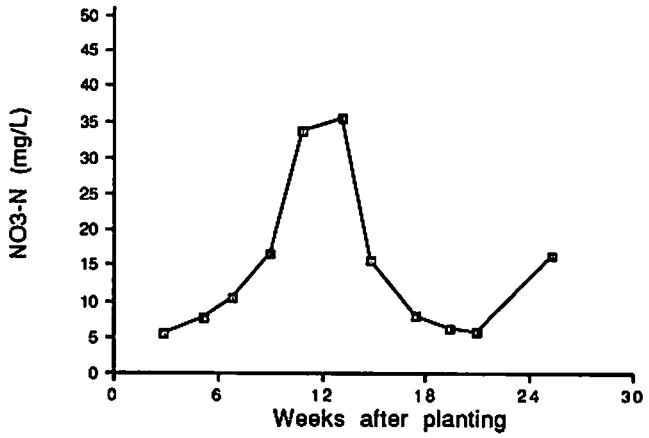

Figure 10. Nitrate-N concentration in soil water at the three ft. depth over the 1992 growing season. Treatment 9: no leaves, 66 lbs/A nitrogen fall applied and 200 lbs/A applied during the growing season.

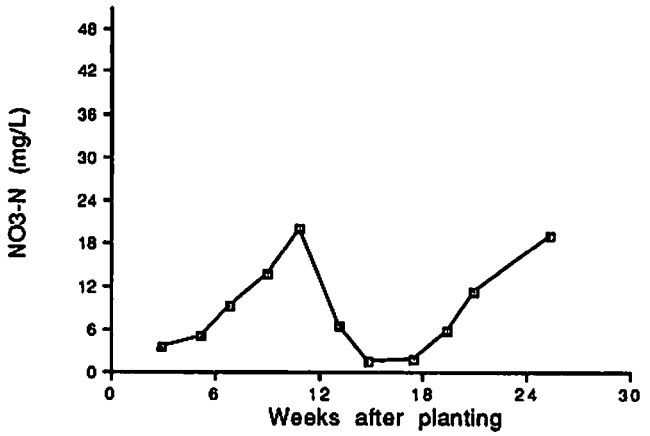

Figure 11. Nitrate-N concentration in soil water at the three ft. depth over the 1992 growing season. Treatment 10: 20 tons/A leaves, 66 lbs/A nitrogen fall applied and 200 lbs/A applied during the growing season.

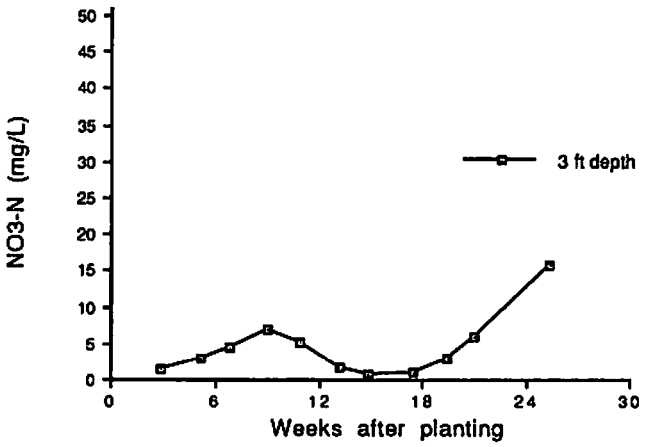

Figure 12: Nitrate-N concentration in soil water at the three ft. depth over the 1992 growing season. Treatment 11: 40 tons/A leaves, 66 lbs/A nitrogen fall applied and 200 lbs/A applied during the growing season.

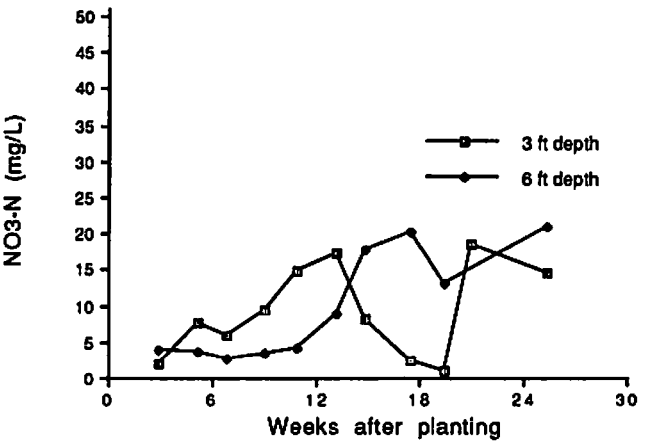

Figure 13: Nitrate-N concentration in soil water at 3 and 6 ft. depths over the 1992 growing season. Treatment 12: 80 tons/A leaves, 66 lbs/A nitrogen fall applied and 200 lbs/A applied during the growing season.

LAND TREATMENT OF SEWAGE SLUDGE INCINERATOR ASH - 1992[1]

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

ABSTRACT: The sixth year of an ongoing experiment was conducted at the Rosholt Research Farm in Westport, MN to evaluate the use of sewage sludge incinerator ash as a phosphorus source for corn production. A major change in the experimental methods was initiated in 1991. Ash was applied at much higher rates than in past years to simulate a one time application, rather than smaller amounts spread yearly. In addition, 6 tons/A lime were incorporated in half of each plot. 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 were 4.3, 8.6 and 17.2 dry tons. Results reported here are from the second year after the final application of ash and phosphate fertilizer. Early plant (6-10 leaf) dry weight and grain yield significantly increased with both ash and fertilizer 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 1.5 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, P concentrations were greater with the fertilizer source compared to the ash source, even though more phosphate was applied with the ash than with the fertilizer. Tissue concentrations of Zn and Cu were higher with ash applications compared to fertilizer applications. Tissue levels of Mo increased slightly with ash applications. Heavy metals such as Cd, Pb, Ni, and Cr did not accumulate in the grain, stover, or cob 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 second year (residual effects) after this one time application of ash was applied.

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. Elemental characteristics of the ashes from each year are presented in Table 1.

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 were 4.3, 8.6 and 17.2 dry tons. Approximate loading rates of elements as a result of sewage sludge ash application are presented in Table 2. Treatments were applied to the same plots as in previous years, except that the rate of application was proportional to the original rate. Because of the increase in the amount of ash applied last year, the phosphate applied by ash was much greater than the amount of phosphate applied with the fertilizer. No additional phosphate fertilizer was applied in 1992. 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.

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

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In 1992, each plot received 0-0-60 (200 lbs/A) and 45-0-0 (195 lbs/A). The fertilizers were broadcast by hand and then disked in. A split plot treatment arrangement with four replications was used. Phosphate treatment was the main plot and lime was the subplot. Field corn (Pioneer 3787 hybrid - 95 day) was planted May 6, 1992 at a population of 32,500 plants/A in 30" rows, along with a furrow application of Counter insecticide. Each plot consisted of four, 15' rows. Irrigation supplemented rainfall to provide approximately 1" of water per week. The entire plot was sidedressed with 100 lb N/A as ammonium nitrate on June 16. On July 3, 4 whole plants were sampled from each plot at the ends of the two middle rows. At this sampling, plant development corresponded to the 6-10 leaf stage. Ear leaf samples were collected from each plot at the mid-silking stage (August 12). Plots were harvested for grain and stover yields on October 14 (10' from the middle two rows). Subsamples of stover and grain plus cob were collected for moisture determinations, shelling percentages, and elemental analyses. All plant samples were ground in a Wiley mill to pass through a 30 mesh screen. Multiple element analysis using ICP procedures were performed on ashed samples dissolved in 1 N HCl. Following Kjeldahl digestion, total nitrogen in plant tissues was determined using conductimetric procedures.

Soil samples were collected on October 5 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 3). At 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 extractable P was greater in fertilizer amended plots compared to ash amended plots. DTPA extractable Zn, Cu, Cd, and Pb increased with increasing ash application. Ammonium acetate extractable Ca, 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 affected by fertilizer or ash treatments. Lime application increased soil pH, soluble salts, extractable K, Ca, and Mg and decreased Olsen P, and DTPA extractable Mn, Fe, Cu, Ni, and Cd. All nitric acid extractable elements increased with increasing ash application (Table 4). Phosphate fertilizer increased nitric acid extractable Al, As, Fe, Mo, P, Ti, and V. Lime application increased nitric acid extractable B, Ca, Co, K, Mg, S, Si, Sr, and V. Lime application tended to decrease nitric acid extractable and Ni.

Yield Data. No differences in stand establishment due to treatment were detected. Both triple superphosphate fertilizer and ash significantly increased early plant dry weight compared to plants growing in the check plot (Table 5). This early plant response to P fertilizer is common in corn grown in low P soils, particularly under cool soil temperatures. Overall, grain yields were low due to cool temperatures preventing maturation. However, grain yield increased with phosphorus fertilizer and ash additions compared to the control plot. Addition of lime also increased grain yields. Stover yield was not affected by fertilizer or ash amendments. These results clearly show a an agronomic benefit to ash application and that the high rates of ash used had no detrimental effects on yield or stand establishment.

Tissue Analyses. Fertilizer and ash treatments increased tissue P concentrations in corn sampled at the 6 - 10 leaf stage (Table 6). Even though rates of ash were higher in total P application than the fertilizer, availability of P was still greater from the fertilizer source than the ash source. Tissue concentrations of Ca, Cu, Mo, and Zn tended to increase with ash applications; however, these nutrients are essential for plant growth and the levels of Mo, Cu, and Zn reported are well below those considered toxic to plants or animals. Although generally low, concentrations of Cd, a nonessential plant element increased with ash application. The other heavy metals, Pb, Ni, and Cr, were generally at background levels or not consistently affected by ash treatments. Increasing phosphate fertilizer rate increased tissue Ca and Mn and decreased tissue Al, Cu, Fe, Ni, and Zn. Liming decreased tissue Mn and Zn.

Ear leaves sampled at silking increased in P with fertilizer and ash applications (Table 7). As in whole plant samples, the increase was greater in the 0-46-0 plots than in the ash plots. Phosphate fertilizer increased tissue Ca, Mg, Al, Cr, and Mn, but decreased N, Cu, and Zn concentrations. Ash application increased Ca, Mg, Mo, and Zn concentrations, and decreased N, Cu, and Mn levels. Liming increased tissue P, Ca, Al, B, and Cu, but decreased tissue Mn.

Concentrations of P increased in stover to a greater extent in plants supplied with 0-46-0 than in plants supplied with ash (Table 8). Concentrations of Cd and Pb in stover were generally below detection limits for all treatments. Ash application increased stover concentrations of Ca, Mo, and Na and decreased concentrations of Mn. Increasing phosphate fertilizer increased stover K, Ca, and Mn and decreased stover B, Cu, and Zn. Lime application increased stover Ca and decreased stover Mn.

Concentrations of P in the cob increased with fertilizer and ash application (Table 9). Cob Zn significantly decreased when P fertilizer was applied and increased when ash was applied. Concentrations of Cd, Mo, and Pb were generally below detection limits. Cu concentrations in the cob decreased with fertilizer application, but were not affected by ash application. Cob Mg increased with both fertilizer and ash application. Cob N increased and K decreased with fertilizer application. Liming decreased cob N and Mn.

Phosphorus concentrations in grain tissue increased with increasing fertilizer and ash amendments (Table 10). Concentrations of Cd, Ni, Cr, and Pb in grain tissue were either at background levels or below detection limits. Molybdenum concentrations were generally below detection limits; however, some accumulation of Mo was detected with ash application. Nitrogen, K, Mg, and Fe concentrations in the grain tissue increased with fertilizer application, while Ca, B, and Zn concentrations decreased. Ash application increased K, Mg, and Zn concentrations in grain. Liming increased grain P, K, and Mg levels and decreased levels of Mn.

GENERAL DISCUSSION

As in previous years, phosphate is not as available from the ash source as it is from the fertilizer source. Over twice as much P_2O_5 was applied with the ash compared to the fertilizer, yet P availability was much 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 actually increased yield over the plots not receiving any P amendments. Ash application did not significantly affect accumulation of elements such as Cd, Cu, Pb, Cr, Mo, and Ni in grain, cob, or stover tissue, although whole plant samples at the 6-10 leaf stage and ear leaf samples did have higher levels of Cd and Mo when ash was applied. Residual effects of ash application in future years will be monitored with vegetable crops.

Table 1. Selected chemical characteristics of incinerator sludge ash collected in 1987 and 1991 (means of 3 samples).

Chemical Characteristic		Ash Sampling Date 1987	1991
Moisture	(%)	37.6	36.0
Calcium Carbonate Equivalent	(%)	13.7	16.5
Available P_2O_5	(%)	8.8	—
pH (1:1 water)		8.0	—
Acid Digestible Elements:		%	%
Phosphorus		7.40	5.06
Potassium		0.48	0.45
Calcium		9.14	8.78
Magnesium		1.86	1.19
Sodium		0.26	0.27
Aluminum		6.38	5.30
Iron		4.05	2.55
		ppm	ppm
Boron		42	49
Cadmium		128	41
Chloride		276	246
Chromium		1888	1055
Copper		3846	2950
Lead		710	515
Manganese		2353	2801
Molybdenum		45	50
Nickel		530	252
Sulfur		3293	3569
Zinc		7213	1946

Table 2. Approximate loading rates of selected elements as a result of 5 years of sewage sludge incinerator ash application.

Cumulative ash application	P_2O_5	P	K	Ca	Mg	S	Cu	B	Zn	Mo	Pb	Ni	Cr	Cd
(dry T/A)	lb/A													
4.3	750	606	40	778	133	30	30	0.4	40	0.4	5.3	3.4	13	0.8
8.6	1500	1212	80	1556	266	60	60	0.8	80	0.8	10.6	6.8	26	1.6
17.2	3000	2424	160	3112	532	120	120	1.2	160	1.6	21.2	13.6	52	3.2

Table 3. Effect of the cumulative six year 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	P	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Pb	Ni	Cr	Cd
				(mmhos/cm)	ppm													
0	Ctrl	0	5.2	0.20	30	18	175	1758	228	<4.7	102	73	1.7	1.6	1.5	2.2	0.09	0.18
350	Fert	0	5.0	0.30	70	40	186	1733	220	<4.6	111	98	1.5	1.1	1.2	2.3	0.09	0.18
700	Fert	0	5.0	0.33	126	73	186	1771	216	<3.5	107	82	1.5	1.3	1.7	2.1	0.10	0.18
1400	Fert	0	5.1	0.28	243	126	194	1764	211	<3.8	103	69	1.8	1.6	1.2	2.2	0.10	0.20
750	Ash	0	5.3	0.23	151	82	172	1883	257	7.7	97	57	4.2	5.8	1.9	2.5	0.08	0.34
1500	Ash	0	5.5	0.33	247	96	175	2011	297	8.5	83	36	5.9	9.4	2.0	2.2	0.06	0.47
3000	Ash	0	5.9	0.23	458	125	173	2151	343	12.9	76	21	8.5	16.1	2.5	2.2	0.05	0.65
0	Ctrl	6	6.5	0.30	25	14	176	2879	259	5.2	60	21	1.2	1.0	<0.5	1.3	0.05	0.16
350	Fert	6	6.3	0.43	61	34	179	2900	272	<4.9	69	25	1.9	0.7	0.7	1.5	0.05	0.14
700	Fert	6	6.2	0.33	113	64	201	2660	240	<2.9	76	28	1.5	0.8	1.0	1.4	<0.04	0.15
1400	Fert	6	6.2	0.30	202	106	188	2790	251	3.0	71	23	1.4	0.9	0.6	1.5	0.05	0.15
750	Ash	6	6.3	0.45	144	57	198	2786	269	6.2	69	21	3.2	4.4	1.1	1.7	0.06	0.29
1500	Ash	6	6.6	0.30	257	81	212	2907	295	5.6	57	15	4.2	7.0	1.2	1.5	0.04	0.38
3000	Ash	6	6.5	0.38	438	115	191	2970	319	9.4	63	15	6.8	12.2	1.9	1.7	0.06	0.55
Significance			**	NS	**	**	NS	**	**	—	**	**	**	**	—	**	—	**
BLSD (0.05)			0.2	—	36	18	—	209	30	—	10	16	1.0	1.1	—	0.3	—	0.05
Main effects																		
Lime	−		5.3	0.27	189	80	180	1867	253	<6.5	97	62	3.6	5.3	1.7	2.3	0.08	0.31
	+		6.4	0.35	177	67	192	2842	272	<5.3	67	21	2.9	3.9	<1.0	1.5	<0.05	0.26
Significance			**	**	NS	**	*	**	**	—	**	**	**	**	—	**	—	**
P Treatment																		
P_2O_5 (lb/A)	Source																	
0	Ctrl		5.8	0.25	27	16	176	2319	243	<5.0	81	47	1.5	1.3	<1.0	1.7	0.07	0.17
350	Fert		5.6	0.36	65	37	182	2317	246	<4.8	90	61	1.7	0.9	1.0	1.9	0.07	0.16
700	Fert		5.6	0.33	120	68	194	2215	228	<3.2	91	55	1.5	1.1	1.3	1.8	<0.07	0.17
1400	Fert		5.6	0.29	222	116	191	2277	231	<3.4	87	46	1.6	1.3	0.9	1.8	0.07	0.17
750	Ash		5.8	0.34	147	69	185	2335	263	6.9	83	39	3.7	5.1	1.5	2.1	0.07	0.31
1500	Ash		6.1	0.31	252	89	193	2459	296	7.1	70	25	5.0	8.2	1.6	1.9	0.05	0.43
3000	Ash		6.2	0.30	448	120	182	2561	331	11.1	69	18	7.7	14.2	2.2	2.0	0.05	0.60
Significance			**	NS	**	**	NS	**	**	—	**	**	**	**	—	NS	—	**
BLSD (0.05)			0.2	—	26	13	—	172	21	—	7	12	0.7	0.8	—	—	—	0.04
Contrasts																		
Ctrl vs Rest			NS	NS	**	**	NS	NS	*	—	NS	NS	**	**	—	NS	—	**
Fert vs Ash			**	NS	**	**	NS	**	**	—	**	**	**	**	—	NS	—	**
Linear Fert			*	NS	**	**	NS	NS	NS	—	NS	NS	NS	NS	—	NS	—	NS
Quad Fert			*	NS	NS	NS	NS	NS	NS	—	*	*	NS	NS	—	NS	—	NS
Linear Ash			**	NS	**	**	NS	**	**	—	**	**	**	**	—	NS	—	**
Quad Ash			NS	NS	NS	**	NS	NS	NS	—	NS	NS	NS	NS	—	NS	—	**
Interactions																		
Lime by P			NS	NS	NS	NS	NS	NS	*	—	**	**	NS	**	—	NS	—	NS

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

Table 4. Effect of the cumulative six year application of sludge ash and phosphate fertilizer on 1N nitric acid extractable elements.

Treatment			1 N Nitric Acid Extractable																								
Cum. P_2O_5 (lb/A)	Source	Lime (T/A)	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
			ppm																								
0	Ctrl	0	1799	1.5	1.6	102	3126	0.4	0.9	1.1	5.5	374	212	<0.2	457	184	0.5	7	4.5	111	7.5	42.7	375	9.1	3.2	1.9	6.7
350	Fert	0	1829	1.5	1.6	103	2890	0.3	1.0	1.0	4.3	403	217	<0.2	404	209	0.5	7	4.8	159	7.5	43.0	362	9.0	3.2	2.0	6.0
700	Fert	0	1882	1.6	1.6	102	3060	0.3	1.0	1.1	5.0	430	205	<0.2	420	197	0.5	8	4.6	265	7.8	44.1	366	9.4	3.5	2.1	6.5
1400	Fert	0	2008	1.7	1.6	107	3120	0.4	0.9	1.5	6.6	504	213	<0.2	417	206	0.6	9	4.8	460	8.5	44.0	379	10.0	4.2	2.4	7.4
750	Ash	0	2111	1.8	1.8	114	3686	0.8	1.0	2.6	20.4	492	223	0.2	496	206	0.6	15	5.4	530	11.4	49.0	441	11.1	4.9	2.3	14.8
1500	Ash	0	2392	2.0	2.2	125	4481	1.4	1.0	4.4	36.5	592	222	<0.3	613	215	0.7	24	5.7	970	14.8	55.6	533	13.1	6.8	2.7	22.2
3000	Ash	0	3055	2.6	2.7	148	6097	2.5	1.1	8.8	75.5	880	245	0.4	807	275	1.0	49	7.1	2068	23.5	70.9	774	17.7	12.1	3.5	40.9
0	Ctrl	6	1753	1.5	1.8	104	6226	0.3	1.0	1.1	5.4	325	239	<0.2	861	172	0.5	8	4.1	111	7.1	74.8	420	12.2	2.7	2.1	6.4
350	Fert	6	1853	1.6	1.9	111	5816	0.3	1.0	1.1	4.5	388	216	<0.2	795	190	0.5	8	4.6	154	7.6	76.5	440	12.6	3.2	2.3	7.5
700	Fert	6	1792	1.5	1.8	102	5448	0.3	1.0	1.1	4.4	389	229	<0.2	714	180	0.5	8	4.3	250	7.2	70.8	385	11.5	3.1	2.3	7.0
1400	Fert	6	1999	1.9	2.6	111	5198	0.4	1.2	1.5	5.6	464	228	<0.4	842	197	0.6	10	4.7	444	8.1	79.8	434	12.8	3.9	2.9	5.7
750	Ash	6	2069	1.8	2.0	116	6268	0.8	1.0	2.7	20.7	468	264	<0.2	856	204	0.6	16	4.9	556	11.0	85.7	489	13.6	4.7	2.5	13.7
1500	Ash	6	2381	2.0	2.3	125	7264	1.4	1.1	4.8	40.1	596	266	<0.2	945	233	0.7	26	5.3	1098	15.2	83.8	613	16.1	6.9	2.9	23.3
3000	Ash	6	2971	2.6	2.8	150	8404	2.4	1.2	8.4	70.4	847	283	<0.3	1091	293	1.0	43	6.8	1943	21.9	103.0	794	20.0	11.2	3.6	40.1
Significance			**	**	**	**	**	**	NS	**	**	**	**	—	**	**	**	**	**	**	**	**	**	**	**	**	**
BLSD (0.05)			183	0.2	0.5	12	763	0.2	—	0.7	6.4	59	37	—	121	25	0.1	4	0.6	174	1.6	12.1	60	1.4	0.9	0.3	4.2
Main effects																											
Lime		−	2154	1.8	1.9	115	3780	0.9	1.0	2.9	22.0	525	219	<0.2	516	213	0.6	17	5.3	652	11.6	49.9	461	11.4	5.4	2.4	14.9
		+	2117	1.9	2.2	117	6375	0.9	1.1	3.0	21.6	497	247	<0.2	872	210	0.6	17	5.0	651	11.2	82.0	511	14.1	5.1	2.7	14.8
Significance			NS	NS	**	NS	**	NS	*	NS	NS	*	**	—	**	NS	NS	NS	*	NS	NS	**	**	**	NS	**	NS
P Treatment																											
P_2O_5 (lb/A)	Source																										
0	Ctrl		1776	1.5	1.7	103	4676	0.3	1.0	1.1	5.4	350	225	<0.2	659	178	0.5	8	4.3	111	7.3	58.8	398	10.7	2.9	2.0	6.5
350	Fert		1841	1.6	1.7	107	4353	0.3	1.0	1.1	4.4	395	217	<0.2	600	199	0.5	8	4.7	156	7.5	60.0	401	10.8	3.2	2.2	6.8
700	Fert		1837	1.6	1.7	102	4254	0.3	1.0	1.1	4.7	410	217	<0.2	567	188	0.5	8	4.4	257	7.5	57.4	375	10.5	3.3	2.2	6.7
1400	Fert		2004	1.8	2.1	109	4159	0.4	1.1	1.5	6.1	484	220	<0.3	630	201	0.6	10	4.8	452	8.3	61.9	407	11.4	4.0	2.6	6.6
750	Ash		2090	1.8	1.9	115	4977	0.8	1.0	2.6	20.5	480	244	<0.2	676	205	0.6	16	5.1	543	11.2	67.3	465	12.4	4.8	2.4	14.3
1500	Ash		2386	2.0	2.3	125	5872	1.4	1.0	4.6	38.3	594	244	<0.2	779	224	0.7	25	5.5	1034	15.0	69.7	573	14.6	6.8	2.8	22.7
3000	Ash		3013	2.6	2.8	149	7251	2.5	1.1	8.6	72.9	863	264	<0.3	949	284	1.0	46	7.0	2005	22.7	86.9	784	18.9	11.7	3.6	40.5
Significance			**	**	**	**	**	**	NS	**	**	**	**	—	**	**	**	**	**	**	**	**	**	**	**	**	**
BLSD (0.05)			128	0.2	0.4	8	542	0.2	—	0.5	4.5	42	26	—	87	17	0.1	3	0.4	123	1.1	8.8	42	1.0	0.7	0.2	3.0
Contrasts																											
Ctrl vs Rest			**	**	*	**	*	**	NS	**	**	**	NS	—	NS	**	**	**	**	**	**	*	**	**	**	**	**
Fert vs Ash			**	**	**	**	**	**	NS	**	**	**	**	—	**	**	**	**	**	**	**	**	**	**	**	**	**
Linear Fert			**	**	NS	NS	NS	NS	NS	NS	NS	**	NS	—	NS	NS	**	NS	NS	**	NS	NS	NS	NS	**	**	NS
Quad Fert			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear Ash			**	**	**	**	**	**	**	**	**	**	**	—	**	**	**	**	**	**	**	**	**	**	**	**	**
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 5. Effect of the cumulative six year application of sludge ash and phosphate fertilizer on final stand count, whole plant dry weight (6-10 leaf stage), and grain and stover yield (dry weight).

Treatment			Final stand count	Whole plant 6-10 leaf dry wt.	Grain yield	Stover yield
Cumulative P_2O_5 (lb/A)	Source	Lime (T/A)		(g/plant)	(bu/A)	(T/A)
0	Ctrl	0	31363	8.4	94	2.54
350	Fert	0	31363	10.7	104	2.88
700	Fert	0	31363	13.0	110	2.73
1400	Fert	0	29403	15.3	108	2.66
750	Ash	0	30927	13.4	104	2.73
1500	Ash	0	32016	11.8	110	2.94
3000	Ash	0	31581	11.5	106	2.91
0	Ctrl	6	30927	7.7	99	2.82
350	Fert	6	31799	10.9	105	2.85
700	Fert	6	31145	13.7	110	3.01
1400	Fert	6	31145	15.6	111	2.76
750	Ash	6	31799	13.0	115	3.15
1500	Ash	6	29621	12.3	110	2.75
3000	Ash	6	31145	13.0	111	3.07
Significance			NS	**	++	NS
BLSD (0.05)			--	2.3	15	--
Main effects						
Lime	-		31145	12.0	105	2.77
	+		31083	12.3	109	2.92
Significance			NS	NS	++	NS
P Treatment						
P_2O_5 (lb/A)	Source					
0	Ctrl		31145	8.0	96	2.68
350	Fert		31581	10.8	104	2.87
700	Fert		31254	13.3	110	2.87
1400	Fert		30274	15.4	110	2.71
750	Ash		31363	13.2	109	2.94
1500	Ash		30819	12.1	110	2.85
3000	Ash		31363	12.2	108	2.99
Significance			NS	**	*	NS
BLSD (0.05)			--	1.6	8.8	--
Contrasts						
Ctrl vs Rest			NS	**	**	NS
Fert vs Ash			NS	NS	NS	NS
Linear Fert			NS	**	**	NS
Quad Fert			NS	*	*	NS
Linear Ash			NS	**	*	NS
Quad Ash			NS	**	**	NS
Interactions						
Lime by P			NS	NS	NS	NS

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

Table 6. Effect of the cumulative six year application of sludge ash and phosphate fertilizer on the elemental composition of whole plants at the 6-10 leaf 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	4.09	0.36	4.54	0.56	0.38	362	6.7	0.5	1.2	10.5	335	97	0.6	20.9	1.5	<3.5	44
350	Fert	0	4.27	0.42	4.80	0.56	0.37	267	6.4	0.5	1.1	9.0	267	106	0.5	18.7	1.2	<2.5	47
700	Fert	0	4.26	0.44	4.26	0.60	0.41	215	6.6	0.5	1.1	7.7	228	104	0.6	23.2	1.3	3.5	41
1400	Fert	0	4.10	0.51	4.24	0.65	0.40	247	6.5	0.6	1.1	6.0	266	117	0.7	19.8	1.2	3.3	33
750	Ash	0	4.21	0.40	3.96	0.60	0.42	270	6.2	0.5	1.0	10.1	263	89	0.7	15.8	1.1	2.4	49
1500	Ash	0	4.23	0.44	4.00	0.62	0.46	301	6.6	0.6	1.1	11.0	298	85	1.1	22.6	1.2	<2.9	56
3000	Ash	0	4.17	0.46	4.12	0.64	0.44	316	6.7	0.7	1.3	11.5	293	80	2.6	21.4	1.3	3.4	54
0	Ctrl	6	4.06	0.34	4.47	0.55	0.35	361	6.6	0.5	1.3	10.7	351	82	0.7	24.3	1.5	3.7	41
350	Fert	6	4.20	0.41	4.09	0.62	0.42	330	6.4	0.4	1.1	8.6	309	91	0.5	18.8	1.2	<2.6	41
700	Fert	6	4.29	0.45	4.48	0.58	0.35	238	6.6	0.5	1.3	7.7	258	92	0.7	20.4	1.4	3.8	38
1400	Fert	6	4.14	0.48	4.14	0.65	0.39	244	6.2	0.4	1.0	5.8	275	99	0.5	15.7	1.0	<2.6	30
750	Ash	6	4.19	0.40	4.24	0.58	0.38	255	6.2	0.5	1.0	10.7	257	80	0.8	18.0	1.2	2.9	47
1500	Ash	6	4.29	0.44	4.22	0.63	0.41	307	6.5	0.6	1.2	11.5	297	83	1.3	20.4	1.3	3.3	50
3000	Ash	6	4.18	0.44	4.25	0.61	0.39	257	6.6	0.7	1.2	11.2	260	84	1.8	18.9	1.3	<3.4	53
Significance			NS	**	NS	**	NS	*	NS	*	*	**	*	**	**	NS	NS	—	**
BLSD (0.05)			—	0.03	—	0.06	—	97	—	0.2	0.5	0.9	88	13	0.5	—	—	—	7
Main effects																			
Lime	−		4.19	0.43	4.27	0.60	0.41	283	6.5	0.5	1.2	9.4	279	97	1.0	20.3	1.2	<3.1	46
	+		4.19	0.42	4.27	0.60	0.39	285	6.4	0.5	1.2	9.4	287	87	0.9	19.5	1.3	<3.2	43
Significance			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	—	*
P Treatment																			
P_2O_5 (lb/A)	Source																		
0	Ctrl		4.07	0.35	4.50	0.55	0.37	361	6.6	0.5	1.3	10.6	343	89	0.7	22.6	1.5	<3.6	43
350	Fert		4.23	0.41	4.45	0.59	0.39	298	6.4	0.5	1.1	8.8	288	99	0.5	18.7	1.2	<2.6	44
700	Fert		4.27	0.44	4.37	0.59	0.38	227	6.6	0.5	1.2	7.7	243	98	0.7	21.8	1.4	3.6	39
1400	Fert		4.12	0.49	4.19	0.65	0.39	245	6.3	0.5	1.1	5.9	270	108	0.6	17.8	1.1	<3.0	31
750	Ash		4.20	0.40	4.10	0.59	0.40	263	6.2	0.5	1.0	10.4	260	85	0.8	16.9	1.1	2.6	48
1500	Ash		4.26	0.44	4.11	0.63	0.43	304	6.6	0.6	1.2	11.2	297	84	1.2	21.5	1.2	<3.1	53
3000	Ash		4.17	0.45	4.19	0.63	0.41	286	6.7	0.7	1.2	11.3	277	82	2.2	20.2	1.3	<3.4	53
Significance			*	**	NS	**	NS	**	NS	**	NS	**	**	**	**	NS	NS	—	**
BLSD (0.05)			0.13	0.02	—	0.04	—	59	—	0.1	—	0.7	51	9	0.3	—	—	—	5
Contrasts																			
Ctrl vs Rest			*	**	NS	**	*	**	NS	NS	NS	**	**	NS	*	NS	*	—	NS
Fert vs Ash			NS	*	NS	NS	NS	NS	NS	**	NS	**	NS	**	**	NS	NS	—	**
Linear Fert			NS	**	NS	**	NS	**	NS	NS	NS	**	**	**	NS	NS	*	—	**
Quad Fert			**	*	NS	NS	NS	**	NS	NS	NS	*	**	NS	NS	NS	NS	—	NS
Linear Ash			NS	**	NS	**	NS	NS	NS	**	NS	*	NS	NS	**	NS	NS	—	**
Quad Ash			*	**	NS	*	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	—	*
Interactions																			
Lime by P			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 7. Effect of the cumulative six year application of sludge ash and phosphate fertilizer on the elemental composition of ear 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	3.22	0.28	1.94	0.53	0.29	18.3	5.1	<0.2	0.8	11.3	250	72	<0.4	29.1	<0.7	<2.3	32
350	Fert	0	3.26	0.30	2.02	0.54	0.28	17.8	5.1	<0.2	0.8	9.6	219	93	<0.4	30.8	<0.7	<2.4	35
700	Fert	0	3.13	0.31	1.93	0.59	0.30	23.4	5.3	0.3	1.0	7.6	224	105	0.6	31.2	1.0	<2.9	31
1400	Fert	0	3.01	0.34	1.92	0.64	0.32	24.9	5.1	0.3	1.1	5.1	240	104	0.7	27.8	0.9	<2.8	19
750	Ash	0	3.16	0.30	1.87	0.58	0.29	19.8	5.3	<0.2	0.9	9.7	236	76	1.0	32.0	0.7	<2.3	40
1500	Ash	0	3.17	0.31	1.85	0.64	0.32	20.8	5.4	0.3	1.0	9.5	222	70	1.9	31.8	0.9	<2.7	49
3000	Ash	0	3.08	0.31	1.83	0.63	0.33	19.1	5.4	<0.2	0.8	8.9	241	55	4.0	30.7	<0.7	<2.3	44
0	Ctrl	6	3.22	0.28	1.92	0.60	0.29	19.5	5.3	<0.2	0.9	12.6	248	56	0.6	28.5	<0.8	<2.4	37
350	Fert	6	3.17	0.31	1.85	0.64	0.31	22.8	5.5	0.2	1.0	9.1	232	66	0.7	35.7	1.0	2.8	36
700	Fert	6	3.31	0.33	1.95	0.66	0.31	22.3	5.4	<0.3	0.9	7.8	232	78	0.6	30.7	<0.9	<2.8	33
1400	Fert	6	3.21	0.34	1.83	0.73	0.34	31.5	5.7	0.3	1.1	6.5	248	82	0.8	31.1	1.0	2.9	23
750	Ash	6	3.23	0.31	1.90	0.65	0.30	23.8	5.6	0.3	1.0	11.9	242	63	1.3	32.2	1.0	2.7	41
1500	Ash	6	3.15	0.32	1.94	0.66	0.29	23.0	5.6	<0.3	1.0	11.2	246	54	2.6	30.7	<1.0	<2.9	38
3000	Ash	6	3.14	0.32	1.89	0.66	0.31	20.3	5.6	0.2	0.9	10.4	228	55	3.2	28.6	0.8	<2.4	42
Significance			NS	**	NS	**	*	*	NS	—	NS	**	NS	**	—	NS	—	—	**
BLSD (0.05)			—	0.02	—	0.05	0.04	8.8	—	—	—	0.6	—	10	—	—	—	—	5
Main effects																			
Lime	−		3.15	0.31	1.91	0.59	0.30	20.6	5.2	<0.2	0.9	8.8	233	82	<1.3	30.5	<0.8	<2.5	36
	+		3.20	0.32	1.90	0.66	0.31	23.3	5.5	<0.2	1.0	9.9	239	65	1.4	31.1	<0.9	<2.7	36
Significance			NS	**	NS	**	NS	*	*	—	NS	**	NS	**	—	NS	—	—	NS
P Treatment																			
P_2O_5 (lb/A)	Source																		
0	Ctrl		3.22	0.28	1.93	0.56	0.29	18.9	5.2	<0.2	0.9	12.0	249	64	<0.5	28.8	<0.7	<2.3	35
350	Fert		3.21	0.31	1.93	0.59	0.29	20.3	5.3	<0.2	0.9	9.3	225	79	<0.5	33.2	<0.8	<2.6	35
700	Fert		3.22	0.32	1.94	0.62	0.30	22.8	5.4	<0.3	1.0	7.7	228	92	0.6	30.9	<0.9	<2.8	32
1400	Fert		3.11	0.34	1.87	0.68	0.33	28.2	5.4	0.3	1.1	5.8	244	93	0.8	29.5	1.0	<2.9	21
750	Ash		3.20	0.31	1.89	0.62	0.30	21.8	5.4	<0.2	1.0	10.8	239	70	1.1	32.1	0.9	<2.5	40
1500	Ash		3.16	0.32	1.89	0.65	0.31	21.9	5.5	<0.3	1.0	10.3	234	62	2.3	31.3	<0.9	<2.8	43
3000	Ash		3.11	0.32	1.86	0.65	0.32	19.7	5.5	<0.2	0.9	9.6	234	55	3.6	29.7	<0.7	<2.3	43
Significance			NS	**	NS	**	**	*	NS	—	NS	**	NS	**	—	NS	—	—	**
BLSD (0.05)			—	0.01	—	0.04	0.02	5.3	—	—	—	0.4	—	7	—	—	—	—	3
Contrasts																			
Ctrl vs Rest			NS	**	NS	**	*	NS	NS	—	NS	**	*	**	—	NS	—	—	NS
Fert vs Ash			NS	*	NS	NS	NS	NS	NS	—	NS	**	NS	**	—	NS	—	—	**
Linear Fert			*	**	NS	**	**	**	NS	—	*	**	NS	**	—	NS	—	—	**
Quad Fert			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	—	—	**
Interactions																			
Lime by P			NS	NS	NS	NS	NS	NS	NS	—	NS	**	NS	*	—	NS	—	—	**

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

Table 8. Effect of the cumulative six year application of sludge ash and phosphate fertilizer on the elemental composition of stover at harvest.

Treatment: Cumulative P_2O_5 (lb/A)	Source	Lime (T/A)	N	K	Ca	Mg	P	Al	B	Cd	Cr	Cu	Fe	Mn	Mo	Na	Ni	Pb	Zn
			%				ppm												
0	Ctrl	0	0.75	0.91	0.26	0.19	550	32.3	4.4	0.2	0.7	6.1	80	40	0.4	16.0	0.8	<2.6	11
350	Fert	0	0.81	1.18	0.28	0.18	584	43.1	4.2	<0.3	0.7	5.0	89	48	<0.4	21.0	<0.8	<2.8	10
700	Fert	0	0.77	1.26	0.30	0.19	572	45.5	4.1	0.3	0.7	3.7	84	50	<0.4	17.8	0.8	2.6	8
1400	Fert	0	0.68	1.19	0.31	0.17	737	40.0	4.0	0.2	0.6	2.7	83	49	<0.3	16.5	<0.6	<2.1	5
750	Ash	0	0.70	1.04	0.28	0.19	537	37.6	4.2	0.3	0.7	5.2	80	41	<0.4	12.6	<0.7	<2.2	12
1500	Ash	0	0.74	1.09	0.30	0.20	568	32.9	4.0	0.3	0.7	5.4	76	34	0.6	13.5	<0.7	<2.2	16
3000	Ash	0	0.66	1.01	0.29	0.19	653	39.9	4.3	0.4	0.8	5.5	79	28	1.2	22.3	<0.9	<3.2	14
0	Ctrl	6	0.76	1.00	0.28	0.19	565	47.5	4.5	0.3	0.8	6.2	93	31	0.5	16.3	0.9	2.8	13
350	Fert	6	0.74	1.03	0.30	0.20	602	41.2	4.3	0.3	0.8	4.5	80	32	<0.5	22.7	<0.9	<2.9	12
700	Fert	6	0.78	1.10	0.30	0.18	597	35.7	4.1	0.3	0.7	3.7	76	35	<0.4	15.7	<0.8	<2.5	8
1400	Fert	6	0.75	1.11	0.33	0.19	833	45.8	4.2	0.2	0.7	3.3	90	34	<0.4	18.5	<0.7	<2.3	6
750	Ash	6	0.74	1.15	0.30	0.18	606	37.4	4.4	0.3	0.7	5.9	87	34	0.5	14.3	0.7	<2.4	12
1500	Ash	6	0.61	1.11	0.29	0.18	549	40.4	4.0	0.3	0.7	5.3	79	26	0.7	13.2	<0.7	<2.4	10
3000	Ash	6	0.71	1.08	0.32	0.19	651	39.0	4.7	0.4	0.9	6.3	79	28	1.2	20.6	1.0	<3.4	13
Significance			NS	NS	**	NS	**	NS	NS	—	NS	**	NS	**	—	NS	—	—	**
BLSD (0.05)			—	—	0.03	—	98	—	—	—	—	0.7	—	5	—	—	—	—	3
Main effects																			
Lime −			0.73	1.10	0.29	0.19	600	38.8	4.2	<0.3	0.7	4.8	81	41	<0.5	17.1	<0.7	<2.5	11
+			0.72	1.08	0.30	0.19	629	41.0	4.3	0.3	0.8	5.0	83	31	<0.6	17.3	<0.8	<2.7	11
Significance			NS	NS	**	NS	NS	NS	NS	—	NS	NS	NS	**	—	NS	—	—	NS
P Treatment: P_2O_5 (lb/A)	Source																		
0	Ctrl		0.75	0.95	0.27	0.19	558	39.9	4.5	0.2	0.8	6.1	87	35	0.4	16.2	0.8	<2.7	12
350	Fert		0.77	1.11	0.29	0.19	593	42.1	4.3	<0.3	0.7	4.7	84	40	<0.5	21.9	<0.9	<2.9	11
700	Fert		0.78	1.18	0.30	0.18	584	40.6	4.1	0.3	0.7	3.7	80	43	<0.4	16.8	<0.8	<2.5	8
1400	Fert		0.71	1.15	0.32	0.18	785	42.9	4.1	0.2	0.7	3.0	87	42	<0.3	17.5	<0.6	<2.2	5
750	Ash		0.72	1.09	0.29	0.19	571	37.5	4.3	0.3	0.7	5.5	83	37	<0.4	13.5	<0.7	<2.3	12
1500	Ash		0.68	1.10	0.30	0.19	558	36.6	4.0	0.3	0.7	5.3	77	30	0.6	13.3	<0.7	<2.3	13
3000	Ash		0.69	1.05	0.30	0.19	652	39.4	4.5	0.4	0.8	5.9	79	28	1.2	21.4	<0.9	<3.3	14
Significance			NS	*	**	NS	**	NS	*	—	NS	**	NS	**	—	*	—	—	**
BLSD (0.05)			—	0.15	0.02	—	65	—	0.4	—	—	0.5	—	4	—	6.1	—	—	2
Contrasts																			
Ctrl vs Rest			NS	**	**	NS	*	NS	NS	—	NS	**	NS	NS	—	NS	—	—	NS
Fert vs Ash			**	NS	NS	NS	**	NS	NS	—	NS	**	NS	**	—	NS	—	—	**
Linear Fert			NS	**	**	NS	**	NS	*	—	NS	**	NS	**	—	NS	—	—	**
Quad Fert			NS	*	NS	NS	*	NS	NS	—	NS	**	NS	*	—	NS	—	—	NS
Linear Ash			NS	NS	**	NS	**	NS	NS	—	NS	NS	NS	**	—	*	—	—	NS
Quad Ash			NS	*	NS	NS	NS	NS	**	—	*	**	NS	NS	—	*	—	—	NS
Interactions																			
Lime by P			NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	**	—	NS	—	—	**

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

Table 9. Effect of the cumulative six year application of sludge ash and phosphate fertilizer on the elemental composition of cobs at harvest.

Treatment																			
Cumulative P_2O_5	Source	Lime	N	K	P	Mg	Ca	Al	B	Cd	Cr	Cu	Fe	Mn	Mo	Na	Ni	Pb	Zn
(lb/A)		(T/A)	%		ppm														
0	Ctrl	0	0.31	0.49	266	167	104	<8.6	1.7	<0.2	<0.5	3.1	7.6	4.0	<0.5	<5.7	<0.9	<3.0	18
350	Fert	0	0.30	0.50	287	148	102	8.9	2.0	0.2	0.6	3.0	6.7	4.3	0.5	5.9	0.9	3.1	16
700	Fert	0	0.30	0.49	279	131	110	10.3	2.0	0.2	0.6	2.8	6.8	4.5	0.5	6.0	1.0	3.3	14
1400	Fert	0	0.28	0.45	293	110	100	10.1	1.8	0.2	0.6	2.4	7.2	3.9	0.6	7.2	1.1	3.5	7
750	Ash	0	0.30	0.46	271	135	104	9.5	1.9	0.2	0.6	3.3	6.2	3.8	0.5	6.5	1.0	3.5	19
1500	Ash	0	0.31	0.48	294	140	109	9.3	1.9	0.2	0.6	3.3	6.2	3.6	0.5	6.1	1.0	3.2	24
3000	Ash	0	0.30	0.46	318	126	109	<8.4	1.6	<0.2	<0.6	3.0	8.3	3.3	<0.5	<6.1	<0.9	<3.0	24
0	Ctrl	6	0.29	0.50	258	151	97	<8.4	1.8	<0.2	<0.5	3.1	6.3	3.3	<0.5	<5.6	<0.9	<3.0	19
350	Fert	6	0.29	0.47	286	137	109	10.5	2.1	0.2	0.6	3.1	6.6	3.4	0.5	9.2	1.0	3.5	16
700	Fert	6	0.29	0.46	288	131	114	9.3	1.8	0.2	0.6	2.7	6.4	3.7	0.5	8.3	1.0	3.2	14
1400	Fert	6	0.29	0.44	304	120	103	10.3	1.9	0.2	0.6	2.6	6.7	3.9	0.6	7.2	1.1	3.6	10
750	Ash	6	0.29	0.46	286	143	108	9.2	1.9	0.2	0.5	3.3	6.3	3.5	0.5	6.4	1.0	3.4	19
1500	Ash	6	0.29	0.45	294	132	106	9.5	2.0	0.2	0.6	3.4	6.7	3.2	0.6	6.4	1.0	3.4	19
3000	Ash	6	0.29	0.47	318	121	103	<8.0	1.7	<0.2	<0.5	3.0	6.8	3.2	<0.5	<5.6	<0.9	<2.8	21
Significance			NS	NS	**	**	NS	—	NS	—	NS	*	NS	**	—	—	—	—	**
BLSD (0.05)			—	—	31	19	—	—	—	—	—	0.7	—	0.5	—	—	—	—	2
Main effects																			
Lime	−		0.30	0.48	286	137	105	<9.3	1.9	<0.2	0.6	3.0	7.0	3.9	<0.5	<6.2	<1.0	<3.3	18
	+		0.29	0.46	290	134	106	<9.3	1.9	<0.2	0.6	3.0	6.5	3.4	<0.5	<7.0	<1.0	<3.3	17
Significance			*	NS	NS	NS	NS	—	NS	—	NS	NS	NS	**	—	—	—	—	NS
P Treatment																			
P_2O_5 (lb/A)	Source																		
0	Ctrl		0.26	0.49	262	159	101	<8.5	1.8	<0.2	<0.5	3.1	7.0	3.6	<0.5	<5.6	<0.9	<3.0	19
350	Fert		0.27	0.48	287	142	106	9.7	2.0	0.2	0.6	3.1	6.6	3.9	0.5	7.6	1.0	3.3	16
700	Fert		0.30	0.47	284	131	112	9.8	1.9	0.2	0.6	2.7	6.6	4.1	0.5	7.1	1.0	3.3	14
1400	Fert		0.29	0.44	299	115	102	10.2	1.9	0.2	0.6	2.5	7.0	3.7	0.6	7.2	1.1	3.6	8
750	Ash		0.26	0.46	278	139	106	9.4	1.9	0.2	0.6	3.3	6.3	3.6	0.5	6.5	1.0	3.4	19
1500	Ash		0.29	0.47	294	136	107	9.4	2.0	0.2	0.6	3.4	6.4	3.4	0.5	6.3	1.0	3.3	22
3000	Ash		0.29	0.47	318	124	106	<8.2	1.7	<0.2	<0.5	3.0	7.5	3.3	<0.5	<5.8	<0.9	<2.9	22
Significance			NS	NS	**	**	NS	—	NS	—	NS	**	NS	**	—	—	—	—	**
BLSD (0.05)			—	—	19	13	—	—	—	—	—	0.4	—	0.3	—	—	—	—	2
Contrasts																			
Ctrl vs Rest			NS	*	**	**	NS	—	NS	—	NS	NS	NS	NS	—	—	—	—	*
Fert vs Ash			NS	NS	NS	NS	NS	—	NS	—	NS	**	NS	**	—	—	—	—	**
Linear Fert			**	**	**	**	NS	—	NS	—	NS	**	NS	NS	—	—	—	—	**
Quad Fert			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	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 10. Effect of the cumulative six year application of sludge ash and phosphate fertilizer on the elemental composition of grain at harvest.

Treatment: Cumulative P_2O_5 (lb/A)	Source	Lime (T/A)	N	P	K	Mg	Ca	Al	B	Cd	Cr	Cu	Fe	Mn	Mo	Na	Ni	Pb	Zn
			%				ppm												
0	Ctrl	0	1.51	0.23	0.40	0.12	67	<7.0	2.3	<0.2	0.6	2.0	21	7.3	<0.4	<3.7	<0.8	<2.5	19
350	Fert	0	1.56	0.25	0.39	0.12	59	7.2	2.4	<0.2	0.6	1.8	21	7.3	<0.4	<4.5	0.9	<2.7	19
700	Fert	0	1.57	0.28	0.40	0.12	61	<5.2	2.1	<0.1	<0.5	<1.1	22	7.6	<0.3	<3.6	<0.6	<1.8	19
1400	Fert	0	1.57	0.32	0.42	0.13	53	<4.7	2.0	<0.1	0.7	<0.8	24	7.3	<0.3	<3.6	<0.6	<1.9	16
750	Ash	0	1.50	0.27	0.39	0.12	62	9.1	2.7	0.2	0.7	2.1	21	7.3	0.7	<4.5	1.1	3.3	20
1500	Ash	0	1.58	0.29	0.40	0.13	61	7.2	2.5	<0.2	0.6	1.8	21	6.8	0.6	<4.3	0.9	2.6	22
3000	Ash	0	1.54	0.32	0.42	0.13	59	<5.5	2.3	<0.1	0.5	1.4	20	6.4	0.6	<3.8	0.7	<2.1	21
0	Ctrl	6	1.51	0.24	0.39	0.12	64	6.9	2.4	<0.2	0.5	1.9	21	6.5	0.5	<3.8	0.8	<2.4	19
350	Fert	6	1.62	0.29	0.41	0.13	62	<7.1	2.5	<0.2	0.6	1.6	23	7.1	0.5	<3.9	0.9	<2.5	20
700	Fert	6	1.58	0.29	0.40	0.13	60	<4.6	2.0	<0.1	<0.4	<1.0	22	7.0	<0.3	<3.6	<0.6	<1.7	19
1400	Fert	6	1.62	0.34	0.42	0.13	57	<4.7	2.1	<0.1	<0.4	<0.9	25	7.0	<0.4	<3.6	<0.6	<1.9	18
750	Ash	6	1.54	0.29	0.40	0.13	57	8.6	2.7	0.2	0.7	2.0	22	6.6	0.6	<4.2	1.0	2.9	20
1500	Ash	6	1.59	0.31	0.42	0.13	60	<5.1	2.2	<0.1	<0.5	1.3	21	6.5	0.5	<3.6	<0.6	<1.9	20
3000	Ash	6	1.56	0.33	0.43	0.13	63	<6.0	2.3	<0.2	0.5	1.5	22	6.6	0.6	<4.4	0.7	<2.3	21
Significance			NS	**	*	**	**	—	NS	—	—	—	**	*	—	—	—	—	**
BLSD (0.05)			—	0.02	0.04	0.01	6	—	—	—	—	—	1.9	0.8	—	—	—	—	1
Main effects																			
Lime −			1.54	0.28	0.40	0.12	60	<6.6	2.3	<0.2	<0.6	<1.6	21	7.1	<0.5	<4.0	<0.8	<2.4	19
+			1.57	0.30	0.41	0.13	60	<6.1	2.3	<0.2	<0.5	<1.5	22	6.8	<0.5	<3.9	<0.7	<2.2	20
Significance			NS	**	*	**	NS	—	NS	—	—	—	NS	**	—	—	—	—	NS
P Treatment																			
P_2O_5 (lb/A)	Source																		
0	Ctrl		1.51	0.24	0.40	0.12	65	<6.9	2.3	<0.2	0.5	2.0	21	6.9	<0.5	<3.8	<0.8	<2.5	19
350	Fert		1.59	0.27	0.40	0.13	60	<7.2	2.4	<0.2	0.6	1.7	22	7.2	<0.4	<4.2	0.9	<2.6	19
700	Fert		1.57	0.29	0.40	0.12	60	<4.9	2.1	<0.1	<0.4	<1.0	22	7.3	<0.3	<3.6	<0.6	<1.8	19
1400	Fert		1.59	0.33	0.42	0.13	55	<4.7	2.0	<0.1	<0.6	<0.9	24	7.1	<0.3	<3.6	<0.6	<1.9	17
750	Ash		1.52	0.28	0.39	0.13	59	8.8	2.7	0.2	0.7	2.0	21	7.0	0.6	<4.3	1.0	3.1	20
1500	Ash		1.58	0.30	0.41	0.13	61	<6.1	2.3	<0.2	<0.5	1.6	21	6.6	0.6	<3.9	<0.8	<2.3	21
3000	Ash		1.55	0.32	0.43	0.13	61	<5.7	2.3	<0.1	0.5	1.5	21	6.5	0.6	<4.1	0.7	<2.2	21
Significance			*	**	*	**	**	—	**	—	—	—	**	*	—	—	—	—	*
BLSD (0.05)			0.07	0.01	0.02	0.01	4	—	0.4	—	—	—	1	0.6	—	—	—	—	1
Contrasts																			
Ctrl vs Rest			*	**	NS	**	**	—	NS	—	—	—	**	NS	—	—	—	—	NS
Fert vs Ash			NS	NS	NS	NS	NS	—	*	—	—	—	**	**	—	—	—	—	**
Linear Fert			*	**	*	**	**	—	*	—	—	—	**	NS	—	—	—	—	**
Quad Fert			NS	NS	NS	NS	NS	—	NS	—	—	—	NS	NS	—	—	—	—	NS
Linear Ash			NS	**	**	**	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 = nonsignificant; *, ** = significant at 5% and 1%, respectively.

AGRICULTURAL UTILIZATION OF NUTRALIME: ON FARM DEMONSTRATION PLOTS - 1992[1]

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

ABSTRACT: The second year of NutraLime demonstrations were conducted in Dakota, Isanti, and Washington counties. NutraLime was applied in 1991 at all three locations. Residual effects were monitored in 1992 on soybeans (Isanti and Washington counties) and potatoes (Dakota county). Application of NutraLime increased soil water sulfur concentrations at the 2.5 ft depth. Some trace metals were detected in soil water at the 2.5 ft depth, but levels in control plots were generally as high as those in NutraLime plots. In cases where NutraLime increased trace elements in soil water, 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 Cu and S, NutraLime did not affect nitric acid extractable elements in the 12-24 inch depth. Soybean yields increased with NutraLime application at the Isanti Co. site, but were not affected at the Washington Co. site. Potato yields were not affected by NutraLime application; however, scab problems increased with NutraLime, as a consequence of increasing soil pH. The scab problem limits the usefulness of NutraLime for potato production. In potato plants, Mo and to a lesser extent Ca and Cu tended to increase with increasing NutraLime application. Potato skins had the highest accumulation of trace elements. Even though the tubers were washed, some of this accumulation may have been due to contamination by soil particles adhering to the skin. In soybeans, tissue P generally increased with NutraLime application and was involved with the yield increases at the Isanti Co. site. As with potatoes, Mo also increased in soybean tissue with increasing NutraLime. The Mo levels accumulated in soybean grain tissue were above those considered safe for ruminants.

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.

PROCEDURES

Three field sites, all used for commercial crop production, were selected for the demonstration plots. The sites were located in Dakota Co. (Wadena loam), Isanti Co. (Hayden silt loam), and Washington Co. (Antigo silt loam). Selected soil characteristics of each site are presented in Table 1. The same basic procedure was followed at each site. Treatments 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 on a wet and dry weight basis in Table 2. Elemental content of the NutraLime at each site was determined on concentrated nitric acid/perchloric acid digests (Table 3). In 1991, the crop at all three sites was corn. In 1992 the crop grown depended on the site.

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

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At the Dakota Co. site, the crop tested for response to Nutralime was potato, variety Norkotah Russet. Potatoes were planted April 26, 1992 at a spacing of three feet between rows and 10 inches within the row. At planting, 50 lbs N/A, 160 lbs P_2O_5/A, 55 lbs K_2O/A, 15 lbs S/A, 15 lbs Mg/A and 0.5 lbs B/A was applied as a band. Additional nitrogen was applied at emergence (100 lbs N/A) and hilling (125 lbs N/A). Irrigation was used to supplement rainfall when needed. At the Isanti Co. site, the crop tested for response to Nutralime was the soybean variety Pioneer 9061. The soybeans were planted May 12, 1992 at a rate of 200,000 seeds/A (15" between rows). No fertilizer was applied during the 1992 growing season. The site was nonirrigated. At the Washington Co. site, the crop tested for response to Nutralime was Jacques 231 soybeans. The soybeans were planted May 18 at a rate of 180,000 seeds/A (30" between rows). No fertilizer was applied during the 1992 growing season. 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. Five whole plant shoot and tuber potato samples, as well as 30 recently matured leaf (diagnostic leaf) samples were collected on July 14. All tuber samples were rinsed in deionized water before drying at 60 C. Whole plant soybean shoot samples (10 feet of row per replication) and 40 first trifoliate leaf (diagnostic leaf) samples were collected on July 9. Potato vines and tubers were hand harvested from two, 20 ft rows on August 20. Tubers were separated into marketable and nonmarketable categories and then weighed. Subsamples of vines were collected for elemental analyses. Twenty-five tubers were sampled for scab incidence, specific gravity, and elemental analyses. To prepare the tubers for elemental analysis, samples were washed in deionized water and then the skin was peeled off. Tuber skin and flesh samples were dried at 60 C and then ground to pass through a 30 mesh screen. Two, 20 ft rows of soybeans were harvested on October 6 at Isanti Co. and October 8 at Washington County. Samples were air dried and shelled, then the grain was weighed. A subsample of grain was dried in an oven at 60 C. Moisture content was determined and then the samples were ground to pass through a 30 mesh screen. Potato and soybean tissue samples were ashed, dissolved in 1 N HCl and then analyzed for elemental composition 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 no effect on growth of potatoes at mid-season (Table 4). Final potato yield and specific gravity were also not affected by NutraLime. Scab incidence was measured because liming is known to be associated with increased scab occurrence. Increasing NutraLime tended to increase incidence of moderate and heavy scab in Norkotah potatoes. This variety is considered susceptible to scab, so an increase in scab incidence with increasing pH was not surprising. The increase in scab incidence limits the usefulness of NutraLime for potato production.

Effects of NutraLime on soybean growth are presented in Tables 6 and 7. Early plant growth at the preflower stage tended to increased with NutraLime application at both sites compared to the control plots, presumably due to higher soil P with Nutralime application. Nutralime had no effect on final soybean stand counts at either location. Soybean yield tended to increase with Nutralime application at Isanti Co., although the 1X rate did not fall cleanly between the 0.5X and 2X rate. The overall trend for increasing soybean yield with NutraLime application, however, was significant. NutraLime had no effect on soybean yield at the Washington Co. location. As with corn results from 1991, these results indicate that when applied at realistic rates, NutraLime can have a beneficial effect on plant growth.

Elemental Concentrations in Soil Water. Elemental concentrations in water collected from suction tubes at the 2.5' depth are presented in Tables 8 - 10. At the Dakota Co. site Al, Cd, Fe, K, Mg, Mo, Ni, and P were all at background levels (Table 8). B, Cu, 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 Ca, Na, and S concentrations with increasing NutraLime were also detected. On one sampling date Cr concentrations decreased with NutraLime application.

At the Isanti Co. site Cd and K concentrations were generally below detection limits (Table 9). Concentrations of Cr were also below detection limits at two dates, but then slightly increased with NutraLime application at the last sampling date. All Cr levels detected were below drinking water standards. Concentrations of Mn and Ni increased with increasing NutraLime at the last sampling date, but as with Cr, levels were below drinking water standard limits. Concentrations of Pb were not consistently affected by NutraLime. At the first sampling date, all Pb levels were below detection limits. At the second sampling date, Pb increased with increasing NutraLime; however, at the third sampling date, Pb levels were not affected by treatment and the control Pb level at this date was actually at a higher concentration than the highest Pb level at the previous date, where a significant trend with NutraLime occurred. Concentrations of Mo were generally at background levels, although at the last sampling date Mo levels at the 1X NutraLime

rate were significantly higher than control levels. Concentrations of Al, B, Cu, Fe, Na, P, and Zn did not show any trend with increasing NutraLime application. Significant increases in S concentrations with increasing NutraLime were detected at all sampling dates. Ca and Mg concentrations also tended to increase with increasing NutraLime at all sampling dates.

At the Washington county site, concentrations of all elements were at background levels. It is interesting to note that the suction tubes had to be reinstalled at this site. The low levels of all elements at both sampling dates may reflect a high adsorption capacity of the ceramic cup used to draw in the soil water. With time, as equilibrium approaches, elemental concentrations might conceivably increase.

Elemental Concentrations in Soil. Soluble salts, soil pH, Bray and Olsen P, ammonium acetate extractable cations and DTPA extractable metals are presented in Tables 11-13. Soil pH was still substantially higher (1.2-1.8 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 0.9-1.6 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. 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. 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. 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 12 inches. 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 Isanti Co. site only. 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. At the Washington Co. site, Cu significantly increased with NutraLime rate in the 12-24 inch depth. DTPA extractable Zn and Pb were not affected by NutraLime application at any of the sites. 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.

Nitric acid extractable soil elements are presented in Tables 14-16. All elements tested, except Be, Co, Li, K, and Ni, increased with NutraLime application in the top 6 inches at all sites. Li was frequently below detection limits, K and Ni increased with NutraLime application at one of the three sites, and Co increased at two of the three sites. Sulfur generally increased with NutraLime application in all depths at all 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, Al, As, B, Co, Fe, Mo, Na, and V increased with NutraLime application in the 6-12 inch depth. At the Isanti Co. site, all elements except Be, Co, Li, K, and Ni increased with increasing NutraLime treatment At Washington County, Cu, P, K, and Na 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 potatoes were grown. For this crop moldboard plowing to a depth of 10-12 inches is common. Except for S and Cu, NutraLime had no consistent effect on elemental concentrations in the 12-24 inch depth at any site. Background concentrations of most elements at this lower depth indicate that minimal leaching had occurred two years after NutraLime application.

Elemental Concentrations in Plant Tissue. Elemental concentrations in potato tubers, shoots, and diagnostic leaves sampled at mid-season, as well as elemental concentrations in tuber skin, tuber flesh, whole tubers (skin + flesh), and potato vines sampled at harvest are presented in Tables 17-23. Of all the elements determined, Mo and Cu consistently increased with NutraLime application in all potato tissues. Concentrations of Mo were below levels (15 ppm) that would cause Mo toxicity (molybdenosis) in ruminants. Mo seemed to accumulate in potato skin. Concentrations of Cu were also highest in the skin, but were below levels that would cause toxicity in plants or animals. Calcium concentrations also increased with NutraLime in potato tuber skin and flesh. Concentrations of Ca and Na increased with NutraLime rate in vines at harvest. Whole tuber and tuber flesh concentrations of trace elements such as B, Cd, Ni, Cr, and Pb were generally not significantly affected by NutraLime application; however, potato skin levels of Cd and B increased slightly with NutraLime rate. Some of the increases in the potato skin may be due to contamination by soil particles. Every effort was made to wash the skins before peeling; however, some soil may have still adhered to the skin. Levels of P in potato shoots or tubers were not affected by NutraLime, presumably due to the high rates of P applied in the starter fertilizer (160 lbs P_2O_5/A).

Elemental concentrations in soybean whole plants and diagnostic leaves sampled at mid-season and grain sampled at harvest are presented in Tables 24-29. As with potatoes, Mo concentrations increased significantly in all soybean tissue sampled and appeared to accumulate in the grain. Levels of Mo were above those considered safe for chronic ingestion by ruminants. Nonruminants are less susceptible to elevated Mo levels. High Mo in ruminant diets induces copper deficiency. A Cu/Mo ratio of < 2 has been shown to induce Cu deficiency. The Cu/Mo ratios in soybean grain tissue in the present study were less than 2 when NutraLime was applied at both sites. At the Isanti Co. site, Cu/Mo ratios were less than 2 in the controls as well. It may be possible to adjust the low Cu/Mo ratio by adding Cu to feed rations. Soybeans seem to accumulate Mo to a much higher degree (even without NutraLime additions) than corn. Concentrations of Mo in soybean grain can normally range from 1-10 ppm. Availability of Mo increases with increasing pH, so the Mo increases in grain tissue may partially be due to a pH response and not the higher Mo content in NutraLime per se. It is known that plants can accumulate high levels of Mo without causing phytotoxicity. Further research into Mo accumulation seems warranted, since sewage sludge applications can also increase Mo in soybeans.

In Isanti Co., P concentrations in soybean whole plant, diagnostic leaf and grain significantly increased with NutraLime application. Mg and Cu concentrations increased in whole plant and diagnostic leaf with increasing NutraLime. In contrast, Ni concentrations decreased in leaf and grain with increasing NutraLime. Concentrations of Zn in whole plants and Mn in diagnostic leaves decreased with increasing NutraLime rate. Concentrations of Cd and Pb in soybean tissue were not affected by treatment.

In Washington Co., P concentrations in whole plant and diagnostic leaves increased with increasing NutraLime rate. N concentrations in diagnostic leaf tissue increased with NutraLime application. Concentrations of Mg increased in whole plants with increasing NutraLime rate. NutraLime application decreased concentrations of Zn, Mn, and B in grain tissue.

GENERAL SUMMARY

NutraLime application increased soybean yield at one of two soybean sites and had no effect on potato yields at a third site. In potatoes, scab increased with NutraLime application, which would limit the usefulness of NutraLime for potato production. Any increases in trace elements with NutraLime were accentuated in tuber skin tissue, although some of this accumulation may have been due to contamination from soil particles adhering to the skin. In soybeans, improved P and Mo nutrition appeared to be involved with increases in yield, although other factors not measured may also have played a role. Accumulation of Mo in soybean grain exceeded 15 ppm when NutraLime was applied. These high Mo levels in soybean grain may limit the general use of this crop in sites where NutraLime is applied. Except for Cu, 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. Results from this second year suggest that NutraLime may be most suited for corn production, since this crop does not accumulate Mo to the same degree as soybean.

Table 1. Selected initial soil chemical characteristics of the demonstration sites. (1991)

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

Table 2. NutraLime treatments applied at each site prior to planting 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 3. Selected chemical characteristics of NutraLime used at each site (means of 4 or 5 samples).

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

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

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

Table 4. Effect of NutraLime on vine dry matter, tuber number and dry matter; sampled July 14, 1992 - Dakota County.

NutraLime Treatment	Tubers	Tuber dry matter	Vine dry matter
	--#/plant--	--g/plant--	--g/plant--
0	10.5	100.0	66.8
0.5X	11.7	115.5	73.2
1.0X	12.1	106.3	68.8
2.0X	9.9	95.2	63.1
Significance	NS	NS	NS
Linear	NS	NS	NS
Quadratic	NS	NS	NS

NS = not significant

Table 5. Effect of NutraLime on potato yield, fresh vine weight at harvest, specific gravity and scab severity; August 19, 1992 - Dakota County.

NutraLime Treatment	Tuber Size				Vines fresh wt.	Specific gravity	Scab Severity			
	<3 oz	3-12 oz	>12 oz	total			slight[1]	moderate[2]	heavy[3]	total
	cwt/A				--tons/A--		% infected			
0	55.3	338.4	87.9	481.7	8.05	1.0787	32.0	13.3	2.7	48.0
0.5X	45.8	346.4	122.0	514.2	7.54	1.0794	46.7	6.6	6.7	60.0
1.0X	41.1	289.7	126.4	457.2	6.63	1.0825	52.0	8.0	9.3	69.3
2.0X	38.8	356.1	102.5	497.4	7.81	1.0805	41.3	33.3	22.7	97.3
Significance	NS	NS	NS	NS	NS	NS	NS	*	NS	*
BLSD (5%)	--	--	--	--	--	--	--	17.8	--	30.8
Linear	NS	NS	NS	NS	NS	NS	NS	*	*	**
Quadratic	NS	*	NS	NS	NS	NS	NS	*	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.
1 slight - surface scab, no pits.
2 moderate - pitted, less than 3 lesions per tuber.
3 heavy - pitted, 3 or more lesions per tuber.

Table 6. Effect of NutraLime on soybean whole plant dry weight at the pre-flower stage, final stand count and grain yield - Isanti County.

NutraLime Treatment	Plant dry wt. pre-flower	Final stand count	Grain Yield
	--g/10' row--	--plants/A--	--bu/A--
0	81	170,755	32.8
0.5X	133	182,952	41.9
1.0X	112	170,755	35.2
2.0X	97	177,724	46.2
Significance	*	NS	++
BLSD (5%)	30	--	10.0
Linear	NS	NS	*
Quadratic	*	NS	NS

NS = not significant, ++ = significance at 10%, * = significant at 5%.

Table 7. Effect of NutraLime on soybean whole plant dry weight at the pre-flower stage, final stand count and grain yield - Washington County.

NutraLime Treatment	dry wt. Plant yield pre-flower	Final stand count	Grain Yield
	--g/10 feet row--	--plants/A--	--bu/A--
0	224	136,488	27.4
0.5X	245	131,261	29.4
1.0X	311	144,619	28.3
2.0X	282	145,200	30.0
Significance	**	NS	NS
BLSD (5%)	35	--	--
Linear	**	NS	NS
Quadratic	**	NS	NS

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

Table 8. 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
		ppm																
June 1, 1992																		
	0	0.44	0.07	93	0.010	0.022	0.08	0.07	3.3	25	0.02	0.03	8	0.06	0.12	0.14	24	0.24
	0.5X	0.55	0.06	106	0.010	0.021	0.09	0.06	2.7	26	0.05	0.03	15	0.08	0.12	0.14	27	0.82
	1.0X	0.40	0.06	92	0.009	0.022	0.07	0.06	2.3	23	0.04	0.02	13	0.07	0.12	0.12	36	0.83
	2.0X	0.42	0.07	44	0.010	0.023	0.08	0.05	1.5	11	0.02	0.03	11	0.05	0.12	0.14	28	0.26
Significance		NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD (5%)		--	--	--	--	--	0.01	--	--	--	--	--	--	--	--	--	--	--
Contrasts																		
Linear		NS	NS	NS	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	NS	*
June 29, 1992																		
	0	0.43	0.07	69	0.011	0.023	0.09	0.05	3.0	19	0.01	0.03	8	0.06	0.11	0.15	19	0.12
	0.5X	0.56	0.06	91	0.010	0.024	0.09	0.06	2.9	21	0.05	0.03	13	0.06	0.09	0.13	24	0.26
	1.0X	0.40	0.06	70	0.009	0.020	0.08	0.06	1.8	16	0.03	0.02	12	0.06	0.09	0.14	29	0.23
	2.0X	0.47	0.08	47	0.010	0.025	0.09	0.05	1.6	12	0.02	0.03	11	0.06	0.11	0.15	28	0.12
Significance		NS	*	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD (5%)		--	0.01	--	--	0.003	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																		
Linear		NS	*	NS	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	NS
October 6, 1992																		
	0	0.49	0.08	58	0.013	0.027	0.09	0.07	2.6	16	0.01	0.03	9	0.06	0.11	0.17	17	0.08
	0.5X	0.67	0.08	108	0.011	0.025	0.10	0.06	5.0	29	0.05	0.03	16	0.07	0.11	0.17	29	0.18
	1.0X	0.53	0.08	76	0.012	0.025	0.09	0.40	2.3	19	0.03	0.03	18	0.08	0.10	0.17	35	0.21
	2.0X	0.56	0.10	60	0.012	0.026	0.09	0.07	1.8	15	0.02	0.03	13	0.07	0.11	0.16	40	0.11
Significance		NS	NS	NS	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	NS	NS	NS
Quadratic		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*

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

Table 9. 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
		ppm																
June 29, 1992																		
	0	<0.24	0.04	26	<0.007	<0.02	0.05	0.05	<0.7	10	0.03	0.016	9	0.042	0.07	<0.084	15	0.07
	0.5X	0.33	0.05	40	<0.007	<0.02	0.06	0.03	<0.8	15	0.07	0.022	12	0.060	0.06	<0.084	25	0.08
	1.0X	0.37	0.05	39	<0.006	<0.01	0.08	0.10	<1.2	14	0.09	0.023	10	0.058	0.12	<0.087	34	0.24
	2.0X	0.40	0.05	45	<0.006	<0.02	0.08	0.14	<1.3	16	0.08	0.018	10	0.063	0.08	<0.084	37	0.19
Significance		--	NS	NS	--	--	NS	NS	--	NS	NS	NS	NS	NS	NS	--	*	NS
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	14	--
Contrasts																		
Linear		--	NS	*	--	--	NS	NS	--	NS	NS	NS	NS	NS	NS	--	**	NS
Quadratic		--	NS	NS	--	--	NS	NS	--	NS	NS	NS	NS	NS	NS	--	NS	NS
August 13, 1992																		
	0	0.28	0.05	24	<0.007	<0.02	0.05	0.02	<0.7	9	0.02	0.020	10	0.046	0.07	0.097	12	0.05
	0.5X	0.36	0.06	42	<0.007	<0.02	0.07	0.03	<0.8	16	0.06	0.018	12	0.062	0.07	0.097	21	0.07
	1.0X	0.34	0.06	36	<0.007	0.02	0.07	0.04	<0.9	13	0.06	0.019	10	0.062	0.08	0.102	30	0.09
	2.0X	0.38	0.07	44	0.008	<0.02	0.07	0.04	<0.8	17	0.08	0.020	11	0.069	0.08	0.104	36	0.08
Significance		NS	NS	*	--	--	NS	NS	--	NS	NS	NS	NS	NS	NS	*	**	NS
BLSD (5%)		--	--	14	--	--	--	--	--	--	--	--	--	--	--	0.005	12	--
Contrasts																		
Linear		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
October 6, 1992																		
	0	0.38	0.06	27	0.009	0.018	0.07	0.05	<0.8	11	0.03	0.021	11	0.055	0.08	0.118	13	0.07
	0.5X	0.57	0.07	48	0.009	0.021	0.07	0.04	<0.9	18	0.07	0.020	14	0.072	0.09	0.115	23	0.12
	1.0X	0.45	0.08	39	0.009	0.023	0.07	0.04	1.0	14	0.06	0.024	10	0.078	0.08	0.121	30	0.06
	2.0X	0.56	0.07	84	0.009	0.022	0.07	0.04	<1.0	32	0.16	0.020	19	0.103	0.08	0.117	49	0.10
Significance		NS	NS	NS	NS	*	NS	NS	--	NS	NS	*	NS	*	NS	NS	NS	NS
BLSD (5%)		--	--	--	--	0.003	--	--	--	--	--	0.003	--	0.024	--	--	--	--
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	NS	NS

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

Table 10. 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 29, 1992																		
	0	<0.18	0.05	40	<0.006	<0.01	<0.05	<0.03	2.5	11	0.04	0.02	11	0.04	0.19	<0.08	27	0.18
	0.5X	<0.18	0.06	50	<0.006	<0.01	0.04	0.03	1.8	14	0.02	0.02	18	0.04	0.13	<0.08	35	0.13
	1.0X	<0.18	0.06	48	<0.006	<0.01	0.04	0.02	1.5	13	0.01	0.02	23	0.03	0.17	<0.08	33	0.07
	2.0X	<0.18	0.05	55	<0.006	<0.01	0.04	0.02	2.0	18	<0.01	0.02	20	0.03	0.43	<0.08	29	0.08
Significance		--	NS	NS	--	--	--	--	NS	NS	--	NS	NS	NS	NS	--	NS	NS
August 13, 1992																		
	0	<0.19	0.05	37	<0.006	<0.01	<0.04	<0.02	2.7	11	0.03	0.01	11	0.03	0.11	<0.08	22	0.15
	0.5X	<0.18	0.07	29	<0.006	<0.01	<0.03	0.04	1.2	9	0.02	0.01	20	0.03	0.15	<0.08	24	0.09
	1.0X	<0.18	0.07	38	<0.006	<0.01	<0.03	<0.02	1.0	10	0.01	0.01	30	0.02	0.13	<0.08	34	0.08
	2.0X	<0.18	0.05	39	<0.006	<0.05	<0.03	<0.03	1.5	12	<0.01	0.01	18	0.02	0.36	<0.08	18	0.07
Significance		--	NS	NS	--	--	--	--	NS	NS	--	NS	NS	NS	NS	--	NS	NS
BLSD (5%)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																		
Linear		--	NS	NS	--	--	--	--	NS	NS	--	NS	NS	NS	NS	--	NS	NS
Quadratic		--	*	NS	--	--	--	--	NS	NS	--	NS	NS	NS	NS	--	NS	NS

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

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

						NH$_4$OAc 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	6.3	0.23	97	46	191	1583	391	10.6	79	16.1	1.6	0.8	1.9	1.5	0.07	<0.03
	0.5x	7.2	0.37	181	73	189	2606	408	11.2	53	7.0	1.5	3.1	1.4	0.7	0.10	0.05
	1.0x	7.3	0.37	250	85	207	3706	441	11.5	51	7.2	1.7	4.6	1.9	0.7	0.12	<0.04
	2.0x	7.4	0.35	281	95	194	3747	444	13.1	50	6.0	1.6	4.9	1.4	0.7	0.09	0.05
Significance		**	NS	**	**	NS	**	*	NS	*	*	NS	**	NS	*	NS	--
BLSD	(5%)	0.5	--	61	14	--	514	30	--	19	6.8	--	1.0	--	0.6	--	--
Contrasts																	
Linear		**	NS	**	**	NS	**	*	NS	NS	NS	NS	**	NS	NS	NS	--
Quadratic		*	NS	*	**	NS	**	*	NS	*	*	NS	**	NS	*	*	--
6-12"	0	6.0	0.17	62	31	102	1544	353	11.9	84	13.9	1.1	0.8	1.6	1.4	0.06	0.04
	0.5x	6.7	0.33	122	46	122	2054	387	13.9	72	9.6	1.1	1.5	1.3	1.0	0.07	<0.03
	1.0x	6.9	0.33	120	46	98	2274	379	12.9	62	7.3	1.3	2.9	1.6	0.9	0.11	<0.03
	2.0x	6.9	0.30	107	37	119	2172	383	13.9	66	7.6	0.9	1.5	1.0	0.9	0.05	0.04
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	--
BLSD	(5%)	--	--	--	--	--	--	--	--	--	--	--	--	--	0.4	0.04	--
Contrasts																	
Linear		NS	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	*	*	--
12-24"	0	6.1	0.10	9	6	53	1251	267	10.9	38	2.1	0.2	0.6	<0.7	0.6	<0.03	<0.02
	0.5x	6.2	0.23	14	10	59	1418	327	14.4	41	2.5	0.2	0.6	0.5	0.7	<0.02	<0.03
	1.0x	6.3	0.20	14	8	54	1426	308	12.9	43	2.1	0.3	0.7	<0.4	0.8	<0.03	<0.03
	2.0x	6.5	0.20	14	8	75	1419	330	12.3	34	1.4	0.2	0.6	0.6	0.4	<0.02	0.06
Significance		NS	*	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	--	--
BLSD	(5%)	--	0.07	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	--	NS	--	--

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

Table 12. Effect of NutraLime on soil pH, soluble salts, Bray P1, Olsen P, ammonium acetate extractable cations, and DTPA extractable metals - 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	5.7	0.10	39	19	186	801	69	6.1	90	27.4	1.47	0.71	1.06	1.15	0.09	<0.04
	0.5x	7.3	0.20	102	33	177	1560	117	9.0	44	9.5	1.27	2.02	1.46	0.64	0.08	<0.03
	1.0x	7.4	0.27	133	34	148	1963	132	9.2	40	8.1	1.28	2.62	0.90	0.64	0.10	<0.02
	2.0x	7.5	0.20	157	43	132	2601	159	9.9	39	7.7	1.51	3.72	1.11	0.61	0.12	<0.03
Significance		**	**	*	NS	*	**	**	NS	**	**	NS	**	NS	**	NS	--
BLSD (5%)		0.3	0.06	71	--	42	792	38	3.1	13	9.0	--	1.00	--	0.11	--	--
Contrasts																	
Linear		**	**	**	*	**	**	**	*	**	**	NS	**	NS	**	NS	--
Quadratic		**	**	NS	NS	NS	NS	NS	NS	**	**	NS	NS	NS	**	NS	--
6 - 12"	0	5.6	0.10	31	17	151	762	71	7.9	80	21.4	1.12	0.63	1.03	1.46	0.07	<0.04
	0.5x	7.0	0.20	70	22	139	1354	109	11.1	55	10.2	1.01	1.57	0.52	0.88	0.08	<0.03
	1.0x	7.1	0.27	91	25	141	1580	115	9.8	56	12.7	1.27	1.93	0.96	1.07	0.06	<0.04
	2.0x	7.2	0.27	93	25	127	1718	133	10.6	50	9.8	1.14	1.92	0.71	0.93	0.10	0.05
Significance		**	**	NS	NS	NS	*	NS	NS	**	*	NS	*	*	**	*	--
BLSD (5%)		0.3	0.07	--	--	--	555	--	--	14	6.2	--	0.85	0.34	0.28	0.03	--
Contrasts																	
Linear		**	**	*	NS	NS	**	**	NS	**	**	NS	*	NS	*	NS	--
Quadratic		**	**	NS	NS	NS	NS	NS	NS	*	*	NS	*	NS	*	*	--
12 - 24"	0	5.8	0.10	22	20	130	1135	205	11.8	86	5.4	0.21	0.61	<0.66	1.11	<0.02	<0.04
	0.5x	6.0	0.10	26	22	124	1175	207	13.6	82	3.9	0.19	0.62	0.44	0.82	<0.03	<0.04
	1.0x	6.4	0.10	22	14	89	1098	160	12.4	55	2.6	0.17	0.82	0.53	0.55	<0.02	<0.04
	2.0x	6.3	0.13	24	18	94	1233	197	12.8	64	4.7	0.20	0.75	<0.36	0.76	<0.05	<0.04
Significance		NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	--	NS	--	--
BLSD (5%)		--	--	--	--	17	--	--	--	--	--	--	--	--	--	--	--
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	--	--

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

Table 13. Effect of NutraLime on soil pH, soluble salts, Bray P1, Olsen P, ammonium acetate extractable cations and DTPA extractable metals - Washington County.

						NH$_4$OAc 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	5.4	0.17	77	47	249	1733	252	3.9	140	48.2	2.3	1.33	2.59	2.67	0.15	0.07
	0.5x	7.1	0.30	145	85	269	3324	345	7.2	89	15.2	2.8	3.09	2.35	1.81	0.17	<0.03
	1.0x	7.5	0.33	166	93	233	4299	371	7.9	76	10.5	2.4	4.46	2.12	1.36	0.20	<0.03
	2.0x	7.7	0.30	228	130	315	4793	472	10.0	65	8.7	3.2	7.94	2.35	1.17	0.24	<0.04
Significance		**	**	**	**	NS	**	*	*	**	**	NS	*	NS	*	NS	--
BLSD (5%)		0.6	0.08	39	33	--	950	118	3.0	32	13.8	--	3.78	--	0.79	--	--
Contrasts																	
Linear		**	**	**	**	NS	**	**	**	**	**	NS	**	NS	**	*	--
Quadratic		**	**	NS	NS	NS	*	NS	NS	*	**	NS	NS	NS	NS	NS	--
6 - 12"	0	5.5	0.13	50	32	163	1862	285	5.1	117	27.1	1.4	1.10	1.88	2.70	0.11	<0.05
	0.5x	6.2	0.23	77	45	196	2507	334	8.3	106	19.4	2.4	2.32	1.89	2.61	0.16	<0.04
	1.0x	6.7	0.27	74	37	139	2626	331	9.8	98	15.7	1.6	2.22	1.63	2.33	0.11	<0.05
	2.0x	6.7	0.30	103	52	199	2640	372	11.7	99	14.6	2.1	2.19	1.39	2.02	0.11	<0.04
Significance		NS	NS	*	NS	*	NS	NS	**	NS	NS	NS	*	NS	NS	NS	--
BLSD (5%)		--	--	35	--	47	--	--	2.9	--	--	--	0.83	--	--	--	--
Contrasts																	
Linear		*	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	5.9	0.10	10	9	121	1940	394	9.5	51	2.7	0.2	0.85	1.08	0.87	<0.02	<0.04
	0.5x	5.9	0.10	11	9	133	2144	406	9.3	60	3.8	0.3	0.89	1.35	1.34	0.04	<0.05
	1.0x	5.9	0.13	11	9	124	2127	381	10.2	56	3.7	0.3	0.92	0.84	1.14	<0.03	<0.03
	2.0x	6.0	0.20	17	11	129	2094	395	10.8	59	3.3	0.3	1.01	0.76	1.09	0.05	0.06
Significance		NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	--	--
BLSD (5%)		--	0.06	--	--	--	--	--	--	--	--	--	0.11	--	--	--	--
Contrasts																	
Linear		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	--	--

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

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

DEPTH	Treatment	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Si	Na	Sr	S	Ti	V	Zn
		1 N Nitric Acid Extractable																									
		ppm																									
0 - 6 inches	0	1708	1.6	121	0.4	1.5	0.3	2827	1.4	1.0	4	746	11	<0.20	710	137	0.53	3.8	199	283	469	10	12	34	10	3.3	6
	0.5x	2275	2.1	136	0.4	2.0	0.9	5606	3.8	1.3	32	1074	17	<0.22	888	225	0.76	3.7	969	303	747	30	16	59	16	4.5	14
	1.0x	2859	2.8	159	0.4	2.7	1.3	8257	6.0	1.5	58	1376	25	0.29	1089	309	1.01	4.9	1713	343	975	53	21	86	21	5.4	22
	2.0x	2782	2.7	148	0.4	2.5	1.4	8578	6.1	1.5	62	1331	24	0.29	1127	304	1.01	4.8	1814	332	946	52	20	82	20	5.2	22
Significance		**	**	**	NS	**	**	**	**	*	**	**	**	—	*	**	**	*	**	NS	**	**	**	**	**	**	**
BLSD (5%)		356	0.3	17	—	0.4	0.5	1923	1.2	0.3	16	250	4	—	226	65	0.19	1.0	438	—	169	9	3	12	3	0.7	4
Contrasts																											
Linear		**	**	**	NS	**	**	**	**	*	**	**	**	—	**	**	**	*	**	NS	**	**	**	**	**	**	**
Quadratic		**	**	**	*	**	*	**	**	*	**	**	**	—	*	**	**	NS	**	NS	**	**	**	**	**	**	**
6 - 12 inches	0	1738	1.6	115	0.4	1.3	0.3	2447	1.4	0.6	3	717	9	<0.21	638	87	0.54	3.3	106	135	481	11	12	31	10	2.9	5
	0.5x	2020	1.9	129	0.4	1.7	0.5	3774	2.4	0.8	14	891	12	<0.23	768	136	0.64	3.3	422	171	605	21	15	58	13	3.7	8
	1.0x	2213	2.0	134	0.4	1.7	0.6	4363	3.0	0.8	21	1011	14	0.27	790	153	0.74	3.5	590	166	697	27	16	60	15	4.0	11
	2.0x	2041	1.8	123	0.4	1.4	0.5	3800	2.5	0.8	16	885	12	<0.23	745	130	0.64	3.2	449	151	622	22	14	55	13	3.6	9
Significance		NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	*	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
BLSD (5%)		—	0.3	—	—	—	—	—	—	—	—	—	—	—	—	—	0.13	—	—	—	—	—	—	20	—	—	—
Contrasts																											
Linear		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Quadratic		*	**	NS	NS	*	NS	NS	NS	*	NS	*	NS	—	NS	NS	*	NS	NS	NS	NS	*	NS	*	NS	*	NS
12 - 24 inches	0	1429	1.4	79	0.3	0.8	0.2	1777	1.2	0.2	3	640	6	<0.23	499	30	0.45	1.7	55	64	442	12	12	21	14	2.5	4
	0.5x	1569	1.4	88	0.3	0.9	0.2	1958	1.3	0.3	3	708	7	<0.25	587	35	0.49	1.9	53	72	489	14	12	31	14	2.8	4
	1.0x	1679	1.6	94	0.3	0.9	0.2	2042	1.5	0.2	4	819	7	0.29	611	36	0.54	2.3	49	75	549	16	13	34	16	3.1	5
	2.0x	1629	1.4	90	0.3	0.8	0.2	1988	1.4	0.2	4	740	7	<0.25	605	33	0.49	1.7	56	76	526	15	13	32	15	2.9	4
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
BLSD (5%)		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10	—	—	—
Contrasts																											
Linear		NS	NS	NS	NS	NS	NS	NS	NS	NS	*	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	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS

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

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

Depth	Trmt	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Si	Na	Sr	S	Ti	V	Zn
		1 N Nitric Acid Extractable																									
		ppm																									
0 - 6"	0	881	1.26	47	0.17	0.79	0.23	1268	0.92	0.42	2.8	960	6.9	<0.20	145	166	0.31	2.6	111	277	189	9	4.4	20	15	3.1	5.3
	0.5x	1025	1.56	55	0.17	1.09	0.54	2862	1.93	0.40	15.1	1080	10.4	<0.20	271	198	0.36	2.6	419	272	307	16	6.6	31	18	3.6	9.4
	1.0x	1203	1.80	62	0.18	1.27	0.76	3790	2.66	0.57	23.1	1215	11.5	<0.20	344	243	0.43	3.2	598	278	382	21	7.8	38	21	3.9	12.7
	2.0x	1404	2.08	67	0.18	1.52	1.07	5543	3.72	0.59	36.3	1294	14.1	<0.20	476	255	0.52	3.3	915	260	476	30	10.2	51	24	4.2	17.0
Significance		NS	NS	NS	NS	NS	*	*	*	NS	*	NS	*	--	*	NS	NS	NS	NS	NS	*	*	NS	*	*	NS	NS
BLSD (5%)		--	--	--	--	--	0.56	2837	1.83	--	22.5	--	4.7	--	212	--	--	--	--	--	173	14	--	21	6	--	--
Contrasts																											
Linear		*	*	*	NS	*	**	**	**	NS	**	*	**	--	**	*	**	NS	*	NS	**	**	*	**	**	*	*
Quadratic		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
6 - 12"	0	829	1.17	43	0.16	0.66	0.20	1158	0.93	0.31	2.2	923	6.0	<0.20	154	132	0.31	3.0	89	216	192	9	4.1	18	16	3.0	4.3
	0.5x	985	1.48	52	0.17	0.94	0.44	2451	1.73	0.28	11.7	1104	8.0	<0.20	257	162	0.36	3.2	315	218	294	17	6.3	32	19	3.6	7.8
	1.0x	1072	1.64	58	0.17	1.07	0.55	2792	1.95	0.45	14.9	1139	9.4	<0.20	275	209	0.39	3.6	383	245	315	18	6.8	39	19	3.6	9.5
	2.0x	1162	1.71	58	0.18	1.13	0.59	3233	2.32	0.43	17.2	1209	9.8	<0.20	340	199	0.42	3.4	445	214	363	22	7.5	43	22	3.9	10.5
Significance		NS	*	NS	NS	*	*	*	*	NS	NS	*	NS	--	*	NS	NS	NS	NS	NS	*	*	*	*	*	*	NS
BLSD (5%)		--	0.37	--	--	0.34	0.30	1417	0.98	--	--	177	--	--	101	--	--	--	--	--	87	8	2.3	15	4	0.5	4.8
Contrasts																											
Linear		*	*	*	NS	*	*	*	*	NS	*	**	*	--	**	*	*	NS	*	NS	**	**	*	**	**	**	*
Quadratic		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
12 - 24"	0	1064	1.26	35	0.18	0.61	0.15	1538	1.61	<0.13	1.9	1261	4.9	0.32	447	38	0.37	2.8	93	136	407	14	5.2	16	24	4.4	3.5
	0.5x	1144	1.84	37	0.21	1.36	0.18	1484	2.01	<0.12	2.9	1322	5.5	0.69	513	31	0.51	2.7	120	141	474	20	5.8	23	26	5.1	<2.8
	1.0x	1063	1.14	37	0.18	0.61	0.17	1624	1.72	<0.12	2.8	1227	5.0	0.36	439	34	0.37	2.1	77	117	455	16	5.4	20	28	4.6	3.9
	2.0x	1168	1.34	36	0.18	0.69	0.20	1717	1.87	<0.20	3.6	1399	5.4	0.41	555	42	0.40	3.0	100	120	506	17	5.5	23	27	4.6	4.5
Significance		NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--
Contrasts																											
Linear		NS	NS	NS	NS	NS	NS	NS	NS	--	*	NS	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	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--

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

Table 16. Effect of NutraLime on nitric acid extractable elements - Washington County.

DEPTH	Treatment	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Si	Na	Sr	S	Ti	V	Zn
		1 N Nitric Acid Extractable																									
		ppm																									
0 - 6 inches	0	1859	1.7	135	0.46	1.4	0.3	2912	1.3	1.0	5	808	12	<0.24	471	151	0.55	5.2	146	343	446	7	15	26	10	3.4	8
	0.5x	2041	2.1	151	0.46	2.0	0.8	6112	3.0	1.2	22	963	16	<0.21	670	210	0.64	5.8	598	358	680	18	19	43	13	4.5	15
	1.0x	2351	2.3	155	0.46	2.2	1.1	7905	4.4	1.2	34	1080	18	<0.23	816	225	0.72	5.8	832	331	838	26	21	54	16	4.9	19
	2.0x	3003	3.0	172	0.47	3.0	2.1	12607	7.2	1.6	75	1391	27	<0.22	1190	310	0.99	6.7	1818	475	1125	50	27	82	22	6.0	33
Significance		*	*	NS	NS	*	*	*	*	*	*	*	*	—	*	*	NS	NS	*	NS	*	*	*	*	*	**	*
BLSD (5%)		837	0.8	--	--	0.8	1.0	5980	3.6	0.4	46	341	10	—	417	94	--	--	1064	--	345	27	8	35	7	0.9	15
Contrasts																											
Linear		**	**	*	NS	**	**	**	**	**	**	**	**	—	**	**	*	NS	**	*	**	**	**	**	**	**	**
Quadratic		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
6 - 12 inches	0	1905	1.7	126	0.45	1.4	0.3	2859	1.4	0.6	4	793	10	0.31	544	96	0.56	5.0	84	215	529	8	15	24	13	3.4	7
	0.5x	1956	1.9	145	0.48	1.6	0.4	4191	1.9	0.7	10	840	11	0.30	647	117	0.59	6.7	220	244	599	13	18	34	13	3.8	10
	1.0x	2016	1.8	142	0.47	1.6	0.5	4475	2.1	0.7	12	874	11	<0.29	674	115	0.59	5.8	256	192	666	17	18	38	14	3.9	10
	2.0x	2035	1.7	139	0.45	1.7	0.5	4492	2.0	0.7	13	888	12	<0.22	690	128	0.58	5.4	298	274	633	19	17	41	14	4.0	11
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS	NS	*	NS	*	NS	**	NS	NS	NS
BLSD (5%)		--	—	--	--	--	—	--	—	—	--	--	—	—	--	—	--	—	--	47	--	7	--	5	--	—	—
Contrasts																											
Linear		NS	NS	NS	NS	NS	NS	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	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
12 - 24 inches	0	2146	1.8	109	0.40	1.1	0.2	2748	1.8	<0.2	4	1039	9	0.49	832	33	0.64	2.4	33	148	758	15	17	19	23	4.1	6
	0.5x	2038	1.8	120	0.43	1.1	0.2	2944	1.8	0.3	4	998	9	0.52	842	35	0.61	3.6	20	141	757	14	18	23	24	4.1	7
	1.0x	1942	1.5	116	0.40	1.0	0.2	2778	1.7	<0.2	4	1036	8	0.43	803	33	0.56	3.0	22	129	764	14	18	25	25	4.0	7
	2.0x	2101	1.7	112	0.39	1.1	0.2	3004	1.7	<0.2	5	1003	8	0.36	817	40	0.59	2.9	58	152	733	16	17	33	22	4.0	6
Significance		NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	**	NS	NS	NS
BLSD (5%)		--	—	--	--	--	—	--	—	—	--	--	—	—	--	—	--	0.7	--	—	--	--	--	4	--	—	—
Contrasts																											
Linear		NS	NS	NS	NS	NS	NS	NS	NS	—	NS	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	NS	*	NS	*	NS	NS	NS	NS	NS	NS	NS

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

Table 17. Effect of NutraLime on the elemental composition of potato tuber samples, July 14, 1992 - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.57	0.27	2.12	623	1019	95	88	27	8.7	13.5	3.1	5.2	<1.68	1.11	0.54	<0.14	<0.24
0.5x	1.62	0.27	2.18	856	1122	68	66	30	7.5	12.2	4.6	5.1	<1.68	0.91	0.52	<0.14	0.90
1.0x	1.54	0.26	2.16	916	1080	84	76	37	7.6	12.4	6.2	5.4	<2.07	1.12	0.54	<0.16	1.48
2.0x	1.58	0.27	2.14	858	1087	73	69	32	7.4	12.2	5.7	5.3	<1.68	1.06	0.47	<0.16	1.63
Significance	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	**
BLSD (5%)	--	--	--	203	--	--	--	--	--	--	--	--	--	--	--	--	0.62
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	NS	--	*

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

Table 18. Effect of NutraLime on the elemental composition of potato shoot samples, July 14, 1992 - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%					ppm											
0	4.86	0.36	5.19	1.73	1.18	563	411	58	176	30	6.7	27	<4.8	4.5	3.0	1.03	0.90
0.5x	4.54	0.32	4.99	1.92	1.32	905	617	82	151	27	11.4	27	7.6	5.4	4.4	1.19	3.91
1.0x	4.52	0.33	4.81	1.95	1.26	695	465	77	147	27	12.3	26	6.7	4.8	3.7	1.29	5.51
2.0x	4.61	0.34	4.87	1.90	1.27	677	441	73	148	23	11.9	26	<5.5	4.3	3.3	1.10	6.02
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	--	NS	NS	NS	**
BLSD (5%)	--	--	--	--	--	--	--	--	--	--	3.1	--	--	--	--	--	2.38
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 = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 19. Effect of NutraLime on the elemental composition of potato diagnostic leaf samples, July 14, 1992 - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%					ppm											
0	5.86	0.44	3.56	0.88	0.69	26.2	81	33	62	22	8.3	22	<4.6	3.0	1.81	0.61	0.75
0.5x	6.00	0.48	3.52	0.99	0.81	22.5	80	33	59	24	11.0	22	<3.3	2.6	1.44	0.71	3.12
1.0x	5.95	0.47	3.42	0.97	0.74	23.5	80	36	43	23	12.2	22	<3.9	2.8	1.41	0.69	5.09
2.0x	5.96	0.48	3.69	0.92	0.72	18.0	83	26	53	23	11.6	22	<1.8	2.1	1.10	0.54	8.19
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	—	NS	NS	NS	**
BLSD (5%)	—	—	—	—	—	—	—	—	—	—	2.7	—	—	—	—	—	2.57
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	NS

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

Table 20. Effect of NutraLime on the elemental composition of potato skin samples, August 19, 1992 - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%					ppm											
0	2.91	0.29	3.05	0.21	0.22	1140	694	92	33	23	9.5	15.7	5.3	3.6	2.1	0.55	1.2
0.5x	2.94	0.28	3.06	0.27	0.21	937	535	89	33	22	14.2	16.5	6.1	4.0	2.1	0.68	4.1
1.0x	3.00	0.29	3.20	0.29	0.24	898	507	98	34	21	15.2	16.7	7.0	3.8	2.4	0.74	6.5
2.0x	3.11	0.28	3.15	0.31	0.24	1296	798	125	47	26	19.6	18.1	7.5	5.2	3.1	0.83	6.7
Significance	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	**
BLSD (5%)	—	—	—	0.03	—	—	—	—	—	—	4.0	—	—	—	—	—	2.5
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	NS	NS	NS	*

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

Table 21. Effect of NutraLime on the elemental composition of potato flesh samples, August 19, 1992 - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.37	0.25	1.80	383	1029	<11.8	26	25	7.2	13	3.3	4.4	<2.8	<1.17	<0.59	<0.24	<0.42
0.5x	1.69	0.27	1.79	521	1074	12.6	24	32	7.0	14	4.9	4.8	<3.4	1.56	0.75	0.33	1.64
1.0x	1.72	0.27	1.89	605	1148	<10.0	26	32	7.7	14	5.1	4.7	<2.7	1.27	0.61	0.26	2.75
2.0x	1.61	0.28	1.92	581	1130	11.6	30	31	7.4	13	4.7	4.5	<2.5	<1.03	<0.55	<0.24	2.31
Significance	*	NS	NS	**	NS	--	NS	NS	NS	NS	*	NS	--	--	--	--	**
BLSD (5%)	0.26	--	--	98	--	--	--	--	--	--	1.1	--	--	--	--	--	0.87
Contrasts																	
Linear	NS	NS	NS	**	NS	--	NS	NS	NS	NS	*	NS	--	--	--	--	**
Quadratic	*	NS	NS	**	NS	--	NS	NS	NS	NS	**	NS	--	--	--	--	**

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

Table 22. Effect of NutraLime on the elemental composition of potato tuber samples, August 19, 1992 - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.71	0.25	1.81	445	1160	59	57	25	8.7	12.8	3.7	5.1	<4.4	<1.5	<0.79	<0.33	<0.74
0.5x	1.59	0.25	1.80	570	1043	48	48	31	7.5	12.2	4.5	5.2	<3.8	<1.4	<0.75	<0.33	1.24
1.0x	1.64	0.25	1.74	583	1078	42	42	32	7.5	12.5	5.1	6.3	<4.2	<1.5	<0.77	<0.36	2.69
2.0x	1.58	0.25	1.84	606	1103	54	52	34	8.1	12.0	5.0	5.4	<4.0	<1.5	<0.76	<0.35	2.66
Significance	NS	NS	NS	*	NS	NS	NS	*	*	NS	*	NS	--	--	--	--	**
BLSD (5%)	--	--	--	87	--	--	--	6	0.8	--	0.9	--	--	--	--	--	0.41
Contrasts																	
Linear	NS	NS	NS	**	NS	NS	NS	**	NS	NS	**	NS	--	--	--	--	**
Quadratic	NS	NS	NS	*	NS	NS	*	NS	**	NS	*	NS	--	--	--	--	**

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

Table 23. Effect of NutraLime on the elemental composition potato vine samples, August 19, 1992 - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%					ppm											
0	2.44	0.17	3.06	1.94	1.36	1060	620	105	237	21	7.2	25	5.2	4.2	3.0	0.72	0.9
0.5x	2.98	0.17	2.83	2.00	1.48	804	474	139	273	21	8.5	24	4.8	4.0	2.8	0.86	2.6
1.0x	2.74	0.17	2.40	2.16	1.58	1077	620	156	207	19	11.5	26	5.1	4.3	3.3	0.79	5.1
2.0x	3.09	0.18	2.98	2.12	1.41	1107	638	137	250	18	12.3	24	5.1	4.0	3.1	0.80	5.9
Significance	NS	NS	NS	*	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	**
BLSD (5%)	--	--	--	0.17	--	--	--	33	--	--	--	--	--	--	--	--	1.6
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	*

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

Table 24. Effect of NutraLime on the elemental composition of soybean whole plant (above ground) samples, July 9, 1992 - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.35	0.25	0.28	12677	3367	456	385	60.1	85.1	35	9.2	29.5	5.5	3.2	1.9	0.35	1.0
0.5x	3.03	0.30	0.27	13570	3891	667	632	78.8	121.5	26	11.3	28.3	4.4	2.5	2.2	0.27	7.9
1.0x	3.51	0.31	0.28	13898	4258	516	460	68.9	84.0	24	11.3	27.4	4.2	2.5	2.0	0.28	9.4
2.0x	3.34	0.32	0.29	14323	4168	487	396	63.1	78.7	27	11.9	28.8	5.2	2.5	1.9	0.34	7.8
Significance	NS	**	NS	*	*	NS	NS	NS	NS	**	NS	*	NS	NS	NS	NS	*
BLSD (5%)	--	0.01	--	1062	578	--	--	--	--	5	--	1.3	--	--	--	--	5.3
Contrasts																	
Linear	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 = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 25. Effect of NutraLime on the elemental composition of recently matured soybean trifoliate leaf samples, July 19, 1992 - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	4.89	0.43	2.85	8735	3434	105.8	114	58.3	61.2	35	9.5	34.8	4.4	6.5	1.5	0.33	0.9
0.5x	4.79	0.52	2.98	9600	3739	85.9	113	37.2	49.0	32	10.1	34.3	2.9	4.7	1.2	0.24	10.8
1.0x	4.86	0.50	2.85	8958	3733	81.9	107	55.6	46.9	30	10.3	33.8	5.1	5.5	1.6	0.37	12.2
2.0x	4.90	0.50	2.92	9041	3689	86.7	106	68.1	45.4	31	10.5	33.8	5.7	5.5	1.7	0.38	12.1
Significance	NS	**	NS	NS	*	NS	NS	NS	*	NS	*	NS	NS	**	*	NS	*
BLSD (5%)	--	0.04	--	--	232	--	--	--	9.3	--	0.7	--	--	0.7	0.3	--	6.5
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 = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 26. Effect of NutraLime on the elemental composition of soybean grain samples, October 6, 1992 - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	6.23	0.59	1.85	1663	2283	36	78	17	28	38	13	19	4.7	8.2	1.2	0.33	8.4
0.5x	6.46	0.64	1.86	1788	2518	38	91	15	28	38	15	16	5.0	5.0	1.3	0.36	22.3
1.0x	6.61	0.66	1.87	1680	2435	44	88	15	28	40	15	18	5.5	5.6	1.4	0.39	23.4
2.0x	6.48	0.66	1.87	1612	2520	31	82	14	27	39	15	19	5.2	5.6	1.3	0.38	35.4
Significance	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
BLSD (5%)	--	0.04	--	--	--	--	--	--	--	--	--	--	--	--	--	--	19.0
Contrasts																	
Linear	NS	**	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

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

Table 27. Effect of NutraLime on the elemental composition of soybean whole plant (above ground) samples, July 9, 1992 - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.81	0.34	3.00	15161	4916	352	297	31	82	37	9.2	39	4.0	4.3	1.6	0.47	0.5
0.5x	3.87	0.36	3.00	15590	5263	296	256	27	63	31	10.0	37	3.7	3.3	1.5	0.44	9.4
1.0x	3.88	0.38	3.08	15581	5291	316	269	28	69	30	10.7	38	4.1	4.0	1.6	0.49	12.2
2.0x	3.74	0.36	2.98	15012	5443	314	267	31	60	26	10.2	37	4.1	3.0	1.7	0.44	22.3
Significance	NS	**	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
BLSD (5%)	—	0.02	—	—	285	—	—	—	—	—	—	—	—	—	—	—	3.7
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	NS

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

Table 28. Effect of NutraLime on the elemental composition of recently matured soybean trifoliate leaf samples, July 9, 1992 - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	5.46	0.63	2.98	9467	4264	71	109	20	74	45	9.0	37	<2.3	11.3	1.1	0.29	<0.3
0.5x	5.74	0.66	3.00	8980	4151	67	104	27	59	42	9.8	36	3.2	9.5	1.3	0.35	11.3
1.0x	5.78	0.68	3.09	8981	4203	64	100	33	62	43	10.4	36	3.9	10.7	1.4	0.45	15.0
2.0x	5.68	0.68	3.08	8975	4318	74	112	25	56	40	9.6	37	2.5	8.5	1.2	0.33	22.1
Significance	**	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	**
BLSD (5%)	0.14	0.04	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.1
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	*

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

Table 29. Effect of NutraLime on the elemental composition of soybean grain samples, October 9, 1992 - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	6.32	0.73	2.17	1373	2221	44	90	12.4	29	45	13.4	38	3.2	12.1	1.00	0.26	1.0
0.5x	6.64	0.73	2.11	1312	2176	51	96	10.9	27	42	12.4	35	<3.0	9.2	0.97	<0.22	19.9
1.0x	6.77	0.75	2.18	1273	2221	31	85	7.9	27	41	12.6	36	<1.9	10.5	0.72	<0.17	28.5
2.0x	6.65	0.76	2.20	1267	2249	40	90	11.0	26	38	12.8	35	<3.0	7.9	1.05	0.25	38.5
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	**	--	NS	NS	--	**
BLSD (5%)	--	--	--	--	--	--	--	--	--	2	--	2	--	--	--	--	3.4
Contrasts																	
Linear	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 = nonsignificant, * = significant at 5%, ** = significant at 1%.

RATE AND TIME OF NITROGEN APPLICATION FOR CORN PRODUCTION IN A RIDGE-TILL PLANTING SYSTEM

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

ABSTRACT: Growers who use ridge-till planting systems have questioned the nitrogen recommendations for corn production as well as the effect of frequency of application on corn yield. Therefore, this study was conducted at 3 locations to evaluate the impact of rate and frequency of application of fertilizer N on yield of corn grown with ridge-till planting systems. The rates of applied N were 0, 60, 120, and 180 lb./acre. Single and multiple applications were used. The optimum N rate was approximately 120 lb./acre at all sites. Although results were not completely consistent, split applications were beneficial in 1992. This is especially true for the low rates of applied N.

Some aspects of nitrogen (N) management for corn production in ridge-till planting systems have been studied extensively for several years. The question of frequency of application of fertilizer N has not received detailed attention. With ridge-till planting systems, there is the option of applying nitrogen fertilizers with the cultivator. The nitrogen can be applied once or as much as three times during the growing season.

Objective:

This study was conducted to evaluate the effect of frequency of nitrogen applications as well as rate applied on the yield of corn grown with ridge-till planting systems.

Experimental Procedure:

This study was conducted in fields of cooperating farmers who used ridge-till planting systems. The corn/soybean rotation was used at all sites and corn followed soybeans in 1992.

Soil samples were collected in late April prior to planting. Samples were collected from three locations (directly under the existing soybean row, the center of 2 rows, combination of row and center of 2 rows). Soil was collected from depths of 0-6, 6-12, and 12-24 inches. Samples were analyzed for NO_3-N and the amount of NO_3-N was reported in terms of lb./acre. The results are summarized in Table 1.

The treatments used are listed in Table 2. The preemergence application (PE) was applied immediately after planting. The N was applied as 46-0-0 over the row and was lightly incorporated. When applied at cultivation, the 46-0-0 was broadcast just prior to cultivation and this was adequate for incorporation.

Corn was planted in late April or early May by the cooperating farmers. Management practices that were conducive to high yields were used at all sites.

Ear leaf samples were collected at silking, dried, ground, and analyzed for N to monitor N uptake. Grain yields were measured in early October and corrected to a basis of 15.5% moisture.

Results and Discussion:

The measurement of residual NO_3-N was affected by the sampling scheme that was used (Table 1). Highest NO_3-N values were recorded when 100% of the sample was collected from the center of 2 rows. The lowest values were measured when 100% of the sample was collected from directly beneath the row from the previous soybean crop. Intermediate NO_3-N values resulted from the mixture of the 2 locations. The soybean crop is noted for extracting NO_3-N from the root zone. Considering the tap root configuration of the soybean root system, these results might be anticipated.

Grain yields are summarized in Table 2. When rate is considered, the application of 120 lb. N/acre appeared to be adequate for optimum yield at all locations. The response to applied N was curvilinear at all sites.

The split application increased yield at the two sites in Renville County. For the Kandiyohi County site, the split application was beneficial only when the rate of applied N was 60 lb./acre. In general, split applications of fertilizer N have not been beneficial when corn is grown with conventional tillage systems on fine textured soils. Perhaps, differences in root development in the two planting systems can be used to explain the differences in response to split applications.

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

Table 1. Effect of location of sample on the measurement of NO_3-N in 1992.

Site	Sample Location	Sample Depth (in.) 0-6	6-12	12-24	Total
		lb. NO_3-N/acre			
Kandiyohi	row	18.4	12.1	17.0	47.5
	center of 2 rows	22.0	20.1	24.8	66.9
	row + center	19.9	17.6	25.3	62.8
Renville (Gi)	row	17.1	12.4	18.2	47.7
	center of 2 rows	36.3	34.3	39.4	110.0
	row + center	28.0	26.3	30.1	84.4
Renville (Gu)	row	19.8	19.0	28.9	67.7
	center of 2 rows	22.0	20.5	33.0	75.5
	row + center	24.0	21.4	40.2	85.6

Table 2. The effect of rate and frequency of N application on corn yield in a ridge-till planting system.

N Applied PE	1st cult	2nd cult	Site Kandiyohi	Renville (Gi)	Renville (Gu)
lb./acre			bu./acre		
-	-	-	117.7	121.5	139.9
-	60	-	139.2	137.8	145.9
-	120	-	157.7	151.2	153.6
-	180	-	163.6	153.6	164.2
30	30	-	154.0	146.6	156.7
30	90	-	160.4	148.2	163.6
30	150	-	163.1	167.3	176.7
30	75	75	158.4	154.8	159.6
30	45	45	156.1	163.6	151.1

The concentration of N in the ear leaf tissue at silking responded curvilinearly to rate of applied N (Table 3). The frequency of N application influenced concentration significantly at the Renville (Gi) site only. There was a reduction in N concentration when split applications are compared to the single application. This is not consistent with the observations with grain yield. Since this observation was not consistent for all sites, a large amount of importance cannot be attached to the results from one site.

Table 3. The effect of rate and frequency of N application on the N concentration of the ear leaf at silking.

PE	N Applied 1st cult	2nd cult	Site Kandiyohi	Renville (Gi)	Renville (Gu)
- - - - - lb./acre - - - - - -			- - - - - - - - - - - % N - - - - - - - - - - -		
-	-	-	1.72	2.33	2.08
-	60	-	2.51	2.96	2.72
-	120	-	2.79	3.19	2.96
-	180	-	2.96	3.13	2.88
30	30	-	2.62	2.81	2.67
30	90	-	2.73	3.09	2.76
30	150	-	2.85	3.10	2.88
30	75	75	2.95	3.07	2.91
30	45	45	2.68	3.05	2.96

RESPONSE OF CORN PLANTED IN RIDGE-TILL PLANTING SYSTEMS TO THE BANDED APPLICATION OF POTASH

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

ABSTRACT: The importance of banded potash for optimum corn production in ridge-till planting systems was demonstrated in 1989. This study was conducted to define the rate of K_2O needed in the banded application. The rates of 0, 20, 40, 60 and 80 lb. K_2O were compared. The banded potash increased grain yield at 1 of 3 sites. Because of weather in the fall of 1991, K_2O was applied in the spring of 1992 at the sites where no response was measured. Application depth was not as deep as desired with the spring application and K_2O could have easily been thrown away from the ridge in the planting operation. This study will be continued in 1993.

The need for additions of potash to fertilizer programs for corn planted in ridge-till and no-till planting systems was established in 1989. There are, however, many questions that must be answered before this management practice can be used most effectively. The rate of potash needed to correct the problem is one major concern.

Objective:

This study was conducted to evaluate the effect of rate of K_2O application on the yield of corn planted in a ridge-till planting system.

Experimental Procedure:

This study was conducted at 3 sites in 1992. These sites were in fields of cooperating farmers. Because of the late fall snow storm in 1991, treatments were applied in the spring of 1992.

The soil at the Meeker (N) site was a sandy loam and 0-0-60 was used to supply 0, 20, 40, 60 and 80 lb. K_2O/acre in a band at 3.5 to 4.0 inches below the existing row. The previous crop was edible beans and the existing ridge was very small. The soil at the Meeker (J) and Kandiyohi sites was classified as a silty clay loam. To avoid major disturbance of the ridge, a spoke injector was used to supply the K_2O at these two sites. The potash was applied in late April and early May. The K_2O source was 0-0-30.

Corn was planted by the cooperating farmer. Recommended cultural practices such as plant population, herbicide selection, etc., were used at each site. Whole plant samples were collected from each plot at approximately 4 weeks after emergence. A second whole plant sample was taken at 6 weeks after emergence. These samples were dried, weighed, ground, and analyzed for K. Grain yields were measured and corrected to 14.5% moisture.

Results and Discussion:

The results from each site are summarized in Tables 1, 2, and 3. The response to applied potash was not consistent for all sites. The banded K increased early growth for both samplings and grain yield at the Meeker (N) site. The response was curvilinear in all cases. The rate of 20 lb. K_2O per acre was adequate to provide for optimum early growth and yield (Table 1).

The banded K_2O did not increase early growth and grain yield at the Meeker (J) and Kandiyohi sites (Tables 2, 3). These results are not consistent with the results of previous studies where fertilizer K_2O in a band increased corn yield even though the soil test for K was in the high or very high range. It is possible that the K_2O applied with the spoke injector at the non-responsive sites was moved away from the row by the planter sweep in the planting operation. The amount of K_2O remaining after planting may have been adequate to increase the K concentration in the young, whole plant tissue. The amount remaining in the band after planting may not have been adequate for increased yield.

The K concentration in the young plants at both sampling times increased with rate of applied K_2O. The increase was linear at all sites. These results indicate that some of the applied K was left in the band after planting. There was, however, no way to determine the amount of applied K_2O remaining in the band.

Potassium uptake was computed from the dry weight and K concentration data. Therefore, the effect of banded rate of K_2O on K uptake would be expected to parallel the effects on K concentration in the young plants. This was true except for the Meeker (J) site.

[1/] Extension Soil Scientist, Junior Scientist, Assistant Scientist, respectively.

Table 1. The effect of rate of banded K_2O on early growth and yield of corn at the Meeker (N) site.

K_2O Applied	1st Sample			2nd Sample			Grain Moisture	Yield
	Plant Wt.	K Conc.	K Uptake	Plant Wt.	K Conc.	K Uptake		
lb./acre	gm/6 plants	%	mg/plant	gm/4 plants	%	mg/plant	%	lb./acre
0	12.8	2.14	45.7	46.1	2.12	249.5	31.6	142.5
20	17.0	2.96	84.8	61.8	2.53	393.6	28.5	152.4
40	18.2	3.68	111.2	59.2	2.81	411.6	31.6	158.9
60	16.4	4.06	110.7	60.0	3.57	534.1	30.8	152.5
80	15.3	4.10	104.6	52.5	3.43	444.3	32.6	154.1

Soil Test K = 109 ppm

Table 2. The effect of rate of banded K_2O on early growth and yield of corn at the Meeker (J) site.

K_2O Applied	1st Sample			2nd Sample			Grain Moisture	Yield
	Plant Wt.	K Conc.	K Uptake	Plant Wt.	K Conc.	K Uptake		
lb./acre	gm/6 plants	%	mg/plant	gm/4 plants	%	mg/plant	%	lb./acre
0	9.7	2.41	38.9	35.0	2.58	225.4	22.0	170.4
20	9.5	2.43	39.0	34.0	2.64	223.8	21.7	162.7
40	9.0	2.72	40.8	34.7	2.95	259.1	22.2	167.4
80	8.2	2.66	36.4	30.5	2.96	223.3	21.1	168.8

Soil Test K = 167 ppm

Table 3. The effect of rate of banded K_2O on early growth and yield of corn at the Kandiyohi site.

K_2O Applied	1st Sample			2nd Sample			Grain Moisture	Yield
	Plant Wt.	K Conc.	K Uptake	Plant Wt.	K Conc.	K Uptake		
lb./acre	gm/6 plants	%	mg/plant	gm/4 plants	%	mg/plant	%	lb./acre
0	16.2	1.61	43.6	26.1	1.49	97.9	29.5	125.5
20	16.7	1.88	51.9	27.4	1.61	112.2	30.0	126.4
40	19.8	2.20	72.7	32.2	2.00	162.6	28.7	128.5
60	16.9	2.21	63.6	27.9	2.13	150.3	29.7	120.8
80	18.6	2.13	65.9	31.7	2.01	160.0	28.0	134.0

Soil Test K = 147 ppm

SOIL SAMPLING SCHEMES FOR RIDGE-TILL PLANTING SYSTEMS

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

ABSTRACT: This study was conducted to evaluate several schemes that might be used for collection of soil samples in a ridge-till planting system. Thirteen schemes were identified and used in three fields. Sampling scheme appeared to have no effect on measured pH. In general, higher values of P and K were measured when a high percentage of the sample was collected from directly under the existing row. Collecting various percentages of the sample from more than one location with respect to the existing row produced values that represented average values for P and K. This study will be continued in 1993.

The procedures needed for collecting soil samples in conventional planting systems have been identified and described for some time. Specific procedures for sample collection must also be described for ridge-till planting systems. This is especially true when phosphate and potash fertilizers are applied in a band instead of broadcast and incorporated prior to planting.

Objective:

The objective of this study was to evaluate the effect of various schemes for collection of soil samples on soil test values for pH, phsophorus (P), and potassium (K).

Experimental Procedure:

This study utilized fields of cooperating farmers. Thirteen soil sampling schemes were identified. These schemes are described in Table 1. Samples were taken to a depth of 0-6 inches for each scheme. The sampling schemes were followed in 3 fields. These fields varied substantially with respect to fertility level, soil texture, and number of years devoted to ridge-till planting systems.

Following collection samples were dried, ground and analyzed for pH, P, (Bray and Kurtz #1), and K. The results are summarized in Table 1.

The Meeker (N) site was planted to edible beans in 1991. The other sites were in soybeans in 1991.

Table 1. The influence of soil sampling scheme on soil test values in a ridge-till planting system.

Location of Sample			Location and Test								
			Meeker Co. (N)			Meeker Co. (J)			Kandiyohi Co.		
row	row centers	shoulder	pH	P	K	pH	P	K	pH	P	K
- - - - - - % from - - - - - -			- - ppm - - -			- - ppm - - -			- - ppm - - -		
100	-	-	5.7	63	131	6.2	35	165	6.0	15	173
-	-	100	5.5	59	107	6.0	19	154	5.9	10	137
-	100	-	5.6	68	129	6.4	23	175	6.3	8	145
33	33	33	5.3	64	113	6.3	23	169	6.3	8	148
50	50	-	5.5	75	115	6.2	34	168	6.2	10	153
50	-	50	5.8	59	105	6.0	31	165	6.2	10	154
-	50	50	5.6	53	102	6.1	22	164	6.0	10	147
33	67	-	5.5	53	112	6.2	25	191	6.1	8	141
-	67	33	5.5	59	122	6.2	23	179	6.0	9	129
33	-	67	5.2	48	92	6.0	23	153	6.1	12	163
67	33	-	5.5	53	98	6.1	37	176	6.0	11	136
67	-	33	5.3	58	96	6.2	26	159	5.8	17	153
-	67	33	5.3	43	97	6.1	27	148	6.1	11	137

[1/] Extension Soil Scientist, Junior Scientist, Assistant Scientist, respectively.

Results and Discussion:

Soil sampling scheme had no apparent effect on the measured pH values at each site. The variability in pH measurements is consistent with the variability in pH measurements in most field conditions.

There was a wide range in soil test values for P and K among the fields sampled. The soil at the Meeker (N) site was an irrigated sandy loam. The soil textures at the other sites would be classified as a silty clay loam.

In general, highest soil test values for P and K were recorded when a major portion of the soil sample was collected from directly under the existing row. Lower soil test values were recorded when the major portion of the sample was taken from the center of two rows (row center position). Intermediate values were recorded when equal portions of the sample were taken from two or more positions.

It's obvious that broad and sweeping recommendations cannot be made from the results of sampling 3 fields in 1 year. These results must be related to crop response to P and/or K before definite recommendations can be made.

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

T. W. Schumacher, J. F. Moncrief, and B. J. Johnson[2]

Abstract: The study to determine the influence of tillage and manure application on corn production at the Dale Flueger farm in Goodhue county, MN was continued in 1992. Results from 1992 showed reduced yields and higher moisture contents than the long term average at this site. Annually applied manure produced the greatest yields (108 bu/A) and anhydrous ammonia applied at 180 lb N/A produced 99 bu/A. Biennially applied manure produced 107 bu/A of grain in the year of application and 66 bu/A of grain in the year following application. Triennially applied manure produced 96 bu/A the year of application, 72 bu/A the year after application, and 50 bu/A two years after application. The amount of surface residue left by the various tillage and N treatments and the corn population was lower than in previous years.

The total amount of N applied to the manure plots was higher than in past years. Total N applied as anhydrous ammonia was similar to past years. Unusual weather conditions this year, a dry spring and cool summer, may have been responsible for the low yields, depressed corn population, and high percent moisture.

Introduction

This study is being conducted to determine the long term impacts of tillage and frequency of manure application on corn yield and soil N levels. The Dale Flueger farm is located near Red Wing in Goodhue County, Minnesota. The research plots are on a Seaton silt loam (Typic hapludalf, fine-silty, mixed, mesic) soil. This study began in 1982.

The experimental design is a randomized complete block with tillage main plots (chisel plow and no till) with N source (commercial fertilizer and manure) and N frequency (annual, biennial, and triennially applied manure) subplots. Liquid dairy manure is injected each spring into the chisel plow and no till annual manure plots, and into the biennial manure plots that did not receive manure the previous year. Triennially applied manure plots only receive chisel plowing, and liquid dairy manure is injected at the same time into the plots that did not receive manure over the previous two years. Commercial fertilizer (anhydrous ammonia) was applied around the same time as the manure injection. Zero N check treatments are also included in this study. Refer to table 1 for details on N treatments and other cultural practices.

From 1982 to 1986 the manure treatments were split with 0 and 200 lbs/A K_2O treatments, and the commercial fertilizer treatments were split with 0, 200, and 400 lbs/A K_2O treatments. These potassium additions were stopped in 1987, but some data in this report is split by K_2O treatment to check for residual effects of the added potassium.

Results and Discussion

Residue Cover and Corn Population. Residue and population counts were both taken on June 5, 1992. Residue was measured in duplicate in and between the rows for all plots. Population counts were made in duplicate for all plots. A table of significance of treatment effects on residue cover and population is provided in table 3. Residue cover between the row in the no till system resulted in 41.7% residue cover (Table 2). Residue cover was reduced to 22.3% between the row in the no till system with the injection of liquid dairy manure. Chisel plowing reduced residue cover to around 10% for all plots. The initial corn population count was abnormally low for all plots. This may have been due to the dry spring and the timing of the population count. At harvest, the plant population was up to normal levels.

[1] Support for this project in part was provided by a USDA-CSRS grant and the Soil Conservation Service. Their support is greatly appreciated.

[2] Research Assistant, Associate Professor, and Assistant Scientist respectively, at Soil Sci. Dept., University of Minnesota, St. Paul, MN 55108.

Grain yields, Moisture, percent N, and N uptake: Biennial study.
The effects of the various annual and biennial treatments on corn grain yields, grain moisture, and grain percent N, can be found in Table 4. Grain yields were reduced about 16% compared to 1991. The trend of yields were as follows: annual manure>biennial manure in year of application>commercial fertilizer>biennial manure in the year following application; this relative ranking was similar to previous years. Grain moisture was about 88% higher in 1992 compared to 1991, most likely due to the cool summer delaying corn maturation. Grain percent N was generally around 1.55%, except for biennial manure the year after application which contained only 1.17% N. Grain N uptake can also be found in Table 4, and was similar to grain percent N.

Grain yields, Moisture, and percent N: triennial study.
The effects of the various triennial treatments on corn grain yields, grain moisture, and grain percent N can be found in Table 5. Grain yields, as expected, decreased with each year after N was applied. Triennially applied manure in the year of application reduced grain yields by 11%, held grain moisture to about the same level, and reduced grain percent N by 10% compared to annually applied manure. Grain moisture was about 85% higher in 1992 compared to 1991. Grain percent N lowered each year after manure application.

Table 1. 1992 cultural practices at the Flueger farm in Goodhue County, MN.

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

Cropping History:

1981-1988	Corn	Pioneer 3906
1989	Corn	Pioneer 3737
1990	Corn	Pioneer 3751
1991	Corn	NK 3624
1992	Corn	Pioneer 3751

Manure Application and Analysis: Liquid dairy manure injected on May 12, 1992.

		1992 rate	
		Mean	Std. Dev.
Manure	(gal/A)	9700	-----
Total N	(lbs/A)	387	35
NH_4 N	(lbs/A)	192	8
P_2O_5	(lbs/A)	65	3
K_2O	(lbs/A)	225	24
Solids	(%)	9.1	.2

Fertilizer:

Material	Tillage	N (lbs/A)	Date Applied	Application
82-0-0	Both	180	June 5,1992	Injected
5-14-42	Both	6	May 18, 1992	As a starter

Planting and Harvest Information: A four row John Deere Maxi-Emerge planter with two inch fluted coulters was used to plant on May 18, 1992. Corn was harvested on October 24, 1992.

Insect control: 5.2 lbs/A Thimet 20G applied May 18, 1992.

Weed Control: .75 lbs/A Prowl and 1.2 lbs/A Bladex 90 DF applied on May 24, 1992.
All plots cultivated on June 10, 1992.

Table 2. Surface residue cover and population as affected by tillage, N source, and row position at the Flueger farm in Goodhue Co., MN.

N source AND FREQUENCY	Row POSITION	RESIDUE (%) NO TILL	RESIDUE (%) CHISEL	6/5/92 Pop. (plants/A)[1] NO TILL	6/5/92 Pop. (plants/A)[1] CHISEL	10/24/92 Pop. (plants/A) NO TILL	10/24/92 Pop. (plants/A) CHISEL
Annual Manure	In	18.7	9.7	17000	18100	24200	25900
	Between	22.2	7.7				
Anhydrous Ammonia	In	29.3	8.7	17600	18300	27600	24900
	Between	33.5	11.3				
Biennial Manure	In	19.7	9.0	17700	19500	23700	28000
(yr. of application)	Between	22.3	10.3				
Biennial Manure	In	36.7	9.7	16200	16300	22700	29400
(yr after application)	Between	41.7	11.0				

[1] Plant population count apparently taken prior to complete germination.

Table 3. Significance table for surface residue cover and population at the Flueger Farm in Goodhue Co., MN.

	Till(T)	N treatment(N)	T*N	Row(R)	T*R	N*R	T*N*R
Residue	.000	.000	.000	.061	.276	.948	.880
Population	.231	.305	1.00	----	----	----	----
Harvest pop.	.021	.752	.011	----	----	----	----

Table 4. Grain yield, grain moisture, and grain N percentage as influenced by tillage, N source and frequency and potassium rates at the Flueger farm in Goodhue Co., MN.

N source & freq.	K_2O lbs/A	Grain Yield NoTill (bu/A)	Grain Yield Chsl (bu/A)	Grain Yield Mean (bu/A)	Grain Moisture NoTill (%)	Grain Moisture Chsl (%)	Grain Moisture Mean (%)	Grain N Notill (%)	Grain N Chsl (%)	Grain N Mean (%)	Grain N uptake No Till (lbs/A)	Grain N uptake Chisel (lbs/A)	Grain N uptake Mean (lbs/A)
Annual	0	94	86	**90**	36.1	36.6	**36.3**	1.45	1.47	**1.46**	64.9	59.9	**62.4**
Manure	200	125	125	**125**	37.1	37.0	**37.1**	1.58	1.52	**1.55**	92.2	91.0	**91.6**
	Mean	**110**	**106**	**108**	**36.6**	**36.8**	**36.7**	**1.49**	**1.50**	**1.50**	**78.6**	**75.5**	**77.0**
Biennial	0	120	99	**110**	37.5	38.5	**38.0**	1.54	1.53	**1.54**	86.0	71.7	**78.9**
Manure	200	91	114	**103**	35.6	39.0	**37.3**	1.62	1.38	**1.50**	68.0	72.0	**70.0**
(yr of)	**Mean**	**106**	**107**	**107**	**36.6**	**38.8**	**37.7**	**1.58**	**1.46**	**1.52**	**77.0**	**71.9**	**74.5**
Biennial	0	44	89	**67**	46.7	36.9	**41.8**	1.30	1.22	**1.26**	27.9	53.2	**40.6**
Manure	200	64	67	**66**	39.8	45.7	**42.8**	1.14	1.02	**1.08**	34.3	32.5	**33.2**
(yr after)	**Mean**	**54**	**78**	**66**	**43.3**	**41.3**	**42.3**	**1.22**	**1.12**	**1.17**	**31.1**	**42.9**	**36.9**
Anhydrous	0	83	115	**99**	40.6	37.1	**38.9**	1.54	1.57	**1.56**	60.7	85.4	**73.1**
Ammonia	200	90	108	**99**	40.4	37.6	**39.0**	1.61	1.63	**1.62**	68.7	83.2	**76.0**
	400	83	117	**100**	40.8	37.6	**39.2**	1.64	1.60	**1.62**	64.4	87.2	**75.8**
	Mean	**85**	**113**	**99**	**40.6**	**37.4**	**39.0**	**1.60**	**1.60**	**1.60**	**64.6**	**85.3**	**75.0**
Overall Mean		**91**	**104**	**98**	**39.3**	**38.2**	**38.8**	**1.53**	**1.47**	**1.50**	**63.0**	**70.7**	**66.8**
Check (0 N)[1]		26.2	41.3	**33.8**	42.9	38.7	**40.8**	1.21	1.21	**1.21**	4.2	7.3	**5.8**

	Till(T)	N source(N)	T*N	K rate(K)	K*T	K*N	K*N*T
Grain Yield	.084	.001	.259	.475	.913	.173	.206
Grain Moisture	.052	.000	.009	.433	.028	.351	.011
Grain N %	.011	.000	.081	.715	.096	.177	.518
N uptake	.238	.000	.109	.517	.866	.037	.337

[1] Check plots not included in the statistical analysis.

Table 5. Grain yields, percent moisture, and N percentage at harvest for triennially applied manure with chisel plowing system at the Flueger farm in Goodhue Co., MN.

Year of manure Application	K_2O lbs/A	Grain Yield ---bu/A----	Grain Moisture ------%-----	Grain N ---%---
First Year	0	93	36.3	1.44
	200	98	38.1	1.35
	Mean	**96**	**37.2**	**1.40**
Second Year	0	76	37.7	1.28
	200	68	38.0	1.15
	Mean	**72**	**37.9**	**1.22**
Third Year	0	50	36.0	1.08
	200	50	37.2	1.09
	Mean	**50**	**36.6**	**1.09**

THE EFFECTS OF TILLAGE AND TIME OF MANURE APPLICATION ON CORN RESPONSE AND LOSSES OF MANURE N AND P AT MEEKER COUNTY, MN[1]

D. Ginting, J.F. Moncrief, S.C. Gupta, M.B. Kells, and B.J. Johnson[2]

Abstract

This is the third year of continuous corn treated with manure and tillage systems. Two manure sources (pig and dairy) applied in fall and spring were compared to spring applied anhydrous ammonia and control (non treated plots). Two tillage system studied were disc once and disc twice in spring. Residue cover were similar among tillages. Residue cover was higher by spring dairy application. Corn stands were similar among tillages. Corn stands at early growth were lower significantly with spring dairy compared to spring hog application. Corn growth stage were similar among tillage, time and manure source application. Grain yields were also similar by tillage. Fall application of manure resulted better yield compared to spring manure and anhydrous ammonia application. Grain moisture were similar among tillage. Fall dairy application resulted in the lowest grain moisture. Application of manure resulted in significantly higher Bray-P. Estimated soil loss were similar with discing once or twice. Estimated soil-P loss however slightly higher with discing once because of higher measured Bray-P on top 2-inch soil. Measured runoff indicates the importance of plant growth and residue cover on reducing runoff and the associated P loss. Distribution of soil-water nitrates over time was higher on plots treated with anhydrous ammonia.

Materials and Methods

In 1990 and 1991 tillage systems applied were fall chisel and fall moldboard followed with spring field cultivation. Different from the two previous years, in 1992 tillage systems applied were spring discing once or twice. The nutrient source treatments were dairy manure, pig manure, anhydrous ammonia and none as a control. The manure were applied in fall and spring and anhydrous ammonia was applied only in spring. The times of application were compared to evaluate corn response and loss of N and P.

Nitrogen (NH_4, NO_3) of soil water was monitored using suction samplers installed at selected treatments. The treatment selected were chisel and moldboard under spring dairy and anhydrous ammonia in 1991. In 1992, chisel was substituted with discing once and moldboard was substituted with discing twice under the same nutrient treatment as in 1991. This was done due to the excessive soil moisture.

Phosphorus loss from the land was measured and also estimated using USLE. Measured runoff and its associated P loss (total P, bioavailable P, and soluble P) was measured from erosion plots (76 feet by 10 feet) installed at selected treatments (fall dairy manure and none, as a control). The runoff was measured by collecting runoff in a 55 gallon barrel. The runoff samples was taken for sediment measurement and P determination. Total P was extracted by perchloric acid digestion. Bioavailable P was extracted by NaOH extraction and soluble P was obtained through filtration with 0.45 micron filter paper. P determination was conducted by spectrophotometer (at 882 nm) with blue Molybdate as a coloring agent.

Estimated soil loss was conducted from every treatment using data R (125), Area weighted K (0.23), LS factor 0.7 (l=200 ft, S=5%), and conservation practice factor (P=1). The K factor was weighted over the percentage of the area of the individual soil as described in Table 1. The C values for different treatment was evaluated based on residue cover and soil loss ratio during the year. The associated P loss with the sediments was estimated from the measured top 2 inch soil Bray-P concentration and an enrichment ratio of 3.4.

Residue cover was estimated by line transect method and characterized in and between the rows within each plots. Corn stands were estimated from the number of plants within the 10 feet row from each plot.
Soil samples for Bray-P measurement was taken in the row and between the rows at three depths (0-2, 2-4, 4-6 inch). Grain yield and corn ears was harvest from rows 40 feet long.

The experiment was arranged in split plot with tillage as main plot and nutrient sources as subplot.

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The design was extended to split-split-split plot to evaluate the row position and soil depth.

Results and Discussion

Residue Cover.Residue cover is similar among tillage treatments (Table 2a). Discing once or twice resulted in similar amount of residue cover. Residue cover was significantly different among manure treatments. Spring dairy application resulted in higher residue cover compared to other manure and time of application. Residue cover under pig manure and fall dairy plots was less than 30%. The least residue cover was on the control plot. In spite of the use of row cleaner attached to the planter, residue cover in row and between row were similar (Table 2b).

Corn Stand. Tillage did not significantly influence corn stands at early stages (Table 3). There was a tendency of difference of corn population under different nutrient source and time of application as presented in Fig.1. Spring dairy manure application resulted in lower corn stand compared to spring hog manure application which mainly due to the difference in residue cover. Corn stand was similar among fall manure and spring hog application.

Corn Growth Stage. Early corn growth was similar with nutrient source or tillage (Table 4). However, tillage and manure interaction showed that discing twice resulted in higher growth compared to discing once for all manure except spring dairy treatment (Fig. 2).

Corn Yield, Harvested ears and grain moisture. Discing once or twice resulted in similar yield. Grain yields are different by nutrient sources. Fall application of manure was better than spring application and the application of anhydrous ammonia. The lowest yield was from the control plots (not treated plots). There was an interaction between tillage and nutrient sources, especially with spring dairy manure application. All other nutrient sources application indicates an increase in yield if discing once compared to discing twice. With spring dairy application, discing twice showed a higher yield than discing once. The trend of grain yield as influenced by nutrient sources are according to the harvested corn ears (Table 7) and consequently also according to the corn population at harvest. Yield was not influenced by corn stand at early growth. Fall application of dairy and pig manure was better than the rest of time of application and nutrient source treatments. The ear number from control plots was the lowest. Grain moisture was similar among tillage treatments. Fall dairy application resulted in lower grain moisture compared to other time and manure application treatments (Table 6).

Soil Bray-P Means of soil Bray-P are different among treatments (Table 8). Manure application resulted in higher Bray-P compared to those from plots treated with anhydrous ammonia and control plots. Top 2 inches of soil treated with spring dairy manure contained the highest Bray-P. Bray P was higher in the row than between the row (Fig 3A). Bray-P was similar by tillage (Table 9). There was an interaction among tillage systems, manure source application and soil depth. Discing once with all manure application treatments except spring dairy treatment resulted in higher soil Bray-P at the top 2 inch soil (Fig. 3B).

Estimated soil and soil-P loss. Discing once or twice resulted in similar estimated soil loss (Table 10). This is mainly due to the amount of residue. The amount of the residue (which influenced C factor), were practically the same. The estimated P loss was a slightly higher with discing once because of a higher Bray-P on top 2-inch soil. Higher estimated sediment loss from control plots and spring hog plots are mainly due to less residue cover. Estimated annual sediment loss from all treatments were higher than 5 t/a. Estimated annual soil P-loss from all treatments were less than 2.5 lb/a.

Measured Runoff and associated P loss. Measured runoff volume from plot disced twice under fall dairy manure compared to control plots was significantly lower (Table 11). This was mainly due to the less residue cover and canopy cover of a poor growth of corn under the control plots. This resulted in a higher amount of sediment produced from control plot. This phenomenon is also followed by total P, bioavailable P and soluble P. Total P eroded from control plots were 103 gram per hectare during the month of July and August, 1992. The distribution of cumulative runoff, sediment and Phosphorus over time under daily precipitation are in Fig. 4 and Fig 5.

Soil-Water Nitrogen. Soil water samples collected were mainly in 1991. In 1992, There were no water samples in the sampler. Soil water nitrogen were mainly in NO_3 form. NH_4 form was mainly negligible (Fig. 7). Distribution of nitrogen with time under daily and cumulative daily precipitation was presented in Fig. 6 . From Fig. 6 it is shown that early at the growing season nitrate concentrations was clustered and with time the concentration diverged among the treatments, where the treatment with anhydrous ammonia indicated higher nitrate concentration. The concentrations were less than 20 ppm.

Table 1. Cultural practices at Meeker County, MN. 1992.

Tillage

1990-Fall chisel plowed, spring field cultivated
-Fall moldboard plowed, spring field cultivated

1991-Fall chisel plowed, spring field cultivated
-Fall moldboard plowed, spring field cultivated

1992-Spring discing twice.
-Spring discing once.

Crop

1990 Corn-Pioneer 375
1991 Corn-Northrop King N 3264
1992 Corn-Pioneer 3751

Planting and Harvest Dates

Plots were planted with a four row John Deere Maximerge planter equipped with spring tine row cleaners at a 38 inch row spacing.

	Planting		
Crop	Date	Rate	Harvested
Corn	May 8,1992	30,000 seeds/A	Oct. 14, 1992

1990 Fertilizer and Manure Analysis

			Actual			
	Material		N	P_2O_5	K_2O	
Crop	Analysis	Rate	----	lb/A	----	Date Applied
Corn	9-23-30[1]	150 lb/A	14	35	45	May 8, 1990
	82-0-0[2]	85 lb/A	70	0	0	April 24, 1990

1. Planter placement 2" beside and 2" below row.
2. Anhydrous ammonia was applied on selected plots.

Chemical composition of dairy and pig manure from barn gutters and an anaerobic pit from farrowing house at Meeker County, Fall-1989.

Manure Type and Rate of Application		Nitrogen				Phosphorus	Potassium
		Mineral	Organic	Total	Available	P_2O_5	K_2O
Source	Rate	-------	lb/A	--------	- lb/A -	lb/A	lb/A
Dairy	13.2 t/A	62	97	159	86	107	134
Pig	4,100 g/A	120	75	195	146	212	100

1. All mineral N and 25% of organic N are available.

Chemical composition of dairy and pig manure from barn gutters and an anaerobic pit from farrowing house at Meeker County, Spring-1990 (4/5/90 for liquid and 5/18/90 for dairy).

Manure Type and Rate of Application		Nitrogen				Phosphorus	Potassium
		Mineral	Organic	Total	Available	P_2O_5	K_2O
Source	Rate	-------	lb/A	--------	- lb/A --	lb/A	lb/A
Dairy	11.6 t/A	149	61	210	164	89	217
Pig	4,100 g/A	93	43	136	108	127	82

1. All mineral N and 25% of organic N are available.

1991 Fertilizer and Manure Analysis

			Actual			
	Material		N	P_2O_5	K_2O	
Crop	Analysis	Rate	----	lb/A	----	Date Applied
Corn	8-23-30[1]	150 lb/A	12	35	45	May 20, 1991
	82-0-0[2]	100 lb/A	82	0	0	May 13, 1991

1. Planter placement 2" beside and 2" below row.
2. Anhydrous ammonia was applied on selected plots.

Chemical composition of dairy and pig manure from barn gutters and an anaerobic pit from farrowing house at Meeker County, Fall-1990 and Spring-1991.

Manure Type and Rate of Application		Nitrogen				Phosphorus	Potassium	Date
		mineral	Organic	Total	Available	P_2O_5	K_2O	Applied
Source	Rate	------- lb/A		--------	- lb/A --	lb/A	lb/A	
Fall Pig	3250 g/A	65	60	125	80	65	75	11/9/90
Fall Dairy	13.9 t/A	4	155	159	43	12	11	11/9/90
Spring Pig	3700 g/A	74	68	142	91	75	85	5/10/91
Spring Dairy	13.9 t/A	6	134	140	40	41	25	5/15/91

1. All mineral N and 25% of organic N are available.

1992 Fertilizer and Manure Analysis

Crop	Material Analysis	Rate	Actual N	Actual P_2O_5	Actual K_2O	Date Applied
			---- lb/A ----			
Corn	9-23-30[1]	120 lb/A	11	28	36	May 8, 1992
	82-0-0[2]	100 lb/A	82	0	0	May 2, 1992

1. Planter placement 2" beside and 2" below row.
2. Anhydrous ammonia was applied on selected plots.

Chemical composition of dairy and pig manure from barn gutters and an anaerobic pit from farrowing house at Meeker County, Fall-1991 and Spring-1992.

Manure Type	Nitrogen NH4	NO3	mineral	Organic	Total	P	K	Solid total	solid volatile	fixed
	----------						%			----------
Dairy	.214	.008	.222	.361	.583	.293	.299	18.15	78	23
Pig	.195	.002	.197	.135	.332	.147	.184	3.24	61	39

Manure Type and Rate of Application		Nitrogen				Phosphorus	Potassium	Date
		mineral	Organic	Total	Available	P_2O_5	K_2O	Applied
Source	Rate	----------			lb/A	----------		
Fall Pig	2554 g/A	42	29	71	79	72	48	11/26/91
Fall Dairy	26.5 t/A	118	191	309	243	356	192	11/25/91
Spring Pig	3550 g/A	59	40	99	103	100	107	4/29/92
Spring Dairy	24.1 t/A	107	174	281	218	323	174	4/28/92

1. All mineral N and 25% of organic N of the year of application and 50% of the previous year is assumed available

Soil

The soils present at this site are as follows: 60% is Koronis fine sandy loam (Mollic Haplaudalfs, fine-loamy, mixed, mesic) with good internal drainage; 20% Cordova loam (Typic Argiaquolls, fine-loamy, mixed, mesic) with poor internal drainage; and the remaining 20% is Marcellon loam (Aquic Argiudolls, fine-loamy, mixed, mesic) with somewhat poor internal drainage.

Weed Control: - Lasso 2 lb a.i./a + Bladex 1 lb a.i./a (5/16/92)

Table 2a. Residue cover as influenced by corn residue and manure source and time of application at Ecker farm, Meeker Co,MN (5/20/92).

Manure Time/Source	Tillage Disc 2X	Disc 1X	Means
	---------- %	----------	
Fall Hog	30.5(21.1)	24.4(14.3)	**27.4(18.2)b**
Spring Hog	21.1(10.7)	24.4(17.3)	**22.8(14.3)bc**
Fall dairy	22.5(12.1)	30.4(16.9)	**26.4(15.1)b**
Spring dairy	41.0(27.4)	28.5(20.5)	**34.8(24.8)a**
A. Ammonia	27.1(12.9)	28.6(19.7)	**27.9(16.5)b**
None	16.1(9.2)	19.3(10.5)	**17.7(9.9)c**
Means	**25.6(16.3)a**	**26.0(16.2)a**	

Means are arithmetic means.
The P>F: tillage=0.879(n=192);manure=0.065(n=64); tillage*manure=0.160(n=32).

Table 2b. Residue cover (%) as influenced by corn residue and manure source and time of application and row position at Ecker farm, Meeker Co,MN (5/20/92).

Manure Time/Source	In row	between row	Weighted Means
	---------- %	----------	
Fall Hog	29.4(22.0)	25.5(13.5)	**26.4(15.3)b**
Spring Hog	23.6(15.7)	21.9(13.1)	**22.2(13.6)bc**
Fall dairy	26.9(16.2)	26.0(14.2)	**26.2(14.6)b**
Spring dairy	37.1(27.0)	32.4(22.5)	**33.4(23.5)a**
A. Ammonia	27.1(17.6)	28.6(15.6)	**28.3(16.0)b**
None	17.5(9.9)	17.9(10.0)	**17.8(10.0)c**
Means	**26.9(19.5)a**	**25.4(15.8)a**	

Means were weighted over in row and between row area.
The P>F: manure=0.065(n=64);Row position=0.288 (n=192);manure*row position=0.801(n=32).

Table 3. Corn population as influenced by tillage and manure source and time of application at Ecker farm, Meeker County, MN (6/9/1992)

Manure Time/Source	Tillage Disc 2X	Disc 1X	Means
	---------- X 1000 plants/a	--------	
Fall Hog	27.3(8.1)	28.5(5.1)	**27.9(6.6)ab**
Spring Hog	30.3(4.6)	30.2(10.4)	**30.2(7.9)a**
Fall dairy	29.4(3.7)	28.2(4.5)	**28.8(4.1)ab**
Spring dairy	23.9(6.0)	30.1(5.5)	**27.0(6.5)b**
A. Ammonia	28.4(3.4)	30.6(7.9)	**29.5(6.1)ab**
None	31.7(5.8)	28.8(4.5)	**30.3(5.3)a**
Means	**28.5(5.9)a**	**29.4(6.6)a**	

The P>F: tillage=0.248(n=96);manure=0.304(n=32); tillage*manure=0.100(n=16).

Table 4. Corn stage as influenced by tillage and manure source and time of application at Ecker farm, Meeker Co, MN (6/9/92).

Manure Time/Source	Tillage Disc 2X	Disc 1X	Means
	---------- leaves/plant	----------	
Fall Hog	4.1(0.6)	3.9(0.5)	**4.0(0.6)a**
Spring Hog	4.1(0.5)	4.0(0.6)	**4.0(0.5)a**
Fall dairy	4.0(0.5)	3.8(0.6)	**3.9(0.6)a**
Spring dairy	3.5(0.5)	3.8(0.6)	**3.7(0.6)a**
A. Ammonia	3.9(0.6)	3.8(0.6)	**3.9(0.6)a**
None	4.0(0.5)	3.7(0.6)	**3.9(0.6)a**
Means	**3.9(0.5)a**	**3.8(0.6)a**	

The P>F: tillage=0.472(n=96);manure=0.233(n=32); tillage*manure=0.023(n=16).

Table 5. Corn grain yield as influenced tillage and manure source and time of application at Ecker farm, MN (10/14/92).

Manure Time/Source	Tillage Disc 2X	Disc 1X	means
	---------- bu/a	----------	
Fall Hog	99.5(22.5)	101.5(12.6)	**100.4(17.9)ab**
spring Hog	64.1(16.4)	86.2(25.8)	**74.4(23.3)de**
Fall dairy	107.6(19.5)	114.2(18.0)	**111.1(18.2)a**
Spr. dairy	101.8(18.6)	82.7(25.6)	**90.9(24.1)bc**
A. Ammonia	70.1(8.6)	94.5(13.3)	**82.3(16.6)cd**
None	66.1(15.3)	63.2(8.6)	**64.7(12.3)e**
Means	**84.6(24.8)a**	**90.5(24.1)a**	

The P>F: tillage=0.426(n=38);manure=0.001 (n=10-13);tillage*manure=0.115(n=5-8).

Table 6. Corn grain moisture as influenced by tillage and manure source and time of application at Ecker farm, Meeker Co, MN (10/14/92).

Manure Time/source	Disc 2X	Disc 1X	Means
	---------- %	----------	
Fall Hog	27.5(0.8)	30.5(2.7)	**28.9(2.4)a**
Spring Hog	32.0(8.4)	29.0(1.1)	**30.6(6.2)a**
Fall dairy	26.7(1.4)	24.8(10.2)	**25.7(7.4)b**
Spr. dairy	29.3(2.7)	31.2(6.1)	**30.4(4.9)a**
A. Ammonia	29.6(1.0)	30.9(2.5)	**30.3(2.0)a**
None	27.4(0.8)	28.7(1.7)	**28.0(1.4)ab**
Means	**28.7(4.1)a**	**29.1(5.6)a**	

The P>F: tillage=0.604(n=38);manure=0.078 (n=10-14); tillage*manure=0.192(n=5-8).

Table 7. Number of corn ears at harvest as influenced by tillage and manure source and time of application at Ecker farm, Meeker Co., MN (10/14/92).

Manure Time/Source	Tillage Disc 2X	Disc 1X	Means
	--------x 1000 /a---------		
Fall Hog	26.6(2.9)	26.5(1.3)	**26.5(2.2)ab**
Spring Hog	24.1(2.7)	23.7(2.9)	**23.9(2.7)c**
Fall dairy	27.5(1.5)	28.1(2.6)	**27.8(2.1)a**
Spring dairy	25.7(3.0)	23.4(3.2)	**24.4(3.2)c**
A. Ammonia	24.4(2.8)	25.7(2.3)	**25.1(2.3)bc**
None	25.1(2.5)	23.6(1.0)	**24.4(2.0)c**
Means	**25.6(2.7)a**	**25.1(2.8)a**	

The P>F: tillage=0.232(n=37-38);manure=0.003 (n=10-13),Tillage*manure=0.409(n=5-8).

Table 8. Spatial distribution of soil Bray-P as influenced by manure treatment at Ecker Farm, MN (8/ 19/92).

Manure source/ time	Depth inch	Row Position In row	Between Row	Means
		---------- ppm ----------		
Fall Hog	0-2	51.9(23.3)	47.6(18.8)	**49.7(20.9)**
	2-4	48.0(26.0)	32.5(13.1)	**40.7(22.0)**
	4-6	34.9(11.9)	27.2(15.0)	**30.4(13.9)**
	means	**46.3(22.9)**	**36.2(17.8)**	**41.1(20.9)**
Spr. Hog	0-2	55.3(22.4)	41.3(19.8)	**47.6(21.8)**
	2-4	32.0(17.2)	33.4(14.6)	**32.8(15.4)**
	4-6	31.2(19.8)	32.2(10.6)	**27.4(16.0)**
	means	**41.4(22.8)**	**34.2(17.6)**	**37.6(20.4)**
Fall dairy	0-2	56.3(21.7)	49.9(18.8)	**53.2(20.3)**
	2-4	56.0(28.1)	28.2(14.8)	**47.3(24.0)**
	4-6	37.5(29.1)	31.7(14.4)	**34.6(22.8)**
	means	**50.7(27.0)**	**40.6(17.7)**	**45.7(23.4)**
Spr. dairy	0-2	76.6(26.2)	53.6(13.5)	**65.1(23.6)**
	2-4	44.6(11.2)	36.0(17.4)	**40.5(18.5)**
	4-6	26.5(11.2)	25.7(10.1)	**26.1(10.6)**
	means	**50.4(28.7)**	**39.7(18.1)**	**45.3(25.0)**
An. ammonia	0-2	40.7(19.3)	29.5(17.0)	**35.1(19.0)**
	2-4	32.1(14.6)	24.6(14.0)	**28.3(14.4)**
	4-6	30.3(16.6)	28.6(17.1)	**29.4(16.4)**
	means	**34.6(17.1)**	**27.7(16.1)**	**31.2(16.8)**
None	0-2	38.2(17.2)	29.2(10.5)	**34.2(15.1)**
	2-4	30.6(8.3)	22.9(10.4)	**26.6(10.1)**
	4-6	38.3(37.2)	23.0(11.9)	**30.7(28.1)**
	means	**35.8(23.4)**	**24.9(11.1)**	**30.5(19.2)**

The P>F:Manure=0.047(n=74-100); Row Position=0.001 (n=246-247); Depth=0.001(n=149-182); Manure*Row position=0.995(n=28-57); Manure*Depth=0.001(n=20-40); Row*Depth=0.281(n=75-91); Manure*Row*Depth=0.055(n=9-17).

Table 9. Distribution of soil Bray-P as influenced by tillage and manure treatment at Ecker Farm, MN (8/19/92).

Manure	Depth (inch) 0-2	2-4	4-6	means
	---------- ppm ----------			
		Disc Once		
F Hog	56.4(17.6)	43.8(17.5)	35.4(15.9)	**46.4(18.7)**
S Hog	61.9(16.3)	37.9(15.3)	34.3(17.9)	**47.4(20.7)**
F Dairy	55.5(18.9)	45.3(17.1)	26.8(9.5)	**44.2(19.7)**
S Dairy	60.4(18.8)	46.3(18.0)	27.8(10.8)	**45.8(20.9)**
A Amm.	39.9(21.5)	30.7(15.2)	35.9(16.7)	**35.8(17.9)**
None	35.0(10.2)	31.5(10.4)	31.8(16.4)	**32.8(12.5)**
Means	**53.4(20.0)**	**40.9(16.9)**	**31.6(14.5)**	**42.7(19.5)**
		Disc Twice		
F Hog	43.3(22.2)	37.6(26.0)	26.8(11.6)	**36.3(21.8)**
S Hog	28.0(9.6)	26.5(13.8)	18.2(5.4)	**24.7(10.7)**
F Dairy	50.1(22.2)	49.9(31.0)	42.5(29.2)	**47.6(27.2)**
S Dairy	69.4(27.0)	34.1(17.3)	24.4(10.4)	**44.7(28.1)**
A. Amm.	29.3(14.5)	25.2(13.8)	19.9(10.9)	**24.9(13.2)**
None	33.6(18.9)	22.8(8.4)	29.5(37.1)	**28.4(23.6)**
Means	**45.6(25.6)**	**33.9(22.2)**	**27.9(22.1)**	**36.3(24.5)**

The P>F:tillage=0.297 (n=238-255); manure=0.047 (n=56-110);depth=0.001(n=149-182); tillage*depth=0.729(n=73-95); manure*depth=0.001(n=16-40); tillage*manure=0.306(n=24-55) tillage*manure*depth=0.007(17-20).

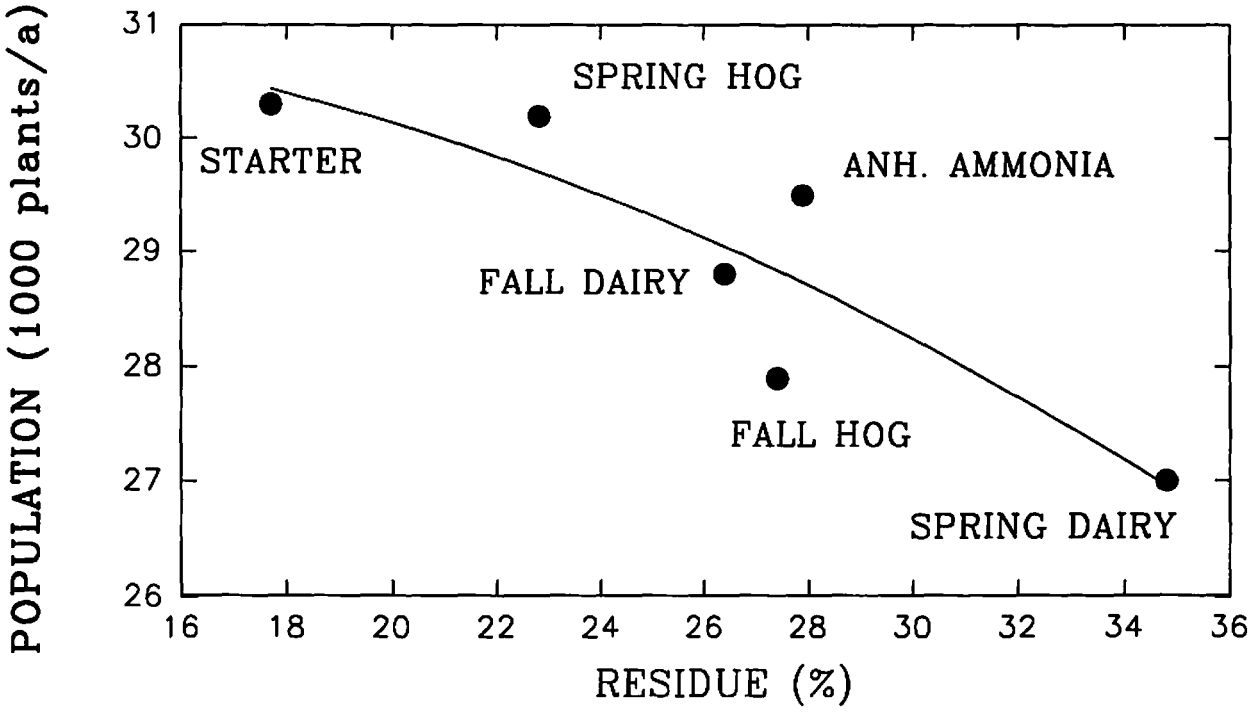
Table 10. Estimated soil and P loss (enrichment ratio 3.4) using USLE as influenced by residue from tillage and manure treatment at Ecker Farm, MN (8/19/92).

Manure	**Disc Once** sed t/a	Bray-P lb/a	**Disc Twice** Sed t/a	Bray-P lb/a	**Means** Sed t/a	Bray-P lb/a
F Hog	5.8	2.2	5.0	1.5	**5.4**	**1.9**
S Hog	5.8	2.4	6.1	1.2	**6.0**	**1.8**
F Dairy	5.1	1.9	5.9	2.0	**5.5**	**2.0**
S Dairy	5.3	2.2	4.3	2.0	**4.8**	**2.1**
A Amm.	5.3	1.4	5.5	1.1	**5.4**	**1.3**
None	6.3	1.5	6.8	1.5	**6.6**	**1.5**
Means	**5.6**	**1.9**	**5.6**	**1.6**		

Table 11. Measured total P, bioavailable P (Bio-P) ,soluble-P, runoff volume and sediment from a standard size plot disced twice under fall dairy manure and without treatment at Ecker Farm, MN (June/1992 - October/92).

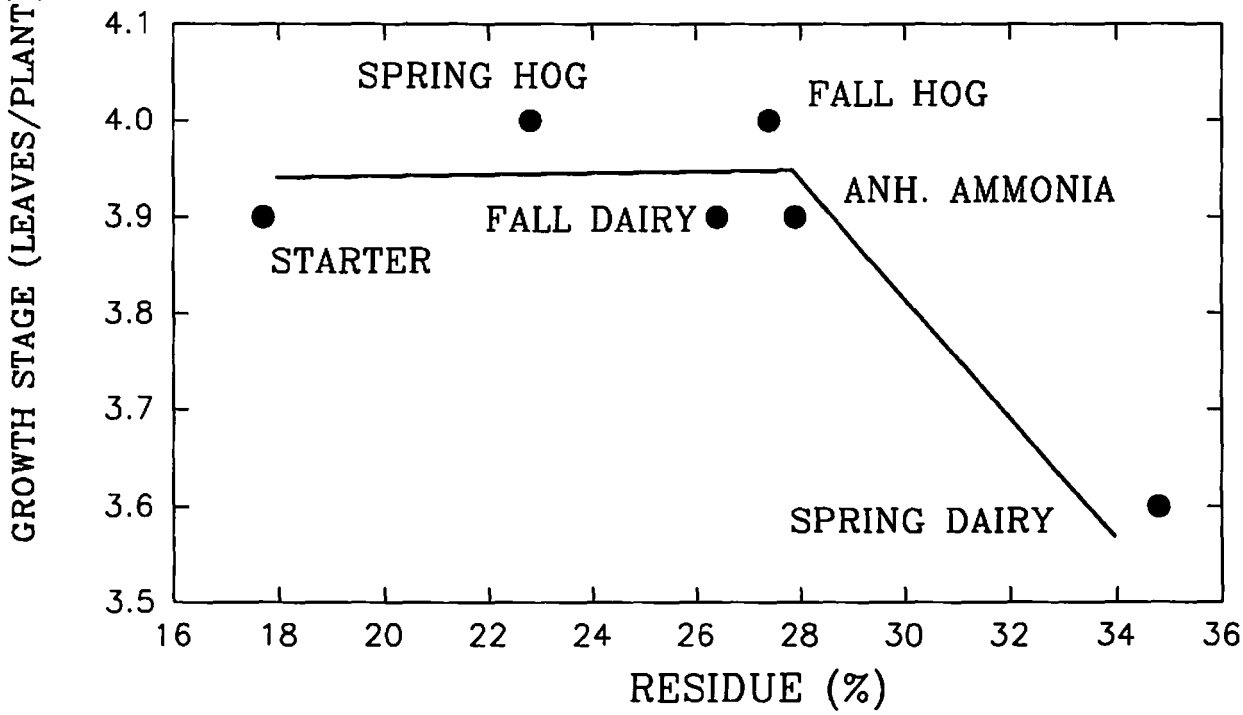
Manure	Total-P g/ha	Bio-P g/ha	Soluble.P g/ha	Runoff KL/ha	Sed kg/ha
F. dairy	**36.0**	**19.9**	**10.7**	**7.4**	**36.3**
None	**103.0**	**82.3**	**19.5**	**31.7**	**232.7**

FIG. 1



CORN POPULATION AS INFLUENCED BY RESIDUE COVER AT ECKER FARM, MEEKER COUNTY, MN (6/9/92)

FIG. 2.



CORN GROWTH AS INFLUENCED BY RESIDUE COVER AT ECKER FARM, MEEKER COUNTY, MN (6/9/92).

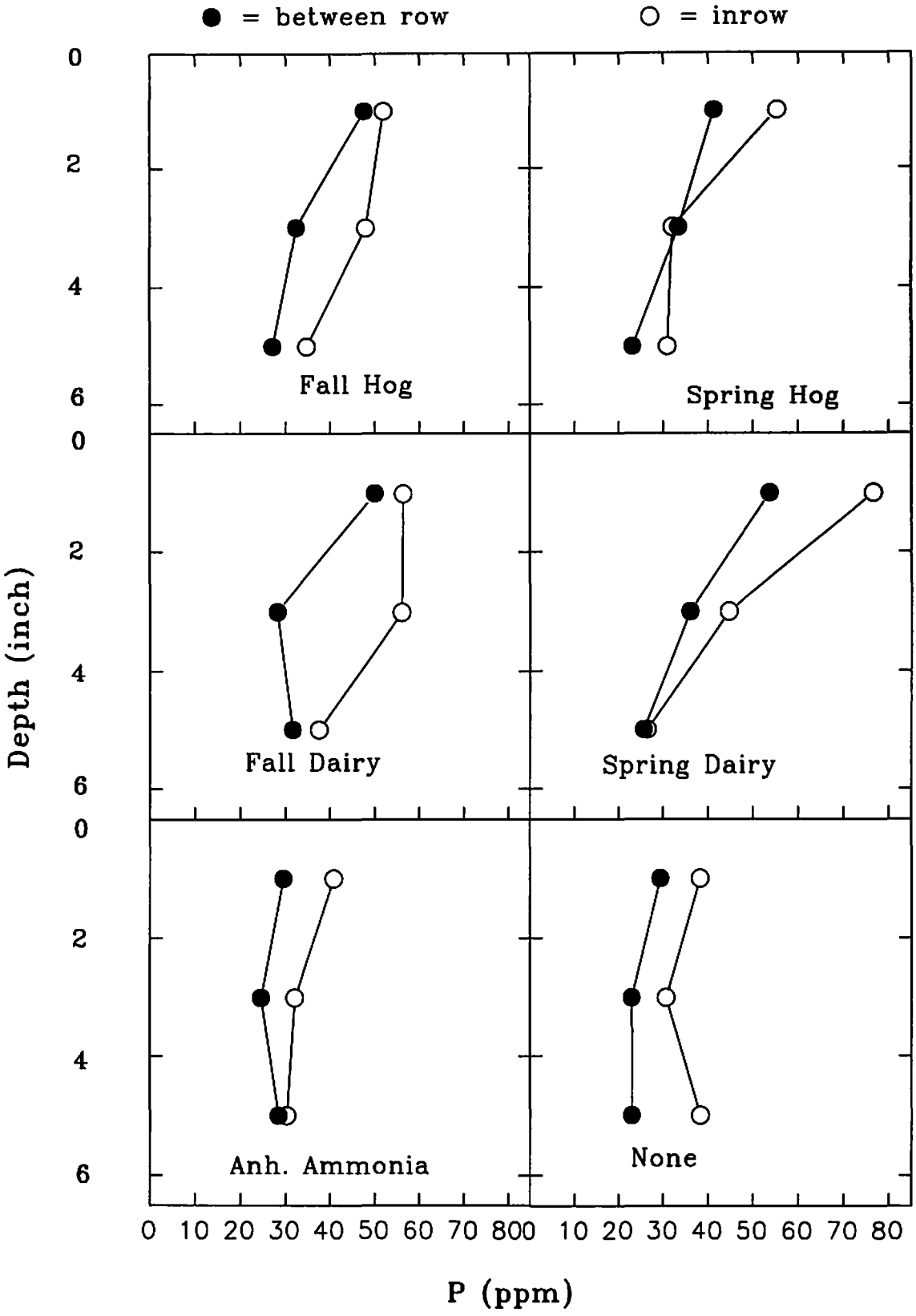


FIG. 3A. SOIL BRAY-P DISTRIBUTION WITH DEPTH UNDER VARIOUS MANURE SOURCE AND ROW POSITION AT ECKER FARM, MEEKER COUNTY, MN (8/19/92)

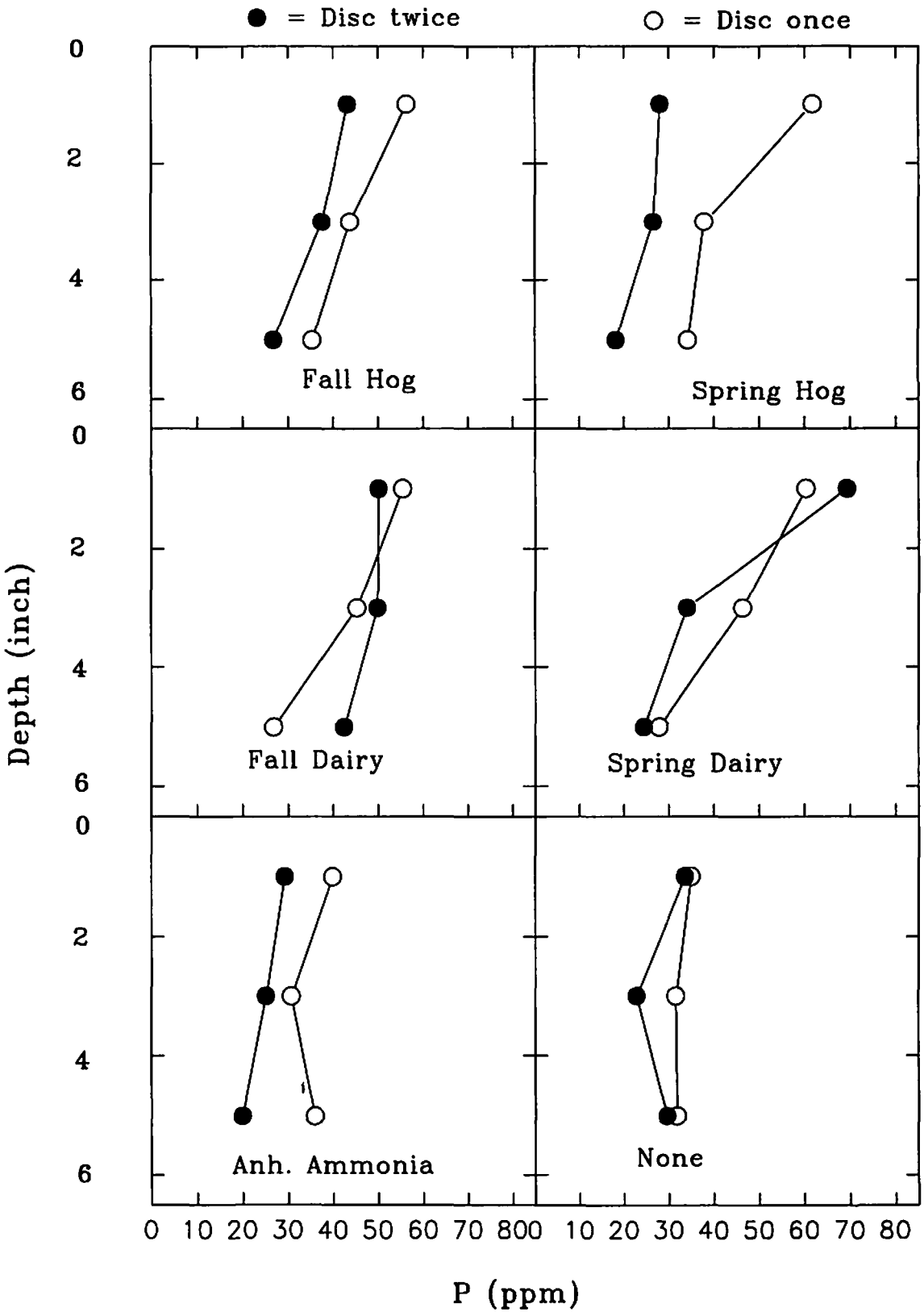


FIG. 3B. SOIL BRAY-P DISTRIBUTION WITH DEPTH UNDER VARIOUS MANURE SOURCE AND TILLAGE SYSTEMS AT ECKER FARM, MEEKER COUNTY, MN (8/19/92)