Evaluation of Agricultural Lime and Pelleted Lime to Increase Soil pH and Crop Yield

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ABSTRACT

Agricultural lime (aglime) is applied to increase pH of acidic soils to values optimum for crop production, and its effectiveness is affected mainly by it calcium carbonate ($CaCO_3$) equivalent (CCE) and fineness. Availability and use of pelletized limestone has increased in recent years, but there is limited information about its effectiveness. Six field trials were established in 2014 at acidic Iowa soils (pH 4.9-6.1) with contrasting texture and organic matter. Treatments replicated three times were commercially available finely ground $CaCO_3$, calcitic aglime, and pelleted lime. All treatments were incorporated into the soil after broadcast application in October 2014. Corn was planted in 2015 and soybean was planted in 2016. Application rates for each source were 0, 1, 2, 4, and 8 ton CCE/acre. Expressing rates as effective CCE (ECCE) based on fineness efficiency factors used in Iowa change little values for pelleted lime but for aglime became 0.61, 1.23, 2.46, and 4.92 ton ECCE/acre. Soil pH increases measured 4.5, 8, 12, 14, 17, and 23 months after liming were statistically similar for $CaCO_3$ and pelleted lime for all sites and application rates. These two sources increased pH faster and to higher maxima than aglime when equivalent ECCE rates were used. All sources and rates reached a maximum pH 12 months after the application, which were 6.1, 6.4, 6.8, and 7.0 with the four $CaCO_3$ and pelleted lime rates and 5.9, 6.0, 6.4, and 6.7 with the aglime rates. The pH began decreasing immediately for the lower two rates of all sources, but not until the 17-month sampling date for the two higher rates. The three lime sources did not differ at increasing crop yield at any site. Corn yield responded at three sites and the 2-ton CCE rate produced the statistically maximum yield. Soybean yield responded at four sites, and the 1-ton CCE rate produced the maximum yield. We concluded that pelleted lime was as effective as powdered $CaCO_3$ at increasing soil pH and that the fineness efficiency factors used in Iowa overestimated the neutralizing power of aglime, although this overestimation was of no consequence for crop yield given the application rates used and conditions of the study.

INTRODUCTION

The effectiveness of a liming material for neutralizing soil acidity is affected by the material fineness, chemical composition, and mineralogy. Calcium carbonate equivalent (CCE) is defined as the acid-neutralizing capacity of a liming material expressed as a percentage of pure and finely ground calcium carbonate ($CaCO_3$). Agricultural limestone (aglime) includes a wide range of particle sizes. The particle size distribution of a liming material influences the dissolution rate and its effectiveness in neutralizing soil acidity. Smaller particles and increased surface area allow aglime to react with a larger soil volume and be more reactive with soil. There is no widely accepted method for estimating the efficiency of aglime particle sizes. In most states of the North Central Region, aglime is sieved through three or four more screens with Tyler mesh sizes ranging from 4 through 60. The State of Iowa requires that the fineness and efficiency of any liming material sold should be determined by a specific procedure called effective CCE (ECCE) (IDALS, 2008). A wet sieving method measures the percentage of material that passes Tyler mesh sizes 4, 8, and 60, and the percentage of the material that passes each mesh size is multiplied by efficiency factors 0.1, 0.3, and 0.6, respectively. The sum of the resulting numbers are multiplied by the CCE of the material to establish its ECCE. Previous Iowa research has evaluated the efficacy of aglime at increasing crop yield and soil pH in acidic soils (Bianchini and Mallarino, 2002; Kassel, 2008; Holmes et al., 2011; Pagani and Mallarino, 2012; Pagani and Mallarino, 2015).

Pelleted lime is a relatively recent available liming material designed to facilitate application, and typically is ground limestone that is granulated using a binding agent. The most commonly used binding agent has been lignosulfonate, although other binding agents have been used (Murdock, 1997; Veverka and Hinkle, 2001). Scarce research has provided contrastingly different estimates of the efficiency of pelleted lime at increasing soil pH compared with aglime. Incubation or field research during the 1980s and 1990s summarized in brief extension or conference proceedings articles (Kelling and Schulte, 1988a, 1988b; Murdock, 1997; Warncke and Pierce, 1997) showed that pelleted lime and aglime did not differ at increasing soil pH or crop yield. More recently, Godsey et al. (2007) compared several rates and frequencies of application of aglime and pelleted lime at two sites managed with grain crops and no-tillage, and reported no yield or pH increase differences between sources. Lentz et al. (2010) evaluated aglime and pelleted lime in one site for one year by applying three rates of effective neutralizing power (1.3, 2.5, and 5 ton/acre) in spring before planting corn. They found that with the lowest rate only aglime increased yield, that there were no source differences with the higher two rates, and that all aglime rates increased pH more rapidly and to a higher value than the pelleted lime did. Lollato et al. (2013) evaluated broadcast incorporated aglime at 1 or 2 ton/acre and pelletized aglime banded to the seed furrow at 200 or 400 lb/acre/year of effective $CaCO_3$ for continuous wheat. The liming did not affect grain yield, both rates of broadcast aglime greatly increased soil pH but only the highest rate of pelleted lime increased it slightly, which should be expected given the lower amounts applied with pelleted lime. A recent incubation study using three Iowa soils by Jones and Mallarino (2016) showed that the efficiency of commercially available pelleted lime at increasing soil pH relative to pure$CaCO_3$ was 60-90% for incubation times of 7 to 210 days, whereas efficiency of calcitic aglime and dolomitic aglime was 47-65% and 12-47%, respectively.

The availability of pelleted lime to producers in Iowa and the north-central region has increased in recent years. The available literature related to pelleted lime use is scarce and has shown variable results. Iowa and several other states of the region have no guidelines for pelleted lime use. Therefore, the objective of this study was to evaluate the effectiveness of pelleted lime at increasing soil pH and crop yield by comparing it with aglime and $CaCO_3$ under field conditions.

SUMMARY OF PROCEDURES

Six two-year trials were established on acidic Iowa soils, with corn in 2015 and soybean in 2016. Table 1 provides information about locations, soil classifications, and selected initial soil properties. The trials were in central (Sites 1 and 2), southwest (Site 3), southeast (site 4, and 5) northwest (Site 6) Iowa. Soil samples (6-inch depth) were collected before applying lime treatments and were analyzed for pH and other properties (Table 1). Soil pH (1:1 soil:water ratio) and buffer pH (Sikora method) were measured as suggested by the NCERA-13 committee (Peters et al., 2012). Extractable cations were measured with the ammonium-acetate method. The soil cation exchange capacity (CEC) was estimated as suggested by the NCERA-13 committee (Warncke and Brown, 1998).

Treatments replicated three times were the factorial combinations of three lime sources and five application rates arranged in a completely randomized design. Table 2 summarizes characteristics of the lime sources used. The liming sources were commercially available finely ground CaCO3, pelleted lime, and calcitic aglime. The pelleted lime used (Calcium Products 98G pelletized limestone) is made from mined ground calcitic limestone from quarries near Gilmore City and Fort Dodge, Iowa. The pellets are created by pan agglomeration using finely ground limestone (99% passing mesh 60, 90% passing mesh 100, and 75% passing mesh 200) and calcium lignosulfonate as the binding agent (Dr. Andrew Hoiberg, Calcium Products, Ames, Iowa; personal communication). The measured granule diameter ranged from 0.08 to 0.16 inches. The chemical analysis and wet sieving methods required in Iowa (IDALS, 2008) were used to determine calcium carbonate equivalent (CCE) and effective CCE (ECCE). The lime sources application rates were 0, 1, 2, 4, and 8 ton CCE/acre. The rates were based on CCE because there are no widely accepted standards across the US to consider particle size for limestone application but the same CCE determination method is generally used. The corresponding ECCE application rates were 0.99, 1.99, 3.98, and 7.96 ton/acre for CaCO3; 0.98, 1.97, 3.93, and 7.87 ton/acre for pelleted lime, and 0.61, 1.23, 2.46, and 4.92 ton/acre for aglime. Plot size was 7.5 by 15 feet.

The treatments were spread to the soil surface in October 2014, and were incorporated into the soil in November after light rain occurred in all sites with a disk harrow that mixed the materials to a depth of about 4 inches. Table 3 provides information about application dates, management, and post-liming sampling dates during the first few months of the trials. All plots were disked again before planting corn. Non-limiting rates of N, P, and K were applied across all plots in spring 2015 after the March soil sampling date and before planting corn. Soybean was no-till planted in spring 2016. After liming, soil samples (6-inch depth) were collected from each plot for pH analysis six times from March 2015 until after soybean harvest in fall 2016 (a period of 23 months). Management practices such as hybrids or varieties, plant population, row spacing, and weed and pest control were among those recommended for each region. Grain was hand-harvested from the two central rows of each plot and grain yield was expressed based on 15 and 13 % moisture for corn and soybean, respectively.

RESULTS AND DISCUSSION

Crop Grain Yield

In the first year, liming increased corn grain yield significantly ($P \leq 0.10$) at Sites 4, 5, and 6, and there were small statistically nonsignificant responsive trends at the other three sites. In the second year, liming applied before the previous year corn crop increased soybean grain yield significantly ($P \leq 0.10$) at Sites 2, 4, 5, and 6, and there were small statistically nonsignificant responsive trends at the other two sites. There were no statistically significant differences between the lime sources at any site in any year and no significant interaction of source and application rate either. Analyses of variance across the responsive sites of each year showed no statistically significant interactions site by lime source or rate.

Table 4 shows yield means across the three corn responsive sites and the four soybean responsive sites. In the first year, corn grain yield was maximized by the 2 ton CCE/acre application rate for all sources in all responsive sites. The average yield increase by the 1-ton rate was 12 bu/acre and the additional increase by the 2-ton rate was 7 bu/acre. The average nonsignificant additional increase by the 4-ton rate was 3.3 bu/acre. In the second year, soybean grain yield was maximized by the 1 ton CCE/acre application rate for all sources in all responsive sites. The yield increase by the 1-ton rate was 7 bu/acre (the nonsignificant additional increase by the 2-ton rate was only 1.3 bu/acre). Figure 1 depicts the grain yield data in Table 1 by expressing the application rates in ECCE units, and further demonstrates a lack of differences among the lime sources.

Moderate to large yield increases were expected at all sites because the initial pH was below the pH considered sufficient for corn and soybean in Iowa (Mallarino et al., 2013). A pH of 6.0 is considered sufficient in soil association areas with calcareous subsoil (Sites 1, 2, 4, and 6) and pH 6.5 is considered sufficient for associations with no calcareous subsoil (Sites 3, 5). However, previous research in Iowa has shown variable and often very low yield increases from aglime application mainly in soils with calcareous subsoil (Bianchini and Mallarino, 2002; Henning, 2006, 2007, and 2008; Pagani and Mallarino, 2012, 2015).

Lime Application Effects on Soil pH

The pH increases due to lime application were different at each site depending mainly on initial soil pH, soil properties, buffer pH, and precipitation following liming. However, there were only minor dissimilarities among soils concerning the relative soil pH differences between the lime sources and application rates. Therefore, this report shows and discusses averages across all the six sites.

Figure 2 shows the effects of three lime sources and four application rates on soil pH over time. The $CaCO_3$ and pelleted lime had approximately similar effects on soil pH. The largest pH increase was observed 4.5 months after these materials were applied (first sampling date) for all rates except for the lowest one, for which there were variable increases until the 12-month sampling date. The highest two rates of $CaCO_3$ and pelleted lime effected the maximum pH 4.5 months after the application and it remained approximately constant until the 17-month sampling date, but for the lower two rates the maximum pH was reached 12 months after the application. For aglime, the maximum pH was reached 12 months after the application for all rates. For the two highest rates the highest increase was observed 4.5 after the lime application but for the lower rates there were variable increases until the 12-month sampling date. After the 12-month sampling date, the pH remained at a high plateau until 17 months after application for the highest application rate of all three sources but began to decrease for the lower rates. The pH decreased faster over time with the lower application rates, but there were no clear differences between sources for the magnitude of decreases over time.

Previous field research with calcitic or dolomitic aglime in Iowa showed that for most sites maximum pH was reached between 3 and 12 months after the application, and that it took longer for the dolomitic aglime to reach a maximum pH (Pagani and Mallarino, 2012, 2015). In the incubation study conducted by Jones and Mallarino (2016), a similar pelleted lime source increased soil pH faster and to a higher maximum the calcitic aglime or dolomitic aglime.

Figure 3 summarizes the soil pH responses to the three lime sources with the application rates expressed as ECCE for the earliest sampling date (4.5 months after application) and the 12-month sampling date, when maximum pH was reached with all sources and rates. It is known that aglime has lower efficiency at increasing soil pH than pure $CaCO_3$. Lime materials' analyses in Table 2 show that the aglime ECCE was much lower (56.2%) than for $CaCO_3$ and pelleted lime (92 and

88.9%, respectively) and, therefore, the aglime ECCE application rates were almost one-half lower than for the other two sources. The $CaCO_3$ and pelleted lime did not differ at increasing pH at either sampling time. Aglime reacted slower, effected smaller pH increases, and the maximum effected pH was lower than for the other two sources even with the highest application rate. As expected, however, the difference between aglime and the other two sources was smaller for the latest sampling date.

The results in Fig. 2 demonstrate that the ECCE measurement method overestimated by a large margin the acid neutralizing capacity of aglime for the early sampling date (4.5 months after application), which should be expected. However, the ECCE method still slightly overestimated the aglime neutralizing capacity for the 12-month date. Aglime effected the maximum pH by the 12-month sampling date and the pH decreased thereafter for all application rates, which indicates that the length of the study was sufficient to assess its maximum effect on soil pH. An overestimation of aglime efficiency for the early sampling date should be expected, is not of much consequence for production agriculture, and had no effect on the crop yield response in any year of the study. However, the overestimation shown for reaching the maximum pH is relevant. The Iowa field research by Pagani and Mallarino (2012) and the incubation study by Jones and Mallarino (2016) also showed this overestimation of aglime efficiency by the current ECCE method used in Iowa, and that it was less accurate for dolomitic aglime than for calcitic aglime.

CONCLUSIONS

Pelleted lime and finally ground $CaCO_3$ increased pH similarly, and faster than aglime did for equivalent effective CCE rates as determined in Iowa. The finely ground limestone used to manufacture the commercially available pelleted lime that we used in the study may explain its better performance than in some of previous studies conducted in the north-central region. The method used to estimate effective CCE correctly measured the acid neutralizing capacity of pelleted lime but overestimated the efficiency of aglime. In spite of lower early pH increases and lower maximum pH by the aglime, the lime sources were similar at increasing crop yield in the two years of the study.

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Table 1. Locations, soils, and soil-test results before treatment application

Site	County	Soil Series‡	pH	BpH	K	Ca	Mg	Na	CEC	OM
			Soil-Test Results†							
					------------ ppm -----------				meq/100g	%
1	Boone	Nicollet L	5.5	6.4	130	2165	291	15	21	3.2
2	Story	Clarion L	4.9	6.2	161	888	179	21	16	2.5
3	Muscatine	Fruitfield S	6.1	7.0	112	541	86	15	3	1.2
4	O'Brien	Galva SiCL	5.3	6.0	198	2684	518	25	31	5.0
5	Washington	Mahaska SiL	5.6	6.4	207	2512	429	19	23	4.9
6	Pottawattamie	Marshall SiL	5.1	6.0	220	1822	337	19	25	4.1

† 6-inch depth; BpH, buffer pH; CEC, estimated cation exchange capacity; OM, organic matter.
‡ L, loam; S, sand; SiL, silt loam; SiCL, silty clay loam.

Table 2. Characteristics of the lime materials used in the six field trials.

Lime Source	Moisture	CCE†	ECCE ‡	Ca	Mg	Passing Screen Sizes 4	8	60
	-------------------------------- % --------------------------------							
$CaCO_3$	0.07	92.5	92.0	37.1	0.1	100	100	100
Aglime	6.50	91.4	56.2	36.8	0.2	100	99	37
Pelleted	0.45	90.1	88.6	36.8	0.2	100	100	97

† CCE, calcium carbonate equivalent.
‡ ECCE, effective CCE on a dry basis estimated as required by the State of Iowa. Assumed efficiency for material passing each screen is 0.1, 0.3, and 0.6 for mesh 4, 8, and 60, respectively.

Table 3. Information about treatment application, corn planting, N fertilization, and the first two post-liming soil sampling dates.

	2014		Spring 2015				
	Lime Application		N Fertilization†		Planting	Sampling Date	
Site	Application	Incorporation‡	Date	lb N/a	Date	1st	2nd
1	27-Oct	7-Nov	12-May	195	12-May	17-Mar	3-Jun
2	23-Oct	7-Nov	12-May	195	13-May	17-Mar	3-Jun
3	24-Oct	3-Nov	13-May	210	28-Apr	19-Mar	10-Jun
4	16-Oct	22-Oct	5-May	150	29-Apr	18-Mar	8-Jun
5	6-Oct	22-Oct	23-Apr	200	19-May	19-Mar	10-Jun
6	8-Oct	22-Oct	16-Mar	164	1-May	16-Mar	5-Jun

† Urea ammonium-nitrate solution.

Table 4. Average grain yield across the corn (three) and soybean (four) responsive sites.

Year	Crop	CCE Rate †	Aglime	$CaCO_3$	Pelleted Lime
		ton/acre	------------------- bu/acre	----------------------	
1	Corn	0	206a	206a	206a
		1	218b	217b	219b
		2	223c	226c	226c
		4	227c	230c	228c
		8	228c	229c	229c
2	Soybean	0	59.4a	59.4a	59.4a
		1	65.6b	65.6b	66.4b
		2	67.0b	67.6b	66.5b
		4	67.2b	66.6b	66.3b
		8	66.5b	66.8b	66.5b

† CCE, calcium carbonate equivalent. The corresponding effective CCE (ECCE) rates were 0.99, 1.99, 3.98, and 7.96 ton/acre for $CaCO_3$; 0.98, 1.97, 3.93, and 7.87 ton/acre for pelleted lime, and 0.61, 1.23, 2.46, and 4.92 ton/acre for aglime.

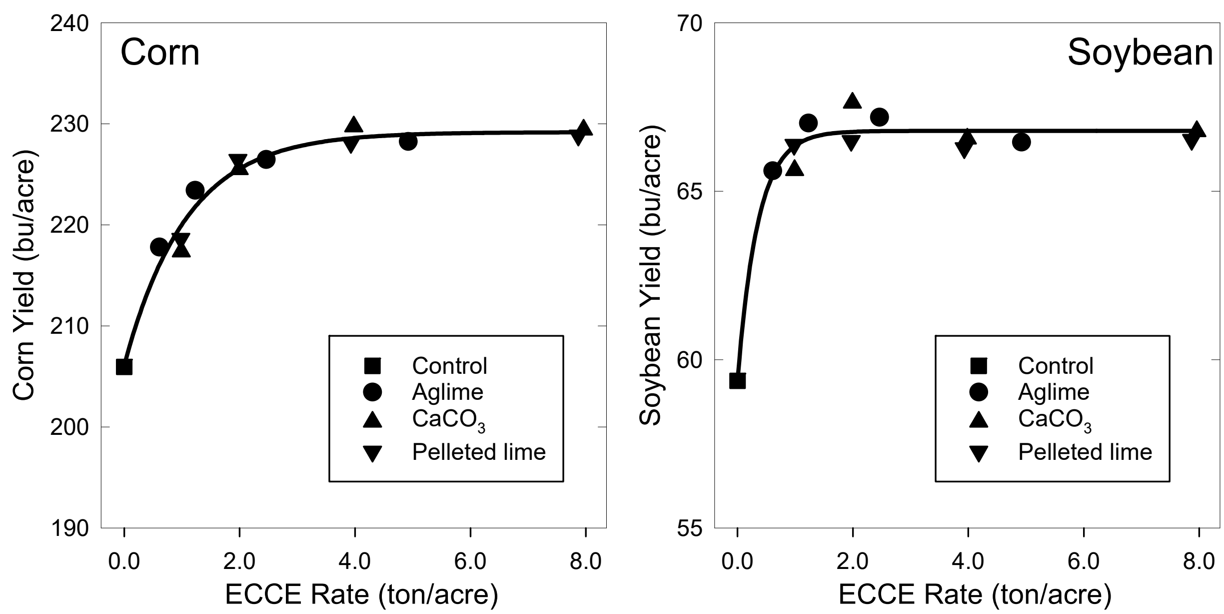

Fig. 1. Effect of lime sources and application rates on crop grain yield. Averages across three corn responsive sites (2015) and four soybean responsive sites (2016).

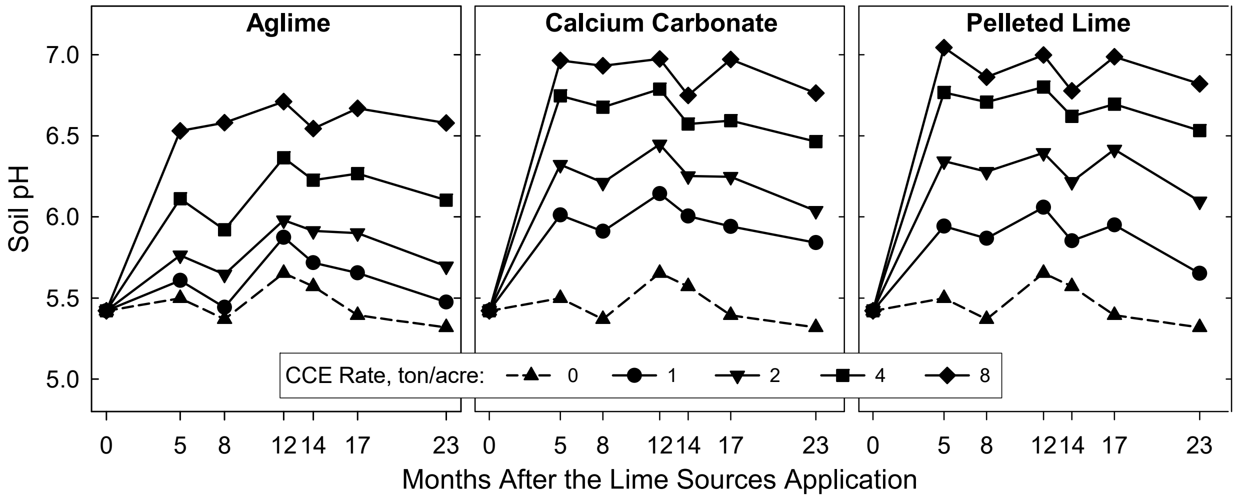

Fig. 2. Effect of lime sources and application rates on soil pH over a 23-month period.

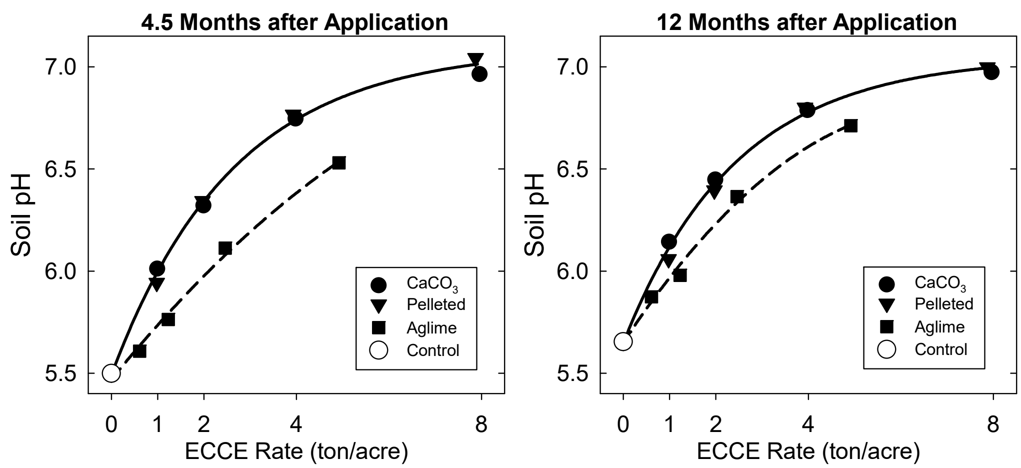

Fig. 3. Effect of lime sources with rates expressed as effective CCE (ECCE) per acre on soil pH for the first spring soil sampling dates and 12 months after application when maximum pH was reached.