Table 4. Nitrate-N concentration of water collected in pan and wick lysimeters in the small plot area, Westport, MN 1991.

N rate #/A		Pan corn-corn	Pan corn-beans	Wick corn-corn	Wick corn-beans
		ppm NO_3-N			
0		1.4	12.9	--	12.4
105	early	1.9	4.2	--	20.3
105	late	3.1	5.8	10.9	--
215	early	2.8	79.3	--	148.8
215	late	0.2	13.2	--	125.9

Table 5. Corn grain yields from large plot area Westport, MN 1991.

Total N-Rate #/A	Early N #/A	Late N #/A	Crop Rotation	Grain Yield Bu/A	Grain N-Content %	Grain N-Removal #/A
160	105	55	Corn-Corn	112.0	1.40	74.4
215	140	75	Corn-Corn	136.2	1.43	82.6
160	105	55	Corn-Soybeans	121.7	1.44	82.9

Table 6. Nitrate-N concentration of water collected from the pan and wick lysimeters in large plot area, Westport, MN 1991.

N rate lb N/A	Rotation	NO_3-N ppm
Pan		
160	corn-corn	30.1
215	corn-corn	38.0
160	corn-soybean	1.9
Wick		
160	corn-corn	24.1
215	corn-corn	84.8
160	corn-soybean	21.7

USE OF THE SPAD 502 CHLOROPHYLL METER TO MONITOR THE NITROGEN STATUS OF CORN[1]

L. A. Kotilinek, G. L. Malzer, and T. J. Graff[2]

Abstract: Nitrogen management decisions which improve fertilizer efficiency should decrease the potential for nitrate contamination of ground water and increase profitability for corn producers. The use of a chlorophyll meter which quantifies leaf greenness could rapidly and effectively monitor N requirements of the crop and thus improve N management programs for those producers with sidedress or fertigation capabilities. In 1991, a study was initiated to determine if the Minolta SPAD 502 chlorophyll meter could be utilized to predict N deficiency in corn. Meter readings and leaf nitrogen concentrations from plants at 4-, 8-, 12-leaf, blister, and milk growth stages were compared for their ability to predict nitrogen deficiencies in corn. The correlation between meter readings and leaf N concentrations and grain yield increased with increasing age of the plant. Correlation coefficients (r) increased by analysis of relative values as compared to actual measurements. Correlation of relative yield x relative meter readings was comparable to that of relative yield x relative leaf N concentrations (r=0.65, 0.50, 0.81, 0.94, 0.95, and 0.68, 0.49, 0.84, 0.98, 0.99 respectively). While it is not possible to recommend rates of N fertilization via chlorophyll meter readings at this time, the data would suggest that the meter and leaf tissue analysis are comparably effective in monitoring the N status of corn.

Tissue analysis may be an effective method for predicting the N status of corn, but cost and time involved prevent such methods from being widely accepted as tools to improve nitrogen management. The chlorophyll meter rapidly and non-destructively measures the degree of leaf greenness and thus has potential for contributing to greater nitrogen fertilizer efficiency for producers that apply nitrogen by sidedress application or through irrigation water. The objective of this study was to compare the chlorophyll meter with leaf N concentrations for their ability to predict nitrogen deficiencies of corn.

Experimental Procedures: This study was conducted at the Herman Rosholt Water Quality Research Farm, Westport, MN, during the 1991 growing season. The soil is an Estherville sandy loam and the crop sequence was continuous corn (Pioneer 3902 - 90 day R.M.). Corn, under chisel and ridge tillage systems was planted on May 9th, at 29,900 seeds per acre. Starter fertilizer 7-22-5 was applied as a band below the seed at a rate of 10 gal/A. Nitrogen fertilizer in the form of anhydrous ammonia was applied at rates of 0, 50, 105, 160, and 215 lbs N/A on June 10th (4-leaf stage) or June 19th (8-leaf stage). Weed control was accomplished with Lasso, Atrazine-90DF, and cultivation.

At 4-leaf(June 8th), 8-leaf(June18th), 12-leaf(July 1st), blister(July 23rd), and milk(August 8th) growth stages, chlorophyll meter readings were taken from 20-30 different plants from one row of each plot. Leaf samples were taken from 10-15 plants in the adjacent row, dried, ground, and analyzed for N concentrations. For the 4, 8, and 12-leaf stages, the youngest leaf with a collar was measured, while the leaf opposite and below the developing ear was used at blister and milk stages. Meter readings (one per plant) were taken at a location approximately midleaf, from base to tip and from the midrib to outer leaf margin. Corn was hand harvested from 100 sq.ft. of plot area on October 9th. Shelled grain was dried and values reported at 15.5% moisture.

General Results: Chlorophyll meter readings, leaf N concentrations, and grain yield are presented in Table 1. Meter readings were highly correlated with yield at all growth stages while leaf N concentrations did not significantly correlate with yield at the 8 and 12-leaf growth stages. Relative values for meter readings, N concentrations, and yield are shown in Table 2. These values were obtained using the following formula: relative value = observed value/highest value obtained for the equivalent tillage and time of fertilizer application. Relative meter readings and relative leaf N concentrations were well correlated with relative grain yield at 4-leaf, 12-leaf, blister, and milk growth stages. Lower correlation was observed at the 8-leaf stage.

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2. Graduate Research Asst., Professor, Asst. Scientist, respectively, Dept. of Soil Science, University of MN.

Since as much as 90% of the yield response was obtained with the lowest rate of fertilizer, the highest coefficients obtained at the later stages of growth should be interpreted with caution. Preliminary data suggests that the chlorophyll meter and leaf N analysis, when standardized to relative values, are equivalent with regards to their ability to monitor the N status of corn.

Table 1. Chlorophyll meter readings, leaf N concentrations, and grain yield for continuous corn. Westport, MN 1991.

Tillage	N Rate (# N/A)	Application Time	Chlorophyll Meter Readings^ 4-leaf	8-leaf	12-leaf	blister	milk	Yield^ Bu/A
Chisel	0		42.3	42.6	36.8	32.7	31.2	63.7
	50	4-leaf	43.8	44.4	47.1	51.8	48.8	100.7
	105		44.5	45.5	48.8	57.2	53.5	113.4
	160		43.5	45.3	48.3	57.9	55.7	107.8
	215		45.1	46.9	49.8	56.9	53.8	128.8
	50	8-leaf	43.4	46.2	43.8	54.0	51.7	108.8
	105		43.7	45.3	41.8	55.3	53.6	118.2
	160		43.4	47.0	45.9	56.6	54.6	105.3
	215		44.4	49.7	48.2	57.7	54.6	109.9
Ridge	0		43.7	44.8	37.1	34.2	31.4	68.4
	50	4-leaf	43.3	42.9	45.9	53.5	51.1	116.3
	105		45.8	45.2	47.5	57.6	56.3	113.1
	160		45.2	46.6	48.0	58.2	56.3	125.6
	215		44.7	46.6	48.0	57.3	56.9	127.9
	50	8-leaf	43.8	44.0	41.8	54.8	52.8	124.6
	105		44.4	46.3	42.8	54.0	54.9	125.8
	160		46.2	47.7	43.8	56.2	55.1	121.0
	215		45.9	48.7	47.5	58.0	55.7	121.8
	(yield x meter) r=		0.60**	0.45~	0.67**	0.90**	0.92**	
				Leaf N Concentration (%)^				
Chisel	0		3.91	2.72	2.42	1.36	1.32	
	50	4-leaf	3.95	2.76	2.67	2.63	2.29	
	105		4.18	3.27	2.94	2.92	2.77	
	160		4.26	2.79	2.81	2.95	2.87	
	215		4.20	3.02	2.85	2.99	2.94	
	50	8-leaf	4.10	2.78	2.55	2.84	2.54	
	105		4.00	2.79	2.49	2.88	2.91	
	160		3.95	2.90	2.58	3.06	2.75	
	215		4.01	2.91	2.76	2.87	2.81	
Ridge	0		4.00	2.66	2.20	1.41	1.39	
	50	4-leaf	4.13	2.61	2.50	2.39	2.32	
	105		4.45	2.85	2.72	2.92	2.80	
	160		4.46	2.95	2.66	2.92	2.97	
	215		4.36	2.85	2.48	3.08	2.89	
	50	8-leaf	4.38	2.62	2.49	2.56	2.60	
	105		4.16	2.85	2.40	2.95	2.88	
	160		4.28	2.91	2.65	2.97	2.78	
	215		4.25	3.11	2.53	2.85	2.92	
	(yield x leaf N) r=		0.64**	0.37	0.40	0.87**	0.91**	

^ Rep Means.

~,*,** Significant at the 0.10, 0.05, and 0.01 level respectively.

Table 2. Relative meter readings, relative leaf N concentrations, relative grain yield. Westport, MN 1991.

Tillage	N Rate (# N/A)	Application Time	Relative Meter Readings^ 4-leaf	8-leaf	12-leaf	blister	milk	Rel. Yield^
Chisel	0		0.94	0.91	0.74	0.56	0.56	0.49
	50	4-leaf	0.97	0.95	0.95	0.90	0.88	0.78
	105		0.99	0.97	0.98	0.99	0.96	0.88
	160		0.97	0.97	0.97	1.00	1.00	0.84
	215		1.00	1.00	1.00	0.98	0.97	1.00
	0		0.95	0.86	0.76	0.57	0.57	0.54
	50	8-leaf	0.98	0.93	0.91	0.94	0.95	0.92
	105		0.98	0.91	0.87	0.96	0.98	1.00
	160		0.98	0.95	0.95	0.98	1.00	0.89
	215		1.00	1.00	1.00	1.00	1.00	0.93
Ridge	0		0.95	0.96	0.77	0.59	0.55	0.53
	50	4-leaf	0.95	0.92	0.96	0.92	0.90	0.91
	105		1.00	0.97	0.99	0.99	0.99	0.88
	160		0.99	1.00	1.00	1.00	0.99	0.98
	215		0.98	1.00	1.00	0.98	1.00	1.00
	0		0.95	0.92	0.78	0.59	0.56	0.54
	50	8-leaf	0.95	0.90	0.88	0.94	0.95	0.99
	105		0.96	0.95	0.90	0.93	0.99	1.00
	160		1.00	0.98	0.92	0.97	0.99	0.96
	215		0.99	1.00	1.00	1.00	1.00	0.97
(Rel. Yield x Rel. Meter) r=			0.65**	0.50*	0.81**	0.94**	0.95**	
				Relative Leaf N Concentration^				
Chisel	0		0.92	0.83	0.82	0.46	0.45	
	50	4-leaf	0.93	0.84	0.91	0.88	0.78	
	105		0.98	1.00	1.00	0.98	0.94	
	160		1.00	0.85	0.96	0.99	0.98	
	215		0.99	0.92	0.97	1.00	1.00	
	0		0.95	0.93	0.88	0.45	0.45	
	50	8-leaf	1.00	0.96	0.92	0.93	0.87	
	105		0.98	0.96	0.90	0.94	1.00	
	160		0.96	1.00	0.94	1.00	0.95	
	215		0.98	1.00	1.00	0.94	0.97	
Ridge	0		0.90	0.90	0.81	0.46	0.47	
	50	4-leaf	0.93	0.89	0.92	0.78	0.78	
	105		1.00	0.97	1.00	0.95	0.94	
	160		1.00	1.00	0.98	0.95	1.00	
	215		0.98	0.97	0.91	1.00	0.97	
	0		0.91	0.86	0.83	0.47	0.48	
	50	8-leaf	1.00	0.84	0.94	0.86	0.89	
	105		0.95	0.92	0.91	0.99	0.99	
	160		0.98	0.93	1.00	1.00	0.95	
	215		0.97	1.00	0.95	0.96	1.00	
(Rel. Yield x Rel. Leaf N) r=			0.68**	0.49*	0.84**	0.98**	0.99**	

^ Rep Means.

*, ** Significant at the 0.05 and 0.01 level respectively.

Impact of Turkey Manure Application on Corn Production and Potential Water Quality Concerns on Estherville Sandy Loam[1]

Manjula V. Nathan, Gary L. Malzer and James L. Anderson[2]

Abstract

A field study was conducted at Westport, Minnesota to study the impact of turkey manure application on irrigated corn production and potential water quality concerns on Estherville sandy loam. Two rates of turkey manure (4 and 8 tons per acre on wet weight basis; these rates were computed to provide 70 and 140 lb of available N per acre respectively), were compared with two rates of commercial fertilizer (used at the rates of 70 and 140 lb N/A) and untreated check. Dry matter production and N uptake at 8-leaf and silking stages were estimated. Grain and stover yields and N uptake were measured at maturity. Water percolation and N leached were measured periodically throughout the growing season. Soil samples were collected at planting, 8-leaf, silking and harvest and analyzed for inorganic N (NH_4^+-N + NO_3^--N). As expected manure and fertilizer treatments increased the dry matter production and grain yield. Grain yield was increased almost by 100 bu/A when fertilizer rate of 140 lb N/A was applied. The low rate of manure was comparable in yield to the high rate of fertilizer, while the high rate of manure produced yield (142 bu/A) higher than the high fertilizer rate (128 bu/A). Treatments applied in 1991 had no influence on the amount of water that percolated through the soil, or the concentration and amount of N lost in the percolate water. Residual impacts of 1991 treatments will be evaluated in 1992. Soil inorganic N levels were significantly higher with high manure rate treatment at 8-leaf, silking and harvest stages. This elevated concentration of inorganic N may be reflected in the leachate water next spring. Considering the grain yield uptake turkey manure at 4T and 8T/A performed equally well or better than the 140 lb N/A fertilizer treatment.

Introduction

Turkey production in Minnesota is ranked second in the nation (Minnesota Statistics, 1990). In 1990, Minnesota's turkey farms boosted their output to a new record of 43.6 million turkeys. A large portion of the turkey production is concentrated in the West Central and Northwest regions of the state. Many turkey producers have limited agricultural production areas available to them for manure disposal. As production increases there will be an increased concern about manure disposal and potential water quality contaminations.

Turkey manure is rich in several nutrients. Recent survey done by University of Minnesota researchers (Moncrief et al. 1991, unpublished date) revealed the nutrient composition of poultry manure on dry weight basis is 5.1% N, 2.2% P and 2.3% K respectively. It is estimated that the 860,000 tons (dry wt.) of turkey manure produced per year will supply 87, 86 and 48 million pounds of N, P_2O_5 and K, respectively.

Increased emphasis on protection of surface water and ground water, and the farmers desire to reduce fertilizer costs have increased the need to evaluate the use of turkey manure in corn production. The objectives of this field study was to compare two rates of turkey manure (4 and 8 T/A on wet weight basis) and two rates of fertilizer N (70 and 140 lb N/A) on dry matter production, N uptake and grain yield, and leaching loss of NO_3-N.

Materials and Methods

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

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[1] Funding provided by the University of Minnesota Agricultural Experiment Station and the Center for Agricultural Impacts on Water Quality.

[2] Postdoctoral Associate and Professors respectively, Dept. of Soil Science, University of Minnesota.

installed and connected to the soil surface by polyethylene tubing. Each lysimeter was placed in the center of 30′ x 30′ plots. Soil at the experimental site was an Estherville sandy loam (Typic Hapludoll) and the lysimeters were backfilled with that soil by depth. Selected chemical and physical properties of the soil are presented in Table 1.

This site did not have any previous history of manure application. Cropping history was corn following corn in a corn-corn-soybean rotation. In 1990, corn was grown at this site without any fertilizers.

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

Irrigation was provided to all plots through a drip-type irrigation system. Drippers were 30 inches apart on a 0.5 inch plastic irrigation line. An irrigation line was placed along each row of corn. Water was pumped through the irrigation system at 13.8 kPa 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.

Treatments consisted of two rates of turkey manure (4 and 8 T/A, wet weight basis) and two rates of commercial fertilizer N (70 and 140 lb N/A applied as urea) and a control with no N. The turkey manure treatments were incorporated, immediately after application. The nutrient composition of turkey manure is presented in Table 2. Estimate of manure N availability was based on the assumption that 80% of the inorganic N and 30% of the organic N will be available during the first year of application. The manure rates applied were expected to provide approximately 70 and 140 lb. of available N/A. The experimental design was a randomized complete block design with three replications. The three blocks (5 plots/block) which were in roto-till during the previous years have been used for this year of the study. The other three blocks which have been in no-till in the past have been roto-tilled this and were left untreated. These untreated blocks will be used in 1992 to study the effect of turkey manure application on soybean production. The plots which were treated this year will be used to study the residual effects of manure application on soybeans following corn in 1992. The entire study area was planted with corn (Pioneer 3790) on May 8 at the seed density of 28,500 seeds per acre. Blanket application of P and K were made at the rate of 50 and 150 lb of P_2O_5 and K_2O per acre respectively to all 30 plots.

Table 2. Turkey Manure Composition.

Nutrients	lb/T*
Total N	48
Inorg. NH_4^--N	12
NO_3^--N	2
Organic N	34
P_2O_5	69
K_2O	50
Moisture %	52

*Nutrient composition presented in wet weight basis.

Dry matter production and N uptake were determined at the 8-leaf and silking stages by hand harvesting four feet of row. Grain and stover yields were determined by harvesting two 20 feet of rows at maturity. Subsamples from stover, cob and grain were analyzed for total Kjeldahl N. Corn grain yields were reported at 15.5% moisture.

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

Soil samples collected (0 to 12 in. depth) at the time of planting, 8 leaf, silking and harvest time were analyzed for inorganic N (NH_4^+-N + NO_3^--N).

Results and Discussion

The manure and commercial fertilizer treatments significantly increased dry matter production and grain yield.

Table 3. Dry matter production and N uptake as influenced by manure and fertilizer treatment at the 8-leaf growth stage and silking.

Treatment	Dry matter		N Concentration		N Uptake	
	8-leaf	silking	8-leaf	silking	8-leaf	silking
	T/A		%		lb/A	
Control	0.49	1.89	0.99	0.65	9	24
Urea 70 lb N/A	0.84	4.11	0.80	0.56	13	45
Urea 140 lb N/A	1.16	4.54	2.55	1.37	59	124
TM 4 T/A	1.16	4.67	0.93	1.44	22	133
TM 8 T/A	1.27	4.76	2.12	1.62	54	154
LSD 0.05	0.45	1.05	0.67	0.30	20	26

Low rates of fertilizer and manure did not influence N concentration and N uptake at the 8-leaf growth stage, but the low rate of manure did increase dry matter production (Table 3). The high rates of fertilizer and manure produced comparable yield and uptake (1.16, 1.27 T/A and 59 and 54 lb/A respectively for high fertilizer and manure treatments) which were significantly higher than the control. At the silking stage, the dry matter production for all fertilizer and manure treatments were similar and were significantly higher than the control (Table 3). The N concentration in the corn plant and total N uptake at silking were significantly reduced at the low fertilizer rate (Table 3). The N concentration in plant and N uptake at 8-leaf and silking suggests that the low rates of fertilizer and manure did not supply sufficient N at the 8-leaf stage. At silking, however the low manure was comparable to the high rates of manure and fertilizer.

A severe wind storm on June 27 (around 14-leaf stage) reduced the plant stands in the manure treated plots. The succulent plant material was broken at the base of the stalk resulting in a 15-20% stand reduction. Grain yield data has been adjusted for the reduced population in the manure treated plots. Significant yield increase was observed with all fertilizer or manure treatments rather than the control (Table 4). Grain yield was increased by almost 100 bu/A when a fertilizer rate of 140 lb N/A was applied. The low rate of manure was comparable in yield to the high rate of fertilizer, while the high rate of manure produced yields (142 bu/A) higher than the high fertilizer rate (128 bu/A).

Table 4. Grain and Stover yield and N uptake as influenced by manure and fertilizer treatment.

Treatment	Grain		Stover		Total N
	yield	N uptake	yield	N uptake	uptake
	bu/A	lb/A	T/A	lb/A	lb/A
Control P	31	18	1.31	11	28
Urea 70 lb N/A	91	48	2.09	15	63
Urea 140 lb N/A	128	87	2.36	20	107
TM 4 T/A	133	88	2.23	20	108
TM 8 T/A	142	104	3.18	39	143
LSD (0.05)	13	21	0.66	10	25

As expected, grain N uptake increased with all fertilizer and manure treatments than the control. Grain N uptake increased by almost 40 lb/A when fertilizer rate was increased from 70 to 140 lb N/A. The lower rate of manure was comparable in grain N uptake to the higher rate of fertilizer. However, increasing manure rate did not result in significant grain N uptake (Table 4). Total N uptake followed somewhat similar pattern as grain N uptake, with the exception of significant increase in total N uptake with increase in manure rates.

The leachate collected from the bottom of the lysimeters has been grouped into two time periods (before planting and planting to harvest, Table 5). Post-harvest leaching data has not been summarized. Concentration of NO_3-N in the leachate before planting ranged from 6 to 11 ppm. Leachate collected during the growing season had NO_3-N concentration in the range of 10 to 12 ppm. Treatments applied in 1991 had no influence on the amount of water that percolated through the soil, or the concentration and amount of N lost in the percolate water. Residual impacts of 1991 treatments will be evaluated in 1992.

Table 5. Water percolation amount and concentration of NO_3^--N in the leachate as influenced by fertilizer and manure treatments.

	Before planting			Planting to harvest		
Treatment	H_2O in	N lb/A	NO_3^--N ppm	H_2O in	N lb/A	NO_3^--N ppm
Control	3.4	5	6	4.0	10	11
Urea 70 lb N/A	3.5	7	9	4.2	10	12
Urea 140 lb N/A	3.6	8	11	4.7	11	10
Manure 4 T/A	4.2	10	11	4.4	12	11
Manure 8 T/A	3.4	6	8	5.7	13	10
LSD (0.05)	NS	NS	NS	NS	NS	NS

Table 6. Soil inorganic N as influenced by manure and fertilizer.

	Inorganic N			
Treatment	Planting*	8-leaf	Silking	Harvest
	lb/A			
Control	20	25	20	21
Urea 70 lb N/A	18	30	21	21
Urea 140 lb N/A	20	33	30	22
Manure 4 T/A	20	35	30	27
Manure 8 T/A	21	40	52	48
LSD (0.05)	NS	11	19	17

*Before treatment application.

Soil inorganic N (NH_4 + NO_3-N) in surface 12" of soil before planting averaged to 20 lb/A (Table 6). The high manure treatment resulted in significantly higher amounts of soil inorganic N as measured at 8-leaf, silking and harvest. This elevated concentration of inorganic N may be reflected in the leachate water next spring.

CALIBRATION AND CORRELATION OF SOIL N TESTS FOR IMPROVED N RECOMMENDATIONS[1]

M.A. Schmitt and G.W. Randall[2]

Soil testing, which allows site specific fertilizer recommendations, offers a means of improving nitrogen (N) management for corn production for a given soil/crop/climate. Research throughout the Corn Belt has shown that soil N tests have great potential for refining N rate decisions.

The primary objective of this project is to develop an N soil test that will enable farmers to apply optimum rates of N for corn under a wide variety of soil, crop, and climatic conditions. To meet this objective, an evaluation of different tests or combination of tests, based on sampling time and depth as well as form of N, will be made for measuring and/or assessing available N before and during the growing season for use in predicting fertilizer N requirements for corn.

Methods and Materials

Experiments were established during March and early April at 15 locations throughout southern and central Minnesota in 1991. Ten sites were on farmer-cooperator fields with five being located at experiment stations. The sites represented three major parent materials with seven being on glacial till, four on loess and four on outwash soils. A range of previous crops was also obtained with corn at four sites, soybeans at six, alfalfa at three, and small grains at two. Soil texture ranged from loamy sand to clay. This wide array of soil, previous crop, and climatic conditions should provide an excellent opportunity to evaluate various soil N tests and their ability to predict available N.

There were nine treatments at most locations. The treatments included a control plot, five preplant N rates (30, 60, 90, 120, 150 lb N/acre) and three split-applied N rates (60 lb N/acre preplant with 30, 60, 90 lb N/acre sidedressed). Where alfalfa was the previous crop, only sidedress treatments of 0, 30, 60 and 90 lb N/acre were included. Preplant applications used broadcast urea and the sidedress applications used subsurface bands of urea. Sidedressing occurred when the corn was 6-12 inches tall.

Soil samples were collected four times each year: 1) preplant, approximately two weeks before planting, 2) about 10-14 days after planting, when the corn had 1-2 leaves (V1 stage), 3) about 5 weeks after planting, when the corn was 6-12 inches tall (V4 stage), and 4) after harvest. Only control plots and two treatments receiving preplant N were sampled throughout the year. Soil samples were collected in 1-foot increments to a depth of five feet for the preplant and postharvest samplings and to a depth of three feet for the in-season samplings.

Stover and grain yields were measured from each plot after physiological maturity. Total Kjeldahl N was measured in the stover and grain, and nitrate-N was measured in the basal stalk section of the corn plants from selected treatments after maturity. Rainfall and temperature data were recorded through July at each site.

Samples were analyzed for ammonium-N and nitrate-N using a Wescan Autoanalyzer. Selected samples were also analyzed for hydrolyzable N using a phosphate-borate buffer extractant. A randomized complete-block design with four replications was used at all sites. Plot size ranged from 10 to 15 feet wide (all with 30" rows) by 40 to 60 feet long.

All analysis of variance and correlation data conducted from 1991 data were performed by PC-SAS software. Data from 1989-1991 were used when regression equations were determined. The dependent variable in all regression models was relative grain yield. Relative grain yield was determined by dividing plots' grain yields by the average grain yield of all plots from treatments that were from the optimum (or greater) N treatments. Optimum N rate was determined by using least significant differences of the treatment means--no economic considerations were included.

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[1] This project has received direct support from Farmland Industries, Tennessee Valley Authority-National Fertilizer and Environmental Research Center, Greater Minnesota Corporation-Agricultural Utilization Research Institute, and USDA-Cooperative States Research Service.

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Results and Discussion

Soil Nitrate-N

Soil nitrate data from the first three sampling times are shown in Table 1. Preplant sample data indicated a large range in residual nitrate remaining in the soil profile. The absence of any concentrations greater than 14.1 ppm in the top one foot indicates that high amounts of carryover from 1990 were not present. At most sites, nitrate accumulation in the deeper profiles closely paralleled the nitrate concentration in the top foot.

Soil samples taken at the 1-2 leaf stage should represent residual (carryover) nitrate as well as N mineralized from the soil organic matter and previous legume sources if applicable. Sites with loess or glacial outwash had marked increases in nitrate compared to the preplant measurements. Most of the glacial till soils either had a decrease in nitrate or no change.

When the corn was 6-12 inches tall, soil nitrate values in the 3-foot profile did not change significantly from the previous sampling values when glacial till was the parent material. With sites on glacial outwash, nitrate tended to decrease from the previous sampling. These data suggest that mineralization and potential N losses early in the growing season can be highly related to soil parent material.

When alfalfa was the preceding crop, nitrate accumulation in the 3-foot profile at the 1-2 leaf stage was significantly higher than at preplant sampling, most probably due to the mineralization of the N pool associated with the alfalfa root system. This same increase was seen when sampled at the presidedress time. In addition, when alfalfa was grown two years previously, there was a marked increase in nitrate at all sampling times. Thus, there appears to be a potential interaction of previous crop with time of sampling for nitrate.

Soil N correlations

When correlating various soil N tests to each other varying sampling times, depths and N forms, there does not appear to be strong correlation among N forms or sampling times (Table 2). Contrasts of nitrate and ammonium measurements between two times of sampling at the two-foot depth resulted in coefficients of 0.11 and 0.30. Comparing nitrate and hydrolyzable N in four contrasts never showed coefficients greater than 0.20. Hydrolyzable N did give highly significant correlations when contrasted between different dates of sampling.

Correlation coefficients for nitrate analyses from different times and depths are listed in Table 3. The issue of sampling time can be evaluated for the two-foot nitrate samplings. The preplant sample is significantly, but not highly, correlated to the 1-2 leaf sampling ($r=0.43$) and to the 6-12 inch corn sampling ($r=0.39$). In comparing sampling time between the middle and late sampling, the correlation for the 1' and 2' depths are much higher ($r=0.67$ and $r=0.68$, respectively).

Table 3 also provides correlation information for depths of sampling. The correlation between the 0-2 ft preplant nitrate and the 2-3 ft value is 0.58. At the 1-2 leaf stage and when corn is 6-12 in. tall, the correlation of the second foot to the first foot in sampling depth are 0.53 and 0.51, respectively. Thus, it is unclear how much additional information is gained by including the additional foot at each of the sampling times.

Fertilizer N recovery

Preplant fertilizer rates were applied at all sites except when alfalfa was the previous crop. Ammonium concentrations did increase in the top foot of soil but only at the 1-2 leaf stage as the rate of preplant applied urea-N was increased (Table 4). Nitrate concentrations increased at both in-season sampling times proportionally to the amount of preplant N applied. While the nitrate increases were greatest in the top foot, there were proportional increases of nitrate in the second foot as well.

Grain yields

Grain yield results shown in Table 5 indicate significant yield responses to applied fertilizer N at 12 of the 15 sites. Alfalfa was the previous crop at the three non-responsive sites. The three sites with second-year corn following alfalfa responded to N rates of 30 lb/A (two sites) and 60 lb/A (one site). Yield responses following small grains (three sites) ranged from 37 to 107 bu/A with optimum N rates of 60 to 120 lb N/A. When following soybeans (five sites), corn yield responses ranged from 9 to 93 bu/A with optimum N rates of 30 to 150 lb N/A. However, the site that optimized yield with only 30 lb N/A (a

9 bu/A response) was planted to alfalfa in 1989. One site (E) experienced relatively low yields due to very wet conditions and late planting (June 7).

Grain yields and soil N

A preliminary relationship between grain yield and soil N parameters can be assessed by calculating correlation coefficients between soil N variables and relative grain yields. In Table 6, the influences of parent material and N form can be related to sampling time and depth. In almost every situation, the correlation between sampling parameters and N forms is affected by the soil's parent material. However, there is consistency when nitrate-N sampled at the 1-2 leaf stage is correlated to yield (r's of 0.75 to 0.81) for the three parent materials and the two depths of sampling. Ammonium-N and hydrolyzable N data resulted in higher or similar correlation values in only limited instances--those situations being generally with outwash parent materials.

Because it is common practice to add some or all fertilizer N before planting, similar correlations between soil nitrate and ammonium variables measured at the 1-2 leaf stage or when the corn is 6-12 inches tall can be calculated for plots that received preplant N (Table 7). Grain yield correlations to ammonium are always significantly less than with nitrate for all conditions.

Regression of relative grain yield and soil N tests is more appropriate for determining the predictive ability of a specific N test for grain yield. In order to increase confidence in the regression analysis, research data from 1989 and 1990 were combined with the 1991 dataset (all data from the same soil N testing project). Unless otherwise noted, data are from the control (0# N/A) plots and their relative grain yields as compared to a non-limiting grain yield at each site.

The model that should be used to fit the data is not always easy to determine. Neither linear nor quadratic models are used in this report because of the principles associated with them. While either models may seem to fit at a given site, theoretically, yields should plateau at increasing soil N test levels. Therefore, the models of linear-plateau and quadratic-plateau are evaluated.

There are three comparisons possible in Table 8 comparing linear- and quadratic-plateau models. The most obvious difference between models is the critical value--the value where the linear or quadratic curve intersects with the plateau line. Simply stated, this is where the responsive sites' data intersects with the nonresponsive sites' data. The quadratic-plateau model's critical value is approximately 12-13 ppm greater than the linear-plateau's. Each model's R^2 is almost identical and the error rates are comparable.

Although the error rates are comparable, the difference in the type of errors are noteworthy. Errors can either be where there is a response and one predicts no N response (R-PNR) or where there is no response when one predicted a response (NR-PR). Errors of R-PNR nature are of greatest concern to the crop producer because yields may have been limited because of underfertilizing. The NR-PR errors will result in fertilizing without a yield response.

Linear-plateau models consistently have a higher R-PNR error rates when compared to quadratic-plateau models--a response to the shift in critical values (Table 8). Conversely, the NR-PR error rates are very high (87-100%) when the quadratic-plateau model is used. Thus, the appropriate model from this dataset is primarily dependent on the type of error one will accept.

The factor of depth of sampling is compared in Table 8 with the V1 and V4 stage of growth. The error rates are similar for the 1-foot and 2-foot sampling depths, whereas, the R^2 is slightly higher for the 2-foot samples. Therefore, the deeper sampling does provide some benefit to the model. This is in agreement with an earlier statistical summary (Table 3) that documents a significant correlation between the two depths.

Sampling time is an important factor in developing a soil N test. Three times of sampling can be compared for either the 1-foot depth or the 2-foot depths in Table 8. Error rates among sampling times had a range of 9%--probably no significant difference. The R^2 values increased with later samplings for the 1-foot samplings and increased from the preplant sampling to the in-season samplings with the 2-foot samples. Based on these regression models, taking samples from the 2-foot depth at either the V1 or V4 stage of growth is the best N test situation.

From earlier soil data (Table 6), there was a distinct effect on nitrate concentrations and fluxes based on the site's parent material. When the V4, 2-foot sampling data were separated by parent material, the model's R^2 were significantly different for the parent materials. From the combined data, the R^2 is 48%, when separated by parent material, the range is from 32-57%.

When separation by parent material is made, the database for each model is significantly reduced, thus more observations are desired. To better compare parent materials, the database was expanded by including plots that received preplant N. In Table 8, the V1, 2-foot samples were analyzed to evaluate the effects of parent material on models. The combined model's R^2 is 45%. When sorted by parent material, the poorest model was from outwash sites (R^2=21%) and the strongest model was from the loess sites (R^2=71%).

Other N forms, such as ammonium and hydrolyzable N were also evaluated in this project. From a regression perspective, the phosphate-borate buffer extraction for hydrolyzable N did not provide data that fit either regression model. Ammonium data, while it did fit the models, was significantly inferior to the nitrate-only models. Combinations of N forms may be tested in the future.

Summary

Grain yield response to N, either from the soil or fertilizer, differs greatly depending on many factors--including soil parent material, previous crop, and previous crop management. Soil N analyses indicate that time of sampling and form of measured N do not correlate well amongst each other. Depth of sampling did correlate well for a given date of sampling. Soil parent material did influence the inorganic N increases (decreases) among sampling dates.

When preplant fertilizer was added, proportional increases were measured in the ammonium and nitrate soil N components. Ammonium N increased at the 1-2 leaf stage of sampling while nitrate N increased at both in-season samplings for both the 1- and 2-foot depths of sampling.

Regression analysis was made on a database from 1989-1991 (43 site-years). Using either the linear-plateau or quadratic-plateau model, error rates were commonly in the 25-40% range. The types of error being somewhat controlled by selection of the model.

Based on the fit of the models (R^2) between relative grain yield and soil nitrate-N concentrations, taking a soil sample from a 2-foot depth at the 1-2 leaf stage or at the 6-12 inch corn stage appears to be superior. From a logistical perspective, the earlier that one can sample, the less risk the user will experience relative to sidedress applications. There is potential for better fitting models when parent materials are separated.

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Table 1. Soil NO_3-N prior to planting, at the 1-2 leaf stage, and when the corn is 6-12 inches tall in the control plots at each site, 1991.

Site Code	Parent Material	Soil Texture[1/]	Previous Crop[2/]	Preplant 0-1'	Preplant 0-3'	Preplant 0-5'	1-2 leaf 0-1'	1-2 leaf 0-3'	6-12" tall 0-1'	6-12" tall 0-3'
				ppm	- - lb/A - -		ppm	lb/A	ppm	lb/A
A	Till	CL	C,A	14.1	130	187	7.7	87	9.7	91
B	Till	CL	Sb	5.9	48	68	3.8	45	4.6	46
C	Till	CL	Sb	4.1	85	173	3/	3/	3/	3/
D	Till	C	Sg	3.6	55	96	6.3	69	7.9	73
E	Till	CL	C	4.7	46	84	4.8	50	2.3	42
F	Till	SiCL	C,A	13.0	124	163	10.9	110	10.5	108
G	Till	CL	Sb	2.2	18	30	0.0	19	4.4	65
H	Outwash[4/]	L	A	10.9	52	54	25.3	158	13.7	97
I	Outwash	SL	Sb	7.2	68	88	13.8	95	9.0	61
J	Outwash	LS	Sg	2.0	14	23	4.2	24	4.3	34
K	Outwash	L	Sb,A	7.2	65	84	12.8	81	5.9	55
L	Loess	SiL	Sg	4.4	27	28	8.0	54	5.8	39
M	Loess[4/]	SiL	C,A	10.8	118	138	17.3	121	12.3	101
N	Loess	SiL	A	8.6	46	54	17.6	88	18.5	99
O	Loess	SiL	A	5.3	68	90	13.7	119	17.9	138

[1/] Abbreviations are: clay (C), loam (L), silt (Si), sand (S)
[2/] Abbreviations are: corn (C), alfalfa (A), soybeans (Sb), and small grain (Sg). The second crop, when listed, is from 1989.
[3/] Samples not collected.
[4/] Samples taken to a 4-foot depth only.

Table 2. Correlation between selected soil N variables from treatments receiving no fertilizer N at 15 sites in 1991.

Variables Contrasted[1/]	r	Pr>r
Pre 0-2′ NO_3 vs Pre 0-2′ NH_4	.11	.41
Pre 0-2′ NO_3 vs Pre 0-1′ PB	.05	.69
V1 0-2′ NO_3 vs V1 0-2′ NH_4	.30	.03
V1 0-2′ NO_3 vs V1 0-1′ PB	.20	.14
V4 0-1′ NO_3 vs Pre 0-1′ PB	.06	.66
V4 0-2′ NO_3 vs Pre 0-1′ PB	.10	.44
V4 0-1′ PB vs V1 0-1′ PB	.85	.00
V1 0-1′ PB vs Pre 0-1′ PB	.83	.00

[1/] Abbreviations used in describing variables are: preplant (Pre), 1-2 leaf stage (V1), and 6-12 inch tall corn (V4) sampling time, sampling depth in feet (0-1 or 0-2), and nitrate (NO_3), ammonium (NH_4), or hydrolyzable N using a phosphate borate extraction (PB) N forms.

Table 3. Correlation coefficients of soil nitrate-N variables affected by time an depth of sampling from plots receiving no fertilizer at 15 sites in 1991.

		Stage of corn growth and depth of sampling							
		Preplant		1-2 leaf (V1)			6-12" tall (V4)		
		0-2′	2-3′	0-1′	1-2′	0-2′	0-1′	1-2′	0-2′
		r[1]							
Preplant	0-2′	-	.58	.31	.59	.43	.33	.39	.39
	2-3′		-	.04[NS]	.44	.16[NS]	.16[NS]	.36	.25
V1	0-1′			-	.53	.97	.67	.31	.62
	1-2′				-	.73	.48	.62	.59
	0-2′					-	.68	.44	.68
V4	0-1′						-	.51	.95
	1-2′							-	.75

[1/] All coefficients are statistical significant at the 10% probability level except those designated with a NS.

Table 4. The effect of time and depth of soil sampling on nitrate-N and ammonium-N concentrations from preplant fertilizer applications averaged across all sites.

		Preplant N applied (lb N/A)								
Sampling Time	Sampling Depth	0			60			150		
		NO_3-N	NH_4-N	Total	NO_3-N	NH_4-N	Total	NO_3-N	NH_4-N	Total
	- ft -	lb N/A								
1-2 leaf	0-1	38	25	63	67	28	95	112	39	151
	1-2	26	13	39	38	14	52	49	16	65
	0-2	64	38	102	105	42	147	161	55	216
6-12" tall	0-1	35	31	77	59	32	90	98	35	133
	1-2	27	19	46	35	19	54	51	20	71
	0-2	62	50	112	93	51	144	149	55	204

Table 5. Corn grain yield response to N fertilizer additions for each of the sites, 1991.

Site Code	Previous Crop[1/]	Soil O.M.	Yield with 0 N/A bu/A	Optimum N Rate[2/] lb N/A	Yield Increase bu/A
A	C, A	High	153	60	33
B	Sb	High	84	150	93
C	Sb	High	96	90	50
D	Sg	High	136	60	37
E	C	High	42	90	15
F	C, A	High	161	30	13
G	Sb	High	104	120	74
H	A	Med	175	0	0
I	Sb	Low	149	90	24
J	Sg	Low	99	120	51
K	Sb, A	Low	177	30	9
L	Sg	Med	115	120	107
M	C, A	Med	159	30	16
N	A	Med	174	0	0
O	A	Med	207	0	0

[1/] Abbreviations used are: corn (C), alfalfa (A), soybeans (Sb), and small grain (Sg). The second crop, when listed, is from two years ago.
[2/] Optimum N rate is determined using statistical separation of N rate treatment means.

Table 6. Correlation coefficients of three N forms affected by sampling time, depth, and parent material correlated to relative grain yield of plots receiving no fertilizer N at 15 sites in 1991.

Sampling Time	Depth -ft-	Parent Material	Nitrate-N	Ammonium-N	Hydrolyzable N
			r[1/]		
Preplant	0-2	Till	0.61	-0.16^{NS}	-0.39
		Loess	0.35^{NS}	0.44*	0.21^{NS}
		Outwash	0.79	0.34^{NS}	0.63
Preplant	0-3	Till	0.67	-0.14^{NS}	-0.37
		Loess	0.35^{NS}	0.19^{NS}	0.24^{NS}
		Outwash	0.70	0.32^{NS}	0.61
1-2 leaf	0-1	Till	0.77	-0.10^{NS}	0.11^{NS}
		Loess	0.75	0.67	-0.13^{NS}
		Outwash	0.80	0.33^{NS}	0.62
	0-2	Till	0.76	-0.19^{NS}	-0.09^{NS}
		Loess	0.81	-0.74	-0.06^{NS}
		Outwash	0.81	0.56	0.60
6-12" tall	0-1	Till	0.62	0.38	0.11^{NS}
		Loess	0.85	-0.20^{NS}	-0.29^{NS}
		Outwash	0.65	0.73	0.73
	0-2	Till	0.71	-0.43	-0.24^{NS}
		Loess	0.86	-0.34^{NS}	-0.14^{NS}
		Outwash	0.78	0.77	0.69

[1/] All correlation coefficients are statistically significant at the 95% level or greater except those designated with a *, which denotes significance at the 90% level, or a ^{NS}, which denotes not significant at the 90% level or greater.

Table 7. Correlation coefficients of relative grain yield and nitrate-N and ammonium-N from selected N sampling parameters for sites that received preplant N at 15 sites in 1991.

Sampling Time	Depth	NO_3	NH_4
	-ft-	- - - - r[1/] - - -	
1-2 leaf	0-1	0.55	0.23
	1-2	0.55	0.12[NS]
	2-3	0.43	0.03[NS]
6-12" tall	0-1	0.47	-0.04[NS]
	1-2	0.55	0.15*
	2-3	0.47	0.13[NS]

[1/] All correlation coefficients are statistically significant at the 95% level or greater except those designated with a *, which denotes significance at the 90% level, or a [NS], which denotes not significant at the 90% level or greater.

Table 8. Selected regression model parameters as affected by soil sampling time and depth, parent material, and model for soil nitrate values and relative grain yield on control plots at 43 sites in Minnesota, 1989-91.

Parent Material	Sampling Time[1/]	Sampling Depth	Model[2/]	R^2	Critical Value	Error Rate[3/] All	Error Rate[3/] R-PNR	Error Rate[3/] NR-PR
		-ft-		%	ppm	- - - - - - - -	%	- - - - - - - -
Combined	Pre	0-1	LP	26	17.2	30		
Combined	Pre	0-2	LP	35	17.9	37	29	50
Combined	Pre	0-2	QP	34	31.1	33	4	87
Combined	V1	0-1	LP	38	15.8	35		
Combined	V1	0-2	LP	49	23.7	33	21	53
Combined	V1	0-2	QP	49	36.1	37	4	100
Combined	V4	0-1	LP	42	13.0	28		
Combined	V4	0-2	LP	48	20.3	28	18	47
Combined	V4	0-2	QP	49	33.3	35	7	87
Till	V4	0-2	LP	51	21.7	18		
Loess	V4	0-2	LP	57	16.3	40		
Outwash	V4	0-2	LP	32	20.1	36		
All[4/]	V1	0-2	LP	45	27.7	26		
Till[4/]	V1	0-2	LP	46	26.7	38		
Loess[4/]	V1	0-2	LP	72	28.4	7		
Outwash[4/]	V1	0-2	LP	21	28.5	25		

[1/] Sampling time abbreviations are preplant (Pre), 1-2 leaf stage (V1), and 6-12 inches tall (V4).
[2/] Models are either linear-plateau (LP) or quadratic plateau (QP).
[3/] Error rates are based on lack-of-fit for models. Errors are sometimes partitioned into responsive-predicted nonresponsive (R-PNR) or nonresponsive-predicted responsive (NR-PR).
[4/] These regression models included plots that received preplant N applications.

FERTILIZER N RESPONSE IN A CONTINUOUS CORN SYSTEM

M.A. Schmitt, G.W. Randall, and C.C. Sheaffer[1/]

ABSTRACT

The optimum fertilizer N rate for corn following corn is dependent on the year. In 1989, at Waseca and Rosemount, there were no statistical differences in corn grain yield among N rates. In 1990, the optimum fertilizer N rate was 90 lb at Rosemount and 60 lb at Waseca. For the 1991 cropping season, 60 lb. N was optimum at Rosemount and 150 lb N was optimum at Waseca. While an overall optimum N rate can be determined over several years for a location, this rate may underapply or overapply N fertilizer when only previous response curves are used to make this decision.

Introduction

Nitrogen equivalency plots are established to develop a response curve for N fertilizer. Normally, these plots are used to determine the fertilizer replacement value of a N source of unknown quantity. For example, if manure of an unknown N quantity were applied to a field, the yield could be placed on the equivalency plot response curve to estimate how much fertilizer N was replaced by the manure.

Long-term alfalfa/manure plots are being established at Rosemount and Waseca, and, in conjunction with these plots, a series of fertilizer N response trials are being conducted. The objective of these plots are to establish N response curves so that multiyear trends can be established.

Methods

Plots were established on a Waukegan silt loam at Rosemount and a Webster clay loam at Waseca from 1989 through 1991. Continuous corn in a conventional tillage system was the cropping history. Fertilizer N rates of 0, 30, 60, 90, 120, 150, and 180 lb N/acre were applied preplant as broadcast urea and incorporated soon thereafter.

Corn planting was conducted during recommended planting periods at populations sufficient for optimum production. Weeds were controlled with a preplant herbicide program. All management was conducted to ensure high yielding corn.

Corn was hand picked at Rosemount and then shelled, whereas a combine/sheller was used to harvest corn at Waseca. Shelled grain samples were dried and bushel weights were calculated for 15.5% grain moisture basis.

Plots were 20-30 feet long and 10 feet wide. A randomized complete block experimental design was used. Each block was replicated four times. Statistical analysis was performed by PC-SAS software. Different plot areas were used each year to avoid residual N effects from the differing N rate treatments.

Results

The grain yield responses to fertilizer N from Waseca are reported in Table 1. While the 1989 average treatment yields ranged from 105 to 115 bu/A, this variation was not significantly different. Thus, there was no response to fertilizer N this year. It is important to note that a major drought occurred the previous year (1988) and there was probably some residual N in the soil that contributed to the lack of response to fertilizer N.

In 1990 at Waseca, the optimum N rate was 60 lb N/acre according to statistical delineation. The optimum N rate increased to 150 lb. N/acre in 1991. Based on long-term N response studies at Waseca, the 150 lb N/acre is in line with the predicted amount of N from other studies for continuous corn.

At Rosemount, there was no grain yield response to fertilizer N in 1989 (Table 2). Again, factors contributing to this were relatively high amounts of N added in 1988 and low yields due to a dry growing season. However, in 1990, grain yield responses were higher with an optimum of 90 lb N/acre. The optimum N rate was 60 lb N/acre in 1991.

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Summary

Previous fertilizer management, crop yields, and the weather during the growing season all affect corn yield response to fertilizer N. Therefore, optimum fertilizer N rates are difficult to predict based simply on the previous years' optimum N rate.

These results emphasize the fact that years are not independent when dealing with N fertilizer. Nitrogen fertilizer recommendations that do not account for preceding environmental information or the results of the past environment (soil N test) may be overrecommending fertilizers.

Table 1. Corn grain yields as affected by n fertilizer rates at Waseca from 1989-1991.

N Rate	Year			
	1989	1990	1991	1989-91
lb N/acre	bu/acre			
0	105.6[1]	95.8	59.4	86.9
30	111.4	117.6	72.7	100.6
60	115.2	125.5[1]	100.6	113.8
90	112.8	127.5	117.9	119.4
120	110.7	139.9	128.4	126.3[1]
150	110.4	135.0	144.5[1]	129.9
180	113.0	136.9	158.9	136.3

[1] The designated yields indicate the N treatment at which yields were not statistically increased using least significant difference procedures.

Table 2. Corn grain yields as affected by N fertilizer rates at Rosemount from 1989-1991.

N Rate	Year			
	1989	1990	1991	1989-91
lb N/acre	bu/acre			
0	150.5[1]	100.7	129.9	127.1
30	141.8	114.7	149.0	135.2
60	150.8	129.2	169.2[1]	149.7
90	151.2	146.1[1]	178.0	158.5[1]
120	144.9	146.8	174.6	158.7
150	159.6	159.7	178.5	165.9
180	161.0	157.8	172.6	163.6

[1] The designated yields indicate the N treatment at which yields were not statistically increased using least significant difference procedures.

NITROGEN SPECIFIC MANAGEMENT BY SOIL CONDITION[1]

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Abstract: Recent advances in technology has brought about considerable interest in developing the methodology for making variable N rate applications within a field. The objectives of this study were to evaluate yield variability within production fields, determine yield response to applied fertilizer N and differential N loss as influenced by soil conditions. Results are being evaluated to determine what measurable soil conditions are best suited for making site specific N recommendations. Experimental locations of 36 and 44 acres were established at Lamberton and Becker, respectively. Different N management treatments were applied in replicated strips across the fields. Yields obtained from segmented harvest areas from control strips (zero N) indicate extreme yield variability. Preliminary results would suggest that variable N rate application can reduce N inputs, maintain or improve yield and increase net return for the producer.

Introduction: Nitrogen Specific Management by Soil Condition (NSMSC) has the potential to increase yields by better evaluating yield potentials of fields, increase profits by lowering inputs and improve water quality by identifying areas of potential N loss. NSMSC originated from recent advances in Geographic Information System (GIS) technology and continued interest in improving Best Management Practices (BMP) for nitrogen. Nitrogen specific recommendations, based on yield goal and soil conditions of production fields, are stored on a computer as digitized maps. The applicator's computer reads the digitized map and applies the specific N rate. An experiment was initiated in 1990 to evaluate site specific application of anhydrous ammonia on corn. The objectives of this study were to evaluate the variability in yield potentials within production fields, determine yield response to applied fertilizer N and differential N loss as influenced by soil conditions and ascertain what measurable soil conditions are best suited for making site specific N recommendations.

Materials and Methods: Experimental sites of 36 and 44 acres were chosen at the Southwest Experiment Station, Lamberton (Dryland) and the Malcolm and Steve Olson Farm, Becker (Irrigated). The sites selected represented soil variability common to their respective areas. Experimental measurements for both sites include: an intensive soil survey (1:5000 scale) and grid soil sampling (analyzed for NO_3-N, NH_4-N, total N, carbon, mineralizable N and soil water). Soil sample grid size was 90 by 100 and 100 by 100 feet and samples were taken to a depth of 4 and 3 feet in early November and mid May at Lamberton and Becker, respectively. Soil samples were separated into one foot increments for analysis. A summary of the sites soil characteristics are presented in Tables 1 and 2. Response measurements include: corn grain yield, grain moisture and N accumulation in grain.

Table 1. Soil data for Nitrogen Specific Management by Soil Condition Lamberton 1991.

Soil Series	Symb.	Acres	Text.	Slope	O. M.	NO_3-N	Subgroup
				%	%	lbs/A	
Canisteo	86	7.2	cl	0-2	5.4	54	Mollic Haplaquoll
Webster	113	7.2	cl	0-2	4.2	47	Typic Haplaquoll
Normania	446	1.1	l	0-2	4.0	50	Aquic Haplustoll
Okoboji	134	2.4	sicl	0-2	6.4	71	Cumulic Haplaquoll
Terril	94	0.8	l	2-6	3.8	38	Cumulic Hapludoll
Ves A	421A	3.3	l	0-2	3.4	40	Udic Haplustoll
Ves B	421B	11.4	l	2-6	3.4	40	Udic Haplustoll
Ves C	421C	2.8	l	6-12	3.1	35	Udic Haplustoll

Symb. Soil series symbol, Text. Soil texture
O.M. Organic matter (values for one foot depth)
NO_3-N Residual Nitrate (value for zero to two foot depth)

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[2] Graduate assistant, Professor and Assistant Professor, Department of Soil Science, and Superintendent, Southwest Experiment Station, respectively.

Table 2. Soil data for Nitrogen Specific Management by Soil Condition Becker 1991.

Soil Series	Symb.	Acres	Text.	Slope	O. M.	NO_3-N	Subgroup
				%	%	lbs/A	
Hubbard A	7A	6.4	ls	0-2	1.9	15	Udorthentic Haploboroll
Hubbard B	7B	11.1	ls	2-6	2.4	19	Udorthentic Haploboroll
Hubbard C	7C	1.2	ls	6-12	4.2	27	Udorthentic Haploboroll
Monticello A	768A	7.8	sl	0-2	2.6	19	Udic Haploboroll
Monticello B	768B	7.7	sl	2-6	2.0	16	Udic Haploboroll
Sandberg	256C	2.4	lcos	6-12	2.4	17	Udorthentic Haploboroll
Fill		7.4	s/p	0-2	3.9	23	

Symb. Soil series symbol, Text. Soil texture
O.M. Organic matter (values for one foot depth)
NO_3-N Residual Nitrate (value for zero to two foot depth)
s/p Sand over peat

Lamberton: Pioneer 3615 was planted on May 11 at a population of 27,700 S/A on 30 inch rows. Starter fertilizer was applied as a side banded application of 100 lbs/A of 12-30-10. Weed control was accomplished by using Lasso at 3 lbs/A on May 13 and cultivation on June 12 and 13. Twelve treatments consisting of eight constant N rates paired with N-Serve (60, 90, 120 and 150 lbs N/A), two variable N rates (soil and residual nitrate) and two checks (zero N) were applied sidedress as anhydrous ammonia on May 22 and 23 (emergence). Treatments were applied in 15 foot strips (6 rows) across the field in a randomized complete block design with 7 replications. Rates for the variable rate by soil treatment were based on yield goal, previous cropping history, and the Crop Equivalency Rating (CER) of each mapping unit. Rates for the variable by residual nitrate were calculated from the grid soil samples using the nitrogen credit equation (AG-BU 0519). The previous crop was soybeans in a corn-soybean rotation. Grain was harvested on October 4, 5 and 6 in 40 foot segments across the field.

Becker: Pioneer 3569 was planted on April 29 at a population of 31,500 S/A on 38 inch rows. Starter fertilizer was applied as a side banded application of 240 lbs/A of a 12-10-30. Weed control was accomplished by using a tank mix of Prowl at 2 pts/A and Aatrex at 1.75 lbs/A and cultivation on June 4. Ten treatments consisting of eight constant N rates paired with N-Serve (120, 150, 180 and 210 lbs N/A), one variable rate (soil), and a check (zero N) were applied sidedress as anhydrous ammonia on June 5 and 6 (sixth leaf Stage). Treatments were applied in 25 foot strips (8 rows) across the field in a randomized complete block design with 4 replications. Rates for the variable by soil treatment were based on yield goal, previous cropping history and the CER of each mapping unit using existing extension recommendations. The previous crop was corn in a corn-corn-soybean rotation. Grain was harvested on October 14, 15 and 18 in 40 foot segments across the field.

Results and Discussion Lamberton: Grain yields on check plots ranged from 66 to 174 bu/A. Variability in grain yield from the check areas was high on all soils except Terril which ranged from 132 to 161 bu/A. This suggests that soil map unit may not be the only parameter needed to describe soil variability. The yield averages for treatments by soil map unit are presented in Table 3. All soil map units responded to fertilizer N, only Okoboji and Terril responded to rates higher than 60 lbs N/A. This implies differential N response to fertilizer N between soil map units. Early indications suggest limited yield response to N-Serve within mapping units, except on Okoboji and terril soil map units, however, statistical analysis has not been performed. The nitrogen fertilizer return (NFR) showed no economic benefit for either of the site specific treatments (VSoil and VNO_3) compared with conventional application (Table 4), but the calculated economic optimum rate of fertilization saved $15 per acre over conventional application. This suggests that significant improvements can be made with site specific application over conventional fertilization. Both variable treatments and calculated economic optimum had lower average rates of N for the field, thus reducing the risk of N contamination to groundwater. The VNO_3 treatment could have been affected by considerable N losses, resulting from cool wet weather conditions experienced after soil samples were obtained in the fall of 1990. Such losses would limit the effectiveness of the fall soil Nitrate test.

Table 3. Grain yield by soil map units for Nitrogen Specific Management by Soil Condition, Lamberton 1991.

NRate lbs/A	NServe	86	113	446	134	94	421A	421B	421C
		bu/A							
60	NI	139	131	150	128	157	142	137	120
90	NI	135	137	136	122	162	144	148	126
120	NI	148	148	---	140	159	142	146	132
150	NI	139	136	---	118	160	142	140	137
0		123	126	120	109	147	125	124	111
60		140*	144*	163*	113	151	144*	142*	143*
90		136	139	148	142*	156*	142	144	135
120		138	139	---	131	157	142	143	137
150		132	144	137	137	157	145	144	130
VSoil	NI^	135	135	141	130	164	144	144	135
VNO_3N		118	129	131	121	153	142	134	118

NI = Nitrification Inhibitor N-Serve.
VSoil Variable by soil.
VNO_3N Variable by residual NO_3.
* Significant Economic optimum rate (LSD 0.05).
--- No Data.
^ N-Serve applied to soils 86, 113 and 134 on VSoil.

Table 4. Economics of Farming by Soil Lamberton 1991.

Treatment Method	N-Rate lbs N/A	N-Cost $/A	N-Serve $/A	Avg Yield bu/A	NFR $/A
Conventional	120	16	0	140	27
VSoil	98	13	3	139	24
VNO_3	42	5	0	135	25
Optimum	64	8	0	143	42

N-Cost 13 cents per pound.
Corn Value $2.45 per bushel @ 15.5% moisture.
Rates and yields averaged for 36 acre field.
NFR = Nitrogen Fertilizer Return.
Additional application cost of Variable treatment over conventional application = $2 per acre.

Results and Discussion Becker: Grain yields on check plots varied from 58 to 162 bu/A. Variability in grain yield from the check areas was high on all soils. This suggests that soil map unit may not be the only parameter needed to describe soil variability. The average yields for treatments by soil map unit are presented in Table 5. All soil map units responded to fertilizer N, only Hubbard C responded to a N rate higher than 120 lbs N/A. This implies differential N response to fertilizer N between soil map units. Early indications show a potential yield response to N-Serve in the Fill area. This area is a sand marsh, it is very wet and frequently has a perched water table, thus the potential for N loss is high. The NFR for the Becker site is presented in table 6. The site specific application (VSoil) returned $9 more than conventional and the calculated economic optimum was $18 better than conventional. The apparent economic success in the VSoil treatment came from lowering N rates while maintaining or increasing grain yield. The optimum and the variable treatment resulted in lower average rates of N applied to the field. Data from this site supports trends and conclusions at Lamberton, in that considerable improvement can be made over conventional application.

Table 5. Grain yield by soil map unit for Nitrogen Specific Management by Soil Condition, Becker 1991.

NRate	NServe	7A	7B	7C	768A	768B	256C	Fill
lbs/A		bu/A						
120	NI	153	157	154	168	161	145	162
150	NI	153	155	158	159	144	---	157
180	NI	165	152	167	166	147	160	162
210	NI	163	158	168	163	156	167	156
0		98	102	138	111	97	105	106
120		162*	158*	156	171*	171*	155*	152*
150		159	158	164*	161	148	---	161
180		160	153	154	156	146	157	140
210		162	160	174	163	153	158	155
VSoil	NI	172	162	160	171	158	150	164

NI Nitrification Inhibitor N-Serve.
VSoil Variable by soil.
* Significant optimum rate (LSD 0.05).
--- No Data.

Table 6. Economics of Farming by Soil Becker 1991.

Treatment Method	N-Rate lbs N/A	N-Cost $/A	N-Serve $/A	Avg Yield bu/A	NFR $/A
Conventional	210	27	0	159	108
VSoil	177	23	7	164	117
Optimum	121	16	0	162	126

N-Cost 13 cents per pound.
Corn Value $2.45 per bushel @ 15.5% moisture.
Rates and yields averaged for 44 acre field.
NFR = Nitrogen Fertilizer Return.
Additional application cost of Variable treatment over conventional application = $2 per acre.

AGRICULTURAL UTILIZATION OF NUTRALIME: ON FARM DEMONSTRATION PLOTS

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NutraLime is a product made from two waste materials: sewage sludge incinerator ash from the Metropolit Waste Control Commission in St. Paul and spent lime from municipal water treatment plants. Land application of these waste products has been studied individually in previous research. The sewage sludge ash was found to supply phosphorus and micronutrients for crop production. At realistic application rates, heavy metals were not found to be taken up by corn plants nor did the metals move significantly in the soil. Spent lime was found to an effective liming amendment. By combining these two waste products, both nutrients and lime could be recycled onto cropland alleviating, the need to rely on landfills for disposal. The objectives of these demonstration plots were to inform growers and the public about NutraLime, monitor crop growth at various rates of applied NutraLime, monitor plant uptake of elements supplied by NutraLime, and follow movement of elements supplied by NutraLime in soil.

PROCEDURES

Three field sites, all used for commercial crop production, were selected for the demonstration plots. The sites were located in Dakota Co. (Wadena loam), Isanti Co. (Hayden silt loam), and Washington Co. (Antigo silt loam). Selected soil characteristics of each site are presented in Table 1. The same basic procedure was followed at each site. Treatments consisted of a control and three rates (0.5X, 1.0X, 2.0X) of NutraLime, replicated three times in strips. The strips were 25-30 feet wide and 300 feet in length. Prior to NutraLime application, 14" suction tubes were buried so that the ceramic tip was at about 2.5' deep. These suction tubes were intended to be used for the duration of the demonstration without having to reinstall them each year. Plastic line from the suction tubes was laid along a 5' trench so that soil above the suction tube would not be disturbed when water samples were collected and the line was buried to allow for tillage operations. The NutraLime was applied as a slurry using a terragator set at the 0.5X rate. To obtain the 1X and 2X rate, the terragator travelled 2 and 4 more times, respectively, over the plots at the same speed. Preweighed plastic trays (3ft x 2ft) were placed in the middle of each 0.5X strip to catch the applied material. The trays were weighed again after application and a subsample was collected in plastic bottles for moisture determination and elemental content. The actual rates applied varied with each site and are presented on a wet and dry weight basis in Table 2. Elemental content of the NutraLime at each site was determined on concentrated nitric acid/perchloric acid digests (Table 3).

At the Dakota Co. site, NutraLime was applied on April 26, 1991 and then chisel plowed in to a depth of 1 inches. The previous crop was potatoes and the crop tested for response to Nutralime was Jacques seed corn - Code 84 was the pollinator and Code 67 was the seed parent. The seed corn was planted May 20, 1991 at a rate of 26,500 seeds/A (2.5' between rows). Anhydrous ammonia was applied preplant at the rate of 140 lb N/A. Irrigation was used to supplement rainfall when needed.

At the Isanti Co. site, NutraLime was applied on November 7, 1990 and then disked in to a depth of 6 inches. The previous crop was soybeans and the crop tested for response to Nutralime was Pioneer 3790 field corn. The corn was planted May 10, 1991 at a rate of 29,000 seeds/A (2.5' between rows). Starter fertilizer was applied at a rate of 30 lb N/A, 30 lb P_2O_5/A, 40 lb K_2O/A, and 10 lb S/A. No additional fertilizer was applied during the season. The site was nonirrigated.

At the Washington Co. site, NutraLime was applied on October 25, 1990 and then chisel plowed in to a depth of 10 inches. The previous crop was corn and the crop tested for response to Nutralime was Jacques 6770 field corn. The corn was planted May 8, 1991 at a rate of 28,000 seeds/A (2.5' between rows). Anhydrous ammonia was applied preplant at the rate of 160 lb N/A. Starter fertilizer was applied at a rate of 23 lb N/A, 58 lb P_2O_5/A, and 75 lb K_2O/A. Irrigation was used to supplement rainfall when needed.

Soil water samples were collected 2-3 times during the growing season. At the Washington Co. site, insufficient water percolated to the 2.5 ft depth and therefore water samples could not be obtained at this site. Water samples were analyzed for multiple elements using ICP procedures. Whole plant samples (8 per replication) were collected at the 10 - 12 leaf stage and 8 ear leaf samples per replication were collected at 50% silk. Two - 40 ft rows were hand harvested to obtain an estimate of final yield. For the seed corn, both male and female parents were harvested. Samples of stover and ears (grain and cob) were collected. Samples were dried at 60 C, moisture content was determined and then the samples were ground to pass through a 30 mesh screen. Samples were ashed, dissolved in 1 N HCl and then analyzed for elemental content using ICP procedures. Tissue nitrogen concentrations were determined following Kjeldahl digestion using

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[1]Funding for this project was provided by the Metropolitan Waste Control Commission.
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conductimetric procedures. Soil samples were collected after harvest. Eight subsamples from each replication were taken at one foot intervals down to three feet. Samples were air dried and then ground. Multiple elements were determined on 1 N nitric acid extracts. Other analyses included soil pH and soluble salts (1:1 soil:water), ammonium acetate extractable cations, and DTPA extractable metals.

RESULTS

Plant Growth and Yield. Effects of NutraLime on corn growth are presented in Tables 4-7. Early plant growth at the 10-12 leaf stage decreased at the highest application rate of NutraLime in Washington County, but had no effect on early plant growth at the other locations. NutraLime had no effect on final stand count at any of the locations. Stover yield significantly increased with Nutralime application at the Isanti Co. location, but had no effect at the other sites. NutraLime increased seed corn yield at the Dakota Co. site at the lowest application rate. In Isanti Co., field corn yield increased linearly with NutraLime application. NutraLime increased yield by 32 bu/A over the control treatment. In Washington Co., the highest rate of NutraLime had a depressing effect on grain yield. These results indicate that when applied at realistic rates, NutraLime can have a beneficial effect on plant growth. However, when excessive applications were applied as in the highest rate at Washington County, some negative effects on growth may occur.

Elemental Concentrations in Soil Water. Elemental concentrations in water collected from suction tubes at the 2.5' depth are presented in Tables 8 and 9. Samples were not obtained from Washington County due to insufficient water movement in this soil. Concentrations of Al, B, Cd, Cr, Cu, Fe, Ni, and Pb were generally below detection limits of the ICP. Concentrations of P and K were below detection limits at the Isanti Co. site. At the Dakota Co. site P and K concentrations were generally above detection limits, but did not show any trend with NutraLime treatment. Concentrations of Ca, Mg, Mn, Na, S, and Zn were above detection limits at both sites; however, they did not show any trend with NutraLime treatment.

Elemental Concentrations in Soil. Soluble salts, soil pH, Bray and Olsen P, ammonium acetate extractable cations and DTPA extractable metals are presented in Tables 10-12. Soil pH increased substantially (1.2-1.8 units) in the top 6 inches with the 0.5X NutraLime rate. With higher NutraLime rates, soil pH increased by an additional 0.1-0.4 units. Soil pH was not affected by NutraLime treatment at the 12-24 inches depth at any site. At the 6-12 inch depth, soil pH increased by 0.8 units with the 2X rate at one site. Soluble salts in the top 6 inches increased with NutraLime application; however, none of the soluble salt levels were in a range considered to be high enough to cause salt toxicity. In the 6-12 inch depth, soluble salts increased with Nutralime application at two of the three sites and in the 12-24 inch depth, increased at one of the three sites. Bray and Olsen P increased with NutraLime application in the top 6 inches at all sites. At the Isanti county site soil P was unaffected by NutraLime application at the lower depths, which probably indicates shallow tillage practices. At the other two sites, soil P increased in the 6-12 inch depth and only slightly at one of the sites in the 12-24 inch depth. Extractable K was not affected by NutraLime application. Extractable Na increased only at the Dakota Co. site in the top 6 inches. Extractable Ca and Mg tended to increase with NutraLime application in the top 6 inches, but not in the lower depths. DTPA extractable Fe and Mn decreased with NutraLime application in the top 6 inches and were unaffected in the lower depths. DTPA extractable Cu increased in the top 6 inches at all sites and was generally unaffected in the lower depths. DTPA extractable Zn was not affected by NutraLime application at the Dakota and Isanti Co. sites, but did increase in the top 12 inches at the Washington Co. site. DTPA extractable Pb and Ni did not increase with NutraLime application at any of the sites and in some cases actually decreased with NutraLime application. DTPA extractable Cd was not significantly affected by NutraLime application. DTPA extractable Cr was generally not affected by NutraLime application; although at the Dakota Co site there was a slight increase in extractable Cr in the 12-24 inch depth.

Nitric acid extractable soil elements are presented in Tables 13-15. All elements tested except Be, Co, Li, K, and S increased with NutraLime application in the top 6 inches at all sites. Li was frequently below detection limits, K increased with NutraLime application at one of the three sites and Co increased at two of the three sites. Interestingly, S did not significantly increase with NutraLime application in the top 6 inches; however, significant increases in S were observed in the 6-12 and 12-24 inch depths. These results indicate that some leaching of S from the NutraLime was occurring. At the Isanti Co. site higher concentrations of elements, other than S, at the lower depths were not observed. Background concentrations at these lower depths indicate that minimal leaching occurred and that tillage operations were relatively shallow. At the other two sites, where deeper tillage was used, Cd, Ca, Cr, Cu, P, Na, and Zn concentrations increased in the 6-12 inch depth with NutraLime application. Except for S, NutraLime had no consistent effect on elemental concentrations in the 12-24 inch depth.

Elemental Concentrations in Plant Tissue. Elemental concentrations in whole plant, ear leaf, stover, husk (seed corn only), kernel, and cob tissue from all sites are presented in Tables 16-37. Of all the elements determined, only Mo consistently increased with NutraLime application at all sites. Concentrations of Mo were below levels (10 ppm) that would cause Mo toxicity (molybdenosis) in cattle. Tissue concentrations of

trace metals such as Cd, Ni, Cr, and Pb were generally not affected by NutraLime application and in some cases decreased with NutraLime application.

In Dakota Co., Cu concentrations increased slightly with NutraLime application in whole plant and cob tissue. The reason for the increase in yield with the low rate of NutraLime at this site is not clear from the nutrient status of the plant. Nutrient levels in ear leaf tissue were in the satisfactory range for plants grown in all treatments, including the control.

In Isanti Co., P concentrations in whole plant and ear leaf tissue significantly increased with NutraLime application. Surprisingly, N concentrations also increased in ear leaf tissue with NutraLime applications. The N content of NutraLime is only about 1 lb N/dry ton, which is probably not enough at the rates applied to affect N nutrition of the plant. It is possible that Mo, which is involved with N metabolism, may be associated with improved N nutrition. The reason for the increase in yield with NutraLime at this site may be due to a number of factors including improved N, P, Mo, and B.

In Washington Co., N concentrations in whole plant and ear leaf tissue increased with NutraLime application. Yields at this site did not increase with NutraLime application and actually decreased at the highest rate. Reasons for the decrease in yield at the highest rate could not be associated with any specific element.

GENERAL SUMMARY

NutraLime application increased corn yield at two of three sites. Improved N, P, and Mo nutrition appeared to be involved, although other factors not measured may also have played a role. High rates of NutraLime (> 30 dry tons/A) may decrease corn yields. Accumulation of heavy metals in plant tissue as a result of NutraLime application was not observed. Heavy metals applied with NutraLime were confined to the top 12 inches of soil and did not leach. NutraLime effectively increased soil pH and plant available P. Results from this first year show that NutraLime does appear to have an agronomic benefit. This study will be continued at the same sites without additional applications to monitor residual metal movement in the soil, metal availability to crop plants, and overall crop performance.

Table 1. Selected initial soil chemical characteristics of the demonstration sites.

Chemical Characteristic	Demonstration sites		
	Dakota Co.	Isanti Co.	Washington Co.
pH	6.3	5.5	5.7
Bray P1 (ppm)	120	40	81
Ammonium Acetate K (ppm)	256	170	214

Table 2. NutraLime treatments applied at each site prior to planting.

Demonstration sites					
Dakota Co.		Isanti Co.		Washington Co.	
NutraLime applied					
Wet tons/A	Dry tons/A	Wet tons/A	Dry tons/A	Wet tons/A	Dry tons/A
0.0	0.0	0.0	0.0	0.0	0.0
9.8	4.3	13.1	5.1	18.6	7.8
19.6	8.6	26.2	10.2	37.2	15.6
39.2	17.2	52.3	20.4	74.4	31.2

Table 3. Selected chemical characteristics of NutraLime used at each site (means of 4 or 5 samples).

Chemical Characteristic	Dakota Co.		Isanti Co.		Washington Co.	
Moisture (%)	55.9		61.1		58.2	
Calcium Carbonate Equivalent (%)[1]	33.3		41.7		45.7	
Soluble Salt (mmhos/cm)	4.5		5.3		4.9	
Chloride (ppm)	201		218		232	
Mercury (ppm)	-		0.007		0.011	
Total nitrogen (%)	-		0.05		-	
Acid Digestible Elements[2]	**ppm**	**lb/dry ton**	**ppm**	**lb/dry ton**	**ppm**	**lb/dry ton**
Aluminum	42543	85	35722	71	33183	66
Arsenic	44	0.09	36	0.07	34	0.07
Barium	1260	2.5	815	1.6	960	1.9
Beryllium	0.7	0.001	0.8	0.002	0.7	0.001
Boron	39	0.08	36	0.07	34	0.07
Cadmium	32	0.06	37	0.07	35	0.07
Calcium	137573	275	159544	319	171478	343
Chromium	769	1.5	648	1.3	638	1.3
Cobalt	4.9	0.01	1.9	0.004	1.7	0.003
Copper	2270	4.5	2205	4.4	2011	4.0
Iron	19982	40	18500	37	17546	35
Lead	412	0.82	417	0.83	383	0.77
Lithium	11	0.02	10	0.02	10	0.02
Magnesium	13566	27	15579	31	15108	30
Manganese	3008	6.0	1809	3.6	1994	4.0
Molybdenum	38	0.08	27	0.05	26	0.05
Nickel	209	0.42	210	0.42	200	0.40
Phosphorus	39010	78	33171	66	29719	59
Potassium	3324	6.6	2766	5.5	2565	5.1
Rubidium	<105	-	<105	-	<105	-
Silicon	366	0.73	433	0.87	401	0.80
Sodium	2038	4.1	1994	4.0	1839	3.7
Strontium	273	0.55	273	0.55	272	0.5
Sulfur	2231	4.5	2543	5.1	2554	5.1
Titanium	318	0.64	312	0.62	266	0.5
Vanadium	38	0.08	33	0.07	32	0.06
Zinc	1591	3.2	1769	3.5	1673	3.3

[1] Calcium carbonate equivalent, chloride, mercury, total nitrogen, and acid digestible elements are expressed on a dry weight basis.

[2] Acid digestible - boiling concentrated nitric acid and concentrated perchloric acid. After 6 hours, 34-41% remained undigested.

Table 4. Effect of NutraLime on whole plant dry weight at the 10-12 leaf stage, final stand count, stover yield, husk yield, and seed corn yield (female parent) - Dakota County.

NutraLime Treatment	Plant yield 10-12 leaf	Final stand count	Stover yield	Husk yield	Seed corn yield
	g dw	plants/A	T/A	T/A	bu/A
0	145	26,523	1.98	0.20	35.4
0.5X	144	31,847	2.31	0.26	45.1
1.0X	143	30,105	2.22	0.20	39.3
2.0X	116	30,976	2.12	0.20	38.8
Significance	NS	NS	NS	NS	*
BLSD (0.05%)	--	--	--	--	4.6
Linear NutraLime	NS	NS	NS	NS	NS
Quad. NutraLime	NS	NS	NS	NS	*

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 5. Effect of NutraLime on whole plant dry weight at the 10-12 leaf stage, final stand count, stover yield, husk yield, and grain yield (male parent) - Dakota County.

NutraLime Treatment	Plant yield 10-12 leaf	Final stand count	Stover yield	Husk yield	Grain yield
	g dw	plants/A	T/A	T/A	bu/A
0	70	43,947	3.06	0.27	13.4
0.5X	50	42,204	2.76	0.35	12.8
1.0X	59	40,656	2.87	0.27	13.5
2.0X	89	41,430	2.93	0.26	14.3
Significance	NS	NS	NS	NS	NS
BLSD (0.05%)	--	--	--	--	--
Linear NutraLime	NS	NS	NS	NS	NS
Quad. NutraLime	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 6. Effect of NutraLime on whole plant dry weight at the 10-12 leaf stage, final stand count, stover yield and grain yield - Isanti County.

NutraLime Treatment	Plant yield 10-12 leaf	Final stand count	Stover yield	Grain Yield
	g dw	plants/A	T/A	bu/A
0	203	25,264	2.70	148.7
0.5X	206	25,264	3.42	172.3
1.0X	211	25,120	3.44	180.5
2.0X	204	24,684	3.05	180.2
Significance	NS	NS	*	*
BLSD (0.05%)	--	--	0.40	18.9
Linear NutraLime	NS	NS	*	**
Quad. NutraLime	NS	NS	*	*

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 7. Effect of NutraLime on whole plant dry weight at the 10-12 leaf stage, final stand count, stover yield and grain yield - Washington County.

NutraLime Treatment	Plant yield 10-12 leaf	Final stand count	Stover yield	Grain Yield
	g dw	plants/A	T/A	bu/A
0	324	23,958	2.57	177.8
0.5X	289	24,394	2.38	185.5
1.0X	279	24,829	2.56	178.5
2.0X	282	24,248	2.32	163.8
Significance	NS	NS	NS	*
BLSD (0.05%)	--	--	--	13.1
Linear NutraLime	*	NS	NS	*
Quad. NutraLime	NS	NS	NS	*

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 8. Effect of NutraLime on elemental composition of soil water collected from suction tubes - Isanti County.

NutraLime Treatment	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Zn
	ppm															
Aug. 8, 1991																
0	<0.19	<0.026	25	<0.006	<0.015	<0.028	<0.02	<0.8	9	0.02	6	<0.024	<0.08	<0.09	6	0.03
0.5X	<0.19	<0.025	28	<0.006	<0.015	<0.028	<0.22	<0.8	9	0.05	6	<0.027	<0.04	<0.09	7	0.04
1.0X	<0.19	<0.025	26	<0.006	<0.015	<0.028	<0.04	<0.8	9	0.05	5	<0.028	<0.05	<0.09	9	0.05
2.0X	<0.19	<0.025	35	<0.006	<0.015	<0.028	<0.04	<0.8	12	0.05	6	<0.028	<0.04	<0.09	10	0.05
Significance	--	--	NS	--	--	--	--	--	NS	NS	NS	---	--	--	NS	NS
Oct. 2, 1991																
0	<0.19	<0.028	25	<0.006	<0.015	<0.028	<0.15	<0.8	9	0.02	6	<0.025	<0.06	<0.09	10	0.06
0.5X	<0.19	<0.025	29	<0.006	<0.015	<0.028	0.03	<0.8	9	0.03	6	<0.029	<0.04	<0.09	12	0.06
1.0X	<0.19	<0.025	21	<0.006	<0.015	<0.028	0.02	<0.8	6	0.02	4	<0.024	<0.05	<0.09	13	0.05
2.0X	<0.19	<0.026	34	<0.006	<0.015	<0.028	0.02	<0.8	11	0.06	6	<0.035	<0.04	<0.09	11	0.06
Significance	--	--	NS	--	--	--	--	--	NS	NS	NS	---	--	--	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 9. Effect of NutraLime on elemental composition of soil water collected from suction tubes - Washington County.

NutraLime Treatment	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Zn
	ppm															
July 25, 1991																
0	<0.19	0.052	82	<0.006	<0.015	<0.028	0.26	5.0	21	0.02	11	<0.030	0.15	<0.09	26	0.12
0.5X	<0.19	0.031	45	<0.006	<0.015	<0.028	<0.03	1.6	8	0.01	5	<0.025	0.12	<0.09	24	0.07
1.0X	<0.19	0.032	51	<0.006	<0.015	<0.028	<0.07	1.9	11	0.02	6	<0.024	0.11	<0.09	21	0.11
2.0X	<0.19	<0.028	105	<0.006	<0.015	<0.028	<0.06	2.0	22	0.04	14	<0.052	0.07	<0.09	31	0.09
Significance	--	--	NS	--	--	--	--	NS	NS	NS	NS	---	NS	--	NS	NS
Aug. 30, 1991																
0	<0.19	<0.044	52	<0.006	<0.015	<0.028	<0.10	4.0	13	0.01	7	<0.030	<0.11	<0.09	26	0.08
0.5X	<0.19	<0.032	74	<0.006	<0.015	<0.032	0.07	2.5	16	0.05	7	<0.049	0.09	<0.09	26	0.25
1.0X	<0.19	<0.026	62	<0.006	<0.015	<0.028	0.09	1.8	14	0.02	5	<0.031	<0.06	<0.09	17	0.15
2.0X	<0.19	<0.029	79	<0.006	<0.015	<0.028	0.27	1.7	17	0.03	14	<0.037	<0.06	<0.09	33	0.50
Significance	--	--	NS	--	--	--	--	NS	NS	NS	NS	---	--	--	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 10. Effect of NutraLime on soil pH, soluble salts, Bray P1, Olsen P, ammonium acetate extractable cations and DTPA extractable metals - Dakota County.

Depth inches	Treatment	pH	Soluble Salts mmhos/cm	Bray P1	Olsen P	NH_4OAc Extractable K	Ca	Mg	Na	DTPA Extractable Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr
				ppm													
0-6	0	6.2	0.33	131	61	273	1576	384	5.2	86	17.9	1.9	0.82	1.72	1.62	0.06	0.04
	0.5x	7.4	0.40	253	83	233	2814	426	7.5	64	9.5	1.6	2.90	1.70	0.90	0.09	0.05
	1.0x	7.2	0.60	265	87	225	3244	439	9.9	75	11.0	2.0	4.12	2.31	1.37	0.14	0.05
	2.0x	7.5	0.47	348	137	258	4048	485	11.3	59	8.1	1.9	5.05	1.93	1.16	0.10	0.05
Significance		**	*	**	*	NS	*	NS	*	**	*	NS	*	NS	**	NS	NS
BLSD (0.05)		0.38	0.17	93	37	-	1570	-	3.6	14	6.7	-	2.67	-	0.35	-	-
Contrasts																	
Linear																	
NutraLime		**	NS	**	**	NS	**	*	**	**	*	NS	**	NS	NS	NS	NS
Quadratic																	
NutraLime		**	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
6-12	0	5.7	0.43	53	27	99	1512	354	6.3	83	13.5	2.4	0.77	1.61	1.15	0.03	0.04
	0.5x	6.2	0.43	77	35	133	1630	362	8.7	82	13.0	1.1	1.02	1.12	0.99	<0.02	0.06
	1.0x	6.0	0.60	105	36	92	1638	342	8.7	97	15.2	1.2	1.11	2.45	1.30	0.03	0.05
	2.0x	6.5	0.57	167	68	118	1783	373	9.4	90	13.1	1.2	1.19	1.67	1.23	0.03	0.05
Significance		*	NS	**	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
BLSD (0.05)		0.5	-	54	20	-	-	-	-	-	-	-	-	-	-	-	-
Contrasts																	
Linear																	
NutraLime		*	NS	**	**	NS	*	NS	NS	NS	NS	NS	*	NS	NS	-	NS
Quadratic																	
NutraLime		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
12-24	0	6.1	0.27	12	6	59	1068	232	7.9	37	1.3	0.2	0.61	0.55	0.52	<0.02	0.03
	0.5x	6.2	0.27	17	8	64	1128	241	8.7	35	1.2	0.1	0.72	0.52	0.41	<0.02	0.03
	1.0x	6.1	0.40	19	8	64	1265	258	8.8	41	1.5	0.2	0.72	0.42	0.57	<0.02	0.03
	2.0x	6.2	0.37	24	9	61	1158	254	9.9	41	1.6	0.2	0.76	0.60	0.78	<0.03	0.06
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-	*
BLSD (0.05)		-	-	-	-	-	-	-	-	-	-	-	0.10	-	-	-	0.02
Contrasts																	
Linear																	
NutraLime		NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-	*
Quadratic																	
NutraLime		NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 11. Effect of NutraLime on soil pH, soluble salts, Bray P1, Olsen P, ammonium acetate extractable cations, and DTPA extractable metals - Isanti County.

Depth inches	Treatment	pH	Soluble Salts mmhos/cm	Bray P1	Olsen P	NH_4OAc Extractable K	Ca	Mg	Na	DTPA Extractable Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr
				ppm													
0-6	0	6.0	0.17	41	19	151	737	78	3.5	85	24.8	1.5	0.62	1.40	1.28	0.10	0.03
	0.5x	7.5	0.37	172	34	159	1907	125	5.5	57	11.0	1.5	2.48	1.35	0.80	0.11	0.04
	1.0x	7.5	0.37	175	34	158	2321	151	8.2	52	9.9	1.6	2.73	1.36	0.78	0.07	0.05
	2.0x	7.7	0.33	220	54	167	3416	192	8.9	54	8.7	1.8	4.11	1.69	0.79	0.12	<0.02
Significance		**	**	**	**	NS	**	*	NS	*	**	NS	**	NS	*	NS	-
BLSD (0.05)		0.4	0.10	38	14	-	1048	60	-	19	4.9	-	1.36	-	0.31	-	-
Contrasts																	
Linear																	
Nutralime		**	*	**	**	NS	**	**	*	*	**	NS	**	NS	*	NS	-
Quadratic																	
Nutralime		**	**	**	NS	NS	NS	NS	NS	*	**	NS	NS	NS	*	NS	-
6-12	0	6.0	0.10	30	17	115	967	154	5.9	77	9.8	1.8	0.58	1.41	1.05	0.05	0.03
	0.5x	6.3	0.20	32	16	116	1013	154	9.2	67	8.1	0.5	0.59	0.59	0.86	0.05	0.03
	1.0x	6.8	0.33	78	22	105	1361	120	7.1	60	9.1	0.8	1.09	1.12	0.92	0.08	<0.02
	2.0x	6.5	0.33	35	16	96	1039	119	7.3	70	7.9	0.6	0.59	1.38	1.13	0.11	0.03
Significance		NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-
BLSD (0.05)		-	0.19	-	-	-	-	-	-	-	-	-	-	0.54	-	-	-
Contrasts																	
Linear																	
Nutralime		NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-
Quadratic																	
Nutralime		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-
12-24	0	5.7	0.10	30	28	125	1327	325	14.1	83	6.9	0.31	0.83	0.79	1.03	0.07	0.05
	0.5x	5.8	0.20	33	25	118	1307	277	15.6	81	8.2	0.35	0.90	0.85	1.25	0.03	0.04
	1.0x	6.1	0.20	32	23	108	1432	280	13.7	70	5.6	0.22	0.78	0.95	1.03	0.07	0.04
	2.0x	6.0	0.23	35	27	113	1460	282	13.8	87	4.4	0.28	0.82	0.89	1.30	0.04	0.05
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD (0.05)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Contrasts																	
Linear																	
Nutralime		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic																	
Nutralime		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 12. Effect of NutraLime on soil pH, soluble salts, Bray P1, Olsen P, ammonium acetate extractable cations and DTPA extractable metals - Washington County.

Depth inches	Treatment	pH	Soluble Salts mmhos/cm	Bray P1	Olsen P	NH_4OAc Extractable K	Ca	Mg	Na	DTPA Extractable Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr
				ppm													
0-6	0	5.4	0.20	75	38	168	1741	250	2.4	135	35.9	2.1	1.30	3.39	2.27	0.12	0.12
	0.5x	7.2	0.43	195	83	206	3780	329	5.1	100	14.7	2.9	3.81	2.62	1.73	0.19	0.07
	1.0x	7.3	0.40	208	100	202	4728	362	8.4	93	11.6	2.4	5.20	3.16	1.57	0.20	0.06
	2.0x	7.6	0.40	247	120	207	4835	434	9.0	75	9.1	3.3	7.62	3.10	1.27	0.19	0.05
Significance		**	**	**	**	NS	*	**	NS	**	**	**	**	*	**	NS	**
BLSD (0.05)		0.2	0.10	29	33	-	495	74	-	20	5.7	0.5	1.46	0.48	0.41	-	0.03
Contrasts																	
Linear																	
NutraLime		**	**	**	**	NS	**	**	*	**	*	**	**	NS	**	NS	**
Quadratic																	
NutraLime		**	**	**	NS	NS	**	NS	NS	NS	**	NS	NS	NS	NS	NS	*
6-12	0	5.7	0.23	27	17	108	1912	311	5.8	83	13.0	0.9	0.96	1.62	1.79	<0.02	0.08
	0.5x	5.8	0.37	41	22	144	2023	309	6.0	95	14.0	1.2	1.04	2.31	1.97	0.05	0.06
	1.0x	5.5	0.37	44	23	119	1969	270	5.4	110	20.6	1.1	1.16	2.08	2.41	0.04	0.09
	2.0x	6.3	0.47	58	23	127	2249	343	5.6	79	10.3	1.0	1.28	2.14	1.55	0.06	0.06
Significance		*	NS	*	*	NS	NS	NS	NS	NS	NS	*	NS	NS	*	-	NS
BLSD (0.05)		0.5	-	20	4	-	-	-	-	-	-	0.2	-	-	0.56	-	-
Contrasts																	
Linear																	
NutraLime		*	*	**	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
Quadratic																	
NutraLime		NS	NS	NS	**	NS	NS	NS	NS	*	*	*	NS	NS	*	-	NS
12-24	0	6.2	0.10	14	8	104	1997	402	8.1	39	1.8	0.3	0.92	1.18	0.75	0.03	0.09
	0.5x	6.0	0.20	13	8	126	2072	407	7.4	45	2.1	0.3	0.82	1.29	0.89	<0.02	0.05
	1.0x	5.9	0.20	11	8	124	2154	396	8.9	48	2.5	0.3	0.92	1.18	0.96	<0.02	0.07
	2.0x	6.3	0.26	20	9	122	2085	429	6.7	38	1.7	0.5	0.93	1.37	0.66	0.04	0.07
Significance		*	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-	NS
BLSD (0.05)		0.3	0.06	-	-	-	-	-	-	-	-	-	0.07	-	0.29	-	-
Contrasts																	
Linear																	
NutraLime		NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
Quadratic																	
NutraLime		*	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*	-	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 13. Effect of NutraLime on nitric acid extractable elements - Dakota County.

Treatment	1 N Nitric Acid Extractable																									
	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Si	Na	Sr	S	Ti	V	Zn
	ppm																									
Depth: 0-6 inches																										
0	1507	1.58	111	0.36	1.1	0.38	2481	1.25	1.02	3.1	630	9.12	<0.20	639	124	0.69	3.39	166	337	451	8	10.4	16.5	8.3	2.98	5.1
0.5x	2101	2.24	128	0.37	1.6	0.86	4857	3.21	1.35	25.3	943	15.15	<0.20	847	199	0.96	3.68	775	325	745	27	14.1	5.8	13.9	4.13	11.5
1.0x	2405	2.53	141	0.37	1.9	1.19	6206	4.51	1.38	41.6	1067	19.25	0.24	908	232	1.17	4.97	1224	309	871	42	17.0	17.6	16.6	4.42	16.5
2.0x	2796	3.12	153	0.36	2.4	1.71	9251	6.66	1.63	69.9	1249	24.83	0.32	1166	303	1.49	5.78	2065	390	1068	63	21.4	12.4	20.7	5.11	24.1
Significance	*	*	NS	NS	*	*	*	*	*	*	*	NS	-	NS	NS	NS	NS	*	NS	*	*	*	NS	*	*	*
BLSD(0.05)	876	0.88	-	-	0.9	0.89	4416	3.38	0.42	44.7	317	-	-	-	-	-	-	1205	-	405	36	7.6	-	7.3	1.26	13.0
Contrasts																										
Linear NutraLime	**	**	*	NS	**	**	**	**	*	**	**	*	-	*	*	**	*	**	NS	**	**	**	NS	**	**	**
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 6-12 inches																										
0	1648	1.58	109	0.27	0.9	0.31	2077	1.33	0.64	2.8	610	8.37	0.21	550	70	0.73	2.53	68	131	495	12	11.5	8.4	9.9	2.73	4.2
0.5x	1790	1.69	114	0.38	1.0	0.38	2352	1.63	0.77	5.0	703	8.53	<0.20	568	94	0.76	2.50	138	145	548	13	11.7	13.1	10.4	3.02	5.0
1.0x	1776	1.67	118	0.38	1.0	0.39	2423	1.68	0.75	5.7	731	9.06	<0.20	576	95	0.75	2.96	163	127	567	15	12.1	25.6	11.0	3.05	5.4
2.0x	1762	1.75	116	0.37	1.2	0.44	2718	1.81	0.80	7.9	718	9.58	0.21	609	101	0.77	2.96	278	149	540	16	12.3	27.4	10.7	3.07	5.9
Significance	NS	NS	NS	NS	NS	NS	NS	*	NS	*	*	NS	-	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS
BLSD(0.05)	-	-	-	-	-	-	-	0.30	-	2.7	86	-	-	-	-	-	-	97	-	-	-	-	-	-	-	-
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	*	*	**	NS	**	*	NS	-	NS	NS	NS	NS	**	NS	NS	*	NS	*	*	*	*
Quadratic NutraLime	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	-	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
Depth: 12-24 inches																										
0	1229	1.26	67	0.22	0.6	0.24	1422	1.04	0.32	2.1	555	4.31	0.22	398	24	0.61	1.59	56	63	424	14	10.3	4.5	13.4	2.29	3.0
0.5x	1366	1.26	72	0.23	0.5	0.21	1491	1.17	0.24	2.6	598	4.99	<0.20	402	28	0.55	1.34	64	65	456	13	10.8	6.7	13.0	2.40	3.0
1.0x	1401	1.42	78	0.25	0.6	0.25	1621	1.39	0.26	3.0	703	5.43	0.21	471	30	0.61	1.92	49	69	535	15	12.0	7.0	15.3	2.73	3.8
2.0x	1249	1.37	69	0.23	0.6	0.26	1521	1.20	0.34	2.9	577	5.47	0.29	421	27	0.58	2.01	70	64	447	15	10.3	10.5	13.2	2.33	3.3
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD(0.05)	-	-	-	-	-	-	-	0.30	-	0.5	136	-	-	-	-	-	-	-	-	-	-	-	5.8	2.2	-	-
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	*	NS	*	*	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 14. Effect of NutraLime on nitric acid extractable elements - Isanti County

Treatment	1 N Nitric Acid Extractable																									
	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Si	Na	Sr	S	Ti	V	Zn
	ppm																									
Depth: 0-6 inches																										
0	766	1.27	38	0.15	0.5	0.36	1006	0.95	0.54	2.0	827	6.40	0.22	143	136	0.42	2.79	87	241	195	11	3.8	6.5	14.5	2.94	4.4
0.5x	1041	1.79	52	0.16	0.9	0.84	3121	2.40	0.67	19.9	1025	10.43	0.26	295	190	0.57	3.23	533	267	341	25	6.7	9.2	19.2	3.54	10.7
1.0x	1167	2.00	56	0.16	1.1	1.01	4073	2.95	0.74	26.4	1046	12.30	0.31	397	201	0.66	4.17	691	250	371	30	8.2	12.7	20.2	3.65	13.3
2.0x	1525	2.56	70	0.17	1.5	1.59	6714	4.90	0.78	47.4	1348	19.35	0.34	567	252	0.87	4.40	1201	271	550	45	11.9	12.0	25.2	4.50	20.8
Significance	**	*	*	NS	**	**	**	**	NS	**	**	**	NS	**	*	**	*	**	NS	**	**	**	NS	**	*	**
BLSD(0.05)	285	0.63	18	-	0.3	0.44	2309	1.45	-	19.0	231	5.43	-	188	66	0.18	1.10	460	-	111	14	3.2	-	3.9	0.75	6.6
Contrasts																										
Linear NutraLime	**	**	**	NS	**	**	**	**	NS	**	**	**	NS	**	**	**	**	**	NS	**	**	**	NS	**	**	**
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 6-12 inches																										
0	957	1.33	33	0.18	0.5	0.35	1276	1.61	0.31	1.9	1025	6.11	0.36	327	62	0.50	2.80	82	150	375	15	4.6	2.8	20.7	3.77	3.7
0.5x	923	1.29	34	0.16	0.5	0.36	1296	1.54	0.30	2.2	961	5.78	0.38	321	57	0.49	2.41	83	144	360	18	4.6	12.3	20.1	3.57	3.5
1.0x	888	1.44	39	0.15	0.6	0.51	1886	1.66	0.41	8.2	871	7.43	0.31	261	94	0.48	2.80	115	157	289	18	5.3	13.9	18.3	3.21	3.5
2.0x	852	1.32	37	0.16	0.5	0.40	1376	1.43	0.21	3.2	1000	5.96	0.27	233	69	0.46	2.81	99	125	296	17	4.7	21.5	19.0	3.59	3.7
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 12-24 inches																										
0	1317	1.68	35	0.22	0.6	0.41	1755	2.34	0.21	2.5	1328	6.06	0.66	661	32	0.65	3.06	140	143	665	25	6.1	0.9	25.3	4.73	4.8
0.5x	1330	1.68	36	0.22	0.6	0.44	1786	2.36	0.29	3.2	1350	6.57	0.69	653	38	0.68	3.39	117	145	661	27	6.2	4.6	25.4	4.72	5.1
1.0x	1276	1.69	35	0.20	0.6	0.39	1825	2.07	0.28	2.9	1129	6.38	0.66	609	30	0.62	3.71	96	140	596	24	6.6	5.7	26.0	4.27	4.6
2.0x	1314	1.77	36	0.21	0.6	0.43	1839	2.32	0.21	3.5	1322	6.63	0.58	578	28	0.65	3.48	122	138	561	23	6.5	9.6	23.3	4.92	4.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 15. Effect of NutraLime on nitric acid extractable elements - Washington County.

Treatment	1 N Nitric Acid Extractable																									
	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Si	Na	Sr	S	Ti	V	Zn
	ppm																									
Depth: 0-6 inches																										
0	1632	1.80	114	0.39	1.2	0.42	2432	1.79	0.95	4.0	685	9.24	0.23	405	119	0.65	4.70	113	206	481	8	12.6	11.8	9.2	3.09	6.6
0.5x	2034	2.14	137	0.39	1.7	0.97	6002	3.45	1.09	25.5	866	13.88	0.25	656	180	0.73	4.91	659	246	751	22	18.3	16.0	12.3	4.01	15.1
1.0x	2450	2.79	148	0.41	2.2	1.52	8877	5.29	1.32	43.8	1048	18.57	0.31	828	223	1.02	5.70	1102	269	945	37	22.0	20.2	15.4	4.65	21.3
2.0x	2819	3.02	149	0.38	2.3	2.06	10944	7.04	1.59	69.4	1213	22.97	0.36	1043	255	1.22	5.85	1756	296	1132	55	24.3	20.4	19.4	5.11	29.7
Significance	**	*	NS	NS	**	**	**	**	**	**	**	**	NS	**	**	**	NS	**	*	**	**	**	NS	**	**	**
BLSD(0.05)	469	0.66	-	-	0.3	0.42	2671	2.15	0.25	17.0	203	4.02	-	167	50	0.17	-	395	60	204	11	4.9	-	2.9	0.69	6.4
Contrasts																										
Linear NutraLime	**	**	*	NS	**	**	**	**	**	**	**	**	*	**	**	**	*	**	**	**	**	**	NS	**	**	**
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 6-12 inches																										
0	1780	1.83	111	0.39	1.0	0.31	2472	1.65	0.58	3.31	764	7.61	0.34	573	60	0.70	3.66	34	133	681	11	14.3	5.1	14.5	3.32	5.6
0.5x	1705	1.56	114	0.39	0.9	0.32	2611	1.52	0.50	4.09	703	7.13	0.27	530	62	0.65	3.60	65	137	598	10	14.7	13.3	13.5	3.14	5.9
1.0x	1755	1.85	121	0.40	1.1	0.37	2638	1.64	0.53	4.98	759	7.88	0.31	503	72	0.66	4.30	79	133	623	12	15.1	17.8	13.9	3.20	6.1
2.0x	1856	1.80	112	0.38	1.1	0.41	3038	1.95	0.64	7.04	789	8.29	0.30	595	73	0.66	3.62	126	146	694	14	14.6	32.6	14.3	3.48	6.8
Significance	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS
BLSD(0.05)	-	-	-	-	-	-	-	0.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.3	-	-	-
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	*	*	*	NS	*	NS	NS	NS	NS	*	NS	NS	*	NS	NS	*	NS	**	NS	NS	*
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 12-24 inches																										
0	1931	1.98	96	0.32	0.9	0.32	2453	2.07	0.27	3.65	1049	7.11	0.51	784	34	0.77	2.82	51	119	903	15	16.8	3.0	21.4	4.09	6.6
0.5x	1858	1.65	101	0.34	0.8	0.28	2380	1.79	0.23	3.45	939	6.31	0.42	736	27	0.69	2.09	25	115	805	14	17.6	6.3	21.5	3.74	6.4
1.0x	1922	1.85	108	0.34	0.8	0.34	2465	2.00	0.28	3.73	1058	6.95	0.51	774	30	0.74	2.44	22	123	890	15	18.3	7.6	22.7	4.08	7.0
2.0x	1932	1.76	96	0.32	0.9	0.34	2522	1.88	0.33	4.51	958	7.28	0.43	756	35	0.74	2.09	70	125	847	16	16.7	12.7	19.2	3.82	6.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
BLSD(0.05)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	37	-	-	-	-	-	-	-	-
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 16. Effect of NutraLime on the elemental composition of female whole plant samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.00	0.39	2.97	5744	3828	35.5	86	14.8	56.9	30	6.7	6.7	<2.7	1.1	1.2	0.2	0.5
0.5	2.91	0.41	3.21	5979	4111	42.3	87	16.8	68.7	34	7.8	7.0	4.4	1.5	1.4	0.4	1.5
1.0	3.08	0.43	3.02	5933	4151	44.4	93	18.0	69.4	34	8.1	7.7	5.4	1.8	1.6	0.4	1.7
2.0	3.02	0.41	3.32	5757	3729	42.4	95	16.0	67.0	32	8.0	7.3	<2.8	1.1	1.2	0.2	1.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	—	NS	NS	NS	*
BLSD (0.05	—	—	—	—	—	—	—	—	—	—	0.9	—	—	—	—	—	0.7
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	—	NS	NS	NS	*
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	—	*	*	*	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 17. Effect of NutraLime on the elemental composition of female ear leaf samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.32	0.35	1.81	8094	3408	19.8	99	11.4	68.9	25	9.6	7.6	<2.5	<0.8	0.9	<0.2	0.5
0.5	3.33	0.37	1.83	8478	3743	24.0	105	14.6	54.7	24	10.2	8.6	<4.3	<1.2	1.2	<0.3	2.1
1.0	3.42	0.37	1.84	8559	3518	24.5	107	11.2	68.9	29	10.7	9.1	<3.3	1.0	1.0	<0.2	2.5
2.0	3.59	0.38	1.91	7817	3607	22.5	102	13.4	62.9	27	10.0	8.8	4.3	1.3	1.2	0.8	2.7
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	—	NS	—	**
BLSD (0.05)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.1
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	—	NS	—	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	—	NS	—	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 18. Effect of NutraLime on the elemental composition of female stover samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.40	0.23	2.05	5364	3836	38.1	60	34.5	54.0	27	5.8	5.9	3.8	1.4	1.2	0.2	0.6
0.5	1.14	0.19	2.00	5196	4027	50.0	66	30.0	62.4	21	5.2	5.7	4.4	1.5	1.3	0.3	1.2
1.0	1.18	0.22	2.07	5104	4011	44.1	62	25.7	51.9	21	5.8	6.2	4.3	1.6	1.3	0.3	1.5
2.0	1.39	0.24	1.81	5509	3634	46.3	67	24.7	65.2	25	6.3	6.3	4.4	1.6	1.3	0.3	0.1
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.4
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutra	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 19. Effect of NutraLime on the elemental composition of female kernel samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.71	0.31	0.52	71	1064	8.4	21	<3.7	6.2	20	1.2	2.3	2.5	0.7	0.5	0.6	0.3
0.5	1.70	0.31	0.52	69	1054	6.5	20	<3.7	6.3	20	1.2	2.4	2.5	0.7	0.5	0.5	0.5
1.0	1.77	0.32	0.55	80	1095	6.4	21	<3.7	6.8	21	1.2	2.4	<2.5	0.7	0.5	0.5	0.5
2.0	1.83	0.31	0.52	71	1086	6.8	21	<3.7	6.4	21	1.2	2.4	2.4	0.8	0.6	0.4	0.6
Significance	NS	NS	NS	NS	NS	**	NS	--	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD (0.05)	--	--	--	--	--	1.1	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	*	NS	--	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutra	NS	NS	NS	NS	NS	**	NS	--	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 20. Effect of NutraLime on the elemental composition of female cob samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.54	0.16	1.08	196	658	10.3	14.6	4.4	8.9	22	2.6	3.0	2.4	1.6	1.0	0.2	0.4
0.5	0.56	0.17	1.11	201	660	9.3	13.7	5.4	9.1	19	2.8	3.3	3.4	1.3	1.1	0.2	0.6
1.0	0.53	0.16	1.11	191	650	9.0	13.7	4.8	9.3	21	2.8	3.1	3.2	1.4	1.1	0.3	0.6
2.0	0.60	0.18	1.21	224	737	10.6	17.2	5.6	11.1	19	3.0	3.6	2.6	1.3	<0.8	0.2	0.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS	--	NS	*
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	*	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 21. Effect of NutraLime on the elemental composition of female husk samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.86	0.24	1.46	997	1467	23.4	39	16.2	18.3	21	4.0	5.1	<2.3	1.3	1.5	<0.2	0.4
0.5	0.77	0.24	1.83	1103	1451	22.3	44	14.9	21.0	22	4.6	5.2	2.3	1.5	2.0	0.2	0.7
1.0	0.91	0.26	1.81	1261	1537	23.4	41	13.5	22.6	23	4.5	6.3	<2.2	1.3	1.8	<0.2	0.8
2.0	0.85	0.21	1.44	1004	1340	19.7	39	16.1	22.4	19	4.4	5.4	<2.4	1.3	1.7	<0.2	0.9
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	*
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.3
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 22. Effect of NutraLime on the elemental composition of male whole plant samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.56	0.45	4.33	4556	3469	51.1	114	21.1	81.5	38	8.0	6.0	4.2	1.4	1.4	0.3	0.4
0.5	3.41	0.44	4.63	5166	4248	46.2	111	19.2	49.1	38	9.2	5.3	3.0	1.3	1.3	0.3	1.1
1.0	3.52	0.45	4.39	4852	3662	88.1	154	23.8	62.6	39	9.9	6.0	3.5	1.6	1.5	0.3	1.5
2.0	3.37	0.43	4.45	4812	3615	67.2	126	22.5	57.0	33	9.1	6.2	3.7	1.3	1.3	0.3	1.8
Significance	NS	NS	NS	NS	NS	**	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	*
BLSD (0.05)	--	--	--	--	--	19.2	--	2.9	--	--	--	--	--	--	--	--	0.7
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutra	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 23. Effect of NutraLime on the elemental composition of male ear leaf samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.11	0.46	2.89	5641	2851	21.1	114	20.7	65.4	25	10.8	5.9	<2.1	0.7	0.9	<0.1	0.4
0.5	3.08	0.45	2.93	5563	2934	20.7	112	18.6	37.9	22	12.5	5.5	<1.7	0.6	0.9	<0.1	1.9
1.0	3.08	0.45	2.94	5493	2836	19.5	114	16.8	54.8	25	12.5	6.0	<1.8	1.0	0.9	<0.1	2.3
2.0	3.07	0.43	2.85	5598	2943	22.5	112	22.2	46.7	23	11.7	6.1	<2.2	0.8	0.9	<0.2	2.3
Significance	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	--	NS	NS	--	**
BLSD (0.05)	--	--	--	--	--	--	--	3.8	--	--	--	--	--	--	--	--	0.7
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	--	NS	NS	--	**

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 24. Effect of NutraLime on the elemental composition of male stover samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.16	0.18	1.85	2757	2411	35.3	62	19.0	32.8	19	4.0	5.4	3.6	1.2	1.0	0.2	0.5
0.5	1.19	0.21	1.79	3197	2742	39.0	66	24.4	27.6	22	5.4	6.7	3.2	1.1	1.0	<0.2	1.3
1.0	1.14	0.18	1.85	2879	2578	36.7	62	19.6	38.2	17	4.7	5.9	3.5	1.2	1.1	0.2	1.4
2.0	1.01	0.16	1.66	2461	2290	28.3	55	18.6	22.4	14	4.2	4.9	3.5	1.1	0.9	<0.2	1.1
Significance	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	*
BLSD (0.05)	—	—	—	507	—	—	—	—	—	—	—	—	—	—	—	—	0.7
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS
Quad Nutra	NS	NS	NS	*	*	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	—	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 25. Effect of NutraLime on the elemental composition of male kernel samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.89	0.34	0.59	126	1299	5.7	24	5.3	6.2	28	3.8	2.2	2.1	0.7	0.5	0.4	0.3
0.5	1.97	0.35	0.65	148	1368	9.6	24	5.3	6.4	30	4.4	2.6	2.9	0.9	0.6	0.5	0.8
1.0	1.89	0.33	0.62	146	1297	7.4	23	6.4	7.0	29	5.4	2.5	<2.4	1.1	0.5	0.4	0.8
2.0	1.95	0.34	0.62	132	1319	10.8	22	5.9	6.1	27	4.4	2.4	2.5	0.8	0.5	0.5	0.8
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
BLSD (0.05)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.2
Contrasts																	
Linear Nutri	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutri	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 26. Effect of NutraLime on the elemental composition of male cob samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.86	0.18	1.02	391	1110	10.2	24	9.1	9.6	24	6.0	3.2	2.0	1.2	1.2	0.2	0.3
0.5	0.94	0.19	1.00	390	1111	9.0	21	6.5	8.4	22	6.4	3.3	2.2	1.2	1.1	0.2	0.5
1.0	0.80	0.15	0.83	340	964	8.8	22	6.5	8.4	20	6.0	2.8	2.0	1.3	1.2	0.2	0.6
2.0	0.93	0.18	1.03	392	1173	12.4	25	8.1	8.9	21	6.3	3.5	2.1	1.3	1.3	0.2	0.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.2
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	**
Quad Nutra	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 27. Effect of NutraLime on the elemental composition of male husk samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.83	0.16	0.79	663	1153	20.6	45	12.0	15.6	17	3.1	3.9	<2.7	1.2	1.4	0.2	0.4
0.5	0.75	0.15	0.67	468	995	16.8	38	12.8	8.9	14	2.9	3.3	3.1	1.4	1.5	0.2	0.7
1.0	0.85	0.16	0.77	708	1230	15.4	35	13.5	15.5	17	3.9	4.0	<2.6	1.1	1.3	0.2	0.8
2.0	0.74	0.16	0.93	654	1087	16.5	34	9.8	14.3	15	3.1	3.8	<2.6	1.1	1.1	0.2	0.7
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	*
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.2
Contrasts																	
Linear Nutra.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS
Quad Nutra.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	**

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 28. Effect of NutraLime on the elemental composition of whole plant samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	2.29	0.29	0.46	3130	1618	31.4	76	20.8	75.0	25	8.1	6.8	5.3	1.7	1.4	0.4	0.6
0.5	2.35	0.36	0.55	3677	2105	<31.4	85	15.9	48.6	26	9.4	7.7	4.4	1.5	1.2	0.4	2.2
1.0	2.97	0.35	0.51	3514	2083	28.1	80	14.6	48.2	27	9.3	7.5	3.8	1.4	1.2	0.4	2.6
2.0	3.15	0.35	0.42	3655	2092	32.8	91	16.0	48.0	26	10.2	7.9	4.2	1.5	1.2	0.4	3.2
Significance	NS	*	NS	*	NS	—	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
BLSD (0.05)	—	0.04	—	221	—	—	—	—	—	—	—	—	—	—	—	—	1.0
Contrasts																	
Linear Nutra.	*	*	NS	**	NS	—	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutra.	NS	*	NS	*	NS	—	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 29. Effect of NutraLime on the elemental composition of ear leaf samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	2.46	0.27	2.06	4866	1712	30.9	108	25.2	77.8	25	12.1	5.8	5.9	1.9	1.2	0.4	1.0
0.5	2.75	0.33	2.16	5546	1971	28.5	108	15.9	50.1	26	13.4	6.5	5.8	1.7	1.3	0.4	4.5
1.0	2.91	0.32	2.13	5334	1959	28.6	113	17.2	58.4	27	14.0	6.5	5.0	1.6	1.3	0.4	5.2
2.0	2.98	0.33	2.14	5347	2063	23.5	111	13.5	57.2	28	13.8	6.1	<3.0	1.1	0.9	0.3	5.0
Significance	**	**	NS	NS	NS	**	NS	NS	*	NS	NS	**	—	NS	NS	*	**
BLSD (0.05)	0.22	0.03	—	—	—	3.0	—	—	19.9	—	—	0.2	—	—	—	0.1	1.1
Contrasts																	
Linear Nutra	**	**	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	—	**	*	**	**
Quad Nutra	*	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	—	NS	NS	NS	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 30. Effect of NutraLime on the elemental composition of stover samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.26	0.04	1.61	1705	926	56.8	79	12.2	51.7	9	4.8	4.0	2.3	0.8	0.9	0.2	0.3
0.5	0.25	0.05	1.28	1647	1019	44.3	55	9.6	33.4	8	5.8	4.1	<1.8	0.8	0.7	0.2	1.1
1.0	0.29	0.06	1.39	1666	926	28.1	35	7.6	33.0	9	7.1	4.1	<1.9	0.6	0.7	0.2	1.4
2.0	0.25	0.05	1.53	1284	811	35.8	44	10.5	27.3	7	6.2	4.1	2.4	0.9	1.1	0.2	1.3
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	NS	*
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.6
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	--	NS	NS	NS	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	NS	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 31. Effect of NutraLime on the elemental composition of kernel samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.05	0.27	0.32	30	932	<3.6	16	<3.6	5.2	17	0.5	1.5	<1.7	<0.4	<0.3	0.1	<0.2
0.5	1.35	0.29	0.32	30	964	<3.6	16	<3.8	4.9	16	0.5	1.7	<1.7	<0.4	<0.3	0.1	<0.3
1.0	1.32	0.30	0.33	28	1029	<3.6	16	<3.6	5.3	17	0.5	1.4	<1.7	<0.4	<0.3	0.1	<0.2
2.0	1.30	0.30	0.33	27	1019	<3.6	16	<3.6	5.3	17	0.5	1.5	<1.7	<0.4	<0.3	0.1	<0.2
Significance	NS	NS	NS	NS	NS	--	NS	--	NS	NS	--	NS	--	--	--	NS	--
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	--	NS	--	NS	NS	--	NS	--	--	--	NS	--
Quad Nutra	*	NS	NS	NS	NS	--	NS	--	NS	NS	--	NS	--	--	--	NS	--

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 32. Effect of NutraLime on the elemental composition of cob samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.21	0.03	0.42	77	206	<4.1	12	<3.6	3.7	52	3.0	1.5	<1.7	1.2	1.3	0.1	<0.2
0.5	0.24	0.03	0.29	91	249	<3.8	8	<3.6	3.6	26	3.2	1.4	<1.7	1.1	1.2	0.1	0.3
1.0	0.25	0.04	0.33	90	205	<3.6	8	<3.6	4.6	24	3.5	1.3	<1.7	0.8	0.9	0.1	<0.3
2.0	0.27	0.04	0.33	86	204	<3.6	8	<3.6	4.0	26	3.4	1.3	<1.7	0.9	0.9	0.2	<0.3
Significance	NS	NS	NS	NS	NS	--	NS	--	NS	NS	NS	NS	--	NS	NS	NS	--
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	--	NS	--	NS	NS	NS	NS	--	NS	NS	NS	--
Quad Nutra	NS	NS	NS	NS	NS	--	NS	--	NS	NS	NS	NS	--	NS	NS	NS	--

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 33. Effect of NutraLime on the elemental composition of whole plant samples - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	2.41	0.30	3.63	5235	3270	28.7	73	18.0	73.4	34	7.7	7.0	3.4	1.5	1.2	0.3	0.4
0.5	2.62	0.36	3.94	5891	3544	32.7	83	17.4	64.2	42	8.2	8.4	3.3	1.5	1.3	0.3	1.0
1.0	2.72	0.35	3.50	5647	3510	32.9	86	17.4	70.0	38	9.3	7.5	<2.7	1.9	1.1	<0.2	1.5
2.0	2.87	0.37	4.17	5634	3312	39.0	93	17.1	57.0	40	8.9	7.9	4.1	1.7	1.5	0.4	1.9
Significance	*	NS	NS	NS	NS	*	*	NS	NS	NS	NS	NS	--	NS	NS	--	**
BLSD (0.05)	0.28	--	--	--	--	6.6	14	--	--	--	--	--	--	--	--	--	0.4
Contrasts																	
Linear Nutra	**	NS	*	NS	NS	**	*	NS	NS	NS	*	NS	--	NS	NS	--	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 34. Effect of NutraLime on the elemental composition of ear leaf samples- Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	2.95	0.34	2.25	7502	2989	46.3	102	22.3	92.5	38	10.8	8.3	4.9	1.5	1.4	0.3	0.6
0.5	2.83	0.34	2.35	7890	2746	34.2	102	19.7	73.8	37	10.7	9.2	4.6	1.5	1.5	<0.3	2.2
1.0	3.12	0.35	2.24	7739	2912	34.7	104	18.5	80.0	36	11.3	8.6	<3.8	1.3	1.3	<0.3	3.1
2.0	3.11	0.35	2.43	7679	3050	36.9	104	26.6	57.3	33	11.3	9.8	5.3	1.7	1.6	0.4	4.4
Significance	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	—	**
BLSD (0.05)	0.20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.8
Contrasts																	
Linear Nutra	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	—	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	—	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 35. Effect of NutraLime on the elemental composition of stover samples - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.55	0.04	1.69	3175	1614	56.9	60	12.1	49.1	7	4.8	3.9	3.4	1.5	1.6	0.3	0.5
0.5	0.58	0.04	1.84	3228	1690	53.7	61	9.5	33.4	7	4.2	3.6	<2.3	1.0	1.3	0.2	0.8
1.0	0.65	0.07	1.66	3908	1960	88.4	90	13.9	48.3	9	6.1	3.9	2.7	1.2	1.4	0.2	1.1
2.0	0.78	0.08	1.81	3492	2016	79.8	81	15.0	29.7	8	7.6	3.9	3.8	1.4	1.4	0.3	1.4
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	—	NS	NS	NS	**
BLSD (0.05)	—	—	—	—	—	—	—	—	—	—	1.5	—	—	—	—	—	0.4
Contrasts																	
Linear Nutra	NS	*	NS	NS	NS	NS	NS	NS	NS	*	**	NS	—	NS	NS	NS	**
Quad Nutra	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 36. Effect of NutraLime on the elemental composition of kernel samples - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.31	0.27	0.35	39	1104	<3.6	21	<3.6	7.1	22	1.7	1.5	<1.7	<0.6	0.4	<0.2	<0.2
0.5	1.35	0.28	0.36	41	1140	<3.6	21	<3.6	6.8	23	1.5	1.7	<1.7	0.5	<0.4	<0.1	0.4
1.0	1.33	0.27	0.35	41	1173	<3.6	20	<4.3	6.6	21	1.6	1.6	<1.7	<0.5	<0.3	<0.1	0.4
2.0	1.43	0.29	0.36	39	1132	<3.6	21	<4.7	6.4	22	1.6	1.7	<1.7	<0.5	<0.4	<0.2	0.6
Significance	NS	NS	NS	NS	NS	—	NS	—	NS	NS	NS	NS	—	—	—	—	**
BLSD (0.05)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1
Contrasts																	
Linear Nutra	*	NS	NS	NS	NS	—	NS	—	NS	NS	NS	NS	—	—	—	—	**
Quad Nutra	NS	NS	NS	NS	NS	—	NS	—	NS	NS	NS	NS	—	—	—	—	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 37. Effect of NutraLime on the elemental composition of cob samples - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.27	0.02	0.77	102	129	<3.8	12	8.1	6.7	9	2.7	1.6	<1.7	1.5	1.8	<0.2	<0.3
0.5	0.35	0.03	0.77	116	164	<4.1	16	14.2	7.8	13	3.5	2.1	<1.7	1.7	2.0	<0.3	0.4
1.0	0.35	0.03	0.75	121	156	4.2	13	12.6	8.1	10	3.3	1.9	<1.7	1.4	1.6	0.2	0.4
2.0	0.30	0.02	0.60	121	155	<4.5	14	15.4	6.7	8	3.4	2.1	<1.7	1.6	1.8	0.3	0.5
Significance	NS	NS	**	NS	NS	—	NS	NS	NS	NS	NS	NS	—	NS	NS	—	NS
BLSD (0.05)	—	—	0.08	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Contrasts																	
Linear Nutra	NS	NS	**	NS	NS	—	NS	NS	NS	NS	NS	NS	—	NS	NS	—	NS
Quad Nutra	*	*	NS	NS	NS	—	NS	NS	NS	NS	NS	NS	—	NS	NS	—	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

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

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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 Olmsted Co. continuous corn yield was optimized at 150 lb N/A with no advantage for split application over a preplant application. Nitrate-N concentrations were highest with split application of N and considerably lower for no tillage (NT) compared to chisel plow (CP) tillage. One-third of each plot that did not receive fertilizer N in 1991 responded to residual NO_3 remaining in the soil profile with CP but not NT. Under these conditions, a portion of the N applied in excess of crop needs in prior years became available for corn in 1991. In Goodhue Co. soybean yields were not affected by the previous N or tillage treatments applied to continuous corn even though large differences in residual NO_3 existed in the soil profile in May. Nitrate-N concentrations in the soil water at 5' did not change from May to November, which indicates that soybean did not remove sufficient NO_3 from the 0-5' profile in one growing season to impact NO_3 concentrations in water below the root zone. In Winona Co. oat responded to carryover NO_3 from the previous CP treatments but alfalfa did not. Nitrate-N concentrations in the soil water in May ranged from 18 to 54 mg/L and reflected the very high amounts of residual NO_3 in the soil profile. By November 20, NO_3-N concentrations at the 5' depth ranged from 0.2 to 17 mg/L. This suggests that establishment-year alfalfa can remove excess NO_3 from the soil profile and reduce the NO_3 concentration in water moving out of the 0-5' root zone.

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 crop 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 1991 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 four replications was established in the fall of 1986 and was continued in 1991. 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 14, 1990. Spring N fertilizer treatments were applied on May 20 and again on June 19, 1991. Liquid hog manure was not applied in 1989, 1990 or 1991. All plots except the no-till treatment were disked on May 20.

Corn (Pioneer 3751) was planted on May 22 at 30,200 plants/A. Lasso (3 lb/A) and Bladex (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 26.

Whole plants were harvested from selected rows at silking and were weighed, dried, ground and analyzed for total N to determine pre-silk N uptake. Stover yields were taken from 20' of row at physiological maturity (Sept. 26). Grain yields and moisture were determined by combine harvesting two rows, each 60' long on Oct. 15. All samples were weighed, dried, ground and analyzed for total N.

Soil samples were obtained from each plot on May 13 and Oct. 30 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).

Suction porous cup samplers 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 10, July 15, August 14, and November 15.

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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 20 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. The corn was cultivated on June 26 with the ridge plots being ridged at that time.

Each plot was intensively soil sampled throughout the season to monitor herbicide movement. Stainless steel suction porous cup samplers 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 1991. Sixteen N and tillage treatments were applied to continuous corn over the four-year period (1987-90). In 1991, the experiment was converted to a corn-soybean rotation to determine (1) if soybean responded to carryover NO_3 in the soil profile and (2) the extent to which excess residual NO_3 could be removed from the soil. Chisel plowing was done with a John Deere Mulch Tiller on November 14, 1990. All chisel plots were disked on May 22.

Soybean (Hardin) was seeded at 9-10 seeds/foot on May 22. Lasso (3.5 lb/A) was applied preemergence on May 24. The chisel plowed plots were cultivated to remove weeds and volunteer corn on June 26. Poast Plus was applied to all no till (NT) plots on July 2 to control wild proso millet and giant foxtail. Seed yield and moisture were determined by combine on October 1.

Soil sampling to the 8-foot depth on May 14 and November 12 was accomplished using the same procedures as in Olmsted Co. Suction samplers installed in six treatments (24 plots) to a 5' depth in 1987 were sampled on May 14, July 18, Aug. 20, and Nov. 12 to determine the NO_3 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 manure 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 through 1990. Twelve N treatments were established for a total of 48 plots. Each plot measured 20' wide by 65' long and were planted to continuous corn.

After four years of continuous corn and because substantial amounts of NO_3 had accumulated in the soil profile with some of the N treatments, this experiment was changed to determine if alfalfa could reduce the amount of residual NO_3 in the soil. Fall chiseling of all plots was conducted on November 15, 1990. A field cultivator was used as secondary tillage just prior to planting. Alfalfa was companion seeded with oats to the whole experimental area on May 13. The oat was harvested as oatlage on July 8. Alfalfa yields were determined from selected plots on August 26 prior to harvesting the whole experimental site by the Kalmes.

Stainless steel and PVC porous cup suction samplers were installed in 1987 at the 5' depth in six treatments (24 plots). PVC suction samplers were installed in 1988 at the 5' depth in three additional treatments and at the 7.5' depth in six treatments. These were sampled on May 10, July 10, Aug. 20, and Nov. 20 to determine NO_3 concentrations in the extracted soil water.

RESULTS AND DISCUSSION

Olmsted County

Corn grain yields in 1991 were increased significantly by the fertilizer N treatments (Table 1). The addition of 75 lb N/A increased yield by 61 bu/A resulting in very high fertilizer N efficiency. Yields were optimized at the 150-lb N rate. In contrast to 1990, yields were not decreased with the fall-applied treatments and with the NT treatment. Yields were not increased by split applying N. Even though manure had not been applied for three years, yields were 25 to 32 bu/A higher with the previous manure treatments compared to the control. This was surprising since very low amounts of NO_3 remained in the 0-5' profile in November, 1990. Grain moisture at harvest was reduced significantly by the fertilizer N treatments. Grain N concentration was increased linearly with increasing fertilizer N rate. Even though the manure treatments produced slightly higher grain yields, grain N concentration was not markedly affected. Grain N removal was highly related to N rate but was not influenced by tillage system or time/method of fertilizer N application; except the fall application plus N-Serve treatment which was slightly higher. Average 5-year yields show a 70 bu/A yield increase with the 75-lb rate of application, but the greatest yield/return with the 150-lb preplant application. Use of higher N rates or split application did not increase yield over the single spring application of anhydrous ammonia.

Nitrate-N amounts in the 0-5' and 0-7' soil profile were closely related to rate of N application for the chisel plow (CP) treatments (Table 2). Somewhat less NO_3 was found in the soil profile with NT compared to CP. A substantial amount of NO_3 was found between 5' and 7' with the annual 150 and 225-lb N rates. Nitrate-N concentrations in the soil water extracted in mid July and mid November from the 5-foot depth were not as closely related to rate of N application as in past years. The NO_3-N concentrations in the 150-lb spring preplant plots seemed abnormally high compared to the other treatments. When applied at 150 lb N/A, NO_3-N concentrations were highest when the N was split applied and lowest when applied to the NT system. The low concentrations with NT were probably due to reduced mineralization. The November 15 sampling showed significantly lower NO_3-N concentrations at the 5' depth than the July 15 sampling, especially when the N rate was limiting (0 and 75-lb and former manure treatments). Samples from the 7.5' depth indicated high NO_3-N concentrations with the 150- and 225-lb N rates and the former 9200 gal/A manure rate. Loss of NO_3-N from the 7.5' depth during the July-November period was likely due to leaching.

Table 1. Effect of N treatments on corn yields, grain moisture, grain N concentration and grain N removal in Olmsted Co. in 1991.

Treatment				Grain				1987-91 Grain
No.	Tillage	N rate	Time/Method	Yield	H_2O	N	N Removal	Yield
		lb N/A		lb/A	%	%	lb/A	bu/A
1	CP	0	-	73.8	19.5	0.98	34.2	81.6
2	CP	75	Spr., preplant	135.1	18.0	1.22	78.3	151.4
3	CP	150	"	152.0	16.9	1.38	99.5	168.4
4	CP	225	"	152.2	16.9	1.56	112.5	164.1
5	CP	150	Fall	153.0	17.5	1.38	100.0	166.1
6	CP	150 + NI[1/]	Fall	158.7	17.0	1.47	110.2	167.0
7	CP	150 Split	50% Spr., preplant					
			50% SD, 8-leaf	152.6	16.7	1.43	103.4	165.2
8	NT	150	Spr., preplant	152.8	17.2	1.34	96.4	165.0
9	CP	315[2/]	Spr., disked in	98.7	18.7	1.03	48.3	-
10	CP	490[2/]	Spr., disked in	105.6	18.8	1.06	53.2	-
Significance level (%) :				99	99	99	99	
BLSD (.05) :				12.5	0.6	.07	8.7	
CV (%) :				7.1	2.3	4.2	8.0	

[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, 1990 or 1991. Total N rates were 315 and 490 lb N/A/yr or approximately 175 and 265 lb "available" N/A/yr.

Table 2. Amount of NO_3-N in the soil profile in May 1991 and NO_3-N concentrations in the soil water at 5' and 7.5' as influenced by N rate and tillage in Olmsted Co. in 1991.

Treatment				Nitrate-N in soil profile		Nitrate-N Conc in Water[1/]			
						5'		7.5'	
No.	Tillage	N rate	Time/Method	0-5'	0-7'	7/15	11/15	7/15	11/15
		lb N/A		lb/A		mg/L			
1	CP	0	-	22	28	1[3]	1	-	2[3]
2	CP	75	Spr., preplant	52	68	13	3	12[2]	8
3	CP	150	"	97	148	25[3]	24[3]	21[2]	20
4	CP	225	"	110	200	22[3]	16[3]	48[2]	44[3]
5	CP	150	Fall			16[3]	11		
6	CP	150 + NI[1/]	Fall			20[2]	18		
7	CP	150 Split	50% Spr., preplant						
			50% SD, 8-leaf	90	133	45[2]	27[3]		
8	NT	150	Spr., preplant	68	102	9	6[3]		
9	CP	315[2/]	Spr., disked in			6[2]	2	6[2]	5[3]
10	CP	490[2/]	Spr., disked in			9[2]	1[2]	28[2]	5[3]

[1/] On July 15 and November 15. All values are an average of four replications unless noted by the superscript which denotes number of samples in average.

Because of the consistent increase in residual soil NO_3 found in November 1990 associated with higher N rates, all plots were split in 1991 with the north four rows of each plot not receiving any additional N. The purpose of this was to determine the impact of residual NO_3 on N uptake and yield of corn and NO_3 removal from the soil profile. Corn production and N uptake parameters from these unfertilized plots are shown in Table 3. Residual NO_3 significantly increased yields, N concentrations and N removal/uptake of the grain, fodder and silage. A linear response to the 1987-90 N rates was clearly shown for all parameters with the CP tillage system. However, there was no response with the

150-lb N rate over the 0-lb rate when NT was used. This suggests that the annual 150-lb N rate for NT may have been optimum, due to reduced mineralization, whereas the annual 150-lb rate for CP exceeded crop demand and resulted in carryover of N for the succeeding crop. Grain:stover ratios were increased from 1.15 with the 0-lb rate, to 1.31 with the 75-lb rate, to 1.49 with the 150-lb rate to 1.57 with the 225-lb N rate. Apparently, higher levels of residual NO_3 enhanced N utilization efficiency and thus increased grain yield substantially while only having a small effect on fodder yield. Comparison of the yields from the plots receiving N in 1991 (Table 1) with those not receiving N (Table 3), shows a 42.6, 35.8, and 25.9 bu/A response to N applied in 1991 with the 75, 150 and 225-lb N rates, respectively, and 73.1 bu/A response to the 150-lb rate applied with NT. These responses clearly suggest that N applied in excess of crop needs in prior years can contribute to the N available for corn in following years under these soil/climate conditions. This was not true in a somewhat similar study on the poorly drained soil at Waseca in 1991.

Table 3. Influence of residual N rates on grain and silage yield, N uptake and N concentration in Olmsted Co. in 1991.

Treatment			Grain			Fodder		Silage	
No.	Tillage	Residual N Rate	Yield	N	Removal	Yield	N	Yield	N uptake
		lb/A	bu/A	%	lb/A	TDM/A	%	TDM/A	lb/A
1	CP	0	75.5	1.01	36.5	1.55	.36	3.34	47.6
2	CP	75	92.5	1.05	45.9	1.70	.37	3.89	58.5
3	CP	150	116.2	1.13	62.0	1.86	.47	4.60	79.5
4	CP	225	126.3	1.20	71.7	1.93	.46	4.92	89.4
5	CP	150	121.8	1.14	65.6	1.90	.44	4.78	82.5
6	CP	150 + NI[1]	99.4	1.08	51.1	1.71	.43	4.06	65.8
7	CP	150 Split	106.1	1.18	59.6	1.88	.48	4.39	77.9
8	NT	150	79.7	1.07	40.2	1.45	.41	3.33	52.2
9	CP	315[2]	99.3	1.06	50.1	1.84	.37	4.19	63.6
10	CP	490[2]	93.7	1.05	46.7	1.79	.36	4.00	59.6
Signif. Level (%) :			99	96	99	98	99	99	99
BLSD (.05) :			17.0	0.14	11.0	0.31	0.08	0.55	13.4
CV (%) :			12.	7.1	15.	11.	12.	9.5	14.

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 or 1990. Total N rates were 315 and 490 lb N/A/yr or approximately 175 and 265 lb "available" N/A/yr.

Corn yields in the pesticide study were not affected by tillage (Table 4). The 5-year average shows approximately an 8-10 bu/A advantage for the moldboard and chisel plow treatments.

Table 4. Effect of tillage treatments on the 1991 corn yields in Olmsted Co.

Tillage	Grain Yield 1991	Grain Yield 1987-91 Avg.
	bu/A	
Moldboard plow	145.4	162.0
Chisel plow	145.1	160.5
Ridge till	141.8	152.9
No tillage	146.4	151.0
Significance level (%):	6	
CV (%) :	7.5	

Goodhue Co.

Soybean seed yields N concentrations in the seed and N removal by the seed were not significantly affected (P = 90% level) by the previous N treatments even though there were substantial accumulations of residual NO_3-N in the 0-5' soil profile (Table 5). Approximately 40 to 60 lb NO_3-N/A resided in the 5 to 7' zone and is likely to be leached toward the groundwater. Nitrogen removal with the seed averaged about 200 lb N/A which is markedly larger than one would expect with corn and should have removed some of the residual NO_3 from the soil profile. Nitrate-N concentrations in the soil water at the 5' depth in mid-May increased with increasing N rate used in prior applications, but was especially high when the N was sidedress-applied. Changes in NO_3-N concentration over the 6-month growing season were small except for the 150-lb sidedress treatment where the very high concentration in May was reduced to concentrations similar to the other 150-lb treatments. These data indicate that soybean did not have a large "cleansing effect" on the NO_3 levels in water at the 5' depth over this growing season. However, soil samples taken in November 1991 indicate very low NO_3-N amounts in the top three feet of all plots (data not shown). Thus, soybean may be somewhat effective at removing excess NO_3 from the upper part of the soil profile, but this study cannot exclude the possibility of leaching as a contributing loss mechanism.

Table 5. Soybean production, residual NO_3-N in the soil profile, and NO_3-N concentration in the soil water at 5' as affected by the 1987-90 treatments in Goodhue Co. in 1991.

1987-90[1/] N Rate	Tillage	Seed Yield	Seed N Conc.	Seed N Removal	Nitrate-N in soil profile 0-5'	Nitrate-N in soil profile 0-7'	Nitrate-N in soil soil water at 5' [2/] 5/14	Nitrate-N in soil soil water at 5' [2/] 11/12
		bu/A	%	lb/A	----- lb/A -----		----- mg/L -----	
0	CP	56.8	6.65	195.8	33	45	5	7
50	CP	60.3	6.48	203.1				
100	CP	59.0	6.81	208.8			19[3]	23[2]
150	CP	57.3	6.36	189.5	96	134	38	43[3]
200	CP	56.9	6.82	201.6	173	239		
0	NT	54.4	6.67	188.2				
100	NT	58.4	6.56	199.4			12	9[2]
150	NT	58.5	6.54	198.8	87	127	26	19
200	NT	59.8	6.65	206.5	142	201		
50 + 50	CP	60.5	6.51	204.3				
50 + 100	CP	59.0	6.64	203.4				
100 + 50	CP	58.8	6.84	208.5				
100 (SD)	CP	57.0	6.61	196.5				
150 (SD)	CP	59.7	6.61	204.8			57	33[3]
150 + NS (SD)	CP	58.9	6.87	209.8				
150 + NS (SD)	CP	57.4	6.56	195.4				
Signif. Level (%) :		24	41	27				
CV :		6.4	4.5	7.6				

[1/] See 1991 Bluebook article for a complete description of treatments.

[2/] On May 14 and November 12. All values are an average of four replications unless noted by the superscript which denotes number of samples in average.

Winona Co.

Similar to the Goodhue Co. study, the experiment in Winona Co. was converted from continuous corn to alfalfa established with oat. Although oat yield was low due to high infestation of leaf rust, a dry matter response to carryover N associated with the previous N treatments applied to chisel plow tillage was found (Table 6). Nitrogen concentration in the dry matter was increased significantly over the control by the 100-, 150-, and 200-lb N rates with no difference among these three treatments. Total N removal by the oat was increased by 10 to 20 lb/A with previous N rates of 100 lb/A or greater.

Table 6. Influence of previous N rates on oat yield and N removal by the crop at Winona Co. in 1991.

Previous N Rate	Oat Yield	Whole Plant N	N Removal
lb/A	TDM/A	%	lb/A
0	1.22	1.43	34.7
50	1.18	1.58	37.5
100	1.31	1.70	44.3
150	1.43	1.79	51.2
200	1.52	1.81	54.7
Signif. Level (%) :	92	99	99
BLSD (.05) :	-	0.21	10.8
BLSD (.10) :	0.25	0.18	9.1
CV (%) :	13.	8.	15.

In contrast to the oat, no effect of either the previous tillage system nor N rate was observed on seeding year alfalfa yield (Table 7). Whole plant N concentration, however, was increased about 0.50% N (3.1% protein) by the previous CP tillage treatment compared to the previous NT system. The previous N rates did not influence N concentration in the alfalfa. Nitrogen removal was increased about 10 lb/A with the CP system.

Table 7. Effect of previous tillage and N rates on alfalfa yield and N uptake at Winona Co. in 1991.

Previous Tillage	Previous N Rate	Whole Plant N	Alfalfa Yield	N removal by crop
	lb/A	%	TDM/A	
CP	0	3.69	1.210	89.4
CP	100	3.85	1.132	87.4
CP	200	3.98	1.124	88.4
NT	0	3.27	1.185	77.2
NT	100	3.50	1.088	77.1
NT	200	3.30	1.164	77.2
MAIN EFFECTS				
Tillage				
CP		3.84	1.155	88.4
NT		3.36	1.146	77.2
Signif. Level (%):		98	18	95
N Rate				
0		3.48	1.197	83.3
100		3.67	1.110	82.2
200		3.64	1.144	82.8
Signif. Level (%):		30	80	1
INTERACTION				
Tillage x N Rate				1
Signif. Level (%):		24	36	
CV (%) :		13.	8.1	15.

Nitrate-N amounts in the soil profile prior to oat-alfalfa establishment were highly related to the past N and tillage treatments (Table 8). Nitrate-N increased with increasing N rate but was consistently lower with NT compared to CP. High levels of NO_3-N were found between 5 and 7' especially with the 200-lb preplant and 150-lb sidedress rates.

Nitrate-N concentrations in the soil water at 5' and 7.5' in mid-May reflected the NO_3 amounts in the soil profile (Table 8). However, by November 20, NO_3-N concentrations at 5' were reduced to levels as low as 0.2 mg/L. The only concentration above 10 mg/L was with the previous 150-lb sidedress treatment that showed extremely high carryover amounts of residual NO_3. Concentrations of NO_3-N at 7.5' were not reduced consistently over this 6-month period. These data suggest that the alfalfa in this seeding year and perhaps some leaching were responsible for the substantial removal of NO_3 from the 0-5' zone resulting in very low NO_3-N concentrations in the soil water at 5'. Considering that water samples taken in mid-August still showed high NO_3 concentrations (data not shown), that seeding year alfalfa would have established a root system to a 5- depth by October, and that rainfall amounts from August thru October were less than normal at this site, it becomes evident that alfalfa in its establishment year has a tremendous capability of scrubbing NO_3 from the rooting zone. Leaching of NO_3 was not likely to have occurred under these conditions.

Table 8. Nitrate-N content in the soil profile in May 1991 and NO_3-N concentration in the soil water at 5' and 7.5' as influenced by previous tillage and N rates in Winona Co. in 1991.

Treatment				Nitrate-N in soil profile		Nitrate-N Conc in Water[1/]			
						5'		7.5'	
No.	Tillage	N rate	Time/Method	0-5'	0-7'	5/10	11/20	7/10	11/20
		lb N/A		lb/A		mg/L			
1	CP	0	Spr., preplant	32	38	-	1^2		
3	CP	75	"	101	151	23	2	-	22^2
4	CP	150	"	198	281	41^3	9	26^2	24^2
5	CP	200	"	262	390	54^3	5^2	38^2	42^2
7	NT	100	"	68	100	-	1^2	-	-
8	NT	150	"	141	201	23^2	0.2^2	21^2	6^2
9	NT	200	"	195	292	42^2	1^2	19^3	-
10	CP	50 + 50	Spr. PP + SD	128	197				
11	CP	50 + 100	"	217	309	18^3	6^3	58^2	34^2
12	CP	150	Sidedress	284	417	37^2	17^2		

[1/] Superscript indicates the number of samples in the mean if less than four.

EFFECTS OF NUTRIENT SOURCES, APPLICATION TIMING AND RATE ON ALFALFA (AND SUBSEQUENT CORN) PRODUCTION

M.A. Schmitt, C.C. Sheaffer and G.W. Randall[1/]

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

This report is an update of a long-term research project investigating the effects of manure and fertilizer on alfalfa establishment and production, soil N contents, and the resulting credits the alfalfa/manure treatment combinations provide for subsequent corn crops. The 1991 growing season was the third year of the study. The specific objectives are:

1. Evaluate the effects of plowdown and topdress fertilizer applications, commercial and manure fertilizer sources, and rates of nutrient applications on alfalfa nutrient uptake, forage quality, stand density, and dry matter production.

2. Monitor soil N forms from the manure treatments while the alfalfa was actively growing to assess potential for excessive nitrate accumulation.

3. Determine the N fertilizer replacement equivalent (credit) that should be recommended for alfalfa/manure treatment combinations for the corn crops grown in the years after the alfalfa is plowed.

Materials and Methods

Trials were established at University of Minnesota Agricultural Experiment stations at Rosemount and Waseca. At Rosemount, hog manure was used on a shallow Waukegan silt loam soil lying on outwash gravel subsoil. Soil P and K tests at Rosemount were categorically "high" (Bray P at 35 ppm and K at 200 ppm). At Waseca, dairy manure was used on a Nicollet clay loam soil, which tested "low" for both P (8.5 ppm) and K (94 ppm). Two adjacent plot areas were established at Rosemount to offset potential confounding effects of years.

Nutrient application rates were based on the estimated two-year nutrient needs of alfalfa and the prevalent range of manure application rates commonly used by farmers. Three rates of manure (3000, 6000, and 12000 gallons per acre) were broadcast and incorporated immediately prior to establishment of the alfalfa. Three inorganic commercial fertilizer treatments were also used--applied to give equivalent phosphorus (P) and potassium (K) application rates as contained in the three rates of manure. A control treatment was also included, thus, seven treatments were replicated four times in a randomized, complete-block design. Specific nutrient amounts are listed in Table 1 and associated production information is given in Table 2.

Along with measures of overall dry matter yield at each harvest, plant samples were collected at each harvest for nutrient analysis. Stand density measurements and weed pressure estimates also were made. After the second year, before the alfalfa was plowed, subplots were undercut and crown counts, crown and taproot dry matter yields and N contents measured. The plots were also subdivided at this time, with one half of the plot having its last cut of alfalfa harvested and the other half of each plot having its late summer regrowth plowed under. Thus, the plot design is now a split plot.

Corn production practices were followed according to optimum management principles. No N fertilizers are added to the plots at any time. Broadcast applications of P and K were made to approximate crop removal amounts. The corn was harvested from 2-20 foot rows within each subplot.

During the alfalfa's growing season, soil samples were collected to a depth of two feet in one-foot increments. These samples were analyzed for nitrate-N and ammonium-N. When corn was being grown, soil samples were collected at various times and depths.

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Results

Production Year Yields

The application of manure did significantly increase alfalfa dry matter yields at Rosemount (South) in 1990 compared to the unfertilized control treatment (Table 3). Despite slight yield increases with the inorganic fertilizer rates at Rosemount, there was no statistically significant difference between the control treatment and the inorganic fertilizer treatment means. The relatively high soil test values for P and K would provide justification for this lack of fertilizer response.

For the Rosemount (North) plots in 1991, statistical analysis of the data results in none of the treatments being statistically different from each other, however, the treatment means (Table 3) show the same trends that occurred in 1990. The control plot had the lowest yields and with each increment of manure added, a yield increase was noted--the highest manure rate treatment yielding 0.55 ton dry matter more per acre than the control. At the same time, the commercial fertilizer treatments did increase yields, but there was no difference among the rates nor was this increase as great as with the manure.

At Waseca, the yield response to both commercial fertilizer and manure was statistically significant (Table 3). While the lowest rate of inorganic fertilizer did not result in a significant increase in alfalfa yield, the low rate of fertilizer produced 0.44 tons of dry matter more than the control. The middle and high fertilizer rate each produced a significant increase in dry matter production. The increase in tonnage was almost a direct linear correlation with the rate of fertilizer application. With the low soil test levels for P and K at this site, the increase in yield was predictable.

Soil Nitrate Levels

Nitrate-N concentrations measured in the soil provide an indicator as to the amount of N that can potentially be lost. Nitrate-N quantities in manure-treated plots above the quantities in the control plots represent nitrate contributions from the manure.

Throughout the 1989 growing season at Rosemount, there were statistically significant differences in soil nitrate-N due to manure rate differences--these differences being somewhat related to the relative application rates of the manure (Table 4). In July and thereafter, the low manure rate nitrate-N concentrations were not different from the control and after August, the medium manure rate was not different from the control.

For the second set of plots at Rosemount initiated in 1990, nitrate concentrations were significantly increased above the control plot concentrations for all manure rates with the spring samplings after application (Table 4). The low and medium manure rate treatments (3000 and 6000 gal/acre) nitrate levels were never significantly higher than the control plots' nitrate concentrations at later samplings.

The higher manure rate treatment did result in higher nitrate levels during the first year of the study, but after the initial flush of N release the second year, the nitrate levels were statistically equal to the control plots. The wide fluctuations in the control plots' nitrate levels indicate how environmental conditions affect the biological processes in the soil.

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

Corn Production after Alfalfa

Two of the three sites had corn grown in 1991. Average corn yields measured in 1991 had no statistically significant differences due to preplant manure and fertilizer treatments that were made to the preceding alfalfa crop (Table 5). Based on current corn N fertilizer recommendations, no response to N fertilizer is expected after alfalfa. Therefore, this first year of corn following various treatment combinations of alfalfa and manure is not surprising. Any residual effects of the manure and/or alfalfa would be more noticeable in subsequent years.

Presidedress nitrate tests were also conducted on the corn plots to ascertain the sufficiency of N according to Iowa State University guidelines. The results indicate that higher nitrate-N was present in early June with increasing manure rates. However, these results are all below the critical level (21 ppm) that Iowa State University recommends where no response to fertilizer will be measured. Thus, the alfalfa/manure treatments are either releasing sufficient amounts of nitrate-N later in the season and/or the nitrate-N may be moving below the sampling depth.

Summary

The application of either manure or inorganic fertilizer can be used to supply the fertilizer requirements of a planned alfalfa crop. Both nutrient sources will increase dry matter production, although there is a consistent trend that manured treatments produced more dry matter than an equivalent amount of P and K fertilizer. Manure does supply a substantial amount of inorganic N to the soil--with its persistence in the soil being a function of the rate of application. Corn yields after the alfalfa is plowed were not significantly affected by the manure treatments on the alfalfa plot. This is consistent with other research supporting the recommendation that first-year corn after alfalfa do not require additional N fertilizer.

Table 1. Nutrient sources and application rates for preplant applications of nutrients at Rosemount and Waseca.

Treatment Code	Nutrient Source	Application Rate	
		Rosemount	Waseca
		- gal/acre or $N-P_2O_5-K_2O$ lb/acre -	
1	None	-	-
2	Manure	3000	3000
3	Manure	6000	6000
4	Manure	12000	12000
5	Fertilizer	0-90-69	0-33-69
6	Fertilizer	0-180-138	0-66-138
7	Fertilizer	0-360-276	0-132-276

Table 2. Calendar dates of manure applications and harvests of alfalfa at two Rosemount sites and at Waseca.

Operation	North Rosemount	South Rosemount	Waseca
Manure application	April 17,1990	April 21,1989	May 10,1989
Harvests-seeding year	July 5,1990 August 16,1990	July 11,1989 August 28,1989	July 27,1989
Harvests-production year	June 3,1991 July 1,1991 August 8,1991 October 10,1991	June 6,1990 July 5,1990 August 8,1990 October 29,1990	June 15,1990 July 23,1990 August, 1990 November 1,1990

Table 3. Alfalfa dry matter yield means for the first full year of production as influenced by preplant manure and fertilizer applications.

Treatment	DM Yields		
	Rosemount-North	Rosemount-South	Waseca
	T/A		
1	4.67	3.81	2.84
2	4.72	4.31	3.40
3	5.09	4.60	4.12
4	5.22	4.55	4.49
5	4.89	3.87	3.28
6	4.83	3.97	3.71
7	4.80	4.17	4.57
Pr.>F	0.1824	0.0001	0.0001
$LSD_{(.10)}$	-	0.36	0.45

Table 4. Two-foot soil nitrate-N concentrations from plots receiving preplant incorporated manure applications in 1989 and 1990.

Location	Date	Manure Rate (GPA) Control	3000	6000	12000	$LSD_{(.10)}$
		ppm NO_3-N				
Rosemount	May 1, 1989	14.2	17.6	16.9	17.8	-
	May 31 "	16.9	41.4	79.5	106.2	31.5
	June 22 "	17.2	42.5	68.8	103.3	17.2
	Aug. 3 "	3.5	4.3	14.1	38.4	3.9
	Nov. 1 "	1.6	1.7	2.1	15.4	4.8
	April 12, 1990	15.6	14.2	27.3	39.1	-
	May 3 "	12.7	14.9	18.1	40.7	15.0
	May 31 "	9.8	9.9	15.3	19.6	-
	July 18 "	11.8	9.7	8.6	13.7	-
	Aug. 20 "	5.9	7.1	7.1	7.3	-
Waseca	June 5, 1989	18.1	25.2	38.1	48.1	5.7
	June 27 "	17.1	24.6	36.1	55.0	7.3
	Sept. 11 "	7.3	15.7	32.8	47.4	12.5
	April 27, 1990	14.5	14.0	21.8	28.9	4.3
	May 23 "	10.2	11.2	16.0	17.7	-
	June 22 "	6.9	7.9	7.2	10.0	-
	July 23 "	3.9	2.8	4.1	5.0	-
Rosemount	May 31, 1990	20.8	47.9	58.6	81.1	20.9
	June 25 "	15.9	17.5	23.5	38.9	-
	July 18 "	12.2	17.2	24.4	34.2	8.7
	Aug 20 "	6.7	6.8	7.8	15.7	6.8
	April 17, 1991	7.2	7.7	8.1	8.3	-
	June 3 "	7.7	8.2	9.4	11.7	1.4
	July 16 "	4.6	4.7	5.1	6.6	-
	Sept 5 "	3.5	4.3	4.6	3.8	-

Table 5. Effects of preplant manure and fertilizer applications on the following corn grain yields and presidedress nitrate levels (PSNT) at Rosemount and Waseca, 1991.

Treatment Code	Rosemount Corn Yields PSNT	No Fall Cut	Fall Cut	Ave	Waseca Corn Yields PSNT	No Fall Cut	Fall Cut	Ave
	ppm	bu/A			ppm	bu/A		
1	17.2	175.1	166.7	170.9	7.2	155.8	156.5	156.2
2	15.2	177.0	167.2	172.1	7.8	170.1	158.6	164.3
3	18.9	188.5	187.9	188.2	8.1	173.4	169.7	171.5
4	19.3	175.7	172.7	174.2	9.3	177.3	163.4	170.3
5		173.4	172.3	172.8		160.8	148.8	154.8
6		176.6	172.1	174.3		172.2	157.1	164.6
7		177.5	176.5	177.0		176.4	170.4	173.4
Pr.>F				0.319				0.335

RESIDUAL EFFECTS OF POTASH AND ALFALFA MANAGEMENT ON CORN PRODUCTION

M.A. Schmitt, M.P. Russelle, and C.C. Sheaffer[1/]

ABSTRACT

Fertilizer management for a previous crop can have a residual effect on following crops. Potassium additions of 0, 375, 750, and 1500 lb K_2O/A were applied to alfalfa from 1985-87. The alfalfa was managed in both 3- and 4-cutting schedules. Although the cutting schedule did not have an effect on corn grain yields in 1990-91, the previous potash rates did. Yields in 1990 and 1991 ranged from less than 14 bu/A for the 0 lb K_2O rate to over 180 bu/A for the 1500 lb K_2O rate. Soil test levels from the topsoil ranged from 53-87 ppm K. Within this relatively narrow soil K test range, yield correlated well with soil K levels.

Introduction

Potassium (K) deficiency in corn is characterized by a marginal necrosis on the leaves. It was this visual symptom that identified a previous research field at the Rosemount research station as one that had a K deficiency and that some of the residual fertilizer treatments were alleviating this problem in some plots. The contrast between the "good" corn and "poor" corn in this bulk corn field in 1990 initiated the process collecting yields and measuring soil tests in the plot area.

The plot area had been part of a previous alfalfa study. That study, initiated in the spring of 1985, investigated the interacting effects of K fertilization, alfalfa cutting management schedules, and alfalfa varieties, which differed in winter hardiness ratings.

The K fertilization rates consisted of 0, 125, 250, and 500 lb of K_2O per acre. This fertilizer was added as a plowdown treatment in 1985 and applied in split, topdressed application in 1986 and 1987.

The initial soil K test was 100 ppm. Oats were grown in 1989 and corn was grown in 1990 and 1991. The field has received no fertilizer since the project ended in 1987.

The objective of this trial was to link current corn growth differences with previous alfalfa treatments as well as current soil test results.

Methods

The soil at this site was a Waukegan silt loam with approximately 28 inches of loam over outwash sand and gravel. Because the symptoms were a residual effect of the beforementioned alfalfa study, no treatments were applied. Top management practices were implemented regarding cultural practices and pest management. Extremely wet conditions in the spring of 1991 delayed corn planting until the first week in June.

At harvest time, plots were flagged according to the original 1985 plot design. One exception was that the effect of alfalfa varieties was not delineated due to the hypothesis (and observation) that this factor was not influencing the current corn crop. Thus, the cutting managements were the main plots and the K treatments were the subplots. There were three replications.

Corn grain was harvested by hand-picking four 10-foot rows. After weighing this, six ears were selected, weighed, dried, weighed again, shelled, and reweighed. This allowed for grain moisture, shelling percentage, and grain yield determinations. In the fall of 1990, soil samples were collected from each plot to a depth of six inches and analyzed for exchangeable K according to standard (ammonium acetate extraction) procedures.

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Results

A summarization of the statistical analyses is listed in Table 1. The factor of alfalfa cutting management had no effect on potassium deficiency and grain yields of the corn in either year. The effect of the potash rates was highly significant, whereas the interaction of cutting management and potash rates
was not significant. Note that there was a highly significant difference between the two years. This difference can mainly be attributed to the lower yields measured in 1991 due to the very late date of planting.

Table 1. Analysis of variance table for individual and combined years for selected sources of variation.[1/]

Source of Variation	1990	1991	Combined
Year	-	-	395.82***
Alfalfa cuts	0.35NS	1.26NS	0.09NS
Potash Rate	150.73***	95.14***	43.20***
Cuts x Potash	0.42NS	1.83NS	0.18NS

[1/] Statistical significance is designated at probability levels of a greater F or 0.001, 0.01, 0.10 and less than 0.10 by ***, **, *, and NS, respectively.

Corn grain yields ranged from 3.8 - 187.5 bu/A in 1990 and from 8.0 - 82.8 bu/A in 1991 (Table 2). In plots that had received no K fertilizer, yields did not exceed 10 bu/A. Corn in these plots did not grow taller than 2 feet and exhibited severe K deficiency symptoms soon after emergence. As the previous K rates increased, so did the height, yield, and overall appearance of the crop. At the highest K rate, no deficiency symptoms were observed and the corn was 6-8 feet tall.

Table 2. Corn grain yields as affected by alfalfa cutting management and potash applications.

Potash Applied 1985-1987	Alfalfa Mgmt 1985-1987	Grain Yields 1990	1991	1990-91
lbs K_2O/A/Yr	- Cuts/Yr -	- - - - - - - -	bu/A	- - - - - - - - - -
0	3	3.8	8.0	5.9
	4	8.3	8.8	8.5
125	3	76.2	27.2	51.7
	4	71.3	36.9	54.1
250	3	160.4	50.8	105.6
	4	160.8	68.1	114.5
500	3	187.5	82.8	135.2
	4	172.3	80.6	126.4

Soil K tests measured 53, 61, 62, and 87 ppm K/A for the K treatments ranging from the lowest K rate (control) to the highest K rate. Except for the two middle means, these values were significantly different from each other. Grain yield was well correlated with soil K tests for each plot (r=0.72 in 1990 and r=0.80 in 1991). According to University of Minnesota fertilizer recommendations, all soil K tests would be in the medium to medium-low range, thus, the resulting range in yields is surprising.

Summary

Results from this trial have led to more questions than answers, and the number of questions continues to grow. While the refinement of soil K tests and the resulting K recommendations can be a future goal from this trial, a broader issue may be the development of fertilization plans for entire rotations. It is important to use a fertilizer management plan that meets current needs and that is adaptable for future needs as well.

EFFECTS OF TILLAGE AND FREQUENCY OF LIQUID DAIRY MANURE ON N AVAILABILITY TO CORN[1]

J. R. Joshi and J. F. Moncrief[2]

Abstract: A study to determine the influence of tillage and manure application on corn production in Goodhue Co., MN was continued in 1991. Results from this long-term experiment showed generally depressed yield levels in 1991. Manure applied annually had greater yields (137 bu/A) than urea (114 bu/A) applied at 163 lb N/A. Manure applied biennially produced 119 bu/A in the year of application of manure and 85 bu/A in the following year. Manure applied triennially in chisel plowing system produced 110, 99, and 76 bu/A yield in the first, second, and third year, respectively. Check yields were 11 and 63 bu/A in no-tillage and chisel plowing systems, respectively. The amount of surface cover provided by various tillage and N treatments were similar to the previous years.

Total amount of N applied through manure was comparable to the previous three years but the amount in mineral form was about 40% smaller. In addition, delayed planting, greater seeding rate, and a change in hybrid may have been responsible for the yield decline.

INTRODUCTION

The objectives of this study are to determine the effects of tillage and frequency of manure application on corn yield, N uptake, and soil nitrogen levels. The site is located on a Seaton silt loam (Typic hapludalf, fine-silty, mixed, mesic) soil on the Dale Flueger Farm near Red Wing in Goodhue Co., MN. The study was initiated in 1982.

Liquid dairy manure is injected either annually, biennially or triennially on chisel-plowed treatments and annually or biennially on no-tillage treatments. A zero-N check treatment and a fertilized check treatment are also included in the study. In 1991, the fertilized check received broadcast urea, instead of ammonium nitrate or anhydrous ammonia applied in previous years. The hybrid used this year was NK 3624. Other cultural practices are listed in Table 1.

From 1982-1986 the manure treatments were split with 0 and 200 lbs K_2O/A and the fertilizer treatments with 0, 200, and 400 lbs K_2O/A. The application of this extra potassium has been stopped since 1987. To evaluate residual effects of additional potassium, data in this report are presented on split basis with respect to K_2O whenever applicable.

The experiment is laid out in a randomized complete block split-split plot design with three replications. Tillage is the main plot and N source is the subplot. Manure as N source is further split by the year of N application as a sub-sub plot.

RESULTS AND DISCUSSION

Residue Cover. Residue measurements were made both in and between the rows in duplicate in manure, fertilizer and check treatments in both tillages on June 6, 1991. A table of significance of treatment effects on residue cover is given in Table 2. Residue cover in between the rows in the no-tillage system without manure was above 80% (Table 3). The injection of manure reduced the residue cover in between the rows to 27 in the year of manure application in the biennial manure and 39% in annual manure treatments. Chisel plowing with or without manure had a cover between 23 to 29%. The amount of cover in the rows was generally below 25% in all treatments except in the biennial manure (53%) in the year following manure application.

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Plant Population, Grain Yields, and Grain Moisture: Biennial Study. The effects of various annual and biennial treatments on plant population, grain yield, and grain moisture are given in Table 4. Average plant population at harvest was about 37,000 plants/A, an increase by about 30% from the previous years. This is because of a higher seeding rate this year. Grain yields were reduced this year by about 25% from the 1990 yield levels. However, the relative magnitude among the N treatments was similar: Annual manure > biennial manure in the application year > fertilizer > biennial manure in the year following the manure application. Fertilizer was applied at 163 lb/A, about 12 lb/A lower than in 1990. Average grain moisture at harvest was about 21%. Greater moisture levels were associated with smaller yields (fertilizer and biennial manure in the year after manure).

Plant Population, Grain Yields, and Grain Moisture: Triennial Study. The effects of various triennial treatments on plant population, grain yield, and grain moisture are given in Table 5. Final plant stand was more in the second year after the application of manure. Grain yield in the year of application of manure was 110 bu/A, about 20% lower than the annual manure treatment. The yield levels declined in the second year by 11 bu/A and in the third year by 24 bu/A. The third year yields were 13 bu/A more than the check treatment. Although the yield levels were reduced compared to the previous years, the general trend between the years was similar. Grain moisture at harvest was uniform among the years.

Table 1. Cultural practices at the Flueger Farm in Goodhue County, MN in 1991.

Tillage

No Till

Chisel Plowed and field cultivated on May 23, 1991.

Cropping History

Corn since 1981-P 3906

1989 Corn Pioneer 3737

1990 Corn Pioneer 3751

1991 Corn NK3624

Manure Application

Injected liquid dairy manure at the following rate and analysis on May 20, 1991.

		1991 rate	
		Mean	Std. Dev.
Manure	(gal/A)	8500	500
Total-N	(lbs/A)	202	12
NH_4-N	(lbs/A)	78	5
P_2O_5	(lbs/A)	119	7
K_2O	(lb/A)	149	9
Solids	(%)	6.4	2.3

Planting Information : A four row 38 inch John Deere Maxi-Emerge planter with 2" fluted coulters was used to plant on May 24, 1991. Corn was harvested on October 12, 1991.

Fertilizer

Material Analysis	Tillage	Actual N -lbs/A-	Date Applied	Method of Application
46-0-0	Both	163	June 19, 1991	Broadcast after planting
9-23-30	Both	111	May 24, 1991	As a starter

Soil: Seaton silt loam (mixed, mesic, fine-silty Typic hapludalf), well drained, 2 to 12% slope.

Insect Control: 5.7 lbs/A Timet 20G applied in furrow on May 24, 1991.

Weed Control: Cultivated all treatments on June 27, 1991.

Table 2. Significance table for surface residue cover in Goodhue Co., MN on 6/6/91.

Till(T)	N Freq(F)	T*F	K(K)	T*K	F*K	T*F*K	Row(R)	T*R	F*R	K*R	T*F*R	T*K*R	F*K*R	T*F*K*R
.033	.000	.000	.987	.916	.700	.707	.000	.001	.005	.660	.001	.736	.736	.453

Table 3. Surface residue cover as affected by tillage, N source and row position in Goodhue Co.,MN on 6/6/91.

N Source And Frequency	Row Position	Residue (%)	
		No Till	Chisel
Manure (Year of)	In	17.0	12.7
	Between	26.7	29.3
Manure (Year After)	In	53.3	16.7
	Between	82.0	23.7
Manure (Annual)	In	18.8	14.0
	Between	38.9	29.2
Urea	In	25.0	8.7
	Between	81.0	25.3
Pr > F (T X F X R)		.001	

Table 4. Corn plant population, grain yield, and grain moisture at harvest as influenced by tillage, and N source and frequency of application in Goodhue Co., MN in 1991.

Frequency & Source of N	K_2O lb/A	PLANT POPULATION No Till	Chisel	Mean	GRAIN YIELD No Till	Chisel	Mean	GRAIN MOISTURE No Till	Chisel	Mean
		-- plants/A*10^{-3} ---			---------bu/A--------			---------%----------		
Manure[1]	0	36.2	33.8	35.0	85	105	95	25.6	20.9	23.2
(Yr after)	200	34.4	31.8	33.1	52	98	75	24.0	20.8	22.4
	Mean	**35.3**	**32.8**	**34.1**	**68**	**102**	**85**	**24.8**	**20.9**	**22.8**
Manure	0	41.1	38.7	39.9	97	124	111	20.4	18.1	19.3
(Yr of)	200	36.6	40.3	38.1	121	128	124	17.9	15.4	16.9
	Mean	**38.1**	**39.6**	**38.8**	**113**	**126**	**119**	**18.7**	**16.6**	**17.8**
Manure	0	35.2	41.0	36.5	126	142	130	19.9	17.0	19.2
(Annual)	200	37.8	34.2	36.6	152	126	143	18.6	19.0	18.7
	Mean	**36.4**	**36.9**	**36.5**	**138**	**133**	**137**	**19.3**	**18.2**	**19.0**
Urea	200	42.6	35.2	38.9	113	115	114	22.4	26.4	24.4
Overall Mean		**37.8**	**36.2**	**37.1**	**115**	**119**	**116**	**20.6**	**20.5**	**20.6**
Check (0 N)[2]		33.6	40.5	37.0	11	63	37	27.3	20.0	23.6

Pr>F	Till(T)	Freq.(F)	T*F	K rate(K)	K*T	K*F	K*F*T
Plant population	.281	.038	.103	.199	.680	.976	.070
Grain Yield	.155	.000	.111	.922	.296	.058	.068
Grain moisture	.471	.022	.356	.556	.669	.778	.921

[1]Manure applied in the spring of 1990 (year after) and 1991 (year of).
[2]Check (0 N) treatments were not included in the statistical analysis.

Table 5. Corn plant population, grain yield, and grain moisture at harvest in triennially-applied manure with chisel plowing system in Goodhue Co., MN in 1991.

YEAR OF MANURE APPLICATION	K_2O lb/A	PLANT POPULATION -- plants/A*10^{-3} --	GRAIN YIELD ---bu/A---	GRAIN MOISTURE ---%---
First Year	0	36.9	106.2	21.1
	200	37.2	113.8	20.4
	Mean	**37.1**	**110.0**	**20.8**
Second Year	0	38.2	98.7	20.2
	200	38.8	99.7	21.2
	Mean	**38.5**	**99.1**	**20.7**
Third Year	0	36.9	77.1	21.5
	200	36.8	74.2	19.6
	Mean	**36.9**	**75.5**	**20.4**