Agronomic Potential of Using Precipitated Calcium Carbonate on Early Plant Growth and Soil Quality in the Intermountain West - Greenhouse Studies

Gary W. Hergert[1], Murali K. Darapuneni[2], Abdullah M. Aqeel[3], Robert G. Wilson[1], Robert M. Harveson[1], Jeff D. Bradshaw[1] and Rex A. Nielsen[1]

[1]University of Nebraska-Lincoln, Panhandle Research & Extension Center, Scottsbluff, NE 69361. [2]Department of Plant and Environmental Science and Agricultural Science Center-Tucumcari, New Mexico State University, Tucumcari, NM 88401. [3]Adjunct Faculty, Bergen Community College, Paramus, NJ 07652.

Corresponding author: Gary Hergert (ghergert1@unl.edu)

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ABSTRACT

Storage and management of large piles of precipitated calcium carbonate (PCC) from sugarbeet processing are a challenge in the western US. Potential uses of this product on surrounding agricultural lands in western NE, eastern WY and northeast CO requires an evaluation of chemical and agronomic impacts of PCC on soils and crop growth. A preliminary greenhouse study was conducted in Scottsbluff, NE using 10 soils from the 3 states. Soils were mixed with 11, 22, 33 and 44 Mg ha^{-1} rates of PCC to test the early plant growth of sugarbeet, corn, and dry bean in addition to determining soil chemical characteristics. Chemical analysis of PCC from the three processing factories indicates that PCC provides some nitrogen and phosphorus, in addition to some iron, depending on rate. Application of four rates of PCC to neutral to slightly alkali soils neither improved nor negatively impacted the soil chemical characteristics. Dry matter of the three crops after 7 weeks showed no significant effects of PCC. Future utilization of PCC in this region will require further research based on long-term investigations of possible effects of PCC on soil chemical characteristics and plant growth under field conditions.

Additional Key words: spent lime, sugar processing, plant growth, soil chemical properties
Abbreviations: ***PCC= Precipitated Calcium Carbonate***

Precipitated calcium carbonate (PCC) is a by-product of the sugar clarification process when sugarbeet (*Beta vulgaris* L.) is processed. This sugar processing step has been around for many years and has not changed significantly (Dedek, 1952; McGinnis, 1971). Calcium oxide and carbon dioxide are injected into extracted juice and calcium carbonate reforms, precipitating impurities to produce the thin juice from which sugar is extracted. Dutton and Huijbregts (2006) identified removal of impurities including organic molecules plus inorganic forms of phosphorus (P), magnesium (Mg) and calcium (Ca) with limited removal of potassium (K), sodium (Na) and nitrates. Western Sugar factories at Fort Morgan, CO, Scottsbluff, NE and Torrington, WY produce approximately 100,000 tons of PCC per year (Jerry Darnell, Western Sugar Cooperative, personal communication) . Historically, PCC has been stockpiled near the factory site and the amount continues to grow. PCC piles can be a management problem as they grow weeds, produce dust during wind storms, and continue to require additional land for storage (Jerry Darnell, Western Sugar Cooperative, personal communication). This is a concern with current EPA regulations on particulate matter as part of the National Ambient Air Quality Standards (https://www.epa.gov/pm-pollution/table-historical-particulate-matter-pm-national-ambient-air-quality-standards-naaqs).PCC has been effectively used in production agricultural as a liming source replacement for agricultural lime. In the Red River Valley (RRV) and southern MN it has generally had a beneficial effect on growth and yield (Brantner et al., 2015a; Bredehoeft et al., 2013; Giles and Smith, 2005; Windels et al., 2008). It has also been shown to reduce *Aphanomyces* severity (Brantner et al., 2015b; Lien et al., 2015; Windels et al., 2006). Most MN soils near sugar beet factories are neutral to above pH 7 except in northern and eastern MN (Sims, et al., 2010). In MI, PCC significantly increased sugarbeet yield (Clark et al., 2015). A large field study in MI (Christenson, et al., 2000) including sugar beet, soybean (*Glycine max* L.) corn (*Zea mays* L.), field (dry) bean (*Phaseolus vulgaris* L.) and wheat (*Triticum aestivum* L.) showed limited effects of PCC on yield up to 5.6 Mg ha-1. Research in California showed a significant effect of PCC on controlling soil-borne pathogens (Campbell and Greathead, 1989). Similar research on field pea (*Pisum sativum* L.) in ND showed disease reduction from PCC (Chittem et al., 2016). In Great Britain, PCC is classified as a specialty lime with 14% less acid neutralizing capacity than pure lime. It is currently marketed as a liming material in parts of Great Britain (Windels et al., 2008).

Most of the soils in the Western Sugar production area (CO, NE, MT and WY) have pH levels that are neutral to basic and many are calcareous and do not require liming. Considering the large quantity of PCC available in the region and the economics associated with transporting PCC, Western Sugar was interesting in exploring potential local uses of PCC from factory sites. Our question was that since the soils were already high pH or calcareous, would additional PCC cause any production problems or could there be some possible benefits.

A multiphase research project was designed using greenhouse, growth chamber and field plots to evaluate PCC effects on crops and soils. Factors considered were PCC characteristics, soil characteristics, problems that might be associated with high Kochia (*Kochia scoparia* L.) seed levels in PCC, and determining PCC effects on plant growth including dry weight, nutrient deficiencies and vigor. Greenhouse studies were proposed as a first step to determine appropriate rates and protocols for field experiments. This paper will discuss the greenhouse research. The objective of this research was to determine the effect of PCC on early plant growth of sugarbeet (*Beta vulgaris* L.), corn (*Zea mays* L.), and dry bean (*Phaseolus vulgaris* L.) and to test the change in soil characteristics of 10 soils collected from western Nebraska, eastern WY , and northeast CO .

MATERIALS AND METHODS

The PCC used in the study was collected from Western Sugar factories at Scottsbluff, NE, Ft. Morgan, CO, and Torrington, WY. Samples from each location were taken by compositing random core samples from different areas in PCC piles from areas where some PCC is currently being taken for other industrial uses. 12 inch deep samples were taken horizontally into the faces of open areas that were 10 to 15 feet tall and composited. The chemical characteristics of PCC collected at different locations are shown in the Table 1.

Soil samples were collected from 1 acre areas in ten farmer field sites in western NE, eastern WY, and northeast CO, usually

Table 1. Chemical characteristics of Precipitated Calcium Carbonate (PCC) obtained from three sugar factories.

Location	**Moisture**	**CCE**†	**pH**	**Soluble Salts**	**SAR**§	**Total N**	**P**	**K**	**Mg**	**S**	**Zn**	**Fe**	**Mn**	**Cu**
	$g\ kg^{-1}$			$dS\ m^{-1}$										
Scottsbluff, NE	153	72.3	8.8	4.8	0.30	2860	4585	1362	6765	5266	45	6765	7	0.22
Torrington, WY	82	70.1	9.4	8.7	0.34	4630	5176	2270	8444	5766	45	8444	9	0.11
Ft. Morgan, CO	141	69.4	9.6	4.1	0.29	3768	4676	2315	7854	5539	45	7854	10	0.38

† Calcium carbonate equivalency (Mamo et al., 2015).
§ Sodium absorption ratio

Table 2. Chemical characteristics of soils from three western states (0 to 20 cm) used in the greenhouse study.

Location	Soil	CCE†	pH	OM§	Nitrate-N	P	K	Zn	Fe
NE soils		%		%	mg kg^{-1}				
A1	Tripp very fine sandy loam	1.4	7.9	1.3	7.9	10	427	1.2	3.9
A2	Otero-Bayard fine sandy loam	2.0	7.9	1.5	9.1	11	358	1.6	3.5
A3	Mitchell silt loam	1.7	7.8	1.9	22.3	39	755	1.3	2.2
A4	Alliance loam	0.5	6.9	1.8	12.6	34	516	1.8	4.4
WY soils									
B1	Bankard loamy fine sand	5.4	8.1	1.4	16.1	24	325	1.9	7.8
B2	Mitchell silt loam	7.7	7.9	2.3	22.6	17	627	1.5	2.5
B3	Kim clay loam, alkali	3.1	7.8	1.6	21.6	10	407	0.5	2.8
CO soils									
C1	Heldt-Limon assoc.	2.8	7.5	2.8	24.1	130	843	3.8	5.3
C2	Rago and Kuma silt loams	0.4	6.3	2.1	13.7	50	625	2.2	18.3
C3	Weld silt loam	0.8	7.5	2.5	27.2	89	1317	3.3	4.4

† Calcium carbonate equivalency (Mamo et al., 2015).
§OM is soil organic matter.

within a 40 to 50 km radius of a factory site. Eight soil cores from 0 to 20 cm were taken and composited. Soil was analyzed for standard soil test parameters including pH, salinity, organic matter, Olsen P, nitrate-N and DTPA-extractable Zn, Mn, Cu and Fe (Table 2). Analytical methods used were: organic matter (Nelson and Sommers, 1996), nitrate-N (Mulvaney, 1996), water pH (Thomas 1996), Olsen P (Olsen et al. 1954), ammonium acetate-extractable Ca, Mg, K, and Na (Chapman 1965) and DTPA-extractable Zn, Fe, Mn and Cu (Lindsay and Norvell, 1978). For the greenhouse study soils and PCC were mixed using a standard hand cement mixer. The PCC rates were 0, 11, 22, 33 and 44 Mg ha^{-1}. The experiment was designed as a split-split design with 4 replications. Soil type was the main factor with crop and PCC rate as sub-factor and sub-sub factor, respectively. After mixing with PCC, the different soils were filled into 15 cm diameter plastic pots with 3 drain holes. The crops used were sugarbeet, corn, and dry bean. Five seeds were planted per pot and thinned to three plants after emergence. The plants were not supplemented with additional fertilizer due to the short growing period. Soil moisture was maintained by weekly watering as needed to maintain a stress-free environment for 7 weeks. Greenhouse temperature ranged from a low near 20 to 22 °C at night up to 30 to 32°C during the day. The light source was LU250S/HTL/EN (30500 lumens) bulbs. Spectrum characteristics are at http://www.eyehortilux.com/products/htl-hps/PerformanceSpecs/lu250shtlen/66640. Light was on for 16 h per day. Plants were harvested at 7 weeks after planting to measure early growth. All three plants in each pot were harvested and dried in an oven at 80°C for 48 hours to determine dry weight. Soil samples were collected before planting (before and after PCC was applied) and after dry matter harvest to determine changes in chemical characteristics. The soil samples were dried, ground, and analyzed for pH, soluble salts, and selected macro and micro nutrients as above.

Data was analyzed in SAS 9.4 (SAS Institute, Cary, NC) using the Proc GLM procedure. Data was not combined for any of the yield and soil characteristics due to heterogeneity of variance and thus the results for each soil type were reported separately. After the examination of main and interaction effects, a mean separation tests were carried out using Fisher LSD at 0.05 probability level for all analyses.

RESULTS AND DISCUSSION

Chemical analysis of PCC and soils used in the greenhouse

The PCC collected at different locations contained varying amounts of plant essential nutrients, including nitrogen (N), phosphorus (P), sulfur (S) and iron (Fe) (Table 1). On average, each metric ton of PCC contains about 3.8 kg of total N, 4.8 kg of P, 5.5 kg of S, and 1.4 kg of Fe. These nutrients are added to the PCC during the sugar clarification process as small suspended beet tissue (Dutton and Huijbregts, 2006). PCC collected from the three factory sites may have varied due to site-specific variation in the sugar extraction process, differences in grower nutrient management or spatial variability of different parts of the pile due to mixing of PCC over time. PCC piles are often reworked and shaped over time and some PCC is sold and used (Jerry Darnell, Western Sugar Cooperative, personal communication). We took samples from areas where PCC was currently being taken from the pile for other uses. The variability in nutrient content is common with PCC (Sims et al., 2010). The question is whether the rate of mineralization of these nutrients would be sufficient to provide additional nutrients over time. Other research has shown slight increases in soil N and P (Sims et al., 2010) indicating some mineralization to no effect on N or P uptake by plants (Christenson et al., 2000) to slight decreases in Zn and Mn in sugar beet and dry bean and soybean (Christenson et al., 2000).

The calcium carbonate equivalency of the PCC from the three locations ranged between 69 to 72%, meaning that this PCC would be as effective or more than regular agricultural lime (60% ECC) for changing soil pH (Mamo et al, 2015).

Chemical characteristics of the different soils (Table 2) showed that soil texture ranged from sandy loam to clay. The pH ranged from slightly acidic to slightly alkaline and organic matter ranged from 1.3 to 2.8%. The nutrient status of CO soils was higher than western NE and eastern WY soils.

Table 3. ANOVA for main and interaction effects of treatments on dry matter content of sugarbeet, corn, and dry bean tested in the greenhouse analyzed by PROC GLM.

Source of variation	DF	Type III SS	Mean Square	F value	Pr>F
Replication (R)	3	2.3075	0.7692	3.15	0.026
Crop Species (CS)	2	302.1259	151.0629	350.55	<.0001
Error (A) (R*CS)	6	2.5856	0.4309	1.76	0.1079
Soil Type (S)	9	172.3629	19.1514	97.65	<.0001
Error (B) (R*S)	27	5.2956	0.1961	0.8	0.7463
Lime rate (L)	4	6.7731	1.6933	12.68	0.0003
Error (C) (R*L)	12	1.6028	0.1336	0.55	0.8823
CS*S	18	32.4624	1.8035	7.89	<.0001
Error (D) (CS*S*R)	54	12.3455	0.2286	0.94	0.6041
S*L	36	16.0998	0.4472	2.49	0.0002
Error (E) (S*L*R)	108	19.3797	0.1794	0.73	0.9639
CS*L	8	4.6690	0.5836	2.37	0.0490
Error (F) (CS*L*R)	24	5.9168	0.2465	1.01	0.4561
CS*S*L	72	19.8157	0.2752	1.13	0.2564
Error (G) (CS*S*L*R)	216	52.7856	0.2444	—	—
Total	599	656.5279	—	—	—

Dry matter accumulation

Statistical analysis of dry matter accumulation as affected by PCC is summarized in Table 3. The ANOVA considered soil type and lime rate as main effects for each crop species. Appropriate error factors were considered for the calculation of F value and probability level for both main and interaction effects. Because the crop by soil interaction was significant, the analysis was rerun by crop (analysis not shown). Soil type had a significant effect on dry weight of all three crops at $Pr>F <0.0001$. The effect of PCC on dry weight of all three crops was significant at the <0.05 probability level. The soil by PCC rate interaction was also significant for both corn and sugarbeet. Soils significantly interacted with PCC rate because of the varied characteristic pH and calcium carbonate content. Crop species responded differently to various soil types and PCC rate in producing dry matter, which is expected given the different physical and chemical characteristics of the soils and crop species as affected by higher soil lime content (Hoeft and Sorensen, 1969; McLean and Brown, 1984).

Mean separation test results were presented in the Table 4. The mean separation in the dry weight accumulation of dry bean showed little to no statistical significance among different PCC rates for all soil types, which confirms the lack of significance of PCC rate and interaction effects as shown in the ANOVA table (Table 3.) However, as there were significant soil type and PCC rate interactions for corn and sugarbeet, means were compared among four levels (0, 11, 22, 33 and 44 Mg ha^{-1}) of PCC rates by each soil type. Although the effect of PCC rate on dry weight accumulation of both crops for most soils was apparent, the trend was not consistent. In one or two soils, PCC application slightly decreased dry weight accumulation in early growth compared to the control, however the cause is unknown and the effect was not shown for all soils. Mean separation of most other soils indicated that the effect of PCC rate on dry weight was not significantly different from the control. A possible reason for lack of response of dry matter to PCC rate may be the short duration of the study (7 weeks) for significant mineralization to occur. Under normal field conditions, mineralization is a growing season-long process that occurs over 3 to 4 months, depending on the crop. Assessing mineralization is difficult and in spite of numerous attempts over the years, no standardized soil test is in use today to measure it (Stanford, 1982). However, it was evident in almost all soils that there were no significant negative effects of PCC application on early plant growth and dry matter accumulation of the three crop species, even at the maximum application rate.

For different comparisons, there was not a consistent significant increase or decrease in dry matter for the check versus different PCC rates or low versus high PCC rates. The results were encouraging as we interpreted these results to indicate that very high PCC rates could be used. If PCC were to be applied to fields, the highest rates would probably not be above 22 Mg ha^{-1} due to the limitations of current lime spreading equipment.

Table 4. Effect of precipitated calcium carbonate (PCC) mixed with ten different soils on dry weight of sugarbeet, dry bean, and corn at seven weeks after planting in a greenhouse experiment.

Location	Soil	PCC Rate (Mg ha^{-1})				
		0	11	22	33	44
		Average Dry Weight (gm plant^{-1})				
Corn						
Scottsbluff, NE	A1	2.52 ab†	2.33 bc	2.58 ab	1.77 c	3.07 a
	A2	3.24 a	3.24 a	3.05 a	2.92 a	3.38 a
	A3	3.57 a	3.57 a	3.02 ab	2.25 b	3.43 a
	A4	3.25 a	2.57 b	2.58 b	2.22 b	2.53 b
Torrington, WY	B1	2.34 ab	2.21 b	2.88 a	2.88 a	2.74 ab
	B2	2.68 a	2.06 a	2.71 a	2.32 a	2.33 a
	B3	2.21 a	2.14 a	2.40 a	2.55 a	2.52 a
Ft. Morgan, CO	C1	4.62 a	4.14 ab	4.24 ab	3.91 ab	3.58 b
	C2	3.55 a	3.20 ab	2.82 b	3.08 ab	3.23 ab
	C3	2.43 a	2.40 a	2.43 a	2.53 a	2.36 a
Dry bean						
Scottsbluff, NE	A1	1.37 a	1.77 b	1.06 a	1.26 a	1.34 a
	A2	1.95 a	1.74 ab	1.63 ab	1.15 b	2.02 a
	A3	1.82 a	2.27 a	1.76 a	2.05 a	1.71 a
	A4	1.59 a	1.02 b	1.26 ab	1.03 b	1.23 ab
Torrington, WY	B1	1.53 ab	1.86 a	1.98 a	1.40 b	1.88 a
	B2	1.80 a	1.77 a	1.92 a	1.93 a	1.72 a
	B3	1.65 a	1.30 ab	1.07 ab	0.85 b	1.37 ab
Ft. Morgan, CO	C1	3.29 ab	4.39 a	3.30 ab	2.93 b	3.19 ab
	C2	3.84 a	3.58 a	2.76 ab	2.51 b	2.91 a
	C3	2.02 b	2.38 ab	2.60 ab	1.83 b	2.84 a
Sugarbeet						
Scottsbluff, NE	A1	0.83 ab	0.41 c	0.60 c	0.61 c	1.00 a
	A2	0.83 a	0.80 a	0.82 a	0.67 b	0.84 a
	A3	1.61 a	1.65 a	1.20 b	1.61 a	1.55 a
	A4	0.78 a	0.68 ab	0.53 b	0.68 ab	0.62 ab
Torrington, WY	B1	0.61 bc	0.51 c	1.10 a	0.75 b	0.93 ab
	B2	1.15 a	0.63 b	0.78 b	0.76 b	0.87 ab
	B3	1.33 a	0.37 d	0.46 cd	0.93 bc	0.81 bc
Ft. Morgan, CO	C1	2.52 a	1.99 b	2.46 ab	1.75 b	2.31 ab
	C2	1.63 a	1.07 b	1.13 b	1.59 a	1.51 a
	C3	1.22 a	1.63 a	1.54 a	1.49 a	1.52 a

†Numbers with different letters represent statistical significance at 0.05 level (12 plants per treatment).

Note: Mean separation was performed for four PCC rates by soil type

Soil characteristics

The effect of PCC rates on selected chemical characteristics of ten soil types at the end of study are shown in Figs. 1 to 4. Soil pH increased in most samples from before to after the study in all PCC application rates and soil types (Fig 1.). Since repeated analysis of the soils before adding PCC was not done, it was not possible to perform a statistical analysis. Initial soil pH of the 10 sites ranged from 6.3 to 8.1 before PCC and from 7.6 to 8.4 after 7 weeks. There was also a significant increase in most of the soils that did not receive PCC. Drinking water (Scottsbluff municipal supply) from the tap was used to water pots. The water was analyzed after the experiment and found to have pH 7.8, salinity of 0.78 dS m^{-1}, 92 mg l^{-1} Ca and 27 mg l^{-1} Mg.

PCC analysis showed it had about 5.5 kg metric ton^{-1} of sulfur as sulfate (Table 1). Presence of such high proportion of S would contribute to the relative stability in the change of soil pH for higher rates of PCC (data not shown). In addition, the presence of sulfate-sulfur in PCC is a likely reason for the antifungal activity that can influence the control of

Fig 1: Effect of precipitated calcium carbonate (PCC) rates on soil pH of ten soil types before and after seven weeks of plant growth with one of three crop types, dry bean, corn, or sugarbeet, under greenhouse conditions in 2012. Rate effects of PCC on pH are statistically not significant at 0.05 level in all soil types.

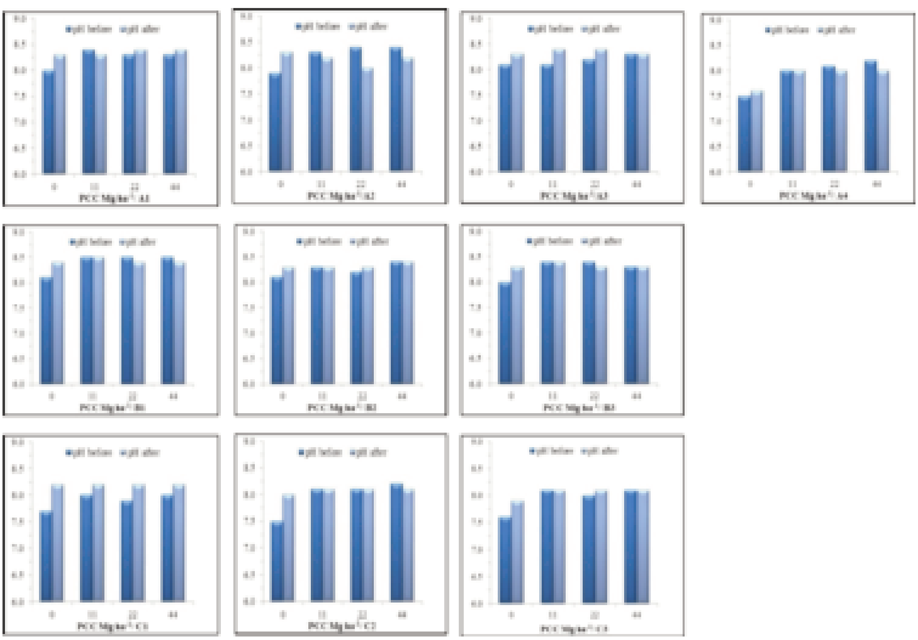
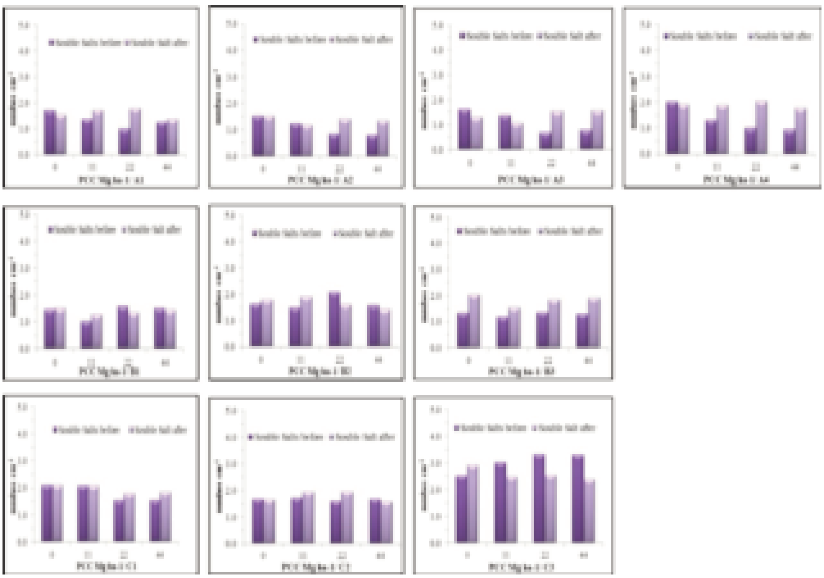


Fig 2. Effect of precipitated calcium carbonate (PCCP rates on soluble salts of ten soil types before and after the study under greenhouse conditions in 2012. Rate effects of PCC soluble salts are statistically not significant at 0.05 probability level in all soil types.

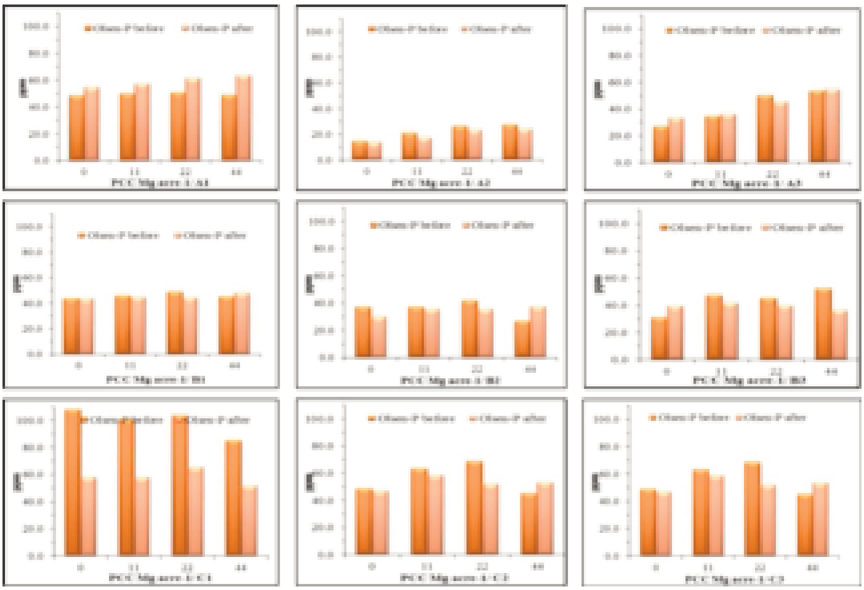


root rot fungi in sugarbeet as indicated by Campbell and Greathead (1989) and Windels et al. (2008).

Salinity (Fig. 2) of the 0 PCC rate plots increased from an average of 1.27 dS m^{-1} to 1.82 dS m^{-1} during the greenhouse study. With the high evaporative demand and hot temperatures in the greenhouse during this study, we hypothesize that there was sufficient drying to provide some salt and lime accumulation from the tap water which may have affected the pH of the check samples. In retrospect, distilled water should have been used. Change in soil pH among different PCC rates (excluding the check) was not significant. The average salinity level of all the PCC rates averaged over soil type (excluding the check) was 1.76 dS m^{-1} which was not much different than the check.

In most of the soils, an increase in Olsen-P was observed for all PCC rates compared to the control (Fig. 3), except for soil C1. The increased Olsen-P was attributed to addition of P from PCC. However, there was no particular trend of Olsen-P among different PCC rates. As the rate of PCC increased from 11 to 44 Mg ha^{-1}, the Olsen-P content was increased in the Scottsbluff soils. However, this trend was not apparent in the Wyoming and Colorado soils. In most of the Colorado soils with soil pH around 7.5, a higher rate of PCC application (44 Mg ha^{-1}) decreased Olsen-P content. The possible reason for the decreased trend of P can be

Fig 3. Effect of precipitated calcium carbonate (PCC) rates on soil Olsen-P of ten soil types before and after the study under greenhouse conditions in 2012. Rate effects of PCC on Olsen-P are statistically not significant at 0.05 probability level in all soil types, except C1.



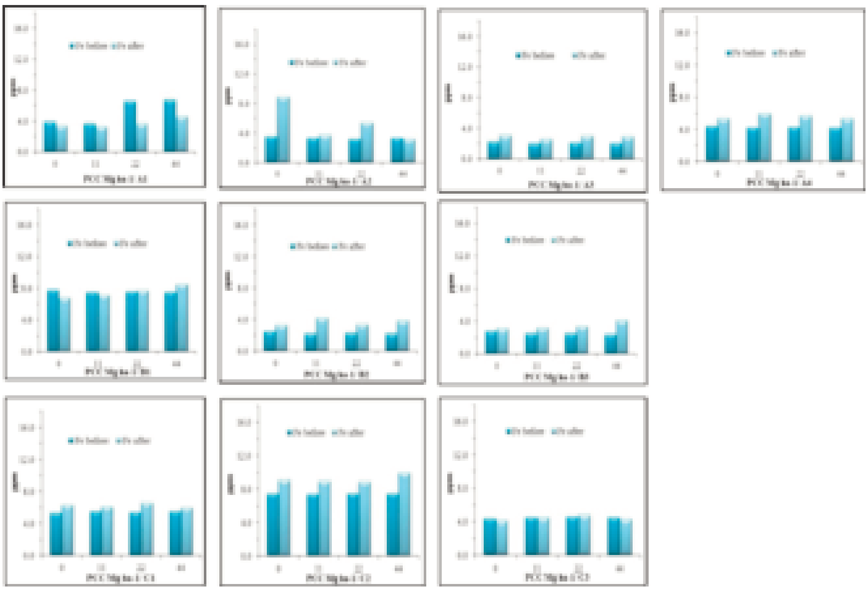
explained by potential fixation of P. P fixation generally peaks around pH 8 to 8.5 (Lindsay, W. L. 1979). which was also a possible factor for the decrease in P content with increase in the PCC rate.

The effect of PCC rate on Fe content is shown in Fig. 4. PCC did not significantly affect the DTPA-Fe level. Before the experiment, the average of the 10 soils was 5.5 mg kg^{-1} and it was 5.6 mg kg^{-1} after the experiment (Fig. 3). This was considered to be a positive result as higher lime and pH can often lead to lower Fe levels. With a few exceptions, the PCC effect on DTPA-Zn was inconsistent in different soil types (data not shown). Overall, the response of different PCC application rates in improving the plant nutrient availability depended on the soil type and soil test level at the time of PCC application.

CONCLUSIONS

Using PCC on grower fields should be a win-win proposition. The greenhouse studies provided sufficient information to test the agronomic potential for further research in field plots. We concluded from the greenhouse study that application of PCC did not significantly change soil chemical characteristics. Dry matter accumulation of sugarbeet, corn,

Fig 4. Effect of precipitated calcium carbonate (PCC) rates on soil Fe of ten soil types before and after the study under greenhouse conditions in 2012. Rate effects of PCC on Fe are statistically not significant at 0.05 probability level in all soil types.



and dry bean was not significantly increased or decreased in most of the soils. Part of the reason for the non-responsiveness may be lack of enough time for PCC mineralization to occur to enhance the soil chemical characteristics. Some of the effect may have been the tap water used to water pots. In order to recommend the agronomic utilization of PCC material in neutral to alkali soils, long term effects on plant growth and soil characteristics need to be examined under field conditions. In addition to that, future evaluation of PCC for the control of diseases and pests would also justify the cause of PCC application for potential agronomic and yield benefits.

Based on the results of greenhouse studies, it is evident that application of up to 44 Mg ha^{-1} PCC did not benefit nor harm the plant yield and soil characteristics. Applying agricultural lime or PCC above rates of 10 to 15 Mg ha^{-1} would be difficult and expensive. Based on this data and other reports (Brantner et al., 2015; Bredehoeft et al., 2013; Christenson et al., 2000; Giles and Smith, 2005; Sims et al., 2010; Windels et al., 2008), we concluded that rates for future field studies should be less than 25 to 30 Mg ha$^{-1.}$ Moreover, optimization of PCC application rate would help producers reduce application costs and possibly increase the overall profitability.

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