SAAESD Southern Cooperative Series Bulletin

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RESEARCH-BASED SOIL TESTING INTERPRETATION AND FERTILIZER RECOMMENDATIONS FOR PEANUTS ON COASTAL PLAIN SOILS

C. C. Mitchell (Editor)

For a complete list of regional project committee members and other contributing authors, see LIST OF CONTRIBUTORS

Foreword

In 1989, an informal group of extension and experiment station scientists from Alabama, Florida, and Georgia met in Headland, Alabama. The meeting was led by Director Gale Buchanan of the Georgia Coastal Plain Experiment Station. The purpose of this meeting was to compare soil test methodology, calibration, and fertilizer recommendations for peanuts on Coastal Plain soils common to all three states where runner-type peanuts are grown and to review pertinent research projects on peanut fertility. There was some concern that soil analyses, calibration, interpretation, and recommendations changed at state lines for peanuts on very similar soils and that current research results had not been utilized in soil testing programs for peanuts on Coastal Plain soils. As a result of this group's efforts, a subcommittee of SERA-IEG-6 (formerly SRIEG-18), "Soil Testing and Peanut Fertility," was established. Gary Gascho (GA) was appointed chairman of this subcommittee.

The subcommittee met again in 1990, 1991, and 1992 with additional peanut researchers and extension specialists from Florida, Georgia, Alabama, and North Carolina. This regional publication is a review of the pertinent research discussed at the meetings and a consensus opinion regarding sampling procedures, soil test calibration for P, K, Ca, Mg, and micronutrients, and suggested fertilizer, lime, and gypsum applications. The interpretation guidelines and recommendations presented in this report are intended to guide soil testing programs for peanuts on Coastal Plain soils. Differences will continue to exist from state to state and region to region because of farming traditions, regional economic differences, political influences on recommendations, and recognized differences in soils, climates, and peanut varieties. The Peanut Fertility Committee of SERA-IEG-6 presents this publication as a guide and justification for research-based changes in local soil test interpretations and recommendations for peanuts.

Note on Units
Because most state soil testing programs are oriented toward user services,

interpretation guidelines and recommendations are often reported in English units of pounds per acre. Calibration research is often reported in mg kg^{-1} mg dm^{-3}, or mg L^{-1} of extractable nutrient and kg ha^{-1} of applied nutrients. This report is intended for use by soil testing laboratories making interpretations and recommendations for peanut producers. Therefore, soil test extractable nutrients are converted (where appropriate) and reported in mg kg^{-1} or mg L^{-1} depending upon source of the data. Fertilizer recommendations are expressed in terms of pounds per acre of $P_2 0_5$, $K_2 0$, Mg, Ca, etc.

C.C. Mitchell, Editor
May 1994

Table of Contents

This bulletin from the Southern Extension and Research Activity Information Exchange Group-6 (SERA-IEG-6) included researchers from Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas, and Virginia. It is being electronically published with the approval of the Directors of the Southern Agricultural Experiment Stations. Under the procedure of cooperative publications, it becomes in effect, a separate publication for each of the cooperating stations listed.

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return to top of page	return to title page

SAAESD Southern Cooperative Series Bulletin

May 1994 SCSB# 380

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Chapter 1
Soil Sampling

C. C. Mitchell

Background

Tillage practices influence nutrient distribution in soil with depth. Long-term fertilization under reduced tillage can result in P and K accumulations in the surface 4 inches of the soil profile whereas regular moldboard plowing and disking result in a relatively uniform distribution of P and K to the depth of plowing (Randall 1980). Routine chisel plowing can result in uniform P and K incorporation. Incorporating P to a depth of 2 to 3.5 inches with a disk does not result in any greater downward movement, than with no-tillage (Touchton et al. 1982).

Reduced tillage practices in peanut production have not been widely adopted. Moldboar plowing remains the accepted practice for controlling diseases and preparing a seedbed (Hartzog et al. 1990). Because of this practice, nutrient distribution is relatively uniform within the plow layer, and preplant soil sampling for soil pH and extractable P, K, Mg, Ca, and micronutrients would be no different from sampling for any other crop. Therefore, soil samples should be taken from the surface 6 to 8 inches.

The possible exception is soil testing for Ca. The production of high yielding, quality peanuts requires a high Ca level in the pegging zone (0 to3 inches) during bloom and subsequent pegging. This is covered in more detail in chapter 6.

Recommendations

Plow-layer samples should be collected any time prior to planting for preplant, broadcast lime and fertilizer application. Recommended lime should be applied after turning the land and mixed with the surface 3 to 8 inches. If a preplant sample is not taken or if recommended lime is turned under or not applied, a pegging zone soil sample should be taken in the upper 3 inches of soil prior to pegging. Topdress gypsum applications should be based on results of this sample.

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Background information and references for this section were prepared from information compiled by W. O. Thom, University of Kentucky, and presented at a joint meeting of SRIEG-18 and NCR-13 at St. Louis, MO, November 7-9, 1988.

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return to top of page	return to contents

Southern Cooperative Series Bulletin

May 1994 SCSB# 380

RESEARCH-BASED SOIL TESTING INFORMATION AND FERTILIZER RECOMMENDATIONS FOR PEANUTS ON COASTAL PLAIN SOILS

Chapter 2
Soil Test Methodology

C. C. Mitchell and S. C. Hodges

Soil test methodology was not a major issue among the three primary southeastern U. S. states producing runner type peanuts. Georgia, Florida, and Alabama all use the Adams-Evans buffer for lime requirement determination and the Mehlich-1 extractant for P, K, Ca, and Mg (Sou. Coop. Ser. Bull. No. 190 1984). Other peanut-producing states of South Carolina and Virginia also use the Mehlich-1 procedure. North Carolina and Oklahoma use the Mehlich-3 procedure while Texas uses an acid, ammonium acetate procedure. This discussion will focus on the states of Alabama, Georgia, and Florida. Representatives from these states actively participated in the subcommittee meetings.

Differences existed in the Mehlich-1 extraction procedure. Alabama and the Georgia (Tifton) Lab use a weight: volume ratio of 1:4 for soil and extracting solution whereas Georgia (Athens) Lab and the Florida Lab use a volume: volume ratio of 1:4 with an assumed soil weight per unit volume. These labs ultimately calculate extractable nutrients in terms of parts per million or pounds per acre assuming 2 x 10^6 pounds of soil per acre furrow slice (parts per 2 million or mg $2kg^{-1}$). Differences in actual and assumed soil bulk densities could result in differences in the reported value for an extractable nutrient. However, previous annual SERA-IEG-6 exchange samples and regional reference sample analyses have not identified probable cause for quality control concerns among those labs using the same extractant even though slight differences in methodology may exist.

Nevertheless, a sample exchange was conducted to determine if the differences in extraction procedure could be a cause for differences in soil test calibration and interpresentation. A random collection of 10 soils from peanut farms in southeastern Alabama was distributed to the Auburn University Soil Testing Laboratory, the University of Georgia (Athens) Lab, and the Georgia Coastal Plain Experiment Station (Tifton) Lab. Samples had a disturbed density ranging from 0.98 g cm^{-3} to 1.43 g cm^{-3} with a mean density of 1.32 g cm^{-3}.

There was a strong correlation between laboratories (see table). There were a few outlying errors in results from each of the labs but errors appeared random. These results led to the conclusion that soil test methodology was quite consistent among the three labs, and any differences in fertilizer recommendations that may exist across state lines were due to calibration/interpretation of the data and not to analytical differences.

Linear Correlations Among Test Results from Three Labs Testing Soil Samples from Peanut Fields

		Laboratory comparison		
Analysis	Range in values	Auburn vs Tifton	Tifton vs Auburn	Athens vs Auburn
pH	5.3-6.8	0.96	0.94	0.87
P	10-62 lb/acre	0.99	0.97	0.98
K	30-336 lb/acre	0.99	0.94	0.93
Ca	14-354 lb/acre	0.99	0.99	0.99
Org. matter	0.83-7.3%	--	--	0.99

Each analysis was also rated (low, medium, high, etc.) according to current interpretations used by the respective laboratories. The only differences in ratings occurred when a sample's analysis fell near a critical level between two ratings. However, with only 10 samples in the survey, a complete range in analyses for each procedure was not possible. Most samples were in the "high" range for Ca according to all laboratories.

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return to top of page	return to contents

SAAESD Southern Cooperative Series Bulletin

May 1994 SCSB# 380

RESEARCH-BASED SOIL TESTING INFORMATION AND FERTILIZER RECOMMENDATIONS FOR PEANUTS ON COASTAL PLAIN SOILS

Chapter 3
Nitrogen and Sulfur

G. Kidder

Nitrogen and sulfur are usually absent from peanut fertilization recommendations in the United States. A brief discussion of the reasons is included here for the sake of completeness.

Nitrogen

Inoculation with *Rhizobium* Bacteria

Peanut is a legume which benefits from symbiotic nitrogen fixation in association with *Rhizobium* bacteria. The success of rhizobial inoculation in improving N-fixation of other legume crops has led to experiments with inoculation of peanuts. Increasing the amount of effective inoculum, especially in soil where peanuts have not been planted for some time, is a potential means of improving the N-fixing capacity of the peanut crop and thus enhancing crop yield.

Cobb and Whitty (1973) reported increased average yield from 2,700 to 3,400 pounds of nuts per acre where five lb acre^{-1} of granular inoculant were applied in the planter furrow. The presence of areas of darker green plants in the un-inoculated portion of the field indicated that inoculation by native *Rhizobium* can easily influence average yields. When they repeated the experiment on fields that had produced peanuts in the preceding three years, they found no response to inoculation. Hickey et al. (1974) increased yield of pods from 1,700 to 3,300 lb acre^{-1} by inoculation of Florunner peanuts grown on Lakeland fine sand. The field, planted to peanuts in 1972, had been cleared of scrub oak in 1970 and planted to watermelons in 1971. In a study conducted on 13 different fields that had not grown peanuts for at least 15 years, Hiltbold et al. (1983) found no yield response to inoculation or to fertilizer N. They concluded that even on land where peanuts had not been grown for many years, modulation and nitrogen fixation by indigenous rhizobia were sufficient for maximum yield under field conditions of southeastern Alabama.

While recent reports of increased yields from inoculation are found in world literature (Raverkar and Konde 1988), inconsistent results continue to cloud the issue in the United States (Scholar and Turpin 1988). The random occurrence and widespread distribution of native legumes of the cowpea cross inoculation group undoubtedly contribute to the inconsistencies experienced in field trials. Since seed inoculation is relatively inexpensive and presents no environmental risk, the Georgia and Florida Cooperative Extension Services recommend inoculation on land which has not grown peanuts for over five years (Plank 1985, Whitty 1991). Where indicated, granular inoculants placed in the seed furrow by a granule applicator are recommended (Whitty 1991). Other states view inoculation as an unwarranted operation and expense and do not recommend the practice.

Application of Nitrogen Fertilizers

Nitrogen fertilization of peanuts in the southeastern United States has been studied over the years. Older experiments (Killinger et al. 1947, Scarsbrook and Cope 1956), where peanut yields were relatively low by current standards (maximum yields <2,600 lb acre^{-1}), serve mostly to show how other production-limiting fictors have been steadily identified and corrected.

After reviewing the literature on nitrogen fertilization of peanuts, Reid and Cox (1973) concluded that most American research found no increase in peanut yields from N fertilization. The less consistent responses reported from Africa, Asia, and Europe (13 references cited as positive and eight cited as no response to N fertilization) could not be readily explained. Lack of sufficient effective *Rhizobium* bacteria, differences in soils used for peanut production, and climatic differences were offered as possible factors. Furthermore, the common use of ammonium sulfate as the N source in those parts of the world suggested the possibility of responses to S rather than N. In an updated review, Cox et al. (1982) acknowledged that "there seem to be a number of conditions conducive to obtaining a response from fertilizer N," but no strong conclusions were drawn.

Research done in the Coastal Plain in the past two decades has generally supported the conclusion of Reid and Cox (1973). Walker et al. (1974) found no response of runner peanuts to N applications (up to 120 lb N acre^{-1}). Spanish-type peanut yield increased when fertilized with 20 lb N acre^{-1}, but did not increase further at higher N rates. They concluded that N should be left out of Georgia peanut fertilization recommendations. Ball et al. (1983) found no economic response to application of 30 lb N acre^{-1} as ammonium nitrate on Spanish or Virginia market-type peanuts in North Carolina. Hartzog et al. (1983) reported no yield response to 100 lb N acre^{-1} in a three-year study of 13 fields in southern Alabama. Pataky and Hollowell (1984) reported a reduction in peanut yields when very high rates of N (up to 416 lb acre^{-1}) were soil applied in an attempt to control *Cylindrocladium* black rot in North Carolina fields.

Pancholoy et al. (1982) reported no yield response from up to 7.5 lb N acre^{-1} applied as a foliar spray of urea or to the soil. Walker et al. (1984) found that foliar application of urea did increase yield of Florunner, Tifrun, and all nonnodulating varieties on a Lakeland sand. Response of Florunner was curvilinear, with maximum yield (ca 4,100 lb acre^{-1}) calculated at 28 lb N acre^{-1}. Response of Tifrun was linear, with maximum yield (3,800 lb acre^{-1}) at the 45 lb N acre^{-1} application rate. Foliar N had no effect on Early Bunch yield.

Recently, Davis-Carter et al. (1992) reported a 21% yield increase in Southern runner peanuts from a granular urea application (25 to 100 lb N $acre^{-1}$). However, no yield differences were found from the same treatments the following year (Davis-Carter and Shannon 1993).

Recommendation Summary

The land-grant universities of the southeastern United States do not recommend application of fertilizer N on peanuts, (Clemson University 1982, Cope et al. 1981, Donohue and Hawkins 1979, Hanlon et al. 1990, Plank 1989, Tucker and Rhodes 1987) with one exception. Auburn recommends 20 lb N $acre^{-1}$ for Spanish peanuts (Cope et al. 1981). Inoculation is recommended in Florida (Whitty 1991) and Georgia (Plank 1989) if peanuts have not been grown on the land for the preceding five years.

Sulfur

Stanford and Jordan (1966) noted that the application of gypsum and dusting peanuts with S would mean that few responses to fertilizer S would be expected. Anderson and Futral (1966) added elemental S to soil in an attempt to separate the effect of S from the response to gypsum. The yield decreases experienced in the S treatments were attributed to pH decreases from 5.9 to 5.7 and 5.1 for 60 and 300 lb S $acre^{-1}$, respectively.

In their treatment of S as a nutrient in peanut production, Reid and Cox (1973) noted that S is deficient in most soils of the world where peanut is produced. They state that S per se has received less attention than most nutrient elements and that it is probable that many responses attributed to other factors were in fact responses to incidental S fertilization.
Use of ordinary superphosphate as a phosphorus source (10 to 12% S), gypsum ($CaSO_4$) as a calcium source (18 to 23% S), and dusting with elemental S for leafspot control (as much as 120 lb S $acre^{-1}$ yr^{-1}) are all practices which were often studied without evaluation of the possible effect of S as a nutrient. Use of sulfate forms of micronutrients or potassium magnesium sulfate as a K source adds to the difficulty of determining when the peanut crop is responding to S fertilization. The value of 20 lb S $acre^{-1}$ removed in a two-ton crop (Potash Institute 1972) is an estimate still in use (Kamprath and U.C. Jones 1986).

Cox et al. (1982) note that there were few reports regarding S fertilization in the Americas. Studies of S fertilization of peanut seem to be reported mostly from Asia and Africa (c.f., Bahl et al. 1986, Hago and Salama 1987), usually on soils very different (e.g., high pH clays) from those used for peanut production in the United States. In the United States, the nutritional effects of S addition have been mostly implied from studies where S nutrition was incidental to the main objectives of the research. For example, Walker et al. (1975) reported that multiple applications of S to foliage increased yield of Florunner that was not related to leafspot control; yield of Tifspan did not increase.

The most compelling evidence that S nutrition is not limiting peanut yields in the U.S. Coastal Plain is found in the Alabama research of Hartzog and Adams. In their extensive comparisons of lime and gypsum as Ca sources over many years and soils, gypsum generally showed no yield advantage over lime (Hartzog and Adams 1973, 1975; Adams and Hartzog 1980). If S deficiency were a major problem, the gypsum should have produced higher yields since it supplies both Ca and S.

Recommendation Summary

None of the land-grant universities of the southeastern United States recommend application of fertilizer S for peanuts (Clemson University 1982, Cope et al. 1981, Donohue and Hawkins 1979, Hanlon et al. 1990, Plank 1989, Tucker and Rhodes 1987). However, several trends in peanut production practices could reduce the amount of sulfur which is applied to the peanut crop for reasons other than fertilization. Decreased use of foliar-applied S for leafspot control, the substitution of lime for gypsum as a Ca source, and the elimination of unnecessary fertilization will reduce the S applied to peanuts. These changes could lead to S deficiencies in the future, and the situation bears watching.

Conclusions

Nitrogen and S fertilization of peanuts has generally not resulted in increased yields in the U.S. Coastal Plain. Under current cultural practices, neither nutrient is recommended for application as fertilizer in the southeastern U.S. peanut-producing region. Changes in cultural practices which have coincidentally supplied S to peanuts could result in deficiencies of S in the future.

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return to top of page	return to contents

SAAESD Southern Cooperative Series Bulletin

May 1994 SCSB# 380

RESEARCH-BASED SOIL TESTING INFORMATION AND FERTILIZER RECOMMENDATIONS FOR PEANUTS ON COASTAL PLAIN SOILS

Chapter 4
Critical Level: Definition and Usage in Interpretation

F. R. Cox

In a soil testing program, the concentrations of nutrients removed with a given extractant are determined. For each nutrient, field experiments are conducted on specific crops to determine the extractable nutrient concentration below which there will be a response to application of that nutrient. The concentration that indicates the division between responsive and non-responsive conditions is termed the "critical level."

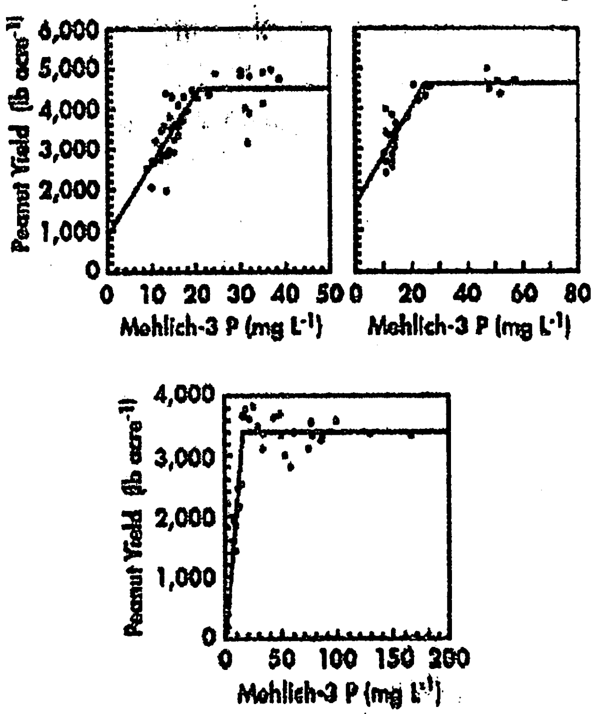
After defining a critical level thus, it would seem a simple matter to interpret a soil test by recommending fertilizer below that concentration and not recommending fertilizer above it. Unfortunately, that is not the case. There are a number of factors to consider.

The first factor that should be realized is that we are dealing with a system that has to be evaluated statistically. Since we use replicated trials and multiple observations, the critical level is a mean value. Given repeated experiments under exactly the same conditions, 50% of the tests would result in critical levels above the original and 50% would be below the original. In other words, there is a typical range in critical values that should be described by a normal distribution, rather than a single point.

The range in critical values will be broadened as conditions vary. There are a host of variable conditions in the categories of soil, management, and climate. Examples of the effect of climate may be shown in recent work conducted in North Carolina. In one experiment, corn, soybeans, and wheat were grown during a nine-year period on a soil with a wide range in Mehlich-3 extractable P (M3P) (Cox 1992). With some double cropping, there were three to five observations for each crop. As expected, there were some differences in M3P critical level among crops, but also there were marked differences from year to year with the same crop. With the linear plateau method, mean ($\bar{x}$) M3P critical level across crops and years was 30 mg L^{-1} with a sample standard deviation (*s*) of 7 mg L^{-1}. Thus, the sample standard deviation was about 1/4 of the mean. In a normal distribution, $\bar{x}$ $\underline{x}$ s takes in 67% of expected observations and $\bar{x}$ $\underline{x}$ $2s$ takes in 95%. With this information, a range in critical values could be given for this soil depending on the degree of inclusion desired.

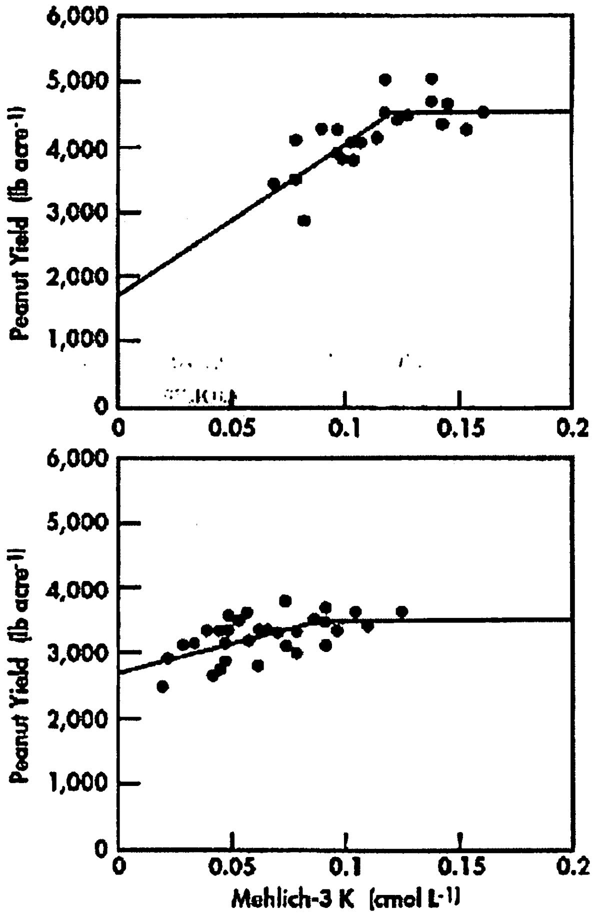
A similar example may be given for peanuts grown by the author on a Goldsboro soil (fine-loamy, siliceous thermic Aquic Paleudult) at the Peanut Belt Research Station in North Carolina. Critical levels of P and K for the Mehlich-3 extractant were determined by means of the linear plateau method (Figures 1 and 2). Residual effects of prior fertilization were measured, and yield responses were noted to P after five years and to K after seven years. The M3P critical levels for three crops were 20, 25, and 17 mg L^{-1}. This averages to 21 mg L^{-1}. Mehlich-3 removes almost twice as much P as Mehlich-1, the extractant used in several other peanut-producing states, so with conversion to a weight basis the average M1P critical level would be about 8 mg kg^{-1}. If the sample standard deviation is similar to that in the prior study, the MlP critical level range would be 6 to 10 or 4 to 12 mg kg^{-1} depending on the degree of inclusion of expected observations desired ($\pm s$ or $2s$).

Figure 1. Effect of Mehlich-3 P on the yield of three crops of peanuts grown on a Goldsboro soil in North Carolina. Critical levels are identified with a linear plateau.



The M3K critical levels were 0.12 and 0.09 cmol L^{-1} (Fig. 2), which average 0.105 cmol L^{-1}. This value would be 32 mg K kg^{-1} with an assumed sample density of 1.3 g cm^{-3}. As Mehlich-3 and Mehlich-1 remove similar amounts of K, the M1K critical level range could be 24 to 40 or 16 to 48 mg kg^{-1} depending on the degree of inclusion of expected observations desired.

Figure 2. Effect of Mehlich-3 K on the yield of two crops of peanuts grown on a Goldsboro soil in North Carolina. Critical levels are identified with a linear plateau (0.1 cmol L^{-1} = 39 mg L^{-1}).



These examples suggest creation of a range in critical levels by differences in annual climatic conditions. There are also differences in soil and management factors that would decrease the precision of the critical level range if they are not taken into account. For instance, the range in P critical level decreases with increasing clay content (Cox and Lins 1984). This may not be an important factor when growing peanuts as the crop is ordinarily grown on sandy, low-clay sites.

The nutrient content of the subsoil also affects the amount of that nutrient required from the topsoil to meet plant needs. Woodruff and Parks (1980) found this especially true for K. If K fertilization is routinely greater than K removal, the subsoil would have a substantial reserve of available K and the critical level in the surface soil could still be rather low.

Disregarding soil and management factors should expand the critical level ranges in soil test interpretation. Similar results can be achieved by combining data from numerous sites, in which case the data are often transformed to "relative yield." This approach is used frequently in soil test interpretation studies. The range would be the same, however, whether using actual or relative yields.

When a critical level range has been established for a crop, points within that range vary in probability of getting a response to fertilization. At the low end of the range, a yield response is highly probable and should occur almost 100% of the time. On the other hand, at the high end of the range, responses would seldom occur. This range is represented by the "medium" class in many soil test evaluation schemes. It covers the variable response range, whereas in the "low" class responses are always expected and in the "high" class responses are never expected.

The examples cited above are based upon interpreting the critical level range with the linear plateau method. When the quadratic plateau technique was applied to the peanut data, critical level ranges were 25 to 30% greater. When an exponential function at 95% of maximum yield was compared to the linear plateau with the three-crop data, the M3P critical level range was 67% greater with the former. The method of interpretation, therefore, may markedly affect the critical level range determined and should be made known.

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return to top of page	return to contents

Southern Cooperative Series Bulletin

May 1994 SCSB# 380

RESEARCH-BASED SOIL TESTING INFORMATION AND FERTILIZER RECOMMENDATIONS FOR PEANUTS ON COASTAL PLAIN SOILS

Chapter 5
Phosphorus and Potassium

C. C. Mitchell and J. F. Adams

Current Calibration

The critical value is that which separates the “medium” from the “high” rating and fits the definition given in Chapter 4. Critical soil-test P concentrations for peanuts among laboratories using the Mehlich-1 extraction range from 17.5 mg P kg^{-1} to 30.mg P kg^{-1} with a mean of 27 (54 lb P $acre^{-1}$ assuming 2 x 10^6 lb $acre^{-1}$ furrow slice). Three states use 30 mg P kg^{-1} (Table 1). No yield response to additional application of a particular nutrient is expected above the critical value. Only Virginia recommends fertilizer P for peanuts if the soil tests greater than this critical amount (Table 2).

Critical Mehlich-1 extractable K values range from 40 mg K kg^{-1} for Alabama soils with a cation exchange capacity less than 4.6 meq $100g^{-1}$ to 87 for Virginia soils with a mean of 69 (138 lb K $acre^{-1}$). Considerable differences in soil test K critical levels exist among neighboring states with similar soils (e.g. low CEC Alabama soils and Georgia soils). Only North Carolina recommends K fertilization for peanuts if a soil tests greater than medium.

Differences in the critical values for P and K may be due to the method of interpretation as explained by Cox in Chapter 4. A quadratic plateau or an exponential function technique of interpreting research data may result in a higher critical value whereas a linear plateau (as used by Cox) results in a relatively lower value. The methods of interpretation by each laboratory are rarely stated in the references cited in Tables 1 and 2. The critical values selected by each laboratory (Tables 1 and 2) may have relied on the individual preferences of those conducting the original research.

A 1991 USDA survey in Georgia and in North Carolina-Virginia indicated that peanut growers in these two areas applied phosphate fertilizers to over 72% of the peanut acreage (USDA-NASS/ERS 1992). The average rate per crop was 45 lb P_2O_5

acre^{-1}. Potassium fertilizers were applied to 78% of the peanut acreage. The average rate was 83 lb K_2O acre^{-1}.

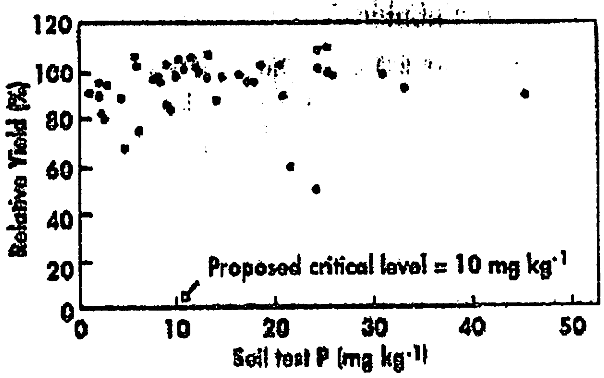
Phosphorus

Research Review

Peanuts seldom respond to fertilizer P applications. Soil test P levels that are adequate for peanuts are often lower than those required for most other crops (Cope et al. 1984). Data from Alabama, Georgia, India, China, and Australia suggest very low critical levels of approximately 5 to 10 mg P kg^{-1} (10 to 20 pp2m).

Alabama research on farmers' fields has shown no correlation between Mehlich-1 extractable P and yield or grade increases from fertilization in 39 experimental sites where soil test P ranged from 1 to 45 mg P kg^{-1} (2 to 90 pp2m) (Hartzog and Adams 1988a, 1988b) (Figure1). Using the current Alabama calibration for peanuts, 20 of the sites would be rated "low" or "very low" in soil test P. Present soil test calibration for P in Alabama clearly does not adequately predict the yield response to applied P. Hartzog and Adams (1988b) suggest that ". . . adjustments in soil-test ratings are needed." In addition to the above studies, long-term (60+ years) fertility experiments on a Dothan sandy loam (fine-loamy, siliceous, thermic Plinthic Kandiudults) in Alabama have never shown a peanut yield response to P fertilization (Cope 1984, Cope et al. 1984).

Figure 1. Relative yield of Florunner peanuts vs. soil-test P levels of unfertilized plots.



One experiment begun in 1954 had Mehlich-1 extractable P of 30 mg kg^{-1}. This would be rated "high" using current Alabama calibration (Table 1).Where no P has been applied in 30 years, the soil test level declined to 11 mg P kg^{-1} which would be rated "low," yet no yield response to P fertilization has been measured.

On the other hand, some early research in Georgia showed positive yield responses to P fertilization. Carter (1951) reported spanish-type peanut yield increases from 927 to 1,613 lb acre^{-1} with the addition of P fertilizer on a soil testing 11 mg P kg^{-1} (extractant unknown). Futral (1952) reported very high yield increases from P fertilization on some soils that were "low in P." A three-year study on a Troup fine sand (loamy, siliceous, thermic Grossarenic Kandiudults)with an initial Mehlich-1 extractable P of 22 mg kg^{-1} showed no apparent response to P fertilization of spanish-type peanuts (Walker et al. 1974). There was an apparent yield increase to drilled applications of P fertilizer on runner-type peanuts. Phosphorus fertilization had no effect on the P concentration in the peanuts nor on peanut quality (percent sound mature kernels). Following an extensive review of earlier fertility research with peanuts on Coastal Plain soils, Walker et al. (1974) concluded that "... the lack of response (of peanuts) to rates of P and K on this soil would certainly raise some questions about medium to high rates of these elements on the better peanut soil."

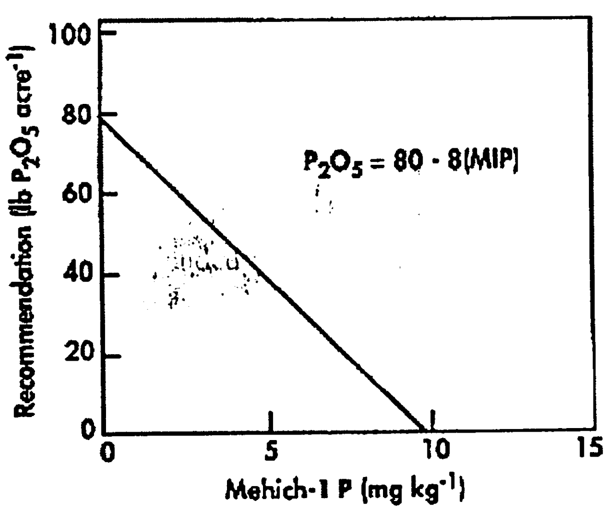
The Mehlich-3 extracting solution extracts between 1.5 and 2.0 times as much soil P as does the Mehlich-1 (Gascho et al. 1990). North Carolina data from a long-term study with virginia-type peanuts on a Goldsboro soil suggest an M3 critical P value of 17 to 25 mg kg^{-1} (mean of 21). (See Chapter 4).

Recommendations

A factual interpretation of current research information regarding soil test P calibration for peanuts would mean dramatic changes in current "critical values" for all states testing soil for runner-type peanut production. This would also result in little or no P fertilizers recommended for peanuts on most Coastal Plain soils. **The subcommittee agreed that an acceptable and realistic "critical value" for Mehlich-1 extractable P would be 10 mg kg^{-1} (20pp2m or lb $acre^{-1}$).**

Figure 2, modified from a figure presented by Gary Gascho (GA), interprets soil test P and fertilizer P_2O_5, recommendations (in pounds per acre) for application to land to be planted in peanuts. Crop rotation is an essential, highly recommended practice for peanut production. Fertilization of any crop grown in rotation with peanuts (corn, cotton, small grains, temporary winter grazing, bahiagrass, bermudagrass, etc.) according to established recommendations based on soil tests will eliminate the need to apply additional P to the peanut crop.

Figure 2. Phosphorus calibration and interpretation for peanuts on Coastal Plain soils



Potassium

Research Review

In general, there are contradictions and poor correlations between plow-layer soil-test K and peanut yield response to K fertilizers (Cox et al. 1982). In personal correspondence, Fred Cox, Professor of Soils at North Carolina State University, explained the contradictions:

> The soil test for K is not too indicative of K availability for peanuts on our low CEC soils. Much of the K utilized by the crop is from the subsoil and that is not currently measured. Topsoil K cannot be built appreciably by fertilization and it will not decrease much below about 0.1 cmol L^{-1}. So, all in all, the soil test for K is not too reliable for indicating K requirements, and I am sure our recommendations are on the high side because of this uncertainty. Fertilization of the previous crop and even the returning of corn stalks normally add enough K for peanuts.

A 1974 literature review found little justification for direct K fertilization of peanuts (Walker et al. 1974). In some reported cases of yield increases from K fertilization on "low" K soils, the increase in yield was not sufficient to pay for the additional fertilizer materials. However, in their three-year study on a Troup sandy loam with an initial Mehlich-1 soil test level of 13 mg K kg^{-1}, both spanish-type and runner-type peanuts produced a positive yield response to K fertilization. In a separate three-year study, Walker et al. (1989) reported a positive yield response to K fertilization on a Lakeland sand (thermic, coated Typic Quartzipsamments) with an initial Mehlich-1 soil test of 10 mg K kg^{-1} but found no yield response to K fertilization on a nearby Fuquay loamy sand (siliceous, thermic, arenic Plinthic Paleudults) with a soil test of 24 mg K kg^{-1}.

In early Alabama research, Scarsbrook and Cope (1956) reported an average yield increase to K fertilization of 170 kg ha^{-1} of peanuts in 13 cooperative experiments where soil test K was rated "low" for other crops. No positive yield response was observed in five tests where soil test K was "high."

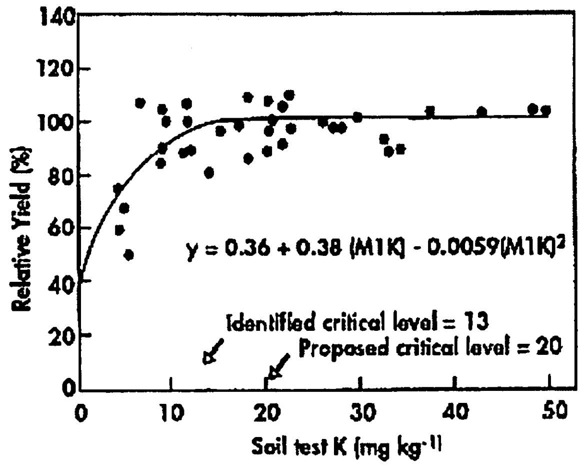
After 34 on-farm tests with no yield response to K fertilization, Hartzog and Adams (1973) concluded that adding fertilizer directly to peanuts was not a good practice but that fertilizer should be added to crops rotated with peanuts. Multiple crops on long-term fertility plots indicate that the relative response to soil test and fertilizer K levels was cotton > grain > sorghum > corn> soybeans > wheat and peanuts (Cope et al. 1984). In one study, with a Mehlich-1 soil test of 38 mg K kg^{-1}, peanuts showed yield increases from the application of up to 20 lb K_2O_5 $acre^{-1}$ from 1973-75. No K response was observed in 1981-83. In another study on the same soil, Dothan sandy loam (fine-loamy, siliceous. thermic Plinthic Kandiudults), with an original soil test of 45 mg kg^{-1}, no peanut response to K fertilization was observed.

Plow-layer, soil-test K levels have decreased very little in over 60 years of cropping in one Alabama study. However, K in subsurface horizons decreased with depth at all K fertilization rates (Cope et al. 1984) observed that ". . although the amounts below the plowed layer were less than in the surface soil, they represent substantial reserves above that of the untreated plots. This helps explain why such soils can produce maximum yields of peanuts or other low K requiring crops for several years without K application after 'high' soil test levels are attained by fertilization."

Negative responses to K fertilizer have been reported, especially where soil Ca supply is short (Cope et al. 1984, Whitty et al. 1986).

Recent Alabama data from on-farm, replicated tests have been used to define a critical Mehlich-1 soil-test K value (Hartzog and Adams 1988a, 1988b). Figure 3 indicates a critical Mehlich-1 K level of approximately 13 mg K kg^{-1} using a quadratic plateau technique. All responsive sites were on soils (Paleudults or Quartzipsamments) with a Bt horizon deeper than 70 cm, while most of the non-responsive sites were on Paleudults with shallower Bt horizons. These results, along with the observations of peanut researchers in other Coastal Plain soils, suggest that subsoil K testing, or at least depth to the argillic (Bt) horizon, should be a consideration in interpreting soil test K results.

Figure 3. Relative yield of Florunner peanuts vs. soil-test K levels of unfertilized plots.



Cox has identified a Mehlich-3 critical extractable K value averaging 0.105 cmol L^{-1} (41 mg K L^{-1}) for virginia-type peanuts in North Carolina (see Chapter 4). For a soil with an assumed sample density of 1.3 g cm^{-3}, this would be 32 mg K kg^{-1}. The critical range would be 16 to 48 mg K kg^{-3}. However, he also found that prior fertilization and recycling of K into the subsoil has an effect on the critical K level for peanuts. Without subsoil sampling to refine the K recommendation, he suggests including some field history on K to adjust the critical level.

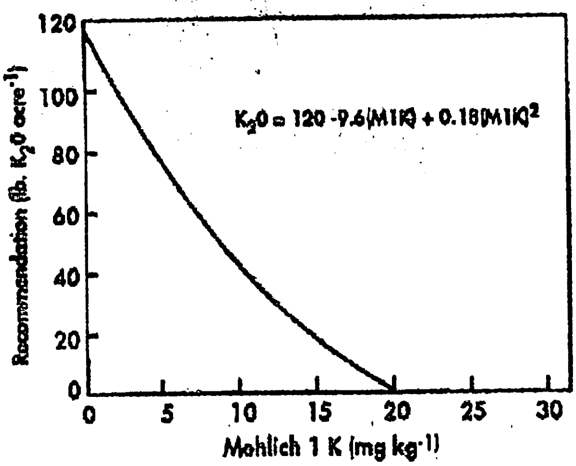
Recommendations

Changes in soil test K interpretations based on research using the Mehlich-1 extract for Coastal Plain soils, like P interpretations, will result in dramatic changes in the traditional approach to soil testing for peanuts. All states producing runner peanuts should re-evaluate the basis for their current calibration and interpretation. Evidence indicates a need to consider depth to argillic horizon and subsoil K levels when interpreting soil test levels. Nevertheless, **sufficient research evidence has been presented to warrant recommending a critical Mehlich-1 soil test value of 20 mg K kg^{-1} for runner-type peanuts on all Coastal Plain soils.** This value is a compromise between that identified by Alabama research (13 mg K kg^{-1}) and values currently used (40 to 88 mg K kg^{-1}). This critical value will result in very little direct K fertilization on most Coastal Plain soils—especially the finer-textured soils where the Bt horizon is often near the soil surface. Moderation of direct K fertilization of peanuts should also decrease incidences of Ca:K imbalances which can result in decreased yields and grade and increases in pod rot especially on sandier soils with a low CEC. A critical value for Mehlich-3 extractable K for virginia-type peanuts may be only slightly higher than this based on North Carolina research.

Figure 4, modified from a figure presented by Gary Gascho (GA), interprets soil test

K and fertilizer K_2O recommendations (in lb $acre^{-1}$) for direct application to land to be planted into peanuts the current year. Crop rotation is an essential, highly recommended practice for peanut production. Potassium fertilization of crops in rotation with peanuts according to soil test interpretations for those crops will assure adequate K for peanuts the following year.

Figure 4. Potassium calibration and interpretation for peanuts on Coastal Plain soils.



Nutrient Removal

Peanuts are very efficient at obtaining P and K from the soil due to a deep and extensive root system. At current yields of 4,000+ lb $acre^{-1}$ of pods, nutrient removal is comparable to other crops traditionally produced on Coastal Plain soils and often grown in rotation with peanuts (Table 3). Failure to replace these nutrients, especially near critical soil test levels of P and K, could have detrimental effects on subsequent crops. However, as previously shown, peanuts have much lower critical levels of P and K than most other crops produced on Coastal Plain soils. Fertilization of the crops in rotation with peanuts according to established soil test interpretation for those crops will assure adequate nutrients for both crops regardless of crop removal.

Conclusions

Modifying soil test calibration, interpretation, and recommendations for P and K on peanuts on Coastal Plain soils will require dramatic changes in existing programs in all peanut-producing states. Programs should emphasize soil testing and proper fertilization for crops in rotation with peanuts rather than direct fertilization of peanuts. This management practice has been encouraged in all states for many years. The "Soil Testing and Peanut Fertility" subcommittee of SERA-IEG-6 suggests the following critical values based upon research conducted over the past 20 years:

Mehlich-1 extractable P 10 mg kg^{-1}

Mehlich-1 extractable K 20 mg kg^{-1}

These values represent the level at which direct fertilization of the respective nutrient will not produce a peanut yield increase. Based on reported yields in research and on-farm tests, sites with soil test P or K near the critical value are capable of producing in excess of three tons (6,000 lb) peanuts per acre, provided other soil and crop limiting factors are controlled.

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RESEARCH-BASED SOIL TESTING INFORMATION AND FERTILIZER RECOMMENDATIONS FOR PEANUTS ON COASTAL PLAIN SOILS

Chapter 6
Calcium and Magnesium

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The unique fruiting habit of the peanut plant and the importance of calcium (Ca) in pod development make Ca a primary feature of any peanut fertility program. For over 50 years, the role of Ca and the means of ensuring adequate supplies have occupied the thoughts of scientists and growers alike. While few will debate the major principles involved in Ca nutrition, there have been disagreements on the soil test levels needed to maintain maximum production and the means of supplying these levels.

While magnesium (Mg) has demanded much less attention in peanut production than Ca, deficiencies have been reported on sandy soils of the Coastal Plain (Adams and Hartzog 1980, Walker et al. 1989). Peanut requirements for Mg are quite low, but Mg must be considered for its role in peanut production, and as part of the total cropping system.

Current Calibration

Soil test ratings for Mehlich-1 extractable Ca and Mg vary considerably among states (Table 1). Alabama, Florida, and Georgia rate peanuts separately from other crops. In the remaining Coastal Plain states, where virginia market types predominate, Ca ratings are essentially the same for all crops, perhaps reflecting the fact that all peanuts will automatically receive application of gypsum. Georgia is the only state that bases its rating on samples taken from the fruiting zone after plants emerge.

Supplemental Ca recommendations also vary, primarily based on the market type of peanut grown. All states except Alabama recommend gypsum applications for virginia market types and seed peanuts regardless of soil test Ca (Table 2). Alabama is the only state that currently recommends reduced rates of gypsum as soil test Ca increases. Since guaranteed analysis of products sold in the state currently range from 15 to 21% Ca, Georgia recommends application rate be based on the Ca content of gypsum. Although not mentioned in the reference by Cope et al. (1981), Alabama growers are advised to add lime after deep turning to concentrate the lime near the soil surface. Additional gypsum is recommended following this practice only where soil Ca levels are "low" (Hartzog and Adams 1988).

Florida recommends Mg at both "low" and "medium" ratings, while Alabama does not recommend treatment other than the use of dolomitic lime where soil tests indicate a need for lime (Table 2). Other states recommend Mg at rates ranging from 10 to 35 pounds Mg per acre when soils are rated "low."

Calcium

Research Review

The unusual interest in Ca nutrition of peanuts results from the striking and well-documented effects of Ca deficiency on peanut yields, grades, disease resistance, and seed germination. Peanuts are very efficient in obtaining other nutrients, but because of their unusual fruiting habit, developing pods must obtain their Ca directly from the soil solution. This results in unusually high soil requirements relative to other crops that are able to supply Ca to developing fruit through xylem transport. These features of Ca nutrition of peanuts were extensively reviewed by Cox et al. (1982). This review will concentrate on the assessment of residual Ca levels and corrective treatments to ensure adequate Ca in the fruiting zone during fruit development.

Critical Soil Calcium Levels

From a practical standpoint, the farmer must ensure an adequate supply of Ca in the fruiting zone during pod development. This can be accomplished in a number of ways. Residual soil levels may be adequate, and the grower simply needs to confirm this through a reliable soil testing procedure. Otherwise, supplemental Ca can be added as lime or gypsum. Cox et al. (1982) concluded that Mehlich-1 Ca levels of 125 mg kg^{-1} were adequate for runner and spanish market types, while 250 mg kg^{-1} were required for virginia market types. Several states have since studied the levels of soil Ca required to achieve maximum yields.

Alabama

A long-term, on-farm testing program with gypsum and lime has been used to establish and confirm soil Ca requirements of peanuts for soils of the Coastal Plain of Alabama (Hartzog and Adams 1973, Adams and Hartzog 1980, Hartzog and Adams 1988). These tests generally consisted of comparisons of gypsum and no gypsum in fields planted to a single variety, or to combinations of gypsum and liming materials. Several runner and virginia type cultivars were tested.

Test sites were selected which were likely to respond to Ca applications based on farmers' soil samples submitted to the Auburn Soil Testing Laboratory (Adams and Hartzog 1980). These sites were predominately located in non-irrigated fields containing loam or sandy loam soils. Farmers were responsible for all phases of production except for application of lime or gypsum. Yields were often not as high as well-managed research plots, but exceeded state average yields and provided comparisons of the treatments under numerous field conditions. Soil Ca levels for calibration were determined in plow depth samples (6 in) collected in the untreated check plots at the end of the growing season.

Hartzog and Adams (1973) summarized the results of experiments from 1967 to 1972 with the following statement:

> The results are clear and consistent: (1) no soil with a soil-test Ca above M80 (100 mg kg^{-1}) needed gypsum; (2) all soils with a soil-test Ca below L70 (87.5 mg kg^{-1}) needed gypsum; (3) the variety had no influence on whether gypsum was needed or not.

The lack of response to gypsum by virginia-type cultivars did not agree with earlier reports (Cox et al. 1982). Further on-farm tests conducted between 1973 and 1986 (Hartzog and Adams 1988) showed significant yield increases for runner types in 12 of 17 cases when the Mehlich-1 Ca was less than 100 mg kg^{-1}, and no yield increases in 27 cases where Ca was above this level. Similar results were obtained in 15 studies with virginia-type peanuts. Grade was significantly increased by gypsum for Florunner in two cases where Mehlich-1 Ca was 110 and 120 mg kg^{-1}, and in one case for GK-3 (a virginia market type) at 230 mg kg^{-1}.

On a Dothan fine sandy loam that had not been limed in 52 years, Cope et al. (1984) reported a 21% reduction in peanut yields relative to limed treatments. Soil Ca concentrations were 140 mg kg^{-1} in the unlimed soil (pH of 5.1), and 490 mg kg^{-1} in the limed soil.

Adams and Hartzog (1991) recently reported increases in germination and seedling survival of seed peanuts at soil Ca levels greater than 120 mg kg^{-1}, although yield and grade were not affected.

Florida
Gypsum and liming tests in Marianna (E. B. Whitty, Univ. of Florida, unpublished data, 1981) showed substantial differences in yield response between Florunner and Early Giant. At a soil Ca level of 370 mg kg^{-1}, Ca treatments did not affect yields and grades of Florunner, but significantly increased yields of Early Giant. Pod rot in Early Giant was also substantially reduced by gypsum. application. Samples taken before and after the season showed that Ca levels dropped from 370 to 290 mg kg^{-1} during the season on this sandy site. Whitty et al. (1986) found that seed germination was the most sensitive measure of Ca fertilization. Yields in five sites were not affected by gypsum application because of high Ca levels in the unfertilized plots (Mehlich-1 values not reported). They also reported that gypsum applications counteracted the effects of excess K in the pegging zone.

Georgia
Calibration work in Georgia has been conducted in numerous environments, but predominately on experiment station sites and usually under irrigated conditions. At least 45 tests on runner market types and 20 tests on virginia peanuts have been conducted in Georgia since 1980 (Walker and Csinos 1980; Gaines et al. 1989, 1991; Gascho et al. 1989, 1991; Alva et al. 1989, 1990a, 1990b; Hodges et al. 1989). Mehlich-1 Ca levels in these studies were determined in plow-layer samples taken before the season or fruiting zone samples taken 10 to 14 days after planting. Soils have varied widely, ranging from excessively well-drained Quartzipsamments and well-drained, loamy Rhodic Kandiudults to somewhat poorly drained Kandiaquults.

In the Georgia tests, gypsum significantly increased runner type peanut yield in three of four cases with soil test levels less than 100 mg Ca kg^{-1}, in zero of three cases in the range of 100 to 150 mg Ca kg^{-1}, in three of eight cases in the range of 150 to 200 mg Ca kg^{-1}, in two of six cases in the range of 200 to 250 mg Ca kg^{-1}, and in zero of 24 cases with greater than 250 mg Ca kg^{-1}. Most of the responses occurred on soils classified as sands, and many have arenic horizons (greater than 20 in to the argillic horizon).

In sandy soils, large seeded virginia market type cultivars have consistently required higher Ca levels than runner and spanish market types (Walker 1975, Walker and Csinos 1980, Walker et al. 1976). Gaines et al. (1989) recently reported significant yield increases in seven of seven experiments with virginia-type peanuts even though Mehlich-1 Ca levels ranged as high as 700 mg kg^{-1}. Where studies were conducted on a Rhodic Kandiudult (Greenville sandy loam) containing from 250 to 365 mg Ca kg^{-1}, gypsum applications did not improve yields of either runner- or virginia-type cultivars (Walker and Csinos 1980, Walker et al. 1979, Walker and Keisling 1978). Gaines et al. (1989) concluded that soil texture influences peanut response to gypsum at different soil Ca levels.

A recent study in Georgia indicated that limestone, incorporated into sandy soil with a pH less than 6.2 and a Mehlich-1 Ca less than 200 mg kg^{-1} to a depth of 2 to 3 inches following turning and prior to planting, was effective for reducing pod rot and for increasing pod yield, grade, and value of both runner- and virginia-type peanuts (Gascho et al. 1993). However, the least pod rot and the greatest yield, grade, and value per acre for the virginia type was only attained when gypsum was applied at early bloom, regardless of limestone application. Incorporation of gypsum prior to planting was not effective.

North Carolina and Virginia

Gypsum applied at a rate of 200 lb $acre^{-1}$ in a 12-inch band increased yields of Florigiant peanuts on a soil containing 305 mg Ca kg^{-1} (Cox 1972). Gypsum applications of 400 and 800 lb $acre^{-1}$ did not result in additional yield increases. No response to gypsum was found at three other sites with soil Ca levels of 190, 360, and 440 mg kg^{-1}.

Hallock and Allison (1981) reported yield increases for virginia market type peanuts in 28 of 43 sites on a range of Hapludults and Paleudults. Although soil type affected Ca uptake by seed, yield and grade responses were not strongly correlated with Mehlich-1 Ca levels. Similar results have been reported by Coffelt and Hallock (1986), Hallock and Allison (1980), Sullivan et al. (1974), and Cox et al. (1976).

Corrective Treatments

If soil levels are low, supplemental Ca may be added in the form of lime or gypsum. The lack of consistent yield increases with lime in early studies led most growers to rely on gypsum for supplemental Ca. Failure to integrate the concepts of critical Ca levels, pegging zone Ca management, application timing, and cultivar differences has until recently slowed progress in this area.

Lime as a Ca Source

Liming has a long history of improving peanut yields in the soils of the Coastal Plain. Reed and Brady (1948) reported that dolomitic lime top dressed at seedling emergence was as effective as gypsum applied at bloom in two of three cases. Cox et al. (1982) cite two examples from sandy soils where limed plots out yielded gypsum-treated plots under leaching conditions. Lime can improve soil conditions for peanut growth through reducing Al, Mn, and Zn toxicity, or through increases in soil Ca and Mg levels.

The limited solubility of lime led some to believe that it could not supply available Ca to the fruiting zone as effectively as gypsum. This was reinforced by studies showing limited responses to lime. Lime application in the seed furrow at planting (Colwell and Brady 1945) or applications in the fall prior to moldboard plowing (Sullivan et al. 1974) were ineffective in supplying sufficient Ca to virginia-type peanuts, not only because of their greater Ca requirement, but also because of spatial unavailability. Timing of applications is also important. Applications at bloom are not effective, since the lime has insufficient time to react with the soil before the critical uptake period (Hartzog and Adams 1988). In many cases, results from virginia market types were erroneously extended to smaller seeded cultivars.

Numerous studies conclusively show that lime can provide adequate Ca for maximum yield of runner-type peanuts when applied and incorporated into the pegging zone after moldboard plowing prior to planting (Hartzog and Adams 1973; Adams and Hartzog 1980; Gascho et al. 1991, 1993). Where recommended to correct low pH, lime incorporated in the surface after moldboard plowing can also supply Ca (at a lower cost) and eliminate a trip across the field before bloom. Lime applied in the spring is less subject to leaching than gypsum, and the possibility of missing a needed gypsum application because of wet fields or scheduling problems is averted.

Lime is not the most appropriate supplemental Ca source in all cases. Applying lime on freshly plowed soil is difficult, increases maintenance costs for spreader trucks, and can lead to undesirable compaction. High flotation equipment is better suited to this task, but very few of these expensive units are available. Many dealers have tractor-pulled spreaders available for farmer use, but timing can become a problem for growers with large acreage. They must turn the land, lime, and apply herbicides before incorporation.

Overliming can become a serious problem in some areas. If poorly drained sands of the Atlantic Coast (Aquults) are overlimed, Mn deficiencies are frequently observed. Parker and Walker (1986) found greatly reduced pod yield at pH 6.8 in comparison to pH 6.0 due to Mn deficiency. For this reason, excessive use of limestone as a Ca source should be avoided. In Georgia, North Carolina, South Carolina, and Virginia, growers are advised to keep pH below 6.3 in susceptible soils.

In addition, other factors such as market type, contractual requirements, soil K levels, climatic conditions, and disease problems may influence a grower's decision to use gypsum rather than lime. These are discussed in more detail below (See Other Considerations).

Gypsum as a Ca Source

Although liming can improve yields of large-seeded peanuts, additional responses to gypsum are frequently observed on limed plots (Gascho et al. 1991, 1993).

Gypsum is a relatively soluble source of Ca compared to lime, and generally is one and one-half to three times more expensive than lime per unit weight. It is especially useful for supplementing available Ca near critical uptake periods. Although nutritional responses to sulfur (S) are seldom reported on peanuts in the region (Cox et al. 1982), the use of gypsum also ensures adequate S levels. While mined deposits have historically been the primary source of gypsum, by-products from phosphorus fertilizer manufacture, industrial acid neutralization processes, and scrubbing operations in coal-fired power generation are becoming more important gypsum sources.

Leaching

The solubility of gypsum leaves Ca from this source more subject to leaching, especially in deep sands, than Ca derived from lime (Adams and Hartzog 1980). Leaching from the pegging zone can occur (Walker 1975, Alva et al. 1990b, Alva and Gascho 1991), but the extent of the problem in the field is variable

Rates

Gypsum is recommended at rates ranging from 250 to 500 lb acre^{-1} applied in 12- to 18-inch bands (equivalent to 500 to 1,500 lb acre^{-1} broadcast) for runner peanuts, and 600 to 800 lb acre^{-1} applied in bands (equivalent to 1,200 to 1,600 lb acre^{-1} broadcast) for virginia types (Table 2). There have been very few gypsum rate studies, and in these studies yield and grade responses are seldom improved beyond the lowest application rate. Thus, little information is available on optimum rates of gypsum required for response. Three experiments with large responses to gypsum indicated that a rate of 250 lb acre^{-1} (12-inch band, equivalent to 750 lb acre^{-1} broadcast) was as good as 500 lb acre^{-1} banded (Hartzog and Adams 1988). Yields of Florigiant peanuts were maximized on a soil containing 305 mg Ca kg^{-1} (Cox 1972) by 200 lb acre^{-1} of gypsum (12-inch band). In essentially all other calibration and gypsum response studies over the last 20 years, regardless of the market type, the lowest application rates reported have been 500 lb acre^{-1} (12- to 20-inch bands) or 900 to 1,500 lb acre^{-1} (broadcast). Additional work is needed in this area.

Other Considerations

The decision to add supplemental Ca is not always based on the soil Ca level or the market type grown. Various site-specific and external factors in a given year may affect the decision. These may include rotational effects, the potential for economic returns, contractual obligations for seed peanuts, climatic conditions, and other soil-based factors.

Rotational Effects

Crop rotation, or the lack of rotation, can influence the levels of both residual nutrients and pathogens. In many irrigated fields, it is increasingly common to see two and even three consecutive years of peanuts, resulting in ever-growing pest and disease problems. When following crops such as corn or cotton, the soil K levels can be very high. In recent years, there is a disturbing increase in some areas for growers to make direct applications of K to peanuts, either to maintain high K levels for other crops in the rotation or to account for K removal where peanut hay is removed at the end of the season. As cited by Cox et al. (1982), several studies have demonstrated the negative effects of excess K or Mg in the fruiting zone on Ca uptake and utilization. Although fungal pathogens are the primary cause of pod rot (Filonow et al. 1988), gypsum has increased seed Ca contents and reduced the incidence of pod rot in numerous studies where K or Mg is excessive (Hallock and Garren 1968, Walker and Csinos 1980, Csinos and Gaines 1986). Less K fertilization is a long-term remedy, but where levels are already high, additional Ca in the form of gypsum can enhance leaching of excess K from the fruiting zone, and increase yield and grade (Cox et al. 1982, Sullivan et al. 1974, Alva et al. 1990b). Georgia currently recommends the use of gypsum where the Ca:K ratio is less than 3:1. This recommendation was apparently based on numerous unreported observations and field demonstrations (McGill 1981), but has not been documented.

The rather small percentage of fields most susceptible to pod rot are typically on sandy soils low in Ca (Gascho et al. 1993) or sites without adequate crop rotation. At present, it seems that good Ca and K management practices will effectively reduce the incidence of pod rot in all but a few problem fields.

Seed Germination

Seed germination is strongly affected by Ca concentration in the seed, and therefore by soil Ca levels in the fruiting zone. Cox et al. (1982) reported acceptable germination of virginia-type peanuts when seed Ca concentrations were in the range of 420 to 680 mg kg^{-1}. Adams and Hartzog (1991) found that gypsum increased germination and seedling survival at extractable soil Ca levels below 400 mg kg^{-1}, while yield and percent sound mature kernals (SMK) were not increased at soil Ca levels of 136 mg kg^{-1}. In a more recent study, Adams et al. (1993) found critical seed Ca levels ranging from 381 to 414 mg kg^{-1}. for four runner-type peanut cultivars. They calculated that maximum germination for the various cultivars occurred at soil Ca levels ranging from 235 to 252 mg kg^{-1}, but indicated that only a few soils with high extractable Ca were included in the study, and the fact that only SMK were included in the germination tests could well affect these critical levels.

Addition of gypsum is commonly recommended for seed peanuts (Table 2). From a pragmatic standpoint, most seedsmen require contract growers to apply gypsum, regardless of soil Ca levels.

Soil Sampling Procedure

Various sampling methods have been used to determine soil Ca for calibration studies. In Alabama, soil samples were taken from the upper 6 in of the untreated check plots at the end of the season. Preliminary studies have shown insignificant changes in soil Ca levels throughout the season (J.F. Adams, Auburn University, personal communication.,1991; Adams and Hartzog 1991). This sampling method could overestimate the Ca-supplying capacity of a soil where leaching could produce large changes within the sampling zone. In sandy soils, such changes in Ca levels can occur following moldboard plowing, and even during the season. Whitty (E. B. Whitty, Univ. of Florida, unpublished data, 1981) reported a 70 mg kg^{-1} drop in Mehlich-1 Ca during the growing season at Marianna, Florida. Walker (1975) mentions similar reductions in fruiting zone Ca in Georgia, and similar declines have recently been documented following gypsum applications (Alva et al. 1990). To compensate for potential losses, Georgia research soil samples were typically taken from the upper 6-inch depth upon initiation of the experiments. Since 1984, most studies have included samples from the upper 3 inches of the fruiting zone taken 10 to 14 days after planting.

Hodges and Gascho (1992, and unpublished data) compared pegging zone samples with samples taken before moldboard plowing. In 48 sites with Mehlich-1 extractable soil Ca levels less than 250 mg kg^{-1}, two-thirds had less Ca in pegging zone samples than in the plowed samples. One-third had more. There was a linear relationship between the two sampling methods:

pegging zone Ca = 8.9 + 0.83 (plow-layer Ca)
$r^2 = 0.72$; std. dev. = 34 mg Ca kg^{-1}

A slope less than 1 indicates a potential for soil samples taken before moldboard plowing to overestimate the pegging zone Ca levels.

Correlation between Ca levels in pegging zone samples and Ca levels in harvest samples was greater even though fluctuations were still large (maximum decreases of 100 mg kg^{-1} and increases of 76 mg kg^{-1}):

pegging zone Ca = -10.1 + 1.01 (harvest Ca)
r^2 = 0.87; std. dev. = 25.8 mg Ca kg^{-1}

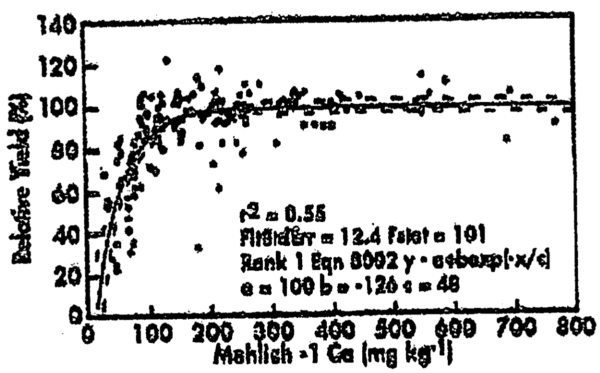
Calcium levels decreased in 28 samples (average of 49.9 mg Ca kg^{-1}) and increased in 20 samples (average of 39.9 mg kg^{-1}). In four of 16 sites with harvest Ca levels less than 125 mg kg^{-1}, the pegging zone Ca levels were above 125 mg kg^{-1}. By comparison, 10 sites with less than 125 mg Ca kg^{-1} by the pegging zone test were found to have higher Ca when samples were taken before moldboard plowing.

These studies indicate that the potential for changes in soil Ca following moldboard plowing, and for leaching during the season is significant in some cases. This has become increasingly important with the increasing use of switch-type plows that are able to turn the soil more deeply and invert the plow layer with less mixing. This increases the potential for bringing unsampled soil to the surface. Such soil is usually more acid and contains less Ca.

Synthesis

There are obvious points of agreement and disagreement on the issue of Ca nutrition for peanuts. In an attempt to resolve these problems, we have attempted to collect all information possible for comparative analysis, and to analyze factors that could account for differences. From the preceding discussion, the primary issue to be resolved is the critical Ca level for optimum yield. Data from numerous sources for relative yield (untreated yield divided by gypsum-treated yield) as a function of untreated soil Ca levels are summarized in figure 1 for runner market types and in figure 2 for virginia market types using the quadratic plateau technique.

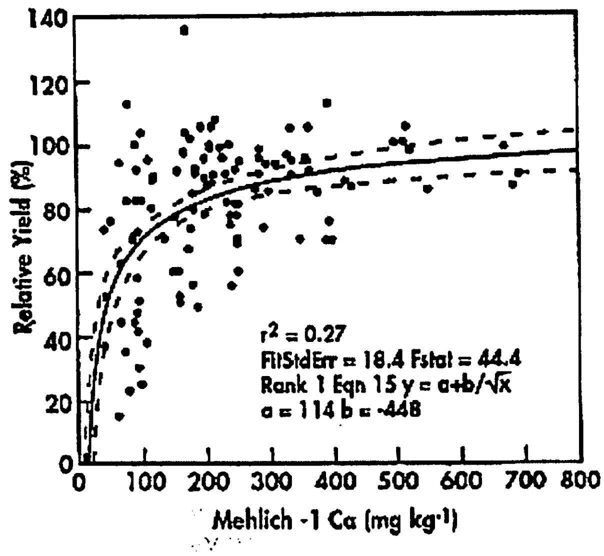
Figure 1. Runner peanut yield vs. soil Ca using a quadratic-plateau relationship. Dashed lines indicate 95% confidence interval.



Studies were initially segregated into groups of sands or loams as well as by market type, but there were no significant differences in the fit of curves for the different textural groups. This does not imply that texture has no effect on ability of the soil to supply Ca. The sands in the data set were mostly irrigated research station plots. Irrigation alone is known to improve Ca uptake, and this could be reflected in the combined data sets. In addition, soil Ca levels for these plots were determined primarily by the pegging zone method, which on these soils tends to give higher values than are present at harvest (Hodges and Gascho 1992). It should be noted that several "outliers" indicative of large responses to applied Ca are found above the 200 mg Ca kg^{-1} level. These represent recent results from irrigated sands conducted in relatively dry years, and cannot be easily dismissed.

Depending on the curve-fitting method used, these data can be used to justify a critical MI extractable soil Ca value for runner-type peanuts from around 125 mg kg^{-1} (linear plateau) to over 300 mg kg^{-1}. Using the regression coefficient as the basis of comparison, an exponential equation (r^2=0 .55) resulted in the best fit of the data. At current prices, the expense of gypsum could be justified for quota peanuts when yields fall below the 97% relative yield level. Within the lower arm of the 95% confidence interval (figure 1), this corresponds to a soil Ca level of 200 mg kg^{-1}.

Figure 2. Virginia peanut yield vs. soil Ca. Dashed lines indicate 95% confidence interval.



For large-seeded peanuts, notable responses occur even above 600 mg kg^{-1}, particularly on sandy soils (figure 2). In this case, MI extractable Ca does not appear to be a suitable test method for correlating soil Ca with response to applied Ca. The pragmatic solution is to recommend gypsum until better testing methods are developed or until we are able to improve our interpretation of results through inclusion of other factors.

In developing the following recommendations, we have considered only the current state of factual knowledge. In summary, Mehlich-1 extractable Ca provides an adequate and convenient measure of available Ca for runner-type peanuts, but not for virginia-type peanuts. A critical level of 200 mg kg^{-1} appears economically and agronomically justifiable. Limestone can provide sufficient Ca if applied in sufficient quantities at the proper time and in the proper manner. Further work appears justified on the best sampling methods to assess Ca status. Until we know more about the nature of change in soil Ca during tillage and within the season, logic dictates that Ca is best assessed by a pegging zone test in sandy soils. Further work is also needed to define the effects of K and Mg on Ca availability, disease incidence, and responses to gypsum.

Recommendations

Runner Market Types

If fall soil test results do not indicate the need for lime and Mehlich-1 Ca is less than 200 mg kg^{-1}, indicate that Ca level is "low" and recommend spring sampling in the pegging zone. If pegging zone Ca test is less than 200 mg kg^{-1}, recommend gypsum at a rate of 250 lb $acre^{-1}$ (50 lb Ca $acre^{-1}$) in a 12-inch band or 750 lb (150 lb Ca $acre^{-1}$) broadcast. Apply gypsum at early bloom.

If fall soil test results indicate the need for lime, apply recommended rate of lime to the surface after moldboard plowing to ensure the applied lime remains in the pegging zone. Incorporate to a depth of 2 to 3 inches to increase reaction of lime with the soil. Gypsum is not required since lime should supply adequate Ca.

Runner Market Types for Seed Production

Apply gypsum at early bloom at a rate of 250 lb per $acre^{-1}$ (50 lb Ca $acre^{-1}$ in a 12-inch band) or 750 lb $acre^{-1}$ (150 lb Ca $acre^{-1}$) broadcast.

If fall soil test results indicate a need for lime, apply recommended rate of lime to the surface after moldboard plowing to ensure the applied Ca remains in the pegging zone. Incorporate to a depth of 2 to 3 inches to increase reaction of lime with the soil. Apply gypsum as recommended.

All Virginia Market Types

Apply gypsum at early bloom at a rate of 500 to 600 lb $acre^{-1}$ (100 to 120 lb actual Ca $acre^{-1}$) in a 12-inch band or 1,500 to 1,800 lb $acre^{-1}$ (300 to 600 lb actual Ca $acre^{-1}$) broadcast.

If fall soil test results indicate a need for lime, apply recommended rate of lime to the surface after moldboard plowing to ensure the applied Ca reamins in the pegging zone. Incorporate to a depth of 2 to 3 inches to increase reaction of lime with the soil. Apply gypsum as recommended.

Magnesium

Research Review

Magnesium deficiency can occur at low soil test levels, and is most likely on deep, excessively drained sands. Brady and Colwell (1945) found no response to Ma on a soil with an extractable Mg content of 32 mg kg^{-1}. Hartzog and Adams (1988) reported no response to addition of $MgSO_4$ on a McLaurin loamy sand even though the Mehlich-1 Mg level was 3.5 mg kg^{-1}. In a comparison of calcitic and dolomitic limestone, Adams and Hartzog (1980) found two cases where plots treated with dolomitic lime clearly out-yielded plots treated with calcitic lime or gypsum. The soils, a Troup and a Bonifay, had Mehlich-1 Mg levels of 3.5 and 4 mg kg^{-1}. They concluded that responses could be expected at Mehlich-1 Mg levels of 3 to 10 mg kg^{-1} in the surface soil.

Cope et al. (1984) found no response to Mg from dolomitic lime (vs. calcitic lime) at Mehlich-1 Mg levels of 20 mg kg^{-1}. They found that Mg levels in this soil increased with depth, even on unlimed plots. Adams and Hartzog (1980) concluded that accumulation of Mg in the subsoil may prevent accurate prediction of Mg availability when testing only surface soil samples.

Application of Mg to Fuquay and Lakeland soils with Mehlich-1 Mg levels of 7 and 4 mg kg^{-1}, respectively resulted in a significant yield response on a Lakeland soil (Walker et al. 1989). Their results over a five-year period indicated no response should be expected when Mehlich-1 Mg levels were greater than 11 mg kg^{-1}. These conclusions were based on the upper 12 inches of soil.

Schmidt and Cox (1992) reported no response attributable to Mg on a Wagram soil with Mehlich-3 extractable levels ranging from 2 to 30 mg kg^{-1}. With no response to Mg, critical soil Mg levels could not be determined from yield response curves. Based on soil and leaf Mg data and assuming a Mg sufficiency level of 2 g kg^{-1} in the leaf, as currently recommended by the North Carolina Department of Agriculture for virginia-type peanuts, they concluded the soil Mg sufficiency level was 7 mg kg^{-1} or less. Unlike previous studies, they found that including data on Mg levels below the 20 cm depth only slightly improved the correlation between soil and leaf Mg levels. They concluded that evaluation of surface soil Mg appears adequate in establishing criteria for critical soil Mg levels.

Davis-Carter et al., (1993) reported on a three-year study on a Lakeland sand (22.5 mg kg^{-1} of Ml extractable Mg) and found that excessive Mg application (50 to 100 lb Mg $acre^{-1}$) can result in reduced yields of both runner-type and virginia-type peanuts. Therefore, Mg recommendations should not be exceeded.

Recommendations

If Mehlich-1 extractable Mg is less than 10 mg kg^{-1}, indicate the soil Mg level is "low".

If lime is needed to correct soil pH, recommend dolomitic lime.

Where no lime is needed and soil Mg is low, recommend 15 to 30 lb Mg $acre^{-1}$ be applied.

References

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return to top of page	return to contents

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RESEARCH-BASED SOIL TESTING INFORMATION AND FERTILIZER RECOMMENDATIONS FOR PEANUTS ON COASTAL PLAIN SOILS

Chapter 7
Micronutrient Deficiencies and Toxicities

J. G. Davis and F. M. Rhoads

Current Recommendations

Micronutrients are required by plants in small amounts, but are no less essential than macronutrients. Micronutrients for crop production include B, Cu, Fe, Mn, Mo, Zn, and Cl. Micronutrient removal by peanuts is estimated to be 1.0, 0.04, 0.04, 0.30, and 0.25 lb acre^{-1} of Cl, B, Cu, Fe, and Mn, respectively, for 3,000 lb nuts acre^{-1}. If the vines (5,000 lb acre^{-1}) are also removed, the nutrient removal increases to 2.0, 0.06, 0.06, 0.50, and 0.40 lb acre^{-1} of Cl, B, Cu, Fe, and Mn, respectively.

All peanut growing states in the Coastal Plain recommend B application to peanuts (Table 1). Some states recommend 0.3-0.5 lb B acre^{-1} (Alabama, South Carolina) and others recommend 0.5 lb B acre^{-1} (Georgia, North Carolina). Only one state presents a condition for B recommendation; Georgia recommends that if (hot-water soluble) B >0.5 mg kg^{-1} then no B should be applied (Table 1).

In addition to B, North Carolina and Virginia recommend Mn and Florida recommends Cu and Zn when soil levels are rated low. No other micronutrients are recommended for peanut production in the Southeast. Most states recommend that farmers maintain soil pH at about 6.0 to prevent most micronutrient deficiencies or toxicities. In addition, it is recognized that micronutrient applications to the rotation crop will provide additional micronutrients to peanuts.

Table 1. Micronutrient Recommendations for Peanuts in the Atlantic and Gulf Coastal Plain

Boron	
Alabama[1]	0.3 - 0.5 lb acre^{-1}
Florida[2]	0.75 lb acre^{-1} in fertilizer or 0.5 lb acre $^{-1}$ foliar
Georgia[3]	0.5 lb acre^{-1} on all peanut soils, unless soil B >0.5 mg kg^{-1}
N. Carolina[4]	0.5 lb acre^{-1}

S. Carolina[5]	0.3 - 0.5 lb $acre^{-1}$
Copper	
Florida[2]	3 - 5 lb $acre^{-1}$ if M-1 soil Cu <0.1 mg kg^{-1} (pH 5.5-6.0), <0.3 mg kg^{-1} (pH 6.0-6.5), or <0.5 mg kg^{-1} (pH 6.5-7.0)
Manganese	
N. Carolina[4]	10 lb $acre^{-1}$ if [101.2 + 3.75 mg M3 Mn dm^{-3} - 15.2 pH] is less than 25
Florida[2]	8-10 lb $acre^{-1}$ if M-1 soil Mn <3 mg kg^{-1} (pH 5.5-6.0), <5 mg kg^{-1} (pH 6.0-6.5), or <7 mg kg^{-1} (pH 6.5-7.0)
Zinc	
Florida[2]	5-10 lb $acre^{-1}$ if M-1 soil Zn <0.5 mg kg^{-1} (pH 5.5-6.5) or <1.0 mg kg^{-1} (pH 6.5-7.0)
[1]Cope et al. 1981. [2]Hanlon et al. 1990 (These are general recommendations; they are not specific for peanuts). [3]Plank 1989. [4]Tucker and Rhodes 1987. [5]Clemson Univ. 1982.	

Boron

Boron (B) is the only micronutrient generally applied to peanuts on Coastal Plain soils. Peanut is a crop with a medium B requirement, requiring 0.1-0.5 mg kg^{-1} available B (water extraction) in the soil (Berger 1949). Perry (1971) recommended 0.5 lb B $acre^{-1}$ for sandy soils and 1 lb $acre^{-1}$ for clay soils, but warned against over application due to potential B toxicity.

Deficiency

Early research in Florida indicated that B deficiency resulted in hollow-heart, compacted branch terminals, and cracks on pods (Harris and Gilman 1957). Application of 0.15 lb B $acre^{-1}$ as H_3BO_3 increased peanut yield and grade in the greenhouse, but B deficiency was not detected in field studies. Harris (1968) stated that B application of 0.4 lb $acre^{-1}$ was beneficial in greenhouse tests.

Research in North Carolina showed that 0.5 lb B $acre^{-1}$ decreased hollow-heart in a field study (Cox and Reid 1964). They also showed that liming increased soil extractable B, but did not increase B content in peanut kernels.

Prior to 1964, B was not recommended for peanuts in Georgia (Giddens 1964). Results had been inconclusive with some positive and some negative responses to B application. By 1966, B was recommended in Georgia at 0.5 lb $acre^{-1}$ for sandy soils, but not for clayey soils (McGill and Bergeaux 1966). Walker (1967) stated that 0.5 lb B $acre^{-1}$ applied as a foliar spray increased peanut yields in Georgia on sandy Ruston and Tifton soils, but not on Greenville soil (a clayey soil).

In Alabama, Hartzog and Adams (1968) determined that topdressing 1 lb B $acre^{-1}$ had no effect on yield, and increased grade in only one out of five experiments. Hartzog and Adams (1971) reported that in eight experiments with hot-water-extractable soil B <0.07 mg kg^{-1}, hollow-heart did not develop, and yield and grade were unaffected by B fertilization. Hartzog and Adams (1973) again reported no yield or grade effect of B fertilization.

In Virginia, hollow-heart symptoms were noted in 1958, but the symptoms were not identified with B deficiency until 1965 (Anonymous 1965). Research showed that 1 lb B $acre^{-1}$ decreased damage to seed kernels, but that 2 lb $acre^{-1}$ could be toxic. Hallock (1966) obtained a marked decrease in hollow-heart by B application, but found that rates of 1 to 2 lb B $acre^{-1}$ did have phytotoxic impacts. He also notes that B deficiency is more common in sandy, droughty soils than in finer-textured soils. Allison (1966, 1980) recommended 0.5 lb B $acre^{-1}$ foliar application at early bloom.

Hill and Morrill (1974) found B deficiency in 50% of field locations, but reported that B application did not affect yield or grade. They stated that hollow-heart was related to soil B (hot-water-soluble) ≤0.15 mg kg^{-1}. Hill and Morrill (1975) found that B application did improve peanut grade, except in soils high in potassium. Morrill et al. (1977) suggested that peanut soils with B ≤0.15 mg kg^{-1} (hot-water-soluble) require B fertilization at a rate of 0.5 lb $acre^{-1}$.

We recommend 0.5 lb B $acre^{-1}$ when soil B <0.2 mg kg^{-1} (hot-water-soluble).

Toxicity

Boron can be toxic to peanuts; therefore, B should be applied at the recommended rate only. McGill and Bergeaux (1966) warned of exceeding 0.5 lb B $acre^{-1}$ applications in Georgia. Morrill et al. (1977) stated that 1.0-1.5 lb B $acre^{-1}$ caused toxicity and reduced yields in Oklahoma. Boron application >6 lb Borax $acre^{-1}$ (0.6 lb B $acre^{-1}$) had an adverse yield effect (Asokan and Raj 1974), and 5 lb Borax $acre^{-1}$ (0.5 lb B $acre^{-1}$) resulted in toxicity symptoms (Reddy and Patil 1980).

In conclusion, care should be taken not to overapply B to peanuts. A soil critical level of 0.2 mg kg^{-1} hot-water-soluble B should be included in B recommendations.

Chloride

Chloride (Cl) toxicity has been described for soybeans in Georgia (Parker et al. 1983), but has not been found in peanuts. Athough Cl is an essential element for plant production, Cl deficiency has not been described for peanuts.

Chloride effects on Florunner peanuts were studied in the greenhouse and field in Georgia (M.B. Parker, Univ. of Georgia, personal communication, 1984). Addition of Cl to an Ocilla sand increased Cl concentration in peanut leaves, but there was no significant effect on dry matter production (greenhouse) or pod yield (field). Chloride application rates which caused toxicity in soybeans had no effect on peanuts.

There are no data that would warrant fertilizer Cl recommendations for peanuts.

Copper

Copper is a micronutrient which is rarely applied to agronomic crops as a nutrient, but is commonly applied in the form of pesticides, particularly fungicides. Bledsoe and Harris (1947, 1948, 1949) reported that application of 5 lbs Cu acre^{-1} as $CuCl_2$ increased the proportion of sound to shriveled nuts for runner peanuts in experiments done in Florida. Three years after application, the residual effect of Cu on peanut quality was maintained. Harris (1952) described Cu deficiency symptoms as affecting the bud area in particular, as well as causing small, irregular leaflets with marginal necrosis and mild chlorosis and small yellow-white spots on the foliage. Harris (1952) stated that spanish-type peanuts were more sensitive to Cu deficiency than runner peanuts, but that yields for all three varieties studied (two runner types and one spanish-type) were increased more than 300% by applying 5 lb Cu acre^{-1} as $CuCl_2$, to an Arredondo loamy fine sand (pH 5.7). Copper application also decreased seed shriveling and increased the percentage of sound, plump nuts (SMKs). The residual effect of soil Cu application (10 lb acre^{-1}) to oats, wheat, rye, or cotton in rotation with peanuts was found to be equally effective as peanut foliar applications (0.1 lb Cu acre^{-1} as $CuCl_2$). However, Harris (1952) concluded that, in general, peanut yields in Florida had not been increased by Cu applications (though yields were increased on the Gainesville experimental farm), and, therefore, Cu application was not recommended.

Boswell (1964) stated that in Georgia research no definite relationship was found between Cu application and peanut yields.

No Cu recommendation for peanuts is warranted.

Iron

Iron (Fe) deficiency in peanuts can be a serious problem in calcareous soils (Hartzock et al. 1971). Most Gulf and Atlantic Coastal Plain soils are acidic, and Fe deficiency has never been reported for peanuts grown in this region. Perkins (1964) stated that the total Fe content of most Georgia soils is greater than 10,000 mg kg^{-1}; therefore, he concluded that Fe is available in Georgia soils in sufficient amounts for agronomic crop production. Iron deficiency in peanuts results in interveinal chlorosis (starting in the youngest leaves), followed by chlorosis of the entire leaf (whitish-yellow) and brown spots leading to marginal necrosis (Lachover and Ebercon 1972b).

Lachover and Ebercon (1972b) showed that yield response to Fe application in Israel was related to % $CaCO_3$, in the soil. Papastylianou (1989) surveyed 35 peanut fields in Cyprus and determined that plants were chlorotic when % $CaCO_3$ >20-25% and Fe content <2.5 mg kg^{-1} (DTPA extractable).

Lachover et al. (1970) applied an Fe chelate (FeEDDHA) to a soil in Israel with pH 7.9 and 15% $CaCO_3$ and measured a 50% increase in pod yield and a 40% increase in hay yield. Lachover and Ebercon (1971) showed that Fe chelate applied to a soil of pH 7.9 and 11% $CaCO_3$ caused leaves to green up and increased yield. Yields were increased 359% by application of 10 lb Fe acre^{-1} (as FeEDDHA) to a loamy clay with pH 7.9 and 31% $CaCO_3$ (Lachover and Ebercon 1972a).

Reddy and Patil (1980) applied $FeSO_4$ spray to spanish-type peanuts grown on an Indian soil with pH 7.5 (2.5% $CaCO_3$ and 9 mg kg^{-1} orthophenonthroline extractable Fe) and measured no yield increase. Hillock (1964) applied Fe chelates to peanuts grown in Virginia (acid soils) and found no yield effect. Schneider and Anderson (1972) did measure yield response to FeEDDHA in Texas, where calcareous soils occur. Patil et al. (1979) determined that foliar application of $FeSO_4$ produced higher yields than soil-applied $FeSO_4$ on a black clay soil with pH 7.7 (2.5% $CaCO_3$ and 1.26 mg kg^{-1} orthophenonthroline extractable Fe). Iron deficiency could be a problem in peanuts grown in Texas, Oklahoma, and New,Mexico, where calcareous soils are widespread. The estimated critical level is <2.5 mg kg^{-1} (DTPA extractable) Fe in soil.

Iron deficiency in peanuts is very unlikely in the Coastal Plain, and no recommendation is made for peanuts in this region.

Manganese

Deficiency

Only North Carolina (Tucker and Rhodes 1987) and Virginia (Donohue and Hawkins 1980) recommend manganese (Mn) application to peanuts, although recent research in Georgia (Parker and Walker 1986) has illustrated the importance of Mn applications to peanuts grown on high pH soils.

Rich (1956) stated that Mn deficiency had long been recognized as a problem for peanuts in Virginia. He reported that Mn concentration in the plant was inversely related to soil pH, Ca, and Mg levels, in a study using 32 Coastal Plain soils. However, Mn deficiency in peanuts has been observed on soils with pH values as low as 5.8 in Virginia. Anderson (1964) reported that research in Georgia showed no yield effect of Mn additions (4 to 18 lb Mn $acre^{-1}$ as $MnSO_4$) to a Tifton loamy sand with pH 6.5, a Norfolk sandy loam, or a Greenville clay loam. Hickey et al. (1974) recorded significant yield increase for peanuts grown on a Lakeland sand (pH 6.3, M1 extractable Mn 0.67 mg kg^{-1} due to addition of 40 lb Mn $acre^{-1}$ ($MnCl_2$). The 1980 Virginia Peanut Production Guide stated that foliar Mn should be applied at a rate of 0.75-1.0 lb $acre^{-1}$ in each of up to three applications, when interveinal chlorosis, which is symptomatic of Mn deficiency, is evident (Allison 1980).

In Virginia, Hallock (1979) reported increased yields due to foliar Mn application to peanut grown in soils with pH values of 6.7 and 6.4. Parker and Walker (1986) studied the interaction of Mn response with soil pH on a Pelham sand in Georgia. Manganese deficiency occurred only on plots with pH levels near 6.8 (M1 extractable Mn = 3.7 mg kg^{-1}), not in plots with pH levels of 5.2 (Ml extractable Mn = 2.3 mg kg^{-1}) or 6.0 (Ml extractable Mn = 2.8 mg kg^{-1}). At pH 6.8, soil application of Mn at 0, 10, 20, and 40 lb $acre^{-1}$ resulted in yields of 3410, 5400, 5730, and 6370 lb $acre^{-1}$, respectively. Parker and Walker (1986) concluded that maintaining a soil pH near 6.0 was optimal for peanut production. In Georgia, regardless of soil pH levels, the only Mn deficient area is in the Atlantic Coast Flatwoods soils with pH levels >6.2. Whitty (1991) stated that Mn deficiency can occur in Florida when soil pH exceeds 6.3.

Soil Mn applications can be used to prevent Mn deficiency when the soil pH is known to be >6.0. Foliar Mn applications can correct Mn deficiency, diagnosed through foliar symptoms (interveinal chlorosis) and plant analysis, more rapidly than soil Mn applications and can be applied with fungicide in the tank mixture, thus eliminating the need for additional trips across the field.

Toxicity

Manganese toxicity can be a problem in low pH soils. Boyd (1971) described Mn toxicity symptoms for peanuts in greenhouse studies as interveinal leaf chlorosis followed by marginal leaf necrosis. He found that soil Mn (NH_4OAc extractable) was correlated with leaf necrosis. Severe symptoms occurred when soil Mn was greater than 10 mg kg^{-1} (NH_4OAc extractable).

More research is needed in the area of Mn toxicity in peanuts. However, if soil pH is maintained above 5.5, Mn toxicity is highly unlikely in Coastal Plain soils.

Molybdenum

Molybdenum (Mo) is essential for N fixation, and is therefore recommended for some legumes (e.g., soybeans, alfalfa). However, it is currently not recommended for peanuts. Harris (1959) stated that Mo application caused peanut foliage to be a darker green and frequently increased the size of the foliage, but it has never caused a significant increase in peanut yield in research in Florida.

Rao et al. (1960) reported that a 0.12 lb Mo acre^{-1} application in India increased pod yield. Walker (1967) found that 0.2 lb Mo acre^{-1} soil application increased yield by 200 lbs on a Tifton soil, but had no effect on yield on a Greenville soil. Welch and Anderson (1962) found that Mo availability was increased by liming and that Mo application increased Mo concentration in peanut leaves, but deficiency symptoms were not evident in areas which received no Mo. They stated that peanut seed Mo concentration may be high enough to provide the plant's Mo requirement even in a low Mo soil. Sellschop (1967) stated that Mo deficiency in South Africa is best corrected by liming, since increasing the soil pH increases Mo availability. Parker (1964) reported that in 15 Georgia experiments, Mo only had a yield response in one experiment. He concluded that Mo had a color response in many experiments, but that this was seldom reflected in yield. In Georgia, Boswell et al. (1967) showed that peanut yield was not well correlated with leaf or soil Mo content, and that Mo addition increased N content of peanut folinge. However, the yield effect of Mo was inconsistent.

In recent research in India, Reddy and Patil (1980) found that 1 lb acre^{-1} ammonium molybdate increased yield of Spanish peanuts. The soil test level was 0.5 mg kg^{-1} extractable Mo, and pH was 7.5. The authors suggested that this beneficial effect may be due to increased N availability which resulted in increased protein in peanut kernels. Kene et al. (1988) found that Mo increased modulation and nodule N content for peanuts in India.

Most of the literature agrees that Mo increases greenness and nitrogen content of peanut leaves, but yield increases due to Mo application are rare. No Mo recommendation is warranted for peanuts.

Zinc

Deficiency

Carter (1964) summarized Georgia research and showed that sometimes zinc (Zn) fertilization tended to increase yield and sometimes it tended to decrease yield, but the differences were not significant. Sellschop (1967) stated that Zn insufficiency was less conspicuous in peanuts than in maize in South Africa, and recommended 15 to 20 lb Zn acre^{-1} where the problem is common. Schneider and Anderson (1972) found that a Zn application of 0.1 lb Zn acre^{-1} gave a positive yield response for spanish-type peanuts in Texas. In a calcareous soil in India with <0.3 mg kg^{-1} extractable Zn, applications of 24 lb Zn acre^{-1} as $ZnSO_4$ had no significant yield effect (Lakshminarasimhan et al. 1977).

Phosphorus application can show antagonistic effects on Zn uptake (Chahal and Ahluwalia 1977). Zinc deficiency is associated with high soil pH and high available P levels (Graham 1979). Patil et al. (1979) found no yield response to either soil or foliar applications of $ZnSO_4$ on chlorotic peanuts in India, although the chlorosis was attributed to high soil pH and heavy P fertilization.

Reddy and Patil (1980) stated that 0.5 mg Zn kg^{-1} (DTPA extractable) was the critical level for Zn deficiency in peanuts in India. Rhoads et al. (1989) applied Zn to soil in a greenhouse study in Florida and determined that Southern Runner was more sensitive to Zn deficiency than Sunrunner. They suggested a critical M1 soil Zn level of 2.5 mg kg^{-1} when soil Ca >400 mg kg^{-1}.

Bell et al. (1990) described Zn deficiency symptoms in peanuts as decreased internode length and restricted development of new leaves. They also found that Zn deficient plants accumulated reddish pigments in stems, petioles, and leaf veins.

Zinc deficiency is also related to high soil pH, high soil Ca, and high soil P. Foliar application is probably the best way to correct Zn deficiency.

Toxicity

Zinc toxicity was first reported in Texas by Quintana (1972) who noted that application of 90 lb Zn acre^{-1} as $ZnSO_4$ decreased yields. Keisling et al. (1977) described Zn toxicity symptoms as chlorosis, stunting, purple coloration of the main stem and petioles, usually a lesion at the base of the plant (stem splitting), and premature necrosis. The tentative Zn toxicity critical value reported by Keisling et al. (1977) was 12 mg kg^{-1} soil (M1) for Georgia Coastal Plain soils. Liming reduced Zn uptake and eliminated toxicity symptoms but did not change the Ml level of Zn in soil. Davis-Carter et al. (1990) showed that leaf chlorosis and stem purpling were not well correlated with leaf Zn levels in a greenhouse study in Georgia and described Zn toxicity symptoms of horizontal leaf growth and leaf closure.

Rhoads et al. (1989) stated that peanut response to Zn appeared to be more dependent on soil Ca level than on soil pH in Florida. Up to 10.3 mg Zn kg^{-1} (Ml extractable) did not adversely affect plant growth when soil Ca >400 mg kg^{-1} and soil pH was 6.5-6.8, but 3.6 mg Zn kg^{-1} (Ml extractable) reduced plant growth when soil Ca ranged from 150 to 200 mg kg^{-1} and pH was ≥6.6. Cox (1990) and Davis-Carter et al. (1991b) stated that since Ml extraction of Zn from soil is not pH sensitive, it is necessary to include soil pH with Ml extractable Zn in any regressions predicting leaf Zn. Davis-Carter et al. (1991b) used such equations to calculate the probabilities for the development of Zn toxicity symptoms in peanuts as a function of soil pH and soil Zn. Georgia recently adopted a sliding scale which recommends minimum pH levels for peanuts as a function of soil Zn concentration (Table 2). According to this scale, if soil pH is 6.0, extractable soil Zn concentration above 10 mg kg^{-1} could cause Zn toxicity in peanuts.

Table 2. Minimum Soil pH to Avoid Zn Toxicity in Peanuts[1]

Mehlich 1 - extractable Soil Zn	Minimum Soil pH
mg kg^{-1}	
<0.5	5.7
0.5 - 2	5.8
3 - 5	5.9
6 - 10	6.0
11 - 15	6.1
16 - 20	6.2
21 - 25	6.3
26 - 30	6.4
31 - 35	6.5

[1]From Davis-Carter et al. (1993).

Rhoads et al. (1991) also noted varietal differences in tolerance to Zn toxicity. Southern Runner had greater dry matter yield and lower plant Zn concentration than Sunrunner at the same soil Zn level. Davis-Carter et al. (1990, 1991a) illustrated the influence of soil texture on critical levels. Peanuts grown on clayey soils required lower soil pH and higher soil Zn levels to develop Zn toxicity symptoms than peanuts grown on sandy soils.

Conclusions and Recommendations

1. Maintaining soil pH between 5.7 and 6.0 is the key to good micronutrient nutrition for peanuts. Lower soil pH values can lead to toxicities (e.g., Mn or Zn) or Mo deficiency, and very high soil pH (>6.5) can result in micronutrient deficiencies (e.g., Mn or Zn).

2. Apply 0.5 lb B $acre^{-1}$ when soil B <0.2 mg kg^{-1} (hot-water-soluble). It is important to give an upper limit for soil B to minimize potential for B toxicity, particularly for fine-textured soils since B buildup in sandy soils is unlikely.

3. No Cl recommendation is warranted for peanuts.

4. No Cu recommendation should be made.

5. No Fe recommendation is necessary for peanuts grown in the Coastal Plain, since Fe deficiency has only been reported on calcareous soils.

6. On soils where Mn deficiency has been documented, soil Mn application of 20 lb $acre^{-1}$ is recommended just prior to planting if soil pH >6.2. If interveinal chlorosis is evident and Mn deficiency is confirmed by plant analysis, foliar application of 1 lb $acre^{-1}$ is recommended. Repeated foliar applications may be required. Critical level for Mn toxicity is estimated to be 10 mg kg^{-1} (M1 extractable) in soil although the critical level is pH dependent. Maintaining soil pH at about 6.0 will prevent most cases of Mn toxicity or deficiency.

7. No Mo recommendation is warranted for peanuts. Increasing the soil pH by liming usually increases available Mo to the extent that Mo is not needed.

8. Soil critical levels for Zn deficiency and toxicity are pH and Ca dependent, as well as being related to soil texture. If soil Zn <2.5 mg kg^{-1} (M1 extractable) and soil pH ≥6.0, soil or foliar application will correct Zn deficiency. If soil pH is< 6.0, soil Zn concentrations above 10 mg kg^{-1} (M1 extractable) could cause Zn toxicity in peanuts.

Appendix 1. Sufficiency Ranges for Micronutrients in Peanut Leaves in Coastal Plain Soils

	B	Cu	Fe	Mn	Mo	Zn
	mg kg^{-1}					
Alabama	20-60	5-30	50-300	15-200	--	20-70
Georgia[1]	20-60	5-30	50-300	20-600	0.1-5	20-60[2]
N. Carolina	20-*[3]	5-*	--	20-*	--	20-*
N. Carolina	20-60	--	50-300	50-350	--	20-60

[1]Plank 1989.
[2]Cz:Zn ratio <50:1 (Parker et al. 1990).
[3]* = no upper limit or toxicity level designated.

References

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return to top of page | return to contents