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AGRONOMY AND SOILS

Soil Calcium: Magnesium Ratios and Lime Recommendations for Cotton

Gene Stevens*, Tina Gladbach, Peter Motavalli, and David Dunn

ABSTRACT

Some crop managers are concerned that repeated use of dolomite lime, which contains 10 to 15% Mg, will produce excessively high soil Mg^{+2} levels relative to Ca^{+2} and reduce cotton (*Gossypium hirsutum* L.) K^{+} uptake and yields. Two cotton field experiments were conducted on well-drained soils to determine the short- and long-term effects of lime applications containing Mg. The first test compared the short-term effects of lime with low and high Mg content on soil characteristics and cotton lint yield. This experiment was conducted at Portageville, MO, in 2000 to 2002 on a field with pH_{salt} 4.7 to compare the effectiveness of calcite (calcium carbonate) and dolomite (calcium magnesium carbonate) lime at recommended rates for increasing cotton yields on acid soils. Averaged across 3 years, both lime sources significantly increased cotton yields by 94 to 112 kg ha^{-1} of lint compared with the untreated check. There were no significant differences between calcite and dolomite lime. A second experiment was conducted from 1999 to 2001 to determine whether long-term use of dolomite lime, which reduces exchangeable soil Ca:Mg ratios, would decrease plant K^{+} uptake and cotton yield. To produce a range of Ca:Mg ratios in a soil with near neutral pH_{salt} (6.2), selected rates of gypsum ($CaSO_4$) and Epsom salt ($MgSO_4$) were applied and incorporated in plots. Soil Ca:Mg ratios ranged from 2.5:1 to 7.6:1 (% base saturation). Whole plant tissue K, fiber quality, and lint yield were not significantly affected by exchangeable Ca:Mg ratios. This study showed that cotton farmers with well-drained Delta soils should not be concerned about potential negative effects of Mg in dolomite lime material.

G. Stevens, Department of Agronomy, University of Missouri-Delta Research Center, P.O. Box 160, Portageville, MO 63873; T. Gladbach; 1005 N. Rumans Road; Centralia, MO 65240; P. Motavalli, Department of Soil, Environ. and Atmos. Sciences, 302 Anheuser Busch Natural Resources Building, University of Missouri Columbia, MO 65211; D. Dunn, Soil Testing Laboratory, University of Missouri-Delta Research Center, P.O. Box 160, 147 State Hwy T, Portageville, MO 63873
*Corresponding author: stevensw@missouri.edu

Two philosophies for interpreting soil test results are dominant in the United States. Eckert (1987) referred to them as the "Sufficiency Level" (SL) and "Basic Cation Saturation Ratio" (BCSR) concepts. Most public soil test laboratories currently use the SL concept for making fertilizer and lime recommendations. Fertilizer applications are recommended to maintain soil test nutrient levels at or above critical values based on response curves developed from field research. Several factors are considered in lime recommendations, including soil acidity, buffering capacity, target soil pH for a specific crop, and neutralizing value of the lime material.

Specialty fertilizer dealers have recently shown interest in the BCSR philosophy for managing cotton fertilization (Kinsey, 1999). The BCSR concept was first promoted in a series of publications in the late 1940s based on research in New Jersey (Bear et al., 1945; Bear and Toth, 1948; Hunter et al., 1943; Hunter, 1949; Price et al., 1947). The ideal base saturation given for the soil cation exchange complex was 65% Ca, 10% Mg, 5% K, and 20% hydrogen (H). In Missouri, Graham (1959) proposed that 65 to 85% of the cation exchange complex should be occupied by Ca and 6 to 12% by Mg for optimum ratios. McLean et al. (1983) and Simson et al. (1979) compared the two interpretation philosophies in field research conducted in Ohio and Wisconsin. Their results did not support the BCSR philosophy, and indicated that basic cations should be applied on crops to provide sufficient levels to maximize crop yields.

Applying lime that contains significant amounts of Mg can reduce Ca:Mg ratios in soil. This is a potential concern for crop managers using the BCSR philosophy. Lime from dolomite contains 10 to 15% Mg, while calcite lime contains less than 1% Mg. The University of Missouri soil test program, which uses the SL philosophy, recommends applying enough effective neutralizing material (ENM) of lime to increase the soil pH_{salt} to between 6.1 and 6.5, the target pH_{salt} range for cotton (Brown and Stecker, 2003; Scharf, 2000). ENM is used to indicate the effectiveness of liming materials based on measured calcium carbonate equivalence and particle size (Missouri Legislature, 1999). If a soil is deficient in Mg, dolomite lime may be recommended to correct soil acidity and increase soil Mg. Otherwise, Mg content in lime is not a factor in lime recommendations. In a strict BCRS nutrient management system, soil acidity is ignored if exchangeable Ca levels are satisfactory relative to exchangeable Mg and K.

Transportation expenses to haul ground limestone from quarries to production fields are a major part of the liming costs for cotton farmers. Total cost to purchase, haul, and apply lime in cotton fields of the upper Mississippi Delta region ranges from \$18 to \$30 metric ton^{-1}. The least expensive liming material (calcite versus dolomite) often depends on the closest quarry producing each type of lime.

The objective of two field experiments on well-drained Delta soils was to determine the short- and long-term effects of lime applications containing Mg on cotton K uptake and lint yield. The first test studied the short-term effects of calcite and dolomite lime at recommended rates for increasing cotton yields on acid soils. The second test was conducted to determine whether a long-term dolomite lime program, which reduces exchangeable soil Ca:Mg ratios, would decrease plant K uptake and cotton yield. Selected rates of gypsum and Epsom salt were applied to create a range of soil Ca:Mg ratios.

MATERIALS AND METHODS

Survey of the Missouri soil test database. Soil test results from 2700 samples submitted to the University of Missouri- Delta Center Soil Test Laboratory in 1993 to 1999 were reviewed. Results were a subset of the Missouri soil test database from cotton producing counties. Producers had requested cotton fertility recommendations for each sample. Excel (Microsoft Corporation; Redmond, WA) spreadsheet software was used to calculate exchangeable cation ratios in each soil and to develop frequency intervals for percentage base saturation and soil cation ratios in the subset.

Field studies: general information. Two field experiments were conducted at the University of Missouri Lee Farm, Portageville, Missouri, (36°N, 90°W) to study different lime materials and the long-term effects of changing soil Ca:Mg ratios on cotton yield. Tests were located on fields that had been cropped in cotton for the previous 2 yr. In both experiments, plots were planted with cv. Stoneville BXN49 (Stoneville Pedigreed Seed; Memphis, TN) cotton in a randomized complete block design. Plots were four (97-cm) rows wide and 9.2 m long and maintained in the same locations throughout the study. Preemergence applications of fluometuron and pendimethalin herbicides and post-emergence applications of bromoxynil were made for weed control. Ammonium nitrate (100 kg ha^{-1} of N) was applied before planting each year. Potassium fertilizer was not applied prior to or during either study.

Short-term lime source test. A 3-yr experiment comparing calcite and dolomite lime was conducted from 2000 to 2002 with eight replications on a Reelfoot fine sandy loam soil (fine-silty, mixed, superactive, thermic Aquic Argiudolls). Average initial soil test results before treatments were applied were as follows: organic matter - 1.5 g kg^{-1}, pH_{salt} - 4.7, neutralizable acidity - 3.5 cmol$_c$ kg^{-1}, Ca - 1356 mg kg^{-1}, Mg - 126 mg kg^{-1}, K - 156 mg kg^{-1}, and cation exchange capacity (CEC) - 11.6 cmol$_c$ kg^{-1}. Average saturation of the soil CEC sites was 58% Ca, 8% Mg, 4% K, and 30% H.

Ground dolomite limestone from Piedmont, Missouri, (Vulcan Materials) and calcite limestone from Jonesboro, Illinois, (Ruble Rock and Lime, Inc.) were used in the experiment. The materials were tested for ENM value by the University of Missouri Experiment Station Chemical Laboratory, Fertilizer Section (Columbia, MO). Particle size properties of each lime material used in treatments are shown in Table 1. Percentages of lime particles passing through and retained on a mesh of U.S. Standard sieves (sizes 8, 40, and 60) were used to develop particle fineness factors. Fineness factors were used with calcium carbonate equivalents (CCE) to calculate lime ENM value for calcite and dolomite lime materials (Buchholz, 1993; Missouri Legislature, 1999). The fineness factors were 65% for calcite lime and 77% for dolomite lime. No neutralizing value was assigned to lime particles coarser than 2.4 mm. Particles passing 2.4 mm sieve openings but remaining on 0.42 mm openings were assigned 25% neutralizing effectiveness. Particles passing 0.42 mm openings but remaining on 0.25 mm openings were assigned 60% neutralizing effectiveness. Particles finer than 2.4 mm were assigned 100% neutralizing effectiveness. Both calcite and dolomite lime sources contained 99% CCE material. The calcite lime contained 0.5% Mg, and the dolomite lime contained 11.6% Mg.

Table 1. Particle size distribution and ENM (effective neutralizing material) rating of calcite and dolomite lime materials used in the short-term lime source experiment

Lime	Particle size distribution (%)^z				ENM (kg metric ton^{-1} lime)
	> 2.4 mm	0.42 to 2.4 mm	0.25 to 0.42 mm	< 0.25 mm	
Calcite	**3**	**36**	**13**	**48**	**255**
Dolomite	**6**	**10**	**24**	**60**	**310**

^{z} Percentages (based on mass) of lime that passed and remained on a mesh of U.S. Standard sieves (sizes 8, 40, and 60). Distribution >2.4 mm indicates percentage of lime retained after sifting over 8 mesh sieve, 0.42 to 2.4 mm indicates percentage of lime retained over 40 mesh screen, 0.25 to 0.42 mm indicates percentage of lime retained over 60 mesh screen, and <0.25 mm indicates percentage of lime passing the 60 mesh screen.

The University of Missouri lime recommendation for the soil was an ENM of 1233 kg ha^{-1}. In April 2000, treatments were established with an untreated check and applications of calcite and dolomite lime, and calcite lime with Epsom salts. The lime rates were 3977 kg ha^{-1} of dolomite lime and 4779 kg ha^{-1} of calcite lime. These rates were determined by dividing the soil test ENM recommendation (1233 kg ha^{-1} of ENM) by the ENM value of each lime material [ENM of 310 kg metric ton^{-1} for dolomite lime and 258 kg metric ton^{-1} for calcite lime]. Lime treatments were applied to the soil surface and incorporated to a depth of 15 cm with tillage. Calcite lime with Epson salt treatment was included to evaluate magnesium nutritional contribution to cotton yield across lime sources. The magnesium per hectare rate in the Epsom salt + calcite lime treatment was equivalent to the magnesium contained in the dolomite lime treatment [Mg (magnesium) at 489 kg ha^{-1}]. Epsom salt was applied on this treatment at 470 kg ha^{-1} in 2000. Calcite lime in the treatment supplied an additional 19 kg ha^{-1} of Mg. No additional lime or Mg applications were made in 2001 and 2002. During the growing season, soil samples from 0 to 15-cm depth were collected at 2-wk intervals and measured for changes in soil pH_{salt}.

Seed cotton was mechanically harvested from the center two rows of each plot and the yield was determined. The resulting seed cotton was ginned using a 20-saw Continental gin stand (Prattville, AL) preceded by an inclined cleaner and feeder extractor, and lint turnout was determined. Lint samples were collected after ginning and analyzed at the International Textile Research Center (Texas Tech University, Lubbock, TX) for fiber quality analysis using a high volume instrument (HVI 900A; Zellweger; Knoxville, TN).

Long-term calcium:magnesium ratio test. A 3-yr soil Ca:Mg ratio experiment was conducted from 1999 to 2001 with four replications on a Tiptonville silt loam soil (fine-loamy, mixed, superactive, thermic Oxyaquic Argiudolls). Average initial soil test results before treatments were applied were as follows: organic matter - 1.7 g kg^{-1}, pH_{salt} - 6.2, [1] neutralizable acidity - 1.0 $cmol_c$ kg^{-}, Ca - 1251 mg kg^{-1}, Mg - 140 mg kg^{-1}, K - 285 mg kg^{-1}, and CEC - 9.2 $cmol_c$ kg^{-1}. The average saturation of the soil CEC was 69% Ca, 12% Mg, 8% K, and 11% H.

Calcium sulfate (gypsum) and magnesium sulfate (Epsom salt) were each broadcast by hand at 1700, 3700, and 5600 kg ha^{-1} and incorporated with a disk to a depth of approximately 15 cm in April 1998 (Table 2). Three treatments received 5600 kg ha^{-1} of Epsom salt in 1998. Two of the three treatments had additional applications of Epsom salt (1800 and 3700 metric ton ha^{-1}) in early April 1999 before cotton was planted on 5 May. Beginning in June 1999, whole plant cotton samples were collected each year from 1 meter of row at first square growth stage. Samples were dried at 100 ^{o}C, ground, digested with a Hach Digesdahl (Ames, IA) using H_2SO_4 and H_2O_2, and analyzed for K content using an atomic absorption spectrophotometer (Model 2380; Perkin-Elmer; Wellesley, MA).

Soil sampling and analysis. Soil samples were collected and analyzed from the 0 to 15-cm soil depth before the experiments began and re-sampled each year after harvest in November. Soil organic matter content was measured by the loss on ignition method (Storer, 1984). Soil pH_{salt} was measured with a glass electrode in 0.01M $CaCl_2$ salt solution and neutralizable acidity was measured in Woodruff buffer solution (Brown and Rodiguez, 1983; Woodruff, 1967). Potassium, calcium, and magnesium were extracted in 1N ammonium acetate and measured on the atomic absorption spectrophotometer (Thomas, 1982). Phosphorus was measured colorimetrically using Bray-1 extraction solution (Bray and Kurtz, 1945).

Table 2. Extractable Ca, Mg, K, P, pH, and Ca:Mg ratio from soil samples collected in November 1999 from the long-term Ca:Mg ratio experiment

Material applied (kg ha^{-1})			Soil test levels (mg kg^{-1} soil)[x]					
	1998	1999	pH_{salt}	Ca	Mg	K	P	Ca:Mg ratio[y]
$CaSO_4$	5600	0	6.3	1434	123	314	136	7.6
$CaSO_4$	3700	0	6.2	1286	111	267	142	7.2
$CaSO_4$	1700	0	6.4	1251	119	304	130	7.4
Untreated	0	0	6.2	1236	122	300	135	6.3
$MgSO_4$	1700	0	6.1	1161	156	271	128	4.8
$MgSO_4$	3700	0	6.2	1195	172	295	138	4.4
$MgSO_4$	5600	0	6.3	1064	267	254	137	2.7
$MgSO_4$	5600	1800	6.1	1043	276	289	125	2.5
$MgSO_4$	5600	3700	6.5	1075	286	301	133	2.5

[x] **Ca, Mg, and K were extracted in 1N ammonium acetate and measured with an atomic absorption spectrophotometer. P was extracted in Bray-1 solution and measured colormetrically.**

[y] **Calculated by % base saturation from extractable Ca and Mg in soil samples.**

Statistical analyses of field studies. The statistical analyses of cotton fiber properties and lint yield relative to soil Ca:Mg ratio and lime treatments were performed using Mixed Model procedures of the Statistical Analysis System (release 6.12; SAS Institute; Cary, NC). The Mixed Model procedure provides Type III *F* values, but does not provide mean square values for each source of variation within the analysis or the error terms. Mean separation was evaluated through a series of pair-wise contrasts among all treatments (Saxton, 1998). Probability levels greater than 0.05 were considered non-significant.

RESULTS AND DISCUSSON

Lint yields from dolomite and calcite lime treatments (including the calcite + Mg mix treatment) were significantly higher than the untreated check for the 3-yr means (Table 3). The interaction between years and lime source was not significant.

Based on bi-weekly pH measurements, dolomite lime reacted slower than calcite lime (Fig. 1), but

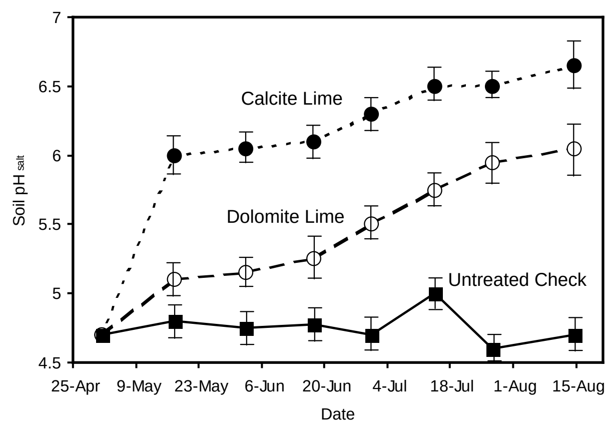

Figure 1. Effect of dolomite and calcite lime applications on soil pH_{salt} at the 0 to 15-cm soil depth. Lime applications were made before cotton planting in 2000 and soil pH_{salt} was measured at 2-wk intervals. Bars indicate standard errors of eight replications.

Table 3. Average cotton lint yields from the short-term lime source experiment for liming treatments

Treatment	Lint yield (kg ha^{-1})[x]			
	2000	2001	2002	Mean
Untreated	663 a	829 b	682 a	725 b
Calcite	809 a	937 ab	713 a	820 a
Dolomite	847 a	934 ab	729 a	838 a
Calcite + $Mg(SO_4)_2$	722 a	983 a	683 a	796 a

[x] **Means within a column followed by the same letter were not significantly different (*P*= 0.05) according to pair-wise contrasts.**

produced the same cotton yield response as calcite lime. Three weeks after lime applications were made, plots with calcite lime had an average pH_{salt} of 6.1 compared with an average pH_{salt} of 5.2 in plots with dolomite lime. By the end of the first growing season, all limed plots had pH values above 6.0. Barber (1984b) summarized that increased crop response to dolomite limestone compared with calcite limestone often occurs when soils are deficient in Mg. In contrast, greater crop response to calcite limestone compared with dolomite limestone can occur due to the faster rate of calcite limestone dissolution.

In the long-term experiment, soil Ca:Mg ratios in plots treated with gypsum and Epsom salts were in the same range as soil samples from cotton fields submitted to the University of Missouri-Delta Center Soil Test Lab over the last decade. Most of the samples in the Missouri soil test database for cotton had exchangeable Ca:Mg ratios ranging from 2 to 4 (Fig. 2). In the long-term experiment, gypsum and Epsom salt treatments altered the exchangeable soil Ca:Mg ratios and produced Ca:Mg ranging from 2.5 to 7.6 (Table 4). Five of the treatments produced soil Mg saturation levels greater than the ideal 6 to 12% range proposed by Graham (1959). Calcium saturation ranged from 57 to 76% and magnesium saturation ranged from 10 to 24%. Soil pH and exchangeable Ca, Mg, and K levels in each treatment remained relatively unchanged from 1999 to 2001 (data not shown).

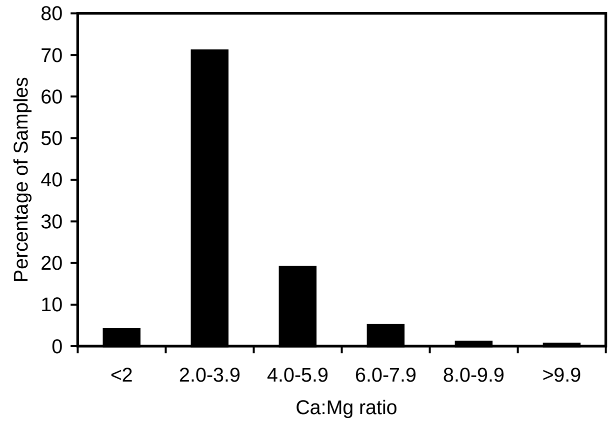

Figure 2. Distribution of exchangeable Ca:Mg ratios (% base saturation) from 2700 soil samples sent to the University of Missouri Delta Center Soil Test Laboratory at Portageville that requested cotton fertility recommendations.

Reducing soil Ca:Mg ratios did not impact cotton K uptake, fiber quality, or lint yield. Whole plant tissue K concentrations at first square were not linearly related to exchangeable soil Ca:Mg ratios (Fig. 3). Also, lint yields were not altered by changes in soil Ca:Mg ratios (Table 4). Researchers studying other crops have also observed little or no effects of high soil Ca and Mg levels on reducing plant K uptake, plant growth and crop quality characteristics (Barber, 1984a; McLean and Brown, 1984; Rehm, 1994).

Table 4. Effect of soil properties from the long-term Ca:Mg ratio experiment on cotton fiber micronaire, uniformity, strength, and lint yields averaged across years

	Soil properties			Harvest measurements			
Ca:Mg ratio	Cation exchange saturation (%)			Cotton fiber properties			Lint yield (kg ha^{-1})
	Ca	Mg	K	Micronaire	Uniformity (%)	Strength (cN tex^{-1})	
7.6	76	10	9	4.3	83.6	27.9	897
7.2	72	10	8	4.3	82.9	28.2	821
7.4	74	10	9	4.2	83.4	28.2	902
6.3	69	11	9	4.3	83.9	28.1	842
4.8	67	14	8	4.1	82.7	27.8	868
4.4	66	15	8	4.2	83.6	28.2	789
2.7	59	22	7	4.4	83.1	28.2	840
2.5	57	23	8	4.2	83.4	28.0	889
2.5	60	24	9	4.3	83.5	27.6	878
Effect[x]				n.s.	n.s.	n.s.	n.s.

[x] **Effects of Ca:Mg ratios on fiber properties and yield were not significant (n.s.) according to pair-wise comparisons (*P*= 0.05).**

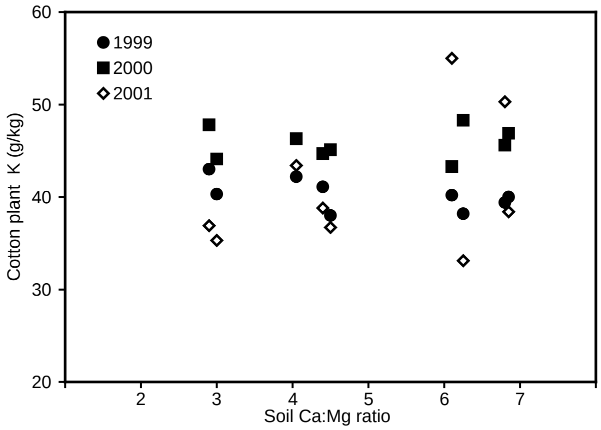

Figure 3. Effect of soil exchangeable Ca:Mg on whole plant tissue K at first square from the long-term Ca:Mg ratio experiment. Each dot represents the mean of four replications.

Dolomite and calcite lime materials were equally effective in increasing yields when applied on acid soil at recommended rates of application. From a long-term perspective, repeated applications of dolomite lime over many years could reduce soil Ca:Mg ratios, but in the Ca:Mg ratio experiment, there were no negative effects on cotton yield from reducing soil Ca:Mg ratios. The highest soil Mg treatment that we tested was 24% Mg base saturation (2.5 Ca:Mg ratio). Under the soil and environmental conditions tested in this research, the BCSR concept did not show any merit for managing cotton fertility on well-drained Delta soils. Cotton farmers with well-drained Delta soils should not be concerned about potential negative effects of Mg in dolomite lime material.

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