WATER QUALITY STUDIES

H. Meredith and Mel Wiens[1/]

ABSTRACT: The Staples Station irrigation pumps lift water from an aquifer about 15 feet below the surface. The sand plain composed of coarse materials permits excessive internal drainage of the soil profile. Leaching of soluble nutrients occurs in the presence of excessive water. Water samples from pumping wells lends a tool to monitor the nutrient status of these wells.

Table 1. Nutrients in Irrigation Water. Staples Irrigation Center, 1989.

Well ID	N	S	Mn	Zn	Na	Ca	Mg
	- - - - - - - - - - - - - - pounds/A inch water - - - - - - - - - - - - - -						
Well A	5.4	1.55	.283	T	1.67	48.5	13.8
Well B	1.4	.46	.302	.213	1.90	49.9	14.1
Well C	2.4	1.18	.250	.051	1.41	54.0	16.1
Well D	3.2	1.07	.16	.015	1.00	36.4	9.7
Barry Torps	10.6	5.25	T	.034	2.06	51.7	22.7
Two Towers	3.1	8.25	.19	T	2.25	61.0	23.1

All other nutrients tested were below detection levels.

It is of value to convert PPM to pounds per acre inch to get a feel for the magnitude of nutrients in irrigation water. It is obvious that the nutrients of greatest value from these wells are the liming nutrients calcium and magnesioum. An acre inch of water is equal to 0.226 million

Table 2. Nutrients in irrigation water expressed in pounds per acre inch of water applied.

Well ID	N	S	Mn	Zn	Na	Ca	Mg	Calcium Carbonate Equivalent (lime)
	- - - - - - - - - - - - - - - - pounds/A inch water - - - - - - - - - - - - - - - -							
Well A	1.22	.35	.064	T	.38	11.0	3.1	40.4
Well B	.32	.10	.068	.048	.43	11.3	3.2	41.5
Well C	.54	.27	.056	.012	.32	12.2	3.6	45.5
Well D	.72	.24	.036	.003	.23	8.2	2.2	29.7
Barry Torps	2.40	1.19	T	.008	.46	11.7	5.1	50.5
Two Towers	.70	1.86	.043	T	.51	13.8	5.2	56.2

If 10 acre inches of water are applied for several years, irrigation water influences the soil pH. In the above case, if 50 pounds of lime is added per acre inch, this amounts to 500 pounds of lime per year if 10 inches of irrigation water are applied each year. Over a 10-year period, 5000 pounds of 2.5 tons of a high quality fine lime is added to the soil.

If 10 PPM N is detected in the irrigation water, application of 10 acre inches would add 22.6 pounds of N per year or 226 pounds of N over a 10-year period. Typically, irrigation water contains considerably less than 10 PPM N. Measurement of nitrogen in precipitation indicates that 10-15 pounds or more N per acre is deposited in areas of moderate to high total precipitation.

[1/] Regional Director, Tennessee Valley Authority, Research Plot Coordinator, Staples Irrigation Center, University of Minnesota, respectively.

SOUTHERN EXPERIMENT STATION
WASECA, MINNESOTA

WEATHER DATA - 1989

Month	Period	Precipitation 1989	Precipitation Normal 1/	Avg. Air Temp. 1989	Avg. Air Temp. Normal 1/	Growing Degree Days 1989	Growing Degree Days Normal 1/
		---- inches ----		------ °F -----			
January	1-31	0.55	0.84	21.1	10.0		
February	1-28	0.80	0.99	9.1	16.4		
March	1-31	2.70	1.99	25.9	27.6		
April	1-30	3.21	2.64	44.7	44.7		
May	1-10	0.70		45.4		34.5	
	11-20	0.46		64.4		153.0	
	21-31	0.40		61.8		147.5	
	Total	1.56	3.76	57.4	57.7	335.0	334
June	1-10	0.10		62.4		136.0	
	11-20	0.33		64.3		151.0	
	20-30	1.78		72.8		219.0	
	Total	2.21	4.48	66.5	67.1	506.0	518
July	1-10	0.56		78.8		262.5	
	11-20	2.73		71.1		207.0	
	21-31	0.65		73.9		261.0	
	Total	3.94	4.02	74.6	71.2	730.5	641
August	1-10	0.05		70.8		205.0	
	11-20	0.46		69.4		193.0	
	21-31	1.92		71.2		230.5	
	Total	2.43	3.99	70.5	68.8	628.5	579
September	1-30	2.35	3.36	59.7	59.8	312.5	311
October	1-31	0.20	2.08	50.1	48.9		38
November	1-30	1.64	1.43	26.8	32.5		
December	1-31	0.35	1.02	8.8	18.0		
Year	Jan-Dec	21.94	30.60	43.0	43.6	2512.5 2/	2421
Growing Season	May-Sep	12.49	19.61	65.8	64.9	2512.5	2383

1/ 30-year normal from 1951 - 1980.
2/ 50 to 86°F base, May 1 until first fall frost.

Notes:
1) Highest temperature on July 10 and August 5 -- 97°.
2) Highest 24-hour precipitation on August 28 -- 1.26".
3) Highest 2-day precipitation on June 25 & 26 -- 1.73".
4) Last spring frost -- May 7.
5) First fall frost -- September 23.
6) Driest year since 1976 and 6th driest year in 75 years of records.

NITROGEN LOSS TO TILE LINES AS AFFECTED BY TILLAGE[1/]

Waseca, 1989

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

ABSTRACT: No tillage (NT) is thought to increase infiltration and, therefore, should increase the amount of water percolating through the soil compared to conventional tillage. This long-term study is being conducted to determine if greater amounts of NO_3-N and pesticides are being lost to tile drainage water with NT compared to moldboard plow (MP) tillage. Rainfall during 1989 was 8.7" below normal and tile flow was limited. Although NO_3 concentrations were similar for the two tillage systems, higher discharge volume with NT (1.64 vs 0.92 acre-inches) resulted in slightly higher NO_3-N losses to the drainage water with the NT system. Corn yields, N uptake, and N removal in the grain were all significantly higher for MP compared to NT. Substantially higher amounts of NO_3 remained in the 8-foot soil profile in October with the MP system compared to NT.

Nitrogen losses to tile lines have been documented in a number of research studies including some conducted at Lamberton and Waseca, Minnesota. These studies primarily showed that N losses were a function of the N application rate and amount of precipitation. To some degree the time of application and crop grown have been shown to influence NO_3-N loss to tile lines. The purpose of this long-term study is to determine if tillage has an effect on N utilization, accumulation of NO_3-N in the soil profile, and the subsequent loss of NO_3-N to tile lines.

EXPERIMENTAL PROCEDURES

A study was initiated in 1975 on a Webster clay loam at Waseca to monitor the movement of N into a tile line installed in each of 12 plots measuring 45' by 50'. Each plot is enclosed with plastic sheeting to a 6' depth. Annual N rates of 0, 100, 200, and 300 lb N/A were applied from 1975-1979. No N was applied for the 1980 and 1981 crops. Residual N from N applied over the 5-year period (75-79) was utilized by the 1980 and 1981 corn crops. Soil samples to 10' and tile water samples taken in late 1981 showed little remaining evidence of the previous treatments.

In the fall of 1981, eight plots with the most uniform tile flow rates over the 1975-81 period were selected. Two tillage treatments (fall moldboard plow and no tillage) were replicated four times and randomized over the previous plot histories. Corn was grown on these plots in 1982 through 1988. The stalks were chopped in October, 1988 and moldboard plots plowed.

On May 11, 180 lb N/A as ammonium nitrate was broadcast applied to the surface of all plots. The moldboard treatment was then field cultivated. Corn (Pioneer 3732) was planted on May 12 at a population of 27700 plants/A with a John Deere Max-Emerge planter equipped with ripple coulters. Starter fertilizer was not used because of the high soil tests. Furadan was applied at 1 lb (ai)/A to control rootworms. Weeds were controlled with a preemergence application of Lasso (3½ lb/A) and Bladex (3 lb/A) applied May 18. Weed and insect control were excellent. Percent surface residue was measured on April 11 and averaged 8 and 94% for the MP and NT systems, respectively.

The leaf opposite and below the ear was taken from 10 randomly selected plants per plot at silking (MP = July 24 and NT = July 31) and was analyzed for N. Silage and grain yields were taken at physiological maturity by hand harvesting 40' and 80' of row, respectively, from each plot.

Tile lines flowed intermittently from April 28 to June 3. When tile lines were flowing, flow rates were measured daily and samples taken on a daily basis for the first week and then on a M-W-F basis thereafter for NO_3 analysis. All analyses were done by the Research Analytical Lab.

Soil NO_3-N in the 0-8' profile was determined from two cores/plot taken in 1-foot increments on October 31, 1989.

1/ Funding provided by the North Central Regional Research Committee (NC-98) and the Southern Experiment Station.

2/ Professor and Asst. Scientist, Southern Experiment Station, Univ. of Minnesota.

RESULTS

Yields, N uptake by the whole plant (silage), and N removal in the grain were all significantly higher for the moldboard plow (MP) system compared to no tillage (NT) (Table 1). This was the fourth year of eight where MP yields were significantly higher. Neither leaf N nor grain N concentration was affected by tillage, however.

Table 1. Influence of tillage system on corn production and N utilization at Waseca in 1989.

Tillage system	Final population	Leaf N	Silage Yield	Silage N uptake	Grain Yield	Grain N	Grain N removal
	x10³	%	T DM/A	lb N/A	bu/A	%	lb N/A
Moldboard Plow	26.2	3.06	7.39	151.8	153.2	1.39	100.8
No Tillage	28.9	2.94	6.33	137.0	128.0	1.41	85.3
Signif. Level (%):[1/]	99	76	99	95	99	42	99
CV (%) :	2.6	4.0	3.0	4.7	2.6	2.9	4.0

1/ Probability level of significance.

Precipitation during the growing season was 8.7" below normal. Thus, tile flow was confined from late-April into early June. Although tile flow for 1989 was very low, discharge in the NT system was 78% higher than for MP (Table 2). Nitrate-N concentrations were not different between the two tillage systems. Consequently, NO_3-N losses to the drainage water were slightly higher for NT. These losses were very small, however, and represent only a small portion of the fertilizer N added to these plots.

Table 2. Influence of tillage system on tile flow, NO_3-N concentration and NO_3-N loss in 1989.

Tillage system	Tile flow	Nitrate-N Concentration[1/]	Nitrate-N Loss
	acre inches	mg/L	lb N/A
Moldboard Plow	.92	13.6	2.71
No Tillage	1.64	12.8	4.75

1/ Flow-weighted

Residual NO_3-N in the soil profile at the end of the 1989 growing season showed about 102 lb/A more N remaining with the MP system (Table 3). The largest differences between the two tillage systems occurred in the top 1' where substantially more NO_3 accumulated with MP. These results are similar to 1987 and 1988.

Table 3. Influence of tillage systems on residual NO_3-N in the soil profile in Oct., 1989.

Profile depth	Tillage System: Mb. Plow	Tillage System: No Tillage
feet	NO_3-N (lb/A)	
0-1	93.7	29.6
1-2	30.5	19.8
2-3	41.5	25.3
3-4	21.1	13.3
4-5	16.3	11.8
5-6	12.0	13.6
6-7	11.8	11.6
7-8	12.6	12.2
Total (lb NO_3-N/A 0-8')	239.5	137.2

EIGHT-YEAR SUMMARY

The cumulative totals for the 8-year period (1982-1989) are shown in Table 4. Corn yields over this period have averaged 11 bu/A better with moldboard plow tillage. Approximately 12% more N has been removed in the grain with moldboard plow tillage. This has been due to both higher yields and slightly higher grain N concentrations with the moldboard tillage system some years. Even so, very little difference in applied N removed in the grain exists between the two treatments (50% vs 45% for MP vs NT, respectively). Even though total water flow and NO_3-N lost through the tile lines was about 9% higher with no tillage, this small difference is considered to be insignificant when considering tile flow variability among the eight plots over this 8-year period.

Table 4. Cumulative effects of the two tillage systems over the 8-year period.

Parameter	Tillage System	
	Mb. plow	No tillage
Fert. N applied (lb/A)	1440	1440
Corn grain removed (bu/A)	1085	997
N removed in grain (lb/A)	724	644
N removed in grain as a percent of applied N (%)	50	45
Tile flow (acre inches)	61.3	66.8
Nitrate-N lost in tile (lb/A)	149.1	162.6
N lost via tile lines as a percent of applied N (%)	10	11

RESIDUAL SOIL NITRATE IN SECOND YEAR CORN FOLLOWING ALFALFA AS INFLUENCED BY TILLAGE AND CORN HYBRID[1/]

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

Experiments were conducted at two locations in 1989 to determine the influence of tillage, N rate and corn hybrid on residual NO_3 for second year corn following alfalfa. Spring residual NO_3 levels were very high in Waseca Co. due to the drought in 1988 and in the moldboard plowed plots that received fertilizer N in Winona Co. On average residual NO_3 increased by 8% and decreased by 26% from October 1988 to April 1989 in Waseca and Winona Counties, respectively. Samples taken from the top foot indicate a slight increase in NO_3-N concentration between preplant sampling and the V2 and V6 stages. Highest levels of residual soil NO_3 occurred at both sites where N had been applied to the MP plots. Residual N was lowest with no tillage in Winona Co. Significantly less residual NO_3 remained with DK547 compared to P3732. These data indicate that soil NO_3-N levels are greatly affected by tillage, N rate, and hybrid even for second year corn following alfalfa. Management systems can be employed that reduce carryover of NO_3 and thus minimize the potential for NO_3 leaching.

Recent evidence has shown that residual soil nitrate (NO_3) in the upper part of the root zone may be helpful in more accurately predicting fertilizer N needs of corn. The purpose of this study was to determine: (1) the amount of residual NO_3-N remaining in the spring after 1st year corn following alfalfa, (2) the effect of tillage on soil NO_3-N at the preplant, V2 and V6 growth stages, and (3) the effect of tillage, corn hybrid, and fertilizer N rate on residual NO_3-N following second year corn after alfalfa.

EXPERIMENTAL PROCEDURES

Studies were initiated into growing alfalfa stands at the Rosemount Agricultural Experiment Station, Southern Experiment Station at Waseca, and on the Gary Luehmann farm in Winona Co. in April, 1988. The primary soil type at each location was Port Byron sil, Nicollet cl, and Seaton sil, respectively. A randomized, complete-block experiment in a split-plot arrangement with four replications was used. Main plots consisted of two primary tillage variables (moldboard plow vs no tillage) while subplots consisted of six genetically dissimilar 105-day RM corn hybrids.

Following harvest and soil sampling in October, 1988, all moldboard plots were plowed at the Waseca and Winona Co. sites. Soil samples were taken in 1-foot increments to a depth of 5' from the 0 and 100-lb plots (1989 N rate) of the P3732 hybrid on both tillage systems in late-April, 1989 prior to planting. Additional samples were taken from the 0-lb N rate plots of this hybrid at the V2 stage (Winona Co.) and V6 stage at both sites. After harvest, soil samples were again taken from both tillage systems in 1-foot increments to a depth of 5' from the P3732 and DK547 plots receiving the 0 and 100-lb N rates. All soil samples were forced-air, oven-dried at 120°F, crushed to pass a 2 mm sieve, and analyzed for NO_3-N.

The corn hybrids planted in 1988 were repeated again on the same plots in 1989. The N rate was raised from 60 lb/A in 1988 to 100 lb/A in 1989 on those plots receiving N.

RESULTS AND DISCUSSION

Spring sampling

Samples taken prior to planting and N fertilization indicate substantial carryover of residual NO_3-N at both locations (Table 1). Residual NO_3 levels were very high for all previous N rate/tillage systems in Waseca Co. because of the extremely low corn yields in 1988 due to drought. In Winona Co., residual NO_3 was highest for the MP system especially those plots that received 60 lb N/A in 1988. Residual NO_3 in the top 5' increased by 8% between October 1988 and April 1989 in Waseca Co. probably due to additional nitrification and very dry conditions that minimized any NO_3 losses. In Winona Co. where significant fall rain occurred after sampling, residual NO_3 decreased by 26% during this 6-month period.

1/ Funding provided by the Minnesota Agric. Exp. Stn. and the So. Exp. Stn. at Waseca.
2/ Professor and Assistant Scientist, So. Exp. Stn., Waseca.

Table 3. Residual soil nitrate-N after harvest in October, 1989 at Waseca as influenced by tillage, hybrid, and N rate.

Profile depth	Moldboard				No-tillage			
	P3732		DK547		P3732		DK547	
lb N/A:	0	100	0	100	0	100	0	100
feet	lb NO_3-N/A							
0 - 1	19.6	101.5	16.4	56.3	22.9	53.9	17.5	50.1
1 - 2	8.4	41.6	6.3	28.3	6.9	27.4	6.2	38.3
2 - 3	13.4	29.5	5.3	23.2	11.7	31.3	8.5	28.0
3 - 4	10.4	16.1	6.6	13.4	13.9	16.3	10.3	13.2
4 - 5	6.3	8.5	6.6	9.0	9.5	8.3	8.2	6.9
Total in 0-5' profile	58	197	41	130	65	137	51	136

Table 4. Residual soil nitrate-N after harvest in October, 1989 in Winona Co. as influenced by tillage, hybrid, and N rate.

Profile depth	Moldboard				No-tillage			
	P3732		DK547		P3732		DK547	
lb N/A:	0	100	0	100	0	100	0	100
feet	lb NO_3-N/A							
0 - 1	33.0	142.5	17.0	89.1	19.3	59.9	18.8	17.9
1 - 2	17.5	86.5	3.3	34.7	3.4	23.7	4.0	5.7
2 - 3	11.9	34.1	3.3	17.1	5.2	13.0	2.6	6.7
3 - 4	10.5	12.4	7.8	7.7	7.3	8.9	4.5	5.6
4 - 5	5.2	7.2	4.7	7.5	6.7	6.5	4.9	5.6
Total in 0-5' profile	78	283	36	156	42	112	35	42

Fall sampling

Samples were taken from the 0-1' and 1-2' depths at the preplant, V2 and V6 growth stages to determine if the NO_3 concentrations would change greatly during this period due to nitrification or loss of N. Information of this type may be helpful as agronomists evaluate the pre-sidedress soil nitrate test. Results shown in Table 2 show a slight increase in NO_3-N concentration in the top foot for both tillage systems at Waseca over this 8-week period. In Winona Co., soil NO_3-N increased in the top foot from preplant (late April) to V2 (early June) but did not change over the next four weeks (V6 stage). Soil NO_3-N changes in the 1-2' layer were small and inconsistent.

Waseca

Soil NO_3 amounts in October 1989 are given in Tables 3 and 5. Main effects showed significantly higher residual NO_3-N with the 100-lb N rate and with P3732 compared to DK547 but no effect of tillage. The significant tillage x N rate interaction indicates a greater effect of N with the MP system compared to NT. Larger differences between the amount of residual NO_3 after P3732 compared to DK547 with the MP system resulted in the significant tillage x hybrid interaction. Proportionately more NO_3 remained after the P3732 hybrid especially when fertilizer N was not applied. When N was applied there was less relative difference between hybrids. These results may have been unduly affected by the poor crop at this site in 1988.

Winona Co.

Fall total profile NO_3-N values shown in Table 4 show a substantial and highly significant effect of tillage, N rate, and hybrid on residual NO_3 (Table 5). The highly significant tillage x N rate interaction shows very low residual soil NO_3 except when 100 lb N/A was applied to the MP system. This high level of residual NO_3 reflects carryover of the fertilizer N which was not needed by the corn because of adequate N being supplied by mineralization of the N in the moldboard plowed alfalfa system. Almost 2X as much residual NO_3 was found after P3732 compared to DK547. This may have been due to slightly higher yields with DK547.

Table 1. Soil nitrate-N in April, 1989 following 1 year of corn after alfalfa.

Profile depth	Tillage:	Waseca				Winona Co.			
		Moldboard		No till		Moldboard		No till	
	N rate:	0	100	0	100	0	100	0	100
feet		lb NO_3-N/A							
0 - 1		37.8	69.4	39.3	45.5	49.3	112.2	41.1	70.1
1 - 2		72.3	104.7	57.6	117.2	43.7	83.1	27.9	63.8
2 - 3		51.9	55.0	46.9	57.6	21.4	30.0	14.4	23.6
3 - 4		17.3	32.1	26.2	23.8	11.4	12.5	9.5	11.0
4 - 5		6.7	13.1	12.7	10.0	6.5	9.8	7.1	10.9
Total in 5-foot profile									
April, 1989		186	274	183	254	132	248	100	117
Oct., 1988		170	235	184	236	178	302	136	182

Table 2. Soil NO_3-N concentration at the preplant, V2 and V6 stages as influenced by tillage.

Soil depth	Moldboard			No tillage		
	Preplant	V2	V6	Preplant	V2	V6
feet	NO_3-N, ppm					
			Waseca Co.			
0 - 1	9.5	-	12.3	9.8	-	13.6
1 - 2	18.1	-	13.8	14.4	-	14.2
			Winona Co.			
0 - 1	17.5	21.8	21.4	10.3	12.9	12.9
1 - 2	16.0	14.2	15.6	7.0	7.9	7.5

Table 5. Means for main effects and interactions for total residual soil nitrate-N (0-5') after harvest at Waseca and Winona Co. in October, 1989.

Treatment		Location: Waseca	Location: Winona Co.
		lb NO_3-N/A	
Tillage			
Moldboard		107	138
No-tillage		97	57
P > F		0.23	0.01
N Rate (lb/A)			
0		54	47
100		150	148
P > F		0.01	0.01
Hybrid			
P3732		114	128
DK547		89	66
P > F		0.01	0.01
Tillage X N Rate Interaction			
Moldboard	0	50	56
	100	164	219
No-tillage	0	58	38
	100	137	77
P > F		0.01	0.01
Tillage X Hybrid Interaction			
Moldboard	P3732	128	180
	DK547	86	96
No-tillage	P3732	101	77
	DK547	94	38
P > F		0.01	0.16
N Rate X Hybrid Interaction			
0	P3732	62	60
	DK547	46	34
100	P3732	167	197
	DK547	133	99
P > F		0.04	0.03
Tillage X N Rate X Hybrid Interaction			
P > F		0.01	0.72
CV (%):		11.4	45.

IMPACT OF NITROGEN AND TILLAGE MANAGEMENT PRACTICES ON CORN YIELD AND POTENTIAL GROUNDWATER CONTAMINATION IN SOUTHEASTERN MINNESOTA[1]

Center for Agricultural Impacts on Water Quality
Gyles Randall, J. Anderson, G. Malzer, D. Wyse,
J. Nieber, B. Anderson, and D. Buhler

ABSTRACT: Studies are being conducted on the silt loam soils of southeastern Minnesota to evaluate specific N and tillage practices for their role in providing profitability (BENEFIT) while minimizing NO_3 occurrences in the water below the root zone (RISK). In general, continuous corn yields were optimized at N rates from 100 to 150 lb N/A except when alfalfa and manure were in the system (1983-85), where 50 lb N/A optimized yields. Corn yields were not improved with split or sidedress N applications. Tillage did not appear to effect either corn yield or NO_3-N concentrations in the soil water. Yields from the residual manure treatments (manure applied in 1987 and 1988) were equal to yields from the 150-lb fertilizer N rate. However, NO_3-N concentrations in the water at 5' still remained very high (38 to 79 mg/L). When profitability was highest, NO_3-N concentrations at 5' averaged about 15 mg/L. In an effort to more clearly define BMP's for these soils, additional years will be needed to more closely ascertain benefit vs risk relationships of these various N and tillage practices.

Current agricultural production systems are being linked closely to the occurrence of agricultural chemicals in the groundwater. This concern is especially prevalent in southeastern Minnesota where agriculture is quite intensive and the soils are rather shallow over a fractured limestone and sandstone bedrock geology (karst). The purposes of these studies are to: (1) determine the cause and effect relationship of specific N and tillage management practices on corn production and NO_3 and pesticide accumulation/movement through the soil and (2) identify best management practices that minimize groundwater contamination while maintaining economic profitability.

EXPERIMENTAL PROCEDURES

Three sites were continued for the 1989 studies. The primary site with the most intensive investigation is being conducted in Olmsted Co. on the Lawler Farm. The other sites are in Goodhue Co. on the Foss Farm and in Winona Co. on the Kalmes Farm.

Olmsted County - Lawler Farm

In April of 1986 a 6.5 acre site of Port Byron soil was identified on the Richard Lawler and Sons Farm approximately 6 miles east of Rochester. A very comprehensive field history for the last 7 years was provided. Corn was grown in 1986. No herbicides and no nitrogen (N) fertilizer were applied to the corn which was cultivated three times.

Nitrogen Study

A randomized, complete-block with 4 replications was established in the fall of 1986 and was continued in 1989. Ten N treatments including both anhydrous ammonia and manure were established for a total of 40 plots (Table 1). Each plot was 30' wide and 65' long. The fall N treatments were applied on November 3, 1988. Spring N fertilizer treatments were applied on May 3 and again on June 29, 1989. Liquid hog manure was not applied in 1989. All plots except the no-till treatment were disked on May 8.

Corn (Pioneer 3737) was planted on May 15 at 30,200 plants/A. Lasso (3 lb/A) and atrazine (2.5 lb/A) were applied preemergence. Force was applied in the furrow at a rate of 8 oz/1000' of row to control rootworms. All chisel plow plots were cultivated on June 22.

Whole plants were harvested from selected rows at silking, were weighed, dried, ground and analyzed for total N to determine pre-silk N uptake. Stover and grain yields were taken from 20' and 80' of row, respectively, at physiological maturity (Oct. 4). All samples were weighed, dried, ground and analyzed for total N.

Soil samples were obtained from each plot on April 18 and Nov. 6 by taking two 2-inch cores in 1-foot increments to the bedrock and then compositing the cores from each increment. The samples were forced-air, oven-dried at 120° F, ground and analyzed for inorganic N (NH_4-N and NO_3-N).

1) Funding provided by the Legislative Commission on Minnesota Resources, Center for Agricultural Impacts on Water Quality, and the Minnesota Agricultural Experiment Station.

Suction lysimeters installed in 1987 at the 5 and 7.5-foot depths in each plot were used to extract soil water from these depths to measure NO_3 concentrations in the soil water. Samples were collected on May 12, June 7, July 26, and September 12.

Pesticide Study

An area adjacent to the N study was established in the fall of 1986 to accommodate a study to evaluate the movement of Lasso, atrazine, Banvel, and Counter through the soil profile as influenced by four tillage systems. The four tillage treatments (moldboard plow, chisel plow, ridge tillage, and no tillage) were initiated in November, 1986. Nitrogen was applied on May 3 at a rate of 180 lb N/A as anhydrous ammonia. All other planting operations were the same as in the N study. The herbicides were applied using specialized plot equipment. Potassium bromide was broadcast-applied to a 15-foot section of each plot. The Br serves as a tracer to which pesticide movement can be compared. The corn was cultivated two times. The ridge plots were ridged in mid-June.

Each plot was intensively soil sampled throughout the season to monitor herbicide movement. Stainless steel suction lysimeters installed at 5' and 7.5' depths were used to extract soil water. Grain and stover yields were taken at physiological maturity (PM).

Goodhue County - Foss Farm

In May of 1986 an area of 5.1 acres of Port Byron soil was identified on the Selmer Foss and Sons (James Foss) farm in Goodhue County. A good field history was provided for the past 6 years. Corn was grown in 1986 and received a minimal amount of N (75 lb N/A) because it was in continuous corn. Weeds were controlled with 4 lb atrazine/A. Due to wet conditions no primary tillage was performed in the fall of 1986.

A randomized, complete-block design with 4 replications was established at this site in April, 1987 and was continued in 1989. Sixteen N treatments all consisting of anhydrous ammonia applied to chiseled and no-till plots were established. Each of the 64 plots measures 30' wide and 65' long. Chisel plowing was done with a John Deere Mulch Tiller on October 31, 1988. Anhydrous ammonia was applied preplant on May 9. All chisel plots were disked on May 12.

Corn (Pioneer 3772) was planted at 30,200 plants/A on May 16. Lasso (4 lb/A) and Bladex (2.5 lb/A) was applied preemergence. Force was applied (8 oz/1000 ft) to control corn rootworms. The chisel plowed plots were cultivated to remove weeds and volunteer corn. Sidedress applications of N as anhydrous ammonia were applied at the 6-leaf stage (June 21) and 8 to 9-leaf stage (June 29).

Plant sampling procedures at silking and at PM were essentially the same as at the Olmsted Co. site except that grain yields were determined by combine harvesting two rows per plot. Soil sampling to the 8-foot depth on May 3 and November 10 was accomplished using the same procedures as in Olmsted Co. Suction lysimeters installed in six treatments (24 plots) to a 5' depth in 1987 were sampled on May 3, June 21, July 20, and Sept. 11 to determine the NO_3 and pesticide concentrations in the extracted soil water.

Winona County - Kalmes Farm

A 3.0 acre contour strip of Seaton soil was identified in early April, 1987. This farm is owned by Eugene Kalmes and son, Robert Kalmes. A field history was provided for the last 4 years. Corn was grown in 1986 and received 70 lb N/A and 2 lb atrazine/A. Alfalfa was grown in 1983-85 and received 6 T manure/A in the fall of 1985.

A randomized, complete-block design with 4 replications was established at this site in mid-April, 1987 and was continued in 1989. Twelve N treatments were established for a total of 48 plots. Each plot measures 20' wide by 65' long.

Fall chiseling was conducted on October 31, 1988. The preplant anhydrous ammonia treatments were applied on May 4. A field cultivator was used as secondary tillage just prior to planting.

Corn (Pioneer 3772) was planted at 30,200 plants/A on May 15. Lasso (3 lb/A) and Bladex (2.5 lb/A) were applied preemergence. Force (8 oz/1000') was used to control corn rootworms. The chisel plowed plots were cultivated to remove weeds. Sidedress applications of N as anhydrous ammonia were applied at the 6-leaf stage (June 20) and the 8 to 9-leaf stage (June 29).

Plant and soil sampling procedures were identical to those used in Olmsted Co. Stainless steel and PVC suction lysimeters installed in 1987 at the 5' depth in six treatments (24 plots) were sampled on May 16,

June 15, Aug. 3, and Sept. 12 to determine NO_3 and pesticide concentrations in the extracted soil water.

RESULTS AND DISCUSSION

Olmsted Co.

Corn grain yields in 1989 were increased significantly by both the fertilizer and previous manure N treatments (Table 1). The addition of 75 lb N/A increased yield by 86 bu/A resulting in very high fertilizer N efficiency. The 150-lb N rate applied preplant (PP) gave the optimum yield among the fertilizer treatments. Yields with the two hog manure treatments were not significantly different than the 150-lb N/A PP treatments. Corn yields with the fall and split 150-lb treatments were not significantly different from the 150-lb PP treatment. There was no significant yield difference between the chisel and no tillage systems. Average 3-year yields showed greatest economic return to the 150-lb PP application with no advantage to higher rates, fall application, or split treatments.

Table 1. Effect of N treatments on the 1989 corn yields and NO_3-N concentrations in the water at 5' in Olmsted Co.

Treatment				Grain Yield		Nitrate-N[3] Conc. in Water	
No.	Tillage	N rate	Time/Method	1989	1987-89	5'	7.5'
		lb N/A		---- bu/A ----		--- mg/L ---	
1	Chisel	0	------	69.0	86.1	1	3
2	Chisel	75	Spr., preplant	155.2	159.1	7	7
3	Chisel	150	Spr., preplant	181.4	178.4	15	7
4	Chisel	225	Spr., preplant	174.6	170.7	28	9
5	Chisel	150	Fall, post tillage	183.1	177.6	17	-
6	Chisel	150+NI[1]	Fall, post tillage	180.8	176.3	15	-
7	Chisel	150-Split	50% Spr., preplant 50% SD, 8-leaf	174.0	173.2	-	-
8	No tillage	150	Spr., preplant	178.8	177.4	-	-
9	Chisel	315[2]	Spr., disked in	186.6	185.2	38	13
10	Chisel	490[2]	Spr., disked in	181.2	183.9	79	6
	Significance level (%)		:	99			
	BLSD (.05)		:	13.1			
	CV (%)		:	6.0			

1) N-Serve
2) Liquid swine manure was applied annually at an average rate of 6050 and 9200 gal/A, respectively, in 1987 and 1988. No manure was applied in 1989. Total N rates were 315 and 490 lb N/A or approximately 175 and 265 lb "available" N/A.
3) September 12, 1989

Nitrate-N concentrations in the soil water extracted from the 5-foot depth were correlated linearly with the spring-N rate (Table 1). Concentrations below 10 mg/L were found only with the 0 and 75-lb N rates, but economical return was also considerably less with the treatments. Contrary to 1988, fall applications of N, regardless of the inclusion of N-Serve, showed similar NO_3-N concentrations as the spring preplant applications. There appeared to be no difference between tillage systems. Highest NO_3-N concentrations occurred with realistic application rates of liquid hog manure. Nitrate leaching from the treatments had not reached the 7.5-foot depth at the end of three growing seasons probably because of the dry conditions in both 1988 and 1989. It should be cautioned that these 5-foot NO_3-N concentrations may not represent the concentrations entering the aquifer because of dilution; however, they do provide an indication as to the environmental sensitivity of the treatments.

Corn yields in the pesticide study were greatly influenced by tillage (Table 2). The yields with the MP system were significantly higher than those from either the ridge till (RT) or NT systems with yields from CP being intermediate. A slight weed infestation in the RT and NT systems may have competed for soil water in this dry year, thus reducing corn yields.

Table 2. Effect of tillage treatments on the 1989 corn yields in Olmsted Co.

Tillage	Grain Yield 1989	Grain Yield 1987-89 Avg.
	bu/A	
Moldboard plow	180.1	174.0
Chisel plow	169.1	170.1
Ridge till	156.5	160.7
No tillage	158.8	157.4
Significance level (%):	98	
BLSD (.05) :	15.7	
CV (%) :	5.5	

Goodhue Co.

Grain yields were increased significantly over the control (both chisel and no tillage) by all of the N treatments (Table 3). Yields were optimized with the 100-lb spring PP treatment. The highest yield, although not statistically speaking, was obtained with the 150-lb PP treatment. There was no significant difference between the two tillage systems except when no N was applied. Under these conditions yields were better with the CP system. None of the split and sidedress treatments enhanced yields over the spring PP anhydrous applications. Benefits were not obtained by including N-Serve with the anhydrous ammonia.

Three-year average grain yields also show: (1) optimum N rate to be 100 lb/A, (2) no improvement in yield with either split or sidedress N application, and (3) no difference between the two tillage systems except at the 0-lb N rate where there was a slight advantage for chisel plowing.

Nitrate-N concentrations in the soil water extracted from the 5-foot depth on Sept. 11 varied considerably and did not relate closely to N treatment (Table 3). This was probably due to the dry conditions and the incomplete number of samples obtained.

Table 3. Corn yield and NO_3-N concentration in the soil water at 5′ as affected by N treatments in Goodhue Co. in 1989.

Treatment No.	Tillage[1]	N rate	Time/Method	Grain Yield 1989	Grain Yield 1987-89	Nitrate-N[3] Conc. in Water at 5′
		lb N/A		bu/A	bu/A	mg/L
1	Chisel	0	--------	55.2	87.1	11
2	Chisel	50	Spr., preplant (PP)	111.9	129.8	-
3	Chisel	100	Spr., preplant (PP)	139.2	146.3	11*
4	Chisel	150	Spr., preplant (PP)	146.4	148.4	33
5	Chisel	200	Spr., preplant (PP)	137.9	148.6	-
6	No tillage	0	--------	38.2	73.8	-
7	No tillage	100	Spr., preplant (PP)	128.8	142.9	8
8	No tillage	150	Spr., preplant (PP)	139.4	148.3	16
9	No tillage	200	Spr., preplant (PP)	126.6	144.5	-
10	Chisel	50+50	Spr. PP + SD 9-lf	135.6	142.3	-
11	Chisel	50+100	Spr. PP + SD 9-lf	142.2	147.0	-
12	Chisel	100+50	Spr. PP + SD 9-lf	142.8	148.7	-
13	Chisel	100	SD 6-lf	138.5	141.8	-
14	Chisel	150	SD 6-lf	136.7	147.0	32
15	Chisel	150+NI[2]	Spr. PP	138.1	152.1	-
16	Chisel	150+NI	SD 6-lf	144.0	148.0	-
	Significance level (%) :			99		
	BLSD (.05) :			11.8		
	CV (%) :			7.4		

1) Chiseling was done in Oct., 1988.
2) NI = N-Serve
3) Sept. 11, 1989
* Average of only 2 samples

Winona Co.

Corn grain yields were improved over the 0-lb control by about 45 bu/A with all of the N treatments (Table 4). Yields were optimized by the 50-lb N rate applied preplant. Higher rates of N and split or sidedress applications showed no additional yield advantage. No difference was observed between the two tillage systems.

Three-year average yields show: (1) no difference between the two tillage systems, (2) no advantage for the split and sidedress applications, and (3) a very slight but inconsistent response to fertilizer N at this site which was in alfalfa from 1983-85. Nitrate-N concentrations in the soil water at 5′ after three years of experimentation still are at 19 mg/L where no N has been used. Concentrations ranged between 39 and 73 mg NO_3-N/L for the treatments that received fertilizer N, with a positive relationship to N rate. These high values must be a result of the previous alfalfa crop which received manure in 1985 and the very dry conditions in 1988 that limited yields and N uptake by the crop severely.

Table 4. Effect of N treatments on the corn grain yield and NO_3-N concentrations in the soil water at 5′ and 7.5′ in Winona County in 1989.

Treatment				Grain Yield		Nitrate-N[2] Conc. in Water	
No.	Tillage[1]	N rate	Time/Method	1989	1987-89	5′	7.5′
		lb N/A		---- bu/A ----		--- mg/L ---	
1	Chisel	0	------	131.9	129.9	19*	-
2	Chisel	50	Spr., preplant	175.1	146.2	-	-
3	Chisel	100	Spr., preplant	174.6	148.3	44	21*
4	Chisel	150	Spr., preplant	173.4	149.7	44	-
5	Chisel	200	Spr., preplant	175.2	154.8	73	42
6	No tillage	0	------	137.0	131.7	-	-
7	No tillage	100	Spr., preplant	174.6	148.2	39*	-
8	No tillage	150	Spr., preplant	171.7	141.8	-	34
9	No tillage	200	Spr., preplant	167.6	146.2	62	36
10	Chisel	50+50	Spr. PP + SD 9-lf	170.7	149.2	-	-
11	Chisel	50+100	Spr. PP + SD 9-lf	177.3	152.0	-	23
12	Chisel	150	SD 6-lf	162.0	142.4	61*	-
	Significance level (%) :			99			
	BLSD (.05) :			12.4			
	CV (%) :			5.5			

1) Chiseling was done in October, 1988.
2) Sept. 12, 1989
* - Average of two samples

SUMMARY

The following summarizes the yield results from the third year of these studies:

1) N rates for continuous corn were optimized at 150 lb/A at one site, 100 lb/A at another, and at 50 N lb/A at the site with an alfalfa and manure history (1983-85).
2) No apparent yield advantages were found with split or sidedress applications of N at any of the three sites.
3) There was no yield difference between the no tillage and chisel tillage systems at any of the three sites except when no N was applied.
4) Previous crop and manure history apparently still impacts corn yield and N management at the Winona Co. site.
5) The role of alfalfa and manure contributions to available N for succeeding corn crops needs to be carefully examined and understood before improved N management is a reality on these soils.
6) Nitrate-N concentrations in the soil water at 5′ (below the root zone) provide a good basis upon which to compare the environmental risks associated with various N management systems.
7) Highest NO_3-N concentrations in the soil water obtained by suction lysimeter were associated with the 1987 and 1988 manure treatments. Concentrations also related very closely to the rate of fertilizer N applied.

ACKNOWLEDGEMENT
This interdisciplinary investigation would not have been possible without the fine cooperation and dedication of the farmer-cooperators and the participation of the Soil Conservation Service and the Minnesota Extension Service. Sincere appreciation is also extended to the Minnesota Valley Testing Lab who graciously conducted the manure analysis in previous years.

TILLAGE SYSTEMS FOR CORN AND SOYBEAN CROP SEQUENCES

Waseca, 1989

G. W. Randall, B. W. Anderson and R. R. Allmaras[1/]

ABSTRACT: A study was started in 1986 to determine the effect of tillage on corn and soybean production when grown in rotation compared to a continuous monoculture. Yield results in 1989 were quite variable due to moisture stress and the presence of soybean cyst nematode. Corn yields were not influenced by tillage. On the other hand, soybean yields were 9 and 24% higher with MP and CP tillage compared to NT. Corn and soybeans in rotation yielded 14 and 42% higher, respectively, than did the continuous monoculture systems. Tillage x crop sequence interactions were not significant for either crop.

Corn-soybean rotations have often been compared to continuous corn and soybean monocultures using a particular tillage system. Seldomly, however, have these comparisons been made over a range of primary tillage systems. The purpose of this study is to determine the effect of tillage on corn and soybean production when grown in a monoculture compared to a rotation.

Experimental Procedures

A study had been established on this Webster clay loam site in the fall of 1980 to determine the relationship between primary tillage and the incidence of corn and soybean diseases in continuous corn, continuous soybeans and a corn-soybean rotation. The tillage systems were fall moldboard plow (MP), fall chisel plow (CP), and no tillage (NT). After this 5-yr study was completed in 1985, the initial tillage plots and some of the monoculture plots were kept intact to take advantage of the past tillage and cropping history. Some of the monoculture plots were changed to a corn-soybean sequence so that there are now four cropping systems over each tillage system. The cropping systems are continuous corn (C-C), corn-soybean (C-Sb), soybean-corn (Sb-C), and continuous soybeans (Sb-Sb). Each treatment is replicated four times in a split-plot design with tillage as the main plot and crop system as the subplot.

Fall tillage was performed in October, 1988 after stalk chopping all corn plots. Spring secondary tillage consisted of disking the CP plots and field cultivating the MP and CP plots on May 11.

Nitrogen was broadcast applied as ammonium nitrate prior to secondary tillage to all 1989 corn plots at a rate of 200 lb N/A regardless of previous crop. Broadcast P and K were not applied because of high soil test P and K levels. Starter fertilizer was not used.

Corn (Pioneer 3737) was planted on May 12 at a rate of 29,700 ppA with a John Deere Max-Emerge II 4-row planter equipped with bubble coulters. Furadan (1 lb ai/A) was applied to all corn plots at the time of planting. Weeds were chemically controlled with a combination of 3½ qts. Lasso and 3 qts Bladex/A applied preemergence on May 23. Row cultivation was performed on June 21 in the MP and CP corn plots.

Soybeans (Hardin) were planted in 30" rows with the aforementioned planter at a rate of 9 beans/foot on May 24. Weeds were controlled with a preemergence application of Lasso (3½ qts/A) + Amiben (6 qts/A) on May 31. The MP and CP soybean plots were cultivated on June 21.

A modified JD 3300 plot combine was used to harvest both the corn and soybeans. Corn and soybean yields are expressed at 15.5 and 13.5% moisture, respectively.

All wheel traffic during the season was confined to the same inter-row areas that were trafficked at the time of planting. This resulted in wheel traffic on one side of each row with the other side non-compacted by machinery operations.

Results and Discussion

Corn yields were below normal and quite variable due to the dry conditions throughout most of the growing season (Table 1). When averaged over crop sequence, there was not a significant difference

---

1/ Soil scientist and assistant scientist, Southern Experiment Station and Professor, Department of Soil Science.

at the P = 90% level in yield among the tillage systems. Crop sequence significantly influenced corn yield. Corn following soybeans yielded 14% higher than continuous corn. There was no tillage x crop sequence interaction. Grain moisture was significantly higher with NT compared to the MP and CP systems but was not influenced by cropping sequence (Table 1).

Table 1. Corn grain yield and moisture content as affected by tillage and crop sequence.

Tillage	Crop Sequence	Grain Yield	Grain Moisture
		bu/A	%
MP	C-C	119.1	14.0
"	C-Sb	142.8	14.0
CP	C-C	129.2	14.2
"	C-Sb	145.1	13.9
NT	C-C	120.0	15.5
"	C-Sb	130.6	14.8
FACTORIAL COMPARISONS			
Tillage			
MP		131.0	14.0
CP		137.2	14.0
NT		125.3	15.1
Signif. Level (%):1/		75	99
BLSD (.05) :			0.8
Crop Sequence			
C-C		122.8	14.6
C-Sb		139.5	14.2
Signif. Level (%):1/		94	91
Tillage x Sequence Interaction			
Signif. Level (%):1/		21	60
CV (%) :		14.	3.4

1/ Probability level of significance.

Soybean yields were also highly variable (Table 2). Highly significant yield differences occurred among the three tillage systems. When averaged over crop sequence, yields with the MP and CP systems were 9 and 24% higher than with the NT system. A severe infestation of soybean cyst nematode became evident in 1989. This was especially true on some of the MP plots that were in continuous soybeans. Consequently, yields for the MP system were lower than expected. The lower yields with no tillage resulted primarily from poor broadleaf weed control in some plots. Lambsquarter and red root pigweed pressures have continued to increase over the years with continuous NT. Continuous soybeans yielded 30% lower than the Sb-C sequence. A significant tillage x crop sequence interaction was not found. Seed moisture at harvest was not influenced by tillage or crop sequence.

FOUR-YEAR SUMMARY

Corn yields from this completely weed-free site were 8 to 12 bu/A higher for NT compared to either MP or CP regardless of crop sequence (Table 3). Corn yields following soybeans averaged 14% higher than continuous corn for the MP system and 9% higher for the CP and NT systems. Soybean yields were not affected by tillage system. Soybeans following corn yielded 15, 22, and 25% higher than continuous corn for the MP, CP and NT systems, respectively.

Table 2. Soybean seed yield and moisture content as affected by tillage and crop sequence.

Tillage	Crop Sequence	Yield	Moisture
		bu/A	%
MP	Sb-Sb	31.7	8.3
"	Sb-C	43.1	8.4
CP	Sb-Sb	36.8	8.4
"	Sb-C	48.2	8.4
NT	Sb-Sb	25.8	8.4
"	Sb-C	42.8	8.4
FACTORIAL COMPARISONS			
Tillage			
MP		37.4	8.3
CP		42.5	8.4
NT		34.3	8.4
Signif. Level (%):		99	78
Crop Sequence			
Sb-Sb		31.4	8.4
Sb-C		44.7	8.4
Signif. Level (%):		99	79
BLSD (.05) :		3.2	-
Tillage x Sequence Interaction			
Signif. Level (%):		50	14
CV (%) :		14.	1.1

Table 3. Four-year corn and soybean yield averages as influenced by tillage and crop sequence.

Tillage	Crop Sequence	Yield	
		Corn	Soybean
		bu/A	
MP	Cont. Corn	128.0	-
"	Corn-Soybean	145.6	47.4
"	Cont. Soybean	-	41.1
CP	Cont. Corn	131.7	-
"	Corn-Soybean	143.2	50.1
"	Cont. Soybean	-	41.1
NT	Cont. Corn	140.6	-
"	Corn-Soybean	153.8	49.4
"	Cont. Soybean	-	39.5

CONSERVATION TILLAGE FOR CORN AND SOYBEAN PRODUCTION[1/]

Waseca, 1989

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

ABSTRACT: This was the 15th year of a study to evaluate five primary tillage systems for corn and soybean production on a Nicollet-Webster soil complex. Because of extremely high weed pressure with the NT system in previous years, all weed growth was eliminated by an aggressive herbicide program in 1989. Surface residue amounts ranged from 8% with MP tillage to 99% with NT. Soybean yields were unaffected by tillage systems under these conditions.

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 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). Because of increased pressure of the grass weeds in the NT treatment, all plots were split so that either the front or rear half received a postemergence application of Poast at a rate of ½ lb/A with 1 qt of oil concentrate.

Ridges for the RP treatment in 1989 were built in June, 1988. After the 1988 corn harvest stalks were chopped and the MP and CP treatments were performed. On May 30 the MP and CP treatments were field cultivated once with the chiseled plots receiving a prior disking. The SD treatment was disked twice. Ridges for 1990 corn were prepared on July 24.

Soybeans (Hardin) were planted in 30" rows at a rate of 160,000 plants/A on May 31. All treatments except RP were planted with a John Deere 7300 planter equipped with bubble coulters. B&H ridge cleaners were attached to a JD 7100 planter for the RP treatment. No starter fertilizer was used. Broadcast P and K were not applied for the 1989 soybean crop because of very high soil tests. Soil tests on this site in 1984 averaged: pH = 6.7, $Bray_1$ extractable P = 60 lb/A and exchangeable K = 424 lb/A. Because of extraordinarily high weed pressures associated with the NT treatments over the last 8 years, and the increasing weed pressure with the CP and SD systems, weed control methods to "eradicate" weeds were employed in 1989. Roundup (2 qts/A) was applied to all NT plots on June 2. Lasso (3.5 qts/A) + Amiben (3 lb/A) were applied broadcast to all plots on June 2. All plots except NT were cultivated with a Hiniker 5000 cultivator on June 30. Poast (0.35 lb/A) was applied broadcast with 1 qt of crop oil concentrate/A to all plots on July 4. This same rate of Poast + oil was applied to the NT, CP, and SD treatments on July 24 and again to the NT plots on August 8. As a result of this chemical arsenal plus cultivation, weed control was perfect.

Surface residue coverage was measured by the line-transect method on April 11 prior to spring tillage. Yields were taken by combine harvesting the center two rows from each plot.

RESULTS

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

1/ Funding provided by the Southern Experiment Station, Waseca.
2/ Professors, Southern Experiment Station and Department of Soil Science, respectively.

Table 1. Influence of tillage methods for soybeans after corn on surface residue before spring tillage at Waseca in 1989.

Treatment	Surface Residue Coverage
	%
No tillage	99
Fall plow	8
Fall chisel	36
Ridge plant	55
Spring disk (2x)	84
Significance Level (%):	99
BLSD (.05) :	10
CV (%) :	13.

Seed yield and moisture were not affected by the tillage systems in 1989 (Table 2). This was in sharp contrast to previous years where yields with NT were severely depressed. However, even though surface residue accumulations were very high, soybean yields were not affected when weeds were completely removed from the system.

Table 2. Influence of tillage method on soybean production at Waseca in 1989.

Tillage	Seed Moisture	Seed Yield
	%	bu/A
No tillage	10.1	39.2
Fall plow	10.1	41.5
Fall chisel	10.0	41.1
Ridge plant	10.2	40.4
Spring disk (2x)	10.0	41.3
Significance Level (%)[1/]:	45	80
CV (%) :	1.2	3.4

1/ Probability level of significant difference between means.

SUMMARY - 1989

This was the fourth crop of soybeans grown following corn in this long-term study with continuous corn from 1975 through 1982 and soybeans in 1983, 1985, and 1987. Surface residues prior to planting were greater than 50% with the NT, RP, and SD tillage. Weeds were completely eliminated from the plots with an aggressive chemical and cultivation program. As a result, soybean yields and moisture content at harvest were not affected by tillage.

FOURTEEN-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 3. 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 3). Corn yields in this sequence have not been different among the MP, CP, RP and SD systems when starter fertilizer has been used. Without starter fertilizer, yields

from the CP, RP and SD systems have averaged about 9% less than from the MP system. 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 3. 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	1984, 86 & 88
		bu/A			
No tillage	Yes	129.2	140.6	34.5	111.5
"	No		136.0	34.3	98.8
Fall plow	Yes	154.5	170.9	51.0	145.6
"	No		170.8	50.2	141.2
Fall chisel	Yes	144.4	161.8	47.7	136.0
"	No		155.5	45.5	124.5
Ridge plant	Yes	149.2	161.5	46.9	137.5
"	No		156.4	47.2	129.4
Till plant (flat) 1/	Yes	144.9	154.8	46.8	139.7
"	No		157.4	47.1	132.1

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

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

1989

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 15% at Waseca and 20% at Morris. Soil test K did not change at Waseca but increased about 20% at Morris. Corn yields were increased 10 to 16% over the long-term control plots at the two sites when soil test Bray P_1 was greater than 30 lb/A. Highest yields occurred at both locations when both P and K were applied to these high testing soils. There appeared to be little effect of soil test K on corn yield 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 corn on the high P and K rate study at the two branch stations in 1989.

Variable	Location: Morris	Location: Waseca
Planting date	5/10	5/15
Row spacing	30"	30"
Planting rate (plants/A)	32,000	30,000
Variety	Dekalb 461	Pioneer 3732
Herbicide	3# Lasso + 2.2# Bladex/A(Bdct)	3.5# Lasso + 3# Bladex/A(Bdct)
Harvest date	10/3	10/12
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 1988. 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.

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.

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 1985-86 rates resulted in highly significant differences in soil test P at both locations and in soil test K at Waseca. At Waseca soil test P ranged from 12 to 110 lb/A (Table 2). Soil test P declined slightly compared to 1988, but soil test K did not. Corn yields were increased significantly by P but plateaued at soil P levels higher than 45 lb/A.

At Morris, Bray P_1 ranged from 13 to 70 lb/A while Olsen's $NaHCO_3$ test ranged from 8 to 44 lb P/A (Table 3). Soil test P values declined about 20% at Morris, while soil K values increased about 20%. Grain yields were increased and grain moisture was decreased significantly by the P treatments.

Table 2. Soil test values, grain moisture, and grain yield as influenced by 16 years' application of P and K at Waseca.

	P and K Treatments			Soil Test[2]			Corn	
	Total							
No.	1973-84	1985-88[1]	pH	P	K		Moisture	Yield
	---- lb P_2O_5 + K_2O/A ----			--- lb/A ---			%	bu/A
2	0 + 1200	0 + 100	6.8	12	306		20.1	140.0
3	600 + 1200	0 + 100	6.4	43	304		19.6	163.3
4	1200 + 1200	0 + 100	6.6	72	290		19.3	167.1
5	600 + 1200	100 + 100	6.6	74	295		19.1	178.4
6	1200 + 0	100 + 0	6.7	110	245		19.2	172.7
7	1200 + 600	100 + 0	6.6	100	231		18.8	166.4
	Signif. Level (%):		44	99	99		93	99
	BLSD (.05) :		-	11	46		-	12.5
	CV (%) :		3.6	9.8	8.7		2.4	4.2

1. Treatments applied each fall. P was discontinued for treatments 6 & 7 in 1988.
2. Samples were taken in October before 1989 treatments were applied.

Table 3. Soil test values, grain moisture, and grain yield as influenced by 16 years' application of P and K at Morris.

	P and K Treatments			Soil Test[2]			Corn	
	Total							
No.	1973-84	1985-88[1]	pH	P_1	P_{ol}	K	Moisture	Yield
	--- lb P_2O_5 + K_2O/A ----			----- lb/A ------			%	bu/A
2	0 + 1200	0 + 100	7.7	13	8	533	21.8	135.1
3	600 + 1200	0 + 100	7.7	32	21	454	20.8	151.1
4	1200 + 1200	0 + 100	7.8	52	34	473	20.8	149.7
5	600 + 1200	100 + 100	7.6	70	44	446	20.4	173.7
	Signif. Level (%):		95	99	99	99	99	99
	BLSD (.05) :		0.1	22	13	53	0.7	17.7
	CV (%) :		1.0	33.	31.	6.5	2.1	7.0

1. Treatments applied each fall.
2. Samples were taken in October before 1989 treatments were applied.

CONCLUSIONS

Long term (12-yr) additions to these two soils created a wide range in soil test P levels. Corn yields were optimized over the no P treatments at soil test P levels of 40 lb/A at Waseca. Yields were not affected by K at Waseca. At Morris, corn yields were significantly improved with the higher soil test P levels. It is interesting to note that the highest yield at each site was produced with the 100 + 100 treatment even though soil tests were already high. Soil test P declined by about 15% at Waseca and 20% at Morris. Soil test K was not changed at Waseca but increased by about 20% at Morris. Additional years will be needed to more accurately determine the decline rates.

WATER QUALITY RESEARCH WITH NITROGEN AT THE HERMAN ROSHOLT WATER QUALITY RESEARCH FARM, WESTPORT, MN 1989 [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. Early N applications provided higher yields than split or late N applications in 1989. Use of a nitrification inhibitor increased yields. A significant inhibitor x method of application interaction indicates that the greatest response to inhibitor is when N is applied at 8-leaf. Nitrogen rates in excess of 105 #/A resulted in excess nitrate - N present in the soil profile at the end of the growing season. This excess nitrate has a high potential of being moved down toward the groundwater before the next growing season.
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 and 1989.

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.

Experimental Procedures

Small Plot N Management/Crop Production Phase:
Two separate N experiments were established at the Rosholt farm in 1988.

Experiment 1 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 1988 the entire experiment was planted to corn and in 1989 soybeans

1. Funding provided by the University of Minnesota Agricultural Expt. Station and the Center for the Impacts of Agricultural Practices on Water Quality. Appreciation is also expressed to Pioneer Hybrid International for supplying the seed.
2. Associate Professor and Asst. Scientist respectively, Dept. of Soil Science, and Associate Professor and Research Asst. respectively, Dept. Agricultural Engineering, University of MN.

were planted in the corn-soybean rotation. 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 of Experiment 1 on April 19th before planting and on October 30th after harvest. The soil samples were analyzed for ammonium and nitrate concentration and the data is reported in tables 3 and 4. Only spring samples were taken on soybeans following corn.

Experiment 2 consisted of 16 N treatments randomized within a split plot design with three replications. The main plot variable was tillage (ridge till and chisel plow). The 16 N treatments within each sub-plot consisted of two N rates (105 and 160 #/A), two N sources (anhydrous ammonia and urea) and two nitrification inhibitor treatments (with and without) at two times of application (early-4 leaf and late-8 leaf). Nitrification inhibitor treatments consisted of 0.5 #/A a.i. of N-Serve applied with anhydrous ammonia or 10% DCD-N with urea. The DCD urea was supplied by Tennessee Valley Authority-National Fertilizer Development Center. Urea treatments were injected at a depth of 6 inches and positioned approximately 6 inches away from the row similar to the anhydrous ammonia treatments.

Experiments 1, and 2: Corn (Pioneer 3902 - 90 day R.M.) was planted on May 12 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 7-22-5 as a band below the seed and Lorsban 15G was banded over the row at planting. Lasso (3 #/A) and AAtrex 90 DF (1#/A) was applied on May 18th for weed control in the corn. Soybeans were planted on May 20 at the rate of 63 #/A. A tank mix of Basagran (1 qt/A), Blazer (0.5 pt/A), Poast (1.5 pt/A) and oil concentrate (1 qt) applied June 8th at the rate of 20 gal/A. For additional weed control the experiments were cultivated twice. The first cultivation was on June 16th, and second on July 1st, ridges were also built on July 1st. Nitrogen treatments were applied on June 13th (early-4 leaf) and on June 28th (late-8 leaf). The irrigation program (traveling boom) was started on June 23rd and continued through August 6th with 7 inches of water being applied through irrigation. An additional 15.36 inches of water was obtained during the growing season as rainfall.

Soybean yields were taken October 8th with a plot combine harvesting two 50 ft rows. Corn grain yields were obtained on October 25th by hand harvesting 100 ft^2 of plot area. All corn grain yields were adjusted to 15.5% moisture and soybeans to 13%. Grain yields and N composition are reported on tables 1 and 2.

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. 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 14), and one-third at the 8-leaf growth stage (June 28). 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 3902 - 90 day R.M.) was planted on May 12 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 7-22-5 as a band below the seed. Lorsban 15G was banded over the row at planting. Lasso (3.0 #/A) and AAtrex 90 DF (1#/A) were sprayed on May 18th and Dicamba (0.25 #/A) on June 6th for weed control on corn.

The irrigation program (traveling boom) was started on June 23rd and continued through August 6th with 7.0 inches of water being applied through irrigation and an additional 15.36 inches of water coming through rainfall during the growing season.

Grain yields were obtained on October 25th 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 1989 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:

Experiment 1 When no fertilizer N was applied corn yields were about 95 bu/A and soybeans yields were about 45 bu/A. Across the entire experiment corn and soybean grain yields were essentially the same utilizing a chisel system of tillage or the ridge tillage for corn following corn and beans following corn.

Yield increases were obtained with fertilizer N up to rates of 215 #/A although 85% of the yield increase was obtained with the first 50 # N/A. The hot dry summer created conditions for some very interesting responses to fertilizer management. Fertilizer use efficiency would normally increase by delaying the time of fertilizer N application thereby minimizing N loss. In 1988 and 1989 highest yields were obtained when the fertilizer was applied early (4-leaf) rather than in split or 8-leaf applications. The lack of a yield response when the timing of fertilizer N was delayed would indicate that N losses during the growing season were not large in 1988 or 1989 growing seasons. A significant yield increase (4 bu/A) was obtained with the use of N-Serve on corn. Since N-Serve is a chemical additive used with fertilizer to minimize N loss from soil, and the amount of N loss was low in both 1988 and 1989, the reason for a response is not well understood at this time. Previous N management practices had no influence on soybean yields.

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 movement of the N below the 0-2 ft sampling region. Since yields were not high it would seem feasible that at least a 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. Nitrate-N concentrations in the spring soil sampling following soybeans were higher with the chisel plow tillage system than with the ridge till system (table 4). 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 soybean plots (table 5). Water samples collected by the wick lysimeters had higher NO_3-N concentrations than the water collected in the pan lysimeters.

Experiment 2 The fertilizer N rate of 105 #/A was at or above the necessary rate to obtain optimum yields. Differences between various fertilizer N management options were therefore minimal. There were no treatment effects due to tillage, N source, N rate, or time of application.

Large Plot Groundwater Phase:

Results displayed in table 6 suggest that there was no yield advantage to the application of fertilizer N over 160 lbs/A in 1989 which corresponded to the results that were obtained in both 1987 and 1988. Corn yields following soybeans were higher than yields following corn. Application of more fertilizer N did not compensate for these differences. Higher rates of fertilizer N resulted in higher concentrations of NO_3-N in the water samples collected in the pan and wick samples (table 7). Concentration of NO_3-N was higher in the corn-soybean rotation than the respective corn-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. Influence of treatments applied in 1988 on soybean yields (soybeans following corn). Westport, MN. 1989

Total N-Rate	Early N	Inh.	Late N	Tillage	Corn Grain Yield	Corn Grain N-content	Corn Grain N-removal	Soybean Yield
#/A	#/A		#/A		Bu/A	%	#/A	Bu/A
Control	----	--	----	C	96.1	1.13	51.29	44.9
50	50	--	----	C	137.3	1.36	88.34	46.9
50	----	--	50	C	134.3	1.37	87.05	44.8
50	35	--	15	C	128.6	1.54	93.44	47.1
50	50	NS	----	C	141.0	1.34	89.01	44.3
50	----	NS	50	C	142.1	1.29	86.93	46.3
50	35	NS	15	C	124.5	1.39	82.14	45.5
105	105	--	----	C	132.7	1.40	87.92	46.9
105	----	--	105	C	123.2	1.36	79.18	46.6
105	70	--	35	C	141.0	1.46	97.34	46.3
105	105	NS	----	C	126.3	1.44	86.23	44.4
105	----	NS	105	C	142.7	1.42	95.95	47.5
105	70	NS	35	C	138.9	1.48	97.03	45.2
160	160	--	----	C	141.0	1.44	96.36	45.6
160	----	--	160	C	126.8	1.52	90.00	50.6
160	105	--	55	C	142.7	1.48	100.01	48.0
160	160	NS	----	C	143.6	1.51	102.84	46.0
160	----	NS	160	C	143.5	1.54	104.48	47.9
160	105	NS	55	C	122.4	1.49	86.36	44.6
215	215	--	----	C	133.6	1.53	96.70	46.2
215	----	--	215	C	141.4	1.46	97.54	40.5
215	145	--	70	C	131.1	1.53	94.95	48.5
215	215	NS	----	C	148.1	1.46	101.91	46.4
215	----	NS	215	C	144.6	1.51	103.09	48.3
215	145	NS	70	C	148.5	1.49	105.05	46.6
Control	----	--	----	R	94.8	1.17	52.44	43.7
50	50	--	----	R	131.9	1.42	88.78	43.1
50	----	--	50	R	126.2	1.39	83.23	45.6
50	35	--	15	R	126.6	1.32	78.95	46.5
50	50	NS	----	R	144.6	1.42	97.07	48.1
50	----	NS	50	R	129.7	1.47	90.06	44.5
50	35	NS	15	R	130.2	1.52	93.47	42.5
105	105	--	----	R	151.0	1.51	107.44	46.8
105	----	--	105	R	105.9	1.34	67.24	44.6
105	70	--	35	R	135.8	1.57	100.70	47.2
105	105	NS	----	R	126.6	1.44	86.59	47.0
105	----	NS	105	R	140.7	1.44	95.86	41.5
105	70	NS	35	R	136.3	1.55	99.61	49.4
160	160	--	----	R	141.5	1.45	96.87	48.1
160	----	--	160	R	139.3	1.50	98.75	43.4
160	105	--	55	R	137.5	1.51	97.98	45.2
160	106	NS	----	R	128.1	1.44	87.35	48.7
160	----	NS	160	R	142.2	1.41	94.63	50.4
160	105	NS	55	R	143.5	1.54	104.13	46.7
215	215	--	----	R	146.7	1.49	103.41	47.5
215	----	--	215	R	134.6	1.56	99.29	40.8
215	145	--	70	R	132.2	1.53	95.44	47.2
215	215	NS	----	R	142.7	1.52	102.35	47.3
215	----	NS	215	R	142.1	1.47	98.81	47.2
215	145	NS	70	R	139.6	1.58	104.45	47.6

Table 1. continued. Continuous Corn Split Plot Statistical Analysis
Corn Soybean Rotation Split Plot Statistical Analysis

	Corn Grain			Soybean
	Yield	N-Content	N-Removal	Yield
	Bu/A	%	#/A	Bu/A
Tillage				
Chisel	136.6	1.45	93.7	46.3
Ridge Till	135.6	1.47	94.7	46.1
P-Value	34	83	59	18
N-Rate X Method X Inhibitor				
N-Rate #/A				
50	133.1	1.40	88.21	45.4
105	133.4	1.45	91.76	46.1
160	137.7	1.48	96.64	47.1
215	140.4	1.51	100.25	46.2
P-Value	99	99	99	78
BLSD (.05)	3.5	0.03	2.42	
Method				
1. 4 leaf	138.5	1.45	94.95	46.4
2. 8 leaf	135.0	1.44	92.00	45.7
3. Split 2/3 1/3	135.0	1.50	95.69	46.5
P-Value	96	99	99	62
BLSD (.05)	3.4	0.32	2.31	
Inhibitor				
None	134.3	1.46	92.79	46.0
N-Serve	138.0	1.46	95.64	46.4
P-Value	99	28	99	54
N-Rate X Method	99	64	99	81
N-Rate X Inhibitor	86	15	66	71
Method X Inhibitor	99	14	99	93
N-Rate X Method X Inhibitor	99	31	99	82
N-Rate X Method X Inhibitor X Tillage				
N-Rate X Tillage	43	76	15	7
Method X Tillage	87	13	91	92
Inhibitor X Tillage	38	63	15	87
N-Rate X Method X Tillage	99	86	99	54
N-Rate X Inhibitor X Tillage	57	98	99	61
Method X Inhibitor X Tillage	98	88	99	28
N-Rate X Method X Inhibitor X Tillage	99	79	99	86

Table 2. Influence of N-rates, N-forms, nitrification inhibitors, time of application and two tillage systems on corn grain yields at Westport, MN. 1989

N-Rate	N-Form	Inh.	Time	Tillage	Corn Grain Yield	Corn Grain N-Content	Corn Grain N-Removal
#/A					bu/A	%	#/A
105	AA	---	1	C	129.5	1.57	96.15
105	AA	NS	1	C	121.0	1.69	96.78
105	UREA	---	1	C	130.6	1.68	103.81
105	UREA	DCD	1	C	115.0	1.57	84.77
105	AA	---	2	C	123.1	1.41	82.02
105	AA	NS	2	C	130.5	1.46	89.16
105	UREA	---	2	C	125.3	1.61	95.78
105	UREA	DCD	2	C	128.4	1.45	88.19
160	AA	---	1	C	121.8	1.63	93.59
160	AA	NS	1	C	131.7	1.59	98.76
160	UREA	---	1	C	101.8	1.72	82.53
160	UREA	DCD	1	C	135.6	1.54	97.96
160	AA	---	2	C	118.5	1.51	84.07
160	AA	NS	2	C	125.7	1.60	94.63
160	UREA	---	2	C	128.0	1.51	91.12
160	UREA	DCD	2	C	128.6	1.68	102.33
105	AA	---	1	R	136.8	1.61	103.74
105	AA	NS	1	R	143.5	1.55	104.80
105	UREA	---	1	R	143.8	1.49	101.50
105	UREA	DCD	1	R	147.0	1.56	108.61
105	AA	---	1	R	138.5	1.59	104.67
105	AA	NS	2	R	140.1	1.59	104.36
105	UREA	---	2	R	141.0	1.53	101.46
105	UREA	DCD	2	R	152.2	1.45	104.47
160	AA	---	2	R	134.7	1.76	111.95
160	AA	NS	1	R	121.8	1.58	91.29
160	UREA	---	1	R	142.7	1.55	104.15
160	UREA	DCD	1	R	140.6	1.58	105.10
160	AA	---	1	R	129.9	1.69	102.91
160	AA	NS	2	R	142.8	1.56	105.14
160	UREA	---	2	R	129.6	1.65	101.21
160	UREA	DCD	2	R	144.8	1.58	108.97

Table 2. continued. Split Plot Statistical Analysis

	Grain		
	Yield	N-Content	N-Removal
Tillage	Bu/A	%	#/A
Chisel	124.7	1.57	92.60
Ridge Till	139.3	1.58	104.02
P-Value	83	11	98
N-Form X Inh. X Time X N-Rate			
N-Form			
Anhydrous Ammonia	130.6	1.58	97.75
Urea	133.4	1.57	98.87
P-Value	67	51	46
Inhibitor			
Without	129.7	1.59	97.54
With	134.3	1.56	99.08
P-Value	89	88	60
Time			
1. 4 leaf	131.1	1.60	99.09
2. 8 leaf	132.9	1.55	97.53
P-Value	47	99	40
N-Rate #/A			
105	134.1	1.55	98.1
160	129.9	1.60	98.5
P-Value	85	99	15
N-Form X N-Rate	8	1	12
N-Form X Time	22	68	61
N-Rate X Time	10	86	77
N-Form X N-Rate X Time	10	34	28
N-Form X Inhibitor	41	40	35
N-Rate X Inhibitor	77	32	84
N-Form X N-Rate X Inhibitor	54	93	97
Inhibitor X Time	66	50	86
N-Form X Inhibitor X Time	37	24	58
N-Rate X Inhibitor X Time	49	96	47
N-Form X N-Rate X Inhibitor X Time	76	61	66
N-Form X Inhibitor X Time X N-Rate X Tillage			
N-Form X Tillage	82	99	13
N-Rate X Tillage	66	62	30
N-Form X N-Rate X Tillage	4	35	40
Time X Tillage	22	98	68
N-Form X Time X Tillage	76	35	93
N-Rate X Time X Tillage	13	71	43
N-Form X N-Rate X Time X Tillage	74	86	24
Inhibitor X Tillage	4	74	56
N-Form X Inhibitor X Tillage	23	99	96
N-Rate X Inhibitor X Tillage	89	83	99
N-Form X N-Rate X Inhibitor X Tillage	37	40	66
Inhibitor X Time X Tillage	69	89	14
N-Form X Inhibitor X Time X Tillage	51	93	37
N-Rate X Inhibitor X Time X Tillage	98	93	93
N-Form X N-Rate X Inhibitor X Time X Tillage	19	37	4

Table 3. 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 1989.

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	2.2	2.4	6.2	5.0
					2	2.0	2.0	3.4	2.0
50	50	---	---	C	1	3.5	2.4	6.9	6.1
					2	2.7	2.4	5.3	3.7
50	---	---	50	C	1	2.7	2.6	9.1	6.3
					2	2.4	2.4	5.4	3.2
105	105	---	---	C	1	2.3	2.9	7.8	7.9
					2	1.9	2.1	5.2	5.9
105	---	---	105	C	1	2.5	2.5	6.6	9.1
					2	2.0	2.2	5.3	6.0
160	160	---	---	C	1	3.2	2.8	10.3	9.1
					2	2.6	2.0	9.4	6.9
160	---	---	160	C	1	3.1	3.1	9.7	11.0
					2	2.2	6.3	11.6	11.1
160	105	---	50	C	1	2.6	2.9	8.7	7.0
					2	2.4	1.7	5.9	3.7
160	160	NS	---	C	1	4.1	4.0	11.8	12.2
					2	2.9	2.4	10.1	7.5
160	---	NS	160	C	1	2.3	11.3	8.8	13.8
					2	1.9	4.4	6.6	16.9
160	105	NS	50	C	1	2.3	2.6	7.4	6.5
					2	2.3	2.3	6.4	4.4
215	215	---	---	C	1	4.1	5.2	15.5	13.3
					2	3.6	3.4	19.3	9.5
215	---	---	215	C	1	2.3	4.1	8.9	23.3
					2	1.9	2.6	8.7	23.0
Control	---	---	---	R	1	2.2	2.2	7.0	5.4
					2	3.5	2.1	6.3	1.5
50	50	---	---	R	1	2.3	2.8	7.7	7.2
					2	2.5	2.6	3.2	2.8
50	---	---	50	R	1	2.6	2.4	7.5	6.7
					2	2.3	2.4	5.2	2.4
105	105	---	---	R	1	3.5	2.0	9.0	9.5
					2	3.3	2.3	5.4	3.1
105	---	---	105	R	1	2.5	3.7	8.0	6.2
					2	2.0	2.6	6.1	3.0
160	160	---	---	R	1	2.7	3.1	12.5	9.4
					2	2.2	2.0	9.2	5.8
160	---	---	160	R	1	4.6	2.6	12.8	8.2
					2	3.9	2.5	14.8	7.1
160	105	---	50	R	1	3.0	2.7	12.5	9.1
					2	2.6	2.4	9.2	4.2
160	160	NS	---	R	1	2.5	2.6	12.3	10.5
					2	2.0	2.6	9.8	8.2
160	---	NS	160	R	1	2.7	2.8	11.3	9.8
					2	2.3	2.5	8.0	7.4
160	105	NS	50	R	1	3.0	2.7	8.4	8.2
					2	2.3	2.6	5.6	3.9
215	215	---	---	R	1	3.9	3.8	15.7	10.4
					2	3.2	2.2	8.5	7.2
215	---	---	215	R	1	3.2	2.2	14.9	10.9
					2	3.3	2.7	29.1	9.3

Table 4. Influence of N-rate, nitrification inhibitors, methods of application and tillage in **soybeans following corn** on soil ammonium and soil nitrate from spring soil samples depth 1 (0-1 ft) and depth 2 (1-2 ft) Westport, MN 1989.

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	3.0	1.6	6.7	7.5
					2	2.7	1.8	7.7	4.4
50	50	---	---	C	1	2.7		9.9	
					2	2.4		12.7	
50	---	---	50	C	1	2.6		5.7	
					2	2.6		3.8	
105	105	---	---	C	1	2.4		9.1	
					2	2.1		12.9	
105	---	---	105	C	1	2.5		6.0	
					2	1.8		7.4	
160	160	---	---	C	1	2.7		13.5	
					2	2.5		12.0	
160	---	---	160	C	1	2.2		9.6	
					2	2.3		9.8	
160	105	---	50	C	1	2.6		7.0	
					2	2.2		6.0	
160	160	NS	---	C	1	2.8		10.5	
					2	2.4		9.4	
160	---	NS	160	C	1	2.2		7.9	
					2	2.1		7.0	
160	105	NS	50	C	1	2.5		11.7	
					2	2.6		5.0	
215	215	---	---	C	1	2.8		11.3	
					2	2.6		9.2	
215	---	---	215	C	1	3.1		17.6	
					2	2.3		22.4	
Control	---	---	---	R	1	3.3	2.1	10.7	7.2
					2	2.5	1.7	7.7	3.7
50	50	---	---	R	1	3.0		5.9	
					2	2.6		8.4	
50	---	---	50	R	1	3.5		8.0	
					2	3.1		6.0	
105	105	---	---	R	1	2.6		10.7	
					2	2.6		7.7	
105	---	---	105	R	1	2.9		8.3	
					2	2.6		5.8	
160	160	---	---	R	1	3.0		9.7	
					2	2.5		8.3	
160	---	---	160	R	1	5.7		16.1	
					2	2.5		8.0	
160	105	---	50	R	1	2.7		8.1	
					2	2.6		4.4	
160	160	NS	---	R	1	4.3		8.7	
					2	5.7		6.7	
160	---	NS	160	R	1	2.7		10.9	
					2	2.3		9.2	
160	105	NS	50	R	1	2.8		8.2	
					2	2.8		6.4	
215	215	---	---	R	1	2.4		5.0	
					2	2.1		3.3	
215	---	---	215	R	1	2.8		9.0	
					2	2.9		8.7	

Table 5. Nitrate-N concentration of water collected in pan and wick lysimeters in the small plot area, Westport, MN 1989.

N rate		Pan corn-corn	Pan corn-beans	Wick corn-corn	Wick corn-beans
#/A		ppm NO_3-N			
0		1.7	2.3	-	0.9
105	early	0.6	0.8	-	5.7
105	late	18.4	1.4	40.9	-
215	early	5.7	3.6	-	40.5
215	late	3.8	0.3	-	13.5

Table 6. Corn grain yields from large plot area Westport, MN 1989.

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	143.1	1.53	103.5
215	140	75	Corn-Corn	144.2	1.50	105.6
160	105	55	Corn-Soybeans	150.4	1.49	106.4

Table 7. Nitrate-N concentration of water collected from the pan and wick lysimeters in large plot area, Westport, MN 1989.

N rate	Rotation	NO_3-N
Pan		
lb N/A		ppm
160	corn-corn	1.7
215	corn-corn	15.5
160	corn-beans	26.4
Wick		
160	corn-corn	44.1
215	corn-corn	51.9
160	corn-beans	80.4

THE IMPACT OF RESIDUAL FERTILIZER TREATMENTS AND TILLAGE ON SOYBEAN YIELDS AND NO_3^- LEACHING[1]

D.E. Clay, G.L. Malzer, and J.L. Anderson[2]

Abstract: Coarse textured soils in central Minnesota are frequently irrigated and fertilized with N to obtain maximum corn yields. The objective of this study was to investigate the impact of tillage, nitrification inhibitor (DCD), and N rates on crop yields, and water and NO_3 leaching under an irrigated corn-corn-soybean rotation in central Minnesota. During the first two years of the study: (i) N rate increased corn yields and the concentration of NO_3 in the percolating water; and (ii) treatment of urea with DCD reduced the NO_3 concentration in the percolating water. In the third year of the study (reported here) tillage or fertilizer treatments applied during the first two years of the study did not impact soybean yields or water and NO_3 movement.

In central Minnesota coarse textured soils are frequently irrigated and fertilized with N to obtain maximum corn (Zea mays L.) yields. When excessive amounts of water or N fertilizer are applied to cropland NO_3 leaching may pose a potential health problem. Nitrate leaching may be reduced by: (i) improved N and water management, and/or (ii) improved N fertilizer recommendations.

The objective of this study was to investigate the impact of tillage, nitrification inhibitor treated fertilizer, and N rates on crop yields, and water and NO_3 leaching under an irrigated 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 (Glycine max) 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 soybeans. Water was pumped through the irrigation system at 13.8 KPa 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.

Soybeans (Pioneer 9061) were planted in the spring of 1989 at a density of 63 lbs/A, while corn (Pioneer 3790) had been planted in 1987 and 1988 at a density of 27,000 seeds/A. Soil temperature, wind speed, air temperature, and rainfall were measured at regular intervals during the 3 growing seasons. The third year of research will be reported at this time.

Treatments consisted of a factorial arrangement of 2 tillage treatments (rototillage 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 high N treatments.

Soybeans were harvested from a 30 ft row at maturity in 1989. Subsamples from the beans were analyzed for water content. Yield was adjusted to 13% moisture.

Following rainfall events, water that had collected on the bottom of the lysimeters was removed, the volume quantified and the concentration of NO_3-N determined.

---

[1] Funding provided by the Center for the Impact of Agricultural Practices on Water Quality.
[2] Adj. Asst. Professor, South Dakota State University; Associate Professor and Associate Professor respectively, Dept. of Soil Science, University of Minnesota.

Results and Discussion

Rainfall was 2.3, 2.2, 1.0, 8.0 and 1.8 inches during May, June, July, August, and September , respectively. Five inches of supplemental irrigation was applied between 12 July and 11 August.

Soybean yields ranged from 40 to 50 bu/A and were not influenced by tillage or previous N rates (table 2).

Water percolated through the lysimeters during the spring (April and May) and fall (August). During spring the amount of water percolating through the lysimeters ranged from 4 to 6 inches and was not influenced by field treatments. The NO_3-N concentration ranged from 3 to 5 ppm and also was not influenced by field treatment (table 2).

The amount of water percolating through the lysimeters in August ranged from 1.6 to 3.3 inches and was not influenced by field treatments. The NO_3-N concentration of the percolating water ranged from 3.7 to 8.5 ppm and also was not influenced by field treatment. The concentration of NO_3-N in the percolate was slightly higher in the fall than in the spring.

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

Table 2. Soybean yields and water and NO_3-N percolation through the soil profile during the 1989 growing season.

		Soybean	Spring			Fall		
Tillage	N rate	Yield	H_2O	N	NO_3-N	H_2O	N	NO_3-N
	lb/A	bu/A	in.	lb/A	ppm	in.	lb/A	ppm
Roto-till	0	47.2	4.7	1.73	3.05	2.5	1.33	5.8
	70	46.3	6.2	2.30	3.14	3.0	1.12	4.41
	140	40.5	5.3	2.10	3.46	2.2	1.35	5.52
	140 DCD	47.9	5.7	1.68	3.09	1.6	1.46	8.50
No-till	0	45.6	4.6	1.78	3.12	2.9	1.24	3.76
	70	49.2	6.0	2.21	3.29	2.7	1.35	4.23
	140	44.6	4.8	2.48	4.74	3.2	1.11	3.89
	140 DCD	42.5	5.1	2.42	3.29	2.0	1.31	6.75
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
					Tillage			
Roto-till		45.5	5.5	1.95	3.19	2.3	1.32	6.06
No-till		45.5	5.1	2.22	3.61	2.7	1.25	4.66
LSD (0.05)		NS	NS	NS	NS	NS	NS	NS
					N rate			
	0	46.4	4.7	1.76	3.09	2.8	1.29	4.78
	70	47.7	6.1	2.26	3.22	2.8	1.24	4.32
	140	42.6	4.7	2.29	4.10	2.7	1.23	4.71
	140 DCD	45.2	5.4	2.05	3.19	1.8	1.39	7.63
LSD (0.05)		NS	NS	NS	NS	NS	NS	NS

LAND TREATMENT OF SEWAGE SLUDGE INCINERATOR ASH[1]

C. Rosen, R. Polta, L. America, P. Bierman, and G. Korbel[2]

ABSTRACT: This 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. 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. The Olsen P soil test seemed to predict response to the ash amended soils better than the Bray P1 or Nitric acid extractants. Tissue analysis revealed that both P sources increased P levels in the plant; however, at equivalent P rates, tissue P concentrations were greater with the fertilizer source compared to the ash source. Although ash was a good source of Zn, movement of this element was apparent through the soil profile. Other heavy metals such as Cd, Pb, Ni, and Cr did not move out of the top 6" nor did they accumulate in the corn grain, 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 third year of a four year 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 characterized as a Estherville sandy loam with an initial pH of 5.7 and Bray P1 of 35 lb/A.

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 two 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 1988. 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 broadcast 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 13, 1989 at a population of 32,000 in 30" rows along with a furrow application of Counter insecticide. 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 23 at a depth of 18". Water samples were collected on June 19, July 18, and September 6 approximately 3 or 4 days after at least 1" of rainfall or irrigation was supplied. On June 19, 8 whole plants were sampled from each plot at the ends of the two middle rows. At this sampling, plant development corresponded to the 6-8 leaf stage. The entire plot was sidedressed with 34-0-0 (295 lbs/A) with a Gandy on June 19. Ear leaf samples were collected from each plot at the mid-silking stage (July 31). Plots (20' from the middle two rows) were harvested for grain plus cob and stover yields on September 26. Subsamples of stover and grain plus cob were

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

[2] Extension Soil Scientist, Soil Science Department, University of Minnesota, and Director of Research and Development, Metropolitan Waste Control Commission, respectively.

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 2 N HCl. Following Kjeldahl digestion, total nitrogen in plant tissues was determined using conductimetric procedures.

Soil samples were collected on September 20 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 was determined on a 1:1 soil - water extract.

RESULTS

Soil and Water Samples. Elemental analyses of the water collected in the suction cup lysimeters are presented in Table 1. For phosphorus and all heavy metals, concentrations were generally below detection limits of the ICP spectrophotometer. Other elements such as Cu, Zn and B were at background levels. One exception was zinc at the second sampling date and at the highest ash rate, which was nearly 3 times higher than the other treatments. However, even at this higher Zn concentration, it was still 30 times lower than the allowable limit for Zn in safe drinking water (< 5 ppm). 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 extracted more P from the soil amended with ash than with fertilizer, while there was no difference between the two amendments when the Bray P extractant was used. 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. Ammonium acetate and nitric acid extractable Na increased slightly with increasing ash rates. All nitric acid extracted elements except K and Co increased with ash applications. Of particular interest are 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). DTPA and nitric acid extractable Zn tended to increase with ash application. Nitric acid extractable S increased with both ash and 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 Zn and Cu increased with increasing ash rates. These results indicate that Zn and Cu are moving to some extent through the soil profile. There was also a slight trend for Cr to increase with increasing ash application.

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 cool soils. For the first time in three years at this site, there was a significant increase in grain yield with ash and fertilizer application compared to the check. Reasons for this increase were due to optimum rainfall and irrigation coupled with a gradual depletion of P from the nonfertilized plots. Stover yield was unaffected by treatment. These results clearly indicate that application of ash does not detrimentally affect yield, but may improve yields if soil P is limiting.

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 triple super phosphate was superior to the ash 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. The other heavy metals, Pb, Ni, Cr, and Cd 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 triple super phosphate plots than with the ash plots. Phosphate fertilizer increased tissue Mn, but decreased Cu and Zn concentrations compared to the ash treatments. Other heavy metals were not consistently affected by fertilizer or ash treatments.

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 tended to increase when fertilizer or ash were applied. Levels of Zn and Cu in the stover were greater with ash application compared to P fertilizer application. Fertilizer application increased P levels in the cob, while there was no effect due to ash application (Table 9). Cob Zn significantly decreased when P fertilizer was applied. Levels of P, K, Mg, and Mn in grain increased with fertilizer and ash treatments compared to those in the control plots (Table 10). Grain Zn linearly decreased with increasing P fertilizer application. Concentrations of Pb, Ni, Cr, and Cd in stover, cob, and grain tissue were either at background levels or below detection limits of the ICP.

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. Further experiments on this same site are required to substantiate the positive yield response and to evaluate longer term effects of incinerator ash on element movement in the soil profile 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
June 19		ppm														
control	--	<0.53	5.8	307	80	0.31	<0.02	7	0.04	0.05	<0.01	0.03	<0.12	<0.05	<0.01	<0.01
70	Fert.	<0.53	5.7	594	146	0.35	<0.01	13	0.15	0.09	<0.01	0.02	<0.12	<0.09	<0.01	<0.01
140	Fert.	<0.53	3.4	390	101	0.35	<0.02	13	0.07	<0.02	<0.01	0.04	<0.12	<0.05	<0.01	<0.01
280	Fert.	<0.53	5.7	300	75	0.38	<0.01	8	0.10	0.02	<0.01	0.03	<0.12	0.24	<0.01	<0.01
70	Ash	<0.53	6.4	416	104	0.41	<0.01	11	0.07	0.02	<0.01	0.04	<0.12	<0.06	<0.01	<0.01
140	Ash	<0.53	5.2	306	80	0.31	0.02	10	0.03	0.04	<0.01	0.03	<0.12	<0.11	<0.01	<0.01
280	Ash	<0.53	2.8	145	41	0.24	<0.01	10	0.02	<0.01	<0.01	0.02	<0.12	<0.05	<0.01	<0.01
July 18																
control	--	<0.53	4.9	300	79	0.31	<0.01	7	0.03	0.05	<0.01	0.04	<0.12	<0.05	<0.01	<0.02
70	Fert.	<0.53	5.5	596	151	0.33	0.01	13	0.14	0.11	<0.01	0.04	<0.13	<0.08	<0.01	<0.02
140	Fert.	<0.53	4.9	416	110	0.31	<0.01	11	0.07	0.06	<0.01	0.05	<0.12	<0.05	<0.01	<0.01
280	Fert.	<0.53	7.1	312	80	0.39	<0.01	8	0.06	0.05	<0.01	0.04	<0.12	0.14	<0.01	<0.03
70	Ash	<0.53	29.1	520	132	0.37	<0.01	9	0.06	0.04	<0.01	0.05	<0.12	<0.05	<0.01	<0.02
140	Ash	<0.53	6.1	367	99	0.34	<0.01	9	<0.02	0.05	<0.01	0.05	<0.12	<0.05	<0.01	<0.02
280	Ash	<0.67	5.0	169	46	0.18	<0.01	13	0.05	0.15	<0.01	0.05	<0.12	<0.05	<0.01	<0.01
September 6																
control	--	<0.53	4.2	464	122	0.40	0.02	11	0.01	0.07	<0.01	0.04	<0.12	<0.05	<0.02	<0.01
70	Fert.	<0.53	4.4	776	195	0.31	0.02	16	0.15	0.07	<0.01	0.03	<0.12	<0.05	<0.01	<0.01
140	Fert.	<0.53	4.2	456	118	0.39	<0.01	11	0.04	0.05	<0.01	0.04	<0.12	<0.05	<0.02	<0.01
280	Fert.	<0.53	6.3	379	95	0.45	0.01	11	0.05	0.03	<0.01	0.04	<0.13	<0.09	<0.01	<0.01
70	Ash	<0.54	5.3	849	216	0.25	<0.01	13	0.02	0.05	<0.01	0.04	<0.12	<0.05	<0.02	<0.01
140	Ash	<0.53	4.5	395	105	0.40	0.02	10	0.01	0.06	0.02	0.04	<0.12	<0.06	<0.01	<0.01
280	Ash	<0.53	3.3	202	57	0.31	0.01	10	<0.01	0.03	<0.01	0.03	<0.12	<0.05	<0.01	<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	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			ppm													
Control	-	5.5	12.8	6.0	132	1772	248	5.1	88.0	50.3	1.3	1.03	1.29	2.26	0.06	0.12
70	Fert.	5.5	41.0	19.8	131	1812	250	6.8	91.0	52.8	1.4	1.01	1.21	2.37	0.09	0.14
140	Fert.	5.4	69.0	32.3	136	1794	249	6.6	86.1	51.1	1.4	1.03	1.23	2.36	0.07	0.12
280	Fert.	5.6	108.4	48.0	123	1805	248	6.0	83.0	46.0	1.4	1.00	1.15	2.47	0.07	0.11
70	Ash	5.5	43.3	18.9	142	1787	250	6.6	86.1	44.9	2.1	1.85	1.31	2.39	0.07	0.17
140	Ash	5.7	66.3	21.8	135	1848	273	6.9	79.0	38.3	2.7	2.73	1.46	2.22	0.05	0.19
280	Ash	5.8	156.6	38.8	134	1926	298	8.6	81.3	33.2	4.4	5.02	1.63	2.41	0.06	0.32
Significance		**	**	**	NS	NS	NS	*	NS	*	**	**	*	NS	NS	**
BLSD(0.05)		0.2	37.9	9.7	-	-	--	1.7	--	13.3	0.6	0.60	0.35	-	-	0.04
Contrasts																
Ctrl vs Rest		NS	**	**	NS	NS	NS	**	NS	NS	**	**	NS	NS	NS	**
Fert vs Ash		**	NS	*	NS	NS	*	NS	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
Linear Ash		**	**	**	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 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	-	66	170	2715	444	1693	372	11.8	141	5.1	3.4	1.3	5.27	4.36	0.97	0.29	1.68	98	0.80	0.62	18
70	Fert	113	173	2879	463	1847	433	13.8	163	5.7	3.7	1.4	5.92	4.92	1.09	0.32	1.83	108	0.89	0.68	20
140	Fert	157	174	2749	441	1818	444	13.3	170	5.4	3.6	1.3	5.69	4.86	1.11	0.32	1.76	102	0.91	0.59	20
280	Fert	226	164	2892	472	1939	501	13.6	171	5.9	3.7	1.4	6.01	5.06	1.21	0.33	1.87	108	0.87	0.63	22
70	Ash	151	178	2760	439	1776	409	14.0	152	6.9	6.0	1.3	5.97	4.71	1.28	0.42	1.76	103	0.82	0.59	20
140	Ash	242	173	3020	495	1951	483	16.5	162	9.4	9.4	1.4	6.89	4.83	1.88	0.59	1.89	107	0.86	0.68	21
280	Ash	528	182	3451	564	2178	578	21.5	172	15.7	18.6	1.6	8.48	5.52	3.17	1.00	2.04	119	0.85	0.71	22
Significance		**	NS	**	*	**	**	**	NS	**	**	**	**	*	**	**	**	*	NS	NS	NS
BLSD (0.05)		81	-	366	94	151	69	2.2	25	1.5	2.0	0.1	0.73	0.62	0.30	0.10	0.14	11	-	0.16	4
Contrasts																					
Ctrl. vs Rest		**	NS	NS	NS	**	**	**	**	**	**	*	**	**	**	**	**	*	NS	NS	*
Fert. vs Ash		**	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	*
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	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			ppm													
Control	-	6.0	3.5	1.8	50	1581	247	6.2	26.6	10.1	0.3	0.77	0.48	1.16	<0.03	<0.02
70	Fert.	5.8	6.8	2.0	58	1797	271	8.2	34.5	11.7	0.5	0.84	0.59	1.41	<0.04	<0.04
140	Fert.	5.9	8.3	3.5	63	1740	263	7.8	34.4	12.8	0.5	0.87	0.51	1.37	<0.04	<0.03
280	Fert.	5.9	8.0	4.5	59	1641	246	7.5	33.9	12.3	0.5	0.72	0.55	1.56	<0.04	<0.03
70	Ash	5.9	5.3	2.5	55	1730	264	7.3	31.0	11.4	0.4	0.86	0.52	1.33	<0.03	<0.03
140	Ash	5.9	6.8	2.3	52	1589	242	6.8	30.0	11.1	0.4	0.78	0.42	1.08	<0.02	<0.03
280	Ash	5.9	8.0	3.5	59	1776	275	9.0	30.8	12.7	0.5	0.87	0.51	1.28	<0.04	0.03
Significance		NS	*	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-
BLSD (0.05)		-	3.7	1.6	-	-	-	-	-	-	-	-	-	-	-	-
Contrasts																
Ctrl vs Rest		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	-	-
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	-	-
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 = 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	-	48	56	2172	564	1591	608	13	53	4.1	2.7	0.8	4.00	3.29	1.35	0.21	1.6	68	0.41	0.53	9.4
70	Fert.	34	63	2507	612	1792	630	15	65	4.9	3.2	1.0	4.65	3.67	1.45	0.24	1.8	89	0.50	0.63	13.0
140	Fert.	49	64	2361	564	1668	603	14	67	4.6	3.0	0.9	4.47	3.77	1.36	0.22	1.7	78	0.48	0.56	12.6
280	Fert.	46	72	2306	563	1679	622	16	64	4.7	2.8	1.0	4.48	4.16	1.38	0.22	1.7	79	0.46	0.57	13.8
70	Ash	45	63	2311	578	1692	628	15	57	4.5	3.0	1.0	4.47	3.56	1.40	0.24	1.8	77	0.47	0.57	11.4
140	Ash	57	58	2157	547	1657	646	14	64	4.5	2.8	0.9	4.21	3.17	1.39	0.23	1.6	74	0.42	0.55	12.9
280	Ash	50	63	2401	639	1816	743	16	62	5.2	3.3	0.9	4.61	3.45	1.60	0.25	1.8	83	0.43	0.60	13.1
Significance		NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD (0.05)		-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.2
Contrasts																					
Ctrl vs Rest		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	NS
Linear Fert.		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	*
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	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			ppm													
Control	-	6.7	3.0	1.3	42	982	159	3.4	16.7	13.9	0.24	0.62	<0.33	0.82	<0.03	<0.02
70	Fert.	6.7	4.3	1.5	45	1121	175	4.0	18.3	14.3	0.26	0.85	<0.37	0.89	<0.03	<0.03
140	Fert.	7.1	4.3	2.8	48	1328	168	<3.5	16.4	14.9	0.26	0.93	<0.31	0.93	<0.03	<0.03
280	Fert	7.1	5.0	2.5	44	1343	174	3.6	15.5	15.0	0.21	0.86	<0.35	0.88	<0.05	<0.02
70	Ash	6.9	4.0	2.0	38	1059	152	2.6	15.7	14.4	0.26	0.66	<0.24	0.83	<0.03	<0.03
140	Ash	7.1	4.8	2.0	38	1299	163	3.0	15.6	12.3	0.24	0.80	<0.26	0.77	<0.02	<0.07
280	Ash	6.8	7.8	2.8	43	1289	179	<3.8	18.2	17.4	0.28	0.80	<0.34	0.85	<0.04	<0.03
Significance		NS	NS	NS	NS	NS	NS	-	NS	NS	NS	NS	-	NS	-	-
BLSD (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	-	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	-	-
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 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	-	114	52	2663	1014	967	717	11	65	3.0	2.1	0.7	2.79	3.80	1.10	0.19	1.3	39	0.24	0.39	6.7
70	Fert.	98	54	3406	1086	1016	696	11	69	3.1	2.5	0.7	2.94	4.35	1.15	0.19	1.4	47	0.29	0.41	7.7
140	Fert.	109	51	4618	1601	900	727	11	74	3.0	2.6	0.8	2.67	4.61	1.10	0.19	1.3	40	0.31	0.34	8.4
280	Fert.	117	54	6096	1970	867	742	13	79	3.0	2.8	0.9	2.88	6.20	1.15	0.22	1.4	43	0.35	0.36	11.0
70	Ash	121	52	5475	2070	881	757	12	77	3.1	2.5	0.9	3.03	4.63	1.14	0.23	1.5	42	0.35	0.38	9.5
140	Ash	136	50	8001	2804	1042	876	14	85	3.7	2.9	1.0	3.44	3.81	1.38	0.26	1.6	40	0.37	0.61	13.4
280	Ash	145	55	6587	2169	1064	916	12	86	3.8	3.0	1.0	3.04	4.23	1.31	<0.25	1.5	50	0.24	0.40	12.1
Significance		NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS	NS	NS	-	NS	NS	NS	*	NS
BLSD (0.05)		-	-	-	-	-	-	-	-	0.7	0.5	-	-	-	-	-	-	-	-	0.17	-
Contrasts																					
Crtl vs Rest		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
Linear Fert.		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
Linear Ash		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 = 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, grain yield (dry weight basis), and stover yield (dry weight basis).

Treatment	P Source	Early plant yield 8-12 leaf	Grain yield	Stover yield
lb P_2O_5/A		g dw	bu/A	T/A
Control	-	4.29	130.1	2.80
70	Fert.	5.77	141.1	2.90
140	Fert.	7.77	147.9	2.78
280	Fert.	8.91	145.7	3.08
70	Ash	5.28	145.7	3.01
140	Ash	6.31	150.9	2.90
280	Ash	6.78	149.3	2.92
Significance		**	**	NS
BLSD (0.05)		1.73	9.36	-
Contrasts				
Control vs Rest		**	**	NS
Fert. vs Ash		*	NS	NS
Linear Fert.		**	**	NS
Quad. Fert.		NS	*	NS
Linear Ash		**	**	NS
Quad. Ash		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	-	3.77	0.27	3.55	0.60	0.38	427	376	35	104	35	7.6	8.4	<1.2	0.78	1.4	<0.24
70	Fert.	3.86	0.28	3.80	0.64	0.34	441	391	38	110	41	6.1	8.1	<1.3	1.03	1.4	0.32
140	Fert.	3.98	0.31	3.98	0.65	0.32	394	367	27	114	30	5.3	9.3	<1.2	<0.96	1.4	<0.27
280	Fert.	4.06	0.38	3.92	0.68	0.33	488	450	43	139	28	4.5	8.1	<1.2	<1.07	1.7	0.61
70	Ash	3.79	0.28	3.68	0.62	0.33	578	481	44	119	39	7.2	8.3	<1.2	0.86	1.5	<0.20
140	Ash	3.87	0.29	3.87	0.57	0.34	403	364	30	104	41	7.8	8.6	<1.4	1.12	1.7	0.44
280	Ash	3.94	0.31	3.85	0.56	0.33	444	395	32	96	43	8.0	7.8	<1.3	<0.96	1.4	0.37
Significance		NS	**	NS	*	NS	NS	NS	NS	**	NS	**	NS	-	-	NS	-
BLSD (0.05)		-	0.03	-	0.08	-	-	-	-	19	-	0.8	-	-	-	-	-
Contrasts																	
Ctrl vs Rest		NS	**	*	NS	*	NS	NS	NS	NS	NS	**	NS	-	-	NS	-
Fert vs Ash		NS	**	NS	**	NS	NS	NS	NS	**	*	**	NS	-	-	NS	-
Linear Fert.		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	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 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	-	3.08	0.24	2.05	0.46	0.31	20	274	19	98	38	10	9.9	<1.1	<0.5	0.24	<0.17
70	Fert.	2.96	0.25	2.06	0.54	0.33	21	252	22	126	34	8	10.2	<1.1	<0.5	0.28	<0.19
140	Fert.	2.90	0.28	2.07	0.58	0.34	24	269	19	127	27	7	10.0	<1.1	<0.5	0.27	0.24
280	Fert.	2.81	0.34	1.94	0.61	0.36	25	262	24	143	20	4	8.8	<1.1	<0.5	0.29	<0.18
70	Ash	3.02	0.26	2.11	0.51	0.30	22	259	18	134	45	9	10.9	<1.1	<0.5	0.23	<0.19
140	Ash	3.00	0.26	2.05	0.50	0.32	22	284	18	100	41	8	9.7	<1.1	<0.5	0.25	<0.14
280	Ash	2.94	0.26	2.04	0.55	0.35	27	273	23	101	42	9	10.0	<1.1	<0.5	0.27	<0.19
Significance		**	**	NS	**	NS	NS	NS	NS	*	**	**	NS	-	-	NS	-
BLSD (0.05)		0.11	0.01	-	0.04	-	-	-	-	29	5	1	-	-	-	-	-
Contrasts																	
Ctrl vs Rest		**	**	NS	**	NS	NS	NS	NS	*	NS	**	NS	-	-	NS	-
Fert. vs Ash		**	**	NS	**	NS	NS	NS	NS	*	**	**	NS	-	-	NS	-
Linear Fert.		*	**	NS	**	NS	*	NS	NS	**	**	**	NS	-	-	NS	-
Quad Fert.		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 8. Effect of sludge ash and phosphate fertilizer on elemental composition of stover at harvest.

Treatment	P Source	N	K	Ca	Mg	P	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
lb. P_2O_5/A		%				ppm											
Control	-	0.68	1.47	0.31	0.31	396	62	117	15	77	20	7	4.8	<1.1	<0.5	0.36	<0.09
70	Fert.	0.74	1.74	0.36	0.27	414	75	122	14	79	16	7	4.8	<1.4	0.8	0.30	<0.12
140	Fert.	0.75	1.96	0.37	0.26	609	82	128	15	85	11	6	4.8	<1.4	<0.8	0.33	<0.10
280	Fert.	0.91	1.59	0.40	0.25	1030	74	141	16	90	9	5	4.9	<1.8	<0.6	0.41	<0.12
70	Ash	0.64	1.78	0.33	0.26	390	60	112	15	88	20	7	5.1	<1.1	<0.6	0.24	<0.10
140	Ash	0.71	1.63	0.32	0.28	398	61	111	14	69	25	7	4.6	<1.7	<0.6	0.34	<0.13
280	Ash	0.78	1.77	0.36	0.29	449	71	126	14	71	19	7	4.9	2.0	<0.7	0.33	<0.11
Significance		NS	*	**	NS	**	NS	NS	NS	NS	*	**	NS	-	-	NS	-
BLSD (0.05)		-	0.26	0.05	-	148	-	-	-	-	9	1	-	-	-	-	-
Contrasts																	
Ctrl vs Rest		NS	**	**	*	*	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	-
Quad Fert.		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	-
Quad Ash		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	K	P	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
lb. P_2O_5/A		%		ppm													
Control	-	0.40	0.48	306	116	504	2.0	15	<3.3	13	40	13	2.6	<2.3	1.03	<0.11	<0.16
70	Fert.	0.35	0.45	292	108	471	1.3	14	<2.7	13	32	11	2.1	<2.0	0.90	<0.11	0.24
140	Fert.	0.38	0.46	353	107	462	1.4	14	<2.3	13	25	11	2.2	<1.5	0.86	<0.11	<0.15
280	Fert.	0.37	0.42	430	110	409	1.7	13	<2.6	14	16	9	2.0	<1.5	0.64	<0.13	<0.18
70	Ash	0.37	0.44	294	103	472	<1.5	14	<3.2	12	39	13	2.3	<1.9	0.65	<0.11	<0.08
140	Ash	0.33	0.46	266	93	455	1.2	14	<2.4	11	36	13	2.1	2.5	0.92	<0.11	<0.13
280	Ash	0.35	0.45	309	95	441	1.3	14	<2.4	11	38	12	2.3	<15.8	0.72	<0.11	<0.16
Significance		NS	NS	**	NS	NS	-	NS	-	NS	**	NS	NS	-	NS	-	-
BLSD (0.05)		0.07	-	84	-	-	-	-	-	4	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	-	-
Linear Fert.		NS	NS	**	NS	*	-	NS	-	NS	**	NS	**	-	*	-	-
Quad Fert.		NS	NS	NS	NS	NS	-	NS	-	NS	NS	NS	NS	-	NS	-	-
Linear ASh		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 = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 10. Effect of sludge ash and phosphate fertilizer on the elemental composition of grain 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	-	1.43	0.20	0.32	36	1147	<0.5	22	<4.4	6.5	22	1.4	2.0	<1.1	<0.5	<0.1	<0.2
70	Fert.	1.44	0.25	0.33	38	1270	<0.5	23	<1.9	7.5	22	0.9	2.1	<1.1	<0.5	<0.1	<0.2
140	Fert.	1.54	0.32	0.38	35	1481	<1.6	24	<4.3	8.8	21	<0.6	2.1	<1.1	<0.5	<0.1	<0.1
280	Fert.	1.53	0.36	0.40	34	1576	<0.9	25	<2.2	9.5	18	<0.3	2.0	<1.1	<0.5	<0.1	<0.1
70	Ash	1.42	0.25	0.34	37	1271	<0.8	23	<2.6	7.4	23	1.3	2.1	<1.1	<0.5	<0.1	<0.1
140	Ash	1.43	0.27	0.35	36	1326	0.7	23	<4.6	7.2	23	1.2	2.1	<1.1	<0.5	<0.1	<0.1
280	Ash	1.43	0.27	0.36	37	1352	<1.4	23	<1.9	7.3	23	1.3	2.2	<1.1	<0.5	<0.1	<0.1
Significance		*	**	**	NS	**	-	NS	-	**	**	-	NS	-	-	-	-
BLSD (0.05)		0.09	0.02	0.02	-	109	-	4	-	0.9	2	-	-	-	-	-	-
Contrasts																	
Ctrl vs Rest		NS	**	**	NS	**	-	NS	-	**	NS	-	NS	-	-	-	-
Fert. vs Ash		**	**	*	NS	**	-	NS	-	**	**	-	NS	-	-	-	-
Linear Fert.		*	**	**	NS	**	-	*	-	**	**	-	NS	-	-	-	-
Quad Fert.		NS	**	NS	NS	*	-	NS	-	NS	NS	-	NS	-	-	-	-
Linear Ash		NS	**	**	NS	**	-	NS	-	NS	NS	-	NS	-	-	-	-
Quad Ash		NS	**	NS	NS	NS	-	NS	-	NS	NS	-	NS	-	-	-	-

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

UREA MANAGEMENT--RATE AND TIME OF APPLICATION AND NITRIFICATION INHIBITORS--FOR CORN PRODUCTION

M.A. Schmitt, R.H. Beck, and W. Connolly[1]

ABSTRACT: A field trial was established in 1986 to study the effects of urea management on continuous corn production on coarse-textured, nonirrigated soils. The results from 1989 show that fall applications of urea, regardless of rate or inhibitor treatment, were inferior to spring or sidedress treatments. However, within all application dates, there were yield differences due to nitrogen rate and nitrification inhibitors. The effect of the inhibitors were more pronounced with the lower rate of nitrogen.

Nitrogen (N) management is continually under scrutiny due to its overall effect on yields and profitability. In recent years the concern regarding groundwater quality has added to this scrutiny--especially in "sensitive" areas. Western Wisconsin and eastern Minnesota can be characterized as "sensitive" due to its coarse-textured soils.

Nitrogen product selection can be difficult for producers in this area. While anhydrous ammonia is the cheapest, its inconvenience is sometimes a drawback. Liquid UAN-28 is very convenient, especially for sidedress applications that are sometimes warranted with these soils, but UAN-28 is relatively expensive. Urea prices fluctuate between these other two product's prices and can therefore be quite attractive since handling a granular product is not necessarily a disadvantage.

The objectives of this project are to examine the effects of: urea application timing, urea N rate, nitrification inhibitor use with urea, and the possible interaction of N management and hybrid selection.

MATERIALS AND METHODS

The field site used in River Falls, Wisconsin is at the University of Wisconsin-River Falls. Soil texture is sandy loam with 2.1% organic matter and the drainage class is well-drained. The pH was 6.7 and the P and K soil tests were in the 'very high' category. The field has been continuous corn for the past 4 years.

Granular urea was the N source for the entire project. For treatments including dicyandiamide (dcd.), urea which had dcd. added in the melt at the Agrico plant in 1985 was used. This was a 5% dcd. N/urea N ratio. The N-Serve treatments had nitrapyrin impregnated at a 2 lbs./A rate equivalent. The N treatments consisted of 2 rates of N (60 and 120 lbs N/A), 3 stabilizer treatments (none, dicyandiamide, and N-Serve), and 3 application times (fall, spring, and sidedress).

All the fall treatments were applied on November 17, 1988. The spring applications were made on April 22, 1989, with all treatment combinations. The urea was incorporated immediately after application was a disk. Sidedress applications were made on June 9, 1989, when the corn was in the V6 stage of growth. At this time, the fertilizer was applied down each row using a drop spreader and then incorporated with a cultivator.

Corn was planted on May 4 at a depth of 2 inches with a band of starter fertilizer in a 2x2 inch placement away from the seed. The starter fertilizer supplied 18 lbs. N, 46 lbs. P_2O_5, and 60 lbs K_2O per acre. The seed was planted in 30-inch rows at a population of 28,200 plants/A.

Three corn hybrids were used in this study. These were selected on the basis of the most widely grown hybrids for the area when the study was initiated. These included Pioneer 3790 and Pioneer 3737, and Cenex 2100 95- and 100-day and 100-day relative maturity hybrids, respectively.

Above-ground plant samples were taken for total N when the corn was in the V4, V9, and R1 stages of growth (on June 9, June 29, and July 21, respectively). Yields were measured by harvesting 40 feet of row and adjusting to a 15.5% bushel per acre equivalent.

Soil samples were taken to a depth of 6 inches and 12 inches in each plot at the same time plant samples were taken. The samples were frozen and then analyzed for ammonium-N and nitrate-N. After harvest, each plot had a soil core removed to a depth of 4 feet. The core was split into one-foot sections and these samples were frozen and analyzed for ammonium-N and nitrate-N.

[1] M.A. Schmitt is an assistant professor and extension soil fertility specialist in the Department of Soil Science at the University of Minnesota, R.H. Beck is a soil scientist with Cenex/Land O'Lakes in St. Paul, Minnesota, and W. Connolly is field supervisor at the University of Wisconsin-River Falls.

The experimental design for this experiment is a split-plot of a randomized complete block, with hybrids being the factor using the split plots. The main plot treatments were determined by using a 3-factor factorial treatment design. The factors were N application date, N application rate, and N stabilizers.

RESULTS AND DISCUSSION

The 1989 growing season was relatively dry in terms of total precipitation; however, the timeliness of the rains did provide for good growing conditions and yields. The springtime conditions did put stress on the corn plants due to a combination of cool and dry soil conditions along with some herbicide injury that did occur. As a result, the phenological uniformity of the stand was not as good as desired.

Plant N and yield

The main effects of N application date, application rate, and hybrid grown had consistent, statistically significant results (Table 1). There were very few interactions of these main effects that were significant. Grain yields were depressed with the fall N applications as well as with the lower rate of N with the spring application (Table 2). Even though the sidedress application of the low N rate equaled the spring application with the high N rate in 1989, the long term results of this study show that sidedress applications are not more efficient than spring applications.

The yield differences with the inhibitor treatments were not statistically different. Although the nitrification inhibitors appeared to have the same effect averaged across all other treatments (Table 3), the yields from the DCD-amended plots were better with the fall and spring treatments while the N-Serve plots were superior with the sidedress treatments (Table 2). Some of these differences may be explained in impregnation and volatilization differences each of these products encounter when used with urea.

Hybrid differences were statistically different for all parameters measured--exemplifying the genetic differences between the hybrids. Since there was a relative maturity difference among the hybrids, the grain moisture differences were expected. Yields were different as well as the N uptake patterns of the plants in the early portion of the season (Table 3). Although the hybrids N contents were a function of the available N in the soil (time and rate effects), the relative amounts were always genetically regulated by the specific hybrid. While the N uptake and use may vary by the hybrid, there is no indication of a hybrid by N rate yield response interaction.

Soil Nitrogen

Virtually every main effect and interaction had a significant effect on the concentration of ammonium-N and nitrate-N in the top 6 and 12 inches in the soil (Table 4). The two depths of soil were selected since the urea was applied and incorporated to a depth no greater than 6 inches. On the June 9th sampling, the sidedress treatments were no applied before the samples were taken so the values are representative of background N levels (Table 5). The fall treatments were significantly higher for both depths than sidedress ("control" at this date) yet lower than the spring application for nitrates. Since no significant ammonium-N differences were noted between the fall and spring applications, nitrification had converted all of the urea (ammonium) to nitrate-N.

At the June 29 and July 20 sampling dates, there was a major influence of the sidedress application on the amount of nitrate found in the soil (Table 5). The ammonium differences were not noticeable with the main effect means. The effect of N rate was consistent across all sampling dates for nitrate. The more N applied, the more nitrate was found in the soil. Ammonium levels were not as affected by N rate.

Nitrate concentrations in the soil peaked on the June 29 sampling and were declining by the July 20 sampling. While nitrification of the fertilizer N created an increase up until this point, it is predicted that the plant demand for N was high during July and this caused the decrease. Whereas the ammonium concentration followed the same pattern, the effect of the nitrification inhibitors did not retain more measured ammonium-N at the sampling dates to alter this pattern.

SUMMARY

The results from this study indicate that the yield response to N management strategies can be interpreted by examining soil N levels. Those strategies that result in low soil N during the season will result in lower yields. While this study did not attempt to calibrate the plant response and soil N concentrations, the correlation holds true.

Table 1. Significance[1] of main effects and interactions based on whole plant N concentrations and grain moisture and yield, River Falls, 1989.

	Plant Sampling Date			Grain	
	June 9	June 29	July 20	Moisture	Yield
Application Date (D)	**	**	**	NS	**
Application Rate (R)	**	**	**	**	**
D x R	NS	NS	**	NS	NS
N Stablizer (S)	*	NS	NS	NS	NS
S x D	**	NS	NS	NS	NS
S x R	NS	NS	NS	NS	NS
S x D x R	NS	NS	NS	*	NS
Hybrids (H)	**	**	**	**	**
H x D	NS	*	**	NS	NS
H x R	NS	NS	NS	**	NS
H x D x R	NS	NS	NS	NS	NS
H x S	NS	NS	NS	NS	NS
H x S x D	NS	NS	**	NS	NS
H x S x R	NS	NS	NS	NS	NS
H x S x D x R	NS	NS	*	NS	NS

[1] **, *, and NS represent probabilities of larger F values of >0.05, >0.10, and <0.10, respectively.

Table 2. Corn grain yields as affected by N application date and rate, and nitrification inhibitors, River Falls, 1989.

Application Date	N Rate	Nitrification Inhibitor	Hybrids Average
	lbs N/A		- - bu/A - -
Fall	78	None	107.4
		DCD	123.2
		N-Serve	121.7
	138	None	147.0
		DCD	147.7
		N-Serve	133.4
Spring	78	None	132.2
		DCD	159.0
		N-Serve	136.3
	138	None	154.7
		DCD	150.2
		N-Serve	148.5
Sidedress	78	None	153.1
		DCD	143.0
		N-Serve	161.6
	138	None	143.0
		DCD	152.4
		N-Serve	171.1

Table 3. Mean plant N concentrations at each sampling date as affected by treatment main effects, River Falls, 1989.

	Plant Sampling Date			Grain	
	June 9	June 29	July 20	Moisture	Yield
	- - - - - - - % N - - - - - - -			- - % - -	bu/A
Time of Application					
Fall	4.68	3.03	1.60	24.6	130.1
Spring	4.85	3.11	1.65	24.4	146.8
Summer	4.55	3.23	2.07	24.5	152.8
N Rate					
60	4.61	3.05	1.66	24.0	136.6
120	4.77	3.19	1.89	25.0	149.8
Stablizer					
None	4.61	3.12	1.79	24.7	139.6
DCD	4.69	3.12	1.80	24.2	144.6
N-Serve	4.77	3.12	1.73	24.5	145.4
Hybrids					
Pio. 3790	4.35	2.88	1.60	21.4	139.5
Cenex 2100	4.80	3.28	1.93	28.1	136.1
Pio. 3737	4.92	3.21	1.79	23.9	154.0

Table 4. Significance[1] of main effects and interactions based on soil ammonium-N and nitrate-N concentrations, River Falls, 1989.

	June 9		June 27		July 20	
NO_3-N	0-6"	0-12"	0-6"	0-12"	0-6"	0-12"
Application Date (D)	**	**	**	**	**	**
Application Rate (R)	**	**	**	**	**	**
D x R	**	**	**	**	**	NS
N Inhibitor (I)	**	**	NS	**	**	*
I x D	**	*	**	**	**	NS
I x R	**	NS	**	NS	**	**
I x D x R	**	**	NS	**	**	NS
NH_4-N						
Application Date (D)	**	NS	**	**	**	NS
Application Rate (R)	NS	NS	NS	NS	*	*
D x R	**	**	**	**	**	**
N Inhibitor (I)	*	NS	**	NS	*	NS
I x D	NS	**	**	**	**	**
I x R	*	**	NS	*	**	NS
I x D x R	**	**	**	**	**	**

Table 5. Soil ammonium-N and nitrate-N means as affected by treatment factors and date of sampling, River Falls, 1989.

NO_3-N	June 9		June 29		July 20	
Time of Application	0-6	0-12	0-6	0-12	0-6	0-12
Fall	18.2	21.1	23.4	14.2	17.4	20.5
Spring	27.0	23.6	31.1	14.9	18.1	25.1
Sidedress	13.1	13.9	48.6	24.9	35.9	34.4
N Inhibitor						
None	20.7	20.2	33.7	16.3	21.6	27.1
Dcd	18.8	17.8	33.7	19.5	26.1	25.1
N-Serve	18.9	20.4	35.7	18.1	23.8	27.8
N Rate						
78	17.0	17.3	27.8	15.3	18.4	22.7
138	22.0	21.8	40.9	20.7	29.2	30.7
NH_4-N						
Time of Application						
Fall	1.72	2.04	2.72	1.48	1.33	1.28
Spring	2.24	1.82	1.86	1.46	0.94	1.43
Sidedress	1.33	1.74	1.84	1.84	1.16	1.34
N Inhibitor						
None	1.96	2.01	2.27	1.63	1.08	1.50
DCD	1.82	2.01	2.63	1.73	1.07	1.29
N-Serve	1.52	1.60	1.51	1.41	1.28	1.27
N Rate						
78	1.82	1.74	2.20	1.63	1.07	1.26
138	1.72	2.00	2.08	1.56	1.22	1.45

INFLUENCE OF NITROGEN AND POTASSIUM FERTILIZATION ON THE YIELD AND NUTRIENT ACCUMULATION OF FOUR DIFFERENT CORN HYBRIDS--1989 [1]

G.L. Malzer, G.W. Randall and T.J. Graff [2]

ABSTRACT: How different corn hybrids utilize fertilizer and soil nutrients may impact the best fertilizer management that a producer should utilize. Previous research results would suggest that hybrids do vary in the total quantity and time period of nutrient absorption. The objectives of this experiment are to evaluate the N accumulation patterns of different corn hybrids and to determine the impact of N rate, K rate, and nitrification inhibitors on yield and N utilization. Results from both Becker and Waseca support the yields and N utilization differences between hybrids. Numerous interactions between hybrid with N and K and nitrification inhibitors treatments would suggest that management treatments can impact the utilization efficiency of a given corn hybrid.

Two experimental locations were selected in 1986 and two experiments established at each location. The two locations were: 1. The Sand Plains Research farm, Becker, MN (irrigated) and 2. Southern Experiment Station, Waseca, MN (dryland). In 1986 a corn and soybean experiment was started at each location to provide for a future corn-soybean sequence. In 1987 nitrogen (N) and potassium (K) treatments were established at each location.

The objectives of these experiments were to: 1. Determine the nutrient accumulation patterns of different corn hybrids grown in a high yield environment, and 2. Evaluate the impact of N, and K, and the use of nitrification inhibitors on the yields and nutrient utilization of different corn hybrids in a corn-soybean sequence.

Experimental Procedures

Becker: A total of 56 treatments with four replications were established on the corn experimental site. A split plot design was utilized with K as the main plot. Nitrogen and hybrid treatments were randomized within the main plots. A modified factorial arrangement consisting of four corn hybrids (Pioneer 3615, Pioneer 3737, LH74 x LH85, and DeKalb 485), three N rates (80, 160, and 240 lbs/A), two nitrification inhibitor treatments (w/wo N-Serve 0.5 lbs/A a.i.), and three K fertilizer rates (0, 100, and 200 lbs K/A) were utilized. To reduce the size of the experiment not all combinations of K were utilized with the 160 lbs/A N treatment.

Potassium treatments were broadcast before planting and incorporated by plowing. The four corn hybrids were planted on April 27th, at a population of 30,700 seeds/A in 30 inch rows. Starter fertilizer was applied as a side banded application of 160 lbs/A of 10-10-10. Weed control was accomplished by using Dual 8E (2.0 lbs/A a.i.) on April 28th and one cultivation on May 30. Nitrogen treatments were applied as anhydrous ammonia on June 7th (4-5 leaf growth stage). The nitrification inhibitors were injected into the anhydrous ammonia flow stream and forced to passed through a bidirectional flow integrator prior to the manifold.

Plant and soil samples were taken four times during the growing season. Plant samples were taken on July 19th, August 8th, August 22th, and September 20th. These dates corresponded to the tasseling, milk stage R3, dent stage R5, and physiological maturity growth stages, respectively. Total plant material was removed from 20 ft^2 of plot area for each of the first three harvests and 100 ft^2 was sampled for the final sampling. For the first harvest total dry matter production was determined and subsamples collected for N concentration and determination of total N uptake. Plant samples obtained during the second, third and fourth harvest were separated into grain and stover samples. Separate determinations were made for dry matter production and N concentrations. Grain yields were adjusted to 15.5% moisture. Soil samples were collected from all N combinations at the high K rate for two hybrids (Pioneer 3615 and LH74 x LH85). Six to eight cores were taken from a depth of 0-1 ft through the anhydrous ammonia injection zone. All soil samples were analyzed for nitrate and ammonium N.

---

1. Funding provided by the University of Minnesota Agricultural Experiment Station and Dow Chemical Co.USA.
Appreciation is also expressed to DeKalb Seed Co., Holden Foundation Seed and Pioneer International for seed utilized in our experiment.
2. Associate Professor, Professor, and Asst.Scientist, respectively, Dept. of Soil Science, University of Minnesota.

The irrigation program began on June 16th and continued through August 25th with a total of 13.05 inches being applied through an overhead solid set irrigation system. An additional 14.45 inches of water was obtained during the growing season as rainfall.

Waseca: The corn experiment at Waseca was similar to that established at Becker except only 4 treatments were evaluated. The experimental design was a split plot with four replications. Treatments included a factorial combination of four hybrids (Pioneer 3615, Pioneer 3475, LH74 X LH51, AND LH74 X LH82), with two N rates (80 and 160 lbs N/A), two K rates (0 and 100 lbs K/A), and two nitrification inhibitor treatments (w/wo N-Serve 0.5 lbs/A). Two controls were included, both with no fertilizer N but one with K and one without.

Potassium treatments were applied in the fall of 1988. The four corn hybrids were planted on May 9th at a population of 32,000 seeds/A in 30 inch rows. Weed control was accomplished with a tank mix of Lasso (3.5 lbs/A a.i.) and Bladex (3 lbs/A a.i.) on May 17 and cultivation on June 14th. Nitrogen treatments were applied as anhydrous ammonia on June 23rd using procedures similar to that used at Becker. Rainfall accumulation over the growing season was 12.49 inches.

Plant and soil samples were taken four times (July 27th, August 16th, August 30th, and September 28th), during the growing season. (This coincides with the comparable growth stages at the Becker location.) The same plant sampling procedures were used at Waseca as was described for Becker. Soil samples were collected from the zero K rate (all N combinations) for two of the hybrids (Pioneer 3615 and LH74 x LH82) at each plant sampling.

General Results

The results from the Becker location are presented in tables 1-14, and a summary of the results from Waseca are presented in tables 15-28. The discussion presented here will not attempt to interpret all of the results. Major emphasis will be placed on the interpretations of the final yield and N utilization by the crop. A more thorough evaluation of the remaining data will be conducted at a later time.

Becker: Due to a suitable growing season in 1989 yields were "good", with the top treatments yielding above 220 bu/A. Yields obtained from the four hybrids were significantly different. At physiological maturity DeKalb 485 was the highest yielding hybrid, P-3737 was intermediate a P-3615 and LH74 X LH85 were the lowest yielding of the four hybrids tested. A significant yie increase of 18 bu/A was obtained when the fertilizer N rate was increased from 80 to 160 lbs/A. There were significant N management hybrid interactions when the final yield was determined. A significant hybrid x N-rate interaction in 1989 suggests that DeKalb 485 and P-3615 were more responsive to higher rates of fertilizer N than were the other two hybrids examined. There was a significant N-rate x K-rate interaction. Although increased K rate tended to decrease yields, reductions were more prominent at the low N rate.

Waseca: Although 1989 was a dry growing season, yields were average or above average at this site. Final grain yields were significantly different between hybrids when there was no K applied, with LH74 x LH82 having the lowest yield, P-3475 being intermediate, and both LH74 x LH51 and P-3615 having the highest overall yields. When fertilizer K was applied hybrids did not vary in yield, but the general response was a reduced yield or no positive yield increase. The P-3615 and LH74 x LH51 hybrids also tended to have the highest yield when no fertilizer N was applied. A yield response to increasing N-rate was observed through the 80 #/A N-rate. The main effect of nitrification inhibitor was significant as the use of N-serve tended to reduce yields. A significant N-rate x K-rate interaction indicated that at the low N-rate K tended to reduce yield, but at the high N-rate additional K increased yields.