

Liming research update and application strategies with low crop prices

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Introduction

Strong soil acidity considerably limits crop yield and the profitability of crop production. Causes of soil acidification in the very long term (dozens or hundreds of years) are cations natural leaching and acid rain (mainly with high atmospheric pollution). In the short term (months or a few years) the most important causes of soil acidification are application of ammonium-based or ammonium-forming fertilizers, some sulfur fertilizers (but not gypsum), and some manures (mainly swine manure because of its high ammonium content). Therefore, periodical soil analysis to monitor soil pH is essential to maintain high crop yield and the profitability of crop production. When crop prices are low, however, lime is one of the first inputs for which farmers reduce application rates or postpone application.

Optimal soil pH for corn and soybean

Soil pH is and should be used to determine whether a soil is too acidic and requires liming but does not indicate the quantity of soil reserve acidity that needs to be neutralized and the amount of lime to apply. In Iowa and most states, the amount of lime needed to increase soil pH to a desirable level is estimated by mixing a strong buffer solution of known pH with soil and measuring the resulting pH change. Low buffer-pH values indicate high reserve acidity and higher lime requirement, and research with different soils and pH values are used to determine the lime required to raise pH to a certain value. Alfalfa is the most sensitive to low pH of the crops grown in Iowa, whereas forage grasses are the least sensitive and both corn and soybean are intermediate. Iowa State University (ISU) recommended optimal soil pH are listed in Extension Publication PM 1688 (Mallarino et al., 2013). For corn and soybean, the recommended optimal pH is 6.5 for most soil association areas and pH 6.0 for soil association areas with predominance of soils with high-pH calcareous, subsoil (mainly western Iowa and the Des Moines Lobe in north central Iowa). Extensive previous Iowa research has evaluated the efficacy of aglime at increasing crop yield and soil pH (Voss, 1991; Bianchini and Mallarino, 2002; Henning, 2004a; Henning, 2004b; Henning, 2006, 2007, 2008; Henning, 2001, 2004, 2008, 2009; Kassel, 2004; Kassel, 2008; Holmes et al., 2011). In spite of this research, however, many farmers have expressed doubts about ISU recommendations in place since the 1970s. Therefore, several research projects were developed since 2007 to investigate lime application effects on soil pH and yield of corn and soybean.

A large on-farm study was conducted from 2007 to 2012 in 14 Iowa fields. Four-year replicated strip trials were established in 2007, 2008, or 2009 using global positioning systems (GPS), dense grid soil sampling (0.3 to 0.58-acre cells), yield monitors, and geographical information systems (GIS). Most fields were managed with corn-soybean rotations, but a few farmers planted two consecutive years of corn. The trials were in Boone, Cedar, Crawford, Greene, Jasper, O'Brien, Pottawattamie, Ringgold, Story, and Union counties. Nine fields were managed with chisel-plow/disk tillage, four with no-till, and one with strip-till. One-time initial treatments for all trials were an unlimed control and one aglime rate. The aglime used came from different quarries, had varied concentrations of carbonate equivalent (CCE), and the effective CCE (ECCE) rate applied was 3 ton/acre for all fields an year. The limestone was analyzed following the method required in Iowa the Department of Agriculture and Land Stewardship (IDALS, 2008) for the sale of liming materials. Preliminary results were summarized at the 2011 conference (Mallarino et al., 2011),

and the complete results were used to update ISU recommendations in 2013 (Mallarino et al., 2013) and were published in a journal article (Pagani and Mallarino, 2015).

Figure 1 shows unlimed and limed soil pH (6-inch depth) of the strips entire length for each year on average across the 14 sites. These averages represent well results observed in most trials. The initial soil pH across fields was 5.04 to 6.47. The pH of unlimed soil varied over time, which is common due to effects of rainfall and N fertilization for corn, but the changes were small compared with the large pH increase due to liming. The pH of unlimed and limed treatments followed approximately the same trend over time. Compared with the initial or unlimed soil pH, the lime effect was the highest in the second year and decreased afterwards. This happened in most fields, and only in very few fields the highest pH increase was observed one or three years after lime application. The pH of limed soil often decreased in the third year and except for two fields decreased significantly in the fourth year after the application.

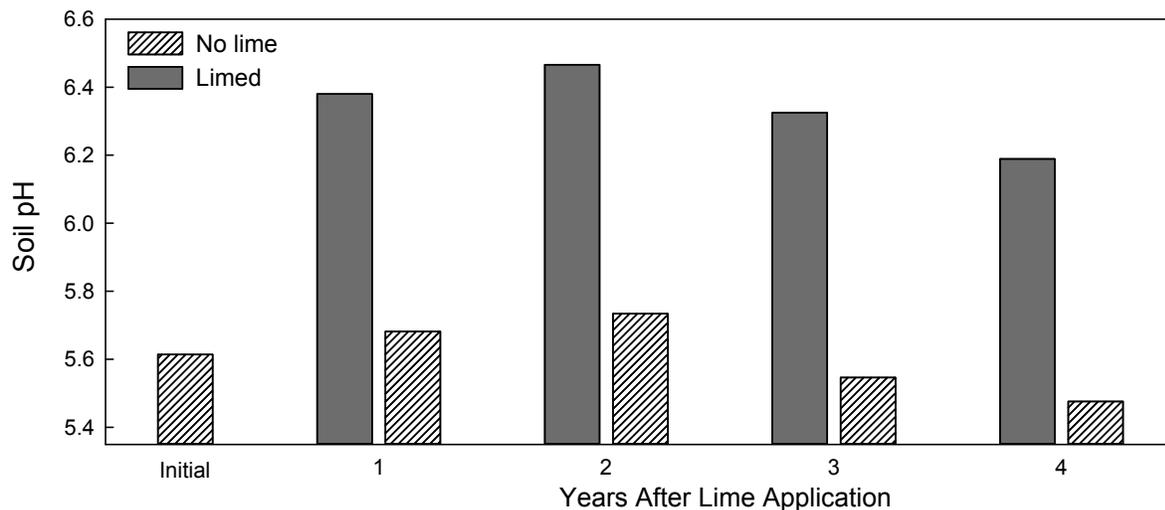


Figure 1. Initial and post-harvest soil pH (6-inch depth) for each year of four-year replicated on-farm strip trials in which treatments were no lime and a one-time application of 3 ton ECCE/acre (averages across 14 trials).

Graphs in Figure 2 summarize the relationship between the relative grain yield response from lime application for different soil pH ranges across all site-years. Results for corn showed a clear decreasing trend from the lowest to the highest pH range. The very small yield increase with pH 6.5-6.9 was not statistically different from zero yield increase but there was a significant decrease with pH ≥ 7.0 . For soybean, the largest yield increase was with pH < 5.0 and increases were lower and variable with pH 5.0-6.4. An apparent yield increase with pH 6.5-6.9 and an apparent yield decrease with pH ≥ 7.0 were not statically different from zero. Comparisons of the responses to lime by corn and soybean across all sites and years indicated no statistically significant differences between crops. Therefore, average results across both crops represent better the observed results because reduce the impact of random variability. On average across both crops, the yield response was the largest with pH < 5.0 , was lower and statistically similar for the pH ranges 5.0-5.4 and 5.5-5.9, was lower with pH 6.0-6.4, and was even lower and not different from zero with pH 6.5-6.9. However, there was a yield decrease with pH ≥ 7.0 .

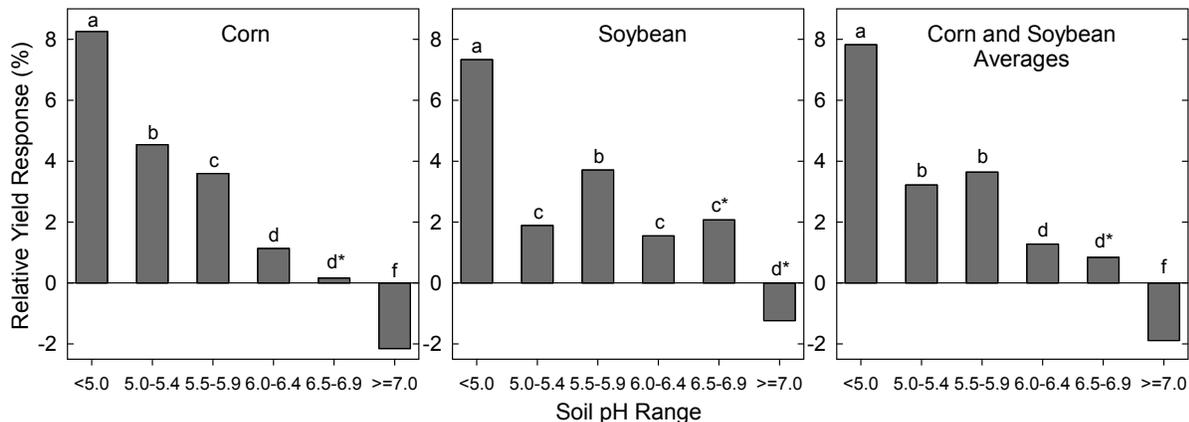


Figure 2. Relative corn and soybean grain yield response to 3 ton ECCE/acre across 14 four-year trials for different soil pH ranges. Bars with different letters are statistically different from each other and from zero, whereas letters with an asterisk indicate no difference from zero ($P \leq 0.10$).

Graphs in Figure 3 summarize relative grain yield responses across both crops for different pH ranges for field location in soil association areas classified as having soil series with low- or high-pH (calcareous) subsoil.

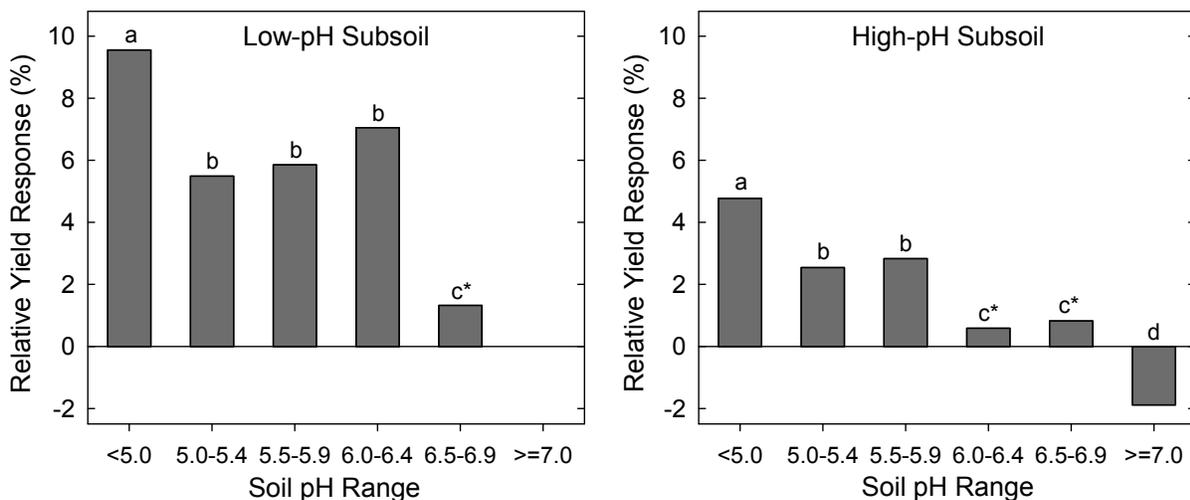


Figure 3. Average relative grain yield response to lime application across corn and soybean crops for several soil pH ranges across 14 four-year trials grouped according to their location in soil association areas having soils with low- or high-pH (calcareous) subsoil. Bars with different letters are statistically different from each other and from zero, whereas letters with an asterisk indicate no difference from zero ($P \leq 0.10$).

With low-pH subsoil, the yield increases from lime application were large and consistent up to pH 6.4 but an apparent small increase with pH 6.5-6.9 was not statistically different from zero yield increase. In soils with high-pH subsoil, however, the yield increases were smaller and responsive only up to pH 5.9. Very small apparent yield increases with pH 6.0-6.4 or 6.5-6.9 were not statistically different from zero, but there was a significant yield decrease with pH ≥ 7.0 . A smaller corn and soybean yield response in soils with high-pH subsoil and only up to pH 6.0 is in agreement with results reported by Bianchini and Mallarino (2002) for fields in central Iowa and by Vetsch and Randall (2006) for fields in southern

Minnesota. Furthermore, the results for this recent study confirmed that ISU recommendations since the 1970s have been correct in that a pH of 6.0 is sufficient for these crops when the subsoil is calcareous.

Effects of different rates of calcitic and dolomitic aglime on soil pH and crop yield

The neutralization capacity of agricultural limestone depends on its mineralogy and the proportion of calcium carbonate and magnesium carbonate, both of which may vary greatly across quarries. By unit weight, magnesium carbonate has a higher neutralizing capacity than calcium carbonate, but its reaction in the soil to increase pH is slower. In production agriculture and limestone trade, limestone containing about 8 to 10% of magnesium or higher is considered dolomitic limestone whereas that with a lower percentage magnesium is considered calcitic. Dolomitic lime is a good source of magnesium for crops, but there is no supported evidence of magnesium deficiency in Iowa soils and most of the north central region. Few field studies have evaluated soil pH and crop yield over time as affected by limestone source and rate in our region, but none has been conducted in Iowa until recently.

Four two-year trials were established in spring 2009 in fields with acidic soil (pH 5.4 to 5.7) at ISU research farms in central, northeast, northwest, and central Iowa. Replicated treatments were the combinations of three lime sources and three application rates. The lime sources were pure finely ground calcium carbonate, calcitic limestone (with only 0.23% magnesium), and limestone with 8.1% magnesium, which will be referred to as dolomitic limestone. 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 CCE concentrations were 99, 89, and 69%, respectively. The application rates were based on the CCE of each source and were 0, 2, 4, 6, and 10 ton CCE/acre. The ECCE (which also considers fineness) was 98, 54, and 39%, respectively. Therefore, the application rates expressed as ECCE differed among the lime sources, and the highest ECCE rates applied were 9.8, 5.4, and 3.9 ton/acre for the calcium carbonate, calcitic limestone, and dolomitic limestone, respectively. The amendments were applied in early April and were incorporated into the soil by disking. Soybean was planted in 2009 and no-till corn was planted in 2010. Soil samples were collected from a 6-inch depth before applying lime and seven times until September 20, 2010. This study was published in a scientific journal (Pagani and Mallarino, 2012)

The results for liming effects on soil pH were consistent across the four fields with only small variation in the magnitude of the effects. Therefore, Fig. 4 shows average soil pH results across the four fields. The application rates effects on soil pH increase over time was curvilinear with decreasing increments to a maximum that was reached 100 to 170 days after liming for all sources and rate. However, the early pH increases and the maximum pH reached was greater for the pure calcium carbonate than for either limestone. The application rate needed to maximize soil pH was the lowest for calcium carbonate, intermediate for calcitic lime, and highest for dolomitic lime. Although the ECCE rates were higher for calcium carbonate and differed slightly between the two limestone sources, a maximum plateau pH was reached before the last sampling date (23 months) all sources and all application rates. Perhaps a longer evaluation could have shown differences in maximum pH reached but this is unlikely. A smaller effect on pH for the dolomitic limestone compared with calcitic limestone can be explained by lower magnesium carbonate solubility and a coarser particle size of the material used.

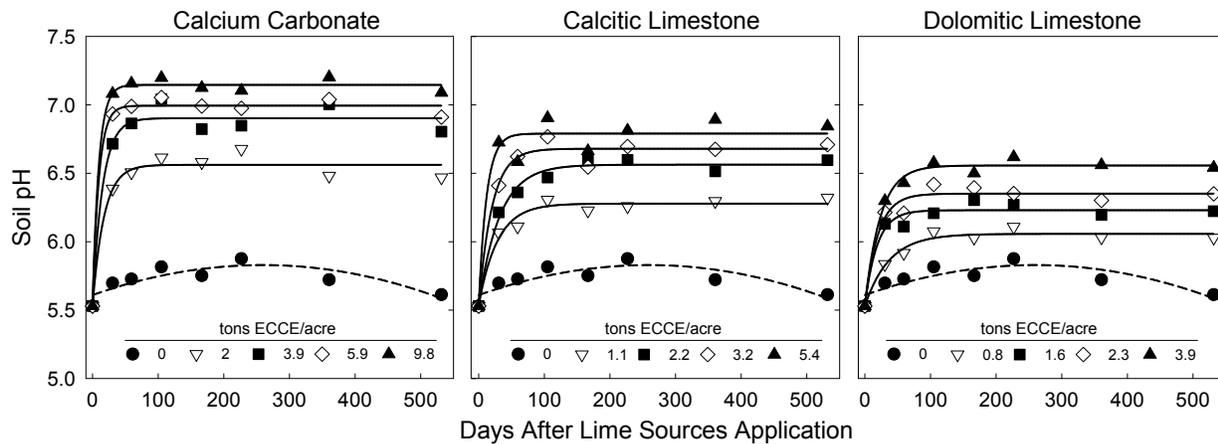


Figure 4. Soil pH as affected by the sampling time after applying three lime sources using similar rates of calcium carbonate equivalent (CCE) per acre which resulted in different effective CCE (ECCE) rates among the sources. Averages across four field trials.

Crop yield increases were observed at only two of the four fields, which had initial pH 5.4 and 5.7. There was no statistically significant yield response in the other two fields, although initial pH was 5.5 in both. There were no statistically significant differences between the lime sources for any crop at any field. Figure 5 shows the average yield results across the responsive sites. The highest two rates of calcium carbonate increased yields of both crops more than with either limestone because the ECCE applied were higher. The trends represented by the data points more or less aligned to the general response curve show no clear differences between sources at comparable ECCE rates. In soybean (first year), the curve depicting yield increases with lime did not reach a plateau, but the difference between the two highest points was very small and show that about 6 ton ECCE/acre maximized yield. In corn (second year) there was a clear high plateau yield, and maximum yield also was attained with about 6 ton ECCE/acre.

Therefore, results of this study showed that lime sources determined different rates of soil pH increase until 100 to 170 days after application. A high plateau pH was reached by all sources and application rates, but was lower for either limestone than for pure calcium carbonate. However, there were no grain yield differences between the sources, and about 6 ton ECCE/acre maximized yield in the two responsive fields. The results for soil pH increases indicated that the method in use by IDALS to evaluate the effectiveness of liming sources clearly overestimates the actual effectiveness of dolomitic limestone. A more recent incubation study using several rates of different lime sources mixed with three Iowa soils showed the same results (Jones and Mallarino, 2018). This also has been observed by research in an eastern state. There is no widely accepted method for estimating the efficiency of liming materials. In states of the North Central Region, aglime is sieved through three or four screens with Tyler mesh sizes ranging from 4 through 60. The State of Iowa requires that the fineness and efficiency liming materials sold should be determined by determining CCE and estimating particle size efficiency by measuring the amounts of the material that pass Tyler screens of mesh sizes 4, 8, and 60, and using particle efficiency factors 0.1, 0.3, and 0.6, respectively. These fineness factor values have been used for many decades in Iowa and the research on which they are based was not documented.

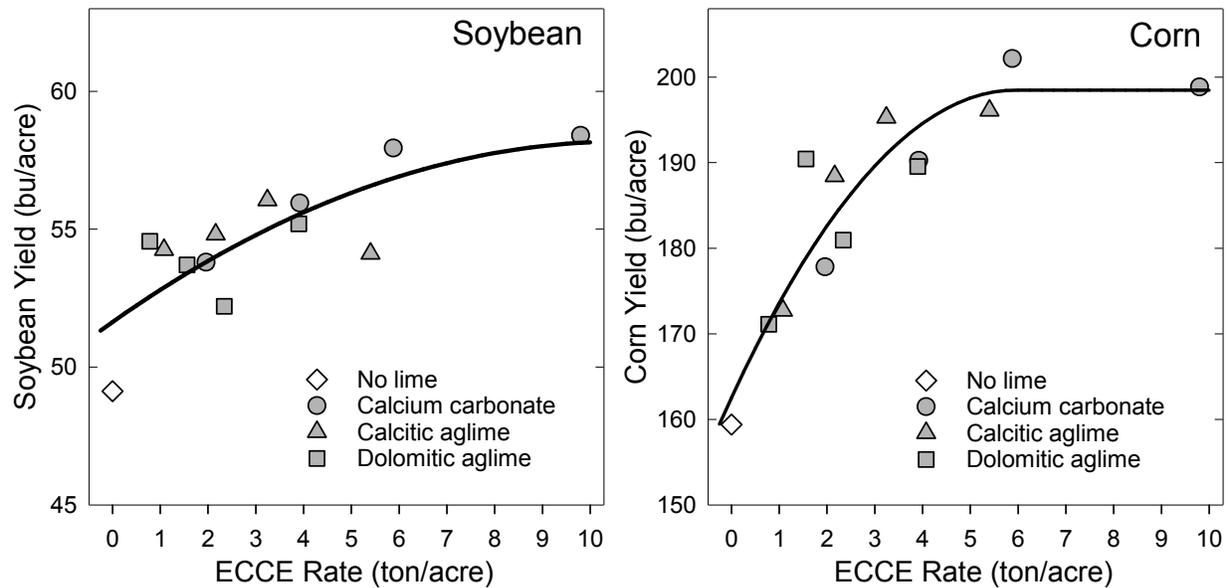


Figure 5. Effect of several application rates of calcium carbonate, calcitic aglime, and dolomitic aglime on grain yield of soybean (first year) and corn (second year). Averages across the same two responsive sites for both crops.

How does pelleted lime compare to aglime for increasing soil pH and crop yield?

Pelleted lime has been available for more than four decades, but is used much less than aglime. It is designed to facilitate application, and typically is ground limestone that is granulated using a binding agent. Pelleted lime is more expensive than aglime, and many farmers and crop consultants are suspicious of its value at increasing soil pH and yield. This is probably because of scarce and not well disseminated research comparing pelleted lime and aglime, because the scarce published research shows inconsistent results. Some studies showed approximately similar efficiency to aglime (Kelling and Schulte, 1988a, 1988b; Murdock, 1997; Godsey et al., 2007) and others showed a lower efficiency of the pelleted lime at increasing soil pH (Warncke and Pierce, 1997; Lentz et al., 2010) or inconsistent results (Laboski et al., 2013).

The availability of pelleted lime to producers in Iowa has increased in recent years. Iowa, as most states of the region, has no guidelines for pelleted lime use. No published field research has evaluated pelleted lime in Iowa. A recently published indoor soil/lime incubation study using three Iowa soils by Jones and Mallarino (2018) showed that on average across soils the efficiency of a commercially available pelleted lime at increasing soil pH relative to pure calcium carbonate was 60 to 90% for incubation times of 7 to 210 days, whereas efficiency of calcitic aglime and dolomitic aglime was 47 to 65% and 12 to 47%, respectively. As expected, the highest reported efficiencies corresponded to the two longest incubation periods.

Therefore, a field study was conducted to evaluate the effectiveness of pelleted lime at increasing soil pH and crop yield. Six two-year trials were established on acidic soils, with corn in 2015 and soybean in 2016. The trials were in central, southwest, southeast, and northwest Iowa. Treatments replicated three times were the combinations of three lime sources and five application rates. The liming sources were finely ground calcium carbonate, 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. 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. The measured granules diameter ranged from 0.08 to 0.16 inches. Methods required in Iowa were used to determine the materials' CCE and ECCE. 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 application rates were 0, 1, 2, 4, and 8 ton CCE/acre. The corresponding 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. The treatments were spread in October 2014, and were incorporated into the soil in November after light rain occurred in all sites with a disk harrow. All plots were disked again in the spring before planting corn, and soybean was no-till planted in spring 2016. Soil samples were taken before liming and six times from March 2015 until after soybean harvest in fall 2016 (23 months).

The soil pH increases due to lime application differed among fields but the relative differences between sources and rates were minor. Therefore, Fig. 6 shows pH averages across the six fields. The largest pH increase for most sources and CCE application rates was observed 4.5 months after the materials application (the first post-liming sampling date). The calcium carbonate and the pelleted lime had similar effects on pH, the two highest rates maximized pH 4.5 months after the application and remained high until the 17-month sampling date, but for the two lower rates maximum pH was reached only 12 months after the application. Aglime had a lesser effect on pH, and for all CCE application rates the maximum pH was reached 12 months after liming. There was significant temporal pH variation evidenced by the untreated soil, and should also have affected the limed treatments. The results in this figure show that the ECCE measurement, which includes a fineness assessment, correctly estimated the calcium carbonate and pelleted lime efficiency at raising soil pH but slightly overestimated the efficiency of aglime. A lower aglime efficiency is expected for the earlier sampling date, but its efficiency also was slightly overestimated for the sampling date when maximum pH was reached. This result agrees with the previous study with calcitic and dolomitic aglime.

Liming resulted in statistically significant corn grain yield (first year) increases in three fields and soybean yield (second year) increases in the same three fields plus in another field. The initial pH of the responsive fields ranged from 4.9 to 5.6. The initial pH of the other two fields were 5.5 (in central Iowa, with calcareous subsoil) and 6.1 (in eastern Iowa sandy soil). There were no statistical differences between the three lime sources at any field although the magnitude of the increases varied among fields. Therefore, Figure 7 shows the average yields and responses across the responsive sites for each crop. The data points show no difference between the three sources, the three rates increased yield significantly, and rates of 2.91 and 1.16 ton ECCE/acre maximized corn and soybean yield, respectively.

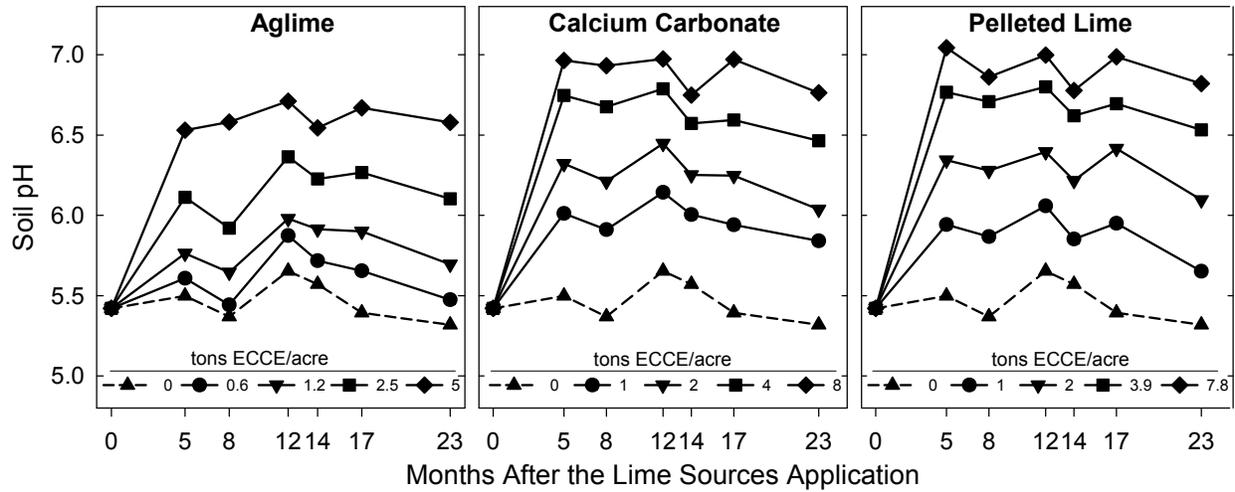


Figure 6. Effect of several application rates of calcium carbonate, calcitic aglime, and pelleted lime on soil pH over a 23-month period (averages across six trials).

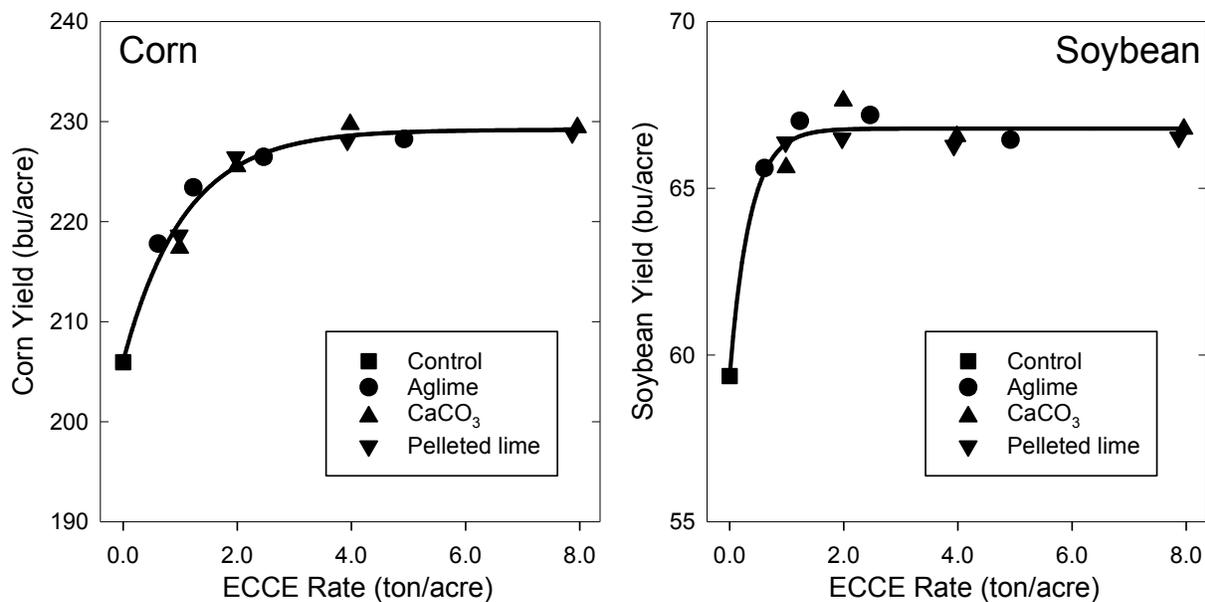


Figure 7. Effect of several application rates of calcium carbonate, calcitic aglime, and pelleted lime on grain yield of corn (first year) and soybean (second year). Averages across three corn responsive sites and four soybean responsive sites.

Summary and most meaningful guiding principles

The summarized recent research has been useful to improve soil pH and lime application management in Iowa. The most important results is summarized in the following points.

1. The ISU guidelines concerning optimal pH for corn and soybean are appropriate. As the ISU extension publication PM 1688 indicates, these crops response to lime application is not likely with pH 6.0 or higher in Iowa regions with high-pH calcareous subsoil (mainly in north central and western Iowa) and with pH 6.5 or higher in other areas.

2. Lime application to soils with pH higher than 7.0 (calcareous) in the surface layer does not increase corn or soybean yield and often decreases yield. Therefore, identifying field areas with calcareous soils is essential. Since calcareous soils often occur in patches of different size in fields, iron deficiency chlorosis in soybean is a very useful tool to identify their location (by direct observation or from aerial images) to complement soil sampling and effective use of variable rate application technology.
3. With acceptable and normal crop prices, soils with lower pH should be limed for long-term high yield and profitability. With unfavorable crops prices, however, the likely small yield increases by liming soils with pH between 6.0 and 6.5 may not offset application costs and liming will be a risky investment with unsafe land tenure.
4. The procedure used in Iowa to evaluate the effectiveness of liming materials (ECCE) is appropriate for pelleted lime, but may slightly overestimate the efficiency of calcitic aglime and can substantially overestimate the efficiency of dolomitic aglime. This in part explains the reason for pelleted lime efficiency at increasing soil pH approximately similar to that observed for pure and finally ground calcium carbonate, and slightly lower efficiency for calcitic aglime but considerably lower efficiency for dolomitic aglime.
5. An important crop yield result was that even when the estimate of effective neutralizing capacity (ECCE) may overestimate the efficiency of aglime at increasing soil pH, no field trial showed corn or soybean grain yield differences between the four lime sources evaluated. The application rates ranged from about 1 to 9 ton ECCE/acre. Therefore, the convenience of using a specific liming source will be determined mainly by the cost of the material and delivery to a field, both of which vary greatly across sources and areas of Iowa.

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