LEVELS OF SPECIFIC NUTRIENTS IN SUGAR BEET FACTORY SPENT LIME AND THEIR IMPACT CROP YIELD AND SOIL INDICES.

Drs. Albert L. Sims (Associate Professor), Carol E. Windels (Professor), University of Minnesota, Northwest Research and Outreach Center, and Carl Bradley (Assistant Professor), North Dakota State University

Spent lime is a by-product of the sugar beet sugar purification process. It is generated by heating mined calcium carbon limestone to form calcium oxide and carbon dioxide. These two products are injected into the thick juice (from the sugar beet processing) and reforms calcium carbonate. When the calcium carbonate reforms it captures or adsorbs many of the impurities in the juice and precipitates from the juice. The precipitate forms a solid lime product that needs to be discarded leaving behind the thin juice from which sugar is extracted. The seven sugar beet processing factories in North Dakota and Minnesota produce approximately 500,000 tons (dry weight basis) of spent lime annually.

Historically, spent lime has simply been stock piled on site at each of the factories. As a result, large mounds of this material are present at each factory site and the mounds continue to grow each year. Storage of spent lime in this manner may create problems in the future for the factories as current storage permits expire, stock piles grow larger and environmental and space limitation awareness increases. One, potential disposal possibility is to apply it to the land or production fields. Spent lime is sold as Lime X in Europe and farmers apply it to their fields. However, these fields tend to have low soil pH and liming is required as a general management practice. Generally, spent lime has about 86% of the acid neutralizing potential as an equivalent quantity of fresh lime. Most soil pH in eastern North Dakota and western and central Minnesota is naturally at alkaline levels. There are isolated areas were soil pH may be acidic and require lime application as part of the management practice. But, many of the soils in the sugar beet factory areas are already at pH levels of 7.5 or above and do not require lime. There is little need to use spent lime from the sugar industry to correct soil pH problems.

In isolated areas near the Minn-Dak Sugar Cooperative, a few growers were concerned about carryover of herbicide that was applied the previous year. The soil in these areas tended to be slightly acidic, which can contribute to herbicide carryover issues. Spent lime from the local sugar processing factory was applied in an attempt to raise soil pH and accelerate the break down, thus reducing the carryover, of the herbicide. Research was also initiated at NDSU to study this potential effect of spent lime. Interestingly, it was observed that Aphanomyces root rot was lessened where spent lime was applied in these experiments. One grower applied spent lime to approximately five acres in 1997 in an attempt to reduce herbicide carry over. When sugar beet was grown in 2003, the entire field had a severe infestation of Aphanomyces root rot except the area that received spent lime 7 years previously.

Aphanomyces root rot in sugar beet is becoming a larger problem in the sugar beet growing areas of North Dakota and Minnesota. There is no effective control of this disease except for developing variety resistance. The possibility of using a factory produced by-product that is becoming troublesome to deal with, but may have a positive impact on this disease, is exciting. Thus, experiments were initiated to examine this potential (See Windels et al., in this volume for details of the disease aspect of the experiment).

Since spent lime is formed during sugar processing and its purpose is to remove impurities from the juice, it seems possible that it may contain numerous chemical components, some of which may be considered nutrients. Factory chemical analysis of spent lime verify that it contains many potential nutrients such as phosphorus (P), nitrogen (N), and other micro and macro nutrients in addition to organic compounds. Exactly what chemical form these potential nutrients exist as in the spent lime and if they can indeed be utilized as crop nutrients is not known. It also seems logical that the impurities removed from the juice when spent lime is formed may differ with juice made from sugar beet grown in different regions on different soils in different environments. Therefore, the impurities in the spent lime may also vary among the factories.

The objectives of this experiment are to:

1. Determine the variability in potential nutrient content of spent lime from among the sugar beet processing factories and during the processing season.
2. Determine the effects of spent lime application on soil indices of certain nutrients.
3. Determine the effects of spent lime application on crop yield, growth, and nutrient uptake (primary focus is on P).

Materials and Methods

General: Experiments were established at Hillsboro, ND on a Fargo sicl soil (Fine, smectitic, frigid, Typic Epiaquert) in mid-October, 2003 and at Breckenridge, MN on a Doran cl (Fine, smectitic, frigid, Aquertic, Argiudoll) in mid-April, 2004. Both sites had histories of Aphanomyces root rot on sugarbeet. Each site was divided into four, 1-acre experiments each treated with five rates of spent lime (including an untreated control) and replicated four times in a randomized complete block design. Treatments applied at Hillsboro were 0, 5, 10, 20, and 30 tons (wet weight) of spent lime per acre and at Breckenridge were 0, 5, 10, 15, and 20 tons (wet weight) per acre. One of the experiments at each site will be planted to sugar beet in each of four years starting in 2005 and ending in 2008. The experiment planted to sugar beet will differ each year. The remaining three experiments at each site will be planted to the same crop as is planted in the surrounding field.

The farmer-cooperator fertilizes and tills the experimental units using the same practices as those on the remainder of the field. In 2004, the entire Hillsboro site was sown with corn (a Roundup Ready hybrid) and the entire Breckenridge site was planted to wheat ('Grandin'). In 2005, one experiment at reach site was sown to sugar beet. The remaining three experiments were planted to hard red spring wheat ('Knudsen') again at Breckenridge, but were not planted at Hillsboro due to excessively wet soil conditions.

Plant Sampling and Analysis: Wheat biomass production and total P accumulation at the Breckenridge site in 2004 and 2005, was determined by sampling two quadrants (3 ft x 2 ft) of wheat plants at the soft dough stage. Plants were cut near the soil surface and combined into one sample, then weighed and subsampled. The subsample was weighed, taken back to NWROC and dried at 65^o C for about 3 days, reweighed, and ground to pass a 2mm sieve. A subsample of ground material was acid digested and analyzed for P (Lachat, 2001b) and N (Lachat, 2001a). Wheat grain yield was determined by harvesting mature wheat from an area approximately 25 ft long and 5 ft wide in each plot with a small plot combine. The grain was dried, weighed, and protein determined using an NIR instrument.

At the Hillsboro site in 2004, grain yield and total biomass and P accumulation were determined by sampling a 10 ft by 2 row area in each plot when the corn was mature. Actually, this corn was frozen several days before natural maturity, but kernel black layer was just starting to show on some kernels in some ears. Ears were harvested from the sample area, taken back to NWROC and dried, then weighed. Grain was shelled, weighed, moisture determined, and subsampled. The subsample was dried at 65^o C for about 3 days, and ground to fine powder. The corn stalks from the sampling area were cut near the soil surface (2-3 inches above the soil), chopped into a container, weighed, and subsampled. The subsample was weighed, taken back to NWROC and dried at 65^o C for 3 days, reweighed, and ground to pass a 2 mm sieve. Subsamples of ground grain and stocks were acid digested and analyzed for P (Lachet, 2001b) and N (Lachet, 2001a).

Soil Sampling and Analysis: Immediately after wheat harvest at Breckenridge in both 2004 and 2005, soil samples were taken from each plot including plots in the experiment planted to sugar beet in 2005. Fourteen (2004) or ten (2005) cores were taken in each plot, split into 0-3 inch and 3-6 inch segments and combined to make one sample for each depth for each plot. Attempts were made to soil sample the Hillsboro site in the fall of 2004 after corn harvest, but soil conditions were too wet. This site was sampled for the first time May 5 and 6, 2005. A second sampling occurred on August 5 and 8th, 2005. The sampling process was the same as described for the Breckenridge site except ten cores were combined at both samplings.

Soil samples were dried at 30^{o}C then ground and subsampled. Soils were analyzed for pH, electrical conductivity, KCl extractable nitrate-N, Olsen ($NaHCO_3$) soil test P, and Ammonium Acetate extractable calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) (Reference Methods for Soil Analysis, 1992).

Spent Lime Sampling and Analysis: Samples of spent lime were collected from each of the seven factories in Minnesota and North Dakota affiliated with American Crystal Sugar Company, Minn-Dak Farmers Cooperative, and Southern Minnesota Beet Sugar Cooperative. Three subsamples were collected from each factory on November 18, 2004 and January 19 and March 17, 2005 (plus or minus a day depending on the location). The subsamples were collected just as the processed spent lime left the factory and was loaded into a truck to be hauled to the stock pile. Therefore, spent lime subsamples are considered fresh spent lime. Spent lime samples were dried at 30^o C, ground to a consistent fine powder, then analyzed for total nitrogen (N), P, Ca, Mg, Na, and K (Edgell, 1988). The three subsamples were analyzed separately and the results averaged.

Results and Discussion

Spent Lime:

The chemical composition of spent lime varied among the seven sugar processing factories and three sampling times. Chemical analyses for some elements are shown in Table 1. The values shown are the average values of three subsamples along with their standard deviations. With few exceptions, the variability, as measured by coefficient of variation (CV = standard deviation ÷ mean), was less than 10% for total N, total P, Ca, and Mg. Sodium and K concentrations were more variable across the three subsamples.

Total N in the spent lime varied among factories and sample times, but ranged from about 2600 mg kg^{-1} (Drayton, 2nd sampling) to 5100 mg kg^{-1} (Minn-Dak, 1st sampling). Most total N ranges were from 3000 to 3600 mg kg^{-1}. Averaged across sample times, Drayton factory spent lime had the lowest total N concentration (2865 mg kg^{-}

^{1}) and Minn-Dak factory spent lime the highest (3809 mg kg^{-1}). Using the afore mentioned N concentrations, approximately 5.7 (0.2865% N @ Drayton) to 7.6 (0.3809% N @ Minn-Dak) lbs N would be applied for each ton of dry spent lime from the respective factories. The exact chemical form in which the N is contained in the spent lime is not known. Complete analyses done by the factories at various times have indicated quantities of organic compounds in the spent lime. Some of the N could be organic N and would need to be mineralized in the soil to become available to a growing crop.

Calcium and Mg concentrations varied somewhat among factories and sample times. Spent lime contains large quantities of both elements, probably most of it in the form of carbonates that were formed during the purifying process. There was approximately 20 times as much Ca as Mg, which may be similar to the original lime materials shipped to the factories. The original lime was not analyzed so this is only speculation.

Spent lime concentrations of Na and K varied among factories and sample times. There was also more variability among the three subsamples for these two elements compared to the other elements measured. Sodium concentrations ranged form 191 mg kg^{-1} (Moorhead, 3rd sampling) to 1185 mg kg^{-1} (Minn-Dak, 3rd sampling). Most Na concentrations were in the 250 to 350 mg kg^{-1} range. Averaged across the three sample times, Moorhead factory spent lime contained the lowest concentration of Na (223 mg kg^{-1}) and Minn-Dak the highest (824 mg kg^{-1}). Potassium concentrations ranged from 528 mg kg^{-1} (Moorhead, 2nd sampling) to 4307 mg kg^{-1} (Minn-Dak, 3rd sampling). The latter K concentration was the mean of three subsamples with a CV of nearly 70%. In this case, the three subsamples contained 1295, 4335, and 7290 mg K kg^{-1}. Averaged over all sample dates, Moorhead factory spent lime had the lowest concentration of K (~700 mg kg^{-1}) and Minn-Dak the highest (~2500 mg kg^{-1}).

Our primary interest was the P concentration in the spent lime. Total P concentration varied among the seven factories and three sampling times. Total P concentration ranged from 3470 mg kg^{-1} (Drayton, 3rd sampling) to 7200 mg kg^{-1} (Crookston, 3rd sampling). When averaged across sample times, spent lime from the Drayton factory had the lowest P concentration (3827 mg kg^{-1}) and the Crookston factory the highest (6259 mg kg^{-1}). Spent lime from the other factories ranged from 5000 to 5600 mg P kg^{-1}.

There are several reasons growers may consider applying sugar factory spent lime to their fields. But, when doing so, the concentration of nutrients in the spent lime must be accounted for. Of the potential nutrients we measured, P may demand the most attention. Using average values for Drayton (0.3827% P) and Crookston (0.6259% P) factory spent lime, 7.6 and 12.5 lbs P would be applied for each dry ton of spent lime from the respective factories applied to the field. This is equivalent to 17.7 and 29 lbs P_2O_5 per dry ton of spent lime. How much of this P is available for the growing crop is not known, but in later discussions it will be shown that soil test P levels are affected by the application of spent lime.

Soil Test Levels of Selected Variables:

Soil cores were divided into 0-3 and 3-6 inch depth increments and analyzed separately. The majority of the crop residue that is originally on the soil surface is incorporated to about half the primary chisel plow tillage depth (Allmaras, 1988; Staricka et al., 1991). We reasoned that unless the spent lime was thoroughly mixed with the soil, which was unlikely, most of the effects of spent lime would be in the surface few inches. Combining the two soil depths may in fact mask some of the more dramatic effects of spent lime on soil test levels. Spent lime had effects in both soil depths, but most of the effects were in the 0-3 inch surface depth. Soil test results for both soil depths along with statistical analysis are shown in Table 2 (Hillsboro site) and Table 3 (Breckenridge site).

At the Hillsboro site (Table 2), spent lime significantly affected soil nitrate-N (NO_3-N), electrical conductivity (EC), and Ca in the 3-6 inch soil depth and everything but NO_3-N, K, and Na in the 0-3 inch soil depth. At the deeper soil depth, spent lime increased soil NO_3-N, though the absolute effect was minimal, EC by 0.12 units, and Ca by 500 ppm. In the surface three inches of soil, the range of spent lime rates increased soil test P by 36 ppm, pH by 0.36 units, EC by 0.09 units, Ca by 2000 ppm, and Mg by 400 ppm.

At the Breckenridge site (Table 3), spent lime significantly affected soil NO_3-N, pH, and EC in the 3-6 inch soil depth and everything but K in the 0-3 inch soil depth. Similar to the Hillsboro site, the effect of spent lime on soil NO_3-N in the deeper soil was significant, but the absolute effect was minimal. Soil pH increased by 0.13 units and EC increased by 0.12 units in the 3-6 inch depth over the entire range of spent lime rates. In the surface 3 inches of soil, the spent lime increased soil NO_3-N by 10 ppm, soil test P nearly doubled (18 ppm increase), pH increased 0.38 units, EC increased 0.38 units, Ca increased 2200 ppm, and Mg increased 200 ppm. The increase in Na with increasing spent lime rates was also significant, but the absolute changes were minimal.

It is note worthy that most of the effects of spent lime were in the surface 3 inches of soil. In time, the spent lime may be more completely mixed with the soil as subsequent tillage operations take place in these fields. However, it must be emphasized that any water runoff from these fields will be in direct contact with the surface soil. Therefore, the soil test levels of nutrients such as P in the surface soil may influence the P content of runoff water (Hansen et al. 2002). Soil test P in the surface soil was increased by 0.9 and 1.2 ppm for each ton of wet spent lime applied at the Breckenridge and Hillsboro sites, respectively. This dramatic increase in soil test P from spent lime would have been masked somewhat in a combined 0-6 soil sample.

Crop Production:

Hard red spring wheat was planted in both 2004 and 2005 at the Breckenridge site. In 2004, corn was planted at the Hillsboro site, but in 2005 this site experienced extremely wet soil conditions and nothing was planted.

In 2004, crop production response to spent lime application was quite similar at both the Hillsboro and Breckenridge sites, even though they differed in the crop grown (Table 4). Spent lime application had no effects on total biomass accumulation or N uptake at either site, but total P uptake did increased slightly with increasing rates of spent lime. This indicates that spent lime did supply additional P to the crop. However, if you consider the soil test P levels in the control plots (Tables 2 and 3), both of these fields were medium to high in soil test P level before the spent lime was applied. Perhaps, if the field would have had a lower soil test P level originally and required fertilizer P application, the impact of spent lime on P uptake may have been more dramatic. Interestingly, crop yields declined with increasing spent lime rates at both sites. Corn yield decreased by 10 bu A^{-1} at the Hillsboro site and wheat yields decreased by 6 bu A^{-1} at the Breckenridge site. At present we have no explanation for these significant grain yield declines when spent lime was applied.

In 2005, effects of spent lime on wheat at the Breckenridge site were very different from what occurred in 2004. Total dry matter, N, and P accumulation increased with increasing spent lime rates (Table 5). Total dry matter increased by 1000 lbs A^{-1} and N accumulation increased by 18 lbs A^{-1}. Phosphorus accumulation increased by just more than 4 lbs A^{-1}. More importantly, unlike 2004, wheat grain yields increased by 10 bu A^{-1} in 2005. We cannot explain the turn around in spent lime effects on grain yield between the two years. However, when sampling these plots in 2005, it was clearly evident that the control plot plant growth and vigor were not consistent with the previous year or with spent lime treated plots. This was not the case in 2004.

Summary:

Soil samples in the 2005 from each plot at both sites are currently being analyzed in the laboratory. In addition, this trial is designed to be continued through the 2008 growing season. At this time, the soils project will not be collecting soil samples or monitoring crop yields and growth in the next few years. However, it is hoped that a final set of soil samples can be taken at the conclusion of the trial. It is also noted that samples of the spent lime that were actually applied to each of these two sites were not analyzed for either moisture or nutrient level. There is anecdotal evidence that suggests spent lime moisture content may vary considerably among the different factories. The Minn-Dak factory supplied the spent lime for the Breckenridge site and the Hillsboro factory supplied spent lime for the Hillsboro site.

The soil test results for the Hillsboro site (Table 2) were from soil samples taken in the spring of 2005, 19 months after spent lime was applied. In contrast, the soil test results for the Breckenridge site (Table 3) were from soil samples taken in August 2004 four months after spent lime was applied. Therefore, some of the differences in spent lime effects observed between the two sites may be the result of different soils and climate, different source of spent lime, and different amounts of time spent lime had to react to the soil.

The data clearly indicate that spent lime from various factories is not all the same. Factory processing practices may be similar but, impurities in the spent lime are the result of sugar beets grown in different geographical locations, different soils that vary in inherit chemical properties, different environments, different varieties, and different management systems. When considering whether to apply spent lime to the fields, a chemical analysis should done on the spent lime if not on a per load basis, which would probably be prohibitive, at least on an average factory basis. It is quite possible that the chemical make up of the spent lime may vary depending on the piling station the beets being processed came from.

Of particular interest, is the potential of spent lime to supply P. Exactly how much of this P is readily available for plant use and how much P fertilizer spent lime can replace cannot be discerned from either of these experiments. What is apparent from these experiments is that soil test P levels are very sensitive to spent lime applications and that most of the added P is located in the surface soil layers. In addition, spent lime is frequently observed on or near the soil surface even after post application tillage operations. Soil test P in the surface 2 inches of the soil is related to the amount of dissolved P in water runoff from the field (Hanson et al., 2002). Particulate P may also be lost in the runoff water as soil and, possibly, spent lime particles are eroded off the field. The application of spent lime to agricultural fields brings with it the added responsibility to make sure management practices are adequate to reduce the potential for P movement into surface waters.

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Table 1. Results of laboratory analysis on spent lime obtained from each of seven sugar beet processing factories at three different times during the 2004-2005 processing season. Top number is the mean and bottom number is the standard deviaton of three subsamples of spent lime.

Factory	Crookston			Drayton			East Grand Forks			Hillsboro			Moorhead			Minn-Dak			So. Minn		
Sample Date[§§]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Nutrient[§]	mg kg^{-1}																				
Total N	3537	2870	3590	3253	2583	2760	3177	3057	3257	3600	3473	3117	3777	3647	3397	5097	3020	3310	4360	3093	2937
	337	145	87	131	91	30	287	170	42	295	208	349	119	206	65	122	131	44	44	436	49
Total P	4470	4070	4237	4483	3527	3470	5577	4457	5370	5997	6193	4023	6893	5553	4433	5727	4453	4677	7043	5023	4673
	410	46	133	162	71	44	337	186	72	405	287	505	400	110	91	38	21	68	110	336	159
Ca (1000s)	231	230	246	241	244	228	244	236	255	229	234	245	243	243	243	243	228	225	223	229	255
	6	4	7	3	7	36	16	5	15	6	3	17	9	10	5	14	192	161	13	8	12
Mg (1000s)	10.2	9.2	10.2	9.7	8.2	7.9	12.3	10.7	12.2	12.9	11.5	10.1	11.4	10.6	9.3	11.9	9.0	9.1	13.7	9.7	7.9
	.2	.1	.2	.3	.2	1.3	.3	.3	.3	.3	.2	.3	.1	.5	.3	.4	.2	.5	.3	84	.4
Na	407	283	385	243	300	369	211	318	308	276	457	215	222	256	191	476	812	1185	294	249	230
	145	68	36	113	61	57	40	39	39	59	55	51	102	149	70	100	57	354	92	21	112
K	1943	1407	2252	1866	1665	1369	1467	1152	1515	1957	1163	1650	960	528	607	2097	1059	4307	1503	883	576
	135	168	114	170	70	126	187	232	28	112	176	396	49	98	7	243	84	2998	44	196	81

§ Total N and Total P represents total nitrogen and phosphorus measured after acid digestion of the lime material. Ca, Mg, Na, and K represent calcium, magnesium, sodium, and potassium, respectively, measured in a separate digestions procedure of the lime. All values are concentrations based on dry weight of spent lime.

§§ Sample Dates 1, 2, and 3 represents dates of 11/18/04, 01/19/05, and 03/17/05, respectively, when spent lime was sampled at each factory location.

Table 2. Various chemical properties (soil test analysis) analyzed on soils collected in May 2005 from the Hillsboro Spent Lime Trial.

Lime Rate	NO_3-N	Olsen P	pH	EC	Ca	Mg	K	Na
Wet Tons A^{-1}	ppm	ppm		dS m^{-1}	ppm	ppm	ppm	ppm
			0 – 3 inch soil depth[§]					
0	12.1	19.5	7.42	0.67	3357	1038	768	35.4
5	12.1	24.1	7.66	0.71	4118	1097	768	35.4
10	12.1	31.5	7.74	0.69	4643	1185	768	35.4
20	12.1	41.7	7.75	0.73	5210	1280	768	35.4
30	12.1	56.6	7.78	0.76	5332	1402	768	35.4
			Single degree of freedom contrast of Spent lime Rates[§§]					
Linear	ns	***	***	**	***	***	ns	ns
Quadratic	ns	ns	**	ns	***	ns	ns	ns
			3- 6 inch Soil Depth[§]					
0	5.6	9.1	7.34	0.58	3487	1267	584	57.8
5	5.9	9.1	7.34	0.61	3781	1267	584	57.8
10	5.8	9.1	7.34	0.63	3769	1267	584	57.8
20	5.5	9.1	7.34	0.66	3863	1267	584	57.8
30	6.7	9.1	7.34	0.70	3964	1267	584	57.8
			Single degree of freedom contrast of Spent lime Rates[§§]					
Linear	***	ns	ns	***	**	ns	ns	ns
Quadratic	**	ns	ns	ns	ns	ns	ns	ns

[§] Where statistical analysis indicated no significant difference, the recorded value for each of the five spent lime rates are the average of the five rates.

[§§] ns, ***, **, and * indicate non-significant and significance at the 0.001, 0.01, and 0.05 level of probability, respectively.

Table 3. Various chemical properties (soil test analysis) analyzed on soils collected in August 2004 from the Breckenridge Spent Lime Trial.

Lime Rate	NO_3-N	Olsen P	pH	EC	Ca	Mg	K	Na
Tons A^{-1}	ppm	ppm		dS m^{-1}	ppm	ppm	ppm	ppm
				0 – 3 inch soil depth[§]				
0	13.1	17.8	7.22	0.47	2759	1117	446	44
5	19.6	25.7	7.47	0.82	4268	1148	446	43
10	18.9	27.4	7.47	0.82	4523	1204	446	45
15	20.6	35.3	7.56	0.84	5145	1336	446	48
20	23.0	36.1	7.58	0.85	4907	1318	446	46
				Single degree of freedom contrast of Spent lime Rates[§§]				
Linear	***	***	***	***	***	***	ns	**
Quadratic	ns	ns	**	***	***	ns	ns	ns
				3 to 6 inch Soil Depth[§]				
0	5.1	9.2	6.59	0.32	2474	1405	402	76
5	6.2	9.2	6.69	0.39	2474	1405	402	76
10	6.0	9.2	6.65	0.42	2474	1405	402	76
15	6.5	9.2	6.77	0.46	2474	1405	402	76
20	6.9	9.2	6.72	0.44	2474	1405	402	76
				Single degree of freedom contrast of Spent lime Rates[§§]				
Linear	***	ns	*	**	ns	ns	ns	ns
Quadratic	ns	ns	ns	ns	ns	ns	ns	ns

§ Where statistical analysis indicated no significant difference, the recorded value for each of the five spent lime rates are the average of the five rates.

§§ ns, ***, **, and * indicate non-signficance and significance at the 0.001, 0.01, and 0.05 level of probability, respectively.

Table 4. Yields, nitrogen (N), phosphorus (P) accumulation in crops grown in the 2004 growing season at the Breckenridge and Hillsboro Spent Lime Trial sites.

Lime rates	Total Dry Matter	N Accumulation	P Accumulation	Grain Yield
Tons A^{-1}	lbs. A^{-1}	lbs. A^{-1}	lbs. A^{-1}	bu A^{-1}
		Hillsboro Corn§		
0	14933	175	30.1	144
5	14933	175	31.2	140
10	14933	175	31.5	138
20	14933	175	32.3	134
30	14933	175	32.4	136
		Single degree of freedom contrast of Spent lime Rates§§		
Linear	ns	ns	*	**
Quadratic	ns	ns	ns	ns
		Breckenridge Spring Wheat§		
0	9728	167	20.0	67.1
5	9728	167	20.6	65.7
10	9728	167	20.2	65.4
15	9728	167	23.5	61.6
20	9728	167	21.3	61.4
		Single degree of freedom contrast of Spent lime Rates§§		
Linear	ns	ns	**	**
Quadratic	ns	ns	ns	ns

§ Where statistical analysis indicated no significant difference, the recorded value for each of the five spent lime rates are the average of the five rates.

§§ ns, ***, **, and * indicate non-signficance and significance at the 0.001, 0.01, and 0.05 level of probability, respectively.

Table 5. Yields, nitrogen (N), phosphorus (P) accumulation in crops grown in the 2005 growing season at the Breckenridge Spent Lime Trial site.

Lime rates	Total Dry Matter	N Accumulation	P Accumulation	Grain Yield
Tons A^{-1}	lbs. A^{-1}	lbs. A^{-1}	lbs. A^{-1}	bu A^{-1}
		Breckenridge Spring Wheat§		
0	6623	77.0	10.9	36.2
5	7184	90.2	13.4	43.5
10	7434	90.1	13.9	44.8
15	7796	99.9	15.2	45.9
20	7714	95.3	12.8	46.0
		Single degree of freedom contrast of Spent lime Rates§§		
Linear	***	***	*	**
Quadratic	*	*	**	ns

§ Where statistical analysis indicated no significant difference, the recorded value for each of the five spent lime rates are the average of the five rates.

§§ ns, ***, **, and * indicate non-signficance and significance at the 0.001, 0.01, and 0.05 level of probability, respectively.