CROP AVAILABILITY OF PHOSPHORUS FROM SUGARBEET FACTORY LIME

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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, 2010). 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. Specifically we were interested in soils with an alkaline pH (at or above 8.0) where lime solubility is very low.

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. Soil for both trials were selected because they have alkaline pH greater than 8.0 and STP levels of Low to Very Low. A response to the addition of P is expected whether it be from fertilizer or factory lime P if it is plant available. However, it is also understood that at this high soil pH the solubility of the factory lime is quite low and lime activity may be limited.

<u>Greenhouse Trial:</u>

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. Throughout the entire growing season the plots were frequently tilled with a rototiller in an attempt to uniformly incorporate the factory lime to the depth of tillage, approximately 6 inches. In late August 2008 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.

During the 2010-2011 winter months a pot experiment was conducted in the greenhouse facility at the Northwest Research and Outreach Center. The experiment was a 3 by 6 factorial randomized complete block with four replications. The first factor was the three rates of factory lime applied in the spring of 2008. This trial would represent third year after lime application. The second factor on the experiment was six P fertilizer rates ranging from 0 to the equivalent of 75 lbs.P_2O_5 A^{-1} in 15 lbs increments. Corn was grown for several weeks and harvested at the V8 growth stage. Plants were harvested by cutting them at the soil surface then dried at 60^o C to estimate dry matter accumulation. Dried plant samples were ground in a Wiley mill and analyzed for P concentration. The P concentration combined with dry matter accumulation estimates total P accumulation in the plant. Each pot was soil sampled after plants were harvested and analyzed for Olsen STP.

When this trial was initiated, based on results of earlier trials (Sims et al., 2010) we assumed most of the factory lime P might be readily available to a growing crop. Thus we used low rates of factory lime that applied 14 and 28 lbs. P_2O_5 A^{-1} equivalent. However, greenhouse trials from previous years suggested this assumption may be false and that low factory lime rates were too low. New field plots were established in fall 2010 with 0, 3, and 6 dry tons factory lime A^{-1}. Soils from these plots were collected in August 2011 and a greenhouse trial using this soil is currently underway at this writing. Results of this trial will be reported next year.

Field Trial

Two field trials were conducted in the SMBSC growing area in 2011. One trial represented the second growing season after fall (2009) application of 0, 1, and 2 dry tons factory lime A^{-1}. In the fall of 2010 it was decided that these factory lime rates were too low (see greenhouse discussion) and a new trial using 0, 3, and 6 dry tons factory lime A^{-1} was established. The second field trial represents the first growing season after the higher rates of factory lime were applied.

In both trials, corn was planted in the spring of 2011. At about the V6-V7 growth stage, eight plants from each plot were harvested, dried, weighted, ground, and will be analyzed for P concentration. In addition, plant stands were also counted in each plot. At maturity, eight additional plants from each plot were harvested and separated into stover, grain, and cob. There plant parts will also be analyzed for P concentration. The laboratory analysis of these plants materials will be completed before March 2012. At the same time, all ears from 20 ft of the two middle rows of each plot were hand-picked and shelled to estimate grain yield. After harvest each plot was soil sampled and those samples will be analyzed for Olsen STP during the winter months.

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 the need for more P than would be supplied by the factory lime for corn production. The higher rates of factory lime applied this past year applied the equivalent of 42 and 84 lbs P_2O_5 A^{-1} in the greenhouse trials and 84 and 168 lbs. P_2O_5 A^{-1} in the field trials.

Greenhouse

The greenhouse trial conduced in the winter months of 2010-2011 revealed a response to both P fertilizer and factory lime rates three growing seasons after 0, 1, and 2 dry tons factory lime A^{-1} was applied and incorporated into the field plots.

Total Dry Matter Accumulation: There was a strong total dry matter accumulation response to P fertilizer rates (Table 1). Total dry matter accumulation increases throughout the entire range of P fertilizer rates with all factory lime rates (Fig. 1a). One of the contrasts describing an interaction between P fertilizer rates and factory lime rates was significant (Table 1), but this interaction is difficult to interpret. At the 0 P fertilizer rate, factory lime increased total dry matter. As P fertilizer rate increased, total dry matter increased to a greater extent at the 0 lime rate and least at the 1 ton factory lime rate (Fig. 1a).

Table 1. Statistical analysis for the 2010-2011greenhouse factory lime study.

Source	Total DM	Total P	Olsen STP
	---------- Pr > F§ -------		
Lime Rate	ns	***	***
Linear	ns	***	***
Quad	ns	Ns	***
P Fert. Rate	***	***	***
Linear	***	***	***
Quad	ns	ns	ns
Lime Rate by P Rate	ns	ns	*
Lime lin by P lin	ns	+	ns
Lime lin by P quad	ns	ns	ns
Lime quad by P lin	*	ns	*
Lime quad by P quad	ns	ns	+

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

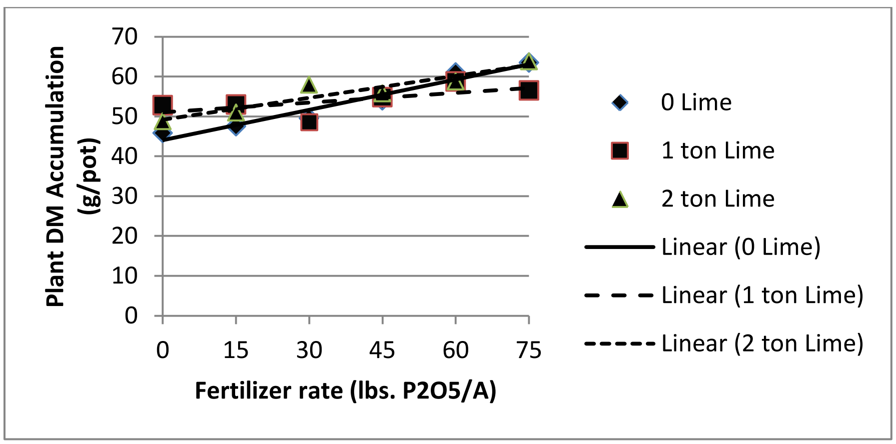

Figure 1a. Total dry matter accumulation response to P fertilizer and factory lime rates in the 2010-2011 greenhouse trial.

Total P Accumulation: There was a strong total P accumulation response to both P fertilizer and factory lime rates (Table 1). The interaction between P fertilizer rates and factory lime rates observed in Fig 1b was significant at the 0.10 level. At the 0 P fertilizer rate, total P accumulation was similar with all factory lime rates. As P fertilizer rates increased total P accumulation increased similarly with both 0 and 1 ton factory lime. With 2 ton factory lime, the increase in total P accumulation was greater from 0 to 30 lbs P_2O_5 A^{-1} fertilizer than with the other two factory lime rates, but then P accumulation tended to level off at higher P fertilizer rates.

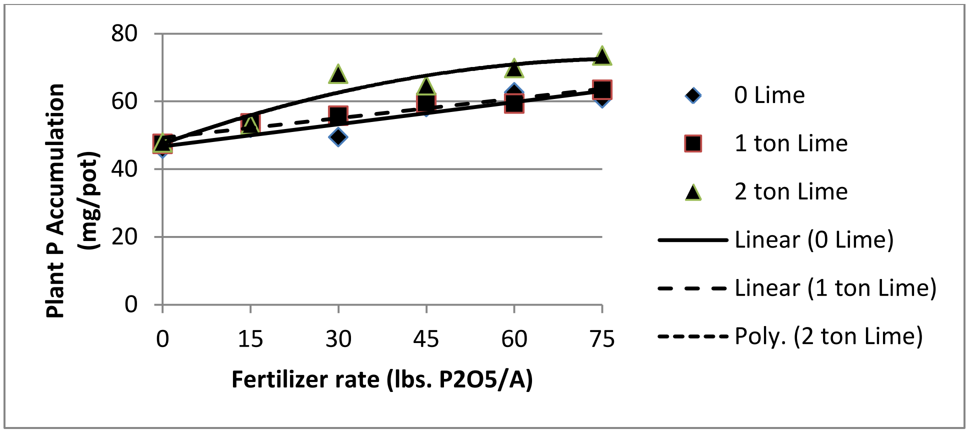

Figure 1b. Total P accumulation response to P fertilizer and factory lime rates in the 2010-2011 greenhouse trial.

Olsen STP: Olsen STP increased as P fertilizer rates increased, but this response was different depending on the factory lime rate (significant factory lime and P fertilizer interaction illustrated in Table 1). Olsen STP response to increasing P fertilizer was similar for both the 1 and 2 ton factory lime rates and both were different than that observed with the 0 factory lime rate (Fig 1c).

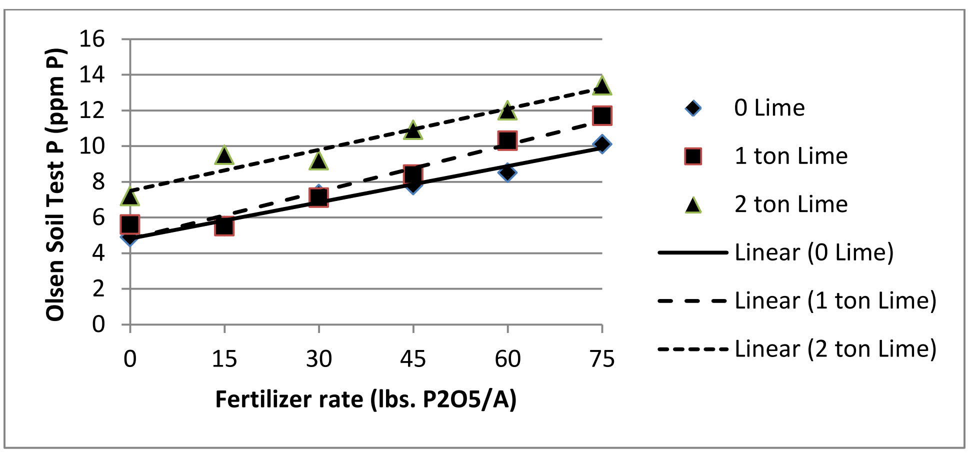

Figure 1c. Olsen Soil Test P response to P fertilizer and factory lime rates in the 2010-2011 greenhouse trial.

<u>Field Trial</u>

Grain yield has been analyzed for both field trials conducted in the 2011 growing season. Even though both trials were on soils with Low STP levels and a response to applied P was expected, none was observed. In the first trial (2nd year after low rates of factory lime), there was neither a grain yield response to P fertilizer rates nor factory lime rates. Overall average grain yield for this trial was 232 bu. A^{-1}. In the second field trial (1st year after higher rates of lime), there was no response to P fertilizer rates, but there may have been a response to factory lime rates. The significance level had to be raised to 0.10 level for this response to be indicated as significant. This is shown in Figure 2.

The laboratory data will be complete in the coming months after this writing. At that time we will have estimates of total dry matter accumulation and combined with P concentration, we will have an estimate of total P accumulation. These data may reveal some information about P contribution of factory lime to the crop. However, the grain yield data suggest there may be a response to the factory lime, but it cannot be attributed to P from the factory lime.

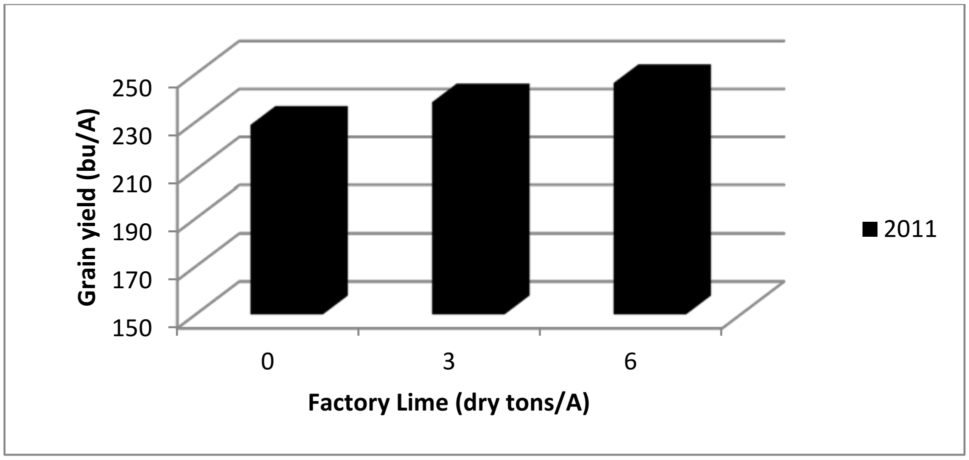

Figure 2. 2011 Grain yield response to factory lime rates applied in fall 2010.

Summary:

The contribution of P from the factory lime is difficult to determine from these trials. The Olsen STP from the greenhouse trial indicates there may be factory lime P being extracted in the laboratory procedure. However, plant response is more puzzling. In the greenhouse, some contribution of factory lime P may be indicated when total dry matter accumulation was greater at the 0 P fertilizer rate when factory lime was applied verses the 0 factory lime rate, however, there was no difference between the 1 and 2 ton factory lime rate. This was not the case with total P accumulation where we thought the difference should have been present. In the field, there is no evidence of P contribution from the factory lime, but the lack of response to P fertilizer was not expected based on the initial soil test P levels. Nevertheless, there was a response to the greater rates of factory lime used in 2011 that cannot be attributed to factory lime P. We are requesting funding for an additional year to run both the greenhouse and field components of this trial in 2012. The field site targeted for the 2012 trial has had the factory lime rates applied this last October.

Acknowledgements:

The authors wish to thank the Minnesota and North Dakota Sugarbeet Research and Education Board, American Crystal Sugar Company, and Southern Minnesota Beet Sugar Cooperative for partially funding this research. The authors also express their profound appreciation to the Mark Bredehoeft, Chris Dunsmore, Kim Hoff and Todd Cymbaluk for their help and assistance in conducting these trials. Without their assistance these trials would not be possible.

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