CROP AVAILABILITY OF SUGAR BEET FACTORY LIME PHOSPHORUS

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Sugar beet factories have traditionally stockpiled factory lime near the factory site resulting in large mountains of this material. In recent years, growers have become interested in factory lime as a field amendment to reduce sugar beet root rot. Factory lime contains significant amount of nutrients, especially phosphorus. With fluctuations in fertilizer prices in recent years, many questions have been raised about the possible value of the factory lime P. While these questions are very appropriate, it cannot be answered at this time. We suspect at least a portion of the factory lime P is plant available, but we currently do not have the data to estimate that proportion.

The seven sugar beet processing factories in Minnesota and North Dakota generate approximately 500,000 dry tons of factory lime (spent lime) annually. Factory lime is produced during the sugar beet thin juice purification process. Milk of lime ($Ca(OH)_2$) and CO_2 are injected into the juice where it forms calcium carbonate (USEPA, 1997) and, along with many impurities (Dutton and Huijbregts, 2006), precipitates from the juice. The purified juice is further processed into crystal sugar, but the precipitated lime and impurities are expelled from the factory and hauled away. This factory lime meets the definition of a liming product (SSSA, 1997) and can be used on acidic soils to raise soil pH. This is being done in many European agricultural areas. However, soils in Minnesota and North Dakota, where sugar beet factories are located, are naturally high in pH and lime is not needed. Without a demand for lime, factory lime produced in the sugar beet processing factories has traditionally been stockpiled near the factory site where it was produced.

In recent years, it was discovered that soil applications of sugar beet factory lime may be beneficial in reducing Aphanomyces root rot (*Aphanomyces cochliodes* Dresch.) in sugar beet (Bresnahan et al., 2000; Bresnahan et al., 2001). This along with observations of similar benefits in a farmer's field near Breckenridge, Minnesota stimulated the establishment of two field trials to examine the effects of factory lime on Aphanomyces root rot in sugar beet (Windels et al, 2006). Soil pH at these two locations ranged from acidic (approximately 6.0) to slightly above neutral (about 7.2). Additional measurements were made on these same plots to examine the effects of factory lime on phosphorus (P) availability. To test the effects on P, soil samples were collected and Olsen soil test P (STP) (Olsen et al, 1954) was determined and several parameters of production were measured on the non-sugar beet crops that were part of this trial. Correlation between factory lime rate and STP level was strong and positive the first growing season after the lime was field applied (Sims et al, 2010). Two growing seasons after lime was applied there was still a strong positive correlation between STP and factory lime rates. However, these trials were established on fields with high STP levels and the grower-cooperators continued to fertilize the experimental area as they fertilized the surrounding commercial field. Therefore, no crop response to increased P levels was expected and none was observed. That is, the crop had sufficient P available before factory lime was applied. Since there was no plant response to factory lime and the STP determination is simply a bench top laboratory chemical extraction process correlated with a crop response to the application of fertilizer, we could not determine the proportion of factory lime P that might actually be available to a growing crop. However, Sailsbery and Hills (1987) reported that sugar beet factory lime did supply P to a sugar beet crop grown on a 'non-acidic, low organic matter' soil in California.

Sims et al (2010) measured P in sugar beet factory lime from the seven Minnesota and North Dakota sugar beet processing factories at three different times during the 2004-05 processing season. They reported average P concentrations ranging from 3500 ppm P to 7000 ppm P. This is equivalent to 16 to 32 lbs P_2O_5 per dry ton of factory lime. In recent years, commercial phosphorus fertilizer prices have equated to about $1 per pound of P_2O_5. Several attempts have been made to directly compare commercial fertilizer P and factory lime P based on commercial fertilizer prices. However, commercial fertilizer has a guaranteed analysis and solubility and is fairly consistent from batch to batch. Factory lime can vary depending on the factory from which it was produced and when it was produced (Sims et al, 2009). Direct comparisons between commercial fertilizer P and factory lime P requires the analysis of P content of the factory lime being delivered to the grower and some knowledge of the proportion of that factory lime P that is readily available to a crop. Given that commercial fertilizer has a guaranteed P content and solubility, it is impossible to apply the same economic measuring stick to factory lime P. The research reported here was conducted to address this issue and determine the proportion of the factory lime P that is plant available or will become plant available once applied to the field.

Objectives:

To determine the proportion of field applied sugar beet factory lime phosphorus that is potentially available to a growing crop.

1. Determine P availability from factory lime P the first year after lime application
2. Determine if P availability from factory lime P changes with time after lime application.

Materials and Methods:

This trial is being conducted in two components, a greenhouse component and a field component. Both are separate trials, but are designed in roughly the same way to address the same objectives. Both trials use corn as the monitoring crop. Both trials soil was selected because they have alkaline pH greater than 8.0 and STP levels of low to very low. A response to the addition of fertilizer P is expected as well as factory lime P if it is plant available.

Greenhouse Trial:

In the spring of 2008 a site on the premises of the Northwest Research and Outreach center was found to have a STP of 2 ppm P. Three adjacent strips 25 ft wide and 125 long were established. Each strip was subdivided into five 25 ft plots. On May 15, 2008 sugar beet factory lime recently produced at the American Crystal Sugar Co. factory in Crookston, Minnesota was applied at rates of 0, 1, and 2 ton A^{-1} on a dry weight basis. Measured amounts of factory lime were hand spread to each 25 by 25 ft plot to ensure uniform distribution and incorporated with a rototiller. During the 2009 growing season, winter wheat was grown on these plots then killed with RoundUp in August. After the winter was dead it was thoroughly incorporated with several passes of a rototiller. In late August 2009 soil was collected to a six inch depth from one 25 ft by 25 ft plot of each lime rate strip. The soil was sieved through quarter inch opening screen and stored in plastic tote tubs. Enough soil was collected to conduct two greenhouse experiments during the winter months. Periodically the soil was stirred and mixed to promote air drying.

In December 2009 and again in February 2010 pot experiments were established in the greenhouse facility at the Northwest Research and Outreach Center. The two experiments were designed as a Randomized Complete Block with four blocks (replications) and a treatment design of a 3 by 5 factorial. The first factor was the three factory lime rates applied to the field soil of 0, 1, and 2 ton A^{-1} dry weight. The second factor was six rates of P fertilizer ranging from 0 to 75 lbs. P_2O_5 A^{-1} in 15 lb. increments. Experimental pots were 8 inches in diameter and 8 inches deep. The bottom of each pot was lined with about an inch of the appropriate soil. Additional soil, enough to occupy the center six inches of the pot, was thoroughly premixed with nitrogen, micronutrients, and the appropriate P fertilizer rate (K_2HPO_4 solution) and placed in the pot. The pot was set in a tub of water to allow water absorption from the bottom of the pot until water had reached the soil surface. The pot was then removed from the tub of water and allowed to set for a couple of hours. Four corn seed were placed on the wet soil surface and covered with another inch of dry soil that was then wetted. All the soil in a given pot was from the same soil or factory lime rate source. At about the 3 leaf growth stage corn in each pot was thinned to 2 plants and all pots were rotated to form corn rows. When the corn was at the V7 to V8 growth stage the plants were cut at the soil surface, dried, and weighed to determine dry matter accumulation. The dried plants were then ground in a Wiley mill and P concentration was determined by acid digestion. Soil samples were collected from each pot after the corn was harvested for Olsen STP determination.

Field Trial

A commercial corn field was selected in October 2008 near Clara City, Minnesota because of the low STP level to conduct the field component of this trial. The experimental design was a Randomized Complete Block with four blocks (replications) and the treatment design was split-plot design. The whole plot treatment was sugar beet factory lime rates of 0, 1, or 2 ton A^{-1} dry weight applied on October 31, 2008. The source of the factory lime was recently produced lime from the Southern Minnesota Beet Sugar Cooperative processing factory in Renville, Minnesota. The factory lime was incorporated with two passes of a chisel plow. In spring 2009, one set of whole plots was planted to soybean and no data was collected. A second set of whole plots was split into subplots, P fertilizer rates applied and corn planted. Results of treatment effects on corn were reported in last year's research report, but are reported again in this report because the analytical P content of the plant materials is now available. In 2010, whole plots that had been soybean in 2009 were split into six split-plots to accommodate six P fertilizer rates ranging from 0 to 75 lbs. P_2O_5 A^{-1} in 15 lb. increments. Corn was then planted. This site was to evaluate potential P supplied from factory spent lime the second growing season after the lime was applied. In the fall of 2009, a second site was selected near Clara City, Minnesota and factory spent lime applied in November 2009. The experimental design and treatments were identical those described for the 2008 trial described above. In 2010, one set of whole plots were split into six split-plots to accommodate six P fertilizer rates ranging from 0 to 75 lbs. P_2O_5 A^{-1} in 15 lb. increments. Corn was then planted. This site was designed to be a repeat of the 2009 Clara City site evaluating factory lime P supply to corn the first growing season after factory lime was applied.

Unfortunately, the site established in 2008 was excessively wet in 2010 and had water setting on the plots for much of the growing season. As a result the site was abandoned and no samples were collected. At the second site, established in 2009, samples were collected. At the V6 growth stage, six randomly selected plants from rows 2 and 5 (plots were 6 rows wide) were cut near the soil surface, dried, weighed for dry matter accumulation, ground and will be analyzed by acid digestion for P concentration. At maturity, another six plants were randomly selected from rows 2 and 5 of each plot and separated into stover (stalk, leaves, and husk), cob and grain. Each component was dried and weighed for dry matter accumulation then ground and will be analyzed by acid digestion for P concentration. Ears from twenty feet of rows 3 and 4 of each plot were hand -picked, shelled, and weighed. A subsample was weighed, dried, and reweighed for moisture determination. The moisture value of the subsample was applied to the whole grain sample to determine grain yield at 15.5% moisture. At the time of this report, the laboratory analysis to determine P concentration in V8 and mature plant components is not completed, but is in progress. After corn harvest each plot was soil sampled and Olsen STP is currently being measured in the laboratory.

Results:

Initial soils used in both the greenhouse and field experiments were selected because of low to very low STP levels and alkaline pH of 8.0 or greater. The factory lime used in these experiments varied in P content. Factory lime from the American Crystal factory in Crookston and used in the greenhouse component contained 0.3% P which is equivalent to 14 lbs. P_2O_5 per dry ton of factory lime. Factory lime treatments for the greenhouse component applied 0, 14, and 28 lbs P_2O_5 A^{-1} in the three factory lime rates. Factory lime from the Southern Minn processing factory and used in the field component contained 0.6% P which is equivalent to 28 kg P_2O_5 per dry ton of factory lime. Factory lime treatments in the field component applied the equivalent of 0, 28 and 56 kg P_2O_5 A^{-1} in the three factory lime rates. In both the greenhouse and field components of this trial, low to very low STP would suggest there is a high probability the corn crop would respond to P applications whether from commercial fertilizer or factory lime. The low rates of factory lime used in these experiments was to prevent overwhelming the system with excess lime P if all or most of it was plant available.

Greenhouse

A first glance at Figures 1 through 6 suggests soil tubs were mislabeled between the 0 lime and 1 ton lime rate. We double checked our labeling and could find no irregularities. Statistically, there was a biomass response to P fertilizer rates in both the greenhouse runs, but to factory lime rates only in the first run (Table 1). The same was true for P content (Table 1). In the first run, a quadratic response to factory lime rates was significant. But, evaluating Figures 1 through 4, the 0 factory lime was not too dissimilar to the 2 ton lime rate and the 1 ton lime rate tended to be different than either the 0 or 2 ton rates. The STP response to factory lime rates followed similar trends (Fig 3 and 5). The 2 ton rate resulted in the greatest STP level. With almost all the measured variables reported here, there was a linear response to applied P fertilizer rates.

The corn grown on this soil responded to the application of P in the fertilizer, but not necessarily to the P in the factory lime. If factory lime P is available to a growing crop, the data suggests only a small proportion of it is available. The 1 ton rate applied about 14 lbs P_2O_5 and the 2 ton rate 28 lbs P_2O_5, which were similar to the 15 and 30 lbs P_2O_5 applied in the fertilizer. If most of the factory lime P was readily available in this high pH soil, it should have been better detected in this P responsive crop/soil system. The lack of clear distinction between the 0 factory lime and the 2 ton lime rate suggests only a small proportion of the factory lime may be available and a higher rate of factory lime may be necessary to detect the lime P availability.

Table 1. Statistical analysis for the greenhouse factory lime study from winter of 2009-2010.

	1st Run				2nd Run			
	Biomass	P conc.	P content	STP	Biomass	P conc.	P content	STP
Source	-------- PR > F§ --------							
Lime rate	ns	ns	**	***	ns	ns	ns	***
Linear	ns	ns	ns	***	ns	ns	ns	***
Quadratic	*	ns	***	ns	ns	ns	ns	*
P rate	***	ns	***	***	*	ns	**	***
Linear	***	ns	***	***	**	ns	***	***
Quadratic	ns	ns	ns	***	ns	ns	ns	***
Lime rate X P rate	ns	ns	ns	**	ns	*	ns	ns

§ ***, **, *, ns represent significance at the 0.001, 0.01, 0.05, and non-significant, respectively.

Field Trial

The field trail resulted in somewhat different results than the greenhouse trial. Field trial grain yield was significantly responsive to factory lime in both 2009 and 2010, the first year after factory was applied the previous fall (Table 2). Only in 2009 was there a significant response to P fertilizer rates (Table 2). Factory lime increased grain yield in both years regardless of P fertilizer rate (Figure 7 and 9). While a linear response to P fertilizer rates was apparent in 2009, no amount of P fertilizer on the 0 lime treatment could match yields where factory lime was applied (Fig 7). Biomass production at V8 in 2009 was responsive to factory lime rates (Table 2), but this was because biomass with 2 ton factory lime tended to be less than either the 0 or 1 ton lime rates (Fig 8). There was no early season biomass response to factory lime rates in 2010 or to P fertilizer rates in either year (Fig 8 and 10).

Table 2. Statistical analysis for 2009 and 2010 Field Trials near Clara City, Minnesota.

	2009					2010		
	Gnyld	V8DM	V8P	R6DM	R6P	Gnyld	V6DM	R6DM
Source	-------- PR > F[§] --------							
Lime rate	+	*	*	ns	ns	***	ns	ns
Linear	ns	*	*	ns	ns	**	ns	ns
Quadratic	ns	ns	ns	ns	ns	***	ns	ns
P rate	*	ns	ns	ns	ns	ns	ns	ns
Linear	**	ns	ns	ns	ns	ns	ns	ns
Quadratic	ns	ns	ns	ns	ns	ns	ns	ns
Lime rate X P rate	ns	ns	ns	ns	ns	ns	ns	ns

§ ***, **, *,+ ns represent significance at the 0.001, 0.01, 0.05, 0.10 and non-significant, respectively .

Summary:

The greenhouse component represents two growing seasons after factory lime application. The field component represents the first growing season after factory lime application. The field component second year after application was lost due to excessively wet conditions that essentially made a lake out of a significant portion of the experimental site.

The results to this point suggest there may be some advantages to factory lime applications, but it cannot be attributed to the contribution of P in the factory lime. It is possible that only a small portion of the factory lime P is actually available and the low lime rates used in this experiment resulted in small undetectable P available amounts. Phosphorus research is difficult at best due to the nature of the P chemistry in the soil. The best we can do is find soils with low STP levels and a high likelihood of a crop response to the application of P regardless of where it comes from. If funded, subsequent years will repeat these trials with higher rates of factory lime, 3 and 6 ton per acre. If only a small portion of the factory lime is available, then perhaps the great rates of application will result in great absolute amounts of P being available from the lime and it may be detectable. Until it is, we cannot address the objective stated above.

Acknowledgements:

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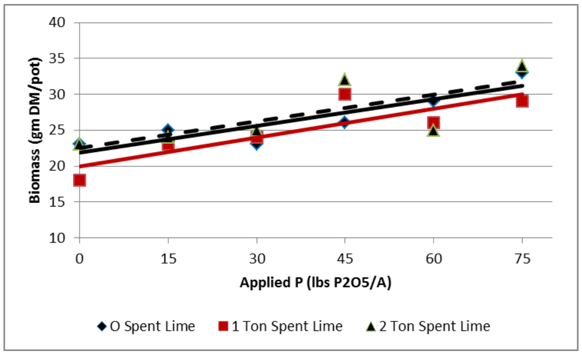

Figure 1. Corn biomass response to factory lime and P fertilizer rates during 1st run of 2009-2010 greenhouse experiment.

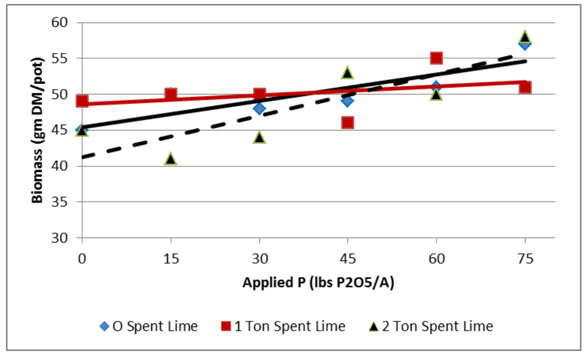

Figure 4. Corn biomass response to factory lime and P fertilizer rates during 2nd run of 2009-2010 greenhouse experiment.

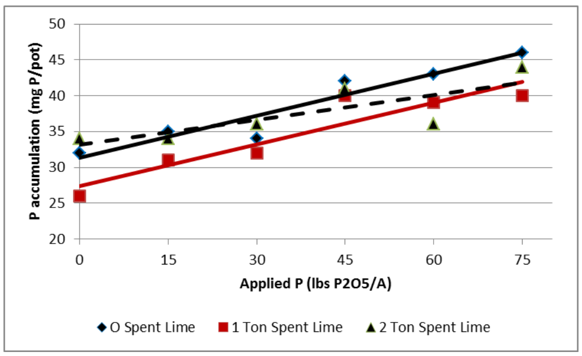

Figure 2. Above ground P accumulation response to factory lime and P fertilizer rates during 1st run of 2009-2010 greenhouse experiment.

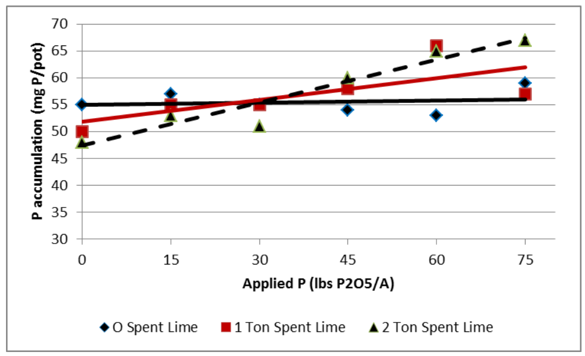

Figure 5. Above ground P accumulation response to factory lime and P fertilizer rates during 2nd run of 2009-2010 greenhouse experiment.

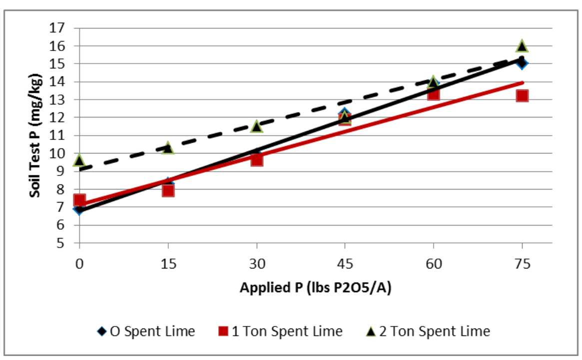

Figure 3. Soil test P response to factory lime and P fertilizer rates during 1st run of 2009-2010 greenhouse experiment.

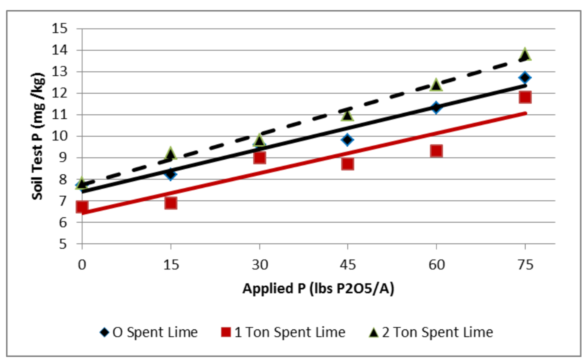

Figure 6. Soil test P response to factory lime and P fertilizer rates during 2nd run of 2009-2010 greenhouse experiment.

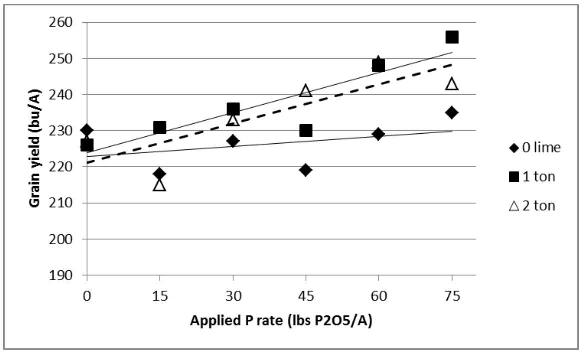

Figure 7. Corn grain yield response to factory lime and P fertilizer rates in 2009 field trial.

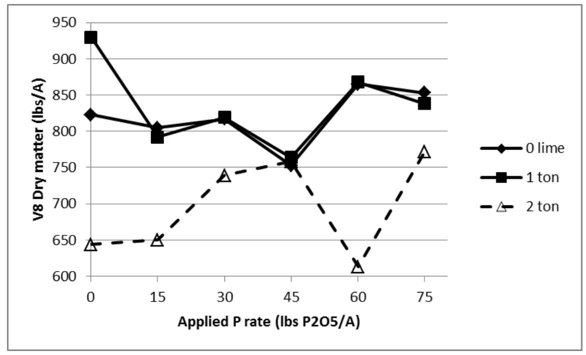

Figure 8. Corn dry matter accumulation at V8 response to factory lime and P fertilizer rates in 2009 field trial.

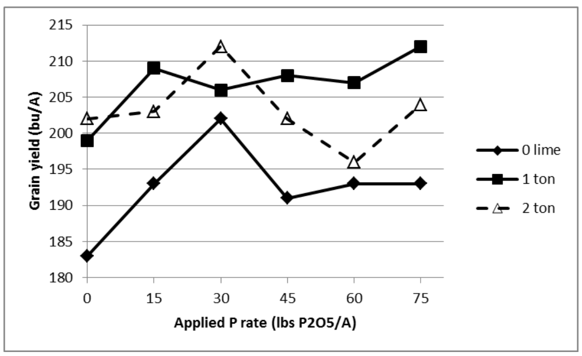

Figure 9. . Corn grain yield response to factory lime and P fertilizer rates in 2010 field trial.

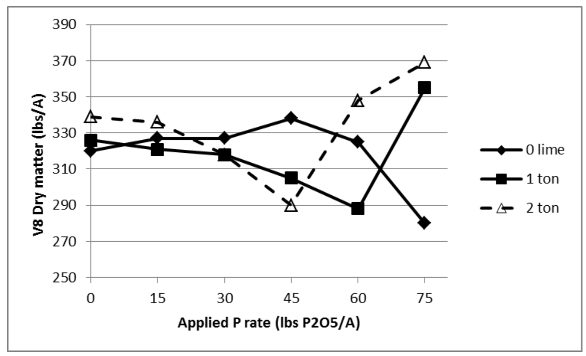

Figure 10. Corn dry matter accumulation at V6 response to factory lime and P fertilizer rates in 2010 field trial.

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