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Chapter 6

LIMING, FERTILIZATION, AND MINERAL NUTRITION

FRED R. COX, FRED ADAMS, AND BILLY B. TUCKER

The nutritional needs of the peanut must be satisfied to attain maximum yields. These needs require that an adequate supply of every essential element is available throughout the growing season and that toxic conditions are eliminated. Assuming sufficient air and water are present, the management of proper mineral nutrition is achieved primarily by liming and fertilization. Prediction of the requirement of these practices and the quantities of materials needed may be by soil testing and plant analysis procedures and with knowledge of prior management. Recent research, especially that within the last decade, on liming and fertilization is reviewed in the following sections.

LIME

Walker (1975) cited an 1895 USDA bulletin as evidence of the early recognition of the need for liming peanuts. Duggar and Funchess (1911), working between 1906 and 1910 in central and southern Alabama, found an average yield increase of 24% from liming 11 field experiments. In spite of these positive responses, Rogers (1948) noted inconsistent yield responses to liming and stated that none of the southeastern states stressed the need for liming peanuts as late as 1940.

It was not until the comprehensive studies at the North Carolina Agricultural Experiment Station during the 1940's that the stage was set for rationalizing the yield responses to lime (Burkhart and Collins, 1942; Brady and Colwell, 1945; Colwell and Brady, 1945; Middleton et al., 1945; Reed and Brady, 1948). It soon became clear that the primary response to lime is the effect it has on available soil Ca in the pegging zone (Rogers, 1948; Reed and Brady, 1948). Adding lime in the row at planting (Colwell and Brady, 1945) or adding it in the fall and turning before planting (Sullivan et al., 1974) results in ineffective lime use; it fails to concentrate the lime in the top 7 to 9 cm of soils where Ca is needed for fruit development. However, if lime is added in a manner to ensure that fine lime is in the pegging zone during fruit development, yield responses have been shown to be consistent with available Ca levels (Rogers, 1948; Reed and Brady, 1948; Hartzog and Adams, 1973; Adams and Hartzog, 1980). Rogers (1948) concluded that the yield response to lime was because a Ca deficiency was corrected (Figure 1). Reed and Brady (1948) reached the same conclusion because topdressed gypsum at bloom and preplant broadcast lime produced the same yield response on 3 very acid soils (Figure 1). Adams and Hartzog (1980) in Alabama directly compared lime and gypsum in 16 experiments on farmers' fields and validated the earlier results (see Figure

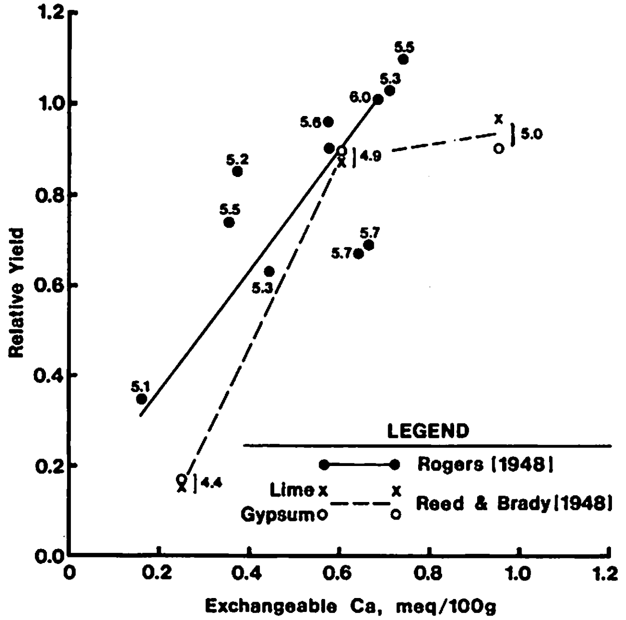

Fig. 1. Yield responses in field experiments of small-seeded peanuts (Rogers, 1948) and large-seeded peanuts (Reed and Brady, 1948) as a function of exchangeable soil Ca (soil pH of each site is shown by number adjacent to data point). Data are graphed from tabulated data by original authors.

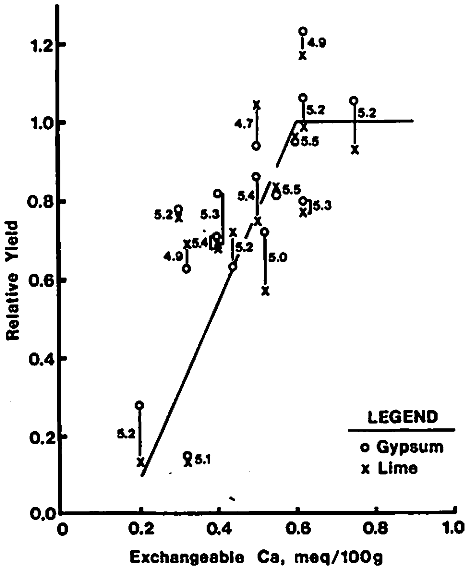

Fig. 2. Yield response of Florunner peanuts in field experiments to topdressed gypsum at early bloom or to preplant broadcast limestone as a function of exchangeable soil Ca (soil pH of each site is shown by number adjacent to paired data points). Data are graphed from tabulated data of Adams and Hartzog (1980).

2). Laurence (1973) found liming and gypsum applications in field trials in Malawi gave equal results on soils with pHs in the range of 4.3 to 4.9.

The peanut has demonstrated a remarkable tolerance to the normal soil factors that make acid soils infertile. It is highly tolerant of solution Mn (Morris and Pierre, 1949) and solution Al (Adams and Pearson, 1970). Peanut yields and root growth are unaffected by soil solution Al levels that are highly toxic to cotton (*Gossypium hirsutum* L.). In a comparison of 18 species planted on an Oxisol at pH 4.7 (Ca level not reported), Munns and Fox (1977) found spanish peanuts ranked near the bottom in relative response to lime.

An additional causal factor of acid-soil infertility for legumes is the intolerance of rhizobia to low soil pH or excess Al. The above data, however, indicate that peanut-associated rhizobia can cause effective nodulation and N fixation at very low soil pH levels. Little work has been reported in this area (Mann, 1935; Munns and Fox, 1977).

Because of the relative insolubility of limestone, one might expect that it would not supply Ca to the pegging zone as efficiently as gypsum. For example, 560 kg/ha of basic slag (a liming material) topdressed at early bloom had little or no effect on yield (Hartzog and Adams, 1973). Reed and Brady (1948) reported, however, that topdressed dolomite at seedling emergence was as effective as gypsum in 2 out of 3 experiments. In a study with a lime slurry, Adams and Hartzog (1979) found that 560 kg/ha of actual liming material broadcast and disked-in just prior to planting was an insufficient rate for maximum yields. Lime will be equal or superior to gypsum if the application methods provide for adequate lime to be in the pegging zone during fruiting because it is not as subject to leaching as gypsum. For example, heavy rains on deep, well drained sandy soils may move applied $CaSO_4$ below the pegging zone while $CaCO_3$ remains in place. This phenomenon may have contributed to the results observed in 2 experiments in Alabama: on a Lakeland loamy sand (pH 4.9; 0.19 meq exch. Ca), gypsum produced 1,580 kg/ha of peanuts while lime produced 4,190 kg/ha; on a Bonifay sand (pH 5.2, 0.20 meq exch. Ca), gypsum produced 1,280 kg/ha while lime produced 2,730 kg/ha.

Based on data obtained before machinery was available to thoroughly mix limestone with soil, the concept that lime needs to be applied several months prior to planting still prevails. However, modern agricultural machinery has made the concept obsolete, as demonstrated by scores of liming experiments in Alabama in which the limestone was applied just prior to planting and disked-in to a depth of 9-10 cm (Hartzog and Adams, 1973; Adams and Hartzog, 1979, 1980).

CALCIUM

Yields are limited more often by a lack of Ca than by a lack of any other plant nutrient on acid, coarse-textured soils in the USA. This is because of the inherent thriftiness of the peanut plant in obtaining soil nutrients for its vegetative growth and because of its unusual fruiting habit. Research in North Carolina during the 1940's clearly established the need for Ca in the fruiting zone, i.e., in the upper 7-9 cm of soil (Burkhart and Collins, 1942; Brady and Colwell, 1945; Colwell and Brady, 1945; Middleton et al., 1945).

Calcium Translocation in Plants

Calcium deficiency in the field is mainfested most often as "pops," a term for pods containing aborted or shriveled fruit. The dual reasons for Ca deficiency being expressed in this manner are the subterranean position of the fruit and the restrictive transport of Ca in the plant. Calcium is passively absorbed by plants; the amount absorbed depends upon its concentration in the soil solution and the amount of water absorbed by the plant (Mengel and Kirkby, 1978). The Ca^{++} ion is transported almost exclusively in xylem tissue. Thus, Ca in the xylem sap is translocated upward with the transpiration stream whereas its downward movement from the leaves through phloem tissue is practically nil.

Once the developing gynophore penetrates the soil surface, it ceases to transpire root-absorbed water and, consequently, loses access to root-absorbed Ca. At this stage of development, the developing fruit must absorb additional Ca from the ambient soil solution (Bledsoe et al., 1949; Skelton and Shear, 1971; Slack and Morrill, 1972; Beringer and Taha, 1976; Wolt and Adams, 1979). The peanut fruit is an inefficient absorber of Ca. Its tissue is much lower in Ca than vegetative tissue, yet the fruit must have a higher ambient Ca supply. This difference is probably because Ca is passively absorbed by both roots and fruits, and the amount absorbed is dependent upon the transpiration rate. Only small amounts of water move from fruit toward the plant tops (Wiersum, 1951; Beringer and Taha, 1976; Wolt and Adams, 1979), resulting in inefficient Ca absorption by the fruit and insignificant movement of Ca from fruit via xylem tissue to vegetative parts.

Characteristics of Calcium Deficiency

Obvious plant responses to insufficient Ca for pod filling are 1) more abundant foliage that remains green later into the season, and 2) a tendency for greater flower production (Colwell and Brady, 1945; Comber, 1959; Harris and Brolman, 1966; Nicholaides and Cox, 1970; Wolt and Adams, 1979). It is clear that soil Ca levels needed for maximum vegetative growth and maximum fruit yield are different. Comber (1959), for example, reported maximum vegetative growth with a Ca/(K + Mg) equivalent ratio of 1:9 and maximum seed yield with a ratio of 1:3 in a pot experiment. Similar results were obtained by Wolt and Adams (1979) with nutrient solutions and potted soils. They identified 3 different critical Ca levels for the small-seeded Florunner peanuts in terms of Ca/total-cation molar activity ratios: (i) maximum vine growth at 0.10, (ii) maximum flower fertility at 0.15, and (iii) maximum pod fill at 0.25 (see Figure 3).

Moderate Ca deficiency for vegetative growth appears first on fully developed leaves as localized pitted areas on the lower surface which subsequently develop into brown necrotic spots (Burkhart and Collins, 1942). The spots may have an outer chlorotic halo and continue to enlarge until they coalesce and the leaf senesces (Wolt and Adams, 1979). In its early stages, symptoms may resemble *Cercospora* leafspot. Severe Ca deficiency (unlikely in the field) results in the death of root tips and terminal buds.

Harris and Brolmann (1966a) were puzzled by their observation that plants bloomed profusely when suffering Ca deficiency. The subsequent work of Wolt and Adams (1979) showed that flowers produced under Ca regimes favorable for maximum vegetative growth were mostly infertile. Flower fertility increased with increasing Ca level and a corresponding decrease in vine growth until practically all flowers were fertile (see Figure 3).

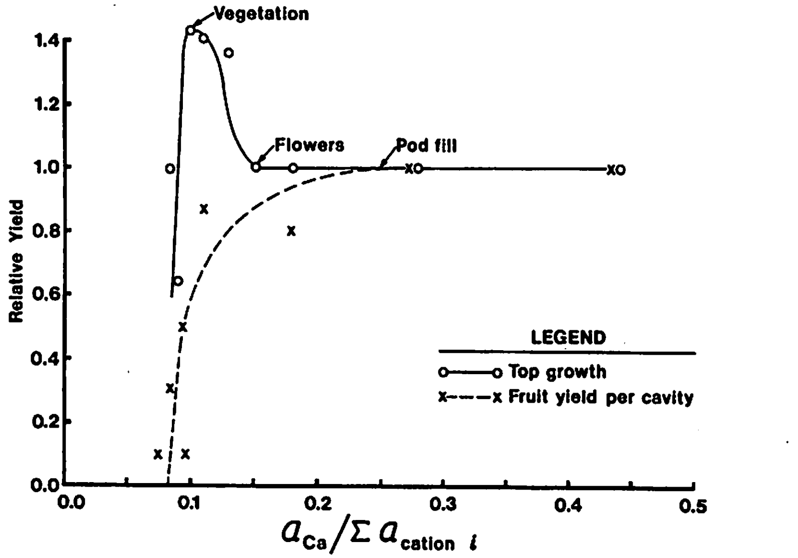

Fig. 3. Relative yields of vegetation and fruit as a function of Ca/total-cation activity ratio in nutrient solutions and soil solutions *in situ*; critical Ca levels are indicated by arrows for maximum vegetative growth, flower fertility, and pod fill. Data are redrawn from data of Wolt and Adams (1979).

Calcium-deficiency symptoms, in addition to aborted, shriveled fruit, include a darkened plumule (Cox and Reid, 1964; Harris and Brolmann, 1966b). Germination of dark-plumule seed is poor and seedling survival is even worse. However, even "normal-appearing" seed will exhibit poor germination if their Ca contents are low. Harris and Brolmann (1966b) reported that

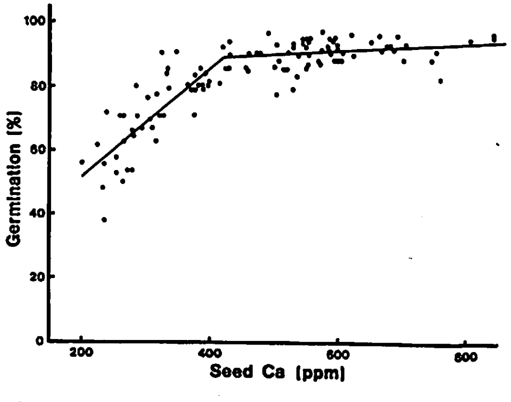

Fig. 4. Relationship between germination percentage and seed-Ca concentration of Florigiant peanuts (Cox et al., 1976).

72% of seed (cv. Florigiant) containing 0.03% Ca germinated and 98% germinated that contained 0.08% Ca. Cox et al. (1976) subsequently identified the critical seed Ca level for maximum germination of this cultivar as 0.042% Ca (Figure 4). Critical Ca content of NC 5 was reported to be between 0.045 and 0.068% (Sullivan et al., 1974).

Genetic Influence on Calcium Need

The ambient Ca level in the fruiting zone required to prevent "pops" varies among cultivars (Middleton et al., 1945; Slack and Morrill, 1972; Beringer and Taha, 1976; Walker et al., 1976; Walker and Keisling, 1978). In general, large-seeded cultivars require a higher level than small-seeded ones. However, it is unlikely that seed size per se is the controlling factor. For example, the Ca requirement of the large-seeded Florigiant may be closer to that of some small-seeded cultivars than to some of the large-seeded cultivars (Hartzog and Adams, 1973; Walker et al., 1976). Walker and Keisling (1978) also reported that Tifrun had a higher ambient Ca requirement than the similar-sized Florunner.

The role that genetics plays in Ca requirement for pod fill has not been adequately explored. Using ^{45}Ca, Beringer and Taha (1976) found that Ca translocation from shell to seed was greater in a small-seeded, pop-resistant cultivar than in a large-seeded, pop-susceptible cultivar. Crompton et al. (1978) studied the progeny of a cross between a small-seeded spanish cultivar and a large-seeded cultivar. They found Ca levels in seed to be highly correlated with adenosine phosphate levels, and percentage germination to be highly correlated with both Ca and adenosine phosphate levels. Seed Ca concentrations of F_3 progeny overlapped that of the parents as well as covering the range in between. A breeding objective yet to be fully realized is the transfer of the Ca-efficient character of small-seeded cultivars to large-seeded cultivars.

Soil Calcium Level

The most practical field problem with Ca nutrition is to ensure that the available Ca level in the fruiting zone exceeds a defined critical level during the time of fruit development. This has led to the general practice of top-dressing with a soluble Ca source at early bloom. The need for supplemental Ca should be calibrated against exchangeable soil Ca or an approximation of it, e.g., the dilute double-acid extraction (0.05 N HCl + 0.025 N H_2SO_4). Approximately 200 field experiments in Alabama between 1943 and 1979 have been used to calibrate the yields of small-seeded runner cultivars as a function of exchangeable Ca (Rogers, 1948; Adams, 1956; Hartzog and Adams, 1973; Adams and Hartzog, 1979). Recent data by Adams and Hartzog (1980) for the Florunner cultivar (Figure 5) show that the critical Ca level is about 120 ppm (0.6 meq/100 g or 270 kg/ha). Spanish cultivars may have an even lower Ca requirement (Middleton et al., 1945). The large-seeded, inefficient Ca utilizers probably have critical soil Ca levels of about 250 ppm (1.25 meq/100 g or 560 kg/ha) (Colwell and Brady, 1945; Reed and Brady, 1948; Sullivan et al., 1974; Hall, 1975; Walker et al., 1976; Walker et al., 1979).

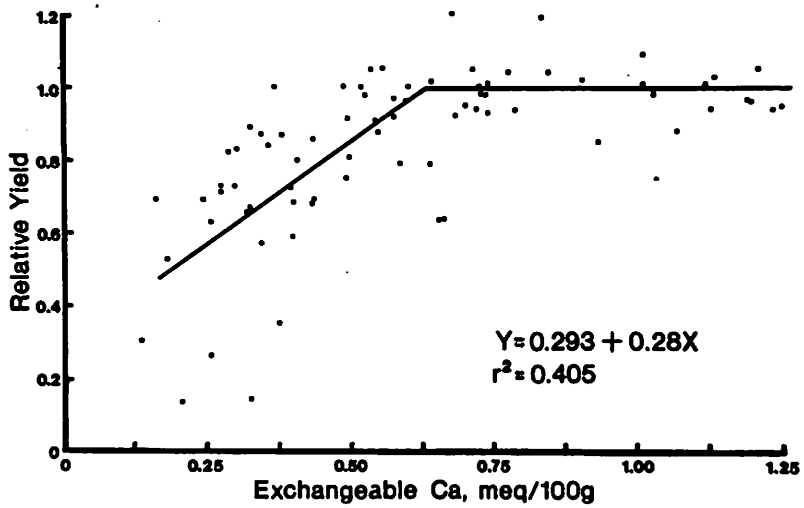

Fig. 5. Effect of extractable soil Ca on the yield of Florunner peanuts (yield of Ca-amended plots assigned value of 1.0). Equation does not apply to horizontal line.

Because of the antagonistic interaction between Ca and the other cations, it has been demonstrated that excess K in the fruiting zone during fruit development will interfere with Ca utilization by fruit and result in the need for a higher level of soil Ca (Brady and Colwell, 1945; Comber, 1959; Anderson, 1970; Laurence, 1973; Hall, 1975; Chesney, 1975b). This, however, should not be a field problem where excessive fertilizer rates are avoided.

Calcium Soil Amendments

The Ca need of small-seeded cultivars is readily met by the proper use of liming materials (Anderson, 1970; Hartzog and Adams, 1973; Laurence, 1973; Adams and Hartzog, 1979, 1980). Reports of lime being an inferior Ca source are based on the applied lime not being concentrated in the fruiting zone (Walker, 1975). Lime efficacy for large-seeded cultivars has not been as thoroughly evaluated, and it may sometimes need to be supplemented by a soluble Ca source during blooming. More definitive experimental data are needed.

Soluble Ca sources used as topdressing during blooming are anhydrite ($CaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$), and "wet" gypsum, a by-product of H_3PO_4 production. The materials may be powdered, granular, or lumpy (Daughtry and Cox, 1974; Jones et al., 1976; Keisling and Walker, 1978), but their effects on yield are essentially the same. All are subject to being leached below the fruiting zone by heavy rainfalls any time after application with the order of leaching rate decreasing with increasing particle size.

It has been hypothesized that the soil Ca level and Ca amendments have an effect on disease incidence in peanuts, particularly those caused by *Pythium myriotylum*, *Rhizoctonia solani*, and *Sclerotium rolfsii*. Moore and Willis (1974) found no relation between Ca rate and pod breakdown caused by these organisms. On the other hand, Hallock and Garren (1968) found reduced pod breakdown as Ca rates were increased. More recently, Walker et al. (1979) found that the *Pythium* population tended to decrease and the incidence of *Sclerotium rolfsii* seemed to increase with an increase in the rate of applied Ca.

From time to time, interest develops in substituting low rates of foliage-applied Ca compounds for a regular liming or gypsum program (Hartzog and Adams, 1973; Walker, 1975). Such a practice is doomed to failure because (i) it is based on the false premise that Ca is phloem translocated and (ii) foliar rates are too low to affect soil Ca level, where Ca uptake by the fruit occurs. It has been shown, for instance, that the yield increase from foliar-applied Ca was only 1/6 that from gypsum on a Ca-responsive soil (Cox, 1972).

Root-cell membrane resistance to efflux of nutrient ions and simple organic compounds is dependent upon ambient Ca level. Based on this phenomenon, Hale (1978) and Shay and Hale (1973) reported exuded sugar from peanut roots was fourfold greater with ambient Ca at 10 ppm than at 50 ppm. They suggested that low Ca soils might be more prone to produce peanuts infected with *Aspergillus flavus* because of the favorable effect that glucose has on their germinating spores. This is highly conjectural and does not appear to have practical consequences for farmers.

Foliage Calcium

The Ca concentration in foliage is genetically controlled to a large extent, provided Ca is adequate for normal plant growth (Mengal and Kirkby, 1978). In the peculiar case of peanuts, where soil Ca requirement is greater for fruit development than for vegetative growth, predicting Ca deficiency for nut yield from leaf-tissue content does not appear to be particularly promising. From culture solution data, however, Nicholaides and Cox (1970) projected a Ca deficiency if the Ca concentration of the tops was less than 1.2% in 9-week-old plants. In an earlier experiment, Cox and Reid (1964) concluded that the critical Ca concentration in the top 10 cm of plants at harvest was 2.1%. Recognizing the strong interactions among cations, Wolt and Adams (1979) reported a critical Ca concentration for plant tops at harvest of about 0.25 Ca/(Ca + Mg + K) mole ratio for flower fertility and, of course, somewhat higher for fruit development. Unpublished data of Adams show the Ca concentration of leaflets to be about 1.8% from 12-week-old Florunner peanuts on 2 plots where one was Ca deficient and the other was Ca sufficient for maximum fruit yield. These examples illustrate the serious difficulty of identifying critical foliage values.

POTASSIUM

The effect of K fertilizer on peanut yields gives an erratic pattern. In a review of the topic, Reid and Cox (1973) pointed out the contradictions and the poor correlation, in general, between soil-test K and yield response to K fertilizer. In a review of experiments in the southeastern USA, Walker et al. (1974) reported responses to K fertilizer only on soils that are "quite low in K."

Peanut roots are apparently highly efficient at obtaining soil K when grown in rotation with other fertilized crops, e.g., corn (*Zea mays* L.), and it is not generally profitable to fertilize peanuts with K in such rotations. Even a continuous peanut rotation is less of a drain on soil K now than in earlier days because currently only the nuts are usually removed from the field. Recent results (Hartzog and Adams, 1973; Walker et al., 1974) suggest that K deficiency is most likely on soils with very low subsoil K, e.g., following such crops as bahiagrass (*Paspalum notatum* Flugge) or Coastal bermudagrass (*Cynodon dactylon* (L.) Pers.). It appears that surface-soil K will be poorly correlated if a supply of subsoil K is available to the root system (Woodruff and Parks, 1980). Thus, if a clayey B_2 layer is within reach of the root system, K deficiency is unlikely with peanuts unless a previous crop has exhausted the subsoil K.

It is not uncommon to find reports in the literature of a negative yield response to K fertilizer (Brady and Colwell, 1945; Comber, 1959; Anderson, 1970; Sullivan et al., 1974; Hall, 1975; Chesney, 1975b; Walker et al., 1979).

Using leaf-tissue content as a guide to K deficiency or sufficiency has not enjoyed the success with peanuts that it has with some other crops. Hallock et al. (1969, 1971) analyzed leaves attached to different branches during the various stages of growth but failed to identify a "best" sampling procedure or time for any of the several elements tested. They also reported that the K concentration reached a maximum in October. In contrast, Jones et al. (1980) reported the K concentration of upper mature leaflets to decrease during the season, but it generally exceeded 1.5% (fields were not K deficient). Nicholaides and Cox (1970) found similar K levels in tops of solution-grown 9-week-old plants. Solution experiments led Fageria (1976) to conclude that the critical K concentration of 39-day-old plants was at least 2.8%. None of these values is very helpful in diagnosing a possible K deficiency in the field.

MAGNESIUM

Although Mg is one of the macronutrients needed by plants, the literature is almost barren of reports that peanut yields are increased by Mg fertilizer. Reid and Cox (1973) record no reports of field-obtained Mg deficiency. Among several field experiments in Alabama (Hartzog and Adams, 1973; Adams and Hartzog, 1980), only one experiment showed a yield response to added Mg on fields with surface-soil exchangeable Mg at only 3 to 10 ppm, levels that would normally elicit a yield response by cotton or soybeans (*Glycine max* L.) (Adams, 1975). The yield response was on a Troup loamy sand (*Grossarenic Paleudult*), a soil with very low clay content in the profile. Chesney (1975a), in a 4-year study on brown sands of Guyana containing only traces of exchangeable Mg, failed to show any positive response to Mg treatments (yield was actually decreased by Mg 1 year). He observed, "It is surprising that with a soil as highly leached and low in bases as this one, a positive response to . . .Mg. . .was not obtained." Peanuts obviously require Mg. They must, therefore, be very efficient at extracting it from the soil. Analogous to the role of subsoil K, it seems probable that Mg requirements can be met by the subsoil supply.

The evidence for critical Mg levels in leaf tissue is almost nonexistent. Nicholaides and Cox (1970) suggested a value of 0.6% Mg for 9-week-old plant tops, but this has not been adequately verified. Fageria (1976) concluded critical Mg to be 0.25 - 0.30% in solution-grown 39-day-old plant tops. Unpublished data by Fred Adams, Auburn University, show that leaflets of 12-

week-old Florunner plants in field experiments contained as little as 0.3% Mg with no evidence of Mg deficiency.

NITROGEN

Being a legume, the peanut is able to obtain nitrogen (N) through its symbiotic association with *Rhizobium*. Whether the crop can maintain an adequate N level during the entire season in this manner is questionable. Factors related to efficiency of N fixation and utilization include crop variety, *Rhizobium* strain, and soil and climatic conditions.

Nitrogen Fertilization

Nitrogen fertilization studies have been conducted in most of the peanut growing regions of the world. The primary subject of these experiments has been rate of N, although source of N and time and method of application have also been covered.

In India, a number of workers have obtained yield responses with relatively low rates of N, 20 to 33 kg/ha (Puntamkar and Bathkal, 1967; Phanishai et al., 1969; Bhan and Misra, 1972). These experiments were conducted on both red and black soils, probably with a spanish variety. A common factor among these studies was that there was also a response to phosphorus (P) in each, and the greatest response was usually from a combination of N and P. Bhan (1977) also noted an increased effect of an N + P combination and was able to correlate pod yields with the N and P concentrations of leaves 30 days after sowing. The interactive effect of these 2 nutrients seemed more apparent in total uptake than concentration, however, due to the increase in dry matter production.

Other reports from India show no response to fertilizer N (Kolar et al., 1976; Dahatonde, 1978). There was no response to P in these studies either. This coincidence should be investigated further.

In Ghana, Ofori reported no response to N in certain studies (1973a, 1975) and a response with up to 15 kg/ha of N in others (1973b). An exception was noted if the site had been in grass-fallow for some years, in which case there was a response to higher rates of N.

High rates of N have proven beneficial in other regions. On a clayey cinnamon forest soil low in N in Bulgaria, Georgiev (1974) obtained highest yields with 200 kg N/ha. In Israel, Gustein (1978) found the highest response with 210 kg N/ha. From studies in Taiwan, Liu (1975) recommended a minimum of 100 kg N/ha. Such responses suggest the absence of effective rhizobia.

In most regions, however, high rates of N have not been beneficial. In fact, Hallock (1969) reported a detrimental effect of N fertilization that increased with rate applied. Of 7 studies conducted in Virginia with virginia type peanuts, he reported 1 positive, 2 negative, and 4 nonsignificant responses to N.

Varietal differences seem to be implicated in N-response data. Walker et al. (1974) found no response to increments of N up to 120 kg/ha with Early Runner peanuts. The spanish type Argentine, however, gave a positive response to 20 kg/ha or greater. In other work, though, Walker and Ethredge (1974) found no response to N with the spanish type Starr. Gutstein (1978) evaluated both virginia and valencia type peanuts and found only the valencia responded to N. In the Sudan, Muktar and Yousif (1979) applied rates of N to 3 cultivars; 1 was an alternate branched or virginia type, and the other 2 were sequentially branched, probably spanish type. Positive responses were obtained only on the sequentially branched varieties. This same conclusion applied to the studies cited previously.

A number of N experiments have also been conducted in South America. Acuña and Sánchez (1968, 1969) found no response to N applications in Venezuela. In Brazil, DeTella et al. (1970) obtained a response to N in 1 of 3 studies (and an increase from P in all 3). In another report, DeTella et al. (1971a) found positive responses in 3 of 5 experiments, but only at high yield levels. No response was shown if yields were low because of drouth or other yield-limiting conditions.

Fertilization of peanut foliage, usually with urea, has been tried a few times. No significant responses were found in India by Peeran et al. (1969) nor in Israel by Halevy et al. (1979). This topic continues to be of interest, however, as physiologists evaluate the importance of the decline in plant N in the latter part of the growing season.

From the studies reviewed, there seem to be a number of conditions conducive to obtaining a response from fertilizer N. The sequentially branched botanical varieties are more responsive than the alternate branched. In India, responses to N seem more likely if P is also low, but this did not hold true for the more acid soils of South America. Nitrogen response could not be shown if other factors were more limiting. Substantial amounts of N were not ordinarily needed unless the site was exceedingly low in N or no effective rhizobia were present.

Inoculation

Application of an inoculant containing the appropriate *Rhizobium* has increased yields in very few instances. Hickey et al. (1973) were able to correct N deficiency by inoculation on a newly cleared site. Inoculation was effective in increasing yields in 1 of 9 sites in South Africa (Van der Merwe et al., 1974) and in 1 of 3 studies in Guyana (Chesney, 1975a). In the latter report, the yield level of the nonresponsive sites was less than 2000 kg/ha, so factors other than N may have been more limiting.

The peanut is in the cowpea cross-inoculation group. Rhizobia that cause nodulation of its members are quite widespread. Gaur et al. (1974) stated that these rhizobia are highly promiscuous and that peanuts are a nonspecific host. Thus, most any cultivar may be infected by many different rhizobia. Nodulation, therefore, commonly occurs without an inoculant being applied.

A number of workers have studied the ability of indigenous peanut rhizobia to fix N. In Texas, Weaver (1974) found adequate numbers of rhizobia for nodulation, but only a few strains were highly effective in fixing N. Staphorst et al. (1975) compared the efficiency of 168 *Rhizobium* isolates from South African soils with a control strain (CB756). They found that 47% of the strains had efficiency levels of 40 to 70% of that of the control strain.

The peanut host may also affect the efficiency of N fixation. Ayala (1978) and Wynne et al. (1978) have noted differences in N fixation among host plants with a given *Rhizobium* strain. There did not seem to be an interaction between host and strain effects, so it appeared that N fixation could be increased by selecting among either, or both, host plants and strains. In a later study, Wynne et al. (1980) found a host x strain interaction that was detectable by a difference in the color and weight of a virginia and a spanish type plant grown in the greenhouse. They suggested that N fixation may be increased either by selecting a specific host-strain combination or by selecting strains adapted to a broader range of host genotypes.

Other factors that may affect N fixation also have been evaluated. For instance, Walker et al. (1976) found no effect of 2 herbicides or 1 nematicide on the nodulation, N content, or yield of Starr peanuts. Similar results were observed in India after the application of 4 insecticides to fields of MV2 peanuts (Kulkarni et al., 1974). It also might be inferred that the mycorrhizal infection was not affected by these management practices. Daft and El-Giahmi (1976) found nodulation and acetylene reduction rates were stimulated by mycorrhizal infection with *Glomus mossae.*

The soil condition perhaps most likely to affect N fixation is acidity. Munns et al. (1977), however, found no change in the % N in peanut plants when an Oxisol was limed from pH 4.7 to 7.1, but yields were increased 30%. Although aluminum toxicity apparently was not a factor restricting yields in the unlimed soil, manganese toxicity may have been important.

Soil acidity affects the availability of other elements. Reddy and Raj (1975) reported a response to cobalt (Co) on high pH soils in India. This nutrient is known to be required for symbiotic N fixation. The Co treatments increased nodule formation and the N concentration of the tops. They cited the work of Lundblad (1959) that Co is absorbed less readily under more alkaline conditions. This subject certainly deserves further investigation.

Climatic factors may also affect N fixation. Ratner et al. (1979) found nitrogenase activity drastically reduced by hot, dry weather. Nitrogen fixation appeared to be more sensitive to these unfavorable conditions than to nodule growth.

In summary, inoculation has seldom increased yields. Native peanut rhizobia are abundant and apparently able to fix adequate N at current yield levels. Both host plants and rhizobia strains may be selected to improve N uptake, so a means of improvement is available if needed. Neither management practices nor most soil conditions have been shown to affect N fixation greatly, but the rate may be decreased substantially by adverse climatic conditions. The role of Co, especially at high soil pH, should be investigated more fully.

Physiology and Plant N

Currently, there is considerable interest in the role of N in the physiological development and yield potential of legumes. This interest was stimulated by the speculation by Sinclair and de Wit (1976) that the soybean became "self-destructive" due to reduced N fixation and increased translocation of leaf N to developing fruit, thus limiting the yield potential of the crop. They did not consider that this possibility was likely, however, with peanuts (Sinclair and de Wit, 1975).

The concentration of N has been shown to decrease linearly during the growing season in peanut foliage (Cox et al., 1970) and leaflets (Schiffmann and Lobel, 1973). In the latter study, the haemoglobin content of the nodules also decreased near the end of the season, so its level correlated with leaf N during that period. The haemoglobin content is indicative of the N fixation rate. Its content was highest from 50 to 100 days after planting, or during much of the reproductive stage. Williams (1979a) also found that the rate of N accumulation was greatest during this stage of growth and that the cessation of N accumulation coincided with the cessation of vegetative growth. The rate of N accumulation did not decrease when reproductive sinks were established, but it was actually still increasing at that time. In another report, Williams (1979b) also noted that the rate of N accumulation was not well related to root carbohydrate content.

Attempts have also been made to relate photosynthetic rate to leaf-N concentration. Using 31 genotypes, Bhagsari and Brown (1976a) found a weak positive correlation in 2 pot studies, but no relation in a field experiment. In another study with 5 genotypes (Bhagsari and Brown, 1976b), they found no relation between net photosynthesis and leaf-N concentration. Measurements were made during the middle of the season and leaf N ranged between 3 and 4%.

The critical level of N in peanut leaves may differ among cultivars. Mukhtar and Yousif (1979) found that the leaves of sequentially branched peanuts must contain 3.7% N at 4 weeks for maximum yields. Lower levels were adequate for an alternate branched variety. Leaf N at this stage of growth is typically much higher, near 5% (Cox et al., 1970; Schiffmann and Lobel, 1973; Williams, 1979b). The effect of a Co treatment on peanuts grown in high pH soils (Reddy and Raj, 1975) was to increase plant N at flowering from 3.4 to 3.8% and 2.9 to 3.3% for crops grown in Rabi (dry) and Kharif (wet) season, respectively.

Physiological studies to date emphasize how little we understand the factors, including N, affecting yield potential. Yet the interpretation of such experiments may hold the key to future advances in breeding, fertilization, and crop management.

PHOSPHORUS

World-wide, inadequate phosphorus (P) may be the most common nutrient deficiency for peanuts. A lack of this element is typical in soils that have never been fertilized, and much of the world's production occurs where fertilization has not been emphasized as a management practice. Deficiencies are readily corrected, however, by application of phosphate materials. Fixation of P in soils used for peanut production is not usually severe since they are ordinarily low in clay. Since a very small amount of P is removed by the crop, and essentially no P leaches, fertilization normally increases the reserve of P of the soil. This reserve may be measured by soil testing techniques. When the reserve is adequate, further fertilization with P is not economical.

For a soil test to be effective, the concentration of a nutrient extracted with a given solution should indicate if the site would be responsive to a fertilizer containing that element. The concentration dividing responsive and nonresponsive soils, the critical level, may vary somewhat with the crop being grown and the soil type. Also, it may vary considerably with the extractant employed. Some typical extractants, their compositions, and critical P levels for peanuts are:

Extractant	Composition	Critical P Level (ppm)
Double Acid	$0.05\,N\,\mathrm{HCl} + 0.025\,N\,\mathrm{H_2SO_4}$	
Bray 1	$0.025\,N\,\mathrm{HCl} + 0.03\,N\,\mathrm{NH_4F}$	7
Bray 2	$0.1\,N\,\mathrm{HCl} + 0.03\,N\,\mathrm{NH_4F}$	5
Olsen	$0.5\,N\,\mathrm{NaHCO_3}$	10
Oxalate	Oxalic acid + potassium oxalate	1
Lactate	Ammonium lactate + acetic acid	16

The above critical levels are not in complete agreement with those of other authors (Olsen and Dean, 1965; Thomas and Peaslee, 1973), but they are the conclusions reached after reviewing the current literature and contacting other workers.

The double acid is used extensively in the eastern USA. Soils in this region have been fertilized for some time, so P levels are seldom low. Walker et al., 1974) found no response to P on a site with 22 ppm P, a typical concentration. Hartzog and Adams (1973) evaluated P fertilization on soils ranging from 4 to 70 ppm and also found no response. In North Carolina, it has been the senior author's experience that no response was obtained on soils with as little as 10 ppm. In studies in Bolivia, however, concentrations of less than 7 ppm indicated P-deficient conditions.

The Bray-1 extractant has been used in South America and Africa. Sánchez and Mata (1972) and Acuña and Sánchez (1968) found large responses to P on soils with 2.5 to 3.5 ppm by this method. Chesney (1975b) conducted several studies in Guyana on sites with about 3.5 ppm P and found responses on only a portion of them. In Africa, Brams (1973) did not get a response to P in a residual study, but the level was never below 22 ppm. Ofori (1973a) was able to show increased kernel yield in a greenhouse pot experiment using a soil with 13 ppm P, but such stress conditions may not be similar to those encountered in the field.

The Bray-2 extractant is used in Colombia. Sánchez and Owen (1978) obtained yields of 750 and 2070 kg/ha with 0 and 150 kg P_2O_5/ha, respectively, on a soil with 6 ppm P. Little other work with this extractant has been reported, but since the acidity of this solution is greater than that of the Bray 1, it extracts more P.

The use of acid extractants is confined to acid soils. The Olsen extractant was designed for calcareous soils, but it has been used quite successfully on noncalcareous soils, too, so it has a wide range of applicability. In Israel, Lachover and Ebercon (1966) found a response to P on a soil low in available P (2 ppm). In India, responses have been noted on soils with 9 to 10 ppm P or less (Goudreddy et al., 1977; Kulkarni et al., 1977), but not consistently. In fact, Kolar et al. (1976) found no response to P on a soil showing only 3 ppm. The previous crop was fertilized and the time of sampling was not clear, however, which may account for the discrepancy. Hagin and Hillinger (1967) also were unable to calibrate yield response with Olsen P levels that ranged from 5 to 30 ppm. In a recent study, though, Singh and Rana (1979) established the critical level of P in some Indian soils to be 8.3 ppm by the Olsen method.

De Tella et al. (1970, 1971a, 1971b) reported a number of studies in Brazil using the oxalate extractant. Nine of the 10 studies were clearly divided by a critical level of 1 ppm P, and the exception was at 0.8 ppm, very close to the divison.

Foster (1970, 1972) used the lactate extractant in Uganda. The critical level of 16 ppm P applied well to the majority of soils which were ferralitic. For a few nonferralitic soils, however, a higher critical level should be used.

Plant analysis may also be used to determine if peanuts are deficient in P. Again, a critical level may be established to differentiate between deficient and nondeficient plants. Plant age and plant part, however, are highly important. Bhan (1977) noted that leaf P declined from 0.35 to 0.15% between 30 and 120 days after sowing. Fertilization, which increased yields, increased the concentration about 0.05% P throughout that time span.

Leaf P at flowering may be the most standard plant part and age. Foster (1980) set a critical level of 0.29% for these conditions. This corresponds well with the senior author's observations in Bolivia of deficiency at 0.24 and sufficiency at 0.34% P in leaves at this stage of growth.

SULFUR

There are few recent reports regarding sulfur (S) fertilization in the Americas. The use of gypsum is common in the eastern USA, but as a source of Ca rather than S. Phosphate materials are also used quite routinely. These have contained considerable S, but the trend is now toward higher analysis fertilizers, so less S may come from phosphate materials in the future. Sulfur-containing fungicides have also been used extensively in the past, and many are still in use. As a result, considerable S has been applied to these soils, and the reserve, especially in clayey subsoils, may be considerable.

Apparently S deficiency has not been a problem in South America, either, or else adequate amounts have been included with other fertilizer materials. Experiments conducted by the senior author in Bolivia showed no response to S on a site that had never been fertilized. Baynes and Walmeley (1974) also found no response to S in Trinidad.

Some research with S has been reported from India. In greenhouse studies, Yadav and Singh (1970), Singh et al. (1970), and Rathee and Chahal (1977) obtained a yield increase with S. In a field experiment under irrigation, however, Kolar et al. (1976) found no response, but noted that the irrigation waters contained 0.1 meq SO_4/liter. This site had also been fertilized previously, so it may have had residual sulfate available. Verma et al. (1973) reported that S application increased the quality of peanuts, but the effect was more pronounced for gypsum than for elemental S or sulfuric acid.

In other reports, Boon-Ampol and Chang (1974) conducted 2 studies on highly sandy Khorat soils known to be low in S in Thailand and found no response. In New Guinea, however, Hill (1970) obtained a 300 kg/ha yield response with White Spanish peanuts grown on a brown clay loam. A portion of the increase due to S fertilization was attributed to increased seed size.

There have been numerous reports of S deficiency in Africa, some of which have been confounded with P responses. For instance, in West Africa, Bromfield (1975) found that the application of P enhanced the development of S deficiency symptoms. Since P responses are ordinarily greater than those of S in that region (Bocklelee-Morvan and Martin, 1966), it is essential that adequate P be present before evaluating S. Often there is a response to both elements, and Bockelee-Morvan and Martin (1966) reported a synergistic effect between the 2. They indicated that 10 kg S/ha was sufficient. Dhery (1969) corrected nutrient deficiencies in Upper Volta with 13 kg P_2O_5 and 8 kg S/ha.

Responses to S have been less consistent in East Africa. Anderson (1970) found a slight beneficial effect to inclusion of S in fertilizer in Tanzania. In Uganda, Foster (1972) found inclusion of S to be beneficial only in certain regions, and perhaps only at certain yield levels. Deficient regions were those lowest in organic matter (O.M.), and he related soil S to % O.M. He also concluded the need for S increased as the yield potential increased. Laurence et al. (1976) obtained yield responses in Malawi to S on soils low ($<$ 50 ppm) or marginal (50 to 75 ppm) in total S. Sulfur dust applied as a fungicide was an effective source, as were soil-applied S and gypsum. Fertilization of low-S soils increased the protein content of the crop, too. Kernel protein contents of less than 26% seemed indicative of S-deficient conditions.

Bromfield (1973) studied the uptake pattern of S with Samaru-38 peanuts. He found that it paralleled the dry matter accumulation pattern very closely. Both were sigmoidal and achieved a maximum rate 8 weeks after germination. Bathla et al. (1977) found a similar S-uptake pattern with high yielding cultivars, but it was different with a lower yielding one.

There are no reports of "available" levels by soil-test extractants. Apparently, since sulfate leaches quite readily in sandy soils, such as are often used in peanut production, soil-test extractants have not been investigated and critical levels established.

There has been an effort, however, to establish plant critical levels of S. Bockelee-Morvan and Martin (1966) indicate that the level is related to the N concentration in leaves, being 0.20% S at 2.5 to 3.0% N and 0.25% S at 3.5 to 4.0% N. This N:S ratio of about 15:1 was also confirmed by Lund and Murdock (1978).

According to Bromfield's work with field-grown peanuts (1973), the S concentration in the whole plant may change little during the season. He obtained very good yields at 0.17%. In another study where there was a yield response (1975), the S concentration of the whole plant was increased from 0.09 to 0.12%. This may be contrasted with the results of Yadav and Singh (1970) with greenhouse-grown peanuts, where a yield response was associated with an increase of plant S from 0.31 to 0.45%.

BORON

Boron (B) deficiency occurs on some deep, highly weathered, sandy soils. In the USA the deficiency ordinarily does not cause a yield decrease, but reduces the quality of the crop. Affected seed do not form properly. The inner faces of the cotyledons are depressed and discolored. This is classified as a form of internal damage and has been termed "hollow heart." The pioneer work on this subject was conducted in the greenhouse by H. C. Harris and co-workers in Florida, as indicated in a previous review (Reid and Cox, 1973).

In Oklahoma, Hill and Morrill (1974) evaluated the effect of B applications on 17 field locations. They found no yield response to B, but there was internal damage due to B deficiency (IDB) when the soil test B (hot-water-soluble) concentration was $<$0.15 ppm. There was a marked increase in IDB when the extractable B was less than 0.06 ppm. Their estimate of this critical level is slightly higher than that found by Cox and Reid (1964) in North Carolina or by Hartzog and Adams (1973) in Alabama. As a result of these studies, concentrations of hot-water extractable B below 0.2 ppm are considered to be deficient on calcareous soils. On acid soils in the eastern USA, the critical level is about 0.05 ppm. These critical values apply only to coarse-textured soils, which are typically used for peanut production, because of the relationship between B availability and texture. Hill and Morrill (1974) also established the critical level of B in leaves sampled 30 to 60 days after planting to be about 26 ppm.

Whenever B additions are needed, only small quantities are necessary for optimum production. On sandy soils recommended rates vary from 1/2 to 1 kg/ha. Rates as low as 2 kg/ha may be toxic on very coarse-textured soils (Hill and Morrill, 1974).

Boron-deficiency symptoms in kernels have also been reported in West Africa (Gillier, 1969). In India, Muthuswamy and Sundararajan (1973) reported a yield response to boron, but gave no evaluation of quality effects.

COBALT

Cobalt (Co), though not essential for the peanut plant, is an integral part of enzymes involved in N fixation by rhizobia. Reddy and Raj (1975) found a yield response to Co applied either as a seed treatment or as a foliar spray. The application of Co increased nodulation and N fixation and enhanced the N concentration in the plants from flowering to maturity. The Co concentration in the plant at midseason was also increased from 1.5 ppm in the untreated to $>$2.0 ppm in the treated plots.

COPPER

Copper (Cu) deficiency seldom occurs on mineral soils, such as those typically used for peanut production. Also, Cu applied in fungicides increases the reserve of this nutrient in the soil. Such fungicides have been used extensively in the past on acid soils in the eastern USA, so the supply is especially adequate there.

Copper deficiency is more likely on organic soils because their Cu contents may be quite low and because organic matter may fix considerable amounts of Cu. Areas are being drained to bring organic soils into production in the East Indies where peanuts are an important component of the cropping system. Chew et al. (1979) evaluated the need for Cu on a newly cleared and drained peat in Malaysia. In 2 experiments, total soil Cu averaged only 6 ppm. They found that 10 to 20 kg copper sulfate/ha was needed for maximum yields, and this quantity should suffice for several years. This treatment increased the Cu concentration in peanut leaves from 3.6 to 4.5 ppm.

Copper deficiency in peanuts has been verified in Texas, and deficiency symptoms resembling those from Cu-deficient plants in Texas have been observed in New Mexico on calcareous soils in the USA Copper-deficient plants are stunted and rosetted. The stunted plants are dark green and wilted in early growth stages. The entire leaflets may become cupped as the leaf margins turn upward. Some bronzing and necrosis of the outer edges of the leaflet may occur if the deficiency persists.

Small rates of soil-applied Cu are adequate to correct deficiencies on calcareous, mineral soils. Recommendations are usually from 2-6 kg Cu/ha as $CuSO_4$ every 3 to 4 years (Carl Gray, Texas A&M Univ., personal communication). The application is discontinued with Cu buildup in soils, and those with 0.2 ppm Cu or more {by the DTPA-TEA (diethylenetriamine pentacetate-triethanolamine) procedure} should not be fertilized with Cu. The chelate sources of Cu also are effective and are especially adapted to foliar application. Much smaller rates of Cu chelate can be used (1 to 4 kg material/ha) to avoid the buildup of Cu.

IRON

Iron (Fe) deficiency in peanuts is characterized initially by interveinal chlorosis on the terminal leaves. If the deficiency becomes more severe, the chlorophyll will eventually disappear from the veins, and later the leaves will become white, indicating the absence of chlorophyll. In very severely deficient soils, deficiency symptoms are first evident a few days after seedling emergence. In some circumstances, the chlorosis disappears as the soils become warmer and as the root system proliferates. Iron-deficient plants have limited root systems, and this may cause other nutrient deficiencies.

Iron deficiencies are found only on calcareous soils. Soil treatment with mineral fertilizers containing ferrous iron has not been effective because of the rapid conversion of soluble Fe into an unavailable state. It has been the experience of the junior author (BBT) that feedlot manure, where available, can be applied to correct Fe deficiencies. Iron chlorosis is often not alleviated until the second year following manure applications of 9 to 14 t/ha. Feedlot manure high in salt (NaCl) should be avoided because peanuts are especially sensitive to excessive salt loads.

Chelated Fe sources, such as Fe-EDDHA [ethylenediaminedi-(o-hydroxyphenylacetate)] and lignosulfonates, are effective for soil application. In Israel, Lachover et al. (1970) obtained a 50% yield increase by applying 10 kg Fe-EDDHA/ha to peanut foliage in a split application at 22 and 45 days after seeding. In other studies, Hartzook et al. (1971) found marked responses with 10 to 15 kg Fe EDDHA/ha applied 40 to 60 days after seedling emergence. In the USA foliar feeding has been the conventional recommendation for alleviating Fe deficiency. Spraying with a 3% Fe solution as ferrous ammonium sulfate generally corrects the deficiency for a few weeks, but in severe cases, three or more sprayings may be required. Some urea in the solution seems to aid Fe absorption. Ferrous sulfate (in a carrier of ammonium polyphosphate) at a rate of 4-6 kg/ha of Fe banded 2.5 to 5 cm to the side of the seed at planting has given season-long control if Fe deficiency is not too severe (Tucker, unpublished).

Hartzook et al. (1974) found certain cultivars to be more "Fe efficient" and to perform reasonably well without supplemental Fe. Whereas a Fe application increased the yield of Fe-inefficient cultivars 22 to 210%, the yield increase was only 8 to 18% for Fe-efficient ones. Yields of the unfertilized Fe-efficient cultivars were comparable to those of the fertilized Fe-inefficient ones.

In India, Dungarval et al. (1974) attempted to correct Fe chlorosis in peanuts with soil applications of elemental S (to acidify soil) and with foliar applications of sulfuric acid. Whereas untreated plots yielded 600 kg/ha, treated ones yielded up to 1500 kg/ha. The S and H_2SO_4 treatments unexpectedly decreased Fe concentration in leaves, but they may have increased the concentration of an active Fe fraction.

MANGANESE

Manganese (Mn) deficiency may occur when low-Mn, acid soils are limed. Increasing the soil pH reduces the availability of Mn but may have little or no effect on the concentration of acid-extractable Mn. The critical soil-test Mn level, therefore, varies with the pH. Such an interpretation (unpublished) is in use in North Carolina.

Hallock (1979) obtained a yield response to Mn on 2 soils. Double-acid extractable Mn was 3.3 and 3.8 ppm, and soil pH was 6.4 to 6.7. Several foliar applications of $MnSO_4$ at a rate of 0.12 kg Mn/ha were as effective as 22.4 to 44.8 kg Mn/ha when soil-applied broadcast. Since Mn is progressively less available with increasing soil pH, foliar applications may be more economical than soil applications.

At low soil pH, the availability of Mn may increase to a toxic level. Benac (1976) grew peanuts in solution culture and found necrotic patterns on leaves if the Mn concentration of leaves reached 4000 ppm. Peanuts are relatively tolerant of excess Mn, as indicated by such high Mn contents.

Leaf Mn usually ranges from 50 to 100 ppm, and Mn deficiency may be expected when it is less than 20 ppm. The typical symptom of Mn deficiency is interveinal chlorosis, but there may also be a distinguishing characteristic of brown spots on the leaf margins.

MOLYBDENUM

Molybdenum (Mo) availability, unlike that of most other micronutrients, increases with increasing soil pH. In fact, Welch and Anderson (1962) found that Mo concentration in peanut kernels may be doubled by increasing the soil pH one unit. A deficiency of this nutrient, therefore, would be expected only if the soil were very acid. It is expressed by a lack of N, probably because the most critical role of Mo is in the N-fixation process.

There are no recent reports of Mo deficiency, perhaps indicating better liming practices. Martin and Fourrier (1965) evaluated several micronutrients in North Senegal and found that only Mo was needed as a supplement. An application of only 28 g/ha of Mo increased yields about 200 kg/ha. In India, Muralidharan and George (1971) found that phosphate and molybdate increased the vegetative growth and weight of nodular material of peanuts.

ZINC

Takkar et al. (1975) studied the direct and residual effects of zinc (Zn) on peanuts in India. The crop was grown on a loamy sand with a pH of 8.8 and a DTPA-extractable Zn concentration of about 0.4 ppm. Crop yield was reduced about one-half if the soil test Zn level was below about 1.2 ppm.

Elsewhere in India, Singh et al. (1972) found that 15 kg Zn/ha applied to the soil or 10 kg Zn/ha applied to the foliage generally increased peanut yields. Since there is a substantial residual effect of Zn applied to the soil, it would appear that a broadcast, incorporated treatment may be the most practical.

Zinc deficiencies have occurred on alkaline soils in the USA that are low in organic matter, high in available P, and usually high in bulk density. The deficiency is manifested more often when soil temperatures are low. In addition to adding Zn fertilizers, other ameliorating practices include: 1) adding large amounts of organic materials, such as feedlot manure or plant residues, 2) avoiding or correcting soil-compaction conditions, 3) avoiding buildup of excessive soil P and, 4) planting after soil temperature is at least 20 C. Amendments to reduce soil pH increase zinc availability, but such amendments rarely are profitable.

Zinc deficiencies can easily be corrected by inorganic sources, and Zn remains available in soils for several years. The most common recommendation is 4 to 10 kg of Zn/ha as $ZnSO_4$, ZnO, or $ZnCO_3$. Chelated Zn is effective but not necessary to correct deficiencies. There appears to be very little difference in effectiveness between broadcast and band-placed Zn fertilizers, provided the Zn is placed in the root zone. Because Zn moves only slowly in soils, topdressed applications are inefficient. Foliar-applied Zn in most experiments has been inferior to soil-applied Zn, perhaps because some reduction in yield had occurred by the time deficiency symptoms were observed.

Zinc deficiency symptoms may occur concurrently with Fe-deficiency symptoms and the 2 can easily be confused. Where Zn deficiency occurs alone, the chlorotic strips are wider and may not run the entire length of the leaflets. The bands will usually be on the leaf portion nearest the petiole. Under severe or prolonged Zn deficiency, the entire leaflet will become chlorotic. High temperatures will cause Zn deficiency to appear as leaflet bronzing and, occasionally, as small necrotic spots.

In North Carolina, the senior author has observed that peanuts are more sensitive to Zn toxicity than corn or cotton. Toxic levels of Zn have usually been derived from some galvanized surface, but since this element may be present in other materials, such as certain lime sources and fungicides, its accumulation is of concern. Keisling et al. (1977) studied Zn toxicity under both greenhouse and field conditions and tentatively established critical values for Zn toxicity of 12 ppm (acid-extractable) in the soil and 220 ppm in plant tissue. Acid-extractable Zn levels are not affected by liming, but tissue-Zn concentrations are reduced, so soil pH also must enter into the soil-test interpretation.

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