Table 6. Soybean yields by soil type and tillage treatment in 1992.

Tillage treatment	Well drained soil[1]		Poorly drained soil[2]		Average
	(bu/ac)	(std. dev.)	(bu/ac)	(std. dev.)	(bu/ac)
No-tillage	40.7	3.4	45.2	6.3	**42.9**
Moldboard plow	35.8	2.5	44.2	2.9	**40.0**
VTI 0 deg. 0 in.	39.6	3.0	46.9	1.9	**43.3**
VTI 15 deg. 5 in.	38.8	1.8	40.0	3.8	**39.4**
VTI 15 deg. 10 in.	38.3	3.2	44.0	2.4	**41.2**
VTI 30 deg. 5 in.	40.7	1.3	47.2	3.9	**44.0**
VTI 30 deg. 10 in.	40.1	1.7	42.7	3.9	**41.4**
Average	**39.1**		**44.3**		**41.7**

[1] No significant difference between tillage treatments.

[2] No significant difference between tillage treatments.

Table 7. Corn yields by soil type and tillage treatment in 1993.

Tillage treatment	Well drained soil[1]		Poorly drained soil[2]		Average
	(bu/ac)	(std. dev.)	(bu/ac)	(std. dev.)	(bu/ac)
No-tillage	80.4	2.7	96.7	9.5	**88.6**
No-tillage (w/. sec till.)	89.3	7.5	101.0	5.7	**95.2**
Chisel plow	90.5	5.0	98.6	8.5	**94.5**
VTI 0 deg. 0 in.	84.9	7.0	105.8	4.0	**95.4**
VTI 30 deg. 10 in.	90.0	5.5	103.8	7.9	**96.9**
Average	**87.0**		**101.2**		**94.1**

[1] $LSD_{(0.05)}$ = 6.1 bu/ac for the tillage treatments in the well drained soil.

[2] No significant difference between tillage treatments.

Table 8. Soybean yields by tillage treatment in 1993.

Tillage treatment[1]	(bu/ac)	(std. dev.)
No-tillage	21.0	2.9
Moldboard plow	32.5	2.8
VTI 0 deg. 0 in.	28.5	2.3
VTI 15 deg. 5 in.	28.7	1.1
VTI 30 deg. 10 in.	29.2	1.7
Average	**28.0**	

[1] $LSD_{(0.05)}$ = 4.4 bu/ac for the tillage treatments in the well drained soil.

PERFORMANCE OF A VARIABLE TILLAGE IMPLEMENT IN CORN RESIDUE[1]

D.S. Long, P.C. Robert, D.J. Fuchs, and D.R. Huggins[2]

Abstract

A study to determine the performance of a variable tillage implement (VTI) was initiated in corn residue in fall 1992. By controlling blade depth and angle, the implement was designed to vary the amount of crop residue incorporated in soil. For purpose of comparison, this study included conventional no-till and moldboard tillage systems. Residue cover was initially 100 percent as measured for no-till. Residue cover decreased to about 60 percent after tillage with the VTI and to about 10 percent with the moldboard. The different blade settings of the VTI were not significantly different in residue cover left after tillage. Mechanical problems or the heavy residue conditions of the 1992 growing season may have rendered the VTI ineffective.

Materials and Methods

A variable tillage implement (VTI), a prototype built by DMI Inc., was tested in corn residue at the Southwest Experiment Station, Lamberton, MN in fall 1992. By controlling the blade angle and blade depth, the VTI is designed to vary the amount of crop residue incorporated in soil. Corn residue was from a crop that was harvested in fall 1992. The experimental design was randomized complete block.

The experiment consisted of subunits of the following tillage treatments: VTI with zero blade angle and depth (VTI00), VTI with intermediate blade angle of 15 degrees and depth of 5 inches (VTI155), VTI with maximum blade angle of 30 degrees and depth of 10 inches (VTI3010), moldboard plow, and no-till (Table 1). Tillage treatments were stripped across three replicated mainplots of poorly drained Webster soils and well drained Ves soils. Each subunit was divided into chopped and unchopped residue treatments. The residue was chopped in fall 1992.

Table 1. Tillage treatments in corn residue.

Tillage Treatment	Timing
No Till	Fall
Moldboard	Fall
VTI 0 deg. 0 in.	Fall
VTI 15 deg. 5 in.	Fall
VTI 30 deg. 10 in.	Fall

Ultra-large scale (1:13) vertical photographs were taken to record the residue cover in each plot before and after tillage. A 35 mm camera was mounted to a frame such that 1 m^2 of the ground surface was photographed from overhead. Each plot was subsampled four times in separate places. The film type used was KODAK Kodachrome Gold.

The percentage of cover was determined from the photographs using image processing techniques. The photographs were electronically scanned at a resolution of 100 pixels per linear inch. Then an image processing system was used to analyze the tonal contrast between soil and residue features. Dark toned soil features were separated from light toned residue features in a procedure termed density slicing. Some photographs were carefully retouched to enhance poor contrast in areas of dry, light colored soils. A binary image resulted that consisted of black residue features (pixel value = 0) and white soil features (pixel value = 255). The steps in computing the percentage of residue cover for each image were twofold: (1) computing a mean pixel value by summing the pixel values and dividing by the total number of pixels, and (2) dividing the mean pixel value by 255 followed by subtraction from unity and multiplication by 100. Percent residue cover left after tillage was calculated by dividing the residue cover after tillage by the residue cover before tillage then multiplying this ratio by 100. The resulting data were then statistically analyzed with the analysis of variance (ANOVA).

For purpose of comparison, measurements of residue cover were made using the common line transect method. The line transect method consists of a 100 foot cable, with beads evenly spaced at 6 inch intervals, stretched diagonally across an area to be sampled. Four transects were obtained by diagonally stretching the cable across each plot from corner to corner (twice) and from a corner in a 45 degree angle to the middle of the length of a plot and from this middle in a 45 degree angle to another corner

[1] Support for this project was provided by a grant from USDA-CSRS, Soil Teq Inc., and DMI Inc.

[2] D.S. Long and P.C. Robert are Scientist and Associate Professor in the Soil Science Department at the University of Minnesota, St. Paul, MN, 55108. D.J. Fuchs and D.R. Huggins are Scientist and Assistant Professor at the Southwest Experiment Station, Lamberton, MN, 56152.

(twice). Percent residue cover was determined by counting the number of beads that contacted residue as vertically viewed from overhead.

Results and Discussion

The residue cover before tillage in fall was 100 percent in all plots. The high cover was due to the luxurious and rank vegetative growth of the crop under the cool and wet growing conditions of the 1992 season. Table 2 presents the summary statistics for percent corn residue cover left after tillage. In general, the results show that corn residue cover was maximum for no-till, followed by the VTI method and moldboard.

Table 3 presents the ANOVA for percent corn residue left after tillage. The F statistic is significant for tillage treatments and hence, there is sufficient evidence to reject the null hypothesis of equal treatment means. Residue and soil are insignificant and hence, there is not sufficient evidence to reject the null hypothesis of equal treatment means for these factors. The soil-by-tillage interaction is insignificant indicating that there is not sufficient evidence to conclude that the effect of tillage on residue cover is different between well drained and poorly drained soils. Likewise, the soil-by-residue interation is insignificant indicating that there is not sufficient evidence to conclude that the effect of chopping on residue cover is different between soils.

Table 4 shows the effect of the tillage treatments on percent corn residue cover as measured across all soils. All VTI treatments incorporated significantly less residue than the moldboard method. However, the VTI treatments are not significantly different in mean residue cover left after tillage. Hence, changing the blade angle and depth with the VTI implement did not effect levels of incorporated corn residue for it is about 60 percent for the three VTI treatments.

The heavy residue conditions resulting from the rank vegetative growth may have overloaded the VTI thus rendering it ineffective. In addition, mechanical problems with the VTI may have occurred.

Figure 2 plots residue cover measured by the photographic method versus residue cover measured by the line transect method. There is a strong one-to-one relationship between both methods. The regression equation (R^2=0.95) relating the photographic method with the line transect method is

$$Y = 0.893(X)$$

where Y is photographic measured residue cover and X is line transect measured residue cover.

Table 2. Summary statistics of percent corn residue left after tillage.

Treatment	Mean	Standard Deviation	Min.	Max.	n
		All Treatments			
No Till	100	-	-	-	12
Mold Brd.	9.9	4.7	4.3	18.7	12
VTI 0 0	61.8	6.8	53.4	69.8	12
VTI 15 5	60.7	7.7	48.8	74.8	12
VTI 30 10	65.1	9.1	48.9	80.5	12
		Poorly Drained Soils, Chopped and Unchopped Residue			
No Till	100	-	-	-	6
Mold Brd.	11.8	6.2	5.2	18.7	6
VTI 0 0	61.5	8.1	53.4	69.7	6
VTI 15 5	56.9	8.0	48.8	69.1	6
VTI 30 10	61.7	12.3	48.9	76.2	6
		Well Drained Soils, Chopped and Unchopped Residue			
No Till	100	-	-	-	6
Mold Brd.	8.1	3.2	4.3	12.8	6
VTI 0 0	62.2	5.4	54.2	69.8	6
VTI 15 5	60.9	7.5	49.0	74.8	6
VTI 30 10	68.5	6.0	56.5	80.5	6

Table 2. Continued.

Treatment	Mean	Standard Deviation	Min.	Max.	n
		Poorly Drained Soils, Chopped Residue			
No Till	100	-	-	-	3
Mold Brd.	11.2	6.9	5.2	18.7	3
VTI 0 0	60.0	8.6	53.4	69.7	3
VTI 15 5	56.7	10.9	48.8	69.1	3
VTI 30 10	59.2	14.8	48.9	76.2	3
		Poorly Drained Soils, Unchopped Residue			
No Till	100	-	-	-	3
Mold Brd.	12.3	5.5	8.4	18.7	3
VTI 0 0	62.9	7.6	54.2	67.4	3
VTI 15 5	57.1	5.0	54.1	62.9	3
VTI 30 10	64.2	9.7	53.0	70.2	3
		Well Drained Soils, Chopped Residue			
No Till	100	-	-	-	3
Mold Brd.	6.7	3.3	4.3	10.5	3
VTI 0 0	63.5	8.2	54.2	69.8	3
VTI 15 5	54.7	7.4	49.0	63.1	3
VTI 30 10	62.3	6.7	56.5	69.7	3
		Well Drained Soils, Unchopped Residue			
No Till	100	-	-	-	3
Mold Brd.	9.4	3.1	6.7	12.8	3
VTI 0 0	60.9	2.6	59.1	63.8	3
VTI 15 5	67.1	7.5	59.8	74.8	3
VTI 30 10	74.6	5.3	70.3	80.5	3

Table 3. Analysis of variance for percent corn residue cover left after tillage.

Source of Variation	df	Sum of Squares	F Statistic	P Value
Soil	1	37.1	0.8	0.37
Residue	1	174.2	3.8	0.058
Tillage	4	49619.8	269.2	0.0001
Soil*Residue	1	34.7	0.8	0.39
Soil*Tillage	4	191.6	1.0	0.40
Error	48	2212.3		
Total	59	52269.8		

Table 4. Effect of tillage treatments on percent corn residue cover.

Treatment	Residue Left After Tillage	Residue Loss From Tillage	Standard Deviation	n
No Till A	100	0	-	12
VTI 30 10 B	65.1	34.9	9.1	12
VTI 0 0 B	61.8	38.2	6.8	12
VTI 15 5 B	58.9	41.1	7.7	12
Mold Brd. C	9.9	90.1	4.7	12

Means with the same letter are not significantly different at the 5 percent level of probability.

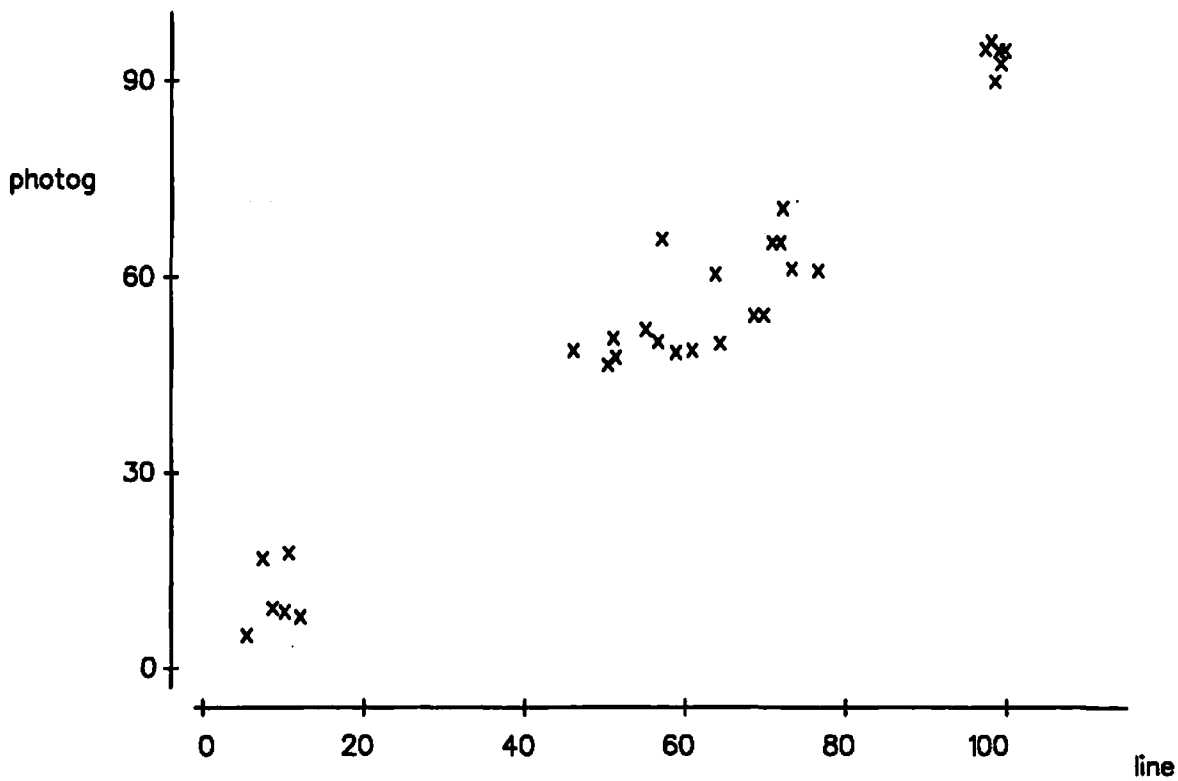

Figure 1. Relationship between photographic measured residue cover and line transect measured residue cover.

PERFORMANCE OF A VARIABLE TILLAGE IMPLEMENT IN SOYBEAN RESIDUE[1]

D.S. Long, P.C. Robert, D.J. Fuchs, and D.R. Huggins[2]

Performance of a variable tillage implement (VTI) was studied in soybean residue. This work was carried out between fall 1992 and spring 1993. By controlling blade depth and angle, the implement was designed to vary the amount of crop residue incorporated in soil. For purpose of comparison, the conventional chisel and field cultivation tillage systems were measured. Residue cover left after tillage with the VTI was 33 percent with zero blade settings to 23 percent with maximum blade settings of 30 degree angle and 10 inch depth. Residue cover after the VTI with zero blade settings was equal to that of chiseling. Residue cover after spring field cultivation was equal to that of the VTI with maximum blade settings.

Materials and Methods

A variable tillage implement (VTI), a prototype built by DMI Inc., was tested in soybean residue at the Southwest Experiment Station, Lamberton, MN in 1992 and 1993. By controlling blade angle and blade depth, the VTI is designed to vary the amount of crop residue incorporated in soil. Soybean residues were from a crop that was harvested in fall 1992. The experimental design was completely randomized block.

The experiment included the following tillage treatments: fall VTI with zero blade angle and depth (VTI 0 0), fall VTI with maximum blade angle of 30 degrees and depth of 10 inches (VTI 30 10), spring field cultivation, fall chisel, and no-till (Table 1). These treatments in turn subdivided five replicated mainplots of poorly drained Webster soils (Typic Haplaquolls) and well drained Ves soils (Udic Haplustolls). The chisel and VTI tillage treatments were applied and measured in fall 1992. The field cultivation treatment was applied and measured in spring 1993.

Table 1. Tillage treatments in soybean residue.

Treatment	Timing
No-till	n/a
Chisel	Fall 1992
Field Cultivator	Spring 1993
VTI 0 deg. 0 in.	Fall 1992
VTI 30 deg. 10 in.	Fall 1992

Ultra-large scale (1:13) vertical photographs were taken to record the residue cover in each plot before and after tillage. A 35 mm camera was mounted to a frame such that 1 m^2 of the ground surface was photographed from overhead. Each plot was subsampled four times in separate places. The film type used was KODAK Kodachrome Gold.

The percentage of residue cover was determined from the photographs using image processing techniques. The photographs were electronically scanned at a resolution of 100 pixels per linear inch. Then an image processing system was used to analyze the tonal contrast between soil and residue features. Dark toned soil features were separated from light toned residue features in a procedure termed density slicing. Some photographs were carefully retouched to enhance poor contrast in areas of dry, light colored soils. A binary image resulted that consisted of black residue features (pixel value = 0) and white soil features (pixel value = 255). The steps in computing the percentage of residue cover for each image were twofold: (1) computing a mean pixel value by summing the pixel values and dividing by the total number of pixels, and (2) dividing the mean pixel value by 255 followed by subtraction from unity and multiplication by 100. Percent residue cover left after tillage was calculated by dividing the residue cover after tillage by the residue cover before tillage then multiplying this ratio by 100. The resulting data were then statistically analyzed with the analysis of variance (ANOVA).

[1] Support for this project was provided by a grant from USDA-CSRS, Soil Teq Inc., and DMI Inc.

[2] D.S. Long and P.C. Robert are Scientist and Associate Professor in the Soil Science Department at the University of Minnesota, St. Paul, MN, 55108. D.J. Fuchs and D.R. Huggins are Scientist and Assistant Professor at the Southwest Experiment Station, Lamberton, MN, 56152.

For purpose of comparison, measurements of residue cover were made using the common line transect method. The line transect method consists of a 100 foot cable, with beads evenly spaced at 6 inch intervals, stretched diagonally across an area to be sampled. Four transects were obtained by diagonally stretching the cable across each plot from corner to corner (twice) and from a corner in a 45 degree angle to the middle of the length of a plot and from this middle in a 45 degree angle to another corner (twice). Percent residue cover was determined by counting the number of beads that contacted residue as vertically viewed from overhead.

Results and Discussion

The residue cover before tillage in fall 1992 averaged 77 ± 9 for the well drained soils and 79 ± 9 percent for the poorly drained soils as measured in all plots (n=75). In spring 1993 residue cover averaged 42 ± 5 percent for the well drained soils and 36 ± 12 percent for the poorly drained soils as measured in field cultivation plots (n=15). The residue at the time of tillage was fresh in fall 1992 and decomposed in spring 1993. Table 2 presents the summary statistics for percent soybean residue cover left after tillage. The results show that residue cover is 33 percent for the fall VTI with zero blade settings, 32 percent for fall chiseling, 23 percent for the fall VTI with maximum blade settings, and 22 percent for spring field cultivation.

Table 3 presents the ANOVA for percent soybean residue left after tillage. The F statistic is significant for tillage treatments and hence, there is sufficient evidence to reject the null hypothesis of equal treatment means. The F value is significant for the soil factor, however, statistical inference for this treatment cannot be made because the experiment was limited to only one field. The soil-by-tillage interaction is insignificant indicating that there is not sufficient evidence to conclude that the effect of tillage on residue cover is different between well drained and poorly drained soils.

Table 4 shows the effect of tillage treatments on percent soybean residue cover as measured across all soils. Residue cover after the VTI with zero settings and chiseling is significantly greater than that after the VTI with maximum blade settings and spring field cultivation. These results indicate that nonzero VTI blade settings decrease the amount of soybean residue left on the soil surface after tillage. Residue cover is highest at 33 percent for the VTI method with zero blade settings and decreases to 23 percent with increasing blade angle to 30 degrees and blade depth to 10 inches. There is little practical difference in residue levels between the fall chisel and fall VTI with zero blade settings, and between spring field cultivation and the fall VTI with maximum blade settings.

Figure 2 plots residue cover measured by the photographic method versus residue cover measured by the line transect method. There is a strong one-to-one relationship between both methods. The regression equation (R^2=0.91) relating the photographic method with the line transect method is

$$Y = 1.12*(X)$$

where Y is photographic measured residue cover and X is line transect measured reside cover.

Table 2. Summary statistics for percent soybean residue cover left after tillage.

Treatment	Mean	Variance	Max.	Min.	N
		----------%	----------		
No Till in Fall	100.0	n/a	n/a	n/a	29
No Till in Spring	48.8	27.4	62.4	41.0	29
Fall Chisel	31.7	224.5	58.1	10.0	30
Spring Fld. Cult.	22.3	130.6	65.4	5.6	30
Fall VTI 0 0	33.1	139.9	52.7	13.0	30
Fall VTI 30 10	23.7	106.2	54.9	7.0	30

Table 3. Analysis of variance for percent soybean residue cover (all soils).

Source of Variation	Sum of Squares	F Statistic	P Value
Blocks	2472.7	5.23	0.0007
Soil	1918.2	16.23	0.0001
Tillage	2752.8	7.77	0.0001
Soil*Tillage	318.3	0.90	0.4449
Error	12642.6		
Total	20017.9		

Table 4. Effect of tillage treatments on percent soybean residue cover (all soils).

Treatment	Residue Left After Tillage †	Standard Deviation	N
	----------%----------		
Spring Fld. Cult.	22.3 A	11.4	30
Fall VTI 30 10	23.4 A	10.3	30
Fall Chisel	31.6 B	15.0	30
Fall VTI 0 0	33.1 B	11.8	30

† Means with the same letter are not significantly different at the 5 percent level of probability.

Table 5. Descriptive statistics for percent soybean residue cover left after tillage (well drained soils).

Treatment	Mean	Variance	Max.	Min.	N
		----------%----------			
No Till in Fall	100.0	n/a	n/a	n/a	14
No Till in Spring	51.2	26.4	62.4	43.9	14
Fall Chisel	27.6	177.4	54.0	10.0	15
Spring Fld. Cult.	20.2	65.7	32.8	5.6	15
Fall VTI 0 0	26.5	84.7	41.1	13.0	15
Fall VTI 30 10	20.6	66.5	34.5	9.9	15

Table 6. Descriptive statistics for percent soybean residue cover left after tillage (poorly drained soils).

Treatment	Mean	Variance	Max.	Min.	N
		----------%----------			
No Till in Fall	100.0	n/a	n/a	n/a	15
No Till in Spring	46.6	19.6	56.1	41.0	15
Fall Chisel	35.9	251.4	58.1	11.6	15
Spring Fld. Cult.	24.5	195.0	65.4	13.1	15
Fall VTI 0 0	39.7	112.7	52.7	14.4	15
Fall VTI 30 10	26.7	131.0	54.9	7.0	15

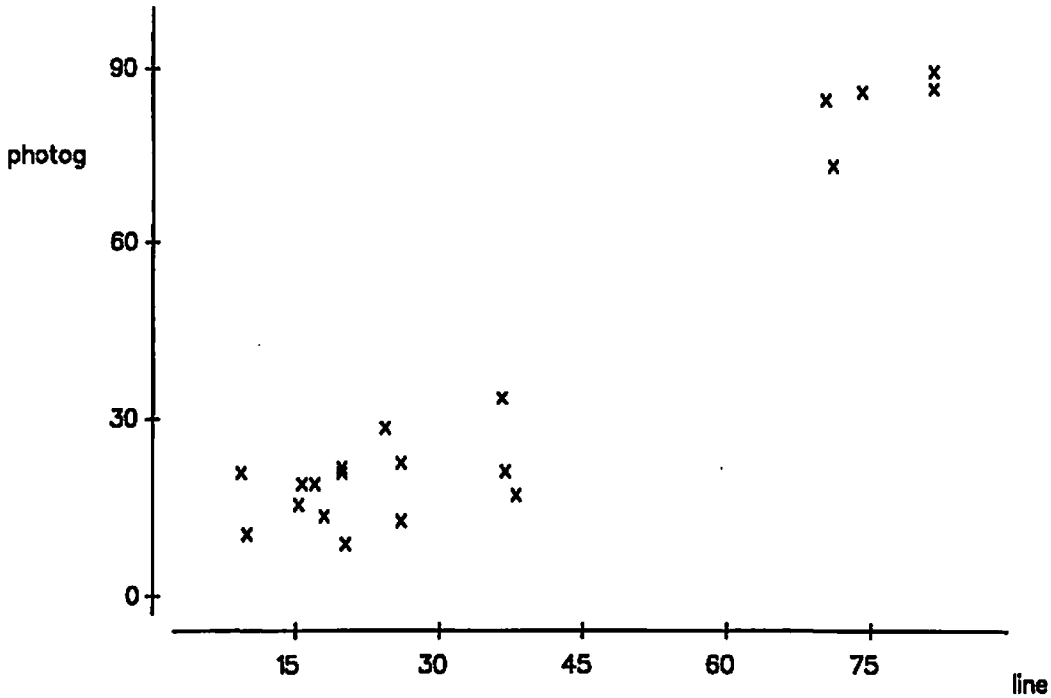

Figure 1. Relationship between photograph measured residue cover and line transect measured residue cover.

MUNICIPAL SOLID WASTE COMPOST USE ON AGRICULTURAL SOILS[1]

M. MAMO, C. J. ROSEN, T. R. HALBACH, J. F. MONCRIEF[2]

ABSTRACT

Field experiments were conducted at Staples and Becker to assess corn yield and nitrate leaching on soils amended with municipal solid waste (MSW) compost. The MSW composts (Truman, Swift, and St. Cloud) were applied in the spring of 1992. The Becker location received Truman and Swift composts, while Staples received Truman and St. Cloud composts. The compost rates were 0, 20,40, and 80 T/A with either 0, 220, or 440 lbs/A N fertilizer. Residual effect of compost treatments were determined in 1993 at both locations. In 1993 at Becker, MSW compost from Truman and Wright Counties were also applied on new plots to see the effect of split vs one time application. The compost rate was 40 T/A (yearly application) and 120 T/A (one time application) with either 0, 110, or 220 lbs/A N fertilizer. In 1992, nitrate leaching was high on non-amended soils compared to compost amended soils. Among the composts, the Truman compost gave lower corn yield but lower NO_3-N leaching. In 1993, yield was relatively high on residual plots compared to the control. The 1993 established plot gave reasonable yield at all compost rates with N application. Yield was lower at all compost rates when N was not applied.

INTRODUCTION

Application of MSW compost (MSW) to agricultural soils could be a beneficial alternative for recycling of solid waste. Minnesota is one of the states that has an expanded production of composted municipal solid waste. We conducted experiments at the Sand Plain Research Farm, Becker, MN, and at the irrigation center, Staples, MN, in 1992 and 1993. The objectives of this waste management/fertility research were to evaluate the effects different MSW compost and nitrogen rate application on agricultural soils and assess the potential for improving soil fertility and physical properties.

MATERIALS AND METHODS

The experiments were conducted at two locations during the 1992 and 1993 growing seasons.

1992

Composted municipal solid waste (Truman, Swift, and St Cloud) was incorporated in plots at two experimental locations. The Staples location received composts from Truman and St Cloud, while the Becker location received composts from Truman and Swift. The experimental design was a split plot arranged in factorial and replicated four times. Compost at Becker was moldboard plowed and disced at Staples. The compost rates on a dry weight basis were 0, 20, 40, and 90 T/A. The N rate applied as urea was 0, 220, and 440 lbs/A.

Field corn (*Zea mays* L.) variety Pioneer 3921 was planted at a rate of 28600 kernels per acre on 5/29/92 at Staples and on 6/1/92 at Becker. A starter fertilizer at a rate of 150 lbs N/A was applied at planting at Becker. Nitrogen fertilizer was sidedressed in two split applications. Ceramic suction cup tubes were installed in two of the four replications of each plot at the 3 and 6 foot depth. Solid set and pivot irrigation was used at Becker and Staples, respectively.

Whole plant samples at the 8-10 leaf stage and ear leaves at initial silking were taken from harvest rows. Final yield was harvested as grain and stover at Becker, and as silage at Staples. Tissue nutrient analyses were done on each harvested plant part.

1993

The 1993 compost utilization project (CUP) is a follow up of the study initiated in 1992 on municipal solid waste (MSW) compost. In addition to residual effect from the 1992 experiment, an additional experiment was established to evaluate split and annual compost application. The new field site utilized MSW compost from Truman, MN (Prairieland composting facility) and Buffalo, MN (Wright county composting facility). The experimental design was a split plot arranged in a complete factorial. The compost rates were 40 T/A as an annual application and 120 T/A as a one time application. The N rates were 0, 110, and 220 lbs/A. Suction ceramic cups were installed in three of the four replications. Weekly soil water sampling was done to analyze for nitrate and trace metals. All other methods and procedures are the same as the 1992 experiment.

Table 1. Chemical characteristics of Hubbard loamy sand and Verndale sandy loam at 0-15 cm depth.

Soil	pH	O.M.	Ca	K	Mg	Zn	B	S	P
		%	mg/kg						
Hubbard	5.8	1.4	463	77	78	0.9	0.4	1.2	20
Verndale	6.3	3.2	960	137	133	2.7	0.6	5.0	23

[1]Support for this project was provided by the Minnesota Office of Waste Management and the Minnesota Pollution Control Agency. Their support is greatly appreciated.

[2]M. Mamo, C. J. Rosen, T. R. Halbach, and J. F. Moncrief are Graduate student, Associate Professor, Extension Specialist, and Associate Professor, respectively.

Table 2. Initial NH_4-N and NO_3-N concentration of Hubbard loamy sand and Verndale sandy loam soils.

Depth	Hubbard			Verndale		
	mg/kg					
	NH_4-N	NO_3-N	Total	NH_4-N	NO_3-N	Total
0-30	2.5	1.5	4.0	4.6	6.7	11.3
30-60	1.0	0.4	1.4	1.0	2.8	3.8
60-90	0.8	0.4	1.2	1.1	1.7	2.8
Total	4.3	2.4	6.7	6.7	11.2	17.9

Table 3. Chemical characteristics of the composts.

Compost Source	pH	O.M.	Total C	Total N	C:N	NH_4-N	NO_3-N
		%				mg/kg	
Truman	7.2	50.2	22.8	0.7	32.6	81.2	6.2
Swift	7.4	39.5	21.9	1.6	13.6	33.8	7.0
St. Cloud	7.7	43.3	10.9	0.8	13.6	100.4	5.0

Table 4. Elemental analysis of the municipal solid waste composts.

Compost	Na	K	Mg	Ca	Fe	P	S	Zn	Pb	Cd	Mo	B
	g/kg							mg/kg				
Truman	4.7	3.6	3.6	24.1	22	2.1	6.2	1260	265	9.6	10.7	70
Swift	6.4	10.6	5.3	42.4	7.1	4.2	4.4	960	390	4.7	8.3	50
St.Cloud	2.6	6.6	4.2	27.0	13.3	2.7	5.0	480	250	7.5	6.7	60

RESULTS

Table 5. Effect of compost type, compost rate, and nitrogen rate on grain yield, stover yield, and plant population at Becker, MN., 1992.

Compost type	N rate LBS/A	Compost rate T/A	Grain BU/A	Stover T/A	Plant/A x 1000
Control	0	0	63.0	1.5	27.2
Control	220	0	103.5	2.4	28.9
Control	440	0	99.3	2.3	29.6
Truman	0	20	72.5	1.8	30.6
Truman	220	20	106.3	2.6	29.4
Truman	0	40	72.4	1.1	28.8
Truman	220	40	86.4	2.4	27.8
Truman	440	40	96.6	2.5	29.0
Truman	0	80	86.6	1.4	28.6
Truman	220	80	79.0	2.0	29.7
Swift	0	40	110.0	3.0	30.5
Swift	220	40	104.8	2.9	29.5
Significance			**	**	NS
BLSD			21.3	0.4	---

BLSD-Duncan Waller
** Highly significant (p=0.01)
NS Not significant

Table 6. Effect of compost type, compost rate, and nitrogen rate on silage yield, and plant population at Staples, MN., 1992.

Compost type	N rate LBS/A	Compost rate T/A	Silage Yield BU/A	Plant/A x1000
Control	0	0	2.7	28.3
Control	220	0	6.1	29.4
Truman	0	20	1.6	26.7
Truman	220	20	4.6	26.4
Truman	0	40	1.3	24.9
Truman	220	40	4.3	27.0
Truman	440	40	4.6	28.1
Truman	0	80	1.4	25.8
Truman	220	80	3.5	25.7
St Cloud	0	40	4.4	28.0
St Cloud	220	40	6.3	29.9
St Cloud	440	40	6.8	28.4
Significance			**	**
BLSD			1.3	3.5

BLSD-Duncan Waller
** Highly Significant (p=0.01)
NS Not significant

Table 7. Elemental analysis of grain at Becker in 1992.*

Compost	N rate LBS/A	Compost rate T/A	N %**	Na	K	Ca	Mg	Fe	Mn	Cu	Zn	Mo	B	P
				mg/kg										
Control	0	0	1.2	5.9	4432	47.8	1071	12.4	4.0	0.9	16.4	0.2	2.8	3140
Control	220	0	1.5	4.7	4289	43.7	1113	18.3	5.1	1.1	18.8	0.2	2.8	2967
Control	440	0	1.4	4.0	4103	46.2	1114	19.1	5.5	1.2	18.5	0.2	2.1	2848
Truman	0	20	1.2	5.1	4531	47.7	1070	12.5	4.1	0.9	18.1	0.2	2.8	3194
Truman	220	20	1.5	6.4	4208	40.9	1115	17.3	4.8	1.1	21.0	0.2	2.5	3088
Truman	0	40	1.4	5.7	4667	52.7	1096	13.9	4.4	1.1	18.9	0.2	2.8	3265
Truman	220	40	1.3	5.8	4611	51.5	1156	18.8	5.1	1.2	21.6	0.2	2.7	3229
Truman	440	40	1.4	4.3	4248	46.4	1098	18.9	5.2	1.2	20.8	0.2	2.3	2922
Truman	0	80	1.2	5.6	4550	43.3	1057	14.3	4.3	0.9	19.8	0.2	2.8	3190
Truman	220	80	1.4	5.8	4533	54.0	1072	18.2	4.7	1.2	20.9	0.2	2.9	3097
Swift	0	40	1.5	5.2	4258	37.8	1127	18.6	4.9	1.0	20.7	0.3	2.5	3267
Swift	220	40	1.7	6.7	4155	39.1	1148	20.6	5.2	0.9	21.7	0.3	2.4	3271
Significance			*	NS	**	**	NS	**	**	**	**	*	**	*
BLSD			0.4	-	446	10.5	-	2.8	0.7	0.3	2.9	0.04	0.3	421

*Pb and Cd were not significant with average values of <1.7 and <0.1 mg/kg on all treatments, respectively.
**Based on three replications.
BLSD-Duncan Waller
* Significant (p=0.1)
** Highly significant (p=0.01)
NS Not significant

Table 8. Elemental analysis of silage at Staples in 1992.*

Compost	N rate LBS/A	Compost rate T/A	N %	Na	K	Ca	Mg	Fe	Mn	Cu	Zn	Mo	B	P
				mg/kg										
Control	0	0	0.9	28.8	11474	2021	1865	80.2	25.7	2.5	31.0	0.4	5.1	2878
Control	220	0	1.3	23.3	12002	2021	1488	72.3	28.7	3.6	23.0	0.3	4.9	1809
Truman	0	20	1.1	36.8	15897	2010	1705	100.0	26.2	3.6	40.5	0.7	7.7	3386
Truman	220	20	1.3	30.0	14655	1944	1435	73.3	26.6	4.0	36.4	0.7	7.8	2278
Truman	0	40	1.3	28.3	15374	2138	1656	85.3	29.9	3.4	36.6	0.7	8.1	3228
Truman	220	40	1.4	23.2	14940	2031	1526	69.3	28.7	4.2	43.9	0.8	8.6	2890
Truman	440	40	1.4	21.2	15624	2131	1503	72.7	30.2	4.9	38.7	0.8	8.7	2215
Truman	0	80	1.2	27.2	17175	2125	1811	89.1	27.2	3.7	46.8	0.8	8.6	3656
Truman	220	80	1.3	24.7	16168	2101	1541	81.7	28.0	4.7	45.8	1.0	10.1	2913
St Cloud	0	40	1.2	28.0	14311	1906	1572	81.1	24.2	3.6	37.5	1.3	7.8	3129
St Cloud	220	40	1.3	27.3	14758	1990	1409	78.9	27.5	4.1	32.4	0.8	7.4	2131
St Cloud	440	40	1.3	23.6	14778	2393	1505	76.0	33.3	4.8	33.4	1.0	8.4	2107
Significance			*	NS	**	NS	**	NS	NS	**	**	**	**	**
BLSD			0.3	-	2430	-	320	-	-	0.7	12.2	0.2	1.7	1109

*Pb and Cd were not significant with average values of <1.7 and <0.1 mg/kg on all treatments, respectively.
BLSD-Duncan Waller
* Significant (p=0.1)
** Highly significant (p=0.01)
NS Not significant

Table 9. NH_4OAC extractable cations, pH, and Bray-P of Hubbard loamy sand at 0-15 cm at the end of the 1992 growing season.

Compost	N rate LBS/A	Compost rate T/A	pH	Ca	Mg	Na	K	Mn	P
				mg/kg					
Control	0	0	6.3	475	85.8	3.1	48.9	3.4	16.5
Control	220	0	5.8	433	71.9	3.6	49.6	4.9	15.2
Control	440	0	5.7	447	76.3	3.3	45.1	6.3	18.8
Truman	0	20	6.1	514	85.2	4.4	54.8	3.9	17.3
Truman	220	20	5.8	470	73.1	3.8	52.6	5.6	16.8
Truman	0	40	6.4	549	85.5	3.9	57.0	3.2	21.5
Truman	220	40	6.1	554	80.9	6.5	59.6	4.6	22.5
Truman	440	40	5.7	464	72.0	4.1	45.8	6.1	20.5
Truman	0	80	6.3	557	79.4	5.0	56.7	3.5	17.0
Truman	220	80	6.3	590	73.8	9.4	59.7	4.0	18.3
Swift	0	40	6.2	606	94.8	19.5	112.7	4.0	21.8
Swift	220	40	5.9	541	79.4	14.0	103.7	6.1	24.7
Significance			**	NS	NS	**	**	**	NS
BLSD			0.4	-	-	9.3	25.3	1.6	-

BLSD-Duncan Waller
** Highly significant (p=0.01)
NS Not significant

Table 10. NH_4OAC extractable cations, pH, and Bray-P of Verndale sandy loam at 0-15 cm at the end of the 1992 growing season.

Compost type	N rate LBS/A	Compost rate T/A	pH	Ca	Mg	Na	K	Mn	P
				mg/kg					
Control	0	0	6.6	1214	165.9	7.6	145.0	7.4	27.3
Control	220	0	6.5	1193	162.8	7.7	135.2	8.5	28.8
Truman	0	20	7.0	1539	181.7	31.3	196.1	6.5	36.0
Truman	220	20	6.9	1637	188.4	25.0	196.0	7.0	32.3
Truman	0	40	7.2	1626	161.9	32.0	214.2	7.7	36.8
Truman	220	40	7.1	1661	153.3	25.3	193.2	6.8	35.8
Truman	440	40	7.1	1580	168.0	23.0	218.2	5.8	39.5
Truman	0	80	7.2	1620	164.9	35.4	229.9	7.4	42.0
Truman	220	80	7.1	1550	158.6	45.0	211.1	8.1	42.3
St Cloud	0	40	7.0	1897	219.1	24.0	289.8	7.1	57.0
St Cloud	220	40	7.0	1969	224.9	24.4	318.7	6.9	57.0
St Cloud	440	40	6.9	1477	168.6	11.8	231.9	6.7	45.5
Significance			**	**	**	**	**	NS	**
BLSD			0.5	332	29.1	19.5	43.2	-	8.6

BLSD-Duncan Waller
** Highly significant (p=0.01)
NS Not significant

Table 11. DTPA extractable trace metals of Hubbard loamy sand at 0-15 cm at the end of the 1992 growing season.

Compost	N rate LBS/A	Compost rate T/A	Fe	Mn	Zn	Cu	Pb	Ni	Cd
			mg/kg						
Control	0	0	16.8	6.9	0.7	0.2	0.6	0.3	0.03
Control	220	0	21.2	9.2	0.7	0.2	0.6	0.4	0.04
Control	440	0	20.8	10.2	0.6	0.2	0.4	0.3	0.04
Truman	0	20	20.0	7.1	1.2	0.4	0.5	0.4	0.05
Truman	220	20	24.6	10.5	1.4	0.4	0.6	0.4	0.05
Truman	0	40	17.6	6.3	2.7	0.9	0.5	0.3	0.05
Truman	220	40	22.4	9.1	3.9	1.4	0.8	0.4	0.05
Truman	440	40	22.2	10.4	2.4	0.8	0.6	0.4	0.05
Truman	0	80	18.8	6.5	3.4	1.3	0.6	0.3	0.05
Truman	220	80	21.9	7.9	5.4	1.6	0.8	0.4	0.06
Swift	0	40	24.3	8.5	3.5	0.9	0.8	0.4	0.06
Swift	220	40	25.8	11.4	3.5	0.6	0.9	0.4	0.06
Significance			*	**	**	**	NS	NS	NS
BLSD			7.4	4.3	2.6	0.9	-	-	-

BLSD-Duncan Waller
* Significant (p=0.1)
** Highly significant (p=0.01)
NS Not significant

Table 12. DTPA extractable trace metals of Verndale sandy loam sand at 0-15 cm at the end of the 1992 growing season.

Compost type	N rate LBS/A	Compost rate T/A	Fe	Mn	Zn	Cu	Pb	Ni	Cd
			mg/kg						
Control	0	0	36.8	19.8	2.9	0.6	0.6	0.7	0.1
Control	220	0	39.5	21.8	3.1	0.5	0.6	0.6	0.1
Truman	0	20	38.2	19.71	3.4	6.0	1.7	0.8	0.1
Truman	220	20	40.2	22.21	2.5	4.2	1.5	0.8	0.1
Truman	0	40	36.8	22.6	17.4	7.3	2.4	0.8	0.2
Truman	220	40	34.8	21.5	14.3	5.3	1.8	0.8	0.1
Truman	440	40	35.4	18.6	16.5	5.7	2.0	1.6	0.2
Truman	0	80	10.4	22.8	20.2	7.1	2.4	0.9	0.2
Truman	220	80	43.3	23.0	20.9	8.9	2.7	1.0	0.2
St Cloud	0	40	55.1	21.9	9.9	3.0	2.7	0.9	0.2
St Cloud	220	40	55.4	21.2	11.5	3.2	2.9	0.9	0.2
St Cloud	440	40	43.7	17.8	8.2	2.3	2.7	0.7	0.2
Significance			**	NS	**	**	**	NS	**
BLSD			12.1	-	3.7	2.0	0.8	-	0.03

BLSD-Duncan Waller
** Highly significant (p=0.01)
NS Not significant

Table 13. Total nitrogen of Hubbard loamy sand soil at two depths at the end of the 1992 growing season.

Compost type	N rate LBS/A	Compost rate T/A	Total %N 0-15 cm	Total %N 15-30 cm
Control	0	0	0.26	0.23
Control	220	0	0.29	0.25
Control	490	0	0.29	0.26
Truman	0	20	0.28	0.32
Truman	220	20	0.30	0.30
Truman	0	40	0.29	0.28
Truman	220	40	0.30	0.31
Truman	440	40	0.28	0.29
Truman	0	80	0.32	0.32
Truman	220	80	0.32	0.32
Swift	0	40	0.38	0.37
Swift	220	40	0.36	0.40
Significance			NS	*
BLSD			-	0.14

BLSD-Duncan Waller
* Significant (p=0.1)
NS Not significant

Table 14. Total nitrogen of Verndale sandy loam soil at two depths at the end of the 1992 growing season.

Compost type	rate LBS/A	Compost rate T/A	Total %N 0-15 cm	Total %N 15-30 cm
			mg/kg	
Control	0	0	0.55	0.47
Control	220	0	0.58	0.45
Truman	0	20	0.69	0.46
Truman	220	20	0.75	0.50
Truman	0	40	0.71	0.49
Truman	220	40	0.74	0.54
Truman	440	40	0.66	0.53
Truman	0	80	0.76	0.48
Truman	220	80	0.73	0.44
St Cloud	0	40	0.90	0.53
St Cloud	220	40	0.95	0.64
St Cloud	440	40	0.78	0.53
Significance			**	**
BLSD			0.07	0.07

BLSD-Duncan Waller
** Highly significant (p=0.01)
NS Not significant

1993:

Table 15. Effect of compost type, compost rate, and nitrogen rate on grain yield, stover yield, and plant population at the new field site in Becker, MN. 1993.

Compost type	N rate LBS/A	Compost T/A	Grain BU/A	Stover T/A	Plant/A x 1000
Control	0	0	83.2	1.82	33.3
Control	110	0	148.3	2.83	33.4
Control	220	0	158.6	2.94	32.8
Truman	0	40	136.6	2.52	31.9
Truman	110	40	157.6	3.13	33.4
Truman	220	40	157.1	3.39	33.0
Truman	0	1~0	133.9	2.45	29.5
Truman	110	120	136.5	2.61	29.5
Truman	220	120	142.3	2.74	28.7
Wright	0	40	138.1	2.71	32.3
Wright	110	40	152.6	3.16	33.5
Wright	220	40	158.0	3.15	31.9
Wright	0	120	153.4	3.04	31.4
Wright	110	120	151.5	3.10	33.4
Wright	220	120	149.7	2.93	32.2
STATISTICS					
Compost type			*	*	*
N rate			**	**	NS
Compost rate			**	**	**
Compost rate*N rate			**	**	NS
Compost type*Compost rate			*	NS	*
N rate* Compost type			NS	NS	NS
Compost type*Compost rate*N rate			NS	NS	NS

BLSD-Duncan Waller
* Significant (p=0.1)
** Highly significant (p=0.01)
NS Not significant

Table 16. Plant moisture stress measured on the 120 T/A compost rate at 220 lbs N/A during the 1993 growing season.

Compost Source	N rate LBS/A	Compost rate T/A	Leaf Tension in bar[1] Morning	Afternoon
Control	220	120	2.4aa	6.8ba
Truman	220	120	5.1ab	8.4aa
Swift	220	120	4.3ab	6.8aa

[1]Tukey's studentized mean comparison. Means with the same letter are not significantly different from each other (alpha=0.05).
Italicized letters compare means of morning and afternoon measurements across.
Bold letters compare means of compost sources.

Table 17. Residual effect of compost type, compost rate, and nitrogen rate on grain yield, stover yield, and plant population at Becker, MN., 1993

Compost type	N rate LBS/A	Compost T/A	Grain BU/A	Stover T/A	Plant/A x 1000
Control	0	0	52.4	1.41	24.6
Control	220	0	154.0	2.94	28.7
Control	440	0	155.0	3.10	28.9
Truman	0	20	113.6	2.25	30.5
Truman	220	20	144.7	3.55	26.2
Truman	0	40	104.3	2.20	29.6
Truman	220	40	156.7	3.24	29.3
Truman	440	40	158.7	3.15	28.5
Truman	0	80	105.1	2.64	25.3
Truman	220	80	138.8	3.20	25.8
Swift	0	40	133.2	2.53	29.9
Swift	220	40	160.7	3.23	30.8
Significance			**	**	NS
BLSD			29.2	0.48	---

BLSD-Duncan Waller
** Highly significant (p=0.01)
NS Not significant

Table 18. Residual effect of compost type, compost rate, and nitrogen rate on grain yield, stover yield, and plant population at Staples, MN. 1993.

Compost type	N rate LBS/A	Compost rate T/A	Grain BU/A	Stover T/A	Plant/A x 1000
Control	0	0	53.3	2.08	23.5
Control	220	0	114.8	1.34	24.7
Truman	0	20	72.2	1.77	22.0
Truman	220	20	119.1	1.56	23.8
Truman	0	40	94.7	1.47	22.9
Truman	220	40	123.8	1.85	24.1
Truman	440	40	112.1	1.71	23.5
Truman	0	80	98.9	1.73	23.3
Truman	220	80	123.5	1.85	24.8
St Cloud	0	40	80.1	1.61	23.3
St Cloud	220	40	122.4	1.72	24.9
St Cloud	440	40	113.3	1.41	23.2
Significance			**	NS	NS
BLSD			11.7	--	--

BLSD-Duncan Waller
** Highly significant (p=0.01)
NS Not significant

SUMMARY OF RESULTS

1992:

Initial soil: The Hubbard loamy sand was under continuous rye before initiation of our experiment. The pH of both Hubbard loamy sand and Verndale sandy loam were slightly acidic (Table 1). The Verndale loamy sand was high in O.M. content, nitrogen (both organic and inorganic) content (Table 2), and essential nutrients.

Municipal solid waste elemental composition: The inorganic nitrogen content of the composts was mainly present as NH_4 (Table 3). This may be a result of reduced (low oxygen) condition during the composting process. The O.M. matter content was high for all compost, being the highest in the Truman compost. The C:N was desirable for the Swift and St Cloud composts, but was very high for the Truman compost. The compost sources used qualified as Class I compost based on the relative concentration of trace metals (Table 4). All trace elements were elevated compared to what we find in natural soils.

Yield: Corn yield for Becker and Staples are presented in Tables 5 and 6. The Truman compost was relatively immature as indicated by the higher C:N ratio. Silage and grain yield was increased by the addition of fertilizer N for Truman compost. Grain and silage yield were much lower for the Truman when no N was applied. Swift and St Cloud compost with lower C:N ratio gave higher yield compared to Truman. Yield generally decreased with an increase in compost rate, regardless of N rate. The compost and N rate showed a significant interaction for the Becker location. The Swift compost at 40 T/A with and without N application had yield similar to the control at 220 lbs N/A.

Plant tissue metals: At Becker, compost and nitrogen treatments had significant effect on grain K, Ca, Fe, Mn, Cu, Zn, Mo, and B (Table 7). At Staples, compost and N treatments had significant effect on silage K, Ca, Fe, Mn, Cu, Zn, Mo, B, and P (Table 8). Neither grain nor silage produced in compost amended plots accumulated trace metals compared to the control.

NH_4OAC extractable cations, pH, and Bray extractable P: Becker- The pH of the soil was significantly affected by the treatments (Table 9). The soil pH was slightly acidic at the end of the growing season. The soil Ca, Mg, and P was not different due to treatment differences. Sodium and potassium was significant due to treatments. Soil K and Na were high in plots amended with Swift compost with or without N.
Staples- The soil pH was affected by treatments. Soil pH, Ca, Mg, Na, K, Mn, and P levels in soil were much higher at Staples than Becker. This may due to the initial conditions of the soil and the difference in compost incorporation between the two locations. All ammonium acetate extractable cations with the exception of MN were significant with treatments (Table 10). Bray extractable P was also significant with treatments.

Soil trace metals: Trace metals in soil were extracted in DTPA at the end of the growing season. Zinc was elevated in soils amended with Truman compost (Tables 11 and 12). The treatments had significant effect on Fe, Mn, Zn, and Cu, at Becker, and on Fe, Zn, Cu, Pb, and Cd at Staples. At Staples, the high compost rates of both Truman and St Cloud gave higher DTPA extractable Cd in soil compared to the control. Iron was elevated in soils amended with St Cloud compost compared to the control or the Truman compost at Staples. Iron was also elevated at Becker in soils amended with Swift compost.

Soil total N: The total N content of the Verndale sandy loam at two depths was much higher than the Hubbard soil (Tables 13 and 14). Generally, the percent N of the 0-15 cm depth was higher than the 15-30 cm depth at both locations. Plots that received St Cloud compost had the highest soil N at all rates. Compared to the controls at all N rates, plots with compost rates of 20, 40, and 80 T/A with no N application gave higher percent N at both depths.

Soil water: Becker- Soil water NO_3-N with no N application was high for the control compared to the Truman compost at all rates (Figs. 1 and 2). However, at the same rate, the Swift compost had much higher soil water NO_3-N compared to the control and Truman compost (Figs. 3 and 4). Truman compost had the least soil water with or without N application.
Staples- Similar to Becker, the soil water NO_3-N was high on the control plots throughout the growing seasons. Truman compost rates at 0 and 220 lbs N/A had lower soil water NO_3-N leaching (Figs. 5 and 6). However, an abrupt increase in soil water NO_3-N leaching was observed for all Truman compost rates at 220 lbs N/A toward the end of the growing season. This peak increase was especially abrupt for the 80 T/A Truman compost rate (Fig. 6). Soil water NO_3-N leaching was lower for the Truman and St Cloud composts throughout the season at both N rates (Figs. 7 and 8). There was an increase in soil water NO_3-N for the control, Truman, and Swift toward the end of the growing season.

The results suggest that compost with high C:N ratio has potential for N immobilization and may decrease yield unless fertilizer N is added. Compost with lower C:N ratio gave appreciable yield with or without N fertilizer application. Compost with a lower C:N ratio does not enhance NO_3-N leaching. Unlike the high C:N ratio compost, the lower C:N compost with no N fertilizer had high NO_3-N leaching due to the availability of mineralized N. Leaching was even enhanced upon the addition of fertilizer N on compost with low C:N ratio.

1993:
Yields were higher in 1993 compared to 1992 partly due to an earlier planting date in 1993. The Truman compost obtained in 1993 was relatively mature compared to the 1992 Truman compost.

New experiment yield: Grain and stover yields were relatively high for the new field (Table 15). Compared to the control, grain yield was high at both compost rates with no N application. Overall, the Wright county compost gave higher yield than the Truman compost.

Plant moisture stress: Plant water stress was measured using pressure bomb apparatus. Water stress was significantly lower in the morning than the afternoon for the control (Table 16). The morning and afternoon plant water stress for the composts were not significantly different. Plant water stress was high for all treatments in the afternoon, but were not significantly different.

Residual yield effect : Grain and stover yields were much higher for the all compost rates with no N application (Tables 17 and 18). The higher grain and stover yield of the compost with no N suggest residual compost effect. Grain yield was higher for the Swift compost compared to the control and the Truman compost.

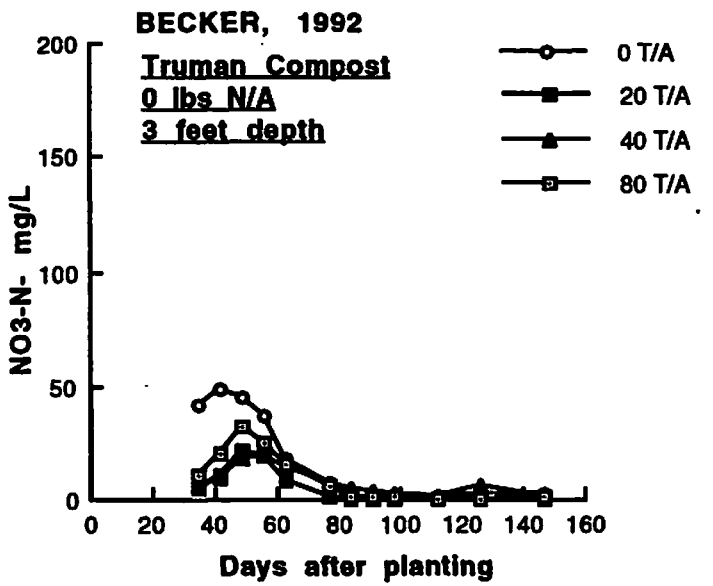

Fig. 1- Soil water NO3-N at Becker at four Truman compost rates.

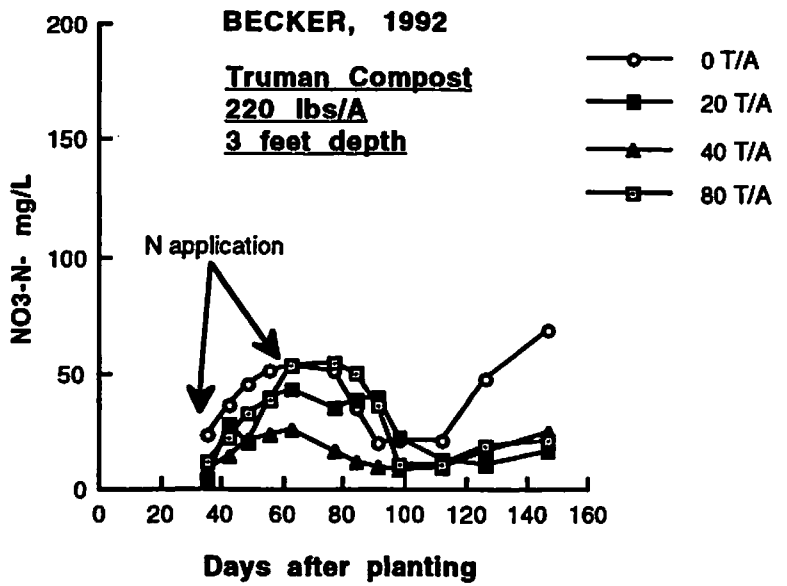

Fig. 2- Soil water NO3-N at Becker at four Truman compost rates.

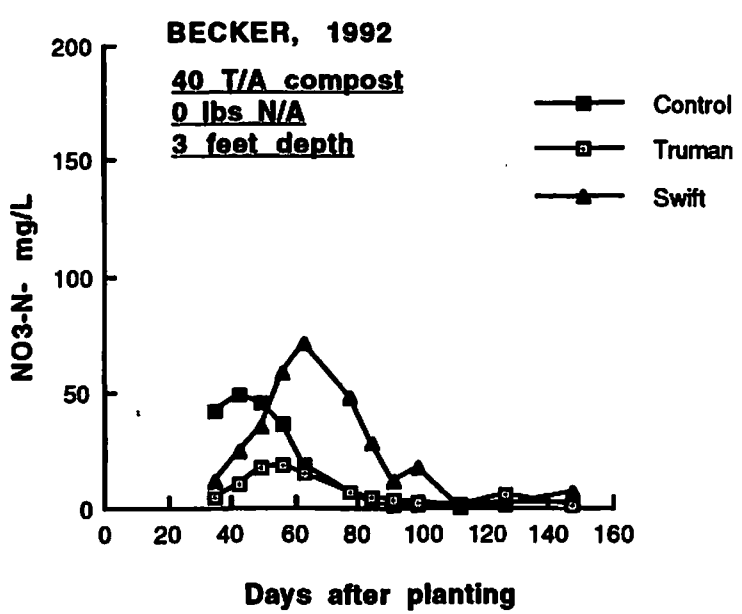

Fig. 3- Soil water NO3-N at Becker with two sources of compost.

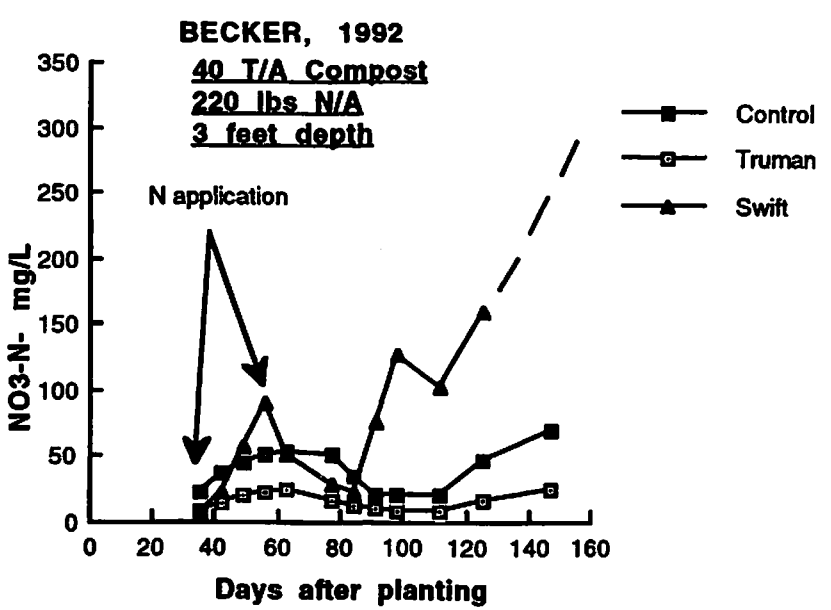

Fig. 4- Soil water NO3-N at Becker with two sources of compost.

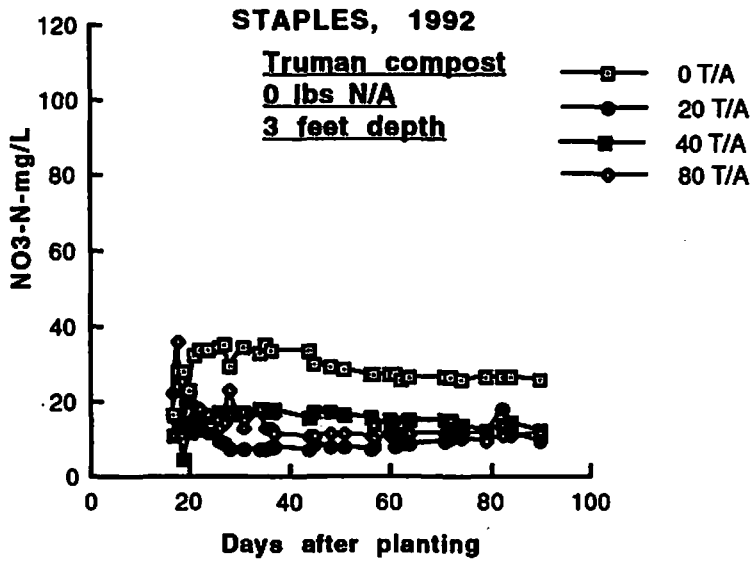

Figure 5- Soil water NO3-N at Staples at four Truman compost rates.

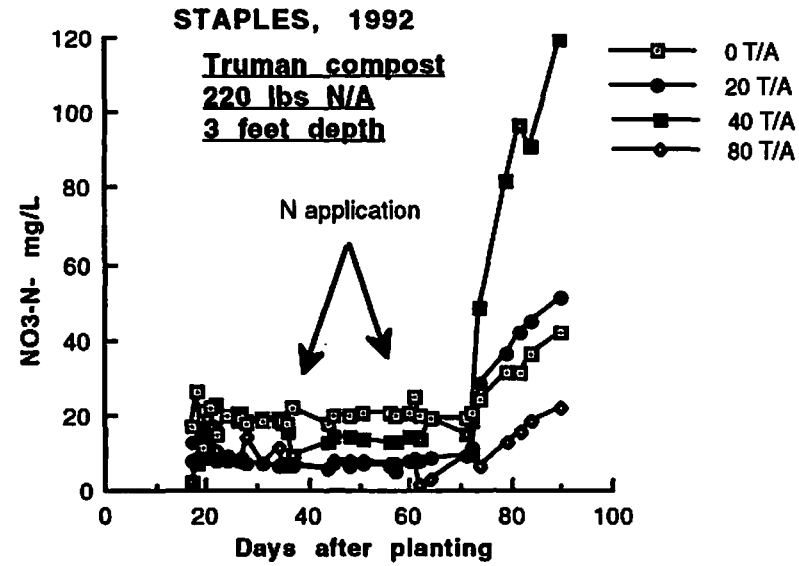

Figure 6- Soil water NO3-N at Staples at four Truman compost rates.

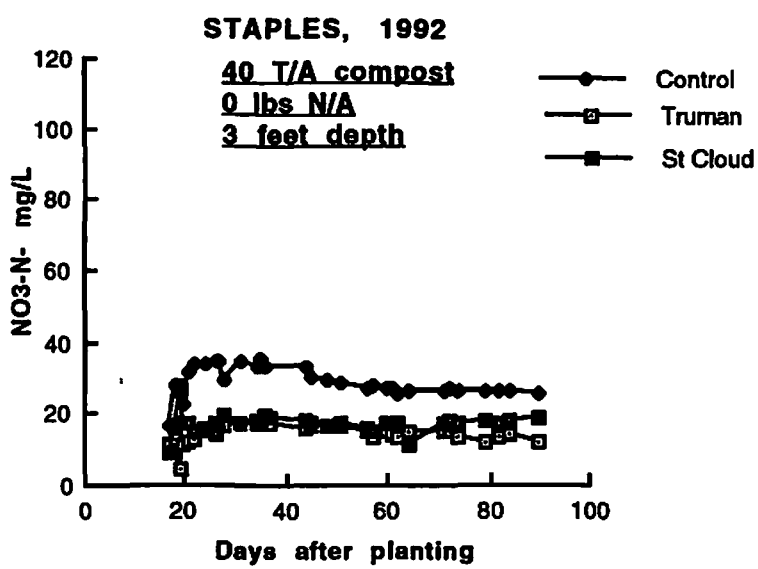

Figure 7- Soil water NO3-N at Staples with two sources of compost.

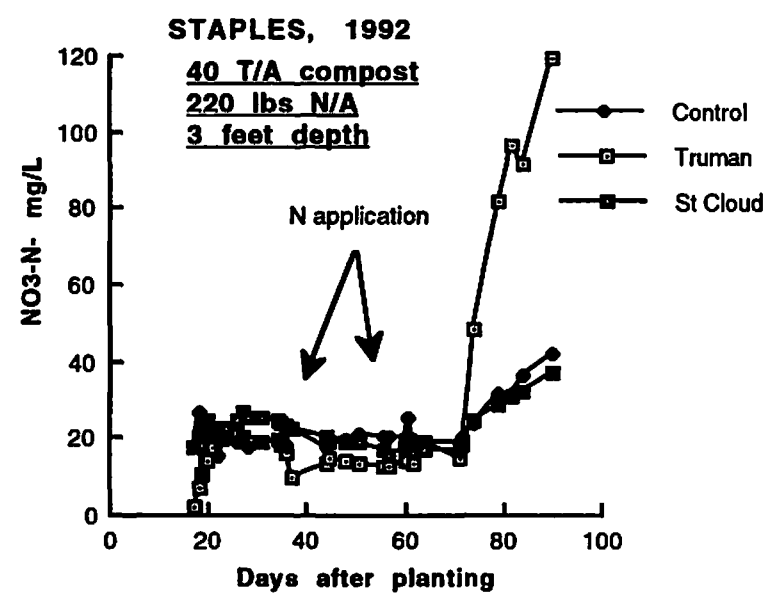

Figure 8- Soil water NO3-N at Staples with two sources of compost.

LAND SPREADING OF YARD WASTE

Matt McNearney, Carl Rosen, Thomas Halbach, David Birong, and Jennifer Weiszel

ABSTRACT: The second year of a field experiment at the Sand Plain Research Farm in Becker, Minn. was conducted to determine the residual effects of land applied yard waste, primarily tree leaves, on corn production and soil nitrate movement. Four yard waste treatments (0, 20, 40, and 80 dry T/A) were applied during the fall of 1991. In 1993, treatments included the four rates of yard waste that were applied in 1991 with 0, 100, and 200 lbs N/A applied during the growing season. During the first year of the study, 1992, yard waste application initially inhibited growth and depressed tissue nitrogen concentration in the corn plants. The inhibitory effect diminished by the middle of the 1992 growing season and final grain yields were similar to 0 T/A yard waste treatment (with 200 lb N/A) when 200 lb N/A was applied to the yard waste treatments. During the second year of the study, 1993, increases in growth and yield were greater with increasing yard waste application rates than with applied fertilizer N. Nitrate leaching tended to increase with increasing yard waste and N fertilizer application. These results suggest: 1) Soil N was initially immobilized during the first year after yard waste application; and 2) Yard waste decomposition increased available N during the second year after application, resulting in a reduced need for fertilizer N inputs. This study needs to be continued to determine nitrogen release rates from residual yard waste in subsequent years.

Until recently, yard wastes (tree leaves and grass clippings) accounted for 15-20% of the bulk in landfills. In 1990 (metro counties) and in 1992 (greater Minnesota), regulations were passed that prohibited dumping of yard wastes in landfills. Because of this legislation, alternatives to landfilling yard waste need immediate attention. Some options for using or recycling the yard waste include: 1) backyard composting and application of the compost to gardens; 2) municipal composting followed by land application of the compost; and 3) direct land application of noncomposted yard waste. While backyard composting is a desirable way to handle yard waste, not all homeowners desire to compost their own yard waste. Several problems with municipal yard waste composting include finding an acceptable site, controlling nutrient runoff, and controlling odors. Direct land application of noncomposted yard waste may be more efficient than composting and does not have the same problems associated with composting. Land application of yard waste may require an adjustment of nitrogen requirements, because of its high carbon to nitrogen ratio. The effects of nitrogen application on crop production also needs to be ascertained. Therefore, the objectives of this study were to: 1) Determine the residual effects of direct application and incorporation of noncomposted yard waste (primarily tree leaves), with and without fertilizer nitrogen, on the productivity of irrigated field corn, and 2) Characterize nitrogen release from the yard waste during the growing season in terms of availability for crop needs and movement through the soil profile.

PROCEDURES

The experiment was conducted at the Sand Plain Research Farm in Becker, MN on a Hubbard loamy sand soil. This was the second year of the study, to determine the residual effects of applied yard waste. The yard waste was collected and applied to 15' x 35' plots with a front end loader in October of 1991. The yard waste primarily consisted of tree leaves, although some garden plants and grass clippings were also present. Twelve treatments were tested: 0, 20, 40, and 80 dry tons/A yard waste with 0, 100, and 200 lbs N/A. The experimental design was a randomized complete block with 4 replications.

The field was plowed to a depth of 8-10 inches two days prior to planting. In addition, 220 lbs/A 0-0-22 and 200 lbs/A 0-0-60 were broadcast and incorporated prior to planting. Pioneer hybrid 3751 (100 day maturity) was planted on April 29, 1993 at a population of 32,000 seeds/A (2.5 ft. between rows). At planting, starter fertilizer was banded 2 inches to the side and 2 inches below the seed at a rate of 185 lbs/A 0-14-42. The nitrogen treated plots received split N applications with 50% rates applied on May 25 and June 15, 1993. Irrigation was used to supplement rainfall (Figure 1).

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[1]Funding for this project was provided by the Legislative Commission for Minnesota Resources
[2]Undergraduate Research Assistant, Extension Soil Scientist, Extension Waste Management Specialist, Assistant Scientist, and Senior Research Plot Technician respectively, Department of Soil Science.

Suction tubes with ceramic cups were installed at a depth of 4 feet in three replications of each treatment. Water samples were collected, after significant precipitation events, and analyzed for nitrate. Whole plant samples (4 per plot) were collected at the 8-12 leaf stage on June 23 after all fertilizer N was applied. Ear leaf samples were collected on August 2 at 50% silking. Two, 20 foot rows were harvested for grain and stover yield from each plot on October 6. Subsamples of stover and grain plus cob were taken for moisture determinations and nitrogen analyses. Plant tissue samples were dried and then ground through a 30 mesh screen. Dried samples were digested in concentrated sulfuric acid and Kjeldahl nitrogen was determined using conductimetric procedures.

After harvest, soil samples were collected from 0-6, 6-12, 12-24 and 24-36 inch depths. Soil nitrate was determined using 2 N KCl extracts.

RESULTS

Corn Growth and Yield: Initial corn growth increased with increasing rates of yard waste. The addition of nitrogen also increased initial growth (Table 1). At the 8 - 12 leaf stage, the greatest growth was found in treatments with the highest yard waste rates and highest nitrogen rates. The addition of yard waste also increased total yield indicating a significant release of nutrients during the second year after incorporation. Corn growth and yield displayed a greater response to yard waste application when nitrogen fertilizer was not applied. The diminishing response to yard waste when nitrogen fertilizer was applied suggests that a reduced rate of nitrogen fertilizer can be used the second year after yard waste application. Neither nitrogen application nor yard waste amendment affected the final stand count. Plant maturity, determined by kernel moisture at harvest, improved with the addition of yard waste and nitrogen. The application of nitrogen reduces kernel moisture response to the addition of yard waste.

Tissue Nitrogen Concentrations and Total Nitrogen Uptake: At the 8 - 12 leaf stage, yard waste application did not create a significant difference in tissue nitrogen concentration. The addition of fertilizer nitrogen did increase initial growth (Table 2). By the silking stage, yard waste amendment Nitrogen uptake increased with increased rates of yard waste. The addition of nitrogen further increased nitrogen uptake. Differences in tissue nitrogen concentration were observed at all growth stages with the application of fertilizer nitrogen.

Soil Nitrate-Nitrogen Content: Yard waste application increased nitrate-N in the soil (Table 4). The 80 T/A yard waste amendment, with or without fertilizer N, provided the greatest nitrogen content in the upper 12" of the soil. Yard waste amendment and fertilizer N application both increased nitrate-N content in the soil. Treatment 12 (80 T/A yard waste, 200 lbs. N/A) provided the greatest residual N in the top three feet of soil.

Soil Water Nitrate Concentrations: Concentrations of nitrate-N in soil water, as affected by treatments, are presented in figures 2 - 13. In all treatments, peak nitrate-N concentrations at the four foot depth occurred at about 11 - 12 weeks after planting. Yard waste application tended to increase nitrate-N concentrations in soil water at the four foot depth even when fertilizer N was not applied. Fertilizer N application further increased soil water nitrate concentrations. Variation in nitrate-N concentration, within treatments, became more pronounced as yard waste application rates increased. Nitrate-N concentrations were greatest in treatments with the highest yard waste and nitrogen applications. At the end of the season, the greatest N concentrations were found in the 80 T/A yard waste, 200 lbs N/A treatment. Application of 40 T/A yard waste with 100 lb N/A resulted in a greater yield, but similar nitrate concentrations at the four ft depth compared to the recommended N application of 200 lb N/A without yard waste application. Based on these observations, N fertilizer must be managed properly in order to minimize losses of nitrate following application of yard wastes.

Table 1. Effect of yard waste and nitrogen application on whole plant dry matter at the 8-12 leaf stage, final stand count, grain yield, and kernel moisture.

Yard waste rate	Nitrogen application	Whole plant dry matter (8-12 leaf)	Final stand count	Grain yield	Kernel moisture
-tons/A-	--lbs/A--	-grams/plant-	-plants/A-	-bu/A-	- % -
0	0	2.0	31581	42	47
20	0	6.5	31581	101	42
40	0	9.6	30274	148	41
80	0	9.2	30383	184	38
0	100	4.4	30274	103	45
20	100	8.3	30601	178	39
40	100	11.4	30928	197	39
80	100	11.5	31472	200	38
0	200	5.0	30274	153	42
20	200	10.3	30710	196	37
40	200	12.4	31254	205	38
80	200	12.6	30383	205	37
Significance		**	NS	**	**
BLSD (5%)		2.0	--	18	1
Main effects					
	Yard Waste Rate				
	0	3.8	30710	99	45
	20	8.4	30964	158	39
	40	11.1	30819	183	39
	80	11.1	30746	196	38
	Significance	**	NS	**	**
	BLSD (5%)	1.1	--	10	1
	Linear	**	NS	**	**
	Quadratic	**	NS	**	**
	Nitrogen Application				
	0	6.8	30955	119	42
	100	8.9	30819	169	40
	200	10.1	30655	190	38
	Significance	**	NS	**	**
	BLSD (5%)	1.0	--	9	1
Interaction					
	Yard Waste x Nitrogen	NS	NS	**	**

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

Table 2. Effect of yard waste and nitrogen application on nitrogen concentrations, dry matter accumulation, and nitrogen content.

Yard waste rate	Nitrogen application	Whole plant N 8-12 leaf stage	Ear leaf N silking stage	Nitrogen Concentration Cob	Stover	Grain	Dry Mass Cob	Stover	Grain	Total	Nitrogen Content Cob	Stover	Grain	Total
-tons/A-	--lbs/A--	-------- % Nitrogen --------		--- % Nitrogen ---			--------- Ton/A ---------				-------- lb N/A --------			
0	0	2.93	1.17	0.88	0.53	1.08	0.15	0.91	1.17	2.23	2.7	9.6	25.5	37.8
20	0	3.10	1.39	0.67	0.44	1.07	0.28	2.04	2.82	5.14	3.7	18.1	60.3	82.1
40	0	3.05	1.79	0.53	0.47	1.10	0.36	2.51	4.15	7.02	3.7	23.8	91.5	119.0
80	0	3.09	2.17	0.46	0.64	1.24	0.46	3.03	5.15	8.63	4.2	40.1	127.7	172.0
0	100	4.21	1.83	0.65	0.43	1.02	0.36	2.41	2.89	5.67	4.6	21.6	59.1	85.2
20	100	4.03	2.46	0.45	0.55	1.17	0.50	3.38	4.97	8.85	4.4	37.1	117.1	158.6
40	100	3.67	2.68	0.45	0.65	1.28	0.54	3.60	5.51	9.65	4.8	46.9	141.7	193.4
80	100	3.96	2.79	0.43	0.70	1.35	0.59	3.57	5.60	9.77	5.1	50.7	151.1	206.9
0	200	4.22	2.60	0.53	0.62	1.20	0.49	3.02	4.29	7.80	5.1	38.0	103.9	147.0
20	200	4.14	2.92	0.45	0.67	1.34	0.55	3.54	5.48	9.57	4.9	47.1	146.3	198.2
40	200	3.99	2.92	0.42	0.67	1.37	0.59	3.58	5.74	9.91	5.0	48.1	156.8	209.8
80	200	4.03	2.90	0.51	0.76	1.41	0.58	3.91	5.75	10.2	5.8	59.6	162.6	228.1
Significance		**	**	**	**	**	**	**	**	**	**	**	**	**
BLSD (5%)		0.32	0.27	0.11	0.20	0.07	0.06	0.39	0.51	0.80	1.0	14.2	14.6	24.0
Main effects														
Yard Waste Rate														
0		3.79	2.35	0.69	0.52	1.10	0.33	2.12	2.78	5.23	4.1	23.1	62.8	90.0
20		3.76	2.47	0.52	0.55	1.19	0.44	2.99	4.42	7.85	4.3	34.1	107.8	146.3
40		3.57	2.56	0.47	0.60	1.25	0.49	3.23	5.13	8.86	4.5	39.6	130.0	174.1
80		3.69	2.76	0.47	0.70	1.33	0.54	3.50	5.50	9.55	5.0	50.1	147.2	202.3
Significance		NS	**	**	**	**	**	**	**	**	*	**	**	**
BLSD (5%)		--	0.16	0.06	0.11	0.04	0.04	0.22	0.29	0.46	0.6	8.0	8.4	13.7
Linear		NS	**	**	**	**	**	**	**	**	**	**	**	**
Quadratic		NS	**	**	NS	*	**	**	**	**	NS	NS	**	**
Nitrogen Application														
0		3.04	1.92	0.63	0.52	1.12	0.31	2.12	3.32	5.76	3.6	22.9	76.3	102.7
100		3.97	2.89	0.49	0.58	1.20	0.50	3.24	4.74	8.48	4.7	39.1	117.3	161.0
200		4.09	2.84	0.48	0.68	1.33	0.55	3.51	5.31	9.38	5.2	48.2	142.4	195.8
Significance		**	**	**	**	**	**	**	**	**	**	**	**	**
BLSD (5%)		0.16	0.13	0.05	0.09	0.03	0.03	0.19	0.25	0.40	0.5	6.8	7.3	11.9
Interaction														
Yard Waste x Nitrogen		NS	**	**	NS	**	**	**	**	**	NS	NS	**	*

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

Table 3. Effect of yard waste and nitrogen application on soil nitrate-N (lbs/A) in the top three feet at the end of the growing season.

Yard waste rate	Nitrogen application	Sample depth (inches) 0 - 6	6 - 12	12 - 24	24 - 36	Total
-tons/A-	--lbs/A--	lbs nitrate-N/A				
0	0	0.70	0.93	1.01	0.26	2.90
20	0	1.47	2.18	1.24	0.43	5.32
40	0	2.00	4.28	2.44	0.84	9.56
80	0	17.35	19.79	7.57	1.80	46.51
0	100	1.00	2.83	0.79	0.41	5.02
20	100	4.07	5.62	2.94	0.72	13.35
40	100	4.10	7.33	2.89	0.67	14.99
80	100	11.14	16.40	7.58	2.18	37.30
0	200	1.33	2.02	1.09	0.66	5.10
20	200	4.23	6.38	3.70	1.02	15.32
40	200	6.04	9.34	5.15	3.21	23.74
80	200	16.93	18.44	12.08	5.15	52.60
Significance		**	**	**	**	**
BLSD (5%)		8.83	8.22	4.32	1.60	18.14
Main effects						
	Yard Waste Rate					
	0	1.01	1.93	0.96	0.44	4.34
	20	3.26	4.72	2.63	0.72	11.33
	40	4.04	6.98	3.49	1.57	16.09
	80	15.14	18.21	9.08	3.04	45.47
	Significance	**	**	**	**	**
	BLSD (5%)	4.52	4.34	2.29	0.88	9.81
	Linear	**	**	**	**	**
	Quadratic	++	NS	NS	NS	++
	Nitrogen Application					
	0	5.38	6.80	3.07	0.83	16.07
	100	5.07	8.04	3.55	1.00	17.66
	200	7.13	9.04	5.51	2.51	24.19
	Significance	NS	NS	++	**	NS
	BLSD (5%)	--	--	2.32	0.77	--
Interaction						
	Yard Waste x Nitrogen	NS	NS	NS	++	NS

NS = nonsignificant, ++ = significant at 10%, * = significant at 5%, ** = significant at 1%.

Table 3. Effect of yard waste and nitrogen application on soil nitrate-N (lbs/A) in the top three feet at the end of the growing season.

Yard waste rate	Nitrogen application	Sample depth (inches) 0 - 6	6 - 12	12 - 24	24 - 36	Total
-tons/A-	--lbs/A--	lbs nitrate-N/A				
0	0	0.70	0.93	1.01	0.26	2.90
20	0	1.47	2.18	1.24	0.43	5.32
40	0	2.00	4.28	2.44	0.84	9.56
80	0	17.35	19.79	7.57	1.80	46.51
0	100	1.00	2.83	0.79	0.41	5.02
20	100	4.07	5.62	2.94	0.72	13.35
40	100	4.10	7.33	2.89	0.67	14.99
80	100	11.14	16.40	7.58	2.18	37.30
0	200	1.33	2.02	1.09	0.66	5.10
20	200	4.23	6.38	3.70	1.02	15.32
40	200	6.04	9.34	5.15	3.21	23.74
80	200	16.93	18.44	12.08	5.15	52.60
Significance		**	**	**	**	**
BLSD (5%)		8.83	8.22	4.32	1.60	18.14
Main effects						
Yard Waste Rate						
0		1.01	1.93	0.96	0.44	4.34
20		3.26	4.72	2.63	0.72	11.33
40		4.04	6.98	3.49	1.57	16.09
80		15.14	18.21	9.08	3.04	45.47
Significance		**	**	**	**	**
BLSD (5%)		4.52	4.34	2.29	0.88	9.81
Linear		**	**	**	**	**
Quadratic		++	NS	NS	NS	++
Nitrogen Application						
0		5.38	6.80	3.07	0.83	16.07
100		5.07	8.04	3.55	1.00	17.66
200		7.13	9.04	5.51	2.51	24.19
Significance		NS	NS	++	**	NS
BLSD (5%)		--	--	2.32	0.77	--
Interaction						
Yard Waste x Nitrogen		NS	NS	NS	++	NS

NS = nonsignificant, ++ = significant at 10%, * = significant at 5%, ** = significant at 1%.

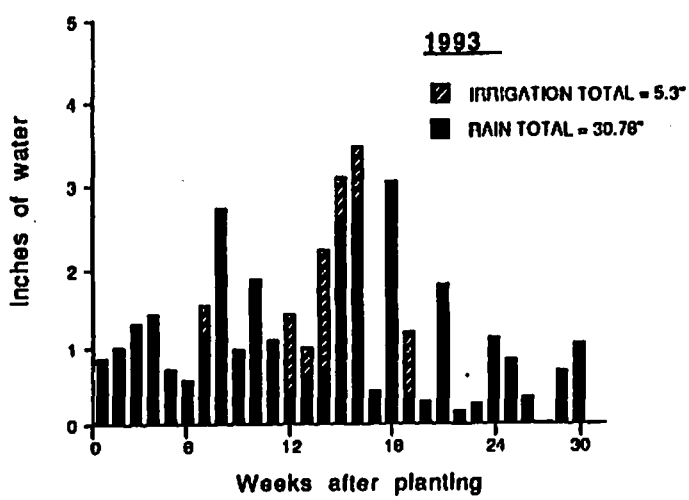

Figure 1. Rainfall and irrigation provided over the 1993 growing season.

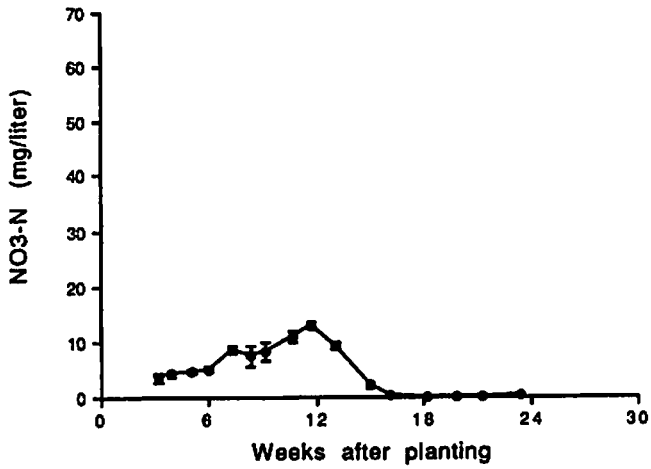

Figure 2. Nitrate-N concentration in soil water at the four foot depth over the 1993 growing season. Treatment 1: no leaves, no nitrogen applied. Error bars represent SE of the mean.

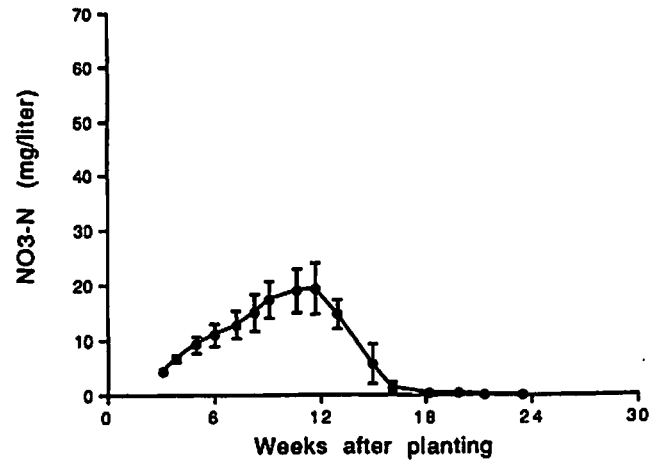

Figure 3. Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 2: 20 tons/A leaves, no nitrogen applied. Error bars represent SE of the mean.

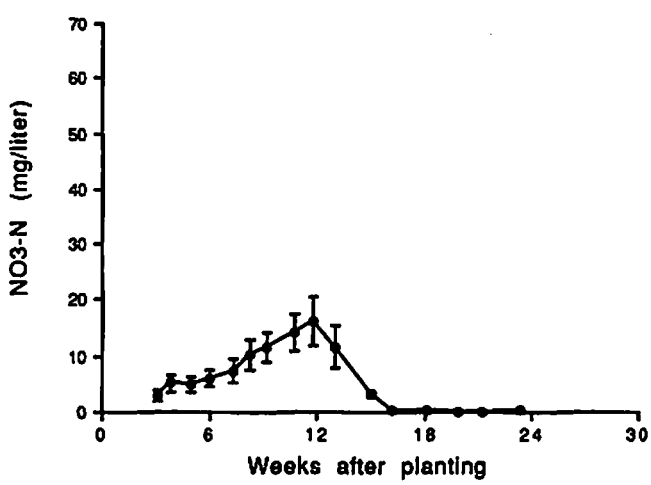

Figure 4. Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 3: 40 tons/A leaves, no nitrogen applied. Error bars represent SE of the mean.

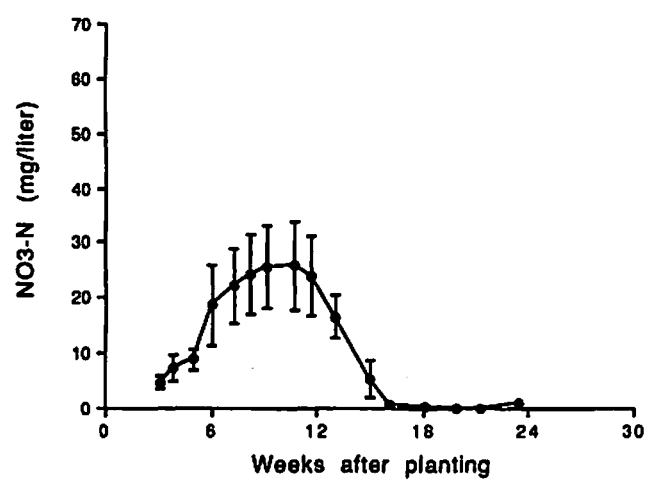

Figure 5. Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 4: 80 tons/A leaves, no nitrogen applied. Error bars represent SE of the mean.

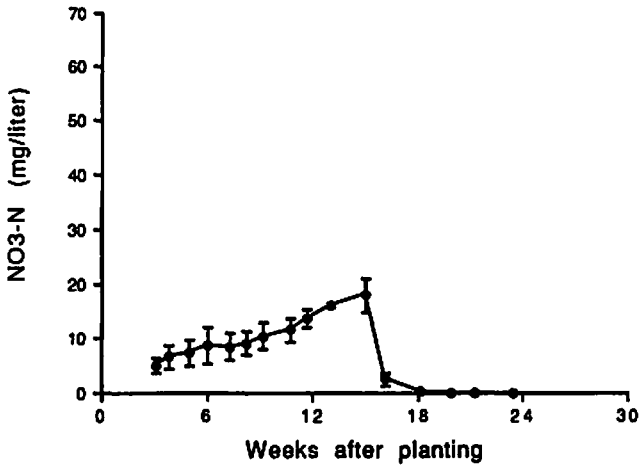

Figure 6. Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 5: no leaves, 100 lbs/A nitrogen applied during the growing season. Error bars represent SE of the mean.

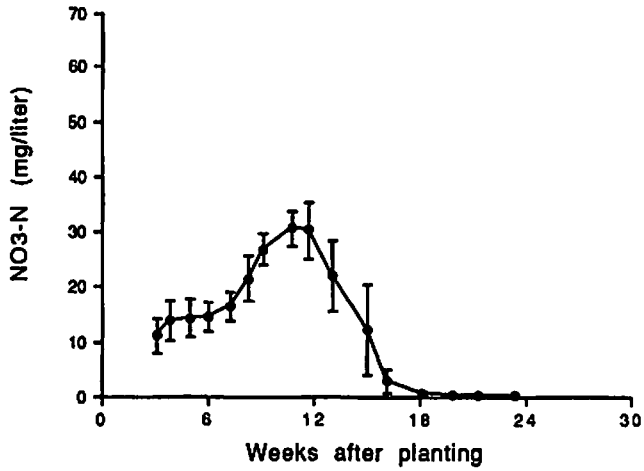

Figure 7. Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 6: 20 tons/A leaves, 100 lbs/A nitrogen applied during the growing season. Error bars represent SE of the mean.

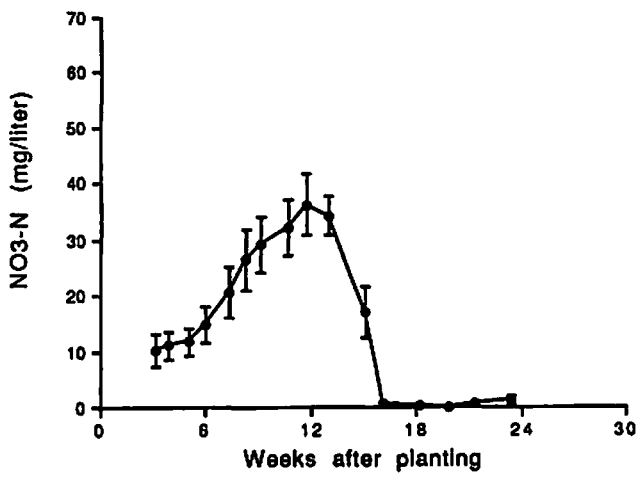

Figure 8. Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 7: 40 tons/A leaves, 100 lbs/A nitrogen applied during the growing season. Error bars represent SE of the mean.

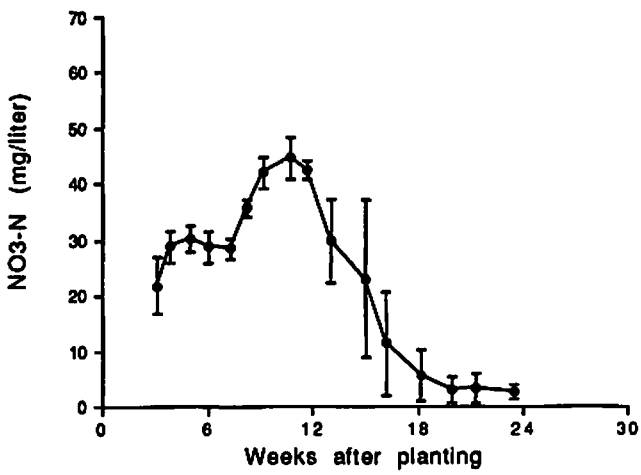

Figure 9. Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 8: 80 tons/A leaves, 100 lbs/A nitrogen applied during the growing season. Error bars represent SE of the mean.

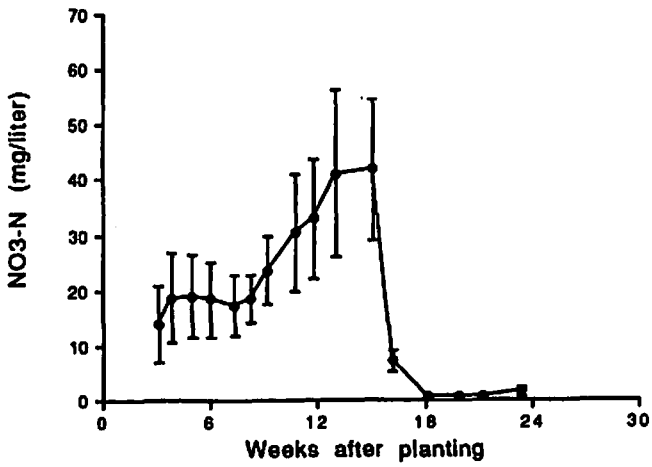

Figure 10. Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 9: no leaves, 200 lbs/A nitrogen applied during the growing season. Error bars represent SE of the mean.

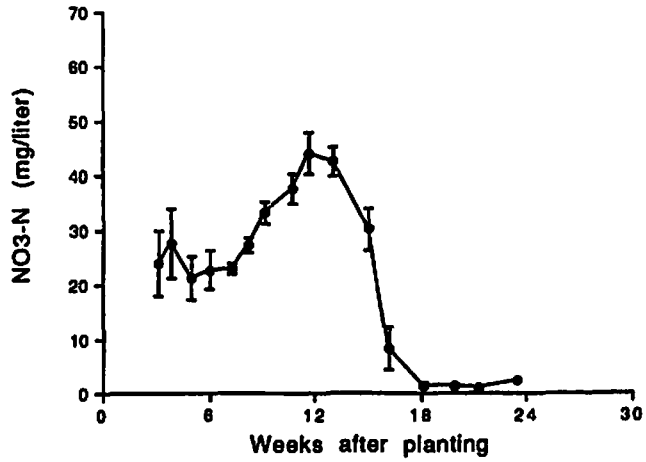

Figure 11. Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 10: 20 tons/A leaves, 200 lbs/A nitrogen applied during the growing season. Error bars represent SE of the mean.

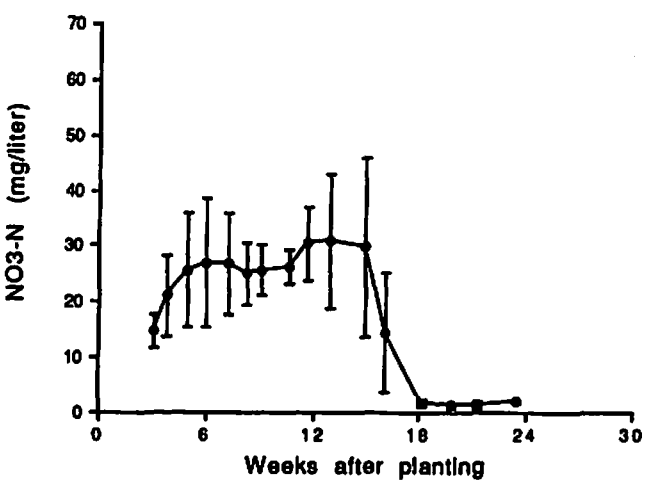

Figure 12: Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 11: 40 tons/A leaves, 200 lbs/A nitrogen applied during the growing season. Error bars represent SE of the mean.

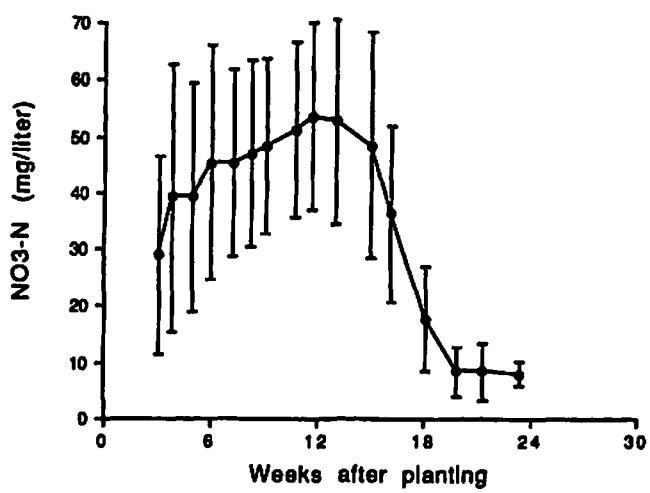

Figure 13: Nitrate-N concentration in soil water at the four ft. depth over the 1993 growing season. Treatment 12: 80 tons/A leaves, 200 lbs/A nitrogen applied during the growing season. Error bars represent SE of the mean.

LAND TREATMENT OF SEWAGE SLUDGE INCINERATOR ASH - 1993[1]

Carl Rosen, Dave Birong, and Peter Bierman[2]

ABSTRACT: The seventh and final year of an experiment to evaluate the use of sewage sludge incinerator ash as a phosphorus source for corn production was conducted at the Rosholt Research Farm in Westport, MN. Ash was applied yearly from 1987 to 1991 and residual effects were determined in the following years. Treatments consisted of a control, three rates of phosphate fertilizer (0-46-0: 70, 140 and 280 lb P_2O_5/A) applied yearly until 1991 and three rates of sewage sludge incinerator ash. The cumulative rates of sewage sludge ash over the five years were 4.3, 8.6 and 17.2 dry tons. In addition, 6 tons/A lime were incorporated in half of each plot in 1991 and 4 tons/A in 1993. Results reported here are from the third year after the final application of ash and phosphate fertilizer. The crop grown was soybean. Early plant (flowering stage) dry weight and grain yield significantly increased with both ash and phosphate fertilizer amendments compared to the control. Lime application also increased grain yield. The Olsen P soil test seemed to predict response to the ash amended soils better than the Bray P1 or nitric acid extractants. Extractable levels of heavy metals increased in the 0-6 inch soil depth with increasing ash application. Lime increased soil pH by 0.9 units and decreased DTPA extractable Mn, Fe, Zn, Cu, Ni, and Cd. Tissue analysis revealed that both P sources increased P levels in the plant; however, at roughly equivalent phosphate rates, P concentrations were greater with the fertilizer source compared to the ash source. Tissue concentrations of Zn were higher with ash applications compared to fertilizer applications. Tissue levels of Mo increased substantially with ash applications. Heavy metals such as Cd, Pb, Ni, and Cr did not accumulate to levels that would be a health concern in grain tissue.

Incineration of sewage sludge is a common means of reducing the volume of municipal waste material. As landfill usage is being reduced, disposal of the resulting ash is becoming more of a problem. Finding an environmentally acceptable disposal method for incinerator ash is important, since increasing quantities of sewage sludge wastes are burned. Sewage sludge incinerator ash contains many elements that are essential for plant growth. In particular, high concentrations of phosphorus, calcium and magnesium have been reported in previous studies. However, this ash also contains heavy metals such as cadmium, lead, zinc, copper, and others which can pose problems to plants and animals in high concentrations. When properly managed, recycling incinerator ash nutrients by land spreading may provide a disposal method that is beneficial to both incinerator operators and crop producers. The purpose of this study was to determine whether sewage sludge ash can be used as a soil amendment/fertilizer without lowering crop quality or polluting the environment. In the past, small amounts of ash were applied yearly to simulate phosphate fertilizer application. In 1991, greater amounts were applied to simulate a one time application. Results reported here are from the third year (residual effects) after the final application of ash in 1991.

MATERIALS AND METHODS

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

Ash was initially collected from the Metropolitan Waste Water Treatment Plant in St. Paul in April 1987 and stored in 5 gallon covered plastic containers. Ash was collected a second time in April of 1991. The ash was analyzed for elemental content in a similar manner to that used in 1987. Particle size analysis both years revealed that 99% passed through a 60 mesh screen and 88% passed through a 100 mesh screen. Composition of the ash has been reported previously.

Treatments consisted of a control, three rates of phosphate fertilizer (0-46-0: 70, 140 and 280 lb P_2O_5/A) applied yearly and three rates of sewage sludge incinerator ash. The cumulative rates of sewage sludge ash over the five years (1987-91) were 4.3, 8.6 and 17.2 dry tons. Because of the increase in the amount of ash applied in 1991, the phosphate applied by ash was much greater than the amount of phosphate applied with the fertilizer. No additional ash or phosphate fertilizer was applied in 1992 or 1993. In addition to the ash and fertilizer treatments applied in 1991, each plot was split and half the plot received 6 tons/A of lime while the other half served as a control. An additional 4 T/A lime was applied to each limed plot in 1993.

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

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Soybeans (Pioneer 9062) were planted on May 18, 1993 at a population of 200,000 plants/A in 2.5 ft rows. As in previous years, a split plot treatment arrangement with four replications was used. Phosphate treatment was the main plot and lime was the subplot. Each plot consisted of four 15 ft rows. Irrigation supplemented rainfall to provide approximately 1" of water per week. On July 26 (flowering stage), 6 whole plants were sampled from each plot at the ends of the two middle rows. Diagnostic trifoliate leaves were sampled on August 23 at the initial pod filling stage. Samples were weighed dried, weighed and ground to pass through a 30 mesh screen. Plots were harvested for grain yield on October 4 (6 ft from the middle two rows). Samples were air-dried and shelled and then the grain was weighed. A subsample of grain was dried in an oven at 60C. Moisture content was determined and then samples were ground to pass through a 30 mesh screen. Multiple element analysis using ICP procedures were performed on ashed whole plant and grain samples dissolved in 1 N HCl. Following Kjeldahl digestion, total nitrogen in plant tissues was determined using conductimetric procedures.

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

RESULTS

Soil Samples. As in previous years, extractable P increased with increasing ash and fertilizer rate in the 0-6" depth (Table 1). At roughly equivalent rates of applied P_2O_5, the Bray P1 extractant extracted more P from the soil amended with ash than with fertilizer. In contrast, Olsen P was greater in fertilizer amended plots compared to ash amended plots. DTPA extractable Zn, Cu, and Cd, increased and Mn decreased with increasing ash application. Ammonium acetate extractable Mg and Na also increased with increasing ash application. Soil pH linearly increased with ash application and slightly decreased with P fertilizer application. Soluble salts were not significantly affected by fertilizer or ash amendments. Lime application increased soil pH, soluble salts, extractable K and Ca and decreased DTPA extractable Mn, Fe, Cu, Ni, and Cd. Except for K, all nitric acid extractable elements increased with increasing ash application (Table 2). Phosphate fertilizer increased nitric acid extractable Al, As, Fe, Mo, P, and V. Lime application increased nitric acid extractable As, B, Ca, Co, K, Mg, S, Sr, and V.

Yield Data. Both residual triple superphosphate fertilizer and ash significantly increased early plant dry weight compared to plants growing in the check plot (Table 3). Residual effects from fertilizer were greater than those from the ash. This early plant response to P fertilizer is common in plants grown in low P soils, particularly under cool soil temperatures. Lime application also increased early plant growth. Grain yield increased linearly with phosphorus fertilizer and quadratically with ash amendments. Addition of lime also increased grain yields. These results clearly show an agronomic benefit to ash application and that the high rates of ash used had no detrimental effects on yield or plant establishment.

Tissue Analyses. Fertilizer and ash treatments increased tissue P concentrations in whole plant soybeans sampled at the flowering stage (Table 4). Even though rates of ash were higher in total P application than the fertilizer, availability of P, based on P concentrations in the plant tissue, was still greater from the fertilizer source than the ash source. Tissue concentrations of Mg, B, and Zn tended to increase with ash applications; however, these nutrients are essential for plant growth and the levels of B and Zn reported are well below those considered toxic to plants or animals. Tissue Mo increased with ash and at the highest ash rate the Mo levels may be of concern for chronic ingestion by ruminants. Availability of Mo increased with increasing pH and resulted in about a 1 ppm increase in tissue Mo. Although generally low, concentrations of Cd and Cr, a nonessential plant element increased with ash application. The other heavy metals, Pb and Ni were generally at background levels or not consistently affected by ash treatments. Tissue Mn decreased with increasing ash rate. Increasing phosphate fertilizer rate increased tissue Ca, B and Ni and decreased tissue Cu and Zn. Liming increase tissue N, K, Ca, Cu, and Mo decreased tissue Mg, B, Mn and Ni.

Diagnostic leaves sampled at initial pod fill increased in P with fertilizer and ash applications (Table 5). As in whole plant samples, the increase was greater in the 0-46-0 plots than in the ash plots on an equivalent P_2O_5 basis. Phosphate fertilizer increased tissue Ca, Mg, B, Mn, and Ni, but decreased K, Cu, and Zn concentrations. Ash application increased N, Ca, B, Cd, Mo, Ni, and Zn concentrations, and decreased Cu, Fe, and Mn levels. Liming increased tissue N, Ca, and Fe, but decreased tissue K, Mg, Al, B, Mn and Zn. Except for Mo in nonlimed control plots all levels of nutrients were in the satisfactory range for soybean growth.

Phosphorus concentrations in grain tissue increased with increasing fertilizer and ash amendments (Table 6). As with the other tissues, the fertilizer was a more effective P source based on tissue P concentrations. Concentrations of Na and Pb in grain tissue were either at background levels or below detection limits. Grain Cd levels slightly increased with ash in the nonlimed soil. Liming reduced Cd availability. Ash

applications increased grain levels of K, B and Zn and decreased Cu, and Mn. Soybean grain accumulated substantial amounts of Mo in ash-amended plots, particularly when limed. Liming alone increased Mo levels in grain by about 5 ppm. Potassium, B, and Ni concentrations in the grain tissue increased with phosphate fertilizer application, while Ca, Al, Cu, Mn, and Zn concentrations decreased. Liming increased grain N, and Mo and decreased levels of B, Mn, and Ni.

GENERAL DISCUSSION

As in previous years, phosphate was not found to be as available from the ash source as from the fertilizer source. For some treatments, over twice as much P_2O_5 was applied with the ash compared to the fertilizer, yet P availability was the same or lower. This may be due to lower P solubility in the ash compared to the fertilizer, which may not be readily detected by the available (citrate soluble) P test. The Olsen P soil test seemed to predict response on the ash amended soils better than the Bray P1 or nitric acid extractants. Ash appears to be a good source of Zn, a nutrient which can be limiting when high rates of P fertilizer are used. The high cumulative rate of ash applied to this site over the five years had no detrimental effects on yield and residual release of nutrients have resulted in increased yield over the plots not receiving any P amendments. Ash application did not increase accumulation of elements such as Cd, Cu, Pb, Cr, and Ni in grain tissue to levels where animal health would be of concern. The one element that needs to be monitored for legumes (especially for soybeans) is Mo. This element did accumulate to levels that would be cause for concern if chronically ingested at levels found in the higher ash amended plots. Whether high Mo in grain or plant tissue is a concern would depend on how much of the high Mo tissue is mixed with low Mo material. In most cases for soybeans, harvested product is mixed from many different sources, which would dilute any concentrated levels of Mo. Additionally if plant material elevated in Mo is fed to ruminants, Mo problems can be alleviated by supplementing the feed with Cu. It is important however that Mo levels in plant tissue be monitored, especially in legumes, so that rations can be adjusted properly.

Table 1. Effect of lime and residual effects of a five year cumulative application of sludge ash and phosphate fertilizer on soil pH, Bray P1, Olsen P, ammonium acetate extractable cations, and DTPA extractable micro-elements (0-6" depth).

Treatment				Soluble	Bray	Olsen	NH_4OAc Extractable				DTPA Extractable							
Cumulative P_2O_5 (lb/A)	Source	Lime (T/A)	pH	Salts (mmhos/cm)	P	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Pb	Ni	Cr	Cd
					ppm													
0	Ctrl	0	5.7	0.10	15	9	93	1953	249	6.2	73	33	1.1	1.0	1.0	1.8	<0.03	0.14
350	Fert	0	5.6	0.15	39	25	108	1980	247	5.8	81	38	1.2	0.9	1.1	1.9	<0.03	0.14
700	Fert	0	5.6	0.10	74	47	106	1958	246	5.7	80	34	1.3	1.0	1.0	1.9	<0.03	0.14
1400	Fert	0	5.6	0.15	124	75	102	1987	241	6.0	77	29	1.3	1.0	1.0	2.0	<0.03	0.14
750	Ash	0	5.8	0.15	75	38	103	2065	279	7.3	71	25	2.2	2.7	1.2	2.0	<0.03	0.21
1500	Ash	0	6.0	0.13	121	53	93	2189	313	9.8	63	18	3.5	4.6	1.3	1.8	<0.03	0.29
3000	Ash	0	6.2	0.13	240	75	92	2190	335	11.8	62	16	4.9	7.5	1.6	1.9	0.04	0.38
0	Ctrl	10	6.5	0.38	16	9	109	2947	250	6.1	50	15	1.0	0.8	0.7	1.2	<0.03	0.12
350	Fert	10	6.5	0.35	27	16	101	2951	270	6.4	53	15	0.9	0.6	0.6	1.4	<0.03	0.10
700	Fert	10	6.3	0.43	71	45	130	2720	247	7.4	61	18	2.2	0.7	0.7	1.4	<0.03	0.11
1400	Fert	10	6.2	0.33	121	69	111	2722	253	6.4	62	16	1.2	0.8	0.7	1.5	<0.03	0.12
750	Ash	10	6.4	0.30	83	34	124	2763	265	6.7	58	16	2.1	2.6	1.8	1.4	<0.03	0.19
1500	Ash	10	6.6	0.35	142	54	118	3080	286	8.1	52	12	2.8	4.2	1.1	1.3	<0.03	0.26
3000	Ash	10	6.6	0.30	209	70	114	3009	316	9.5	54	12	3.8	6.0	1.2	1.5	<0.03	0.32
Significance			**	**	**	**	NS	**	**	**	**	**	**	**	NS	**	--	**
BLSD (0.05)			0.3	0.12	34	13	--	317	42	1.4	10	21	0.8	0.9	--	0.3	--	0.05
Main effects																		
Lime	-		5.8	0.13	98	46	99	2046	273	7.5	72	28	2.2	2.7	1.2	1.9	<0.03	0.20
	+		6.4	0.35	95	42	115	2885	269	7.2	56	15	2.0	2.2	1.0	1.4	<0.03	0.17
Significance			**	**	NS	NS	*	**	NS	NS	**	**	NS	*	NS	**	--	**
P Treatment																		
P_2O_5 (lb/A)	Source																	
0	Ctrl		6.1	0.24	15	10	101	2450	250	6.1	62	24	1.1	0.9	0.8	1.5	<0.03	0.13
350	Fert		6.0	0.25	33	20	104	2466	258	6.1	67	26	1.0	0.7	0.8	1.7	<0.03	0.12
700	Fert		6.0	0.26	73	46	118	2339	246	6.5	70	26	1.8	0.8	0.9	1.6	<0.03	0.12
1400	Fert		5.9	0.24	123	72	106	2355	248	6.2	69	23	1.2	0.9	0.9	1.7	<0.03	0.13
750	Ash		6.1	0.23	79	36	113	2414	272	7.0	64	20	2.2	2.7	1.5	1.7	<0.03	0.20
1500	Ash		6.3	0.24	131	53	105	2634	300	9.0	57	15	3.2	4.4	1.2	1.6	<0.03	0.27
3000	Ash		6.4	0.21	224	73	103	2600	326	10.6	58	14	4.3	6.7	1.4	1.7	<0.03	0.35
Significance			**	NS	**	**	NS	NS	**	**	**	**	**	**	*	NS	--	**
BLSD (0.05)			0.3	--	24	9	--	--	28	1.0	7	4	0.6	0.7	0.6	--	--	0.03
Contrasts																		
Ctrl vs Rest			NS	NS	**	**	NS	NS	*	**	NS	*	**	**	NS	*	--	**
Fert vs Ash			**	NS	**	**	NS	*	**	**	**	**	**	**	**	NS	--	**
Linear Fert			NS	NS	**	**	NS	NS	NS	NS	*	NS	NS	NS	NS	*	--	NS
Quad Fert			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS
Linear Ash			**	NS	**	**	NS	NS	**	**	NS	**	**	**	NS	NS	--	**
Quad Ash			NS	NS	NS	**	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	--	*
Interactions																		
Lime by P			NS	NS	NS	NS	NS	NS	NS	**	NS	**	*	NS	NS	NS	--	NS

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

Table 2. Effect of lime and residual effects of a five year cumulative application of sludge ash and phosphate fertilizer on 1N nitric acid extractable elements.

Treatment			1 N Nitric Acid Extractable																								
Cum. P_2O_5	Source	Lime	Al	As	B	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P	Pb	S	Si	Sr	Ti	V	Zn
(lb/A)		(T/A)	ppm																								
0	Ctrl	0	1592	1.5	1.3	88	2798	0.3	0.6	1.0	3.9	398	113	0.3	449	111	0.5	8	3.8	64	5.3	15.9	437	8.6	5.0	1.9	5.0
350	Fert	0	1594	1.5	1.3	90	2849	0.3	0.7	0.9	3.5	379	128	0.3	411	124	0.5	7	4.0	101	5.5	18.0	383	8.8	4.1	1.8	4.8
700	Fert	0	1647	1.5	1.3	89	2960	0.3	0.7	1.0	3.8	410	130	0.3	458	133	0.5	7	3.9	153	5.8	17.2	401	8.9	4.4	2.0	5.1
1400	Fert	0	1747	1.6	1.3	93	3005	0.3	0.7	1.1	4.4	448	126	0.3	436	129	0.5	7	4.3	229	6.1	17.8	422	9.5	5.0	2.1	5.5
750	Ash	0	1734	1.6	1.4	99	3132	0.5	0.7	1.6	9.7	445	127	0.3	475	128	0.5	10	4.3	218	6.8	17.9	454	9.7	5.4	2.1	7.9
1500	Ash	0	1934	1.8	1.6	102	3633	0.8	0.7	2.6	17.9	514	120	0.3	554	137	0.6	16	4.4	433	8.9	17.9	526	10.9	6.7	2.4	12.5
3000	Ash	0	2160	2.0	1.7	112	4145	1.3	0.7	4.1	31.1	619	127	0.4	630	154	0.7	23	5.0	789	11.6	19.1	607	12.5	8.9	2.7	18.9
0	Ctrl	10	1542	1.5	1.5	91	5042	0.3	0.8	1.0	4.0	330	138	<0.2	644	127	0.5	9	3.6	80	5.4	54.0	424	11.1	3.6	2.0	5.0
350	Fert	10	1582	1.5	1.4	93	4969	0.3	0.7	1.0	3.5	376	123	0.3	623	121	0.5	8	3.9	79	5.3	54.9	462	11.7	4.5	2.1	4.9
700	Fert	10	1604	1.6	1.6	90	4743	0.3	0.8	1.0	3.6	394	159	0.3	617	136	0.5	10	3.8	157	5.7	86.6	424	11.3	4.2	2.1	5.5
1400	Fert	10	1683	1.6	1.5	94	4797	0.3	0.8	1.2	4.0	428	140	0.2	591	136	0.5	9	3.9	255	5.8	49.6	421	11.4	4.5	2.2	5.4
750	Ash	10	1793	1.8	1.6	100	5870	0.6	0.8	1.9	13.7	431	162	<0.3	637	150	0.6	13	4.2	337	9.1	46.8	485	12.8	5.4	2.3	9.5
1500	Ash	10	1941	1.9	1.7	102	6613	0.9	0.8	2.9	21.9	500	156	0.3	810	161	0.6	17	4.2	559	9.52	48.6	540	14.1	6.7	2.5	13.0
3000	Ash	10	2178	2.2	1.9	116	6406	1.3	0.8	4.2	33.1	600	157	0.3	818	175	0.7	23	5.0	863	11.9	51.0	625	15.5	8.9	2.8	19.2
Significance			**	**	**	**	**	**	**	**	**	**	NS	--	**	**	**	**	**	**	**	**	**	**	**	**	**
BLSD (0.05)			147	0.2	0.3	10	812	0.2	0.1	0.6	5.2	75	--	--	129	25	0.1	3	0.6	144	1.6	28.2	101	1.5	1.4	0.3	2.4
Main effects																											
Lime	-		1772	1.6	1.4	96	3217	0.6	0.7	1.7	10.6	459	124	0.3	488	131	0.6	11	4.2	284	7.1	17.7	461	9.9	5.6	2.1	8.5
	+		1760	1.7	1.6	98	5491	0.6	0.8	1.9	12.0	437	148	<0.3	677	144	0.6	13	4.1	333	7.5	55.9	483	12.6	5.2	2.3	8.9
Significance			NS	**	**	NS	**	NS	**	NS	NS	NS	**	--	**	**	NS	**	NS	NS	NS	**	NS	**	NS	**	NS
P Treatment																											
P_2O_5 (lb/A)	Source																										
0	Ctrl		1567	1.5	1.4	89	3920	0.3	0.7	1.0	4.0	364	125	<0.3	547	119	0.5	8	3.7	72	5.3	35.0	431	9.9	4.3	1.9	5.0
350	Fert		1588	1.5	1.4	92	3909	0.3	0.7	0.9	3.5	378	125	0.3	517	122	0.5	8	4.0	89	5.4	36.4	423	10.3	4.3	2.0	4.9
700	Fert		1625	1.6	1.4	89	3851	0.3	0.8	1.0	3.7	402	145	0.3	537	134	0.5	9	3.8	155	5.7	51.9	413	10.1	4.3	2.1	5.3
1400	Fert		1715	1.6	1.4	93	3901	0.3	0.7	1.2	4.2	438	133	0.3	514	132	0.5	8	4.1	242	5.9	33.7	422	10.5	4.7	2.2	5.4
750	Ash		1763	1.7	1.5	99	4501	0.6	0.7	1.8	11.7	438	144	<0.3	556	139	0.6	12	4.2	277	8.0	32.3	470	11.2	5.2	2.2	8.7
1500	Ash		1938	1.9	1.6	102	5122	0.8	0.8	2.7	19.9	507	138	0.3	682	149	0.6	17	4.3	496	9.2	33.3	533	12.5	6.4	2.4	12.8
3000	Ash		2169	2.1	1.8	114	5275	1.3	0.8	4.2	32.1	609	142	0.3	724	165	0.7	23	5.0	826	11.8	35.1	616	14.0	8.5	2.7	19.0
Significance			**	**	**	**	**	**	NS	**	**	**	NS	--	**	**	**	**	**	**	**	NS	**	**	**	**	**
BLSD (0.05)			102	0.2	0.2	7	601	0.2	--	0.4	3.7	51	--	--	93	17	0.1	2	0.4	101	1.1	--	66	1.1	1.1	0.2	1.7
Contrasts																											
Ctrl vs Rest			**	**	**	**	*	**	NS	**	**	**	NS	--	NS	**	**	**	**	**	**	NS	NS	**	**	**	**
Fert vs Ash			**	**	**	**	**	**	NS	**	**	**	NS	--	**	**	**	**	**	**	**	NS	**	**	**	**	**
Linear Fert			**	*	NS	NS	NS	NS	NS	NS	NS	**	NS	--	NS	NS	*	NS	NS	*	NS	NS	NS	NS	NS	*	NS
Quad Fert			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear Ash			**	**	**	**	**	**	*	**	**	**	NS	--	**	**	**	**	**	**	**	NS	**	**	**	**	**
Quad Ash			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions																											
Lime by P			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 = nonsignificant; *, ** = significant at 5% and 1%, respectively.

Table 3. Effect of lime and residual effects of a five year cumulative application of sludge ash and phosphate fertilizer on whole plant dry weight (pre-flower stage) and grain yield.

Treatment			Whole plant dry wt. pre-flower	Grain yield
Cumulative P_2O_5 (lb/A)	Source	Lime (T/A)	(g/plant)	(bu/A)
0	Ctrl	0	2.8	32.0
350	Fert	0	3.1	34.5
700	Fert	0	2.9	34.5
1400	Fert	0	3.7	36.5
750	Ash	0	3.3	37.0
1500	Ash	0	3.8	40.0
3000	Ash	0	3.8	36.6
0	Ctrl	10	3.2	37.6
350	Fert	10	4.2	39.1
700	Fert	10	4.3	40.5
1400	Fert	10	5.0	39.0
750	Ash	10	4.3	39.9
1500	Ash	10	4.0	39.6
3000	Ash	10	3.8	38.6
Significance			**	**
BLSD (0.05)			1.3	3.5
Main effects				
Lime -			3.3	35.9
+			4.1	39.2
Significance			**	**
P Treatment				
P_2O_5 (lb/A)	Source			
0	Ctrl		3.0	34.8
350	Fert		3.7	36.8
700	Fert		3.6	37.5
1400	Fert		4.3	37.8
750	Ash		3.8	38.5
1500	Ash		3.9	39.8
3000	Ash		3.8	37.6
Significance			*	**
BLSD (0.05)			0.9	2.6
Contrasts				
Ctrl vs Rest			**	**
Fert vs Ash			NS	NS
Linear Fert			**	*
Quad Fert			NS	NS
Linear Ash			NS	NS
Quad Ash			NS	**
Interactions				
Lime by P			NS	NS

NS = nonsignificant; *, ** = significant at 5% and 1%, respectively.

Table 4. Effect of lime and residual effects of a five year cumulative application of sludge ash and phosphate fertilizer on the elemental composition of whole plants at the pre-flower stage.

Treatment: Cumulative P_2O_5	Source	Lime	N	P	K	Ca	Mg	Al	B	Cd	Cr	Cu	Fe	Mn	Mo	Na	Ni	Pb	Zn
(lb/A)		(T/A)	%					ppm											
0	Ctrl	0	3.75	0.32	2.62	1.70	0.70	293	37	0.3	1.0	10.5	252	87	0.4	16.1	3.4	2.4	37
350	Fert	0	3.83	0.37	2.57	1.65	0.67	272	38	0.3	1.0	8.7	244	88	0.4	21.0	3.4	2.4	35
700	Fert	0	3.91	0.39	2.39	1.74	0.70	293	40	0.3	1.1	6.8	255	91	0.4	16.1	3.4	2.5	33
1400	Fert	0	3.95	0.45	2.67	1.79	0.69	301	39	0.3	1.1	6.0	257	89	0.4	15.4	3.7	2.5	32
750	Ash	0	3.88	0.40	2.61	1.69	0.70	307	39	0.4	1.1	9.4	267	85	0.7	15.4	3.4	2.5	43
1500	Ash	0	3.98	0.42	2.55	1.70	0.73	304	41	0.4	1.2	9.5	263	81	1.9	17.0	3.3	2.6	48
3000	Ash	0	3.82	0.43	2.48	1.72	0.78	300	40	0.5	1.2	9.7	265	72	6.2	18.7	3.2	2.6	47
0	Ctrl	10	4.08	0.33	2.84	1.72	0.64	259	32	0.3	0.9	11.8	242	77	1.4	17.9	3.1	<2.2	38
350	Fert	10	3.89	0.38	2.81	1.76	0.67	291	33	0.2	1.0	9.2	270	83	1.3	15.3	3.1	<2.2	35
700	Fert	10	3.83	0.40	3.02	1.73	0.63	263	34	0.3	1.1	7.2	245	80	1.5	24.2	3.2	<2.6	34
1400	Fert	10	4.06	0.43	2.69	1.88	0.71	245	36	0.4	1.1	6.1	237	88	1.1	21.3	3.5	<2.6	33
750	Ash	10	4.40	0.39	2.85	1.76	0.65	280	33	0.3	1.0	11.6	260	84	2.7	19.1	3.3	<2.2	43
1500	Ash	10	3.97	0.41	2.87	1.76	0.67	285	35	0.4	1.2	11.7	261	79	6.2	22.5	3.0	<2.6	44
3000	Ash	10	4.11	0.40	2.80	1.77	0.68	258	36	0.4	1.1	11.0	244	75	7.3	16.8	2.9	<2.3	45
Significance			NS	**	**	**	*	NS	**	**	NS	**	NS	**	**	NS	NS	--	**
BLSD (0.05)			--	0.03	0.30	0.11	0.09	--	2	0.1	--	0.9	--	10	1.4	--	--	--	4
Main effects																			
Lime	-		3.87	0.40	2.55	1.71	0.71	296	39	0.3	1.1	8.6	258	84	1.5	17.1	3.4	2.5	39
	+		4.05	0.39	2.84	1.77	0.66	269	34	0.3	1.1	9.8	251	81	3.1	19.6	3.2	<2.4	39
Significance			*	NS	**	**	**	NS	**	NS	NS	**	NS	*	**	NS	*	--	NS
P Treatment																			
P_2O_5 (lb/A)	Source																		
0	Ctrl		3.91	0.33	2.73	1.71	0.67	276	34	0.3	1.0	11.1	247	82	0.9	17.0	3.2	<2.3	38
350	Fert		3.86	0.37	2.69	1.71	0.67	282	35	0.3	1.0	9.0	257	85	0.8	18.2	3.3	<2.3	35
700	Fert		3.87	0.39	2.70	1.73	0.67	278	37	0.3	1.1	7.0	250	85	1.0	20.1	3.3	<2.5	34
1400	Fert		4.00	0.44	2.68	1.83	0.70	273	38	0.3	1.1	6.0	247	88	0.8	18.3	3.6	<2.5	33
750	Ash		4.14	0.39	2.73	1.73	0.67	293	36	0.4	1.1	10.5	263	85	1.7	17.2	3.3	<2.4	43
1500	Ash		3.97	0.41	2.71	1.73	0.70	294	38	0.4	1.2	11.6	262	80	4.0	19.7	3.2	<2.6	46
3000	Ash		3.97	0.41	2.64	1.74	0.73	279	38	0.4	1.2	10.4	254	73	6.7	17.7	3.0	<2.5	46
Significance			NS	**	NS	**	NS	NS	**	**	*	**	NS	**	**	NS	NS	--	**
BLSD (0.05)			--	0.02	--	0.08	--	--	2	0.1	0.2	0.7	--	7	1.0	--	--	--	3
Contrasts																			
Ctrl vs Rest			NS	**	NS	NS	NS	NS	**	**	*	**	NS	NS	**	NS	NS	--	NS
Fert vs Ash			NS	NS	NS	NS	NS	NS	NS	**	*	**	NS	**	**	NS	*	--	**
Linear Fert			NS	**	NS	**	NS	NS	**	**	NS	**	NS	NS	NS	NS	*	--	**
Quad Fert			NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	--	NS
Linear Ash			NS	**	NS	NS	**	NS	**	**	**	NS	NS	**	**	NS	NS	--	**
Quad Ash			NS	**	NS	NS	NS	NS	*	**	NS	NS	NS	NS	NS	NS	NS	--	**
Interactions																			
Lime by P			NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	*	NS	NS	--	NS

NS= nonsignificant; *, ** = significant at 5% and 1%, respectively.

Table 5. Effect of lime and residual effects of a five year cumulative application of sludge ash and phosphate fertilizer on the elemental composition of recently matured trifoliate leaves.

Treatment: Cumulative P_2O_5	Source	Lime	N	P	K	Ca	Mg	Al	B	Cd	Cr	Cu	Fe	Mn	Mo	Na	Ni	Pb	Zn
(lb/A)		(T/A)	%					ppm											
0	Ctrl	0	5.04	0.37	1.75	1.64	0.38	34.6	51	0.2	0.6	10.8	215	134	<0.2	<7.2	2.1	<1.9	39
350	Fert	0	5.00	0.41	1.71	1.77	0.40	36.8	57	0.2	0.6	10.4	212	157	<0.2	13.2	2.6	<1.9	41
700	Fert	0	4.91	0.42	1.69	1.81	0.43	30.8	58	0.2	0.6	9.3	195	144	<0.2	<7.8	2.8	2.0	41
1400	Fert	0	5.13	0.43	1.66	1.79	0.40	27.2	59	0.2	0.6	7.9	180	158	<0.2	<8.8	3.4	<2.0	39
750	Ash	0	5.39	0.41	1.64	1.69	0.37	32.1	56	0.3	0.6	10.0	198	142	0.3	<11.5	3.1	1.9	43
1500	Ash	0	5.36	0.42	1.54	1.74	0.39	27.5	56	0.3	0.6	9.4	183	124	0.9	<6.5	2.9	<1.8	45
3000	Ash	0	5.53	0.43	1.66	1.71	0.39	31.1	58	0.3	0.6	9.0	184	117	4.6	<11.9	2.9	<1.9	48
0	Ctrl	10	5.24	0.37	1.69	1.66	0.31	33.6	41	0.2	0.6	11.3	219	127	0.8	<7.3	2.3	2.1	38
350	Fert	10	5.31	0.40	1.59	1.77	0.34	35.6	41	0.2	0.6	10.1	224	131	0.9	10.9	2.4	<2.1	36
700	Fert	10	5.22	0.42	1.63	1.89	0.36	26.0	49	0.2	0.6	8.7	202	146	0.8	<6.9	2.8	<2.0	38
1400	Fert	10	5.30	0.43	1.62	1.83	0.36	25.8	51	0.2	0.6	7.4	190	142	0.9	<6.6	3.2	<1.9	36
750	Ash	10	5.35	0.40	1.56	1.82	0.36	22.5	46	0.2	0.6	10.7	199	134	2.1	<11.2	2.8	2.0	42
1500	Ash	10	5.36	0.42	1.66	1.81	0.34	21.5	50	0.2	0.6	10.6	198	131	7.1	10.8	2.5	<2.1	44
3000	Ash	10	5.42	0.42	1.64	1.77	0.35	25.4	53	0.3	0.7	10.3	197	122	9.4	<7.3	2.9	2.2	46
Significance			**	**	**	*	**	NS	**	**	NS	**	**	**	--	--	**	--	**
BLSD (0.05)			0.37	0.02	0.10	0.15	0.04	--	4	0.1	--	1.1	19	16	--	--	0.6	--	4
Main effects																			
Lime	-		5.19	0.42	1.67	1.74	0.39	31.4	56	0.2	0.6	9.5	195	139	<1.0	<9.5	2.8	<1.9	42
	+		5.31	0.41	1.63	1.79	0.35	27.2	47	0.2	0.6	9.9	204	133	3.2	<8.7	2.7	<2.1	40
Significance			*	NS	*	*	**	*	**	NS	NS	NS	*	*	--	--	NS	--	**
P Treatment: P_2O_5 (lb/A)	Source																		
0	Ctrl		5.14	0.37	1.72	1.65	0.35	34.1	46	0.2	0.6	11.0	217	130	<0.5	<7.3	2.2	<2.0	39
350	Fert		5.15	0.41	1.65	1.77	0.37	36.2	49	0.2	0.6	10.2	218	144	<0.6	12.1	2.5	<2.0	38
700	Fert		5.06	0.42	1.66	1.85	0.39	28.4	53	0.2	0.6	9.0	199	145	<0.5	<7.4	2.8	<2.0	40
1400	Fert		5.22	0.43	1.64	1.81	0.38	26.5	55	0.2	0.6	7.6	185	150	<0.6	<7.7	3.3	<2.0	38
750	Ash		5.37	0.41	1.60	1.76	0.36	27.3	51	0.2	0.6	10.4	198	138	1.2	<11.4	2.9	1.9	42
1500	Ash		5.36	0.42	1.60	1.78	0.37	24.5	53	0.3	0.6	10.0	190	128	4.0	<8.5	2.7	<1.9	45
3000	Ash		5.47	0.43	1.65	1.74	0.37	28.3	55	0.3	0.6	9.7	190	120	7.0	<9.6	2.9	<2.0	47
Significance			**	**	**	**	*	*	**	**	NS	**	**	**	--	--	**	--	**
BLSD (0.05)			0.24	0.02	0.07	0.10	0.03	8.2	3	0.1	--	0.8	13	11	--	--	0.4	--	3
Contrasts																			
Ctrl vs Rest			NS	**	**	**	*	*	**	**	NS	**	**	NS	--	--	**	--	**
Fert vs Ash			**	NS	NS	*	NS	NS	NS	**	NS	**	*	**	--	--	NS	--	**
Linear Fert			NS	**	*	**	*	*	**	**	NS	**	**	**	--	--	**	--	NS
Quad Fert			NS	**	NS	**	**	NS	*	NS	NS	NS	NS	NS	--	--	NS	--	NS
Linear Ash			**	**	NS	NS	NS	NS	**	**	*	**	**	**	--	--	**	--	**
Quad Ash			NS	**	**	*	NS	*	*	*	NS	NS	**	NS	--	--	*	--	NS
Interactions																			
Lime by P			NS	NS	*	NS	NS	NS	**	**	NS	NS	NS	*	--	--	NS	--	NS

NS = Nonsignificant; *, ** = significant at 5% and 1%, respectively.

Table 6. Effect of lime and residual effects of a five year cumulative application of sludge ash and phosphate fertilizer on the elemental composition of grain at harvest.

Treatment																			
Cumulative P_2O_5	Source	Lime	N	P	K	Mg	Ca	Al	B	Cd	Cr	Cu	Fe	Mn	Mo	Na	Ni	Pb	Zn
(lb/A)		(T/A)	%					ppm											
0	Ctrl	0	6.18	0.61	1.73	0.28	0.32	18.8	29	<0.1	0.5	15.0	103	40	0.4	<3.7	7.2	<1.7	48
350	Fert	0	6.03	0.72	1.84	0.29	0.32	15.7	30	<0.1	0.5	13.9	103	41	0.3	<3.6	8.5	<1.7	50
700	Fert	0	6.09	0.72	1.83	0.29	0.30	12.6	30	<0.1	0.4	11.1	92	39	0.4	<3.6	8.7	<1.7	49
1400	Fert	0	6.08	0.74	1.84	0.28	0.30	11.2	30	0.1	0.5	9.0	88	40	0.5	<3.6	9.5	<1.7	48
750	Ash	0	6.31	0.67	1.83	0.28	0.29	12.2	29	0.2	0.4	11.9	87	38	1.2	<4.1	7.5	<1.7	50
1500	Ash	0	6.38	0.69	1.85	0.28	0.29	12.3	29	0.2	0.4	11.2	85	35	4.0	<3.6	7.1	<1.7	52
3000	Ash	0	6.36	0.71	1.85	0.27	0.29	11.6	29	0.3	0.5	10.6	82	34	12.4	<3.6	7.1	<1.7	53
0	Ctrl	10	6.42	0.61	1.76	0.28	0.31	13.0	25	<0.1	0.4	15.7	91	35	5.2	<5.2	5.7	<1.7	49
350	Fert	10	6.46	0.67	1.81	0.28	0.30	12.7	25	<0.1	0.4	11.7	93	35	4.9	<3.6	6.9	<1.7	47
700	Fert	10	6.34	0.70	1.86	0.28	0.29	10.2	27	<0.1	0.4	9.6	86	36	4.7	<3.6	7.6	<1.7	48
1400	Fert	10	6.40	0.71	1.85	0.28	0.30	9.8	28	<0.1	0.4	7.7	86	36	5.2	<3.6	8.5	<1.7	47
750	Ash	10	6.44	0.68	1.86	0.28	0.28	8.6	26	<0.1	0.4	14.0	86	33	8.5	<3.6	6.8	<1.7	51
1500	Ash	10	6.35	0.68	1.86	0.28	0.29	13.0	26	<0.1	0.5	14.0	97	33	16.0	<4.2	6.2	<1.7	52
3000	Ash	10	6.35	0.70	1.85	0.28	0.29	13.1	27	0.2	0.4	12.9	89	33	22.0	<3.6	6.7	<1.7	53
Significance			**	**	**	**	**	NS	**	--	NS	**	NS	**	**	--	**	--	**
BLSD (0.05)			0.17	0.03	0.07	0.01	0.02	--	2	--	--	0.9	--	2	3.1	--	1.3	--	3
Main effects																			
Lime	-		6.20	0.69	1.82	0.28	0.30	13.5	30	<0.2	0.5	11.8	92	38	2.7	<3.7	7.9	<1.7	50
	+		6.39	0.68	1.83	0.28	0.29	11.5	26	<0.1	0.4	12.1	90	34	9.5	<3.9	6.9	<1.7	49
Significance			**	*	NS	*	*	NS	**	--	NS	NS	NS	**	**	--	**	--	NS
P Treatment																			
P_2O_5 (lb/A)	Source																		
0	Ctrl		6.30	0.61	1.75	0.28	0.31	15.9	27	<0.1	0.5	15.3	97	38	2.8	<4.4	6.4	<1.7	48
350	Fert		6.24	0.69	1.82	0.29	0.31	14.2	28	<0.1	0.5	12.8	98	38	2.6	<3.6	7.7	<1.7	49
700	Fert		6.21	0.71	1.84	0.28	0.30	11.4	28	<0.1	0.4	10.3	89	38	2.6	<3.6	8.2	<1.7	49
1400	Fert		6.24	0.73	1.84	0.28	0.30	10.5	29	<0.1	0.4	8.3	87	38	2.9	<3.6	9.0	<1.7	48
750	Ash		6.37	0.68	1.84	0.28	0.28	10.4	28	<0.1	0.4	12.9	86	36	4.9	<3.8	7.1	<1.7	50
1500	Ash		6.37	0.69	1.85	0.28	0.29	12.6	28	<0.2	0.5	12.4	91	34	10.0	<3.9	6.7	<1.7	52
3000	Ash		6.36	0.70	1.85	0.28	0.29	12.4	28	0.2	0.5	11.8	86	33	17.2	<3.6	6.9	<1.7	53
Significance			*	**	**	**	**	NS	**	--	NS	**	NS	**	**	--	**	--	**
BLSD (0.05)			0.14	0.03	0.04	0.01	0.02	--	1	--	--	0.7	--	2	2.2	--	0.9	--	2
Contrasts																			
Ctrl vs Rest			NS	**	**	NS	**	*	**	--	NS	**	NS	**	**	--	**	--	*
Fert vs Ash			**	**	NS	**	NS	NS	*	--	NS	**	NS	**	**	--	**	--	**
Linear Fert			NS	**	**	NS	**	*	**	--	NS	**	*	NS	NS	--	**	--	NS
Quad Fert			NS	**	**	NS	NS	NS	NS	--	NS	**	NS	NS	NS	--	NS	--	NS
Linear Ash			NS	**	**	NS	NS	NS	*	--	NS	**	NS	**	**	--	NS	--	**
Quad Ash			NS	**	**	NS	*	NS	NS	--	NS	**	NS	*	NS	--	NS	--	NS
Interactions																			
Lime by P			**	NS	NS	NS	NS	NS	*	--	*	**	NS	**	**	--	NS	--	NS

NS = nonsignificant; *, ** = significant at 5% and 1%, respectively.

AGRICULTURAL UTILIZATION OF NUTRALIME: ON FARM DEMONSTRATION PLOTS - 1993[1]

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ABSTRACT: The third year of NutraLime demonstrations were conducted in Dakota, Isanti, and Washington counties. NutraLime (spent lime and sewage sludge incinerator ash) was applied in 1991 at all three locations. Residual effects were monitored in 1993 on seed corn (Dakota county), field corn (Washington County) and alfalfa (Isanti County). For alfalfa at the Isanti county site, spent lime without ash was applied on half the control plot to determine effects of raising pH without the elements in the ash. Alfalfa yields increased substantially with NutraLime application and to a lesser extent with spent lime application. Elevated Mo tissue alfalfa tissue concentrations were associated with NutraLime application. The Mo levels accumulated in alfalfa tissue were above those considered safe for ruminants. Higher Mo was also found in alfalfa grown on limed plots, but levels were not in a range considered to be and animal health problem. Field corn yields significantly increased with NutraLime application and was associated with an increase in soil pH from 5.3 in the control plots to above 7.0 in the amended plots. In contrast, seed corn yield decreased with NutraLime application. Causes for this yield decrease are unclear, but may be due to pH induced Mn deficiency. Seed corn has a limited root system and most roots were probably confined to the high pH region where NutraLime was applied. Application of NutraLime increased soil water sulfur concentrations at the 2.5 ft depth. Trace metals were generally below detection limits at the 2.5 ft depth. In cases where NutraLime increased trace elements in soil water (Zn for example), the levels detected were all well below limits set for drinking water. Soil pH and plant available P increased with increasing NutraLime application. DTPA extractable Cd and Cu increased with NutraLime in the top 6 inches, whereas DTPA extractable Ni and Mn decreased. NutraLime had no effect on DTPA extractable Pb, Zn, or Cr. Nitric acid extractable elements increased in the top 6 inches and to a lesser extent in the 6-12 inch depth. Except for S, NutraLime did not consistently affect nitric acid extractable elements in the 12-24 inch depth.

NutraLime is a product made from two waste materials: sewage sludge incinerator ash from the Metropolitan 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. All results reported here are based on residual effects of NutraLime following a one time application in 1991.

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 were presented previously. The same basic procedure was followed at each site. Treatments were applied in 1991 and 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 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 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 in Table 1. Elemental content of the NutraLime at each site was determined on concentrated nitric acid/perchloric acid digests and presented previously.

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

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At the Dakota Co. site in 1993, the crop tested for response to NutraLime was seed corn, Jacques Y001XJ46 (female inbred). The seed corn was planted May 16 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, the crop tested for response to NutraLime was Alfalfa (Agate). In addition to the NutraLime applied in 1991, spent lime (without the ash) was applied on half of the control plots at a rate of 20 dry tons/A on April 24, 1993. Potassium was applied as KCl at the rate of 600 lb K_2O/A. The lime and potassium were disked in to a depth of 6" and the alfalfa was planted on April 25. The site was nonirrigated. At the Washington Co. site, the crop tested for response to NutraLime was Jacques 6770 field corn planted on April 29. The plant population was 28,000 seeds/A (2.5' between rows). Anhydrous ammonia was applied preplant at the rate of 150 lb N/A and 150 lb K_2O/ was broadcast and incorporated in the spring. Starter fertilizer was applied at a rate of 13 lb N/A, 34 lb P_2O_5/A, and 15 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 each site. Multiple elements were determined in water samples using ICP procedures. In Isanti Co., alfalfa was harvested twice: July 12 and August 26. Harvested area included 5 sq. ft. per replication. Samples were dried, weighed and then ground. At the Dakota Co. site, whole plant seed corn at the 8-12 leaf stage was sampled on July 20. Ear leaves were sampled at silking on August 6 and the plot was harvested on September 1 (two 25 ft rows per replication). At the Washington Co. site, field corn whole plants (8-12 leaf) were sampled on July 7. Ear leaves were sampled at silking on August 6 and the plot was harvested on October 12 (two 25 ft rows per replication). For both corn plots, 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 conductimetric procedures. Soil samples were collected after harvest. Within each replication, eight subsamples were combined at one foot intervals down to a depth of 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. NutraLime had a negative effect on seed corn grain yield at the Dakota Co. site (Table 2). Causes for this negative response are not known, but may be due to delayed maturity due to NutraLime. Grain moisture was significantly higher with increasing NutraLime application. Early plant growth, final stand count and stover yield were not affected by NutraLime application. In contrast to the negative effects on seed corn NutraLime significantly increased grain yield in field corn at the Washington Co. site (Table 3). Associated with this increase was an increase in early plant growth due to NutraLime application. No effects due to NutraLime application were found for grain moisture, final stand count, or stover yield.

Effects of NutraLime on alfalfa growth in Isanti Co. are presented in Tables 4. For both cuttings, NutraLime increase alfalfa yield substantially compared to the nonlimed control. Yield with NutraLime also tended to be greater than yield with the limed control. This comparison is somewhat biased toward the NutraLime treatment since the lime application was recently applied and only disked in prior to planting. Except for the seed corn results from this year, the yield data from 1993 indicate that when applied at realistic rates, NutraLime can have a beneficial effect on plant growth. Causes for the negative effects on seed corn in 1993 need to be investigated further.

Elemental Concentrations in Soil Water. Elemental concentrations in water collected from suction tubes at the 2.5' depth are presented in Tables 5 - 7. At the Dakota Co. site Al, Cd, Cr, Cu, Fe, K, Mg, Mo, Na, Ni, Pb, and P were all at background levels or below detection limits (Table 7). S and Zn concentrations increased slightly with NutraLime application on some sampling dates. None of the elements detected were at levels above drinking water standards. Slight trends in increasing B, Mg, and Ca concentrations with increasing NutraLime were also detected.

At the Isanti Co. site Al, B, Cd, Cr, Cu, Fe, K, Mo, Ni, P, and Pb concentrations were generally below detection limits (Table 6). Ca, Mg, Mn, and Zn slightly increased with NutraLime application. Concentrations of S increased with increasing NutraLime at the both sampling date. Concentrations of Na were not consistently affected by NutraLime.

At the Washington county site, concentrations of all elements were at background levels or below detection limits except for Ca, Mg, and S (Table 7). These elements tended to increase with NutraLime application.

Elemental Concentrations in Soil. Soluble salts, soil pH, Bray and Olsen P, ammonium acetate extractable cations and DTPA extractable metals are presented in Tables 8-10. Soil pH was still substantially higher (1.3-1.7 units) in the top 6 inches with the 0.5X NutraLime rate compared to the control. With higher

NutraLime rates, soil pH increased by an additional 0.1-0.6 units. At the 6-12 inch depth, soil pH was 0.3-1.3 units higher in the 2X rate compared to the control. Soil pH was not affected by NutraLime treatment at the 12-24 inch depth at any site. Lime applied at the Isanti site resulted in similar pH changes as the 2X NutraLime rate at all depths. Soluble salts in the top 6 inches generally increased with NutraLime application rate; however, none of the soluble salt levels were in a range considered to be high enough to cause salt toxicity. Lime application at the Isanti site resulted in higher salt levels than the 2X NutraLime rate. In the 6-12 inch and 12-24 inch depths, soluble salts tended to increase with NutraLime application, although the increase was not always statistically significant. Bray and Olsen P increased with NutraLime application in the top 6 inches at all sites. In the 6-12 and 12-24 inch depths, soil P tended to increase with NutraLime application at all sites. As with soil pH, this increase was not always statistically significant. Lime application resulted in similar extractable P levels as the control. Extractable K was not consistently affected by NutraLime application. In Isanti Co. extractable K decreased with NutraLime application rate, while in Dakota and Washington Counties, no trend with NutraLime was apparent. Extractable Na increased with NutraLime rate at the Washington Co. site in the top 24 inches. Slight trends Na levels were also found at the Dakota and Isanti sites at the 6-12" depth. Extractable Ca and Mg increased with NutraLime application in the top 6 inches at all sites. At the 6-12 inch depth, Ca and Mg increased with NutraLime rate at the Washington and Isanti Co. sites. In the 12-24 inch depth, Ca and Mg were not significantly affected by NutraLime treatment. DTPA extractable Fe, Mn, and Ni decreased with NutraLime application in the top 6 inches and were unaffected or continued to decrease with NutraLime rate in the lower depths. DTPA extractable Cu increased in the top 6 inches at all sites and generally increased in the 6-12 inch depth. DTPA extractable Zn in the top 6" increased slightly with NutraLime rate at the Isanti Co. site, but was not affected at the other sites. Extractable Pb either was not affected or decreased with NutraLime rate. DTPA extractable Cd tended to increase with NutraLime rate in the top 6 inches. In the 6-12 inch depth, DTPA Cd was not consistently affected by NutraLime rate and in the 12-24 inch depth, DTPA Cd was generally below detection limits. DTPA extractable Cr was not affected by NutraLime application, with most concentrations below detection limits of the spectrophotometer. In general, DTPA extractable trace elements were not affected by NutraLime in the 12-24" depth. Lime treatment at the Isanti Co. site generally decreased availability of Mn, Pb, Ni, and Cd in the top 6" with not difference in trace element levels at lower depths compared to the control.

Nitric acid extractable soil elements are presented in Tables 11-13. All elements tested, except Be, Co, K, and Li increased with NutraLime application in the top 6 inches at all sites. Li was frequently below detection limits, K increased with NutraLime application at two of the three sites, and Co increased at two of the three sites. Sulfur generally increased with NutraLime application in all depths at the Isanti and Washington Co. sites, indicating that S was moving through the soil profile. The results substantiate the increases in S with NutraLime treatment in soil water. At Dakota County, As, Cu, and Na increased with NutraLime application in the 6-12 inch depth. At the Isanti Co. site, Ca, Cr, Cu Na, and Si increased with increasing NutraLime treatment. At Washington County, As, Ca, Co, Pb, Mg, Mo, Si, Na, Ti, and V tended to increase with NutraLime application rate. It is likely that most of the increases in elements with NutraLime treatment at the 6-12 inch depth are due to tillage operations. Tillage operations at the Dakota County site would be expected to have had the most influence on mixing of NutraLime to lower depths since deeper tillage was used. Significant increases in elements with NutraLime application at the 12-24 inch depth were not detected at the Dakota Co. or Isanti Co. sites. At Washington County, Al, As, Cu, Mo, P, Na slightly increased at the 12-24" depth. Background concentrations of most elements at this lower depth indicate that minimal movement had occurred three years after NutraLime application. Lime treatment at Isanti Co. resulted in higher levels nitric acid extractable As, Ca, Mg, Mn, Si, and S in the 0-6" depth relative to the nonlimed treatment. At lower depths the limed treatment resulted in similar concentrations of nitric acid extractable elements compared to the nonlimed treatment.

Elemental Concentrations in Plant Tissue. Elemental concentrations in seed corn whole plant at the 8-12 leaf stage, ear leaf at silking, stover, cob, and kernels are presented in Tables 14-18. Whole plant samples increased in Mo concentrations with NutraLime application. Ear leaf (diagnostic leaf) concentrations of Mo and Cu increased and Fe decreased with increasing NutraLime application. All other elements were not significantly affected by NutraLime application and except for Zn, were within sufficiency ranges expected for healthy plants. Even though Fe concentrations decreased with NutraLime application, they were still well above a range where any deficiency would be expected to occur. The decrease in yield with NutraLime application at this site does not appear to be caused by nutritional imbalances. The only element that appeared to be in the deficiency range was Zn, but the control was also low. Concentrations of Mn were on the low side for the NutraLime treatments, but still considered adequate for optimum corn growth. Perhaps seed corn with its more limited root system requires higher levels of nutrients compared to field corn. Concentrations of Mo increased and Mn decreased with increasing NutraLime application in seed corn stover. It is possible that the higher pH induced a Mn deficiency causing the yield decrease. Further research would have to be conducted to substantiate this possibility. Concentrations of Mo, B, Zn, Cu, Fe, Mg, Ca, and K tended to increase in cobs with NutraLime application. Concentrations of Mo, N, and Zn increased in kernel samples with increasing NutraLime application. Levels of Cd, Ni, Pb, and Cr were either below detection limits or not significantly affected by NutraLime application.

Elemental concentrations in field corn whole plants at the 8-12 leaf stage, ear leaf at silking, stover, cob and kernels are presented in Tables 19-23. In whole plant samples, concentrations of Mo, Mg, and Ca increased and concentrations of N, Fe, Mn and Zn decreased with increasing NutraLime application. Ear leaf (diagnostic leaf) concentrations of Mo, Cr, Al, Ca, and P increased with increasing NutraLime application. All other elements were not significantly affected by NutraLime application and were within sufficiency ranges expected for healthy plants. The increase in yield with NutraLime application at this site is difficult to explain on a nutritional basis from nutrient levels in the diagnostic leaf. Concentrations of Mo, B, Cu, and Cd increased with increasing NutraLime application in seed corn stover. It is possible that the low Mo in plants growing in the control plots were deficient, resulting in a lower yield compared to plants in the NutraLime amended plots. Even though Cd levels increased in stover, they were well below the level of 0.5 ppm required to cause problems in animals. Concentrations of Mo increased and Zn and Mn decreased in cobs with NutraLime application. Concentrations of Mo increased in kernel samples with increasing NutraLime application. Levels of Cd, Ni, Pb, and Cr in kernels were below detection limits in all treatments.

Elemental concentrations in alfalfa tissue at the two harvests are presented in Tables 24 and 25. In the first harvest concentrations of N, P, K, Na, and Mo increased and Al, Mn, Zn, B, and Ni decreased with increasing NutraLime. Spent lime applications increased N, P, K, Mg, Na, Mo, Mn, Zn, B, and Ni compared to the nonlimed treatment. Alfalfa tissue concentrations of Mo in NutraLime amended plots, were at a level where molybdenosis could be a problem. As discussed in previous years when soybean was grown, legumes have a high demand for Mo and seem to accumulate this element in foliage and grain. Implications for using NutraLime for alfalfa are that it needs to be monitored for Mo content so that rations can be supplemented with copper or mixed with forage that is much lower in Mo. Although the lime treatment also increased Mo concentrations, the level was below that considered a problem for ruminants. At the second harvest, concentrations of Mo increased and N, Mg, Fe, Mn, Cu, B, and Ni decreased with increasing NutraLime application. Concentrations of Mo were lower in the second harvest compared to the first harvest due to the fact that the root system had begun to explore lower depths where the pH was lower resulting in lower Mo availability. The limed treatment resulted in higher Mo concentrations and lower Ca, Mn, Zn, Cu, B, and Ni compared to the nonlimed treatment. For both harvests, Cd, Cr, and Pb were either not affected by NutraLime treatment or were below detection limits.

GENERAL SUMMARY

NutraLime application increased field corn yield and alfalfa yield, but decreased yield of seed corn. For alfalfa, yield increases were substantial with increasing NutraLime, but tissue levels of Mo increased to levels where molybdenosis could be a problem if the forage was chronically ingested. Improved P and Mo nutrition appeared to be involved with increases in alfalfa yield. Reasons for the decrease in seed corn yield with NutraLime application are unclear, but may be related to a pH induced Mn deficiency. The increase in field corn yield was related to an increase in soil pH from 5.3 in the control to above 7 in NutraLime amended plots. The main nutrient associated with the yield increase was Mo. Concentrations of Cd, Cr, Ni and Pb in plant tissues were below the levels where animal health problems would be a concern. In general, trace metals applied with NutraLime were confined to the top 12 inches of soil. NutraLime effectively increased soil pH and plant available P. Trace elements detected in soil water at the 2.5 foot depth were below limits set for drinking water.

Table 1. NutraLime treatments applied at each site prior to planting in 1991.

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 2. Effect of NutraLime on whole plant dry matter at the 10-14 leaf stage, final stand count, grain and stover yield, and grain moisture - seed corn, Dakota County.

NutraLime Treatment	Whole plant dry matter (10-14 leaf)	Final stand count	Grain yield	Dry stover	Grain moisture
	-grams/plant-	-plants/A-	-bu/A-	-tons/A-	- % -
0	209	22796	51.3	3.61	19
0.5x	213	24394	42.1	3.67	26
1.0x	201	25264	42.6	4.07	29
2.0x	207	23522	37.8	4.14	28
Significance	NS	NS	NS	NS	NS
BLSD (5%)	--	--	--	--	--
Linear	NS	NS	*	NS	*
Quadratic	NS	NS	NS	NS	NS

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

Table 3. Effect of NutraLime on whole plant dry matter at the 8-12 leaf stage, final stand count, grain and stover yield, and grain moisture - field corn, Washington County.

NutraLime Treatment	Whole plant dry matter (8-12 leaf)	Final stand count	Grain yield	Dry stover	Grain moisture
	-grams/plant-	-plants/A-	-bu/A-	-tons/A-	- % -
0	71	28750	125.4	2.12	45
0.5x	92	29040	145.3	2.05	44
1.0x	88	27298	140.2	2.22	45
2.0x	97	28750	140.7	2.37	46
Significance	*	NS	*	NS	NS
BLSD (5%)	17	--	13.6	--	--
Linear	*	NS	NS	NS	NS
Quadratic	NS	NS	*	NS	NS

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

Table 4. Effect of NutraLime on alfalfa whole plant dry weight at the 1 to 10 percent bloom stage - Isanti County.

NutraLime Treatment	Plant dry weight first cutting	Plant dry weight second cutting
	-tons/A-	-tons/A-
0	0.74	0.79
Lime	1.07	1.68
0.5x	1.45	1.70
1.0x	1.55	2.16
2.0x	1.62	2.11
Significance	**	**
BLSD (5%)	0.39	0.38
Linear	**	**
Quadratic	**	**
Lime vs 2.0x	*	*

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

Table 5. Effect of NutraLime on elemental composition of soil water collected from suction tubes - Dakota County.

Date	Trmt	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Zn
July 6, 1993										ppm								
	0	<0.18	<0.02	63	<0.006	<0.01	<0.03	<0.02	<1.7	16	<0.01	<0.01	7	<0.02	<0.04	<0.08	12	0.06
	0.5x	<0.18	<0.02	62	<0.006	<0.01	<0.03	<0.03	4.0	17	0.03	<0.03	12	<0.02	<0.05	<0.08	21	0.19
	1.0x	<0.21	<0.02	70	<0.006	<0.01	<0.03	<0.02	1.1	15	<0.02	<0.01	12	<0.02	<0.04	<0.08	22	0.18
	2.0x	<0.18	0.04	67	<0.006	<0.01	<0.03	<0.02	<1.4	16	<0.01	<0.01	6	<0.02	<0.04	<0.08	12	0.10
Significance		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	**	NS
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5	--
Contrasts																		
Linear		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	NS	NS
Quadratic		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	**	NS
August 6, 1993																		
	0	<0.19	<0.03	86	<0.006	<0.01	<0.03	<0.02	1.9	21	<0.01	<0.01	10	<0.02	<0.05	<0.08	13	0.08
	0.5x	<0.22	<0.03	53	<0.006	<0.01	<0.03	<0.02	4.0	14	<0.04	<0.01	11	<0.02	<0.04	<0.08	20	0.14
	1.0x	<0.25	<0.03	102	<0.006	<0.01	<0.03	<0.03	2.0	25	0.04	<0.01	16	<0.03	<0.04	<0.08	27	0.21
	2.0x	<0.20	0.06	133	<0.006	<0.01	<0.03	<0.02	2.8	35	<0.02	<0.01	10	<0.02	<0.04	<0.08	14	0.13
Significance		--	--	NS	--	--	--	--	NS	NS	--	--	NS	--	--	--	*	NS
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	10	--
Contrasts																		
Linear		--	--	NS	--	--	--	--	NS	NS	--	--	NS	--	--	--	NS	NS
Quadratic		--	--	NS	--	--	--	--	NS	NS	--	--	NS	--	--	--	**	NS
September 1, 1993																		
	0	<0.18	<0.03	69	<0.006	<0.01	<0.03	<0.02	1.7	17	<0.01	<0.01	7	<0.02	<0.05	<0.08	12	0.05
	0.5x	<0.22	<0.02	50	<0.006	<0.01	<0.03	<0.02	3.3	13	<0.04	<0.01	11	<0.02	<0.06	<0.08	20	0.12
	1.0x	<0.28	0.03	99	<0.006	<0.01	<0.03	<0.02	1.9	24	0.05	<0.01	15	<0.03	<0.04	<0.08	30	0.20
	2.0x	<0.20	0.05	94	<0.006	<0.01	<0.03	<0.02	2.6	24	<0.02	<0.01	8	<0.02	<0.04	<0.08	13	0.07
Significance		--	--	NS	--	--	--	--	NS	NS	--	--	NS	--	--	--	*	NS
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	13	--
Contrasts																		
Linear		--	--	NS	--	--	--	--	NS	NS	--	--	NS	--	--	--	NS	NS
Quadratic		--	--	NS	--	--	--	--	NS	NS	--	--	NS	--	--	--	**	*

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

Table 6. Effect of NutraLime on elemental composition of soil water collected from suction tubes - Isanti County.

Date	Trmt	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Zn
June 22, 1993										ppm								
	0	<0.18	<0.02	25	<0.006	<0.01	<0.03	<0.02	<0.7	9	<0.02	<0.01	9	<0.03	<0.04	<0.08	9	0.06
	0.5x	<0.18	<0.02	50	<0.006	<0.01	<0.03	<0.02	<0.7	17	0.05	<0.02	12	<0.03	<0.04	<0.08	20	0.07
	1.0x	<0.18	<0.02	41	<0.007	<0.01	<0.03	<0.02	<0.8	14	0.05	<0.01	9	<0.03	<0.04	<0.08	24	0.15
	2.0x	<0.18	<0.03	49	<0.006	<0.01	<0.03	<0.03	<0.9	17	0.06	<0.01	9	<0.04	<0.05	<0.08	32	0.10
Significance		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	**	NS
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7	--
Contrasts																		
Linear		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	**	NS
Quadratic		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	NS	NS
August 3, 1993																		
	0	<0.18	<0.02	23	<0.006	<0.01	<0.04	<0.02	<0.7	8	0.02	<0.01	8	<0.03	<0.04	<0.08	9	0.07
	0.5x	<0.18	<0.02	46	<0.006	<0.01	<0.03	<0.02	<0.7	16	0.05	<0.01	12	<0.03	<0.04	<0.08	20	0.06
	1.0x	<0.18	<0.02	38	<0.006	<0.01	<0.03	<0.02	0.9	14	0.05	<0.01	10	<0.03	<0.10	<0.08	24	0.10
	2.0x	<0.22	<0.02	45	<0.006	<0.01	<0.04	<0.02	<1.0	16	0.07	<0.01	9	<0.03	<0.06	<0.08	30	0.12
Significance		--	--	NS	--	--	--	--	--	NS	NS	--	NS	--	--	--	**	NS
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	9	--
Contrasts																		
Linear		--	--	NS	--	--	--	--	--	NS	NS	--	NS	--	--	--	**	NS
Quadratic		--	--	NS	--	--	--	--	--	NS	NS	--	NS	--	--	--	NS	NS

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

Table 7. Effect of NutraLime on elemental composition of soil water collected from suction tubes - Washington County.

Date	Trmt	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Zn
		ppm																
June 8, 1993																		
	0	<0.18	<0.03	35	<0.006	<0.01	<0.03	<0.02	3.2	10	0.01	<0.01	4	<0.02	0.06	<0.08	16	0.07
	0.5x	<0.18	<0.03	27	<0.006	<0.01	<0.03	<0.02	<0.8	8	0.02	<0.01	21	<0.02	<0.04	<0.08	21	0.07
	1.0x	<0.18	<0.03	46	<0.006	<0.01	<0.03	<0.02	<3.6	13	0.01	<0.01	14	<0.02	<0.09	<0.08	20	0.06
	2.0x	<0.18	<0.02	46	<0.006	<0.01	<0.03	<0.02	<0.8	12	<0.01	<0.01	12	<0.02	<0.31	<0.08	16	0.06
Significance		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	NS	NS
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																		
Linear		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	NS	NS
Quadratic		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	NS	NS
July 6, 1993																		
	0	<0.18	<0.03	34	<0.006	<0.01	<0.03	<0.02	4.3	10	<0.02	<0.01	4	<0.02	<0.04	<0.08	7	0.06
	0.5x	<0.18	0.04	42	<0.006	<0.01	<0.03	<0.02	<0.9	11	0.02	<0.01	25	<0.02	<0.04	<0.08	12	0.08
	1.0x	<0.18	<0.03	51	<0.006	<0.01	<0.03	<0.02	<4.3	15	<0.01	<0.01	14	<0.02	<0.04	<0.08	16	0.06
	2.0x	<0.18	<0.03	51	<0.006	<0.01	<0.03	<0.02	<0.9	13	<0.01	<0.01	11	<0.02	<0.23	<0.08	13	0.05
Significance		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	NS	NS
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																		
Linear		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	NS	NS
Quadratic		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	NS	NS
August 23, 1993																		
	0	<0.18	<0.02	21	<0.006	<0.01	<0.03	<0.02	1.5	6	<0.01	<0.01	4	<0.02	0.04	<0.08	7	0.05
	0.5x	<0.18	0.04	36	<0.006	<0.01	<0.03	<0.02	<0.7	10	<0.02	<0.01	23	<0.02	<0.04	<0.08	10	0.05
	1.0x	<0.18	0.04	55	<0.006	<0.01	<0.03	<0.02	<1.8	15	<0.01	<0.01	14	<0.02	<0.05	<0.08	15	0.05
	2.0x	<0.18	<0.04	86	<0.006	<0.01	<0.03	<0.02	1.1	24	<0.01	<0.01	13	<0.02	<0.20	<0.08	20	0.09
Significance		--	--	*	--	--	--	--	--	*	--	--	NS	--	--	--	NS	NS
BLSD (5%)		--	--	36	--	--	--	--	--	12	--	--	--	--	--	--	--	--
Contrasts																		
Linear		--	--	**	--	--	--	--	--	**	--	--	NS	--	--	--	*	NS
Quadratic		--	--	NS	--	--	--	--	--	NS	--	--	NS	--	--	--	NS	NS

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

Table 8. Effect of NutraLime on soil pH, soluble salts, Bray P, Olsen P, ammonium acetate extractable cations and DTPA extractable metals - Dakota County.

						NH_4OAc Extractable				DTPA Extractable							
Depth	Trmt	pH	Soluble Salts	Bray P	Olsen P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr
			mmhos/cm	ppm													
0-6"	0	6.1	0.10	104	59	213	2239	508	6.0	81	16.1	1.7	1.0	1.5	1.0	0.08	<0.03
	0.5x	7.4	0.20	231	107	194	2978	415	6.1	41	5.3	1.7	3.6	1.5	0.6	0.13	0.03
	1.0x	7.6	0.23	299	130	190	4124	437	9.2	43	4.9	1.9	5.5	1.8	0.6	0.15	0.04
	2.0x	7.7	0.20	315	134	209	4324	452	8.5	42	4.7	2.0	6.2	2.5	0.6	0.16	0.04
Significance		**	**	**	**	NS	**	NS	NS	**	**	NS	**	NS	**	**	--
BLSD	(5%)	0.3	0.06	57	24	--	771	--	--	16	3.0	--	0.7	--	0.2	0.02	--
Contrasts																	
Linear		**	**	**	**	NS	**	NS	NS	**	**	NS	**	NS	**	**	--
Quadratic		**	**	**	**	NS	*	NS	NS	**	**	NS	**	NS	**	**	--
6-12"	0	5.9	0.10	30	18	69	1601	355	6.8	67	8.8	0.6	0.6	0.9	0.8	0.04	<0.03
	0.5x	6.2	0.13	52	27	74	1727	381	8.5	71	8.4	0.9	0.7	1.1	0.8	0.06	0.03
	1.0x	5.9	0.17	57	32	68	1680	357	10.8	81	10.0	0.8	0.7	1.1	0.9	0.05	0.03
	2.0x	6.2	0.17	45	23	76	1701	370	9.8	72	7.6	0.7	0.8	1.8	0.8	0.05	0.03
Significance		NS	NS	NS	NS	NS	NS	**	**	NS	NS	NS	NS	NS	NS	NS	--
BLSD	(5%)	--	--	--	--	--	--	10	2.0	--	--	--	--	--	--	--	--
Contrasts																	
Linear		NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	*	NS	NS	NS	--
Quadratic		NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	--
12-24"	0	6.2	0.10	7	4	27	708	136	4.3	22	1.1	0.1	0.4	<0.2	<0.1	<0.01	<0.03
	0.5x	6.2	0.17	8	6	33	875	181	5.8	23	0.9	0.1	0.5	0.2	0.1	<0.01	<0.03
	1.0x	6.2	0.10	7	5	31	881	177	6.2	25	0.9	0.1	0.5	0.2	0.1	<0.01	<0.03
	2.0x	6.2	0.17	8	5	31	888	167	6.3	24	1.0	0.1	0.4	<0.2	0.1	<0.01	<0.03
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	--	--	--
BLSD	(5%)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	--	--	--
Quadratic		NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	--	--	--	--

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

Table 9. Effect of NutraLime on soil pH, soluble salts, Bray P1, Olsen P, ammonium acetate extractable cations, and DTPA extractable metals - Isanti County.

						NH_4OAc Extractable				DTPA Extractable							
Depth	Trmt	pH	Soluble Salts	Bray P	Olsen P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr
			mmhos/cm	ppm													
0 - 6"	0	5.8	0.20	36	15	259	930	81	4.6	83	24.9	1.4	0.6	0.9	0.8	0.07	<0.03
	Lime	7.5	0.43	30	16	188	3981	252	5.3	44	9.5	1.0	0.6	0.6	0.5	0.06	<0.03
	0.5x	7.6	0.27	114	31	213	2010	118	4.6	30	6.2	1.1	2.4	0.7	0.4	0.09	<0.03
	1.0x	7.7	0.27	134	36	185	2610	138	5.1	28	5.7	1.1	2.9	0.8	0.4	0.10	<0.03
	2.0x	7.6	0.23	150	40	194	2976	167	6.6	30	5.1	1.2	3.3	0.8	0.4	0.11	<0.03
Significance		**	*	**	**	NS	**	**	NS	**	**	NS	**	**	**	**	--
BLSD (5%)		0.4	0.12	24	5	--	713	60	--	19	4.4	--	0.6	0.1	0.2	0.02	--
Contrasts																	
Linear		**	NS	**	**	NS	**	**	**	**	**	NS	**	NS	**	**	--
Quadratic		**	NS	**	**	NS	*	NS	NS	**	**	NS	**	**	**	NS	--
Lime vs 2.0x		NS	**	**	**	NS	**	**	NS	NS	NS	NS	**	**	NS	**	--
6 - 12"	0	5.5	0.27	19	11	113	896	119	5.7	60	11.7	0.6	0.4	0.5	0.5	0.03	<0.03
	Lime	6.1	0.20	27	13	102	927	100	4.6	60	10.5	0.7	0.4	0.5	0.5	0.04	<0.03
	0.5x	6.9	0.30	50	16	107	1449	151	6.9	47	6.9	0.6	0.9	0.6	0.4	0.04	<0.03
	1.0x	6.8	0.30	54	16	96	1432	128	6.3	42	7.2	0.6	0.9	0.5	0.4	0.05	<0.03
	2.0x	6.7	0.33	49	14	86	1302	137	7.5	49	6.4	0.7	0.8	0.5	0.5	0.05	<0.03
Significance		**	NS	NS	*	NS	NS	NS	*	NS	NS	NS	*	NS	NS	NS	--
BLSD (5%)		0.4	--	--	5	--	--	--	1.7	--	--	--	0.4	--	--	--	--
Contrasts																	
Linear		**	NS	*	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--
Quadratic		**	NS	*	*	NS	*	NS	NS	NS	NS	NS	*	NS	NS	NS	--
Lime vs 2.0x		**	NS	NS	NS	NS	NS	*	**	NS	NS	NS	NS	NS	NS	NS	--
12 - 24"	0	5.6	0.10	23	23	128	1460	314	13.8	77	5.6	0.2	0.7	0.5	0.6	<0.01	0.04
	Lime	5.7	0.10	23	20	94	1423	283	10.6	80	5.1	0.2	0.7	0.4	0.5	<0.01	<0.04
	0.5x	5.8	0.13	23	20	96	1498	329	16.5	62	6.0	0.3	0.7	0.5	0.6	<0.01	<0.04
	1.0x	5.7	0.17	22	17	86	1357	260	12.0	58	4.0	0.2	0.5	0.5	0.4	<0.01	0.03
	2.0x	5.7	0.17	20	17	81	1411	271	13.4	68	4.5	0.2	0.6	0.5	0.5	<0.01	0.03
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	--
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	--
Quadratic		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	--
Lime vs 2.0x		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	--

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