SUGAR BEET LIME EFFECTS ON HIGH pH SOILS AND CROPS IN THE NORTHWEST U.S.

David D. Tarkalson and Dave L. Bjorneberg, USDA-ARS Northwest Soils and Irrigation Research Laboratory, Kimberly, ID

INTRODUCTION

Precipitated calcium carbonate (PCC) is a byproduct of sucrose extraction from sugarbeet (*Beta vulgaris* L.). To remove impurities from the sugarbeet sucrose liquid juice stream, calcium oxide and carbon dioxide are added to the stream to form calcium carbonate ($CaCO_3$) that precipitates out of the liquid juice stream with the impurities. The combination of the $CaCO_3$ and impurities form the PCC and is removed from the juice stream as a solid material.

Various lime materials are used in agriculture is to ameliorate the negative effects of soil acidification on crop production (Havlin et. al, 1999). An estimated 25 to 30% of world soils are acidic (Havlin et. al, 1999). In the Amalgamated Sugar Company growing area in Idaho, Oregon and Washington the pH of most soils range from 7.5-8.5 and do not require lime applications to adjust soil pH. Not only are lime applications not needed to correct soil pH, there are questions regarding potential negative effects of increasing salt concentrations with added PCC.

The Amalgamated Sugar Company LLC's major sugarbeet processing factories (Paul, ID; Twin Falls, ID; and Nampa, ID) produce approximately 387,000 tons of PCC annually. In 2018, PCC stockpiles at these factories totaled approximately 12.6 million tons. Without an offsite beneficial use or disposal method for the PCC, the stockpiles will continue to grow. The difficulty in finding more land to stockpile PCC due to availability issues and high land prices, and potential environmental issues have resulted in the need for Amalgamated Sugar Company LLC to find more offsite beneficial use or disposal methods. Agricultural land application is a practical method to dispose the PCC.

The objective of the study was to assess the effects of added PCC to a common alkaline soil on a sugarbeet-dry bean-barley rotation yields and soil chemical properties. The data will be used to help determine if PCC can be land applied on high pH soils.

MATERIALS AND METHODS

This study was conducted from 2014 to 2020 at the USDA-ARS Northwest Irrigation & Soils Research Lab in Kimberly, ID on a Portneuf silt loam soil. The treatments included four PCC application rate/timings. Table 1 outlines the treatments application details.

Table 1. PCC treatment annual rates and cumulative total amounts applied (in parentheses), crop grown, soil sample date, and lime application date.

Year	2014	2015	2016	2017	2018	2019	2020
Crop	--	Sugarbeet	Dry Bean	Barley	Sugarbeet	Dry Bean	Barley
	tons acre^{-1}						
Control	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
3A	3 (3)	3 (6)	3 (9)	3 (12)	0 (12)	0 (12)	0 (12)
10A	10 (10)	10 (20)	10 (30)	10 (40)	0 (40)	0 (40)	0 (40)
40T	40 (40)	0 (40)	0 (40)	0 (40)	0 (40)	0 (40)	0 (40)
Soil Sample Date	Oct. 19	Apr. 22	Apr. 18	Mar. 21	Apr. 3	Apr. 18	Apr. 9
Lime Application Date	Oct. 29	Nov. 18	Nov. 30	Nov. 24	--	--	--

The treatments were selected to: a) determine the effects of PCC on crop production and soil chemical properties (method: Control vs 3A, 10A, 40T); b) compare the effects of a "low" rate of PCC compared to a "high" rate of PCC (method: 3A vs 10A and 40T); and c) compare the effects of the same rate of PCC application applied differently over time (10A vs 40T). The treatments were arranged in a randomized block design and each treatment was replicated four times. Each plot was 22 ft wide and 60 ft long.

Soils were sampled in the spring and fall of each year from 0 to 12 in (Table 1). In the fall of each year the soil sampling was done before PCC application. The soil samples were analyzed for pH (Kalra, 1995), electrical conductivity (EC) (Rhoades, 1996), Total P , Bicarbonate Extractable P (Olsen P, 1954), NO_3-N and NH_4-N (Mulvaney, 1996), Total C and N using a FlashEA1112 CN analyzer (CE, Elantech, Lakewood, NJ). Due to the significant concentration of P in the PCC (Table 2) and the marginal concentrations in the soil over the study area, to eliminate the crop productivity responses to P, in spring 2015, 400 lbs P_2O_5/acre (mono ammonium phosphate fertilizer) was applied over the entire study area. Soil fertilizer recommendations were determined each year based on University of Idaho recommendations for each crop.

Following PCC applications each fall the entire study area was disked, moldboard plowed, and roller harrowed. The study area was planted to sugarbeet (BTS 21RR25), in 2015 and 2018, dry beans (Ruby Small Red) in 2016 and 2019, and barley (Moravian 69) in 2017 and 2020. The crops were furrow irrigated to meet estimated crop evapotranspiration (ET_c) rates (Wright, 1982). The harvest areas within each plot for each crop were 201, 275, and 275 ft^2 for sugarbeet, dry bean, and barley, respectively.

Analysis of variance was conducted for treatment main effects for selected production factors (sugarbeet root yield, sugarbeet ERS yield, sugarbeet root sucrose concentration, sugarbeet root brei nitrate concentration, barley grain yield, and dry bean yield) using a randomized block design model in Statistix 8.2 (Analytical Software, Tallahassee, FL). For significant (0.05 probability level) main effects, the LSD mean separation method were used to determine treatment differences.

RESULTS AND DISCUSSION

PCC Composition (Tables 2 and 3):

- PCC is a major source of P, a moderate source of K, and a minor source of other nutrients and elements.
- The PCC pH (8.5) was slightly higher than most soils in the study area. The control treatment (no PCC) pH levels ranged from 7.8 to 8.1 across all years.
- The calcium carbonate equivalency (CCE) is the acid neutralizing value of PCC compared to 100% calcium carbonate.

Table 2. Selected constituent contents and characteristics of the PCC used in this study.

CCE (%)	75
pH	8.5
EC (mmhos/cm)	2.5
NO_3-N (mg/kg)	183.8
NH_4-N (mg/kg)	8.5
P (mg/kg)	8114.6
K (mg/kg)	873.7
Cu (mg/kg)	17.2
Na (mg/kg)	1528.1

Table 3. Total cumulative rates of selected constituents applied from the PCC treatments. The cumulative amount of PCC added for the 3A, 10A, and 40T treatments were 12, 40, and 40 tons/acre.

Constituent	lbs/ton	3A	10A	40T
		------------------	Total lbs/acre	------------------
NO_3-N	0.4	4.8	16	16
NH_4-N	0.02	0.24	0.8	0.8
P_2O_5	37	444	1480	1480
K_2O	2.1	25.2	84	84
Cu	0.03	0.36	1.2	1.2
Na	3.1	37.2	124	124

Crop Yield and Quality (Tables 4 and 5):

- The sugar beet production values and the mean separations for the 2018 sugar beet root yields are presented in Table 4. Yield data for dry bean and barley are presented in Table 5.
- The addition of PCC at all rates and timings did not affect crop production compared to no PCC. PCC raised soil pH but not significantly. For all crops, the only statistical differences of PCC effects on yield and production factors was sugar beet root yields in 2018 (Table 4). The significant differences in sugar beet root yields were not easily interpreted according to PCC application rates and timings. Increased root yields in 2018 with PCC could have been the result of increase P concentrations in the soil, but the control treatment soil P levels were sufficient based on soil test recommendations. Also, there were greater differences in soil P between PCC treatments and the control in 2015, with no differences in root yield. It is common in research studies to have significant differences between treatments that are not explained by the treatments.

Table 4. Sugarbeet production factors and analysis of variance (ANOVA) for treatment effects on production factors. Significance was determined at P<0.05. For significant treatment differences, LSD mean separations were performed. Within each production factor, study, and year values with the same letters are not different.

Year	Treatment	Cumulative Lime Applied Prior to Listed Year Sugarbeet Crop (tons/acre)[a]	Root Yield	ERS Yield	Sucrose	Root Nitrate	Root Conductivity
			tons $acre^{-1}$	lbs $acre^{-1}$	%	mg kg^{-1}	mmhos
2015	Control	0	41.2	12522	17.8	140.1	0.70
	3A	3	39.2	11949	17.8	139.4	0.69
	10A	10	39.3	11884	17.7	140.3	0.70
	40T	40	41.0	12447	17.7	135.8	0.68
	Mean		**40.2**	**12201**	**17.8**	**138.9**	**0.69**
			-------------------------	*ANOVA (P value)*	-------------------------		
			0.4359	*0.3007*	*0.9853*	*0.6994*	*0.9694*
2018	Control	0	28.6 b	9550	193	84.0	0.64
	3A	12	32.8 ab	10599	189	90.2	0.75
	10A	40	37.3 a	11744	184	129.3	0.73
	40T	40	31.9 ab	10281	188	78.8	0.71
	Mean		**32.7**	**10544**	**189**	**95.6**	**0.71**
			-------------------------	*ANOVA (P value)*	-------------------------		

	0.0420	*0.0816*	*0.2361*	*0.4563*	*0.2555*

[a]As-Is Root Water Content (approx. 77% water)

Table 6. Dry bean and barley grain yields, and analysis of variance (ANOVA) for treatment effects on crop yields. Significance was determined at P<0.05.

Crop	Year	Treatment	Cumulative Lime Applied Prior to Listed Year Crop	Bean or Grain Yield [a]
			tons acre^{-1}	lbs acre^{-1}
Dry Bean	2016	Control	0	No Yield[b]
		3A	6	No Yield
		10A	20	No Yield
		40T	40	No Yield
Dry Bean	2019	Control	0	3851
		3A	12	3835
		10A	40	3557
		40T	40	3838
		Mean		**3770**
				ANOVA (P value)
				0.3166
Barley	2017	Control	0	5247
		3A	9	4933
		10A	30	4995
		40T	40	4621
		Mean		**4949**
				ANOVA (P value)
				0.3101
Barley	2020	Control	0	7341
		3A	12	7359
		10A	40	7309
		40T	40	7108
		Mean		**7279**
				ANOVA (P value)
				0.9053

[a]Oven Dry Yield
[b]Hail damage

Soil pH (Figure 1):

- Soil pH levels varied based on date of measurement. Base pH levels of the control varied between sample time; all other treatments following the same variation. These temporal variations may be the result of several soil factors such as temperature, soil water, microbial processes, etc.
- The important pH comparisons are between treatments within each sample date. The data shows that before lime applications (Fall 2014), all soils from the study had the same pH. Overtime, the plots with lime application showed a trend for increasing pH. However, the increase in pH was not great. Although the PCC was adding acid neutralizing anions, the amount of these ions in the soil were much greater than the amount added in the PCC. This is analogous to adding a few drops of water to a glass of water, the drops of water do not significantly increase the volume of water in the glass.

- The important take away from Figure 1 is that the increase in soil pH from the PCC is not likely to cause any negative effects associated with soil chemistry that would affect plant growth.

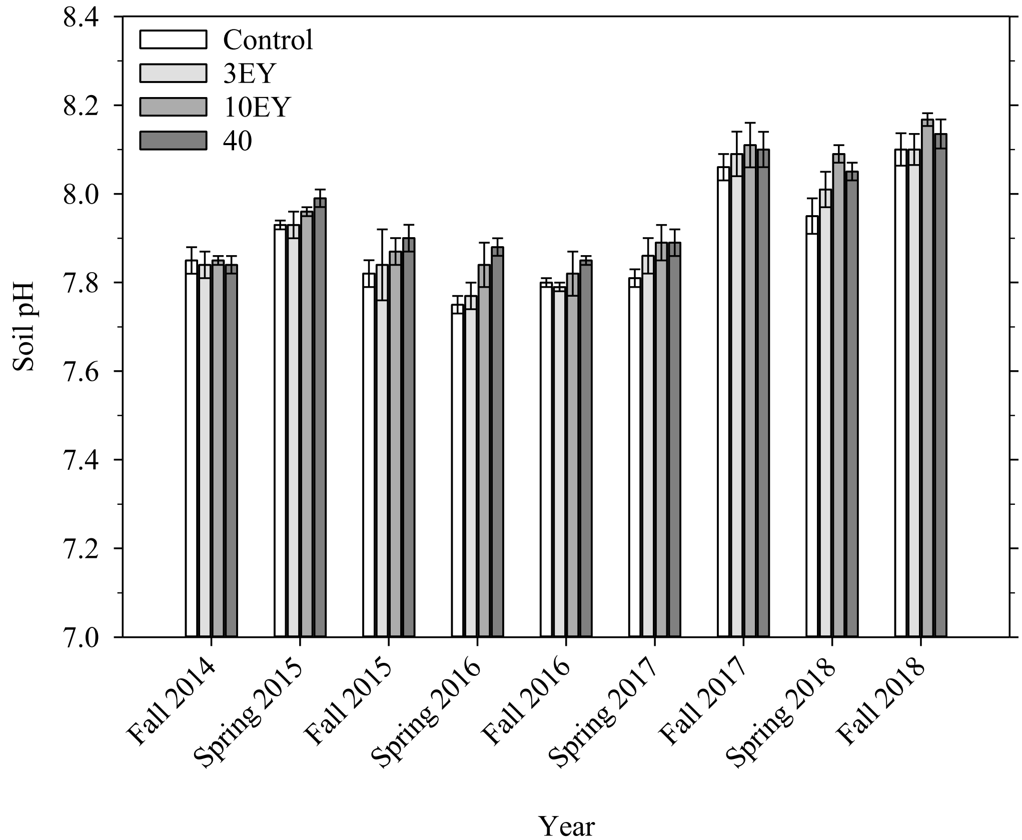

Figure 1. Soil pH for study treatments over time.

CONCLUSIONS

Application of PCC at rates up to 40 tons/acre did not negatively affect crop production in a silt loam soil and serves as a P fertilizer source.

Soil Test P (Figure 2):

- PCC increased plant available soil P.
- PCC has an added P fertilizer value.
- In soils that have high soil P, PCC can potentially increase negative environmental impacts. The extent of the environmental impacts will vary based on management practices that affects the amount of runoff that enters off-site water streams. Practices that reduce runoff will reduce risks.

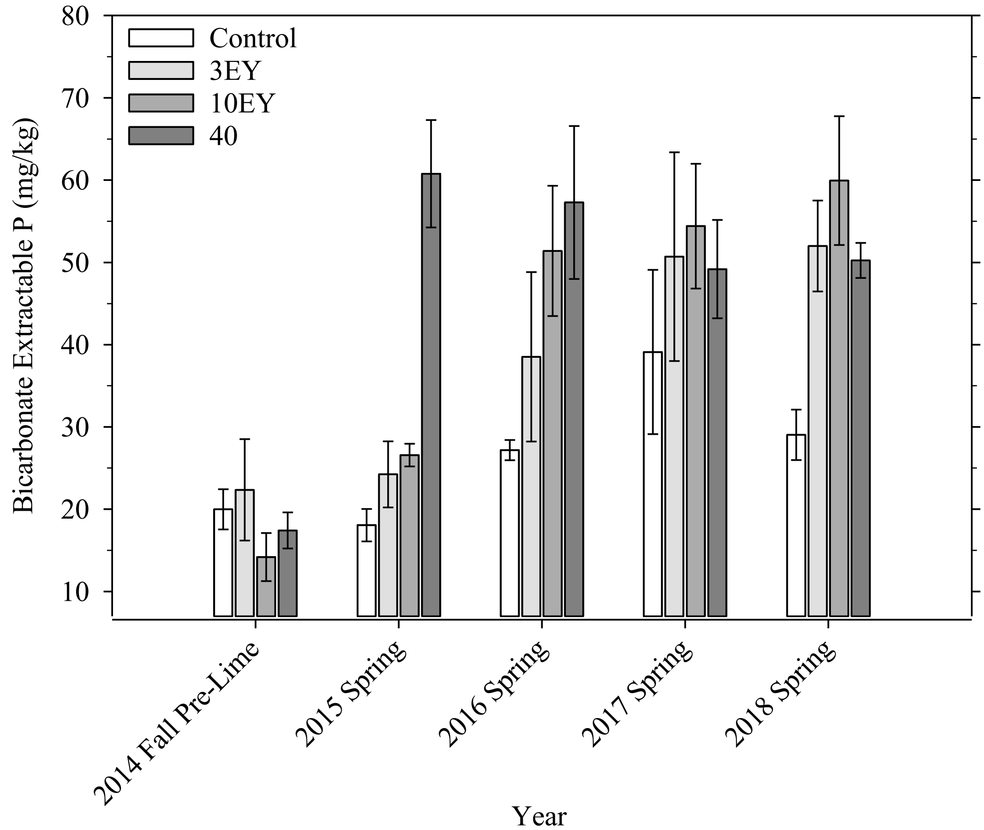

Figure 2. Soil bicarbonate extractable P (Olsen P) for study treatments over time.

REFERENCES

Analytical Software (2003) Statistix 8. Tallahassee, FL.

Havlin, J.L., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 1999. Soil fertility and fertilizers: An introduction to nutrient management. 6th ed. Prentice Hall. Upper Saddle River, N.J.

Mulvaney, R.L. 1996. Nitrogen-inorganic forms. p. 1123-1184. In D.L. Sparks (ed.) Methods of soil analysis: Part 3. SSSA Book Ser. 5. SSSA, Madison, WI.

Olson, R.A., M.B. Rhodes, and A.F. Dreier. 1954. Available phosphorus status of Nebraska soils in relation to series classification, time of sampling and method of measurement. Agron. J. 46:175-180.

Rhoades, J.D. Salinity: Electrical conductivity and total dissolved solids. p. 417–435. D.L. Sparks (ed.) Methods of soil analysis. Part 3. Chemical methods. SSSA Book Ser. 5. SSSA, Madison, WI. 1996.

Wright, J.L. 1982. New evapotranspiration crop coefficients. Journal of Irrigation and Drainage Division, Proceedings of the ASCE 108:57-74.