Chapter 8

Soil Properties, Mineral Nutrition and Fertilization Practices

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Peanuts, like most crop plants, depend on the soil for support and mineral sustenance. Soils are important in peanut nutrition to the extent that they: (a) affect the storage and supply of essential and non-essential plant nutrients; (b) affect the availability and supply of air and water; (c) influence the temperature; and (d) harbor and influence the growth of beneficial and destructive organisms.

York and Colwell (163) described the "ideal" soil for peanut production as a "well-drained, light-colored, loose, friable, sandy loam, well supplied with calcium and a moderate amount of organic matter." They based this definition on certain factors: Well-drained soils promote adequate exchange of air to meet the N, CO_2 and O_2 requirements of the crop. Light-colored soils normally do not contain materials which stain the pods. Pods can easily be removed from loose, friable, sandy loam soils which generally do not stain or adhere excessively to the freshly dug fruit. Soils well supplied with Ca produce fruits with higher contents of sound mature kernels. Also Al is usually present in such soils in less than toxic amounts. A moderate amount of organic

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matter provides additional water and plant nutrient holding capacities sufficient to meet the plant needs (assuming adequate and well-distributed rainfall), but is not high enough to stain the pods.

In view of recent developments, many other considerations seem warranted, that are not given in York and Colwell's definition. When describing soil conditions and practices conducive to the production of high yields of quality peanuts, calcium level is just one of the many soil properties which can be altered by management. Under present day conditions, maintenance of Ca supply should not be emphasized more than several other practices which must be utilized to obtain high yields of quality peanuts. Certain detrimental properties which may or may not be controlled by management also deserve attention.

In this chapter, emphasis is placed on the manners in which soil properties affect the factors that directly influence the growth of the peanut plant. Furthermore, the properties are considered principally to the extent that they affect the mineral nutrition of the peanut. The influence of soil properties on air, water, temperature, pests and ease of cultivation, digging, harvesting and curing, etc., are discussed in accompanying chapters.

SOIL PROPERTIES WHICH AFFECT THE MINERAL NUTRITION OF PEANUTS

A complete review of soil properties is beyond the scope of this paper. However, brief discussions of certain properties as they directly affect peanuts are given. For thorough discussions of soil properties and plant growth, the reader is referred to Black (10), Russell (128), Tisdale and Nelson (155), Shaw (139) and Buckman and Brady (19) as examples of treatises which provide more thorough discussions of soil properties.

Texture: The medium-to-coarse textured soils are preferred by peanut farmers. The use of fine textured soils is avoided whenever possible. Satisfactory harvests of clean unstained pods generally can be obtained in humid areas only from the coarse textured soils which contain less than 2% organic matter. From a plant nutrition standpoint, somewhat finer textured soils would be easier to manage because soils of sandy texture have low exchange capacities and it is necessary to lime and fertilize them frequently. The buffering capacity of such sandy soils is low and small accumulations of certain elements, such as Al, may prove toxic to the plants. The very low exchange capacity provides an environment where acidity will increase rapidly and plant nutrients may be subject to leaching. Coarse textured soils also have a lower water-holding capacity than fine textured soils. In fact, plants may freqently suffer from insufficient water on sandy soils because the moisture-holding capacity is quite limited. This problem certainly would be less severe if finer textured soils were used. However, the difficulty of harvesting from heavy soils generally precludes their use. Until the demand for production exceeds that of the sandy soils or major breakthroughs occur in harvesting technology, peanut production will occur predominately on the coarser textured soils.

Drainage: Drainage affects peanut plant root respiration. Soils with excessive quantities of water contain inadequate O_2 for respiration. Abnormal respiration inhibits root growth and retards metabolic functions. For example, temporary flooding of land for only a few days may cause peanut plants to become chlorotic due to a deficiency of N. This is a combination effect caused by the inability of roots to take up soil nitrogen due to a deficiency of O_2 and the ineffectiveness of the N-fixing bacteria in an oxygen deficient environment. On the other hand, excessive drainage may result in an inadequate moisture supply for the plants and excessive leaching of plant nutrients.

Type and amount of colloid: The buffering capacity of a soil is determined by the type and kind of clay and organic matter which it contains. Tisdale and Nelson (155) and Russell (128) point out that cation-exchange is one of the most important chemical reactions of nature in that it has a larger influence on life than any other process except photosynthesis. In brief, the cation-exchange capacity contributed by the clay and organic matter in the soil serves as a storehouse for nutrients later utilized by plants. It further buffers the soil against large changes in acidity and the accumulation of toxic elements. A detailed discussion of exchange reactions is beyond the scope of this monograph but the importance of the clay and organic matter cannot be overemphasized. Without these two components, soil would be little more than an inert medium for supporting plants. Clay and organic matter also contribute to the water-holding capacity of soils.

THE FERTILIZATION OF PEANUTS

Peanuts have lost their reputation for being unpredictable. At least the rapid increase in yield in the past 20 years would so indicate. Fig. 1 shows the change which has occurred in average yields in Virginia since 1945. This is a record which is challenged by few other crops. Farmers in the peanut growing area of the United States now predict their success with peanuts as well as with any crop.

This rapid increase in yield resulted from team research which has resolved many limiting factors in the production of peanuts. Perry *et al.* (106) emphasized that unless all limiting factors are corrected satisfactory high production cannot be expected. York and Colwell (163) pointed out that prior to 1950 the southern experiment stations recommended that peanuts be grown following other well fertilized crops. Probably much of the previous "unpredictability", such as low yields and lack of response of peanuts to many practices has been due to limiting factors other than those being studied.

Responses of peanuts to application of fertilizer have never been large. Adams and Pearson (1) reported that peanut roots have a tolerance for Al in solution which exceeds that of cotton and other crops commonly grown in rotation with peanuts. Therefore, peanut roots can exploit many acid subsoils for nutrients in conditions which are toxic to other plants. Furthermore, because peanuts are a high-value crop, farmers frequently over-fertilize in order to insure that nutrients do not become limiting. Thus, peanuts can seldom be expected to respond to applications of N, P or K unless crops grown in rotation with them are seriously limited by the respective deficiencies.

Hallock (44) reported results of a long-term experiment with P and K fertilizers in a 2-year peanut-corn rotation. On ½ the plots the corn received all the fertilizer and on the other half of the experiment the fertilizer was split between the corn and the peanuts. Over a five-year period, there was no difference in yield between methods of fertilization, but the number of large seeds was increased when all the fertilizer

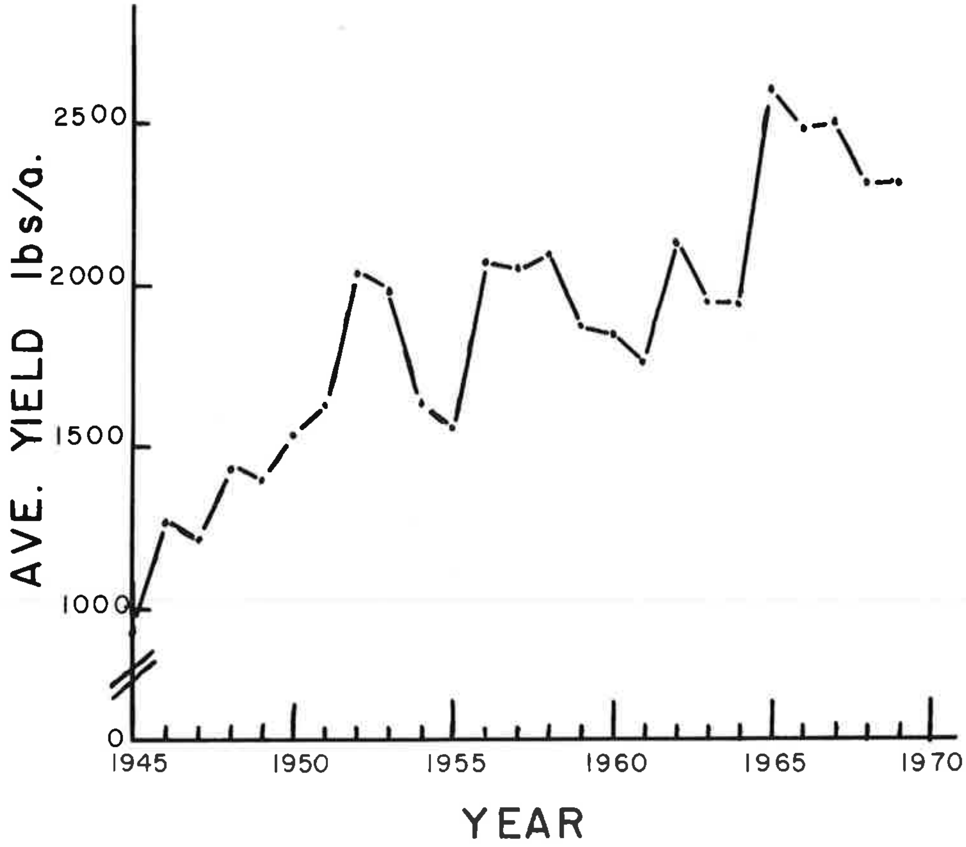

Figure 1. Average yields of peanuts in Virginia 1945-1960, Courtesy Virginia Crop Reporting Service, Richmond.

was applied to the corn. More fruit dropped off the plant when one half of the fertilizer was applied to the peanuts.

Other workers have studied means of application of fertilizer directly to the peanuts. Marchant (79) found broadcast fertilizer as effective as in-the-row fertilizer in Georgia. On the other hand, Futral (32) and Romulu (126) found fertilizer broadcasted at planting was more effective than side-dressing following emergence. The rate of application may be a factor in this anomaly. Bockelee-Morvan (15), in Senegal, found that at low rates side-dressed fertilizer was more effective than broadcast but that at higher rates the method of application had little effect.

Thompson and Robertson (151) and Scarsbrook and Cope (133) found little response to fertilizer except when other crops in the rotation were inadequately fertilized. Throughout the United States best results have been obtained from fertilization of the rotation to maintain optimum soil fertility levels. Scarsbrook and Cope found no response to P when the other crops in rotation had been fertilized adequately. They did obtain a response to K in some Alabama soils. Shibuya and Susuki (141) found that poor nutrition caused abortion of ovules and Reid and York (117) noted large differences in the percentage of flowers which formed fruit when peanut plants were deficient in a single element.

Table 1. Response of peanuts to plant nutrients throughout the world. Martin (82)

				Response* to		
Continent	Location	N	P	K	Ca	Mg
Asia	India	—	+	±	0	0
	Indonesia & Philippines	—	0	0	+	0
	Burma	±	0	0	0	0
	Thailand	0	0	0	+	0
	China	+	+	0	0	0
Australia		+	+	0	0	0
Africa	Congo	+	0	0	+	0
	Central Africa	+	+	0	0	0
	Upper Volta	0	+	0	0	0
	Dahomey	+	+	±	0	0
	Senegal	+	+	+	0	0
	Tanganyka	0	+	0	0	0
	Ghambia	±	+	0	0	0
	Sierra Leone	0	0	+	+	+
	Nigeria	0	+	0	0	0
	Ghana	+	+	0	0	0
North America	Georgia	—	±	+	+	0
	Florida	—	±	+	+	0
	North Carolina	—	±	±	0	0
	South Carolina	—	+	+	0	0
South America	Brazil	0	+	+	0	0
	Venezuela	+	+	0	+	0
Europe	Bulgaria	+	+	+	0	0
	Hungary	+	+	0	0	0
	Spain	+	+	0	0	0
Middle East	Turkey	+	+	±	0	0
	Israel	+	+	+	0	0

*Response obtained +
No response obtained —
Response doubtful ±
No information 0

Martin (82) summarized the use of fertilizers for peanuts throughout the world. The summary shown in Table 1 indicates that responses to the various essential elements can be anticipated in some parts of the world but not in others. The inconsistency of response undoubtedly reflects the differences in climatic, soil and managerial conditions from one country to another.

Obviously, high yields can be obtained only by maintaining optimum levels of each of the essential elements in the growth medium. High fertility levels in soils are required for profitable peanut yields. Care must be exercised against excessive fertilization as peanuts are sensitive to salt damage (138). The following pages will deal with each nutrient individually.

Nitrogen

Function: Nitrogen is a component of amino acids which make up protein. It is also a structural unit of chlorophyl. Nitrogen probably occurs in more compounds which are involved in peanut metabolism than any other element (with the exception of C, H and O).

A deficiency of N in the peanut plant results in stunted growth, chlorotic foliage, and reddish coloration of stems. Harris and Bledsoe (55) quote references which show that often peanuts with many nodules are deficient in N. Berenyi (9) found plants frequently had many nodules on the roots but were still deficient in N. Reid and York (117) showed that N deficiency interfered with fruit development and that pod and kernel development were prevented when the deficiency was severe. The plants developed deficiency symptoms very rapidly when the supply of N was withdrawn.

Nitrogen fertilization: Peanuts, being a legume, can use atmospheric N after it has been symbiotically fixed by *Rhizobium* spp. However, the question of whether or not rhizobia can fix adequate N for peanut production remains unsettled. Many workers (3, 15, 62, 71, 72, 75, 78, 103, 124, 132, 144, 152, 158) found yields to be increased by N fertilization. Others (40, 41, 68, 96, 116, 119, 133, 136) found no response. Unfortunately, most of these studies did not adequately evaluate the contribution of the symbiotic N bacteria.

The inconsistency in results may, in some cases, be explained by variety or soil relationships. For example, in the United States, N fertilization of large-seeded Virginia type peanuts is not recommended generally. However, growers who produce the smaller runner and Spanish peanuts frequently apply a complete fertilizer to their crop. This would indicate a varietal difference in N response. It is interesting that the most consistent responses occur in the highly weathered soils of India and Africa. Many of these soils frequently may be too acid for efficient functioning of the

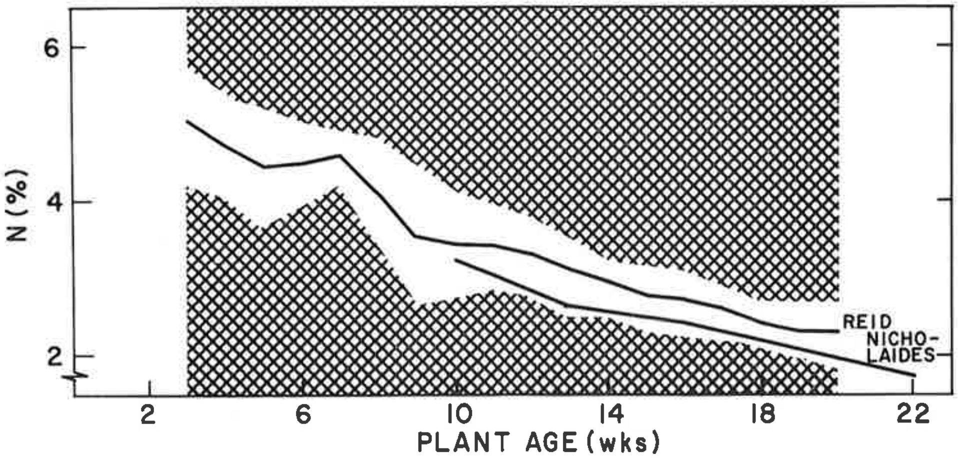

Figure 2. Percent N in peanut foliage from 3 weeks growth through harvest. Courtesy Cox *et al.* (25).

rhizobia. Since ammonium sulfate is the most common source of N in the European and Asian countries, it is impossible to tell whether the responses measured by many of the previously cited workers were due to N or to S. Ollagnier and Prevot (101) and Mann (78) state that the responses obtained in their trials may have been from the S contained in the fertilizer. In fact, Ollagnier and Prevot (101) in Senegal received responses of 600 to 900 kg of pods/ha from ammonium sulfate but no response from urea.

Considerable research from many areas indicates that when soils are adequately limed, drained and inoculated, responses to N fertilization will not be obtained or probably will be very small. How important then is it to inoculate when planting? Numerous investigators have obtained yield responses and/or increased nodulation from inoculation. American—(142, 156), Israeli—(134), 135), Yugoslavian—(129, 130, and 131), and Chinese—(66) workers have obtained large responses to inoculation, but Berenyi (9) and others were unable to obtain responses on soils which have a history of peanut production. However, inasmuch as responses have been obtained and the cost of inoculation is small, many experiment stations recommend that seed be inoculated.

Nitrogen interactions: Nitrogen requirements of peanut plants are affected by the amounts of other elements available. Wahab and Muhammad (158) found that N applications reduced the response obtained from P fertilization. Prevot (110) found a three-way interaction among N, P, and S. For optimum production, he recommended that peanuts be fertilized to provide the levels of N, P, and S in the leaves which are shown in Table 2.

Table 2. Combination of N, P and S in peanut leaves for optimum production. Courtesy of Prevot (110)

When N is	P should be	and S should be
2.5%	0.15%	0.19%
3.0%	0.19%	0.22%
3.5%	0.23%	0.24%
4.0%	0.25%	0.26%

Roche *et al.* (125) recommend that the ratios in leaves be within the following ranges: N/NPK = 0.58 to 0.65, P/NPK = 0.03 to 0.05, and K/NPK = 0.32 to 0.40. Holland (63) found yields correlated with either N+K/Ca or N/P+K ratios but never with both. Huber (64) and Lachover (67) found a positive response to N when P was applied but a reduction in yield when N was applied without P. Stanford and Jordan (147) suggest a N/S ratio in proteins of 15. The relative amounts of each to maintain this ratio were not specified. Thornton (153) showed that P fertilization can cause increased uptake of N, P and K. This may have been a stimulation of root growth or some other factor.

Assaying for N requirements: Many attempts have been made to assay the N needs of peanuts by analysis of leaves and other tissue. Reid (114) showed that interruption of the fruiting process caused high N levels in the leaves. Apparently, N failed to move to the developing fruit. Work by Nicholaides (97), Prevot and Ollagnier (112), and Reid (114) showed a marked reduction occurs in N concentration of the plants as they enlarged. Fig. 2 shows that shortly after emergence N level is highest (above 5%), then decreases progressively during the season to lower levels (below 2%). None of these experiments established critical levels of N at any time during the season. Plants in all these experiments made apparently normal growth indicating adequate N was present.

In summary, the following factors should be considered in any plant analysis program whose objective is to determine the adequacy of the N nutrition:

(a) Age of the plant.
(b) Total N level.
(c) P level.
(d) S level.
(e) Protein-N level.
(f) Protein-S level.

Most American research to date indicates that when the soil has been inoculated with the proper *Rhizobium* sp., and that when the soil has been adequately limed and other plant nutrients are available in adequate supply responses to fertilizer N will not be obtained. On the other hand, more or less consistent responses have been obtained in some African, Asian, and European countries (82). Whether the deficiency of N in these countries is due to an inadequate concentration of effective strains of the bacteria, to the climatic and soil conditions or to other reasons is unresolved.

Phosphorus

Functions of P: Phosphorus is intimately involved in many plant functions. It serves as an energy storehouse for plant metabolism through the adenosine diphosphate-adenosine triphosphate transformations. It is an essential constituent of the ribonucleic and desoxyribonucleic acids which are the genetic templates. As a constituent of protein it is necessary for the growth of the plant.

Phosphorus-deficient plants are stunted (50, 115). Frequently, accumulations of anthocyanins will cause stems and leaves to turn purple and red. Plants often exhibit severe P deficiency symptoms when they are small, particularly during periods of cool weather, but the deficiency generally disappears as the root system expands and the weather becomes warmer.

In spite of the great number of metabolic functions which require P, the total amount taken up by peanut plants is small. The North Carolina Handbook for Agricultural and Home Economics workers (5) indicates that less than 14 lbs. of P are required to produce 1.5 tons of hay and 1.5 tons of peanuts on one acre of land. Although only small amounts are required, the efficiency of uptake from fertilizer P is low so that large amounts have traditionally been applied as fertilizer.

There are numerous reactions which P undergoes when it is applied to the soil. More complete discussions may be found in Black (10), Russell (128), Tisdale and Nelson (155), and many other treatises. Briefly stated, P is fixed as Fe and/or Al phosphate in acid soils and as tricalcium phosphate in basic soils. Maximum availability is obtained at about pH 6.5

Phosphorus fertilization: The source of P in most field studies has been superphosphate. Because ordinary superphosphate is a mixture of calcium phosphate and calcium sulfate, plants which are deficient in P, Ca or S will respond to applications of superphosphate. Therefore, the results of such P trials may be easily misinterpreted.

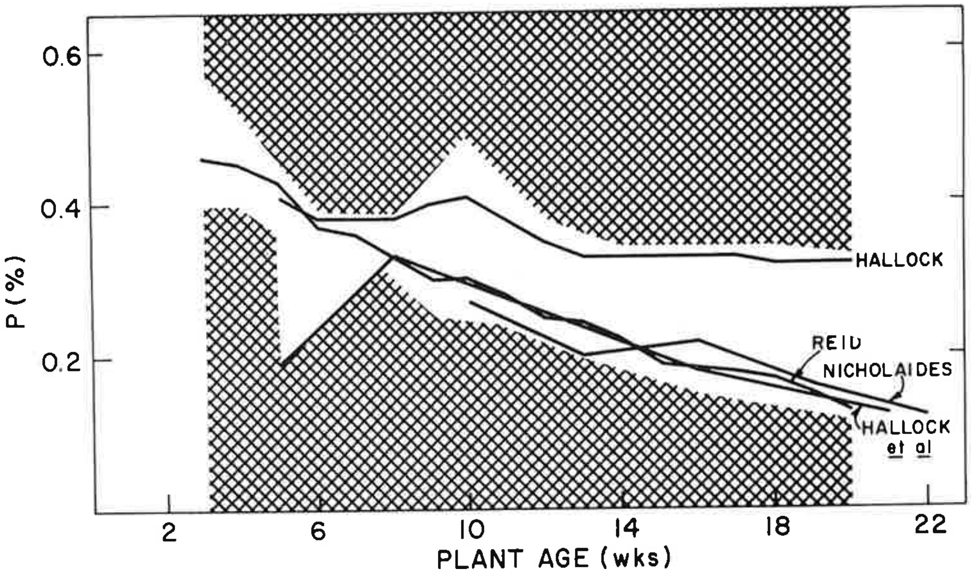

Figure 3. Percent P in peanut foliage from 3 weeks growth through harvest. Courtesy Cox *et al.* (25).

Evidence of this confusion is given by review of fertilizer studies throughout the world. In the United States where Ca and S are applied as gypsum and S is used as a fungicide, responses to P fertilization have been infrequent. Responses have occurred only on soils with small reserves of P. On the other hand, responses frequently are obtained in Asia, Africa, and Europe. It is unknown what portion of these responses may have been due to S or Ca deficiencies. The interaction of S with P and N was discussed previously. Reports from Sierra Leone (4, 108) have attributed the response to superphosphate to its Ca content.

Robertson *et al.* (119) conducted an extensive N, P, K and lime factorial experiment in Florida. There was no response to N or K but a significant P response was obtained which was closely correlated with Truog and Bray soil tests for P. Less P was required for maximum yields on limed than on unlimed soils. Reid and York (116) in greenhouse studies found a detrimental effect from K when the plants were not adequately fertilized with P but when P and K were both supplied yields increased greatly.

Studies in other states (2, 31, 44, 79, 133) indicate that P fertilization is best accomplished by building soil fertility levels. Applications of additional P to other crops in the rotation with none applied directly for peanuts generally is recommended. Prior to this concept, Blackstone (11) recommended the application of 18 lbs/a of P to all peanuts grown in Alabama.

Field experiments with P have been conducted in many nations outside the U. S. Responses to P fertilizer are reported from India (28, 78, 104, 113, 143, 157), Pakistan (158), Senegal (7, 14, 15, 34, 111), Tanganyika—(20), Gambia (30, 153, 154), Ghana (99) Nigeria (37 and 38), Madagascar (124), Uganda—(85, 148), Australia (6, 107), Israel (36), China (160), and Madras—(126). However, Lachover *et al.* (68) found no response to P in Israel.

Hallock *et al.* (48), Nicholaides (97), Reid (114), and Prevot and Ollagnier (112) showed that % P decreased in peanut plants as the plant aged (Fig. 3).

Hallock (45) did not obtain the same decrease in concentration as the other workers. Reid (114) showed that P moved rapidly from the foliar portions of the plant to the developing fruit late in the season. Hallock (45) included the pods in his studies which may account for the failure to observe a decline in P concentration late in the season.

Duby (29) found *Sclerotium rolfsii* to be more severe on P fertilized peanuts than on plants which were unfertilized.

Satyanarayana and Rao (132) reported 0.20% as the critical level for P. Roche *et al.* (125) also reported 0.2% as the critical level and that the P/NPK ratio should be at least 0.3. In plant analysis studies by Hallock *et al.* (48), Nicholaides (97) and Reid (114) all values were above 0.2% and no P deficiency was indicated.

In summary, P fertilization studies have been complicated by the S and Ca contents of P fertilizers. Where bona fide P responses have been obtained, soil P levels were low and previous P applications were limited. Sufficient P for peanut production apparently can be provided by building soil fertility through liberal P fertilization of other crops in the rotation.

Potassium

Functions of K: Potassium occurs in plants as soluble inorganic salts and as salts of organic acids in plant cells. It moves readily in the plant and young, physiologically active parts of plants are always rich in K. Older leaves and other organs frequently lose K as it is transported to growing regions (86).

Potassium is usually the most abundant mineral cation in plants, but its specific role is still somewhat obscure. It is required for certain enzymatic processes in which the role of K is apparently regulatory and catalytic. Specific processes which do not proceed normally in K deficient plants are: (a) The synthesis of simple sugars and

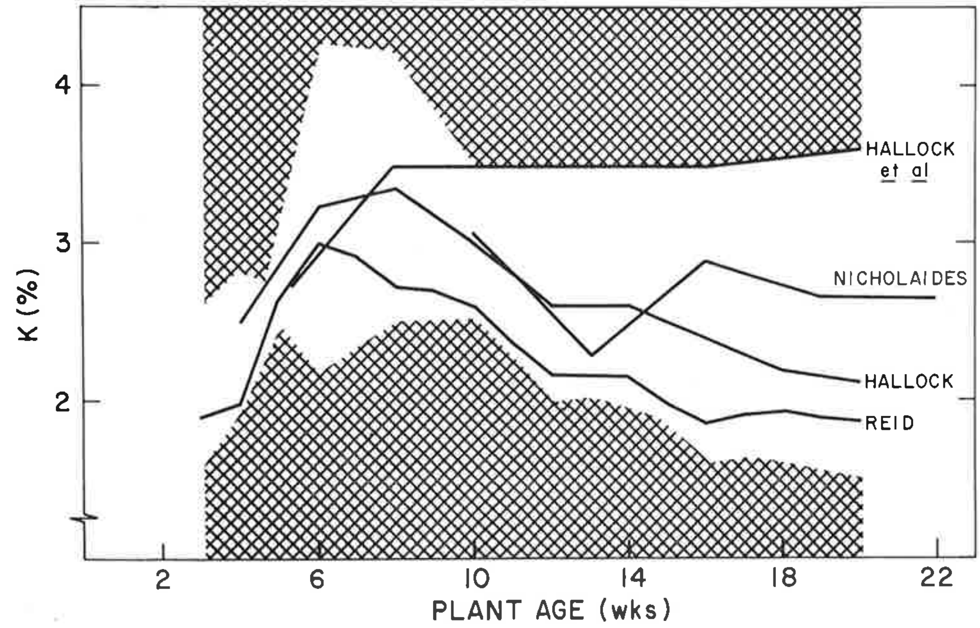

Figure 4. Percent K in peanut foliage from 3 weeks growth through harvest. Courtesy Cox *et al.* (25).

starch, (b) the translocation of carbohydrates, (c) reduction of nitrates, (d) the synthesis of proteins, and (4) cell division.

Potassium deficiency symptoms appear in peanut plants as a yellowing of the margins of the older leaves, (13, 117). This is usually followed by interveinal chlorosis and finally by necrosis of the leaves, beginning at the margins and proceeding inwards until the leaf falls off. The terminal leaves are the last to be affected. Plants may be stunted and yields reduced before the visible deficiency symptoms occur.

Potassium fertilization: A crop of growing peanuts may absorb large amounts of potassium. Levels of K up to 4% in plants during early stages of growth are not uncommon. Nicholaides and Cox (98) found 2.15% in plants making the maximum reproductive development. Lachover and Arnon (69) indicated a level of 0.75% K for the appearance of deficiency symptoms. Potassium uptake values of 140 lbs/a and above are not uncommon.

Responses to K fertilization are not consistent in spite of the large amount of K taken up. In Israel (70), 5 years of cropping were required to reduce a sandy soil with 406 lbs/a of exchangeable K to a level where a response was obtained. Even after 5 years cropping, a loess soil did not give a response. Robertson et al. (119) found a negative response to more than 15 lbs/a of K. An exchangeable soil K level of 76 lbs/a was sufficient for the highest yields obtained.

York and Wiser (164) found a response to direct fertilization in 2 out of 3 experiments, but topdressed K was of no help. Hagin and Koyumdjisky (42) obtained responses in only 2 of 24 experiments and these responses were poorly correlated with exchangeable or soluble K in the soil, or with K in leaves.

Characteristic K deficiency symptoms, which were overcome by 5 kg/ha of K_2O, were found in Bombay by Bockelee-Morvan (16). In the absence of other sources of S, potassium sulfate gave a larger response than other sources.

Prevot and Ollagnier (112) and Serry and El-Banna (137) found no correlation between extractable K and response to K fertilization although the latter investigation showed K uptake to be correlated with extractable K. On the other hand, Scarsbrook and Cope (133) obtained K responses on soils testing low by Alabama soil test procedures. Comber (22) found the ratio of K:Ca:Mg to be important. Optimum yields were obtained when this ratio was 4:1:1 in the tops, 8:4:3 in the shells, and 4:4:2 in the kernels.

The concentration of K in the plant varies markedly with the age of the plant (Fig. 4). The uptake of K is very rapid in the first 6 or 8 weeks of growth and decreases thereafter until harvest. The decrease in K concentration which was found by Hallock (45), Nicholaides (97), and Reid (114) was probably the result of the plants entering a period of rapid growth which caused a dilution of the K. There is some evidence that movement to the developing pods resulted in lower foliar concentrations late in the season. Hallock *et al.* (48) did not find the late season drop in concentration when the total plant was analyzed. Reid, (114) also found that peanut plants bearing a full crop of fruit had higher K concentration in the foliage than those in which the fruiting process had been interrupted by removing the flowers.

Apparent anomalies in the K data presented may be clarified by the following considerations:

(a) Many K fertilization experiments have been conducted under conditions in which factors other than K were limiting, causing misinterpretations.

(b) Peanuts will take up much more K than required if it is available. Thus, K requirements estimated from amounts contained in the plant can lead to erroneous conclusions.

(c) Apparent responses observed in foliage growth frequently are not reflected in pod yields. Pods will develop at the expense of the plant growth under conditions of mild deficiency.

(d) The large volume of soil exploited by peanut roots permits them to yield well under conditions where the concentration in the soil is not great.

(e) The ratio of K:Ca:Mg is perhaps more important than the total amounts of any one of them.

(f) The coarse textures of many soils in the United States on which peanuts are grown make it difficult to build K levels.

Calcium, Magnesium, and Lime

The roles of Ca and Mg as essential elements are frequently confused with their effect in controlling the soil reaction. As the principal basic elements in the soil, they function both to control the pH and as essential elements. A favorable soil pH affects plant growth in the following manners:

(a) It prevents the accumulation of toxic levels of Al and other elements.

(b) It promotes a favorable environment for the microflora.

(c) It enhances the availability of many essential elements. (81, 118, 161).

Research workers (8, 43, 84, 106, 118, 159) in the southeastern United States recommend maintenance of soil pH within the limits of 5.5 — 6.2. The upper limit is to prevent the change of certain micronutrients, particularly manganese, to forms which are unavailable to the plants. The 5.5 — 6.2 range suggested for soil pH cannot be applied to other areas, however. Peanut production proceeds quite successfully in

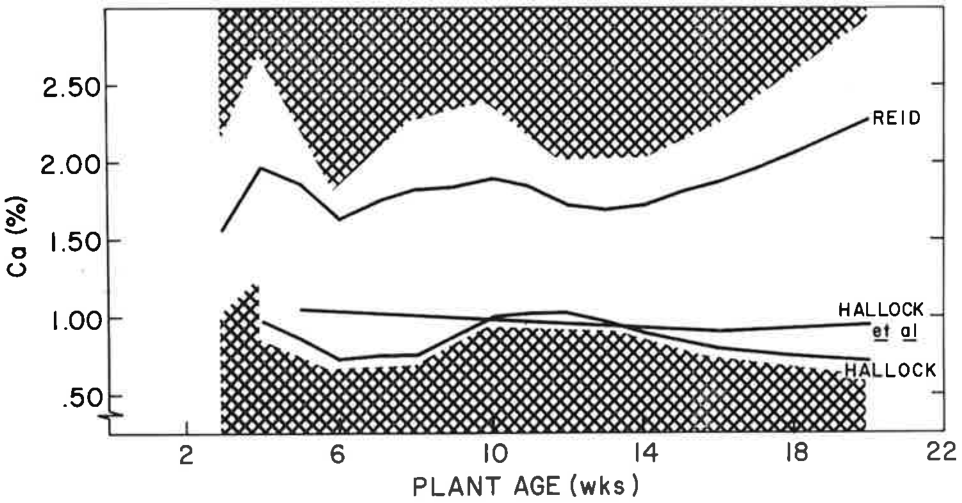

Figure 5. Percent Ca in peanut foliage from 3 weeks growth through harvest. Courtesy Cox *et al.* (25).

Oklahoma, Israel, and Latin America on soils with higher pH values. The authors are not aware of reports of highly successful peanut production where the soil pH is less than 5.0. The optimum pH is dependent upon the climatic and soil conditions at any particular location.

Calcium — function, interrelationships, fertilization: Calcium is a component of Ca pectate, which cements cells together and is required for cell division. Ca, also, serves as a specific activator for certain enzyme systems.

Calcium deficiency of peanuts is reflected by unfilled pods (7, 8, 17, 22, 57, 87, 89, 140, 145, 146, 150) darkening of the plumule of the seed embryo (23, 26, 58, 59), reduced pod development (117) and in severe cases chlorosis, petiole breakdown, wilting and death of terminals and root disorganization (13, 50, 117).

Wiersum (162) used dyes to show that water movement was always from the developing fruit towards the tops of the plant. Inasmuch as transport in the xylem is from moist toward dry areas and because the xylem is the principal source of Ca transport in the plant, movement of Ca is always from the pods toward the top except in cases of extreme dryness around the pods. Bledsoe *et al.* (12) also used Ca^{45} to trace the movement of Ca in the peanut plant. The tracer Ca moved from the fruiting zone throughout the upper portion of the plant. When the Ca^{45} was applied to the tops or roots, it moved throughout the tops, as well as pegs which had not penetrated the fruiting medium. However, very little Ca^{45} was found in the pegs which penetrated the medium or in the shells of fruit which formed on them and it could not be detected in the seed. These findings well explain why Ca must be in the immediate area of the fruit for it to develop satisfactorily. Mizuno (88, 89, 90, 91, 92, 93, 94, 95) from 1959 through 1963 carefully studied the role of Ca in peanut production. Working with culture solutions and using tracer techniques he summarized in detail the function of Ca including movement, response, and effects on growth. His work substantiated the previous work discussed above.

Pal and Lalory (102) showed that Na interfered with the uptake of Ca. Hallock and Garren (47) showed that K reduced the effects of Ca. Mass action of highly mobile cations would be expected to reduce the uptake of Ca, particularly by the fruiting organs where soil-tissue contact is limited.

As a result of the frequency of "pops" (empty pods) in peanuts produced under low available soil Ca levels, and the possible adverse effects of fertilizer salts and weather on the uptake of Ca by the fruit, Ca fertilization is suggested in most areas which produce the large-seeded peanut, except those with calcareous soils. Robertson *et al.* (121), Bailey (8) and Perry (105) recommend gypsum as a source of Ca. In some cases, (84) other sources such as basic slag or calcareous limestone were satisfactory.

Calcium uptake values may vary considerably among locations (Fig. 5), but usually only small differences have been found in plants of different ages at a given location. Calcium is not highly mobile in plants and its concentration in any part of the plant is apparently dependent upon the available supply at the time that part was formed. No critical level in the tissue has been established.

Magnesium — function, nutrition: Magnesium is a component of chlorophyll and is involved in many enzyme systems. Deficiency symptoms were described by Harris (50), Bledsoe and Harris (13), and by Reid and York (117). The first symptom of Mg deficiency is interveinal chlorosis of the terminal leaves and stunting of the plant. In severe cases, plants completely lose their green color and die.

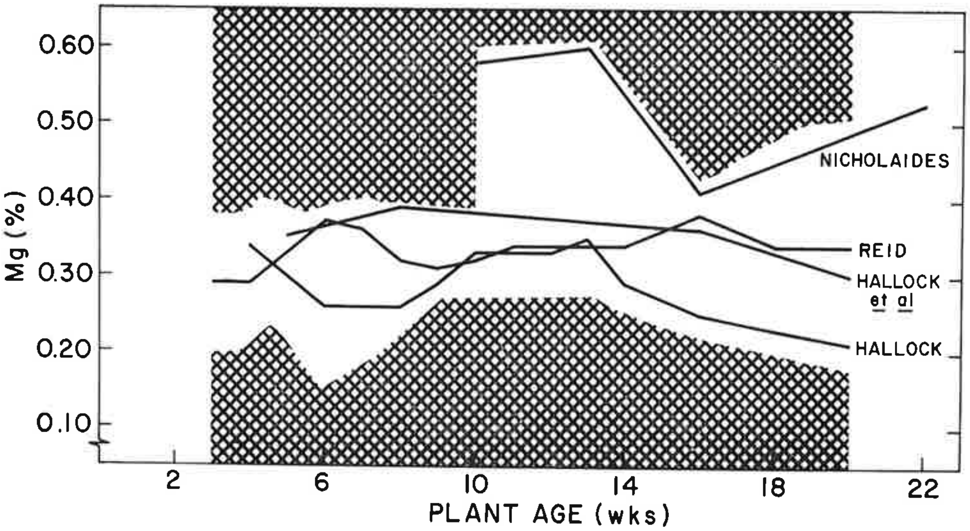

Figure 6. Percent Mg in peanut foliage from 3 weeks growth through harvest. Courtesy Cox *et al.* (25).

Fig. 6 shows the results of periodic analyses of peanut plants for Mg by independent workers in North Carolina and Virginia. The Mg levels found by Nicholaides (97) were greater than those found in the other three studies probably as a result of the higher soil levels in this study. Reid (114) found that prevention of fruit development by flower removal resulted in much higher foliar contents of Mg.

Very little information is available concerning the response of peanuts to Mg applications in the field. Peanuts often have failed to respond to Mg applications even when corn, cotton, or small grain growing on the same fields previously showed severe Mg deficiency. Perhaps peanuts can exploit acid soils better than some other crops as discussed by Adams and Pearson (1).

Lime: Many reports have shown yield responses to lime applications, but it is not always easy to separate the lime response from the nutrient response. Robertson *et al.* (120) found peanuts responded more to calcitic than to dolomitic limestone but corn responded more to the dolomitic source. Cox (24), Robertson et al. (119), Thompson and Robertson (152), and Martin (81) all report responses to limestone applications to acid soils. Scarsbrook and Cope (133) concluded that Ca is the most limiting factor in peanut production in Alabama. Rocha et al. (123) found that P deficiency and inadequate lime were the principal limiting factors in the red and yellow latosols of Brazil.

Sulfur

Probably no single element is more deficient in the soils of the world for peanut production than is S, yet it has received less attention than most of the major or secondary elements. Kanwar (65), for example, estimates that 75% of the soils in Samrala State of India are deficient in S. Dalal *et al.* (27) estimates the S in gypsum gives an average yield response of 13 — 15% in the Punjab. It is quite probable that many of the responses attributed to other factors have in reality been S responses. This anomaly exists because many other treatments commonly applied to peanuts supplies

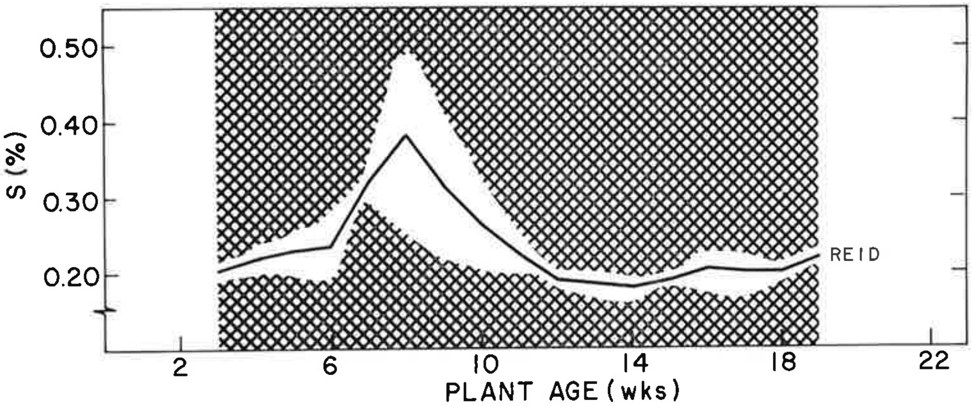

Figure 7. Percent S in peanut foliage from 3 weeks growth through harvest. Courtesy Cox *et al.* (25).

S. Examples of such treatments include the following:

(a) Application of superphosphate which contains 10% to 12% S.

(b) Application of gypsum which contains 18 — 23% S.

(c) Dusting for leafspot control with elemental S which may supply up to 120 lbs/a of S, annually.

High analysis fertilizers are now coming into usage that do not contain superphosphate with its high S content. New fungicides are being tested continually which may replace S as a fungicide. Many farmers are seeking Ca sources which can be applied more conveniently than gypsum. Peanut producers should constantly be alert for the appearance of S deficiency when routine practices which are employed do not include the application of S bearing materials.

Functions and nutrition: Sulfur occurs in plants as a constituent of essential amino acids. Thus, it is necessary for the development of proteins. Much of the S in plants remains in the sulfate form and probably functions in osmotic balance and reaction control. Hanover and Brzozowska (49) found that the foliage of S-deficient plants were low but their roots were high in sugars. A sulfur deficiency increased arginine and asparagine but decreased the cystine and glutamic acid contents in the plant.

Deficiency of S is difficult to visually distinguish from N deficiency except that the terminal leaves are the first to show S deficiency and the older leaves or the entire plant first show N deficiency. However, verification frequently requires plant analyses.

Harris (52) showed with tracer studies that S could be absorbed by both the roots and the fruit. Absorption by the fruit was rapid. Brzozowska and Hanover (18) found that S was rapidly absorbed and distributed in plants. Middle-aged leaves contained less S than older or younger leaves.

Reid (114) traced the S level of peanuts throughout the season. The results are plotted in Fig. 7. The S level fluctuated around 0.2% in the leaves except during the period from 6 to 10 weeks after planting (maximum flowering stage) when the S level rapidly increased. No explanation is offered for this period of high S content.

Stanford and Jordan (147) report that the protein-N/Protein-S ratio should be about 15. No critical level is given. This supports the previously quoted work of Prevot (110) that the S requirement is dependent upon N and P levels in the plant.

Micronutrients

The micronutrients are a class of elements typified by the minute requirement of each for normal plant growth. Three of the seven essential micronutrients are present in the soil as anions (B, Mo, and Cl) and four as cations (Fe, Mn, Zn, and Cu). Since they are required in such small concentrations, their role is presumably primarily catalytic, being part of enzymes or activators of enzyme systems.

Attempts to determine the requirements of peanut crops for the micronutrients have given variable results. Many of the studies designed to demonstrate visual deficiency symptoms have been performed in purified media in the laboratory or greenhouse. Reid (114) and Martens *et al.* (80) sampled peanut plants in North Carolina and Virginia periodically through the growing season and analyzed for the micronutrients. The results are shown in Fig. 8. None of the plants in these studies exhibited noticeable deficiency. The reader is referred to Cox *et al.* (25) for more detailed discussion of these experiments.

Some of the specific roles of the micronutrients have been delineated and are recorded in various texts and journals of plant physiology. Visual deficiency symptoms are difficult to identify positively. Frequently, the symptoms of micronutrient deficiency resemble those of other nutrient deficiencies so plant analysis or other diagnostic procedure is needed for positive identification of the deficiency. Plant physiologists have studied the metabolic reactions of many of the nutrients at a subcellular level. It is impossible to extrapolate from such "test tube" studies to growing plants with the limited number of field experiments which have been conducted. Many more trials are needed to narrow the gap between the isolated subcellular reactions and the integrated growth processes of plants in the field.

Many field experiments concerning fertilization with micronutrients indicate, in general, that B and Mo are most likely to be deficient in the United States. Gillier

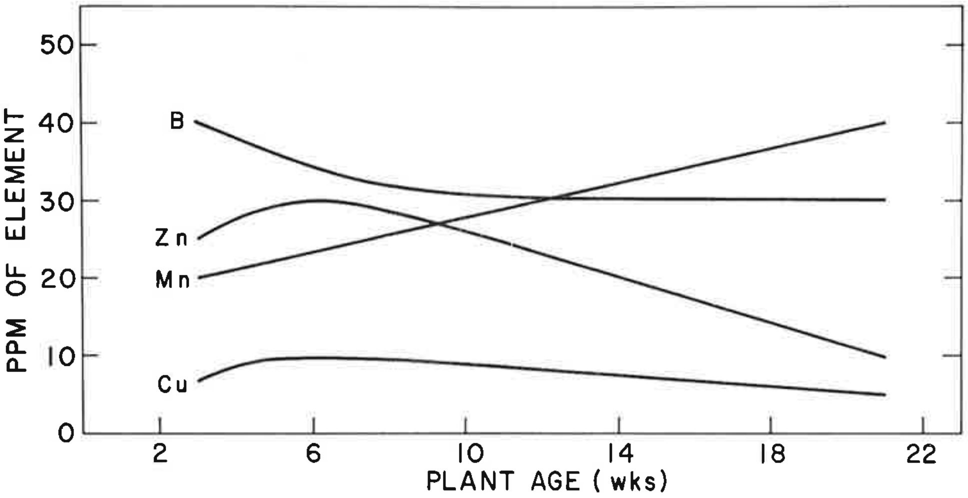

Figure 8. Concentrations of B, Zn, Mn and Cu in peanut foliage during the growing season which are considered satisfactory for optimum growth. Courtesy Cox et al. (25).

and Silvestre (35) indicate that this is also the case in tropical areas. Oram (100) also noted that B deficiency had been recorded in Africa and that nodulation may be reduced on soils deficient in Mo.

Boron: Boron deficiency in peanuts usually causes "hollow heart." Peanut kernels with this defect have not developed properly, leaving a depressed area in the center, which is often brown or will become brown upon roasting. Harris and Gilman (60) conducted the first greenhouse studies showing that peanuts grown without sufficient B had a large amount of hollow heart damage. This was practically eliminated by the application of B. Field work in North Carolina (26), Virginia (46), Alabama (61), and other states have substantiated this and B fertilization of peanuts is now common to insure having the highest quality crop possible. However, as noted by Harris and Gilman (60), and Harris (54), hollow heart is not completely eradicated by the use of B. Cox and Reid (26) and Hallock (46) have obtained similar results also. Usually, 0.45 kg/ha of B gives economic control of this form of damage. Higher applications of B have not further decreased this damage appreciably and may be phytotoxic. Yields may be decrease at rate greater than 1 lb/a. Therefore, the rate commonly suggested is ½ lb/a of B.

Harris and Brolmann (56) have studied the histological effects of B deficiency, but the metabolic relations are still unknown. It appears that the conversion to oil is inhibited and there is an unusually high concentration of sugars and starches present, probably due to the lack of a particular enzyme. B, also affects the rate of synthesis of certain nitrogenous compounds (149) which are needed to form specific enzymes.

Reid (114) using a solution culture technique, demonstrated that fruiting was very restricted when B was withheld during the fruiting period even if B was supplied in adequate quantity until that time. For adequate growth a threshold level of B in solution of 0.005 ppm has been determined by Maistre (77), while Leveque (73) indicated the optimum rate was 0.75 ppm B. Large discrepancies in rates such as these indicate different methods of experimentation and different environmental conditions.

The above workers all noted restricted flowering under conditions of B deficiency. Harris and Brolmann (57) studied this aspect in the greenhouse using a soil low in B. Without added B, the rate of flowering was not as intensive but the period of flowering was more prolonged than with B so that total flowers produced were not changed by treatment. With adequate B there were many more flowers early in the growth of the plant and the pattern was more typical.

Yield responses to B in the field are infrequent but they do occur when B deficiency is severe. Rotini (127) reported that an application of B increased yields 15% on certain acid, low organic matter soils in Europe. It seems apparent, however, that yield responses to B are of less importance than quality maintenance.

The Alabama workers indicated that the deficiency occurred on soils "low" in soil B. Unfortunately, there is no set standard for soil test levels of B in soils on which peanuts are grown. Cox and Reid (26) reported less than 0.04 ppm soil B (hot water soluble) in two experiments. Such values may be relatively common in the sandy soils of the southeast. Soil test critical values, when established for B, will differ among textures, probably increasing with increasing clay content.

Many methods of application of B appear feasible. Boron fertilizer has been applied by itself or with other fertilizers and fungicides with equal results. Likewise, time of application does not seem critical as long as it is before the pod-filling stage.

Residual effects of such low rates of B have not been studied. Luke (76) used higher rates to determine if a potential toxicity problem may develop. He found most of the B was leached from sandy surface soils in a few months. However, the rate of removal from the subsoil with more clay was slower and an appreciable content of available B persisted for several years but decreased with time.

Luke's results indicate little possibility of a toxicity problem to residual B from reasonable applications. However, rather large differences in plant B concentration occurred with very small differences in the level of available soil B. Thus, plant analysis may provide a better means for determining the status of B nutrition than soil testing.

Boron becomes toxic to peanuts when the tissue level reaches 80-100 ppm (76, 149). Gopal and Rao (39) found less Fe, protein, and chlorophyll in the leaves under toxic conditions. They hypothesized that less Fe led to degeneration of proteins which caused a breakdown of the chlorophyll.

Molybdenum: Molybdenum is perhaps the most "micro" of the micronutrients, being needed in extremely small quantities by the peanut plant. Reid and York (117) were unable to characterize a visible Mo deficiency symptom *per se* using culture solutions. Even when Mo was omitted, the plants continued to flower and form fruit, though growth was reduced.

One of the major roles of this nutrient is in oxidation-reduction reactions involving N. In this case, it is needed not so much by the plant as by the N-fixing bacteria, the rhizobia, in nodules on the roots. When Mo is deficient the bacteria cannot fix sufficient N for the plant and thus the symptom shown is typical N deficiency.

Greater quantities of Mo are needed for N fixation than for metabolic reactions in the plant. Harris (53) has noted on several occasions that foliage was greener due to more N when Mo or lime was applied. Liming increases the availability of Mo, and this has been shown specifically for peanuts by Welch and Anderson (161).

The application of Mo frequently increases N fixation without affecting yield as has been noted by Silvestre (143) and other workers mentioned above. Occasionally, however, responses are obtained. Martin and Fourrier (83) found an application of Mo to markedly increase peanut yields at a site in Senegal. Also, Gillier (33) reported yield responses in parts of Senegal that averaged 100 kg/ha. Undoubtedly, many other examples exist from experiments conducted on quite acid soils, but few have been reported.

Fertilization with Mo is inexpensive and easy. Approximately ½ oz/a of Na_2MoO_4 is required. This quantity can be applied to the seed with or without the inoculum at planting. Because of the low cost and simplicity, it is often furnished with seed sold commercially. Molybdenum fertilization is best viewed as a means of insuring adequate N fixation for a crop, but there are several considerations which may justify its general use besides low price. The pH of sandy soils typically used for peanut production may decrease rather rapidly. There are variations within a field and certain areas are very acid.

Manganese: The availability of all the micronutrients except Mo tends to decrease with increasing soil pH. This relation to soil reaction is more pronounced with Mn that with the other elements. Thus under very acid conditions Mn is very available and toxicity may occur whereas at high pH the availability is often decreased to the point of deficiency. Martin (81) has noted Mn toxicity in peanuts grown on very acid soils. The condition is readily controlled by liming, however, and if the pH is maintained at the proper level this problem should not be encountered.

Leveque and Beley (74) studied the effects of high levels of Mn in sand culture trials. They found that accumulation of Mn in the leaves led to brown spots on the leaf margin spots, delayed flowering and maturing, and impaired fruit development. Also, it appeared that under toxic conditions the tissue concentrations of N, P, and Mg increased while that of K and Ca decreased.

A deficiency of Mn is more common than a toxicity. The typical symptom for a deficiency is chlorosis of the interveinal area of the leaflet while the veins tend to remain green. Also, Bussler (21) termed the deficiency as "marsh spot" and related its occurrence to levels of Mn in the fruit.

Manganese deficiency in peanuts is usually confined to certain soil conditions. Soils which have developed from coastal sediments under relatively high rainfall and poor drainage are low in Mn. Acid-reducing conditions have allowed the divalent form of Mn to be leached. When these soils are limed the availability of Mn is reduced and a deficiency may develop, especially near neutral soil pH levels.

Rich (118) pointed out that Mn deficiency is more common on fine-textured soils than on coarse-textured ones. This relates to the fact that finer textured soils in the Coastal Plain have developed under poorer drainage conditions than coarse-textured ones. Since soils with appreciable clay may present problems in harvesting they have not been used extensively for peanut production. Thus, Mn deficiency is usually quite localized.

The relation between soil pH and Mn availability was also pointed out by Rich (118). In his study, he related the Mn content of tissue to many soil properties. He

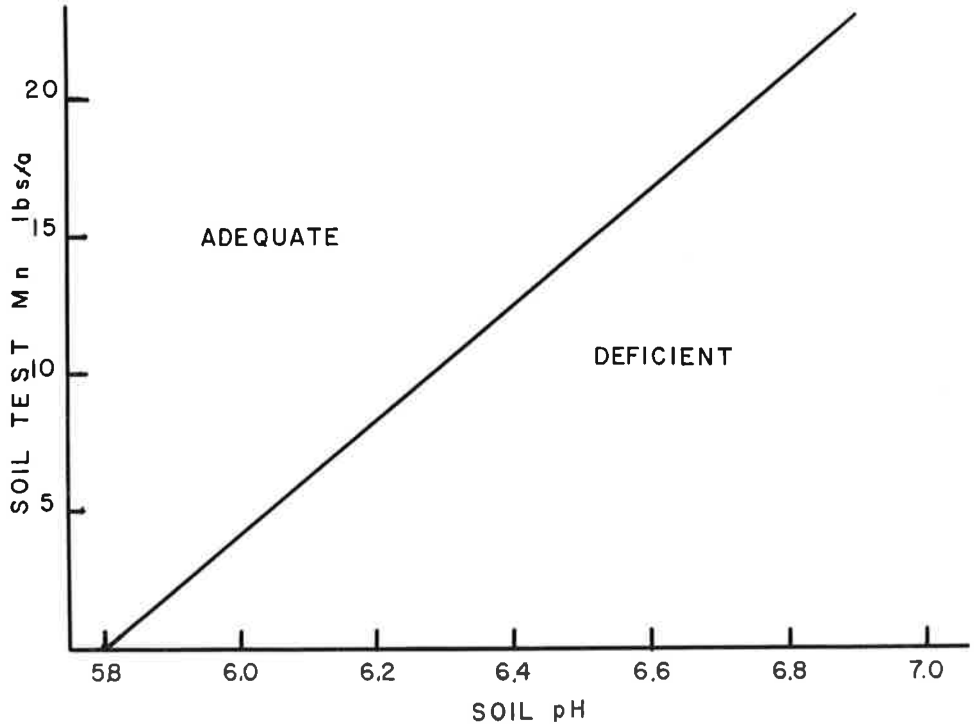

Figure 9. The relationship of Mn critical soil test level to pH of the soil. Unpublished data N. C. Experiment Station.

found 28% of the variation in plant Mn was accounted for by pH variations. Soil pH, easily reducible Mn and exchangeable Ca, Mg and Mn accounted for 62% of the variability in plant Mn.

In North Carolina, two soil factors, pH and dilute acid extractable Mn, are used to interpret soil test data. As shown in Fig. 9, the critical soil test level of Mn is negligible at soil pH 5.8, but increases with increasing pH. The use of Mn is recommended for any combination of Mn level and pH falling below this line. Below soil pH of 5.8 peanuts apparently obtain sufficient Mn from sources not measured by the N. C. soil test.

Manganese may be applied to the soil or to the plant and furthermore both means may be required for correction of severe deficiencies. Under such conditions even the Mn applied to the soil may be oxidized rapidly and thus not provide sufficient Mn for the full season.

Yield responses have been noted in North Carolina and Virginia, though most of the data is unpublished. In Africa, Silvestre (143) has reported some small responses, all small, indicating that Mn deficiency is also of minor importance in that region.

Copper, Zn, and Fe: These three micronutrients are rarely deficient for peanut production. Many years ago Zn responses were noted in a few peanut fields in Florida. However, Zn has been applied to other crops such as corn and no deficiencies have been noted on peanuts recently.

Harris (51) noted a similar situation with Cu. He described the visual symptoms of Cu deficiency and obtained yield responses to both Cu applied directly to the soil and to Cu which was residual from previous applications. Since fungicides containing Cu have been used on peanuts for many years it is likely that the soils which he used are now well supplied with this nutrient.

Young (165) studied Fe deficiency in peanuts grown in Texas. Soils with greater than 5.5 tons of total $CaCO_3$ per acre in the surface foot produced chlorotic peanuts but were satisfactory for cotton and sugar beets. Such soils are typified by considerable caliche or high levels of $CaCO_3$ in the upper solum. Young suggested that significant areas of such soil not be used for peanut production.

Iron chlorosis was corrected in Texas by sprays of $FeSO_4$ or by Fe chelates or complexes. The sulfate source tended to burn the foliage. About three sprays were needed for a growing season.

Peanuts showing only mild Fe chlorosis did not show a yield response when sprayed. Moderate and severe chlorosis, however, decreased yields 20 and 50%, respectively.

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