EFFECTS OF HCl ACID AND LIME AMENDMENTS ON SOIL pH AND EXTRACTABLE Ca AND Mg IN A SANDY SOIL

KEY WORDS: Dolomitic lime, soil depth, high water table soil
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ABSTRACT

High water table sandy soils present special problems when establishing soil pH variables under field conditions. In order to examine the response of a coarse-textured soil to lime and HCl acid treatments, data are reported for soil pH and extractable Ca and Mg for a field experiment where Mn treatments on soybeans was the primary objective. Three treatments included HCl acid, control, and lime. Acid (742 liters/ha 3N HCl) was added only at the beginning of the experiment but dolomitic lime treatments were added each year (2240, 2740, and 2900 kg/ha). The lime and acid were applied to the soil surface and incorporated to a depth of 10 to 13 cm. Soil samples were taken every 2 to 3 months at 3 depths (0 to 15, 15 to 30, and 30 to 45 cm) and analyzed for pH and extractable Ca and Mg. Acid treatment decreased the pH by 0.2 units below the untreated soil at the 0 to 30 cm depth and the effect lasted the entire 3 years of the study. Calcium
values were lowered only slightly by the acid treatment. Lime additions caused steady increases in soil Ca. Magnesium values increased several months after each of the first and second lime applications. Lime raised the subsoil (30 to 45 cm) pH after 4 to 6 months. Seasonal variations in pH were very wide with the untreated soil pH varying from 6.1 to 6.8. The high pH level of 7.0 was not maintained for an entire season until the third year of the experiment. Soil pH as well as extractable Ca and Mg showed fluctuations that were the result of seasonal variations and soil moisture content at the time of sampling. Soil pH variables on a sandy soil should be established at least a year in advance of starting an experiment and must be closely monitored in order to maintain the desired pH levels.

INTRODUCTION

Soil pH values fluctuate during the season and generally decline over longer time periods due to leaching of bases, organic acid production, and addition of acid-forming fertilizers. Hester and Shelton recognized that soils were more acid in the summer and early fall than in winter and early spring especially for low buffer capacity soils. They reported pH variations of 0.2 to 2.0 pH units which were influenced by rainfall, fertilization, and nitrification. Similar variations in pH values of 0.5 units were observed in a Cecil soil in Georgia. Collins et al. found that field-moist samples showed a maximum seasonal variability of 1.6 pH units and an average variation of 0.8 pH unit when measured for one growing season at 19 sites. Monitoring soil pH and extractable or exchangeable Ca and Mg for one season following the application of dolomitic lime usually has shown an increase in all three variables. Several reports have shown data for fluctuations in pH, Ca and Mg on limed soils when monitored for several seasons.

In a five-year experiment Parker et al. found that 2240 to 4480 kg/ha lime amendments maintained the soil pH between 6.0 and
6.5 on a Greenville soil in the Coastal Plain region of Georgia. Liebhardt\textsuperscript{10} warned that high rates of a dolomitic limestone can cause an upset of the Ca to Mg ratio and cause decreased yields on low CEC Coastal Plain soils. Lime caused a drastic increase in pH from 5.5 to 6.7 the first few months but decreased through the winter and increased again the next summer in a Florida soil\textsuperscript{11}. The pH increased again the next season and continued to rise the next year showing that sandy soils can show considerable pH fluctuations. Where no lime was applied, pH values remained steady or dropped slightly during the 2 1/2-year period. In Canada, soils limed to pH 6.5 to 7.0 declined by 0.48 units over an 8-year period\textsuperscript{12}. In that study the average loss of lime was equivalent to 495 kg of CaCO\textsubscript{3}/ha annually. In England, soil pH for limed soils increased for six years in a sandy clay loam and for three years in a loamy sand followed by a steady decline when pH was monitored for a total of 12 years\textsuperscript{13}. Rates of CaCO\textsubscript{3} losses from the top 23 cm of soil ranged from 225 to 852 kg/ha per year.

Besides influencing pH, Ca and Mg in the surface layer, lime can also cause changes in the subsoil, especially on porous, sandy soils. Even on fine-textured soils liming caused substantial increases in subsoil pH for 3 of 6 soils studied\textsuperscript{12}. Calcitic limestone increased Ca in the 30-46 cm depth in a loamy sand and Mg in the 30-46 cm depth in two sandy soils at all rates of dolomitic lime applied to the surface\textsuperscript{14}. The Ca and Mg added to sandy soils leached considerably, the amount of which was generally related to the CEC or the original levels of extractable elements in the soil\textsuperscript{15}.

Few experiments have been reported where the effects of acid added directly to soils in the field have been studied. The usual approach is to use sulfur or acid-forming fertilizers such as ammonium sources of nitrogen. Little information is available on the influences of acid treatments on soil Ca and Mg values.

Since many experiments in soil fertility deal with pH variables usually imposed with other treatments, it is important to
know what can be expected in the way of seasonal variation in pH values due not only to lime treatments but also due to natural causes on unlimed soils and on soils that have been acidified. Further, it is important to know how surface applied and incorporated materials affect sub-surface layers to depths where plant roots generally penetrate. In order to help answer some of these questions, an experiment was monitored where lime and acid treatments were applied with the objective of determining changes in soil pH along with extractable Ca and Mg at 3 depths for a period of 3 years.

MATERIALS AND METHODS

The experimental area was located in the Atlantic Coast flatwood region near Tifton, Georgia. The soil, an Olustee-Leefield sand (sandy, siliceous, thermic Ultic Haplaquod-loamy, siliceous, thermic Arenic Plinthaquic Paleudult), has a high water table with 88% sand, 2% clay, 1.0% organic matter and a cation exchange capacity of 5.7 meq./100 g. The 3 pH level plots were large blocks (88 m by 7.3 m) replicated 4 times as part of a Mn experiment. To minimize tillage mixing between plots 2 border rows without any treatment were planted on each side of the plot and 3m at each end of the plot was fallowed. Included within these blocks were 5 Mn rates split with initial and annual applications. The pH levels were prepared using acid, no treatment, or dolomitic lime. The acid rate was 371 liters/ha of 3N HCl applied with a gravity flow, all plastic applicator on 5 November, 1974, and again at the same rate on 21 April, 1975. The high pH plots were treated with 2240 kg/ha of dolomitic limestone on 5 November, 1974. The limestone contained 29.3% Ca and 5.1% Mg. In order to maintain the high pH level, further lime applications of 2740 kg/ha and 2900 kg/ha were made on 20 November, 1975, and on 10 February, 1977, respectively. Fertilizer was uniformly added as 20% superphosphate and 60% muriate of potash at the rates of 750, 760 and 600 kg/ha of 0-4.3-25 in May of each year, respectively, before soybeans were planted. Imme-
diately after the acid or lime was added, the field was disked one or two times at a depth of 10-13 cm. Before the May soybean planting the soil was moldboard plowed 25 cm deep and then roto-tilled 8 cm deep to incorporate 'Vernam' and the Mn treatments. Soybeans were cultivated 2 or 3 times 8 cm deep as needed. Soybeans were harvested in October and the straw was left on the plots. All plots were fallowed in the winter.

Soil samples were taken approximately every 2 to 3 months (Figs. 1 to 3) throughout the year. Ten cores were collected from each pH block and combined in plastic bags. Three depths were taken with successive probes at 0 to 15 cm, 15 to 30 cm, and 30 to 45 cm. The sample at the final depth was a yellowish, loamy sand subsoil with the middle sample showing the plow layer-subsoil line very distinctly. Samples were mixed and air-dried in a greenhouse. Following drying, they were mixed again and subsamples taken for pH analyses (1:1 aqueous suspension) and extraction with double acid\(^{16}\) using a 1:4 soil to solution ratio and a 15 minute shaking time (no charcoal). The solutions were analyzed for Ca and Mg by atomic absorption spectrophotometry.

Rainfall measurements were taken at the field site for four years (Table 1).

The standard error vertical lines in the figures are pooled over dates since individual errors did not vary significantly according to F tests.

Table 1. Monthly rainfall for 4 years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
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<th>Jun</th>
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<th>Sep</th>
<th>Oct</th>
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<th>Dec</th>
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<td>mm</td>
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<td></td>
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<tr>
<td>1974</td>
<td>81</td>
<td>158</td>
<td>79</td>
<td>124</td>
<td>117</td>
<td>118</td>
<td>218</td>
<td>96</td>
<td>164</td>
<td>18</td>
<td>35</td>
<td>81</td>
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<tr>
<td>1975</td>
<td>192</td>
<td>73</td>
<td>165</td>
<td>262</td>
<td>88</td>
<td>105</td>
<td>177</td>
<td>119</td>
<td>56</td>
<td>90</td>
<td>36</td>
<td>114</td>
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<td>1976</td>
<td>79</td>
<td>27</td>
<td>60</td>
<td>42</td>
<td>312</td>
<td>71</td>
<td>62</td>
<td>36</td>
<td>174</td>
<td>135</td>
<td>145</td>
<td>99</td>
</tr>
<tr>
<td>1977</td>
<td>89</td>
<td>68</td>
<td>140</td>
<td>25</td>
<td>94</td>
<td>66</td>
<td>119</td>
<td>154</td>
<td>80</td>
<td>17</td>
<td>86</td>
<td>78</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Since the 0 to 15 cm and 15 to 30 cm depth samples were mixed in the plowing process to a depth of 25 cm, the values were similar and are reported as one depth (0 to 30 cm). Soil pH changed immediately due to acid application at the 0 to 30 cm depth dropping lower than the values for the control plots (Fig. 1). After adding additional acid and turning the soil, the pH rose slightly but remained about 0.2 pH units lower than the control until mid 1976 when these plots were within 0.1 pH unit of the control plots. At the end of the 3 years the acid-treated plots were nearly the same as that for the untreated plots. The effects of acid treatment on soil pH were significant and were fairly long lasting considering that a liquid was added and not a solid that dissolves over a long time period. In the early spring of 1976 the acid-treated soil pH decreased while the untreated soil pH increased. The acid may have had some residual effect during the wet spring season when the water table was high. The following spring both the acid-treated and untreated plot pH values decreased. Additional acid was not applied since pH values were sufficiently low in the acid-treated plots to result in near maximum soybean yields without added Mn\textsuperscript{17}.

The soil pH values changed slowly due to lime treatment and were similar to the untreated plots the first year. The second lime treatment, however, increased pH values to a peak of 7.2 in March of the second year and then receded rapidly with spring tillage to the previous level of 6.8. The limed plots remained about 0.2 pH units above the untreated plots throughout 1976 until the third lime treatment when the pH values steadily increased until the end of the experiment. The untreated plots decreased in pH values during the final year separating the untreated and limed plots even further. There was little response to Mn in 1976 even though the applied lime increased the soil pH to 7.2. By the time the beans were planted, the pH level had decreased to 6.8 and increased very little during the growing season. By contrast the dramatic soybean yield response to Mn in
Fig. 1. Soil pH values for control, acid treated, and limed plots at 2 depths for 3 years. Vertical lines are pooled standard errors.
1977\textsuperscript{17} was a result of the higher pH level near 7.0 that except for the March sampling, was well maintained throughout the growing season.

The interesting feature of the pH values for the 0 to 30 cm depth is a wave-like pattern where generally the pH decreased in the summer and increased in the winter. All the values followed this pattern with the treated plots paralleling the untreated. One possible reason for the decrease in the spring is tillage which would mix unlimed and limed soil. However, the pattern is also evident in the 30 to 45 cm depth samples, well below the plow layer in a different colored B horizon (Fig. 1). There the acid had little effect except to decrease the pH in relation to the untreated plots in the summer of 1975 and in the spring of 1976. The lime eventually leached to this level and increased pH values in the spring of 1976 after the second lime application and in the fall of the final year. The lime moved downward in the profile slowly with the effects at this depth becoming evident 4 to 6 months after liming.

Acid treatment had little effect on Ca values in the 0 to 30 cm depth the first year but by October, 1975, the Ca in the acid-treated plots was about 100 kg/ha lower than for the untreated plots and maintained some difference until the spring of 1977 (Fig. 2). In the last year of the experiment, the Ca values for the acid-treated and untreated plots were similar. It is interesting to note that the Ca values in the untreated plots fluctuated from a low of about 650 kg/ha at the beginning of the experiment to a high of 1100 kg/ha in January, 1976 and February, 1977. The third lime application did not influence the acid-treated or untreated plots since their Ca values continued to decline during 1977. However, at the end of the experiment these plots had around 800 kg/ha Ca or about 150 kg/ha higher than at the beginning (a significant difference). The limed plot Ca values rose steadily except for peaks immediately following the first two lime applications. The decline in the spring of 1975 and 1976
Fig. 2. Soil Ca values for control, acid treated, and limed plots at 2 depths for 3 years. Vertical lines are pooled standard errors.
was probably partly due to soil mixing when the soil was plowed and disked for planting.

Calcium values at the lower depth (30 to 45 cm) were changed only slightly by the treatments (Fig. 2). Allowing for normal fluctuations the three treatments paralleled each other until after the third lime treatment where the limed plots did exhibit Ca values higher than for the other two treatments. Movement of Ca to this depth was minimal but did raise the values by 200 kg/ha after the third lime application. Fluctuations in Ca values were not as great as for the 0 to 30 cm depth.

The initial lime application greatly increased the soil Mg values in the 0 to 30 cm depth (Fig. 3). The Mg values for the acid-treated plots increased at the second sampling but declined thereafter to a level below the untreated plot values until the second lime application. One or more of the January, 1976 samples for the acid-treated plots were probably contaminated by lime and did not reflect the true Mg values in these plots. On the next sampling the Mg value declined significantly below the control values dropping as much as 20 kg/ha lower than untreated areas during the fall and winter of 1976-1977. The 1977 samples show that the Mg values in the acid-treated plots were similar to the untreated plot values. The soil Mg values for the limed plots reached a peak after each lime addition but this peak was delayed by one sampling after the second and third additions. The Mg values did not increase until the lime had several months to react with the soil. The Mg values were considerably higher for the limed plots than for the untreated plots the entire time that the study was conducted. No obvious seasonal variations were observed in the Mg values as were observed for the pH values. In general, the trend for the values of the untreated plots and even those of the treated plots was to increase at the beginning of the experiment and gradually decline thereafter. Even the limed plot values dropped sharply the last two samplings paralleling drops in the values for acid-treated and untreated plots.
Fig. 3. Soil Mg values for control, acid treated, and limed plots at 2 depths for 3 years. Vertical lines are pooled standard errors.
Table 2. Seasonal Effect on pH, Ca, and Mg Values of the Control Treatment (0 to 30 cm).

<table>
<thead>
<tr>
<th>Season of sampling</th>
<th>1975</th>
<th>1976</th>
<th>1977</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter Soil pH</td>
<td>6.73a</td>
<td>6.63a</td>
<td>6.79a</td>
</tr>
<tr>
<td>Fall Soil Ca (kg/ha)</td>
<td>1027a</td>
<td>1106a</td>
<td>1111a</td>
</tr>
<tr>
<td>Winter Soil Mg (kg/ha)</td>
<td>128a</td>
<td>109a</td>
<td>89a</td>
</tr>
<tr>
<td>Fall Soil Mg (kg/ha)</td>
<td>91b</td>
<td>88b</td>
<td>67b</td>
</tr>
</tbody>
</table>

Values followed by the same letter within a variable and year are not significantly different at the 5% level according to an LSD test.

Subsoil Mg values (30 to 45 cm) were all lower than for the top two depths (Fig. 3). All plots had similar Mg values until October, 1975, when the untreated plot values increased. The Mg values of the acid-treated plots remained below the untreated plots for the summer of 1976 and the spring of 1977. The values were somewhat erratic for both acid-treated and limed plots at this depth. Possibly some sampling error may have been the cause as these cores were removed through the top two depths. The limed plot samples showed increases in Mg after the first two lime treatments but none after the third. The increase in November, 1976 is unusual since it occurred before lime was applied the third time, but it also was evident in the 0 to 30 cm depth. Possibly moisture conditions caused Mg in the previously added lime to become more soluble for that particular sampling period.

Soil P and K values were also monitored during the entire time period at three depths. Neither the acid nor lime treatments significantly affected double acid extractable P or K at any time during the experiments.
Liming or adding acid to obtain field pH variables in a research setting may seem like a routine procedure, but the data presented show that it is not a simple matter. The predictability for final soil pH values is low when adding lime or acid to a coarse-textured, high water table soil. The pH values are subject to changes in the environment. The acid treatment did not effect a great pH change (0.2 pH units) but it did influence certain soil parameters for nearly the entire 3 years. Seasonal fluctuations are emphasized by the data in Table 2. Not only was soil pH higher in the winter but extractable Ca and Mg were higher as well. The decrease in Ca and Mg during the summer and fall could be due to plant uptake. However, calculations using seed yields and percent Ca and Mg of the seed indicate that only 6.7 kg/ha Ca and 6.4 kg/ha Mg were removed each year as an average over years. Therefore the variations shown in Table 2 cannot be accounted for by crop removal. Since the straw was left on the plots, decomposition of plant residues may have contributed to the increase in soil Ca and Mg during the winter by recycling. Seasonal variation should be considered when taking research samples. Sampling should be timed so that it occurs during the same season of the year each year in order to have comparable results. Another reason for the fluctuations shown in the figures is the moisture content of the soil at the time of sampling. Initial soil samples in November, 1974, were taken in dry soil (Table 1). The lowest pH values (October, 1975, and May, 1977) both occurred when the soil was dry. The soil was very wet at the time samples were taken in November, 1976, and September, 1977, and pH levels both times were above those immediately preceding. Therefore, moisture conditions at sampling time as well as seasonal fluctuations can influence soil pH values.

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REFERENCES

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2. Assistant Professor, Coastal Plain Station.


