Evaluation of the Magnesium Soil Test Interpretation for Peanuts[1]

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ABSTRACT

Decreasing concentrations of extractable Mg in soils of peanut (*Arachis hypogaea* L.) production regions of North Carolina have resulted in increased Mg fertilizer recommendations. There is little soil or plant criteria, however, on which to base Mg deficiency. The objective of this study was to determine the yield and Mg status of peanuts relative to the level of soil Mg. Five counties were surveyed for leaf and soil data in 1989-90. Similar data were available from nine counties in 1970-72. A field experiment was also conducted in 1989-90 in an on-going lime and Mg study. Although the 1990 survey data suggested that phosphogypsum usage during the last decade may be reducing Mg levels in the surface soil, leaf Mg was almost invariably above 2.0 g kg^{-1} for both surveys, reflecting adequate amounts of soil Mg according to current plant analysis standards. In the field study, prior lime and Mg treatments resulted in soil Mg ranging from 0.02 to 0.25 $cmol_c$ L^{-1}, but there was no yield response that could be related directly to Mg. Leaf Mg was positively correlated to surface soil Mg, and inclusion of subsoil Mg slightly improved this relationship. The data from these studies indicated that sufficient leaf Mg (above 2.0 g kg^{-1}) was attained when surface soil Mg was as low as 0.06 $cmol_c$ L^{-1} or as low as 3 percent of the CEC. We feel these estimates of the soil Mg critical level for peanut production are high, as there was not a Mg deficiency with leaf Mg as low as 1.5 g kg^{-1} in the field study.

Key Words: Peanuts, Magnesium, Soil test, Critical level, Plant analysis.

Magnesium fertilization for peanuts is recommended in North Carolina when the Mehlich-3 extractable Mg in the surface soil (0 to 20 cm) is either below 0.25 $cmol_c$ L^{-1}, or below 0.50 $cmol_c$ L^{-1} if the Mg saturation of the cation exchange capacity (CEC) is less than 10% (Tucker and Rhodes, 1987). These critical levels are based on guidelines for tobacco (*Nicotiana tabaccum* L.), a crop sensitive to low soil Mg levels. These critical levels are apparently too high for peanuts, as a Mg deficiency has never been reported in the region.

Recommendation for Mg fertilization of peanuts (*Arachis hypogaea* L.) have increased during the past 10 years in North Carolina (Personal communication, M. R. Tucker, 1990), reflecting decreasing amounts of Mg in the soils and increasing the possibility of Mg deficiencies. This change may be due to differences in Ca fertilization, as the use of phosphogypsum has increased steadily over the last decade. Phosphogypsum is a moist calcium sulfate by-product from processing rock phosphate. Previously, the main source of Ca was bagged landplaster, which is banded over the row, or over half the land area. Since phosphogypsum is applied by broadcasting, to attain similar amounts of Ca in the fruiting zone, twice the amount of Ca per acre is required. Shortened crop rotations in the past decade have also resulted in increased applications of Ca. The increased use of phosphogypsum and the greater frequency of application may be resulting in increased exchange of Ca for Mg, allowing Mg to leach (Alva and Gascho, 1991).

Brady and Colwell (1945) found no peanut yield response to Mg fertilization on a soil that had an extractable Mg content of 0.27 $cmol_c$ kg^{-1}. Although they did not use the Mehlich-3 solution, most extraetants used in routine soil testing will remove essentially the same concentration of Mg (Gascho *et al.*, 1990; Hanlon and Johnson, 1984). Adams and Hartzog (1980) grew peanuts in the field on six soils with Mg contents of 0.03 to 0.11 $cmol_c$ kg^{-1}. Yields were improved with the application of Mg only on the soil with the lowest extractable Mg. This soil had a grossarenic (deep, sandy) surface horizon and was the only one without a clayey subsoil within the rooting zone. Walker *et al.* (1989) also obtained peanut yield responses two of three years on a similar soil, a Typic Quartzipsamment, and concluded that the minimal soil Mg sufficiency level should be 0.09 $cmol_c$ kg^{-1}.

Adams and Hartzog (1980) noted that surface soil Mg can be quite low without affecting peanut yield, and postulated that Mg sufficiency may well be determined by Mg in the subsoil. They noted that a clayey subsoil is a source of Mg accumulation, similar to K, as reported by Woodruff and Parks (1980). Chesney (1975) also found that peanuts did not respond to Mg treatments on a Kasarema loamy sand, a soil with trace amounts of extractable Mg in the surface soil. Clay content increased with depth in this soil, but not enough to establish an argillic horizon. Based on information provided in the original article, this soil would most probably be classified as an Ustic Quartzipsamment.

The response of peanuts to Mg fertilization may depend on the concentration of other cations in the soil. Strauss and

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Grizzard (1947) showed that the number of nuts produced per plant was positively related to the K:Mg ratio. Aluminum may also be important. Adams and Pearson (1970) evaluated the effect of increased subsoil acidity, i.e., increased Al, on peanut roots. They found peanut roots to be tolerant of acidic conditions when provided adequate Ca. Excavation revealed numerous peanut roots to a depth of 90 cm in acid subsoils.

Interpretations of the Mg concentration in the most recently matured leaf of virginia-type peanuts at flowering are (1) deficiency with less than 2.0 g kg^{-1} Mg and (2) sufficiency with 3.0 to 8.0 g kg^{-1} Mg (Personal communication, C. R. Campbell, 1991). Walker *et al.* (1989) found that the minimum sufficiency level of leaf Mg for maximum yield of runner peanuts was 2 g kg^{-1}. Although information in the literature regarding the critical level of leaf Mg is sparse, the current level identifying deficiency appears to be too high. Reid (1956) grew peanuts in sand culture and supplied both a complete nutrient solution and one excluding Mg. Foliar analysis of the leaves from deficient plants revealed Mg to be 0.6 g kg^{-1}, so the critical level is probably between 0.6 and 2.0 g kg^{-1}. In essence, it appears that little is known of the actual soil or plant Mg critical level for peanuts.

The objectives of this study were to (a) determine the effect of Mg concentrations in the soil and leaf on peanut yield, (b) determine the relationship between leaf and soil Mg, (c) determine if the use of phosphogypsum seems to be related to lower Mg in the topsoil, and (d) make more realistic estimates of Mg critical levels, both in the soil and in leaves, for peanut production.

Material and Methods

Field Procedures

Field Study: 1989-1990

Peanuts were grown in 1989 and 1990 on a Wagram loamy sand (loamy, siliceous, thermic Arenic Kandiudult). The experimental design was a split-plot with main plots arranged in four randomized complete blocks. Main plot treatments consisted of residual effects of dolomitic limestone (approximately 10% Mg and 20% Ca by weight) applied in July 1980 at rates of 0, 1700, and 3400 kg ha^{-1}. Calcitic lime (approximately 0.3% Mg and 34% Ca by weight) was applied in February 1989 to the 0 and 1700 kg ha^{-1} main plot treatments at the rate 3600 and 900 kg ha^{-1}, respectively, to eliminate surface soil pH differences. Subplot treatments of Mg were also residual effects. Magnesium was applied as $MgSO_4$ in 1981 at rates of 0, 8.5, 17, and 29 kg ha^{-1}, and 1982-85 and 1987 at rates of 0, 11, 22, and 44 kg ha^{-1}. Main plot size was 33.5 x 9.3 m and subplot size was 16.75 x 4.65 m.

Peanut cultivar NC 7 was planted on April 27, 1989, the first year peanuts were grown at this site, and May 1, 1990. Peanuts were inoculated with Rhizobia, treated with molybdenum, planted, and cultivated according to common cultural practices. Molybdenum was applied because high acidity is known to reduce Mo availability. Landplaster, 90%, $CaSO_4$, was banded over the peanut row at pegging at 670 kg ha^{-1}. Boron was applied with the first application of fungicide at 0.56 kg ha^{-1}. To address N deficiency symptoms that apparently resulted from poor rhizobial infection, N was applied at 112 kg ha^{-1} as NH_4NO_3 during the first week of August, 1989. Peanuts were dug October 6, 1989, and October 8, 1990.

Soil samples were collected March 15, 1989, and July 11, 1990. In 1989, soil samples (a composite of 2 cores per plot) were collected to a depth of 120 cm at 20 cm increments. The 1990 soil samples were collected from the top 20 cm and were a composite of 6 cores per plot. Soil samples were taken from the center 2 or 3 rows of the plot and not closer than 3 m to the end of the plot.

Leaf samples were collected on June 8 and August 2, 1989 (42 and 97 days after planting), and July 11, 1990 (71 days after planting). Flowering usually begins about forty days after planting. The samples consisted of 100 of the most recently matured leaves per plot selected from the 3 innermost rows not closer than 3 m to the end of the plot.

Two center rows from each plot were harvested. Peanuts were placed in nylon mesh bags and dried to approximately 10% moisture in forced-air bins. The dried peanuts were weighed and a random subsample taken for grading as virginia-type peanuts.

Survey: 1989-1990

Leaf and soil samples were collected from peanut fields of average producers in five counties. One site per farm was selected; two if there were different soil types or cropping/management systems. In 1989, 22 sites were selected. In 1990, 101 new sites were selected, 1/5 of which were from Bladen County, where phophogypsum usage is rare, and 4/5 from four counties where phosphogypsum usage is common. The 1989 soil and leaf samples were collected July 25 to 27. No landplaster had been applied to the 1989 sites. The 1990 soil samples were collected May 15 to 23, prior to landplaster application. Leaf samples (100 of the most recently matured leaves) were collected July 3 to 9, after the application of landplaster, from an area of approximately 40 m^2. Soil samples were composites of 5 cores per sample area at 20 cm increments to a depth of 80 cm. At some sites, dry subsoils limited depth of probe penetration to less than 80 cm.

Survey: 1970-1972

A survey of the peanut production regions in North Carolina was conducted by F. R. Cox and C. D. Sopher from 1970 to 1972 (Unpublished data). Three hundred thirteen sites were selected from 30 farms in nine counties. Three or four farms of average to above average producers were selected from each of three different counties each year. Approximately 10 sites, located on different soil series, were selected from each farm. Each site was two rows wide and 15 m long. Surface soil samples (0 to 20 cm) were collected shortly after planting, while leaf samples were collected during early flowering, before application of landplaster.

Laboratory Analyses

Magnesium, K, and Ca were extracted from the 1989-90 soil samples using the Mehlich-3 solution (Mehlich, 1984). Water pH (1:1) and Mehlich-buffer acidity were determined according to the procedure described by Mehlich (1976). The CEC was calculated as the sum of the Mehlich-buffer acidity and extractable Mg, K, and Ca. The concentration of cations removed with the Mehlich-3 solution is highly correlated to that removed with neutral 1 *M* ammonium acetate (Mehlich, 1984). Base saturation was calculated as the percentage of the CEC occupied by extractable Mg, K, and Ca. Saturation of any cation was calculated as the percentage of CEC occupied by that cation.

All chemical analyses of the 1972 soil samples were performed by the North Carolina Department of Agriculture (NCDA) Agronomic Division using the Mehlich-1 extractant (0.050 *M* HCl + 0.0125 *M* H_2SO_4).

Leaf samples for 1989-90 were analyzed by the Analytical Service Laboratory, Department of Soil Science, North Carolina State University. Samples were dried in a forced-draft oven at 70 C for 48 h, ground to pass a 1 mm sieve, dry ashed for 12 h at 500 C in a muffle furnace, and dissolved in 6 *M* HCl. For the 1989 samples, P, K, Ca, Mg, Mn, Cu, Zn, Fe, and Al were determined by ICP. Magnesium was determined for the 1970 to 1972 and the 1990 samples by atomic absorption. Kernel samples for the 1989 data were analyzed similar to leaf samples except for using a special mill to produce a peanut flour prior to dry ashing.

Statistical Analyses

Statistical analyses were conducted using least squares to fit linear models. The particular procedures used, notably GLM and REG, were from Version 6 Edition of SAS (SAS Institute Inc., 1987). F-tests for the analyses of variance of the field study data were considered significant at the 5% probability level. Although the treatments are quantitative, LSD values (P=0.05) for significant F-tests are included for the reader's

Table 1. Repeated measures analyses of variance table for soil Mg in 1989.

Source	Degrees of Freedom	Mean Squares	F	Pr > F
Block	3	0.01014	1.61	
Lime	2	0.10088	94.96	0.0002
Block*Lime (Error a)	6	0.00224	0.36	
Mg	3	0.00807	1.28	0.3010
Lime*Mg	6	0.00251	0.04	0.8732
(Error b)	27	0.00630		
Depth	5	2.17960	39.79	0.0001
Depth*Block (Error c)	15	0.00548		
Depth*Lime	10	0.06182	1.66	0.1363
Depth*Block*Lime (Error d)	30	0.03716		
Depth*Mg	15	0.01584	0.80	0.6798
Depth*Lime*Mg	30	0.00751	0.38	0.9986
(Error e)	135	0.01989		

convenience. Class variables consisted of the residual effect of three dolomitic lime rates as whole plot treatments, residual effects of four Mg rates as subplot treatments, and four blocks. Univariate repeated measures analyses of variance were used to compare soil variables with depth (six 20-cm increments) and to compare separate measurements in time on individual experimental units (Moser *et al.*, 1990). To illustrate the repeated measures analysis of variance, the analysis for soil Mg is presented in Table 1. Regression and correlation were used to determine relationships among factors in both the field study and the surveys. The Maximum R^2 technique (SAS Institute, Inc., 1987) in stepwise regression was used to determine the relationship between leaf Mg and linear and quadratic terms for soil Mg at various depths in both the field study and survey data.

Contrasts between Bladen County, where phosphogypsum has not been used extensively, and the other counties where phosphogypsum has been applied commonly, were used in evaluating differences in leaf Mg, surface soil extractable Mg, Ca, Mg:Ca ratio, and Mg and Ca saturation. Single-degree-of-freedom F-tests were considered significant at the 5% probability level.

Results

Field Study

Yield and Grade

Yield, percent sound mature kernels (% SMK), and percent extra large kernels (% ELK) for the 1989 season were increased with increasing residual lime rate, but were unaffected by this treatment in 1990 (Table 2). The residual effect of prior Mg rate did not affect peanut yield, % SMK, or % ELK in either year (Table 2).

Leaf Analyses

Both residual lime and Mg treatments significantly increased leaf Mg at 42 and 97 days after planting in 1989, and at 71 days after planting in 1990 (Table 2). An average increase in leaf Mg of 0.4 g kg^{-1} occurred between 42 and 97 days after planting in 1989, an increase that was not significantly different across all treatment combinations. In July 1990, leaf Mg averaged 0.7 and 1.1 g kg^{-1} lower than in June and August 1989, respectively.

Table 2. Residual effect of lime and Mg treatments on yield, grade, kernel Mg, and leaf Mg in the field study in 1989 and 1990.

Lime 1980	Lime 1989	Yield	SMK	ELK	Kernel Mg	Leaf Mg 42 d[§]	Leaf Mg 71 d	Leaf Mg 97 d
kg ha^{-1}		kg ha^{-1}	--- % ---		------------ g kg^{-1}	------------		
					1989			
0	3600	1615	60.0	41.8	1.8	1.9		2.5
1700	900	2699	61.4	46.2	1.7	2.7		3.3
3400	0	3571	64.5	51.2	1.8	4.0		4.0
SE[†]		341*	0.95*	1.23*	0.02	0.08*		0.08*
LSD		1182	3.3	4.3	NS	0.3		0.3
					1990			
0	3600	2964	52.0	42.3			1.5	
1700	900	2767	52.6	42.8			2.1	
3400	0	3171	54.2	44.7			3.0	
SE[†]		123	1.06	1.10			0.08*	
LSD		NS	NS	NS			0.3	
Mg					1989			
0		2700	64.2	48.9	1.8	2.5		2.9
11		2522	61.2	45.2	1.8	2.8		3.3
22		2464	60.1	44.0	1.8	2.8		3.3
44		2827	62.4	47.5	1.8	3.3		3.6
SE[‡]		98	0.65	1.05	0.02	0.09*		0.07*
LSD		NS	NS	NS	NS	0.3		0.2
					1990			
0		2956	52.0	42.0			1.9	
11		2964	53.4	44.0			2.1	
22		2928	52.9	42.8			2.3	
44		3024	53.5	44.3			2.5	
SE[‡]		116	0.81	0.95			0.07*	
LSD		NS	NS	NS			0.2	

[†] Standard errors were calculated using $(MS\ block*lime/16)^{0.5}$.
[‡] Standard errors were calculated using $(MSE/12)^{0.5}$.
* Significant difference with treatment and LSD at P = 0.05.
[§] Days after date of planting.

Table 3. Residual effect of lime treatments on extractable cations and soil reaction at each depth in the field study, March 1989.

Depth	Lime (kg ha^{-1}) 0	1700	3400	SE[†]	LSD	Lime (kg ha^{-1}) 0	1700	3400	SE[†]	LSD
cm	Ca					K				
	---------- cmol$_c$ L^{-1} ----------									
0-20	0.47	0.42	0.66	0.064	NS	0.06	0.07	0.10	0.006*	0.02
20-40	0.46	0.35	0.51	0.005	NS	0.07	0.08	0.10	0.009	NS
40-60	0.34	0.47	0.54	0.120	NS	0.11	0.13	0.11	0.097	NS
60-80	0.86	1.01	0.78	0.088	NS	0.19	0.19	0.14	0.011*	0.04
80-100	0.75	0.78	0.69	0.147	NS	0.17	0.16	0.13	0.015	NS
100-120	0.60	0.59	0.58	0.114	NS	0.16	0.14	0.13	0.009	NS
cm	Soil Reaction					Mg				
	---------- pH ----------					-------- cmol$_c$ L^{-1} --------				
0-20	5.0	5.1	5.3	0.084	NS	0.03	0.05	0.16	0.010*	0.03
20-40	5.0	5.2	5.4	0.083*	0.3	0.02	0.04	0.13	0.013*	0.05
40-60	4.6	4.8	4.9	0.049*	0.2	0.10	0.22	0.34	0.079	NS
60-80	4.6	4.7	4.7	0.018*	0.1	0.31	0.54	0.51	0.030*	0.10
80-100	4.6	4.7	4.6	0.057	NS	0.38	0.59	0.52	0.056	NS
100-120	4.5	4.6	4.6	0.062	NS	0.46	0.63	0.51	0.042	NS

[†] Standard errors at each depth were calculated using $(MS\ block*lime/16)^{0.5}$.
* Significant difference with treatment and LSD at P = 0.05.

Soil Analyses

Although residual lime caused an increase in pH at 20 to 80 cm (Table 3), there was no lime x depth interaction, and the mean soil pH across all treatments decreased from 5.1 at the surface to 4.6 at about 100 cm. Magnesium and K contents at specific depths increased with residual lime, but with no lime X depth interaction. Basic cation content, thus, increased with depth for all treatment combinations. Surface soil variables affected by lime treatments in 1989 were extractable Mg and K, Mg saturation, and base saturation. By 1990, the only surface soil variables affected by the lime treatments were extractable Mg and Mg saturation (Table 4).

Residual Mg treatments increased extractable Mg in 1989 and extractable Mg and Mg saturation in 1990 for the top 20 cm (Table 4), but did not affect these variables in the subsoil. No other soil variables evaluated were affected by Mg treatments at any depth for either year.

Survey: 1989-1990

Leaf Mg ranged from 2.0 to 6.2 g kg^{-1} with a mean of 4.0 g kg^{-1}. Mehlich-3 extractable Mg in the top 20 cm ranged from 0.08 to 1.07 cmol$_c$ L^{-1} with a mean of 0.36 cmol$_c$ L^{-1}.

Leaf Mg and extractable Mg and Mg: Ca ratio were all significantly higher in Bladen County (Table 5). Calcium saturation was lower in Bladen County. Extractable Ca and Mg saturation were not different between Bladen and the other four counties.

Survey: 1970-1972

Leaf Mg ranged from 1.3 to 7.9 g kg^{-1} with a mean of 3.7 g kg^{-1}. Mehlich-1 extractable Mg in the topsoil ranged from 0.03 to 1.35 cmol$_c$ L^{-1} with a mean of 0.30 cmol$_c$ L^{-1}. Average

Table 4. Residual effect of lime and Mg treatments on surface soil variables in the field study in 1989 and 1990.

Lime 1980	Lime 1989	Mg	K	Ca	CEC	Base sat.	Mg sat.	pH
kg ha^{-1}		---------- cmol$_c$ L^{-1}			---------	----- %	----	
				1989				
0	3600	0.03	0.06	0.47	2.38	27.2	1.3	5.0
1700	900	0.05	0.07	0.42	2.75	24.9	2.2	5.1
3400	0	0.16	0.10	0.66	2.84	39.3	6.6	5.3
SE†		0.010*	0.006*	0.064	0.253	3.27*	0.54*	0.084
LSD		0.03	0.02	NS	NS	11.3	1.9	NS
				1990				
0	3600	0.05	0.04	1.34	2.84	50.7	1.7	5.0
1700	900	0.06	0.05	1.09	2.62	45.1	2.2	4.8
3400	0	0.10	0.05	1.20	2.78	49.0	3.7	4.9
SE†		0.004*	0.002	0.081	0.170	2.13	0.11*	0.046
LSD		0.01	NS	NS	NS	NS	0.4	NS
Mg kg ha^{-1}				1989				
0		0.06	0.07	0.49	1.82	34.3	3.4	5.2
11		0.07	0.08	0.54	2.96	32.4	3.3	5.1
22		0.07	0.08	0.50	2.50	28.8	3.1	5.2
44		0.12	0.08	0.55	3.39	26.7	3.9	5.1
SE‡		0.010*	0.005	0.059	0.427	3.49	0.47	0.083
LSD		0.03	NS	NS	NS	NS	NS	NS
				1990				
0		0.06	0.05	1.14	2.72	46.3	2.3	4.9
11		0.06	0.05	1.20	2.81	46.2	2.3	4.9
22		0.07	0.05	1.26	2.74	50.1	2.6	4.9
44		0.08	0.05	1.24	2.71	50.5	3.0	4.8
SE‡		0.004*	0.002	0.085	0.113	1.93	0.11*	0.040
LSD		0.01	NS	NS	NS	NS	0.3	NS

† Standard errors were calculated using (MS block*lime/16)$^{0.5}$.
‡ Standard errors were calculated using (MSE/12)$^{0.5}$.
* Significant difference with treatment and LSD at P = 0.05.

Table 5. Means and standard errors of leaf Mg, extractable Mg, Ca, and Mg:Ca ratio, saturation of Mg and Ca, and CEC for the 1990 survey.

	Leaf Mg	Extractable			Saturation		CEC
		Mg	Ca	Mg:Ca	Mg	Ca	
	g kg^{-1}	---- cmol$_c$ L^{-1}		---	---- %	-----	cmol$_c$ L^{-1}
			Bladen County (n=21)				
Mean	5.1	0.45	2.03	0.22	10.9	50.6	4.0
SE†	0.14	0.054	0.186	0.010	0.688	2.086	0.306
			Four Counties‡ (n=20 for each)				
Mean	3.9*	0.35*	1.20	0.18*	9.9	56.1*	3.5
SE†	0.09	0.019	0.091	0.007	0.364	0.951	0.125

† SE = Standard errors.

‡ Four Counties = Northampton, Halifax, Bertie, and Martin.

* Significant difference between Bladen and Four Counties at the 5% probability level.

extractable Mg:Ca ratio for the 1970-1972 survey was similar to the four counties in the 1989-90 survey that were exposed to the use of phosphogypsum, and slightly lower than Bladen County.

Discussion

Field Study

Increases in yield, % SMK, and % ELK in 1989 occurred concurrently with increases in leaf Mg, surface soil extractable Mg and K, and base saturation; factors associated with increased residual lime. In 1990, there was no increase in yield or grade with increasing lime rate, but there was an increase in leaf Mg, extractable Mg, and Mg saturation. In 1990, leaf Mg with the 0 residual lime treatment was well below the current critical level without response in yield, suggesting that 2.0 g kg^{-1} is too high a limit for indicating Mg deficiency in peanuts (Table 2). Because no yield or grade response occurred in 1990, but occurred in 1989, base saturation appears to be contributing to increased yield and grade in 1989. The importance of adequate base saturation for soybean has been demonstrated by Evans and Kamprath (1970), but there are no reports clearly defining adequate base saturation for peanuts. The difference in soil and leaf Mg across lime treatments appears to have no effect on peanut yield.

Leaf and soil Mg increased with increasing Mg rate for both years without any differences in yield, grade, or other soil variables, indicating adequate leaf and soil Mg levels across these treatments (Tables 2 and 4). Leaf Mg was less than 2.0 g kg^{-1} in 1990 and soil Mg was less than 0.1 cmol$_c$ L^{-1} both years in the plots where no Mg had been applied.

Despite differences in leaf and soil Mg across lime and Mg treatments, there is no yield response that can be attributed to differences in leaf and soil Mg. Therefore, the critical level of soil Mg can not be ascertained from a yield response curve, implying adequate soil Mg even at the lowest treatment level. However, the soil and leaf Mg relationship can be evaluated to determine the level of soil Mg required to attain the current critical level for leaf Mg.

To evaluate the relationship between leaf and soil Mg in June 1989, a stepwise regression indicated that the linear and quadratic terms of soil Mg from the top 20 cm resulted in $R^2 = 0.87$. A slight improvement in the R^2 (0.90) occurred when the linear term of Mg from 60 to 80 cm was included in the regression (Table 6). Similar results were obtained with the August 1989 leaf samples. Although soil Mg from 60 to 80 cm contributes significantly to the relationships between leaf and soil Mg, the surface soil Mg explains most of this relationship. Complicating the practical use of this model by including soil Mg at 60 to 80 cm does not seem justified by the small improvement of the R^2 value. Surface soil Mg appears to adequately explain the leaf Mg in these samples.

For the 1990 leaf samples, soil Mg values from the 1989 soil samples were included for depths below 20 cm. Again, surface soil Mg explained most of this relationship (Table 6). The quadratic term of extractable Mg from the top 20 cm

Table 6. Regression equations for relationship between leaf Mg and extractable soil Mg in the field study and surveys.

Sampling date	Regression equation†	r^2 or R^2
Field study		
June, 1989	LFMG = 0.19 + 1.15(MG1)	0.78
	LFMG = 0.15 + 2.22(MG1) - 3.89(MG1)^2	0.87
	LFMG = 0.12 + 2.01(MG1) - 3.38(MG1)^2 + 0.10(MG4)	0.90
August, 1989	LFMG = 0.27 + 0.77(MG1)	0.61
	LFMG = 0.23 + 1.72(MG1) - 3.47(MG1)^2	0.72
	LFMG = 0.20 + 1.53(MG1) - 3.02(MG1)^2 + 0.09(MG4)	0.77
July, 1990	LFMG = 0.07 + 2.14(MG1)	0.73
	LFMG = 0.06 + 1.91(MG1) + 0.10(MG3)	0.81
	LFMG = 0.05 + 1.58(MG1) + 0.11(MG3) + 0.05(MG5)^2	0.83
Surveys		
1970-72	LFMG = 0.30 + 0.25(MG1)	0.19
1989	LFMG = 0.25 + 0.32(MG1)	0.52
	LFMG = 0.15 + 0.96(MG1) - 0.77(MG1)^2	0.64
1990	LFMG = 0.33 + 0.23(MG1)	0.26

† LFMG = leaf Mg concentration as a percentage of dry weight.
MG1 = extractable soil Mg (cmol$_c$ L^{-1}) at 0 to 20 cm.
MG3 = extractable soil Mg (cmol$_c$ L^{-1}) at 40 to 60 cm.
MG4 = extractable soil Mg (cmol$_c$ L^{-1}) at 60 to 80 cm.
MG5 = extractable soil Mg (cmol$_c$ L^{-1}) at 80 to 100 cm.
Each variable included in a regression equation is significant at the 5% probability level.

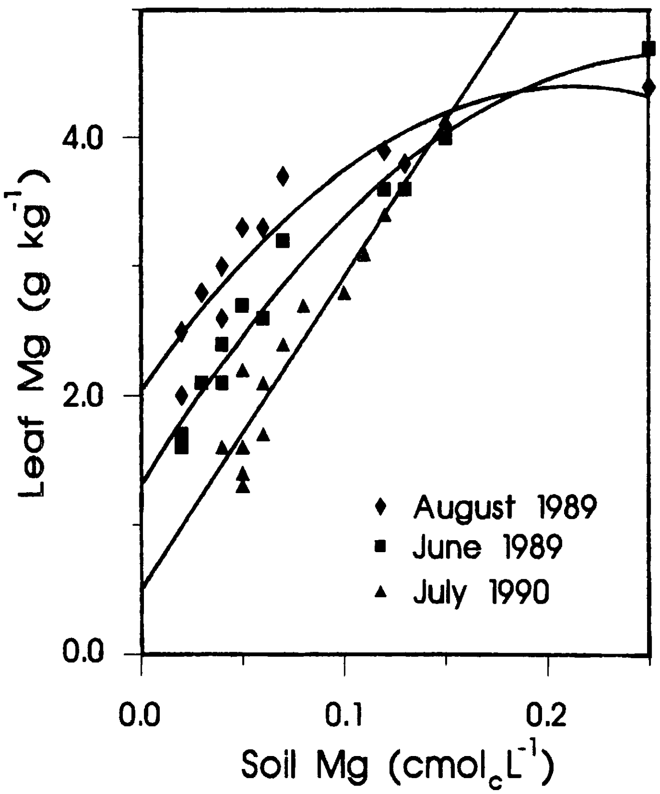

Fig. 1. Relationship between leaf and extractable surface soil Mg for the field study in 1989 and 1990. Equations and r^2 values are given in Table 6.

was missing in 1990, as compared to 1989, but the absence of the quadratic term was a result of a smaller range of soil Mg (Fig. 1). Subsoil Mg did contribute slightly to the relationship with leaf Mg, but in our opinion, the additional complication of the model was not justified by the improvement in the R^2 value (Table 6).

The relationship between leaf and soil Mg was similar regardless of whether one considers soil Mg in terms of $cmol_c L^{-1}$ or percent saturation of the CEC (data not shown). Using surface soil Mg to estimate leaf Mg, leaf Mg of at least 2.0 $g kg^{-1}$ is attained for all sampling dates when extractable Mg is 0.06 $cmol_c L^{-1}$ or when the Mg saturation is 3%. These soil Mg criteria for estimating leaf Mg are lower than the current critical levels of 0.25 $cmol_c L^{-1}$ extractable Mg and 0.50 $cmol_c L^{-1}$ when Mg saturation is less than 10%, as currently used in North Carolina.

Leaf Mg concentration was significantly different between sample dates in 1989 (0.29, std error = 0.007 and 0.33, std error = 0.004 for 42 and 98 days after planting, respectively), and between 1990 (0.22, std error = 0.005) and 1989 sample dates, but the differences were the same for all treatment combinations. This decrease in leaf Mg from 1989 to 1990 could possibly be due to an antagonistic effect of Ca on Mg uptake. After applying large amounts of Ca in the form of landplaster in 1989 and 1990, the extractable Mg;Ca ratio in the surface soil had decreased dramatically by July 1990 (Table 4). Strauss and Grizzard (1947) have shown that peanuts can be sensitive to cationic ratios, as yields were shown to be related to K:Mg ratios in the soil. Although leaf Mg was lower in 1990, the leaf and soil Mg relationship was similar over the same range of soil Mg as in 1989. Adequate leaf Mg was attained at 0.06 $cmol_c L^{-1}$ of surface soil Mg (Fig. 1).

Despite the low subsoil pH of this Wagram soil, Mg accumulated in the subsoil appears to be a nutritional source for the peanut plant based on the leaf and soil Mg regressions. Research by Adams and Pearson (1970), Sullivan, *et al.* (1974), and F. R. Cox (Unpublished data, 1989) has indicated that peanuts are tolerant to acidic soil conditions and may root to a depth of 90 cm in acidic subsoils. Such roots could take up Mg and K from the subsoil. Woodruff and Parks (1980) found a significant contribution to soybean leaf K from K in the B horizon. In studies with very low Mg in the topsoil, such as reported by Adams and Hartzog (1980) and Chesney (1975), it has been suggested that Mg from the subsoil contributed to the nutrition of peanuts. Although subsoil Mg appears to contribute to leaf in this soil, surface soil Mg explained most of the relationship between leaf and soil Mg (Table 6).

Despite low surface soil Mg and an accessible accumulation of subsoil Mg, an evaluation of surface soil Mg appears adequate in establishing criteria for critical soil Mg levels.

Survey: 1989-1990

Two geographical areas of the Coastal Plain of North Carolina were represented in the 1990 survey. The northeast part of the state was represented with four counties where farmers have used phosphogypsum the past ten years. The southeast part of the state, where phosphogypsum is seldom used, was represented with Bladen County. Contrasts between these two areas indicated that leaf Mg, extractable Mg, and extractable Mg:Ca were all higher in Bladen County. Calcium saturation was lower in Bladen County and extractable Ca, Mg saturation and CEC were not significantly different (Table 5). These results suggest the possibility that phosphogypsum may be responsible for decreasing the level of Mg in the surface soil.

Sufficient to high levels of leaf Mg in the 1989-1900 survey samples reflect an adequate supply of soil Mg (Fig. 2). A regression evaluating the contribution of extractable Mg from the 20 cm increment that included the top of the B_t horizon, as noted in the field, to leaf Mg did not result in a significant correlation.

The linear term of extractable Mg in the top 20 cm for the 1990 survey was significantly correlated with leaf Mg (r^2 = 0.26, Table 6). Addition of the quadratic term of soil Mg did not contribute significantly to the model. This model suggests a linear relationship between leaf and surface soil Mg.

Although with fewer samples, the 1989 data resulted in linear and quadratic terms of soil Mg contributing significantly to the model (r^2 = 0.64, Table 6). While the quadratic term was not included in the 1990 regression, the 1989 observations are fewer and not as representative of the higher end of the soil Mg scale (Fig. 2). Therefore, the linear model for the 1990 data appears more representative of the leaf and surface soil Mg relationship for the 1989-1990 survey data.

Combining data from the field study and the survey provided a wider and more continuous set of data points for soil Mg content, from as low as 0.02 $cmol_c L^{-1}$ to as high as 1.07 $cmol_c L^{-1}$ (Fig. 2). The field data was best described by a quadratic relationship (June 1989) and represented the lower end of the soil Mg spectrum, while the survey data was best described with a linear relationship (1990) and represented higher values of the soil Mg spectrum. Since the

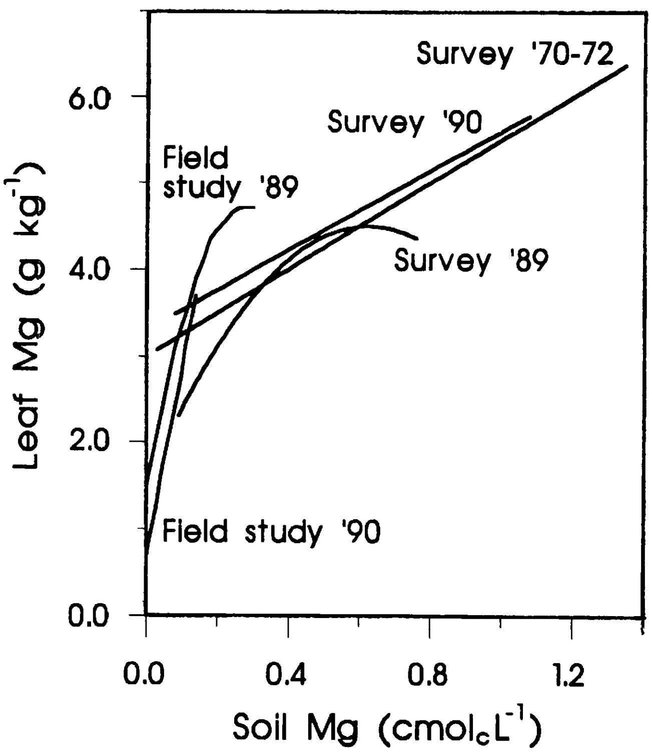

Fig. 2. Relationship between leaf and extractable surface soil Mg for the field study and survey data.

field data represented observations from a single experiment and were restricted to soil Mg levels much lower than generally found in the survey, there was not enough overlap of data to statistically determine if one curve could represent the relationship between leaf and soil Mg over the range of surface soil Mg from 0.02 to 1.07 $cmol_c\ L^{-1}$. However, placing the predicted curves from each set of data on the same graph illustrates how one curve might describe the leaf and Mg relationship over a broader spectrum of soil Mg (Fig. 2). As the soil Mg increased from near zero to approximately 0.2 $cmol_c\ L^{-1}$, leaf Mg increased in a quadratic fashion to approximately 4.0 g kg^{-1}, as seen with the 1989 field data. Continuing with increasing soil Mg levels from 0.2 to 1.1 $cmol_c\ L^{-1}$, the 1990 survey data indicated that leaf Mg increased gradually in the range of 4.0 to 6.0 g kg^{-1} leaf Mg.

Survey: 1970-1972

Reviewing the data collected by F. R. Cox and C. D. Sopher (Unpublished, 1972) may permit a broader interpretation of the current studies. Since phosphogypsum was not used as a calcium fertilizer in 1970-1972, a comparison between the data from the current survey with the 1970-1972 data permits an evaluation of Mg:Ca content of the surface soils over this time period. If increased use of phosphogypsum has resulted in "loading" of Ca on the exchange sites and the leaching of Mg down the soil profile, expected Mg:Ca ratios in the topsoil should be lower in 1989 and 1990 than in 1970-1972. However, mean values for these data indicated that Ca is not occupying any more exchange sites relative to Mg in 1989 and 1990, as compared to 1970-1972. Magnesium in the surface soil in 1989 and 1990 has not decreased to an average level lower than that in 1970-1972. In fact, results indicated increasing amounts of extractable Mg and Mg:Ca in the soils of the peanut production areas of North Carolina during this time period. This increase in Mg and Ca in the surface soils could be a result of increased use of fertilizers in recent years. Although Mg fertilizer recommendations for peanuts have increased during the past ten years, the comparison between the 1970-1972 study and the 1989 and 1990 studies does not specifically represent the ten year trends, but changes over a twenty year period. The contrasts between counties with and without the use of phosphogypsum, as mentioned previously with the 1990 survey, provides a better evaluation of this situation.

The leaf and soil Mg relationship for the 1970-1972 survey indicated a similar relationship as found with the 1990 survey (Table 6, Fig. 2). All surveys indicated that adequate levels of soil Mg existed in the peanut production regions of North Carolina both in 1970-1972 and in 1989-1990. Although the use of phosphogypsum may reduce levels of surface soil Mg, the field study has shown that current critical levels for soil Mg in peanuts are too high. Surface soil Mg as low as 0.06 $cmol_c\ L^{-1}$ provided leaf Mg above the critical level of 2.0 g kg^{-1}.

Literature Cited

1. Adams, F. and D. L. Hartzog. 1980. The nature of yield responses of Florunner peanuts to lime. Peanut Sci. 7:120-123.
2. Adams, Fred and R. W. Pearson. 1970. Differential response of cotton and peanuts to subsoil acidity. Agron. J. 62:9-12.
3. Alva, A. K. and G. J. Gascho. 1991. Differential leaching of cations and sulfate in gypsum amended soils. Commun. Soil Sci. Plant Anal. 2:1195-1206.
4. Brady, N. C. and W. E. Colwell. 1945. Yield and quality of largeseeded type peanuts as affected by K and certain combinations of K, Mg, and Ca. J. Am. Soc. Agron. 37:429-444.
5. Chesney, H. A. D. 1975. Fertilizer studies with groundnuts on the brown sands of Guyana. I. Effect of nitrogen, inoculum, magnesium, and fritted micronutrients. Agron. J. 67:7-10.
6. Evans, Clyde E. and E. J. Kamprath. 1970. Lime response as related to percent Al saturation, solution Al, and organic matter content. Soil Sci. Soc. Am. Proc. 34:893-896.
7. Gascho, G. J., T. P. Gaines, and C. O. Plank. 1990. Comparison of extractants for testing Coastal Plain soils. Commun. Soil Sci. Plant Anal. 21:1051-1077.
8. Hanlon, E. A. and G. V. Johnson. 1984. Bray/Kurtz, Mehlich-3, AB/D and ammonium acetate extractions of P, K and Mg in four Oklahoma soils. Commun. Soil Sci. Plant Anal. 15:277-294.
9. Mehlich, A. 1976. New buffer pH for rapid estimation of exchangeable acidity and lime requirement of soils. Commun. Soil Sci. Plant Anal. 7:637-652.
10. Mehlich, A. 1984. Mehlich-3 soil test extractant: A modification of Mehlich-2 extractant. Commun. Soil Sci. Plant Anal. 15:1409-1416.
11. Moser, E. B., A. M. Saxton, and S. R. Pezeshki. 1990. Repeated measures analysis of variance: Application to tree research. Can. J. For. Res. 20:524-535.
12. Reid, P. H. 1956. Some physiological and chemical changes in peanuts affected by fruit development and the level of nutrient elements. Ph.D. diss. North Carolina State University, Raleigh (Diss. Abstr. 56-3157).
13. SAS Institute Inc. 1987. SAS/STAT Guide for Personal Computers, Version 6 Edition. SAS Institute Inc., Cary, North Carolina.
14. Strauss, J. L., and A. L. Grizzard. 1947. The effect of calcium, magnesium, and potassium on peanut yields. Soil Sci. Soc. Am. Proc. 12:348-352.
15. Sullivan, G. A., G. L. Jones, and R. P. Moore. 1974. Effects of dolomitic limestone, gypsum, and potassium on yield and seed quality of peanuts. Peanut Sci. 1:73-77.
16. Tucker, M. R. and R. Rhodes. 1987. Crop fertilization based on North Carolina soil tests. North Carolina Department of Agriculture, Agronomic Division, Raleigh, North Carolina.
17. Walker, M. E., T. P. Gaines, and M. B. Parker. 1989. Potassium, magnesium, and irrigation effects on peanuts grown on two soils. Commun. Soil Sci. Plant Anal. 20:1011-1032.
18. Woodruff, J. R. and C. L. Parks. 1980. Topsoil and subsoil potassium calibration with leaf potassium for fertility rating. Agron. J. 72:392-396.

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