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.

Greenhouse Trial:

In the spring of 2008, a site on the premises of the Northwest Research and Outreach Center was found to have a soil test phosphorus level (STP) of 2 ppm P. Plots were established with 0, 1, and 2 ton Ac^{-1} applied factory lime obtained from recently produced factory lime at the American Crystal Sugar Company factory in Crookston, Minnesota. The factory lime was incorporated with a rototiller. Low rates of factory lime were applied because of the results from earlier trials (Sims et al., 2010) that suggested most of the P in the material may be available to ag growing crop. These low factory lime rates applied 0, 14, and 28 lbs. P_2O_5 Ac^{-1} equivalent. Soil from the various plots was collected at the end of each summer and used in subsequent greenhouse experiments. After two seasons of greenhouse experiments it was concluded that perhaps something much less than most of the factory lime P was available and new plots were established in fall, 2010 with 0, 3, and 6 ton of factory lime Ac^{-1}. Factory lime rates are based on dry weights and applying approximately 0, 42, and 84 lbs. P_2O_5 Ac^{-1}. In August of 2011, soil was collected from these plots and two greenhouse trials were conducted during the winter months of 2011-2012.

The greenhouse trials were established using 8 inch pots and conducted in the greenhouse facilities at Northwest Research and Outreach Center. Each trial was a 3 by 6 factorial randomized complete block with four replications. The first factor was the three rates of factory lime applied in fall, 2010. These trials would represent the first 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 about 3-5 days after the plants were harvested and analyzed for Olsen STP.

New greenhouse trials have been initiated at the time of this writing using soils collected in August 2012 representing the second year after factory lime application.

Field Trial

Field trials were established I the SMBSC growing area using the same 0,1, and 2 tons of factory lime as previously described. After two field seasons, and combined with the findings of the greenhouse trials, it was decided to reestablish the field component using 0, 3 and 6 ton Ac^{-1} factory lime from the SMBSC factory in Renville. Trials were established in the fall of 2010 and again at another location in the fall 2011. Both trials were set up as a split-plot randomized complete block trial with four replications. Whole plot treatments consisted of the three factory lime rates. Each whole plot was split into six split-plots to accommodate six fertilizer P rates ranging from 0 to 75 lbs. P_2O_5 Ac^{-1} in 15 lbs. increments. In 2012, one field trial was conducted representing results the first year after factory lime application and the second trial represents results the second year after factory lime application.

In both trials, fertilizer P was hand broadcast on individual split-plots and incorporated in the spring prior to planting the corn. At maturity, eight plants from each plot were harvested and separated into stover, grain, and cob. These plant parts will be analyzed for P concentration. The laboratory analysis of these plants materials currently in progress. At the same time as the plant harvest, ears from the harvested rows were counted and used as an estimate of plant stand. 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 are also currently being analyzed for Olsen STP.

Statistical analysis was conducted on individual trials in both the greenhouse and field components of this project using Proc Mixed procedures in SAS. For the greenhouse trials the analysis was done using a 3 by 6 factorial model. For the field trials the analysis was done using a split-plot model.

Results:

Greenhouse Trials:

Two greenhouse trials were conducted during the 2011-2012 winter months. Soil for both trials were collected in mid-August, 2011 from the same plots where factory lime had been applied the fall of 2010. All the soil was collected, stored, and handled the same way. Both trials were set up the same and were conducted in the same greenhouse. The only difference was Trial 1 was initiated in mid-December and concluded in early February and Trial 2 was initiated later in February and concluded in early April. The soil used in both trials was identical and all nutrient solutions and trial set up conditions were done using written protocols to ensure consistency. The actual environmental conditions in the greenhouse may have been somewhat different because of the monthly environmental differences that naturally occur as the winter progresses. In addition, the soil used in the second trial was stored in the container about two months longer before use compared to what was used in the first trial. The difference between the trials should have been subtle at some level. But, the response differences to the factory lime and fertilizer P factors seem to be quite different in the two trials.

Following both trials, soil samples from all pots were tested for soil test phosphorus (STP). In both trials, STP increased as fertilizer P increased and with the application of factory lime (Table 1, Fig 1). The difference between the two trials was the interaction of the two factors. In Trial 1, STP increase with increasing fertilizer P was greater when factory lime had been applied compared to the 0 Lime treatment. In Trial 2, there was no significant interaction. That is, STP increase with increasing fertilizer P was similar regardless if factory lime had been applied or had not been applied. In both trials, factory lime increased STP. Overall STP was greater in Trial 2 than Trial 1. The increase in STP with increasing fertilizer P or with the application of factory lime is consistent with previous observations. The increase in STP in the same soil between Trial 1 and Trial 2 is an indication of the dynamic P chemistry that naturally takes place in the soil. It is part of the reason that STP is not a direct measure of the soil P availability, rather it is an index!

Total dry matter accumulation above the soil surface (TDM) was very responsive to fertilizer P application in both trials (Table 1, Fig 2). Though the probability a crop will respond to an increase in P availability is never 100% regardless of the STP level, the original STP levels of this soil suggested a high probability the crop would respond to an increase in P availability. The TDM response to the application of fertilizer P is verification the crop was responsive and the soil P availability was initially insufficient. Again, however, the variation in the TDM response to fertilizer P when factory lime was applied differed between the two trials. In Trial 1, maximum TDM was reached with 55 lbs. P_2O_5 Ac^{-1} at 0 factory lime. With 3 ton Ac^{-1} factory lime, maximum TDM occurred at 46 lbs. P_2O_5 Ac^{-1}. Mmaximum TDM in both cases was similar suggesting 3 ton Ac^{-1} factory lime contributed the equivalent of about 10 lbs. P_2O_5 Ac^{-1} . Six ton Ac^{-1} factory lime had a slightly different result, but it was more similar to the 3 ton rate than the 0 ton rate. At the 0 fertilizer P rate, 3 ton factory lime produced the same TDM as 23 lbs. P_2O_5 Ac^{-1} fertilizer P and 0 lime. With the 6 ton rate, TDM was similar to 30 lbs. P_2O_5 Ac^{-1} P fertilizer with 0 lime. Taken individually, one might be justified in concluding the factory lime contributed 10, 23, or 30 lbs. P_2O_5 Ac^{-1} to the crop. This represents an estimated 23, 53, and 36% , respectively, of the factory lime P is available to the crop. However, in previous experiments we have observed a positive effect of the factory lime on crop growth that we could not attributed to the P in the factory lime.

Trial 1 strongly suggests at least 23% of the factory lime might be available to the crop. Unfortunately, we must interpret the entire body of evidence. In Trial 2, TDM increased with increasing fertilizer P rates and with increasing factory lime rates, but there was not interaction of the two factors. The TDM increase with fertilizer P was similar regardless whether factory lime had been applied or not and maximum TDM occurred at a similar fertilizer P rate in all factory lime rates. However, the positive effect of the factory lime itself is apparent, but cannot be attributed to the P in the factory lime.

Total P accumulation above the soil surface (TP) might be a better indicator of factory lime availability. In both trials, TP increased as fertilizer P increased and with the application of factory lime (Table 1, Fig 3). In Trial 1, the best fit quadratic model was used to describe the TP response to increasing fertilizer P rates. Using these models, maximum TP occurred at 73, 69, and 108 lbs. P_2O_5 Ac^{-1} fertilizer P with 0, 3,and 6 ton Ac^{-1} factory lime, respectively (note the 108 lbs. is beyond the range of our actual data). However, the maximum TP increased as the factory lime increased. In Trial 2, maximum TP would occur with 60, 64, and 54 lbs. P_2O_5 Ac^{-1} with the same respective factory lime rates. Again, the maximum TP increased as factory lime increased. If TP in only the 0 fertilizer P was evaluated from Trial 1 it would appear 3 and 6 ton of factory lime would contribute 21 and 68 lbs. P_2O_5 Ac^{-1} to the crop or roughly 49 and 81% of what was originally in the material. In Trial 2, the contribution would be about 9 and 11 lbs. P_2O_5 Ac^{-1} or 21 and 13% of the P in the material.

Field Trials:

Two field trials were conducted in 2012 in the Southern Minnesota Beet Sugar Cooperative growing area. One trial represents the results the first year after factory lime had been applied (applied fall 2011) and the second trial represents results the second year after factory lime application (applied fall 2010). Plant samples and soil samples are currently in the laboratory for analyses and will not be presented here. Presented here are the grain yields from the two trials (Table 2, Fig 4). The first year after factory lime application there appears to be a positive linear response to increasing fertilizer P rates with 0 and 6 ton Ac^{-1} factory lime rates. However, there is a negative linear response with 3 ton Ac^{-1} factory lime. Though the interaction between fertilizer P and factory lime rates is significant, it doesn't make sense and I cannot explain it. In the second trial, two years after factory lime application, grain yield response to fertilizer P was quite variable and there appeared to be no response to factory lime application.

Summary:

New greenhouse trials are currently being conducted using soil collected the second year after factory lime application at NWROC. Laboratory analyses is also being conducted on plant and soil samples collected from the field trials. We will not be asking for further funding to continue this trial. However, we will provide a final written report next year combining all the data collected from all the years of the project.

At this point, the greenhouse trials suggest factory lime can supply a portion of its P to a growing crop. However, the confounding general positive effect of factory lime prevents us from confirming the hypothesis or to what extent factory lime P is contributed. We caution the readers to beware of P contribution claims based on a fertilizer P response curve and a value for a factory lime application that is overlaid on the P response curve. The general positive effect of factory lime can disguise what is really occurring. What is attributed to factory lime P using this methodology may actually be just a positive effect of the factory lime and have little or nothing to do with factory lime P. As we have shown using fertilizer P response curves imposed on each factory lime rate, determining the factory lime P contribution is very difficult. The field trials have been little help to this point. So, at this point we can neither reject or affirm the hypothesis that factory lime contributes its P to a growing crop in a high pH soil with low STP levels.

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Table 1. Statistical analysis of the two greenhouse experiments conducted during the 2011-2012 winter months.

Source	**Trial 1**					**Trial 2**			
	STP[§]	**TKP**[§§]	**Total DM**	**Total P**		**STP**[§]	**TKP**[§§]	**Total DM**	**Total P**
	------------- Significance level[§§§] -------------								
Lime rate	***	***	***	***		***	*	***	***
Linear	***	***	***	***		*	*	***	***
Quad	ns	ns	ns	ns		***	ns	ns	**
P rate	***	***	***	***		***	ns	***	***
Linear	***	***	***	***		***	ns	***	***
Quad	ns	ns	**	*		***	ns	***	***
Lime rate by P rate	***	ns	ns	ns		ns	ns	ns	ns
Lime lin by P lin	ns	ns	*	ns		ns	*	ns	ns
Lime lin by P quad	*	ns	*	ns		ns	ns	ns	ns
Lime quad by P lin	***	**	*	ns		ns	ns	ns	ns
Lime quad by P quad	**	ns	ns	ns		ns	ns	ns	ns

§ STP represents the Olsen $NaHCO_3$ extraction soil test phosphorus
§§ TKP represents the P concentration in the plant as determined through acid digestion
§§§ *, **, ***, and ns represent significance at the 0.05, 0.01, 0.001, and non-significant respectively.

Table 2. Grain yield statistical analysis for the 2012 field experiments the first and second year after spent lime application.

Source	**Grain yield analysis**	
	1st year after Lime[§]	**2nd Year after Lime**[§§]
	---------- Significance level[§§§]----------	
Lime rate	ns	ns
Linear	ns	ns
Quad	ns	ns
P rate	ns	**
Linear	ns	ns
Quad	ns	+
Lime rate by P rate	+	ns
Lime lin by P lin	ns	ns
Lime lin by P quad	ns	ns
Lime quad by P lin	*	ns
Lime quad by P quad	ns	ns

§ Grain yield analysis the 1st year after spent lime application
§§ Grain yield analysis the 2nd year after spent lime application
§§§ +, *, **, ***, and ns represent significance at the 0.10, 0.05, 0.01, 0.001, and non-significant respectively.

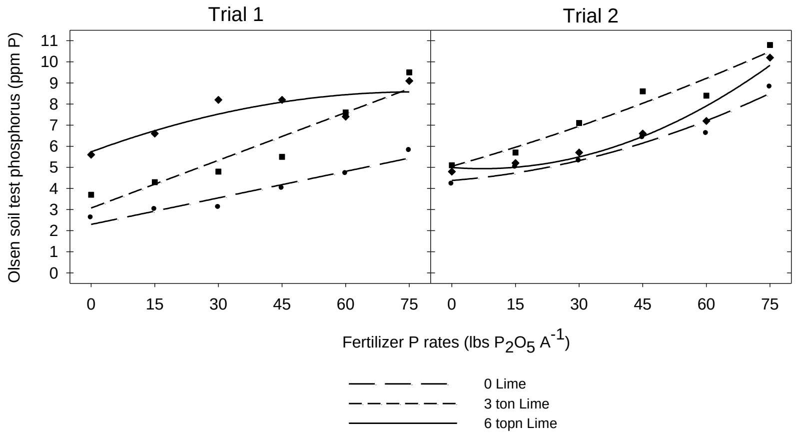

Figure 1. Soil test phosphorus after the two greenhouse experiments conducted during the 2011-2012 winter months.

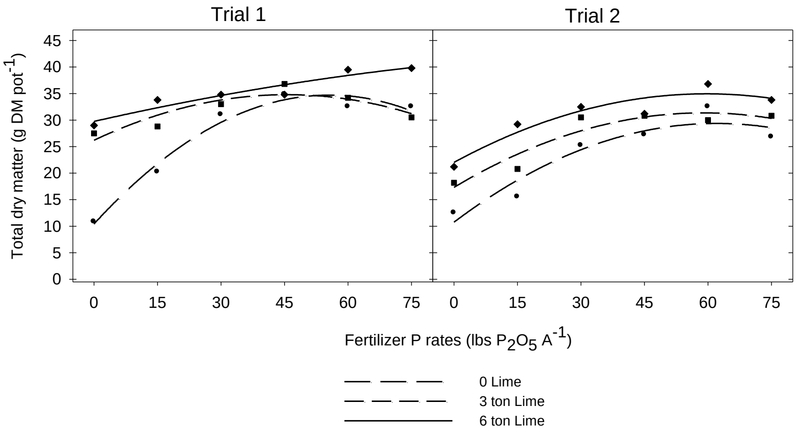

Figure 2. Total above soil dry matter accumulation in the two greenhouse experiments conducted during the 2011-2012 winter months.

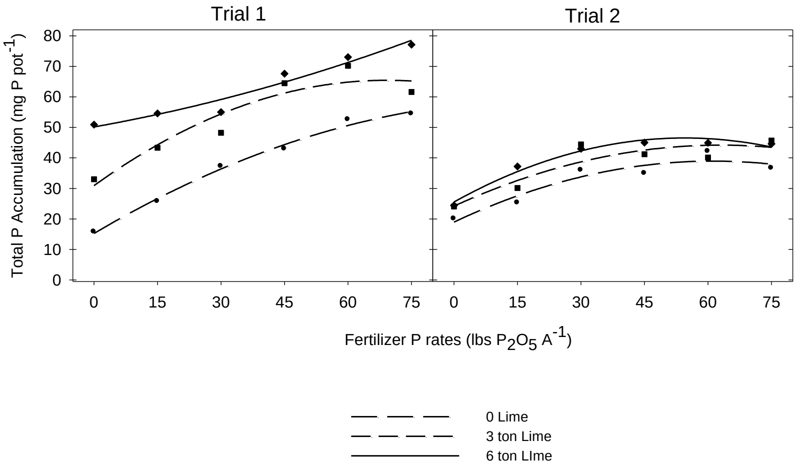

Figure 3. Total above soil phosphorus accumulation in the two greenhouse experiments conducted during the 2011-2012 winter months.

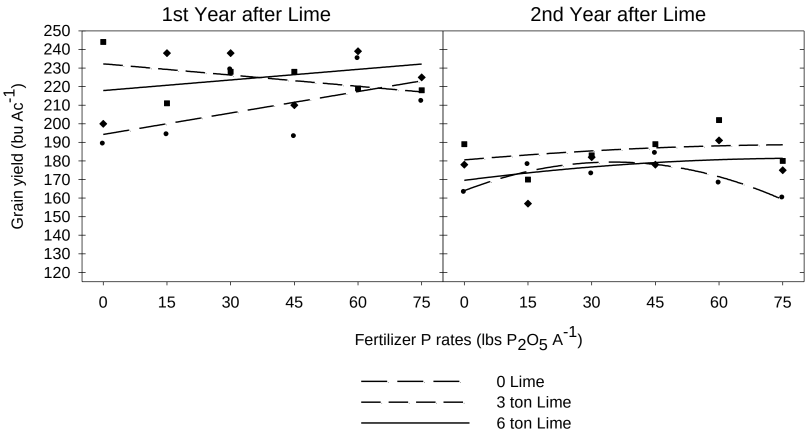

Figure 4. 2012 Grain yield response to Spent Lime and P fertilizer the first and second year after Spent Lime application.