the exception of N applications--were conducted by the farmer cooperators according to their individual cropping system programs. Excellent corn stands were obtained and the pest management programs at both sites was excellent.

The N management treatments consisted of a combination of N rates, application methods and inclusion of the urease inhibitor NBPT. Two times of N application were used, an early sidedress application and a late sidedress application. At the early time of application, urea rates of 50, 100 and 150 lbs N/acre were applied as broadcast applications with and without the inclusion of the urease inhibitor NBPT. The second date of application included these treatments and also included urea placed in subsurface bands at 50, 100 and 150 lbs N/acre. There was also a control plot included in this randomized complete block design.

Grain yields and moisture contents were measured after physiological maturity had been attained. Within each plot, two-20 ft sections of row were hand-harvested. At the same time, basal stalk sections, were taken from 12 plants within the harvested area to be analyzed for nitrate-N concentrations. These samples were collected by removing the section of stalk that was between 6 and 14 inches above the soil surface.

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Results and Discussion

The Isanti county site produced yields that were quite high and contained a great deal of variability both betweeen and among treatments (Table 1). It was also discovered that this site had a high residual nitrate-N amount in the third foot of the soil profile. Therefore, the statistical analysis of the yield data from this site concluded that there was no significant treatment effects and the resulting evaluation of individual main effects, such as urease inhibitors, is unwarranted.

The postharvest stalk nitrate evaluation did indicate statistically significant differences among treatments and between levels of main effects (Table 1). There was an linear response in stalk nitrates at the four N application rates even though the yields were not significantly different. Similarly, the stalk nitrate concentrations were highly correlated to the main effect yields for the urease inhibitor and the time of application.

The Dakota county site soil was coarser-textured than was the Isanti site and had very little residual nitrate-N in its profile. There was a statistically significant response of grain yield to N rates up to the highest N rate applied, 150 lbs N/acre (Table 1). Based on the site location, previous crop and yield history, the optimum N fertilizer rate according to University of Minnesota recommendations would be approximately 150 lbs N/acre.

Two application times were evaluated in this study since many corn producers could conceivably broadcast urea right after emergence or later as a sidedress treatment if volatilization were not a concern. The early urea application at Dakota site was rained upon within 24 hours after the urea was applied and, in the month of June, rainfall amounts were well above average. Thus, the early applications resulted in lower yields than the later applications, most likely due to leaching events.

The urease inhibitor did not have an effect at the early application date due to the beforementioned rainfall event after treatment application. However, the inhibitor did have a positive effect on grain yields with the later urea applications when comparing the broadcast treatments (Table 1). Injection applications of urea, although not an option for most farmers, were still the highest yielding treatments.

Stalk nitrate concentrations at maturity were highly correlated to grain yield and were a function of the urea treatments at the Dakota county site (Table 1). In the overall calibration and correlation of of the stalk nitrate concentrations, there is a distinct linear-plateau response curve at both sites (Figures 1 and 2). This is in good agreement with recent results from Iowa State University (Binford, et al., Agron. J. 82:124-129). Although the Isanti site has more variability in its graph, the variability associated with the yields and the subsurface residual nitrate amounts must be considered. Overall, the stalk nitrate concentrations provided sound relative indication of excess N applications.

Table 1. Corn grain yields and postharvest stalk nitrate-N concentrations as a function of urea application management strategy, Dakota and Isanti counties, Minnesota, 1990.

N Rate	Application Date[1]	Application Method[2]	Chemical	Grain Yield Dakota	Grain Yield Isanti	Stalk Nitrate-N Dakota	Stalk Nitrate-N Isanti
lb N/A				---- bu/A ---		----- %N -----	
0	-	-	-	91.2	148.1	0.0045	0.0286
50	Early	Brd.	-	168.1	161.7	0.0066	0.0239
50	Early	Brd.	NBPT	159.1	167.6	0.0071	0.0333
100	Early	Brd.	-	172.2	146.9	0.0057	0.1314
100	Early	Brd.	NBPT	179.0	171.6	0.1479	0.2961
150	Early	Brd.	-	184.8	167.2	0.0371	0.4290
150	Early	Brd.	NBPT	197.1	168.0	0.1784	0.5409
50	Late	Brd.	-	137.0	145.0	0.0056	0.0424
50	Late	Brd.	NBPT	176.1	124.6	0.0075	0.0367
50	Late	Inj.	-	168.1	147.2	0.0067	0.0541
100	Late	Brd.	-	185.0	154.7	0.1350	0.0250
100	Late	Brd.	NBPT	180.8	150.2	0.0987	0.1676
100	Late	Inj.	-	197.7	160.8	0.0174	0.1193
150	Late	Brd.	-	199.5	140.3	0.2457	0.1177
150	Late	Brd.	NBPT	208.9	153.1	0.3194	0.3086
150	Late	Inj.	-	210.3	162.1	0.3845	0.2116
Pr.>F				0.0001	0.1200	0.0026	0.0001
FLSD (0.10)				23.0	-	0.1341	0.1323
Main Effects							
N rate:			0	91.2	148.1	0.0045	0.0286
			50	156.8	149.8	0.0067	0.0341
			100	182.5	155.9	0.0968	0.1279
			150	197.6	157.1	0.1951	0.2369
N application time:			Early	176.7	163.8	0.0638	0.2425
			Late	181.2	144.7	0.1353	0.1163
Urease Inhibitor			None	174.5	152.6	0.0726	0.1283
			NBPT	183.5	155.9	0.1265	0.2305

[1]-Early application dates were May 22 at both sites and late application dates were June 25 at Dakota and July 2 at Isanti counties.

[2]-Application methods consisted of broadcast (brd.) and injected (inj.) treatments.

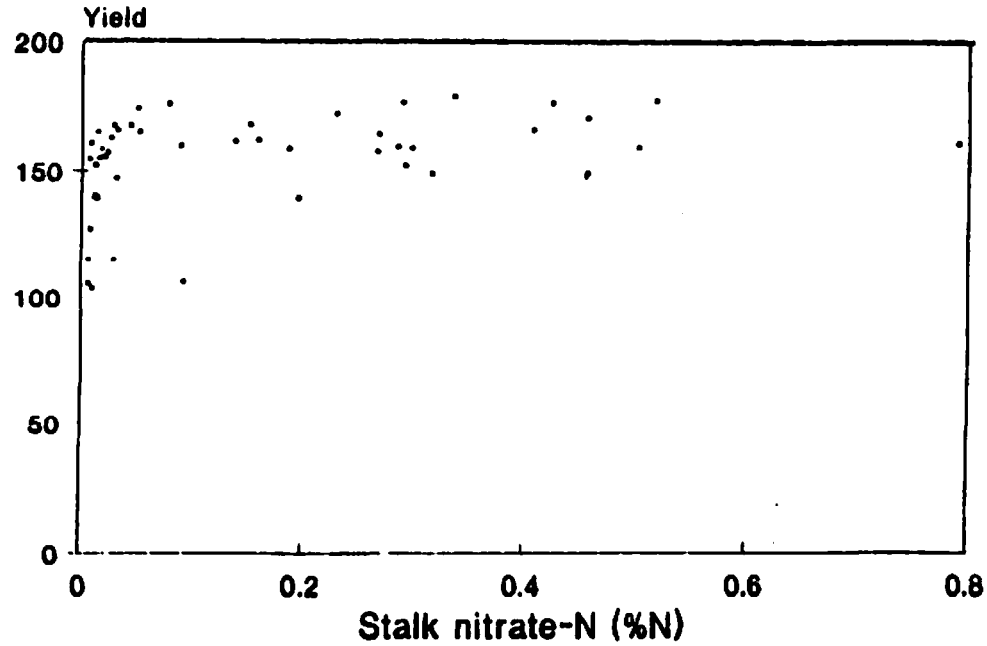

Figure 1. Grain yields regressed as a function of basal stalk nitrate-N concentrations, Isanti County, 1990.

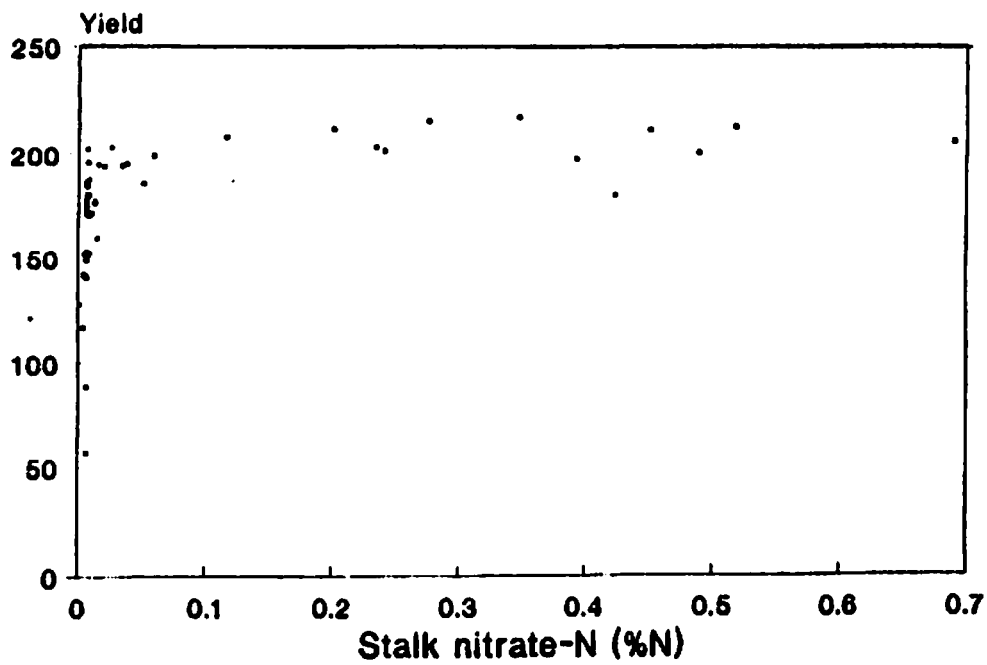

Figure 2. Grain yields regressed as a function of basal stalk nitrate-N concentrations, Dakota County, 1990.

CALIBRATION AND CORRELATION OF SOIL N TESTS FOR CORN'S N RECOMMENDATIONS[1]

M.A. Schmitt, G.W. Randall, G.W. Rehm, G.L. Malzer[2]

Throughout the academic community there is a pressing need to develop a system of analytical testing procedures with correct interpretation that can be used to provide more precise, efficient, and environmentally sound N rate recommendations for corn. Because there is presently not a good predictive tool to assess availability of soil N, application rates of N are often greater than needed by the plant. The potential impacts of this excess N on groundwater quality have created pressure from the farming and non-farming public for refined N recommendations.

Objectives

The primary objective of this project is to develop an N soil test that will enable farmers to apply optimum rates of N for corn under a wide variety of soil, crop, and climatic conditions. Specific objectives include:

1. Evaluate different tests or combination of tests for determining potentially available N before and during the growing season for use in predicting fertilizer N requirements for corn.

2. Determine the optimum time or times that soil samples should be collected to enable an accurate prediction of N needed by corn.

3. Determine the optimum depth of soil sampling that relates best with potentially available soil N.

Methods and Materials

Twenty-nine experimental sites were established in conjunction with participating organizations in 1989 and 1990. The sites were located primarily on farmer-cooperator fields in south-central, southeastern, and east-central Minnesota. Soils in these are derived from glacial till, loess, and glacial outwash, respectively. All sites had well-documented fertilization and manure records and had a range of previous crops.

Two sets of treatments were used at these locations. One set had a series of six preplant fertilizer N rates, four sidedress fertilizer N rates, and three split N rates. The second treatment scheme had four sidedress N rates. Both sets of treatments included a control treatment. The sidedress and split treatments were applied in mid to late June when the corn was in the V5 stage of growth.

Soil samples were collected four times each year: 1) preplant, approximately two weeks before planting, 2) about three weeks after planting, when the corn was in the V2 stage of growth, 3) about 5 weeks after planting, at the V5 growth stage, and 4) after harvest. Only control plots and plots receiving preplant N were sampled before harvest. All plots were sampled after harvest. Soil samples were collected in 1-foot increments to a depth of five feet for the preplant and postharvest samplings and to a depth of three feet for the in-season samplings. The 5-foot samples were collected from two subsamples taken with a hydraulic probe while the in-season samples were collected using hand probes and contained at least six cores per sample.

All soil samples were analyzed for ammonium-N and nitrate-N using a Wescan Autoanalyzer. All samples, except those taken after harvest, were also analyzed for two forms of mineralizable N. The difference in these two methods is the extraction procedure. One method used a phosphate-borate buffer extractant; the other method used a hot potassium chloride extractant. Preplant soil samples were also analyzed for total N and total C for soil characterization purposes.

Stover and grain yields were measured from each plot after physiological maturity. Total Kjeldahl N was measured in the stover and grain, and nitrate-N was measured in the basal stalk section of the corn plants after maturity. Rainfall and temperature records were recorded until the V5 growth stage at each site or taken at a nearby weather reporting station.

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[1] This project has received direct support from Farmland Industries, Tennessee Valley Authority, Southern Experiment Station, and the Garvin Brook Watershed Project.

[2] Schmitt and Rehm are Extension Soil Fertility specialists, St. Paul, Randall is Soil Scientist, Southern Experiment Station, Waseca, and Malzer is Soil Scientist, St. Paul, all with the University of Minnesota.

A randomized complete-block design with four replications was used at all sites. Plot size ranged from 10 to 15 feet wide (all with 30" rows) by 40 to 60 feet long. While data from each site will be subject to descriptive statistical analysis that will assist in interpretation, the pooling of the data across locations and the resulting regressions and analyses of variance will be paramount.

Results and Discussion

Grain yields

Grain yield response to N rates were lower than expected in 1989, with 7 of the 14 locations not responding to additional fertilizer N (Table 1). None of these sites had received manure applications in the year previous to these trials, and since alfalfa was not a previous crop, all of these sites would have had N fertilizer recommended by University of Minnesota guidelines. Only one of the sites not responding to fertilizer N had soybeans as the previous crop, while three of the sites with soybeans as a previous crop had a fertilizer N response up to 60 lb N/acre. This may be important since 1988 was a drought year and no fertilizer N would have been applied to these soybean fields. Therefore, residual N would be of minor significance.

In 1990, four sites did not respond to fertilizer N, although one of these sites had alfalfa as a previous crop (Table 2). Six of the 15 sites had an optimum N response of 60 lb N/acre. Rye, soybeans, and corn were all previous crops for these 60-lb N rate responses. For those five sites that responded to greater than 60 lbs N/acre, the previous crops included oats, soybeans, and corn (3).

Preplant, sidedress, and split N applications were compared at seven sites over the two years,. There were no distinct yield advantages associated with specific application methods in this study. At three of the seven site-years, there was no response to N, so no application method differences are possible.

Preplant N effects on soil N tests

Seven environments that received preplant N applications had nitrate-N and ammonium-N measured on each of the plots when the corn was in the V2 and V5 stage of growth. These measurements are indicative of the recovery of the added N as inorganic N fractions.

Already at the V2 stage of growth, nitrate-N concentrations had increased linearly as the preplant N applications increased at all seven site-years (Tables 3 and 4). Although the majority of the nitrate-N increase is in the top foot of soil, in all cases, the nitrate-N concentrations roughly doubled between the 0 and 180 lbs N/acre rate in the 1-2 foot sample, indicating some downward nitrate movement in this relatively short period of time between application and sampling.

Ammonium-N concentrations also increased significantly as the N application rate increased at the V2 stage of corn growth at all environments except at the Isanti location in both years. Except for the Olmsted site in 1989, the ammonium-N increases occurred primarily in the top foot of soil.

Nitrate-N concentrations at the V5 stage of corn growth were still a function of the preplant N application rate in both the 0-1' and 1-2' samples (Tables 3 and 4). The magnitude of these concentrations were greater than at the V2 sampling stages. This would be expected simply due to nitrification of the urea fertilizer. This is somewhat evident in the decrease in ammonium-N concentrations from the V2 to V5 sampling times and the proportional increase in nitrate-N concentrations. Very little effect of preplant N on ammonium-N concentrations was noticed with any of the V5 samples.

Soil N concentrations in control plots

In plots that received no preplant N additions, the change in N test levels is indicative of the N transformations occurring in each particular soil. Since N processes are dependent on inherent soil properties, the sites are categorized by the soil's parent material.

At the sites where the soil is derived from glacial outwash, there was no distinct pattern regarding the effect of sampling time on soil nitrate-N concentrations (Tables 5 and 6). The nitrate-N is primarily in the top foot of soil except at the Isanti-1, 1989 and Isanti, 1990, locations where a significant amount of nitrate is measured deeper. Ammonium-N concentrations increase at these sites as the sampling time proceeded later into the growing season. The amount of N measured using a phosphate-borate buffer extraction, which includes ammonium-N, also increased slightly with the later sampling dates. The majority of this mineralizable N was in the top foot of soil.
With loess parent material, nitrate-N concentrations exhibited no patterns of increase or decrease with time of sampling. There was a wide range of nitrate concentrations within each site based on sampling

time and/or depth as well as between environments. Ammonium-N concentrations were generally greatest in the 0-1′ sample and did not show a relationship between quantity and time of sampling. The N measured with the phosphate-borate extractant ranged greatly depending on site and year. There was consistency in this N value between sampling times at all sites in 1990 as well as some of the 1989 sites.

Sampling time had little effect on the nitrate-N concentrations for those sites derived from glacial till. While most of the sites had the majority of the nitrate-N in the top 1′, some of the sites had appreciably more nitrate-N in the 1-2′ and 2-3′ samples. With just a couple of exceptions, the combined ammonium-N and mineralizable N concentrations were consistent among sampling times and, in 1989, were consistent among all of the till locations.

The overall effect of sampling time and sampling depth is summarized for nitrate-N concentrations in Table 7. Within one particular sampling time, the correlations between the depths had strong positive correlations. Thus, if there is a lot of nitrate-N in the 0-1′ sample compared to other sites, there is relatively more nitrate-N in the lower depths′ samples. Contrarily, when the time of sample changes, regardless of whether the depth is constant or not, there is a poor correlation in the numbers. Hence, knowing what is happening at one sampling date was not very useful in predicting what will happen at another sampling date. The correlation results were consistent in both years of the project.

Summary

Grain yield responses to fertilizer N have been relatively low for the first two years of this project. Some of these lower than predicted responses can be attributed to some relatively high soil N concentrations. However, there has not been good consistency between soil N concentrations and sampling date and N form. Regression equations (not reported here) have been very inconsistent in fitting the data between sites and years. Until more data can be collected to develop better prediction equations, soil N tests should be used only to identify excess N scenarios.

Table 1. Corn grain yields as function of N application rate and timing, 1989.

N Treatment[1]	Waseca-1 Corn	Olmsted Soybeans	Winona-1 Corn	Isanti-1 Corn	Waseca-2 Soybeans	Waseca-3 Soybeans	Steele Corn	Houston Corn	Winona-2 Corn	Isanti-2 Soybeans	Chisago Corn	Dakota Soybeans	Waseca-5 Oats	Waseca-4 Corn
lb/A	bu/acre[2]													
PP 0	107.8e	162.7e	185.7	131.6	146.3b	137.6b	178.4	175.4	133.1c	63.7b	98.7bc	150.5	105.6	182.1
30	148.1cd	176.4d	174.5	137.3								141.8	111.4	
60	157.5abc	178.3cd	178.2	141.2								150.8	115.2	
90	160.2abc	187.8abcd	193.6	142.8								151.2	112.8	
120	166.7ab	185.7abcd	180.0	124.4								144.9	110.7	
150	166.1ab	189.5abc	182.4	151.1								159.6	110.4	
180	167.1a	192.3a	177.9	140.2								161.0	113.0	
SD 60	145.1d	183.2abcd	178.6	153.0	166.3a	149.0a	181.9	177.7	143.5bc	88.5a	101.1bc			178.5
90	152.7cd	190.0ab	182.6	133.4	165.0a	152.6a	190.6	175.7	158.1ab	90.4a	80.2c			178.1
120	154.6bcd	187.8abcd	193.3	136.0	166.9a	154.7a	185.1	176.7	168.8a	95.4a	110.0ab			168.9
150	160.4abc	184.2abcd	173.0	152.4	167.1a	150.0a	171.4	175.8	156.4ab	90.9a	123.8a			173.2
60+30	157.7abc	179.0bcd	185.4	127.4										
60+60	158.2abc	179.0bcd	178.5	123.6										
60+90	160.3abc	193.2a	186.1	128.2										
Pr>F	0.000	0.008	0.605	0.114	0.025	0.071	0.278	0.996	0.072	0.006	0.033	0.417	0.897	0.435
LSD(.10)	12.5	11.7			11.2	10.0			15.4	12.7	21.1			

[1] Nitrogen applications were made a preplant (PP), sidedress (SD) of split (preplant + sidedress) applications.

[2] Grain yields at each location are statistically similar if the same letter proceeds different treatment yields.

Table 2. Corn grain yields as a function of N application rate and timing, 1990.

N Treatment[1]	Waseca-1 Corn	Olmsted Corn	Isanti Corn	Waseca-2 Alfalfa	Waseca-3 Soybeans	Watonwan Corn	Goodhue Oats	Wabasha-1 Peas	Wabasha-2 Corn	Winona-1 Corn	Winona-2 Corn	Dakota Soybeans	Sherburne Rye	Chisago Soybean	Waseca-4 Corn
	Location and Previous Crop														
lb/A	bu/acre[2]														
PP 0	80.1h	88.5i	136.2	160.1	147.1b	106.2b	96.5c	140.0	166.6c	144.7	160.7b	107.1c	80.8b	41.2c	122.5b
30	108.0g	108.7h	131.8												
60	118.1gf	117.9gh	142.7												
90	134.9ed	138.6ef	174.1												
120	144.6abcd	153.7bcd	152.5												
150	149.0abc	161.8abc	132.4												
180	155.5a	170.0a	145.8												
SD 60	130.3ef	127.6fg	135.8	162.1	164.0a	151.2a	140.6b	151.4	174.2cba	151.6	171.6a	160.5b	114.9a	89.9b	156.6a
90	125.8ef	140.0def	152.8	171.9	170.7a	154.0a	160.5a	150.1	172.8cb	151.3	175.4a	183.9a	118.7a	96.7ba	158.4a
120	151.3ab	150.4cde	146.4	159.5	166.3a	149.9a	151.7ba	144.1	175.5ba	153.6	170.9a	192.1a	133.1a	102.2ba	156.1a
150	139.3bcde	153.0bcd	141.1	162.9	164.2a	151.2a	167.3a	150.4	182.3a	152.8	160.8b	197.0a	137.4a	106.9a	162.7a
60+30	136.0cde	141.1def	142.9												
60+60	144.7abcd	155.9bc	145.3												
60+90	148.6abcd	164.9ab	147.0												
Pr>F	0.000	0.000	0.768	0.354	0.104	0.000	0.000	0.356	0.063	0.268	0.049	0.000	0.006	0.000	0.013
LSD(.10)	14.0	14.0			14.5	10.6	16.3		8.2		9.0	18.4	22.7	13.7	18.3

[1] Nitrogen applications were made a preplant (PP), sidedress (SD) of split (preplant + sidedress) applications.

[2] Grain yields at each location are statistically similar if the same letter proceeds different treatment yields.

Table 3. Soil inorganic N amounts as affected by rate of preplant N application, time, and depth of sampling, 1989.

Site	Sampling Time	N Form	Depth	Preplant N - lb/A 0	30	60	90	120	150	180
			ft	lb N/acre						
Waseca-1	V_2	NO_3-N	0-1	33.8	72.0	55.9	48.7	93.8	85.2	85.6
			1-2	32.7	41.2	38.9	38.3	49.7	57.2	62.8
	V_2	NH_4-N	0-1	26.9	30.7	33.5	36.7	56.6	59.9	61.6
			1-2	11.1	10.6	15.6	15.1	21.4	24.7	19.6
	V_5	NO_3-N	0-1	27.8	53.0	60.0	63.5	80.1	124.1	176.7
			1-2	27.8	30.5	35.6	20.4	49.9	42.6	46.4
	V_5	NH_4-N	0-1	18.8	25.2	26.7	26.0	27.4	36.6	34.1
			1-2	8.4	6.6	7.7	6.6	9.6	9.9	8.6
Olmsted	V_2	NO_3-N	0-1	44.0	70.1	57.3	78.4	85.1	154.3	220.6
			1-2	24.1	28.0	28.0	37.5	30.3	34.1	45.4
	V_2	NH_4-N	0-1	30.4	33.4	33.6	41.8	59.3	67.4	99.9
			1-2	20.4	23.5	25.2	28.1	30.5	38.2	48.2
	V_5	NO_3-N	0-1	61.2	89.3	109.0	129.6	104.0	148.9	176.0
			1-2	37.7	61.1	69.2	84.8	126.8	103.1	110.9
	V_5	NH_4-N	0-1	35.2	34.7	39.4	43.3	39.4	47.4	45.8
			1-2	25.4	23.5	25.9	39.1	40.1	35.9	42.8
Winona-1	V_2	NO_3-N	0-1	83.3	91.5	96.4	150.6	183.8	197.5	190.9
			1-2	68.9	73.2	65.8	86.2	99.4	92.7	126.7
	V_2	NH_4-N	0-1	28.8	59.8	29.1	26.8	30.2	33.6	57.8
			1-2	20.9	20.6	20.3	17.8	20.3	19.5	24.6
	V_5	NO_3-N	0-1	53.7	79.4	94.3	95.8	164.5	164.9	152.6
			1-2	52.0	95.7	67.4	64.3	69.8	66.2	66.6
	V_5	NH_4-N	0-1	83.0	66.8	72.7	75.7	81.2	73.1	79.6
			1-2	53.8	40.1	40.2	43.8	51.6	42.5	45.5
Isanti-1	V_2	NO_3-N	0-1	60.3	69.2	161.1	106.5	136.8	152.1	165.5
			1-2	66.9	83.1	132.7	100.6	84.7	47.2	128.2
	V_2	NH_4-N	0-1	27.1	15.5	30.5	10.1	16.2	23.6	14.4
			1-2	10.1	10.2	9.1	8.4	6.7	7.9	9.3
	V_5	NO_3-N	0-1	79.3	99.2	130.1	84.0	42.0	121.4	152.5
			1-2	95.7	47.4	65.5	69.2	49.6	67.4	80.6
	V_5	NH_4-N	0-1	54.6	58.9	74.0	83.3	45.0	61.2	58.7
			1-2	48.3	44.9	48.7	44.2	45.1	48.5	35.1

Table 4. Soil inorganic N amounts as affected by rate of preplant N application, time, and depth of sampling, 1990.

Site	Sampling Time	N Form	Depth	Preplant N - lb/A 0	30	60	90	120	150	180
			ft	lb N/acre						
Waseca-1	V_2	NO_3-N	0-1	27.5	50.4	64.4	67.6	132.1	124.6	151.6
			1-2	22.0	28.7	32.4	35.6	58.7	58.6	51.4
	V_2	NH_4-N	0-1	18.5	24.2	28.7	28.0	36.0	42.1	37.8
			1-2	5.5	5.8	5.8	6.3	6.9	6.1	6.6
	V_5	NO_3-N	0-1	17.1	21.2	28.1	44.2	42.2	57.7	52.7
			1-2	14.3	27.6	28.3	39.2	35.6	57.8	52.6
	V_5	NH_4-N	0-1	21.2	23.6	26.3	28.1	26.7	25.5	24.4
			1-2	4.5	5.6	5.3	5.4	4.9	4.2	5.8
Olmsted	V_2	NO_3-N	0-1	21.6	30.4	35.2	60.1	85.8	114.6	142.3
			1-2	17.6	17.1	16.6	30.4	32.6	43.0	43.6
	V_2	NH_4-N	0-1	37.8	33.5	34.0	35.9	34.0	41.1	48.2
			1-2	24.6	17.7	19.9	23.8	17.3	22.9	21.1
	V_5	NO_3-N	0-1	30.2	25.9	27.6	48.6	62.1	127.2	137.6
			1-2	17.6	17.9	19.3	29.4	29.3	55.1	50.4
	V_5	NH_4-N	0-1	28.4	29.4	28.4	30.7	27.6	31.4	31.0
			1-2	21.7	17.5	17.7	19.0	17.3	23.7	20.6
Isanti	V_2	NO_3-N	0-1	34.5	47.0	60.8	97.8	81.1	88.5	84.8
			1-2	41.2	32.1	42.4	46.9	47.5	58.5	59.0
	V_2	NH_4-N	0-1	9.3	3.8	9.0	4.0	8.9	9.0	11.2
			1-2	6.9	3.6	8.6	4.4	7.5	6.2	15.0
	V_5	NO_3-N	0-1	34.7	43.1	57.8	42.6	49.6	52.8	53.3
			1-2	31.2	35.8	52.5	33.7	33.6	35.3	38.8
	V_5	NH_4-N	0-1	19.6	15.8	15.8	19.6	25.2	15.2	32.4
			1-2	22.8	13.8	22.7	21.6	29.1	21.8	26.0

Table 5. Soil N concentrations as a function of sampling depth and time for all plots that received no preplant N, 1989.

Site[1]	Sampling Time[2]	NO_3-N 0-1′	NO_3-N 1-2′	NO_3-N 2-3′	NH_4-N 0-1′	NH_4-N 1-2′	NH_4-N 2-3′	Hydrolyzable N[3] 0-1′	Hydrolyzable N[3] 1-2′	Hydrolyzable N[3] 2-3′
		ppm N								
Outwash										
Isanti-1	Pre	8.1	19.1	2.6	0.8	1.1	1.1	22.2	6.9	5.2
	V_2	15.1	16.7	7.0	6.8	2.5	1.6	32.2	10.7	6.5
	V_5	19.8	23.9	7.3	13.7	12.1	8.6	41.8	17.7	14.0
Isanti-2	Pre	2.1	1.9	2.7	1.3	0.9	0.7	16.6	7.0	3.9
	V_2	2.5	1.5	1.4	11.5	6.5	6.0	32.4	17.4	15.4
	V_5	2.4	1.8	1.4	10.2	7.4	5.9	26.3	14.7	11.3
Chisago	Pre	2.3	4.5	2.8	1.1	1.6	2.6	24.3	6.2	6.3
	V_2	18.4	16.8	13.2	4.4	2.3	4.0	38.7	10.0	9.4
	V_5	10.9	11.8	10.4	12.5	7.2	6.2	48.3	23.0	16.7
Loess										
Olmsted	Pre	7.5	5.7	10.0	6.7	3.4	3.1	57.0	30.2	15.1
	V_2	11.0	6.0	5.3	7.6	5.1	4.4	64.4	35.4	20.3
	V_5	15.3	9.4	8.5	8.8	6.3	4.5	66.6	35.3	18.1
Winona-1	Pre	20.3	24.4	12.2	3.2	2.2	2.0	61.3	32.2	16.8
	V_2	20.8	17.2	9.4	7.2	5.2	4.8	62.3	33.8	18.3
	V_5	13.4	13.0	9.6	20.8	13.5	9.0	89.3	47.2	24.5
Houston	Pre	39.5	31.8	11.6	0.7	1.1	1.1	52.6	27.7	11.7
	V_2	1.4	10.6	7.6	13.2	15.9	7.5	86.9	41.3	21.2
	V_5	36.3	38.6	33.1	9.3	5.6	5.3	79.7	44.6	30.6
Winona-2	Pre	13.3	11.7	5.8	4.1	2.4	2.5	28.1	9.7	8.9
	V_2	19.4	16.3	10.4	6.7	4.5	4.8	43.0	19.3	15.0
	V_5	21.7	14.3	9.4	7.6	5.0	5.1	44.6	20.0	17.9
Dakota	Pre	6.7	10.2	5.6	14.4	11.6	8.4	73.6	48.0	26.1
	V_2	17.1	10.0	7.0	21.6	14.0	9.6	91.9	56.9	35.4
	V_5	7.9	7.0	5.7	10.0	8.0	6.4	72.0	42.4	22.2
Till										
Waseca-1	Pre	11.5	9.2	4.3	4.1	2.1	2.2	51.5	18.2	7.0
	V_2	8.5	8.2	5.1	6.7	2.8	3.8	66.1	28.9	14.9
	V_5	7.0	6.9	5.8	4.7	2.1	2.2	61.9	17.2	13.9
Waseca-2	Pre	8.5	6.0	5.1	3.6	1.3	2.0	37.3	8.4	5.7
	V_2	8.0	6.6	5.5	5.5	2.1	3.4	62.0	15.5	8.8
	V_5	10.9	6.6	5.9	5.6	2.0	2.9	63.1	17.4	15.5
Waseca-3	Pre	12.3	10.3	6.9	4.4	2.7	3.2	51.4	21.7	9.1
	V_2	9.1	6.2	5.7	9.0	4.2	3.3	67.5	28.6	15.7
	V_5	10.5	7.6	6.5	8.2	3.3	2.5	63.7	25.2	17.6
Steele	Pre	13.5	9.6	3.4	1.4	1.4	1.9	40.0	16.3	11.8
	V_2	14.5	13.2	8.3	6.2	4.5	4.5	53.6	27.6	18.6
	V_5	15.1	13.8	8.1	4.7	3.2	3.1	50.9	27.0	20.5
Waseca-4	Pre	19.6	18.8	21.3	7.3	2.5	2.1	51.2	15.4	6.5
	V_2	14.8	15.4	19.4	8.4	2.3	2.9	68.1	20.4	12.0
	V_5	13.4	13.2	16.7	6.6	2.2	2.4	65.8	24.1	15.8

1/ Sites are also categorized by soil's parent material.
2/ Sampling times were before planting (Pre) and at the morphological growth states of V2 and V5.
3/ Includes ammonium-N.

Table 6. Soil N concentrations as a function of sampling depth and time for all plots that received no preplant N, 1990.

Site[1]	Sampling Time[2]	NO_3-N 0-1'	NO_3-N 1-2'	NO_3-N 2-3'	NH_4-N 0-1'	NH_4-N 1-2'	NH_4-N 2-3'	Hydrolyzable N[3] 0-1'	Hydrolyzable N[3] 1-2'	Hydrolyzable N[3] 2-3'
		ppm N								
Outwash										
Isanti	Pre	12.1	23.6	11.2	0.5	0.9	1.0	25.5	7.7	4.6
	V_2	8.6	10.3	15.2	2.3	1.7	2.9	28.0	10.2	7.9
	V_5	8.7	7.8	12.5	4.9	5.7	6.9	39.0	13.3	11.4
Dakota	Pre	7.2	3.8	2.0	1.5	1.1	0.7	50.3	26.4	5.1
	V_2	13.1	6.7	4.4	1.4	1.9	0.6	53.7	30.1	11.2
	V_5	11.8	8.7	5.2	2.6	1.5	1.7	58.9	37.3	17.0
Sherburne	Pre	4.1	1.4	1.2	1.3	2.3	1.0	28.3	15.3	4.8
	V_2	4.1	2.0	1.8	1.0	0.6	0.7	24.6	11.0	11.0
	V_5	4.3	0.6	0.1	2.3	2.6	1.0	34.2	18.6	9.6
Chisago	Pre	3.8	1.9	2.4	1.9	0.8	0.9	14.1	2.8	2.8
	V_2	3.8	2.0	2.2	3.3	2.2	1.8	14.3	6.9	5.0
	V_5	2.7	2.0	2.6	5.4	2.8	2.1	21.9	13.0	7.3
Loess										
Olmsted	Pre	3.4	0.4	0.3	6.3	4.3	3.7	72.3	43.3	21.9
	V_2	5.4	4.4	2.4	9.5	6.2	4.5	72.5	55.8	32.3
	V_5	7.6	4.4	2.1	7.1	5.4	4.7	75.8	50.4	28.6
Goodhue	Pre	7.7	4.5	2.5	5.9	3.4	1.8	73.4	27.1	6.8
	V_2	4.9	4.0	3.2	5.9	1.4	1.2	78.8	18.2	6.8
	V_5	7.0	5.0	3.1	8.3	2.6	1.9	88.6	25.5	10.8
Wabasha-1	Pre	6.1	9.5	10.3	2.6	3.1	2.6	41.7	17.4	10.7
	V_2	18.5	11.9	11.5	3.2	3.0	3.6	38.3	17.9	14.3
	V_5	18.4	12.7	11.9	4.8	3.1	4.5	46.1	19.7	17.2
Wabasha-2	Pre	10.0	20.6	10.7	1.7	1.5	1.9	39.3	12.0	8.6
	V_2	17.9	11.4	13.2	1.9	1.1	1.2	39.9	15.4	8.0
	V_5	21.5	11.4	12.9	3.1	4.7	3.8	37.9	16.5	12.4
Winona-1	Pre	14.4	11.0	4.9	2.3	3.5	2.6	37.8	13.2	9.7
	V_2	23.7	10.9	11.3	3.8	2.7	4.1	29.9	13.2	21.3
	V_5	15.6	8.6	11.2	4.6	4.9	6.3	45.0	19.1	19.6
Winona-2	Pre	1.4	5.9	9.2	1.7	1.7	2.2	77.6	24.5	10.6
	V_2	20.1	12.5	15.3	1.5	0.9	0.8	70.0	29.5	13.7
	V_5	14.2	11.2	17.1	5.2	5.2	4.8	78.5	39.4	21.8
Till										
Waseca-1	Pre	5.1	2.5	2.2	4.4	1.9	2.2	47.4	9.3	6.3
	V_2	6.9	5.5	4.4	4.6	1.4	1.8	50.0	12.8	5.3
	V_5	4.3	3.6	3.4	5.3	1.1	1.3	54.0	15.6	9.0
Waseca-2	Pre	13.4	4.8	0.7	8.1	2.2	1.4	83.3	33.2	10.2
	V_2	14.9	13.4	7.4	9.7	1.9	0.8	86.8	27.7	6.5
	V_5	9.5	10.0	8.6	13.6	3.8	2.1	91.1	31.5	13.2
Waseca-3	Pre	8.8	10.2	5.2	8.4	2.7	1.9	89.4	37.1	12.4
	V_2	5.1	7.2	8.5	9.5	3.6	1.8	89.7	37.3	12.5
	V_5	5.2	5.2	7.7	11.7	3.6	2.4	89.1	32.2	13.8
Watonwan	Pre	8.4	8.1	12.3	4.3	1.5	1.5	39.3	8.1	4.8
	V_2	4.6	3.9	6.5	4.3	1.4	1.2	40.7	11.0	5.3
	V_5	5.2	4.1	5.5	4.3	1.5	1.7	44.0	10.2	6.3
Waseca-4	Pre	12.7	10.3	15.9	7.1	2.1	1.7	59.5	17.4	5.6
	V_2	11.1	10.6	12.1	6.5	2.0	2.3	57.6	17.9	8.3
	V_5	5.8	6.8	10.0	9.3	3.0	2.5	64.6	32.8	17.9

[1] Sites are also categorized by soil's parent material.
[2] Sampling times were before planting (Pre) and at the morphological growth stages of V_2 and V_5.
[3] Includes ammonium-N.

Table 7. Selected soil nitrate-N correlations (r) of plots receiving various preplant N applications as a function of soil sampling time and depths in 1989 and 1990.

Soil sampling time and depth comparison	1989	1990
	---- r ------	
Preplant 0-2′ vs. Preplant 0-3′	0.975	0.999
Preplant 0-3′ vs. V2 0-1′	0.242	-0.076
Preplant 0-3′ vs. V6 0-1′	0.139	-0.009
Preplant 0-3′ vs. V6 0-2′	0.151	0.011
V2 0-1′ vs. V6 0-1′	0.398	0.415
V6 0-1′ vs. V6 0-2′	0.904	0.961