Chapter 11

SOIL FERTILITY AND PLANT NUTRITION

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Nutrition of the peanut is still paramount in obtaining high yields with good quality. In many aspects nutrition of the peanut is similar to the nutrition of many other agronomic crops. Certainly the fertilization needs for peanut are less than many crops for the macronutrients nitrogen (N), phosphorus (P), and potassium (K). However needs for calcium (Ca) are exceptional in several aspects as is it's uptake by the peanut plant. The peanut fruit develops via nutrients absorbed directly from the soil rather than from nutrients transported from roots to shoots and back to the fruits. It is this unique aspect that has required much research and which guides the application of nutrients, especially calcium, for greatest yield, quality, and seed germination.

Sixteen elements are considered essential for plants. Consideration of nutrients in this chapter will be provided for only the nutrient elements known to be important for peanut. Amounts of nutrients removed from the field by peanut pods and vines are presented in Table 1. Those values should not be confused with the nutrients needed to grow and develop the crop. The latter values are greater because much of the plant (roots and often vines) is returned to the soil and the nutrients may be available for recycling.

Peanut mineral nutrition research has been carried out for the past several decades (Harris, 1959). Previous reviews of the subject have covered the available knowledge up to 1982 (York and Colwell, 1951; Gillier and Silvestre, 1969; Reid and Cox, 1973; Cox *et al.*, 1982). However, in the decade following these reviews, additional advances have been made in our understanding of mineral nutrition of the peanut. The advances have been applied to enhance yield and quality of the peanut crop. In this chapter, emphasis will be placed on important principles of peanut nutrition and particularly to advancements made in the past decade.

Table 1. Nutrient removal by peanut (from Gascho, 1992).

Plant part	Yield	N	P	K	Ca	Mg	S
	t/ha	kg/ha					
Pods	3	120	11	18	6	9	7
Vines		72	11	48	51	16	8
Total		192	22	66	57	25	15

CALCIUM

Calcium is often considered the essential element most commonly deficient for peanut in noncalcareous soils. The consequences of Ca deficiency are blackened plumules, high incidences of pod rot, and unfilled pods (termed "pops") resulting in low yield and substandard grade. Peanuts produced in Ca-deficient conditions will exhibit much poorer germination than those produced with an adequate Ca supply. The effects of poor Ca nutrition will be elaborated later in this chapter.

Needs Related to Uptake

For peanut, the exceptional requirement for Ca is for the most part, not in order to grow a healthy plant, but for developing a properly filled pod with a high quality seed. Bell *et al.* (1989) evaluated the external Ca requirements of six tropical legumes in flowing solution culture and found that the Ca requirements of red spanish peanuts for growth and nodulation were not great in relation to pigeon pea, guar, soybean, and cowpea. Guar and pigeon pea required >50 mM Ca for nodule formation while peanut had nodules at 2 mM Ca. Maximum growth of peanut was found at 50 mM, soybean at 100 mM and cowpea at 2500 mM Ca. Even though Ca requirements for growth and nodulation of peanut are not great relative to other plants, the exceptional needs of Ca for peanut seed maturation and quality are stressed below.

Barber (1984, p. 272) stated:

> Calcium appears to have its greatest significance in providing the appropriate balance for levels of other nutrients within the plant. Because calcium is not translocated within the plant once it has been used in plant growth, the calcium needed during reproductive growth must be supplemented by uptake. In modeling calium uptake, mass flow is a dominant supply factor. Concentration in the soil solution will have an effect on supply, by both diffusion and mass flow.

For most plants, Ca is oversupplied to the root surface by mass flow and only a small proportion of the Ca is absorbed and subsequently translocated via the xylem to leaves in response to the flow of the transpiration stream. Much of the Ca is deposited in the leaf as Ca oxalate and is not retranslocated. This is a different mechanism than employed in root uptake of several other ions. In the root, the uptake of many ions is termed "active", indicating that roots select the most required nutrient elements from the soil solution. Uptake of Ca is fairly "passive", i.e., roots take up the element as it is presented in the soil solution without a selection mechanism. Therefore, the amount of Ca taken up by the plant is dependent both on its concentration in the soil solution and on the amount of water moving into the plant (Mengel and Kirkby, 1982). Because Ca is not easily translocated within the plant, Ca needed during reproductive growth must be directly supplied by uptake by the pod.

Classic research with the peanut has shown that Ca is transported upward in the plant from root uptake via the xylem, but little or no Ca is transported from the leaves downward through the pegs to the developing pod via the phloem (Bledsoe *et al.*, 1949; Wiersum, 1951; Mizuno, 1959). The Ca absorption problem for the developing fruit is compounded by the fact that there is little water movement upward from the gynophore to the plant tops in order to provide a gradient to carry needed Ca into the developing fruit via mass flow (Wiersum, 1951; Beringer and Taha, 1976; Wolt and Adams, 1979).

Calcium requirements for seed development must be absorbed by the gynophore via passive uptake by diffusion (Sumner *et al.*, 1988). Therefore, it is clear that a relatively great concentration of Ca is needed in the pod development zone of the soil for averting Ca deficiency. Calcium in that zone must be replenished throughout gynophore and seed development periods in order to maintain a gradient of Ca toward and into the pod. The development period critical for Ca absorption begins about 20 days following the entrance of the peg into the soil and may extent for an additional 60 days. Mizuno (1959) determined that 92% of the Ca was taken up by the pod during that time period and 69% was taken up between day 20 and 30. Smal *et al.* (1989) found that withholding Ca from the pod zone during the first 30 days following initial pegging resulted in the smallest seeds and the least seed dry weight in comparison with treatments where Ca was withheld later. They determined that a continuous Ca supply of 3.75 mM Ca solution resulted in greatest seed size and weight, but suggested that the 30-day period following pegging is most critical.

For soils with great Ca supplying power and rapid replenishment of soil solution Ca, no deficiency is expected. However, peanut is often grown on sandy soils which possess limited ability to supply Ca to replenish the soil solution. Additionally, such soils are often relatively droughty and, since peanut is relatively drought tolerant in comparison to most plants grown in semi-humid regions, it is often grown in locales with limited rainfall during some portion of gynophore and seed development. The problem of limited soil moisture in the developmental period adds to the Ca deficiency woes of the peanut since added Ca compounds will not dissolve or move to the pod without soil moisture. Calcium in droughty soils is, therefore, not rapidly replenished in the soil solution close to the developing pod due to lack of Ca dissolution and due to lack of the maintenance of a diffusion gradient toward the pod. Therefore, Ca deficiency results.

Effects of drought on Ca uptake by developing fruits has been reviewed by Boote *et al.* (1982). They emphasized studies showing poor uptake in drought periods and the enhancement of uptake of Ca with adequate water in the fruiting zone. Peanuts showing Ca deficiency symptoms during periods of drought also had lower Ca concentrations in seeds and hulls than those lacking Ca deficiency symptoms. Alva *et al.* (1991) determined soil solution Ca following gypsum application and incubation in the laboratory. They imposed four drying cycles over a period of 70 days in two soil types that represent the textural extremes of the peanut soils industry of Georgia. Following the drying cycles, the soils were returned to field capacity moisture, and soil solution Ca was determined. Soil solution Ca increased with increasing soil moisture in both soils for the first 14 days following gypsum application. Subsequently, soil solution Ca decreased for all moisture regimes in the Bonifay sand (grossarenic Plinthic Kandiudult), but only decreased in the driest regime for the Greenville sandy loam (thermic Rhodic Kandiudult). The results indicated that soil solution Ca deficiency is especially likely in sands due to low moisture retention. Calcium nutrition for the developing seed is intimately associated with soil moisture. For this reason, it appears simplistic to cite a critical soil Ca test level for peanut. The true "critical level" will depend on the moisture during fruit development and, by necessity, change both geographically and temporally, even for a given cultivar.

Concentrations of other cations in the soil, particularly K and Mg, can affect Ca uptake and thereby affect peanut yield and quality. Several reports of the deleterious effects of high soil and seed K on peanut have been published (Bolhuis and Stubbs, 1955; Hallock and Allison, 1980; Alva *et al.*, 1989b; Lynd and Ansman, 1989). Top growth is depressed with addition of K alone, but increased by addition of K + Ca (Lynd and Ansman, 1989). Using the Mehlich 1 (double acid) extractant, Alva *et al.* (1989b) determined that an optimum Ca/K ratio in the peanut pegging zone topsoil is near 10. They found the optimum Ca/Mg ratio for obtaining maximum percentage of sound mature kernels is 24 to 28.

Genotypes and Ca Nutrition

In general, greater soil concentrations of Ca are required for larger seeded than for smaller seeded cultivars (Walker *et al.*, 1976; Walker and Keisling, 1978). However, Cox *et al.* (1982) cites several exceptions. Gaines *et al.* (1989) determined both runner- (cv. Florunner) and virginia-type (cvs. NC 7 and Early Bunch) peanut responses to gypsum application relative to Mehlich 1 soil Ca. Yield response for Florunner was limited to experiments with Mehlich 1 soil Ca less than 270 mg/kg; while the virginia-type peanut responded to all levels of soil Ca available in the experiments. Recently, data from experiments conducted in Alabama, Georgia, North Carolina, and Virginia were combined to show the effect of Mehlich 1 soil Ca on relative yield of virginia-type peanut (Hodges *et al.*, 1994). Maximum yield was attained at about 525 mg Mehlich 1 Ca/kg (Fig. 1). Likewise, experiments conducted in Alabama and Georgia were combined to indicate that maximum yield of runner-type peanut was attained at a Mehlich 1 Ca test of approximately 225 mg Ca/kg (Fig. 2).

No good evidence exists to show that the internal Ca requirements of peanuts are affected by seed size. Adams *et al.* (1993) found that the Ca concentrations in seed needed to provide maximum germination ranged from 381 to 414 mg/kg for four small-seeded runner cultivars. Those values are close to a value of 420 mg/kg which was found to give maximum germination of cv. Florigiant, a larger seeded cultivar, in an earlier study in North Carolina (Cox *et al.*, 1976). Gascho *et al.* (1992) correlated germination with seed Ca and found that the large-seeded virginia type (cv. GK 3) had an

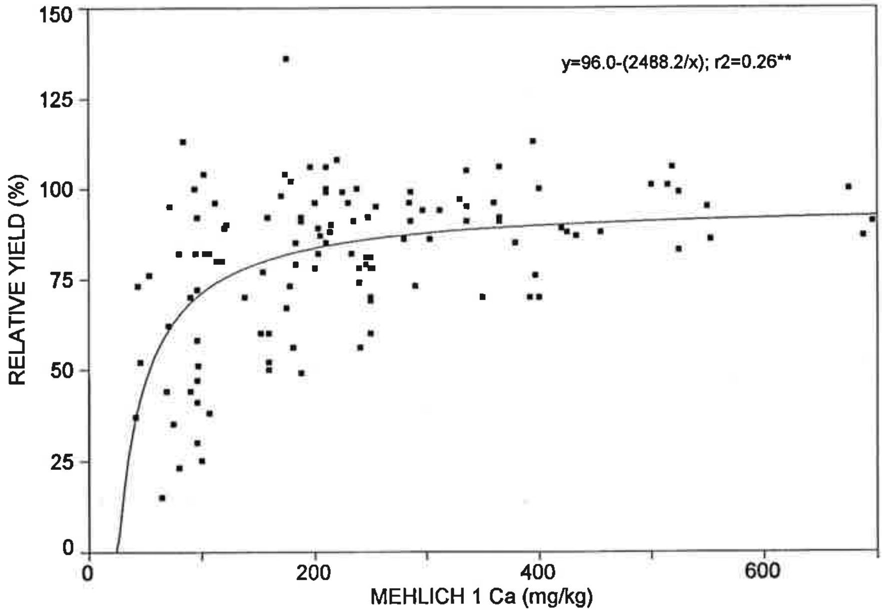

Fig. 1. Relative pod yield of virginia-type peanut receiving no calcium additions to those receiving calcium as affected by Mehlich 1 extractable calcium in soil prior to addition of any calcium. Data from 122 experiments conducted in Alabama, Georgia, North Carolina and Virginia.

internal Ca requirement of approximately 600 mg/kg for maximum germination which is greater than the internal requirement found for the small-seeded runner type (cv. Florunner).

Sumner *et al.* (1988) evaluated eight genotypes with widely varying pod and maturity characteristics over two seasons and four drought stress periods which were applied at different times. They found strong relationships of Ca concentration in the hull with surface area of the pod. Since a larger seeded pod has a lesser surface area:weight ratio than a smaller seeded pod, it is less efficient in diffusion and requires a greater concentration of soil solution Ca and/or greater soil moisture in order to provide adequate Ca to the pod. Acceptance of diffusion as the mechanism by which Ca moves to the developing gynophore explains the observed need for greater Ca applications for the large-seeded cultivars in order to obtain adequate internal Ca concentration.

However, there are variables other than seed size to surface ratio involved in external Ca needs among cultivars. Kvien *et al.* (1988) used stepwise regression to list five genotypic characteristics which significantly influence seed and hull Ca concentrations: (a) days required to mature a pod, (b) specific hull weight, (c) pod surface area, (d) hull thickness, and (e) pod volume.

Cox *et al.* (1982) suggest that Ca efficiency may be increased by breeding

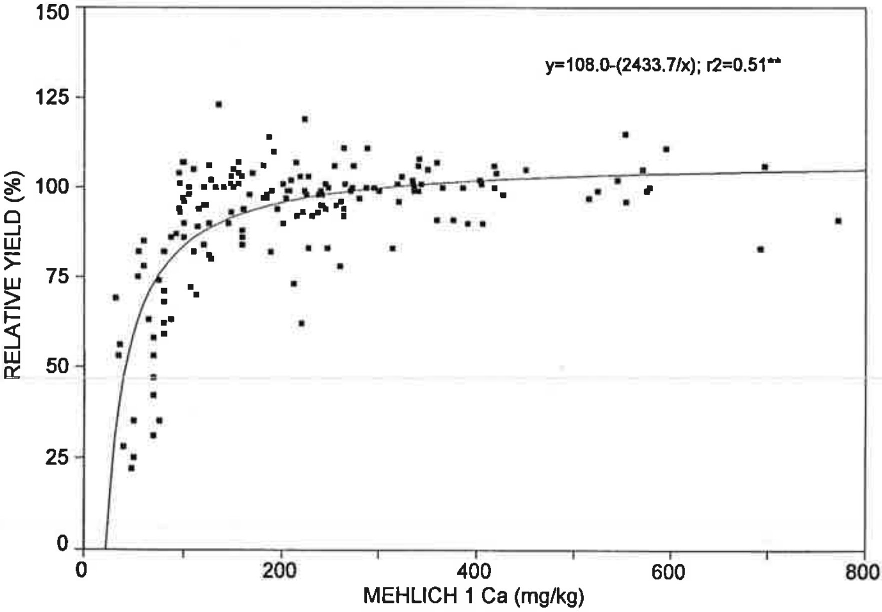

Fig. 2. Relative pod yield of runner-type peanut receiving no calcium additions to those receiving calcium as affected by Mehlich 1 extractable calcium in soil prior to addition of any calcium. Data from 168 experiments conducted in Alabama and Georgia.

the Ca efficient characteristics of small-seeded runner-type peanuts into the large-seeded cultivars. Recent literature does not reveal much effort in this regard. In an attempt to identify peanuts that may be suitable for culture on marginal soils and for low-input agriculture, Branch and Gascho (1985) evaluated 24 cultivars of four U.S. market types (runner, virginia, spanish, and valencia) for their tolerance of low soil fertility. They found that the standard southeastern U.S. runner-type cultivar Florunner gave the greatest pod and total sound mature kernel yield, but the kernels had a greater incidence of concealed damage than the other cultivar. The preeminence of the Florunner cultivar may be due, at least in part, to its Ca efficiency; defined as its ability to produce high yields in a relatively low ambient Ca environment. However, in their efforts to improve yield, market grade, disease resistance, and decrease aflatoxin concentrations, etc., the added improvement of nutrient efficiency does not appear to be a major objective with peanut breeders. Recent evaluations of the effects of supplemental Ca application on yield, grade, and seed quality of promising runner-type cultivars (Adams *et al.*, 1993) suggested that promising new runner-type cultivars may require different ambient soil solution Ca levels than Florunner. In their study, Ca concentrations in seeds (averaged by cultivar across 14 sites and for plots with and without gypsum) were 360, 356, 345, and 301 mg/kg for cvs. Florunner, Sunrunner, GK 7 and Southern Runner, respectively. These results indicate that no currently produced runner-type cultivar is more efficient than Florunner in Ca absorption and the relatively new Southern Runner cultivar was less efficient, especially in cases where no gypsum was applied (seed Ca concentration for Florunner = 319 and for Southern runner = 235 mg/kg).

Symptoms of Ca Deficiency

The important consequences of Ca deficiency occur in the reproductive stages of development, but some indication of insufficiency for quality seed production may be evident in the vegetative stages of growth. Symptoms summarized by Cox, *et al.* (1982) from the literature include: (a) more abundant foliage that remains green later in the season; (b) tendency for a greater number of flowers, many of which may be infertile; (c) localized pitted areas on the lower surface of fully developed leaves that can later develop into brown chlorotic spots which may have halos on their perimeters, coalesce and senesce the leaves and; (d) death of root tips and terminal buds (only in extreme deficiency). Death of seedlings due to Ca deficiency occurred in a sandy field when the Mehlich 1 soil Ca level in the upper 15 cm was 6 to 21 mg/kg (Gascho, unpubl. data, 1990). Pod production, grade, seed viability and seedling survival are reduced greatly by, and are the final results of, Ca deficiency. The primary reason for these results is the high proportions of pods with aborted and shriveled fruits ("pops") and darkened plumules ("black heart"). These deleterious effects are strongly related to concentrations of soil, as well as seed and hull Ca (Adams and Hartzog, 1980; Hallock and Allison, 1980; Walker and Csinos, 1980).

Germination of seed produced in low Ca soils is greatly reduced. Harris and Brolmann (1966b) observed 100% germination and 98% seedling survival when seed Ca was >800 mg/kg and 23% germination with no seedling survival for seeds with <300 mg Ca/kg. Adams *et al.* (1993) found germination and seedling survival to be highly correlated with seed Ca concentration of four runner peanut cultivars. They found maximum germination and seedling survival were attained at 368-414 and 361-445 mg Ca/kg of seed , respectively. Soils used to produce seed peanuts need a greater concentration of soil test Ca than those used for general production (Hodges *et al.*, 1994).

Garren (1964), Hallock and Garren (1968), and Walker and Csinos (1980) presented data indicating that pod rot (caused by several organisms, but especially *Pythium myriotylum* Drechs. and *Rhizoctonia solani* Kuhn) is related to low Ca supply based on experiments where pod rot incidence was reduced by application of gypsum. Hallock and Garren (1968) and Csinos and Gaines (1986) suggested that the balance among Ca, K, and Mg was important, with high K or Mg supply increasing the incidence of pod rot. The reported effect of Ca on pod rot has been disputed by Filonow *et al.* (1988). They infected soil with *P. myriotylum* and *R. solani* and found no effect of increasing Ca applications on pod rot incidence. Their work supports the effect of the organisms on the etiology of pod rot, but argues against Ca deficiency in the hull as a primary cause of the problem. Recent work in Georgia supports the relationship between Ca and pod rot. Gascho *et al.* (1993) conducted field experiments in soils with Mehlich 1 extractable Ca less than 200 mg/kg. They found that pod rot averaged 8 to 9% in control plots of both the small-seeded Florunner and the larger-seeded GK 3 and pod rot incidence was decreased significantly by the application of Ca.

Calcium supply may also be related to aflatoxin concentration in peanut seed. Davidson *et al.* (1983) and Wilson *et al.* (1989) determined that Ca applications on sandy soils with a low Ca status decreased infection by the *Aspergillus flavus* group of organisms that are sometimes associated with high concentrations of aflatoxins.

Diagnosis of Ca Needs

Soil analysis is the most useful diagnostic tool for determining the need for supplemental Ca fertilization. Samples taken from the surface 15 to 20 cm prior to planting the crop are often used. The critical Ca level varies with the soil extractant and the type of peanut to be grown. Adams and Hartzog (1980) determined that 125 mg/kg of Mehlich 1 extractable Ca was the critical value for Florunner peanut in Alabama. Hodges *et al.* (1994) combined data from the literature for 168 experiments conducted in Alabama and Georgia and determined that 95% of maximum yield was obtained when the Mehlich 1 extractable Ca was 200 mg/kg (Fig. 2). In practice, supplemental Ca applications for runner peanut are normally recommended for soil tests less than 150 (Alabama) to 250 mg Ca/kg (Georgia) to help ensure adequate Ca (Cope *et al.*, 1981; Plank, 1989b).

For the larger-seeded virginia-type peanut, soil-test Ca is less valuable since supplemental Ca is normally recommended regardless of the soil test level (Plank, 1989a). Gaines *et al.* (1989) indicated 95% of maximum yield was attained for virginia-type peanut for a Mehlich 1 test of approximately 775 mg Ca/kg. M. B. Parker, T. P. Gaines, and M. E. Walker (unpubl. data, 1989) combined data from the literature for 88 experiments conducted with large-seeded virginia-type peanut in Alabama, Georgia, North Carolina, and Virginia. They determined that 98% of maximum yield was obtained when Mehlich 1 Ca was 525 mg/kg. There is a soil Ca level above which no yield or quality responses to applied Ca would be expected for large-seeded peanuts. However, some additional data, particularly in relation to grade, are needed before revising present gypsum recommendations for the larger peanut.

For all peanut types, a particular soil test value should not be chosen as a "critical level" as that terminology infers precision greater than possible in farmers' fields. The level of soil test above which a response is not expected will vary with many peanut genotypic characteristics, but also with soil moisture available to transport Ca to the developing gynophore.

An ideal soil test would evaluate Ca concentration in the soil solution just prior to bloom. Applications of a slowly soluble Ca source (such as gypsum) could be made to supply Ca if needed. Attempts have been made to directly measure concentrations in the soil solution, or to use weak extractants that mimic the soil solution, without dissolution of soil-solution-insoluble Ca. Smal *et al.* (1988) evaluated 0.01 N $NaNO_3$ in comparison to a stronger extractant (Mehlich 1) which is widely used to measure cations in the acid soils of the southeastern U.S. They concluded that peanut yield and grade parameters were better related to Ca by the $NaNO_3$ extractant than Ca by the Mehlich 1 extractant. Such tests with weak extractants should be valuable for measuring soil Ca in the pegging zone, especially following the application of limestone prior to planting as they should not solubilize limestone particles to the extent of the stronger extractant. However, later studies have re-emphasized that Mehlich 1 is the superior extractant (Alva *et al.*, 1991). In cases where limestone has been recently applied and sampling may encounter limestone particles which can be dissolved by Mehlich 1, this test may give unreasonably high Ca levels. In some cases, Ca extracted by $NaNO_3$ was less correlated with peanut needs for Ca than was the standard extractant for soil Ca (Mehlich 1) in experiments conducted in Georgia. Alva *et al.* (1991) found that the $NaNO_3$ extractant did not predict a need for supplemental Ca on a very sandy site, but Mehlich 1 extraction accurately predicted a response. Adequate soil solution Ca (evaluated via a weak extractant) for such a soil is no guarantee that adequate Ca will be available when required by the peanut. Mehlich 1 extracts are more reliable for predicting Ca needs of peanut than are 0.01 N $NaNO_3$ extracts on soils with low ability to hold Ca. The limitations of the weak extractants likely occur because such tests provide no allowance for, or evaluation of, the Ca which may become available during the 60-day critical developmental period in which Ca is in constant demand. Need for supplemental Ca application to soils which have little ability to supply Ca from reserves can be grossly underestimated by soil solution Ca or by weak extractants.

If limestone is applied by the preplant incorporated method (see Correction of Ca Deficiency section below), the post-planting soil test will be of less value as there will likely be some lime particles in the pod development zone that may be dissolved by the strong extractant, raising the test to a very high value. However, those particles may not be dissolved during pod development, in order to benefit the current crop.

Foliar analysis has been used in peanut to a limited extent. Due to the unique method of uptake of the developing gynophore discussed above, it has been difficult to obtain satisfactory correlations between leaf nutrient concentrations and peanut yield and seed quality parameters. Nicholaides and Cox (1970) predicted a Ca deficiency when Ca in the tops of 9-week-old plants is less than 1.2%. Others have determined different critical levels which vary widely (Cox and Reid, 1964). Determination of foliage Ca concentrations is diagnostic for gross deficiencies for growth of the plant, but not as a tool that should be relied upon to ensure a good harvest. Sufficiency levels in peanut leaves are given in Table 2.

Correction of Ca Deficiency

Getting soluble Ca into the pegging zone and maintaining a supply to replenish depletion by crop uptake and leaching can be especially difficult in sands. Very soluble Ca sources such as $CaCl_2$ are generally expensive and short lived due to leaching losses. Gypsum (calcium sulfate) is much less soluble, but its application on the soil surface at first bloom is generally

Table 2. Sufficiency levels of nutrients in peanut leaf dry matter (from Gillier and Silvestre 1969; Plank, 1989a)

Plant part	Time	Nutrients						
		Macronutrients						
		N	P	K	Ca	Mg	S	
		%						
Seventh leaf	40 DAP[a]	3.3-3.9	0.15-0.25	1.0-1.5	2.0	0.3	0.19-0.25	
Upper mature leaf	Bloom	3.0-4.5	0.20-0.50	1.7-3.0	1.25-2.0	0.3-0.8	0.20-0.35	
		Micronutrients						
		Mn	Fe	Zn	Cu	B	Mo	Al
		mg/kg						
Upper mature leaves	Bloom	20-350	50-300	20-60[b]	5-20	20-60	0.1-5.0	<200

[a] DAP=days after planting.

[b] Ca:Zn ratio <50:1.

appropriate for supplying Ca over the 60-day period when there is a great requirement (Sridhar *et al.* 1985).

In addition to mined gypsum, byproduct, and phosphogypsum (Alva *et al.* 1989a, Gascho and Alva, 1990) are also available in many places at lower cost. When soil Ca is less than the chosen threshold level, gypsum is either broadcast or banded over the peanut row at first bloom. Most products have a range of particle sizes that solubilize over time to provide Ca. Gypsum has been a very successful source of Ca for peanuts; however, its application can add considerable cost to peanut culture. Dependent on source and recommended rate of application the applied costs may range from about 40 to $80/ha.

Limestone is an important source of Ca for peanuts grown in the acidic soils of southeastern U.S. and other locales. The main response of peanut to limestone is due to its supply of Ca, whether it was applied for that purpose or to increase soil pH. Adams and Hartzog (1980) conducted 16 field experiments with runner-type peanuts in Alabama with the stated conclusion that "Lime appeared to do little more than serve as a source of calcium. Spring-applied lime provided all of the Ca needed for maximum yield and grade when it was properly incorporated into the pegging zone." Since good farmers will lime their soils for their chosen crop rotation, they should attempt to apply it in a manner that will supply Ca to their peanut crop and thereby reduce or eliminate the expense of a gypsum application. Adams and Hartzog (1980) have shown that when limestone is applied to the soil prior to planting and incorporated to a shallow depth of 5 to 12 cm, adequate Ca is normally available for runner-type peanuts as judged by the fact that yield responses to gypsum applied at bloom were rare following such applications. Gascho and Hodges (1991) confirmed those results in Georgia but found that preplant-incorporated limestone, applied at rates satifactory to increase pH to the recommended value, did not supply adequate Ca for the larger seeded virginia-type peanut. On the other hand, Bell (1985a) worked on the irrigated sands of the Ord River area of Australia with cv. Virginia Bunch and determined that shallow incorporation of 1000 kg/ha of limestone (90% $CaCO_3$) before planting produced maximum yields of sound mature kernels. In his study, additional applications of gypsum at flowering had no significant effects on yield. Much of the inconsistency in reported results may be due to the prevailing moisture conditions. A wet growing season will result in good solution Ca regardless if its source is gypsum or limestone. If conditions are extremely wet on a deep sand, there is the possibility that Ca may be leached to a depth below the pegging zone. Application of gypsum at bloom followed by dry soil conditions can result in poor dissolution of Ca while heavy rainfall on such a soil could result in Ca leaching.

Limestone placement is critical in evaluating its usefulness to a peanut crop. Most limestone applied in agricultural fields is incorporated much deeper than the peanut pegging zone either by harrows or plows. Nearly all peanut fields in the U.S. are turned by moldboard plowing in order to bury trash and provide a loose bed for fruit development and removal. The modern moldboard plow essentially inverts the top 25 to 30 cm of soil. If limestone is applied prior to plowing, it will remain far below the zone of seed development and not provide Ca needed by the peanut. Gascho and Hodges (1991) found no benefit to runner-type peanuts for preplow application and benefits were equal to gypsum for preplant-incorporated-limestone applied after turning the soil (Table 3).

Unfortunately, the practice of shallow incorporation of limestone has been slow to be adopted in many peanut areas of the world. In some cases, limestone is not available or is too expensive, and no Ca is applied. In other cases, limestone is plowed under or otherwise incorporated too deeply into the soil or gypsum is considered the only appropriate source of Ca.

Dolomite is the limestone of choice when soils are deficient in Mg but, for peanut, the soil test value must be very low to see a benefit to Mg application.

Table 3. Effect of limestone placement[a] on soil pH and Ca and peanut yield and grade.

	Soil		Pod	
Placement	pH	Mehlich 1 Ca	yield	SMK[b]
		mg/kg	kg/ha	%
Turned under	5.7	32	2285	66
PPI	6.4	155	4426	73
No Lime	5.7	30	2455	66

[a] 2.2 t dolomitic limestone/ha either turned under with a moldboard plow or applied on soil surface following turning and incorporated approximately 8 cm (PPI).

[b] SMK=sound mature kernals.

Adams and Hartzog (1980) determined that dolomite was equal to calcite as a Ca source (consideration must be given to the lower Ca concentration in the dolomite) for all cases except one where Mehlich 1 Mg was 4 mg/kg. Gascho and Hodges (1991) also found dolomite to be superior on sandy soils in Georgia only when soil Mg was very low. However, most rotational crops have a greater Mg requirement than peanut, and their needs must also be considered in a liming program.

NITROGEN

Approximately 190 kg/ha of N is removed with a 3 t/ha peanut pod crop when the vines are also removed (Gascho, 1992). Peanut is a legume and under most conditions enough N is fixed through symbiotic relations with *Bradyrhizobium* spp. to avoid deficiency throughout the plant's life cyle. During reproductive stages, N is continually mobilized from leaves to the developing fruit (Kvien *et al.*, 1986) and, under some conditions N deficiency can occur. For that reason, N is commonly applied to peanut in most growing areas of the world (Gascho, 1992). However, N is not recommended in the U.S., except in cases where symbiotic fixation is low or expected to be inefficient. In China, 30 kg N/ha is commonly topdressed following an initial application of organic manure and PK fertilizer. Ten to 25 kg N/ha is commonly applied in India. Approximately 12 kg N/ha is recommended in Senegal.

Conditions that affect N supply to the peanut include: peanut type, peanut cultivar, presence of inoculum, soil type, soil moisture, and temperature. Cox *et al.* (1982, p. 149) summarized the N fertilization studies prior to 1982 by stating:

> 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 more acid soils in 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.

Nitrogen concentrations in peanut leaves decrease with plant age and vary with cultivar, making leaf N a difficult diagnostic tool for determination of the plants need. Analysis of the seventh leaf 40 days after planting should be in the sufficiency range of 3.3 to 3.9% (Gillier and Silvestre, 1969; Plank, 1989a)

Studies since 1982 have not appreciably changed any of the previous interpretations of needs of peanut for fertilizer N. Several studies with fertilizer N application still lead to differing conclusions due to variations in the factors given above. Walker *et al.* (1982), Hiltbold *et al.* (1983), and Cope *et al.* (1984) found no responses to N application for the runner-type peanut in Georgia and Alabama. In further studies, Walker *et al.* (1984) found that yields of nonnodulating peanuts and of cultivars Florunner and Tifrun were linearly increased with the number of foliar applications of N of 13.5 kg N/ha beginning 28 days after emergence. Patel *et al.* (1988) found that N application increased yield in only 1 of 5 years in India. Mali *et al.* (1988) found increased N uptake and yield due to application of 20 kg/ha N at planting in India, while Lal and Saran (1988) also measured increases in pods/plant and in oil and protein contents.

Inoculation of seed with a correct strain of *Bradyrhizobium* seldom increases growth and yield by alleviating N deficiency. Cox *et al.* (1982, p. 150) stated:

> Native 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.

In 1983, Wynne and associates in North Carolina published the results of several studies on N fixation of peanut. In the initial experiment, Ball *et al.* (1983) found no increased plant weight or yield of either spanish- or virginia-type peanut due to inoculation with *Bradyrhizobium* spp., while application of N fertilizer increased both plant weight and yield, but reduced N-fixing rates. The data suggested that there is no need for inoculation when the soil contains a high population of the proper strain of *Bradyrhizobium*, but either the peanut-rhizobia symbiosis does not fix enough N for maximum yield or fixed N was not used as efficiently as fertilizer N. Arrendell *et al.* (1985) used host selection in an attempt to increase symbiotic N fixation and found a significant correlation of nitrogenase activity with shoot weight, but lower correlations between nitrogenase and yield. They concluded that selection for greater N-fixing activity should be possible and should result in indirect selection for improved yield. However, in a later study, Arrendell *et al.* (1988) were unable to generate any variability in N fixing ability among F_2 selections. Finally, Phillips *et al.* (1989) determined the presence of nonadditive genetic effects in two crosses and concluded that early generation selection for N fixation factors would be ineffective. Thus, it appears that little progress to date has been made in improving N fixation via genetics.

Nitrogen application has been considered a control measure for Cylindrocladium black rot (CBR) in some instances. Black *et al.* (1984) found that while N decreased CBR severity for nodulating peanuts when *Bradyrhizohum* density was low, N increased CBR severity in non-nodulating peanut lines.

PHOSPHORUS

Peanut is grown on P-deficient soils in many areas of the world. On a global scale, P may be the most deficient element for peanuts. However, the deficiency is primarily limited to areas which have never been fertilized with P due to fertilizer availability or fertilizer cost. Phosphorus deficiency in peanut is well documented in several areas (Cox *et al.*, 1982; Bell, 1985b; Survanvesh and Morrill, 1986; Dwivedi *et al.* 1987; Chauhan *et al.*, 1988; Mali *et al.*, 1988), but is uncommon in countries such as the U.S., where P fertilizers are commonly used (Walker *et al.* 1982; Cope *et al.* 1984). In general, P deficiency in peanut can be easily corrected by application of P fertilizers since the crop is grown on sandy soils with low amounts of clays. In such soils P fixation is not a common problem. Fertilization generally not only provides enough P for the crop but also increases available P in such soils, because removal is low due to the low peanut plant requirement. (Table 1), and little P is lost by leaching. An exception is made for peanut culture on calcareous sands where P fixation can lead to P deficiency in spite of fertilization.

Soil analysis is considered the best method to determine P fertilizer needs. Extractants vary among locations and, therefore, care must be exercised in comparisons of "available soil P" values in the literature. The predominant extractants, proposed critical levels for peanut, and responses obtained in peanut soils throughout the world were discussed by Cox *et al.* (1982). These will not be discussed here.

Soil P levels required for peanut are often lower than those required for other crops (Cope *et al.*, 1984). A summary of data from India, Bolivia, South Africa, Guyana, Columbia, Israel, Uganda, China, Australia, and the U.S. with a number of extractants suggests a very low critical level of approximately 10 mg P/kg. A review of recent research emphasizes the low P requirements of the runner peanut. Hartzog and Adams (1988a,b) found no correlation between Mehlich 1 extractable P and either yield or grade of runner peanuts from fertilization in 39 experimental sites in Alabama where soil P ranged from 1 to 45 mg/kg. Cope *et al.* (1984) found no response to P fertilizer in long-term experiments even when Mehlich 1 P was reduced to 11 mg/kg by continuous cropping without fertilization. The critical level for Mehlich 1 P in the Southeastern runner-type peanut belt is approximately 10 mg/kg (Mitchell and Adams, 1994).

Bell (1985b) found responses to applied P at very low levels of 0.5 M $NaHCO_3$ extractable P on sands in Australia. He determined that the critical level for $NaHCO_3$ extractable soil P was 7.3 to 7.9 mg/kg for cv. Virginia Bunch. Chauhan *et al.* (1988) also reported reponses, but only at very low levels of soil P (6.15 mg/kg, unknown extractant). The Mehlich 3 extractant is now used in North Carolina and is under consideration in other Southeastern states currently using the Mehlich 1 extractant (formerly called Double Acid). Mehlich 3 commonly extracts one and a half to two times more P than Mehlich 1 (Gascho *et al.* 1990). Therefore, critical levels are considered to be proportionally greater for Mehlich 3. The corresponding critical level for Mehlich 3 is 17 to 25 mg/L (Cox, 1994). In areas where P fertilizers are readily available and relatively inexpensive, maintenance of such low levels is nearly always assured by P applications to rotational crops, and P fertilization of the peanut crop is generally not needed.

For areas where P fertilizers are not plentiful, or P is fixed due to calcareous conditions, some cultivars may be developed which are tolerant of low soil P. Dwivedi *et al.* (1987) conducted field experiments on a P-deficient calcareous soil and noted the variance in both dry matter accumulation and P accumulation in plant parts for one adapted peanut line in comparison to five unadapted genotypes. From their results they proposed a model which they claim will predict the resistance of lines/cultivars to P deficiency.

Some researchers have considered foliar applications of P in cases where soil applications are fixed by high concentrations of Fe, Al, or free phase $CaCO_3$. Survanvesh and Morrill (1986) foliarly applied P in the greenhouse and found that it was effective in increasing growth and plant P concentrations when the root supply of P was inadequate, but not when root availability was adequate. In field experiments, Walker *et al.* (1982) found no response to foliar P when adequate fertilizer was applied preplant on a soil with a low P-fixing potential.

Plant P analysis has been useful in peanut to a limited extent, but applications of P cannot correct deficiency effectively following a diagnostic tissue test. Therefore plant analysis is only helpful in knowing what to do the next time that peanuts are planted in that field. Care must be taken in the interpretation of plant analysis results since concentrations are significantly affected by plant age and plant part. Bhan (1977) noted that leaf P declined from 0.35 to 0.15% between 30 and 120 days following planting. Fertilization with P, which increased yields, only increased P concentration about 0.05% throughout that time period. Partitioning of uptake indicates only 10% of the total is taken up in the vegetative stage while 39 and 51% are taken up in the reproductive and maturation stages, respectively (Longanathan and Krishamoorthy, 1977). Foster (1980) set a critical P level of 0.29% P for leaves at flowering. However, others use a range of sufficiency levels. A compilation of sufficiency ranges (Gillier and Silvestre, 1969; Plank, 1989b; Gascho, 1992) indicates a wide variance. Reported ranges are 0.15 to 0.25% for the 7th leaf 40 days after planting and 0.25 to 0.50% for upper mature leaves at bloom.

POTASSIUM

Removal of K from the soil by peanuts is considered to be low relative to soybeans or bermudagrass when the vines are returned to the soil (Table 1). Removal of the vines as hay quadruples K removal. These data should be considered in planning a cropping system, but may not be of great importance to the peanut when grown in a rotation with several other crops since peanuts will not respond to direct K fertilization unless soil available K is very low (Scarsbrook and Cope, 1956; Walker *et al.* 1979). Reports of peanut responses to K are mixed. Scarsbrook and Cope (1956) reported an average pod yield response of 170 kg/ha to K fertilization when the Mehlich 1 soil K test was rated "low" by the Alabama soil K interpretation. They found no response when K was rated "medium" or "high".

However, the world literature remains rather mixed in terms of the response of peanut to applied K. In many cases, the literature does not provide good supporting documentation of soil K levels. Piggot (1960) established that K application was necessary for peanut in Sierra Leone. Potassium is rarely needed in India, but is added as insurance (Kernick, 1961). Goldsworthy and Heathcote (1963) conducted trials in northern Nigeria and found no response to K application. Later Heathcote (1972) found that continuous peanut crops responded to K in the third and fourth years, but not in the first 2 years. This is consistent with the idea that peanut removes relatively small amounts of K; however, peanuts will respond to K once soil K is reduced to low concentrations of this element. Haggin and Koyumjisky (1966) recorded significant responses to K in only two of 24 fields in Israel. Oil and protein percentages as well as yield of peanuts grown in the tropics responded positively to 15 kg K/ha in two experiments with initial soil K levels of 0.28 and 0.40 meq K/100 g extracted with neutral normal ammonium acetate (Kayode, 1987). However, yield responded negatively to greater rates of K application in Kayode's study.

Hartzog and Adams (1973) conducted 34 on-farm K fertilization trials in Alabama without yield response and concluded that direct fertilization of peanut was not a good practice, but K fertilization should be made to the crops grown in rotation with peanut. In Ca and K experiments on sandy soils in the Coastal Plain of Georgia, Walker *et al.* (1979) found a decrease in yield with increased K fertilization rates of 0, 112 and 224 kg/ha which resulted in Mehlich 1 soil test K levels of 20, 25, and 91 mg K/ha, respectively. On long-term fertility plots, Cope *et al.* (1984) found a modest, but significant, response to annual applications of 19 kg/ha of fertilizer K over a period of 30 years. The Mehlich 1 soil K test remained fairly constant at 44 mg/kg during the 30-year period. They concluded that the relative response of multiple crops to soil- and fertilizer- K levels was: cotton > grain sorghum > corn > soybean > wheat and peanut.

Potassium levels in the soil and applied K should be considered in relation to levels of other cations, especially Ca, as they compete for uptake by the developing pods. This subject is covered in the former section on Ca.

The soil K levels required for greatest yield and quality depend on extractant which in turn is determined by region and soil type. For the Mehlich 1 extractant used in the runner-type peanut belt of the Southern Coastal Plain of the U.S., the identified critical level is 11 to 13 mg K/kg (Walker *et al.*, 1979; Mitchell and Adams, 1994). The minimum sufficiency level used in K recommendations is 20 mg K/kg in order to provide "insurance" of adequate available K (Mitchell and Adams, 1994). Cox (1994) evaluated the Mehlich 3 extractant for use in the virginia-type peanut belt of North Carolina and determined the critical level to average 32 mg/kg. However, correlations of peanut yield response to surface soil K levels are not high in the soils of the peanut belt of the Southeast U.S. because much of the unused K accumulates in the subsoil. Some of this K is accessible to the deep roots of peanut. Therefore a low soil test from the top soil does not consider the K available to the peanut in the subsoil, and can underestimate K availability.

Thereby fertilizer K application may be recommended when there is scant chance of response. In addition, large variations in critical levels are found due to year (Cox, 1994). Therefore, Cox suggests a range should be presented rather than a single critical level. Recognition of the nonresponse of the peanut has recently directed the states in the southeastern runner-type peanut belt to reduce application of K by lowering critical levels in the Mehlich 1 soil K test to 20 mg/kg (Mitchell and Adams, 1994).

Leaf K has not been widely used as a guide to fertilization of the peanut since the timing of this diagnostic tool is generally too late for making corrections. Also, as reviewed above, the problem may be high rather than low leaf K; thus leaving little that may be done to make a correction. The exception is to add a soluble Ca source, such as gypsum, when the K/Ca ratio is high. However, leaf K concentration can serve as a diagnostic for future peanut fertilization in fields with a similar history. Since the review of Cox *et al.* (1982), Walker *et al.* (1989) determined minimum sufficiency levels of runner-type peanut from youngest mature-leaflet samples at approximately 100 days following planting to be 1.0% K for maximum yield.

MAGNESIUM

Little response has been recorded for application of Mg to peanut. Cox *et al.* (1982, p. 147) stated "The literature is almost barren of reports that peanut yields increased by Mg fertilization."

Responses only occur at very low soil test levels and they are most likely on deep, excessively drained sands. Since 1982, Hartzog and Adams (1988b) reported no response to $MgSO_4$ on a McLaurin loamy sand with a Mehlich 1 Mg test of 3.5 mg/kg. Walker *et al.* (1989) found no response to Mg on a Fuquay sand with an initial Mehlich 1 Mg test of 7 mg/kg, but application of 67 kg Mg/ha increased peanut yield by an average of 15% over the 3 years of the study on a Lakeland sand with an initial soil test of 4 mg Mg/kg. In the latter study, both K and Mg were deficient and application of both increased yield by 69% over the no K and no Mg control. It is very likely that the deep rooting pattern of peanut allows it to forage deeply for Mg as well as for other nutrients. As mentioned for K, some soils retain greater concentrations of Mg in the subsoil than in the surface horizon. Such is the case for the Fuquay sand, while the Lakeland soil has essentially no colloidal matter in the rooting zone. The findings of Walker *et al.* (1989) therefore seem consistent with the subsoil retention explanation for the lack of response to Mg fertilizer in soils that have had dolomitic lime applied in the past, but have low soil-test Mg just prior to peanut. Schmidt and Cox (1992) did not find a yield response that could be attributed to Mg fertilization in North Carolina soils with soil tests as low as 0.02 cmol/L (approximately equivalent to 5 mg/kg). Their soil tests were with Mehlich 3, which removes about the same concentration of Mg as Mehlich 1 (Hanlon and Johnson, 1984; Gascho *et al.*, 1990).

Soil analysis may be useful for prediction of Mg needs if the entire rooting depth is sampled. However, such samples seem impractical and surface samples are probably not reliable. Walker *et al.* (1989) suggested a Mehlich

1 extractable level of 11 mg/kg in the topsoil. For the present, the sufficiency level is set at 15 mg/kg in the runner peanut belt of Alabama, Florida, and Georgia (Hodges *et al.* 1994). Schmidt and Cox (1992) indicated that sufficient leaf Mg was attained when Mehlich 3 Mg in the soil was as low as 0.06 cmol/L (approximately equivalent to 15 mg/kg). At this low concentration, Mg was only 3% of the cation exchange capacity of the soil. The actual critical level has not been attained in most studies and is often complicated by the peanut plant's ability to forage deeply in soil horizons which may supplement the surface horizon in supplying Mg to peanut.

Use of leaf Mg concentrations for peanut suffers from all the same arguments as listed for K above, including variance with plant age. Walker *et al.* (1989) suggested a critical concentration of 0.2% in the recently mature leaflets of runner-type peanuts sampled at approximately 100 days after planting. Schmidt and Cox (1992) found no Mg deficiency with leaf concentrations as low as 0.15%. As for soil analysis, the lower limits of the sufficiency range have not been reached in enough studies to provide a firm critical level.

As for K, Mg may also interfere with Ca uptake by the developing pod; however, published evidence is scanty. Gascho *et al.* (1992) found that germination percentage in peanut is somewhat better related to a ratio of Ca/(Ca+K+Mg) in the fruit than to Ca concentration.

SULFUR

Even though S is a required nutrient for peanut, reports of responses to S applications are scarce in recent literature. Reports are often confounded by the fact that elemental S application not only supplies S, but also decreases soil pH, thereby changing the availability of other nutrients. Also, application of S as gypsum also supplies Ca, an element of paramount importance in peanut. Recent reports from India indicate some yield responses on calcareous soils to S applications as ammonium sulfate, single superphosphate, elemental S and gypsum (Bahl *et al.*, 1986; Hago and Salama, 1987; Sahu and Singh, 1987; Maliwal and Tank, 1988). Bahl *et al.* (1986) found that application of both S and Zn resulted in a synergistic effect on increased yield; whereas the effect in the studies of Hago and Salama (1987) was to increase chlorophyll a and b in an area where peanuts were chlorotic due to iron deficiency. The latter results are attributed to decreased soil pH due to S application. Cox *et al.* (1982) provided a review of reports of S responses by peanut growing areas of the world and discussed the complications of the reports due to interactions with pH, P, and micronutrients.

In the past, S was supplied to most peanuts incidentally due to the application of S-containing fertilizers such as single superphosphate. However, most modern fertilizers, such as triple superphosphate contain little S. Therefore, more S deficiency is expected to appear with time in many crops. Peanuts probably are unique, as much of the crop receives gypsum to supply Ca and thus are provided adequate S incidentally. In addition, several of the fungicides used in the past contained S, but use of S-containing fungicides has now decreased in peanuts. Atmospheric S is deposited on soils from burning of fossil fuels. Such deposits are particularly significant in industrialized areas and are usually sufficient for crop needs. Common levels of S deposits from the atmosphere range from 10 to 20 kg/ha/year. Sulfur concentrations can also be significant in irrigation waters, thus eliminating the possibility of any response to application (Cox *et al.* 1982).

Sulfur deficiency is most likely to occur on very sandy soils which possess little anion exchange capacity and will not hold the sulfate anion. Depth of the sand is an important factor since clay accumulation in deeper horizons within the rooting zone will tend to hold the sulfate anion and will lessen the possibility of S deficiency.

Soil tests for S are not important because critical levels have not been established. Such an effort would probably be fruitless due to the previously discussed problems of soil type and incidental application of S.

Several attempts have been made to establish critical levels of S in the peanut plant. Although the literature is not consistent with regard to a specific S critical level, in general, the whole plant concentration should be similar to the P concentration. As for several other crops, S concentration is also related to the N concentration and an N:S ratio of about 15:1 is desired based on a balance of S-containing and non S-containing amino acids (Bockelee-Morvan and Martin, 1966; Lund and Murdock, 1978).

MICRONUTRIENTS

Micronutrient availability in soils for peanut and other plants is related to soil pH as well as soil physical and other chemical characteristics. Most micronutrients are more likely to be deficient at high pH, particularly in calcareous soils. Micronutrients in this catergory are Mn, Zn, Fe, and Cu. Manganese and Zn may be available at toxic levels in very acid conditions. Alternatively, Mo is less available in acidic soils. The single most important consideration in proper availability of micronutrients for plants is soil pH. Other factors include cation and anion exchange capacities. Low exchange capacities, such as in deep sands, can result in deficiencies due to leaching and possible toxicities due to overapplication. Thirdly, interactions of nutrients can result in nutrient imbalance (e.g., a low Ca:Zn ratio may induce Zn toxicity in peanut). Fourthly, the ambient concentrations of micronutrients in soils and in irrigation waters vary due to soil formation factors and to cropping history.

Boron

Boron can be important when available either at deficient or toxic levels. The major problem in peanut is deficiency on highly weathered sandy soils due to their inability to retain H_3BO_3 (neutral charge) or the relatively mobile H_2BO_3 anion. All peanut-growing states of the U.S. recommend B application to peanut.

Deficiency. A deficiency of B most often results in internal fruit damage termed "hollow heart" which greatly reduces the quality and value of the crop. In some cases deficiency has also been reported to reduce yield. Hollow heart refers to the inside of cotyledons which are concave and discolored. Early research in Florida (Harris and Gilman, 1957) and Virginia (Anonymous, 1965) found that B deficiency resulted in hollow-heart, compacted branch terminals, and cracks on pods. Research in North Carolina using sand cultures showed that B deficiency resulted in deep green and mottled leaves and terminal death with extensive secondary branching and decreased internode length (Reid and York, 1958). Harris and Brolmann (1966a,b) described a longer flowering period resulting from B deficiency, and showed that plumules were discolored and plumule tips were pointed or poorly developed. Shiralipour *et al.* (1969) determined that B deficiency resulted in increased nitrogen and amino acid contents in peanut leaves without affecting protein levels.

Boron-deficient conditions can usually be alleviated by soil or foliar B applications. Application rates required to reduce plumule damage due to B deficiency vary from 0.6 kg B/ha (Cox and Reid, 1964; Allison, 1966, 1980), to 1.1 kg B/ha (Anonymous, 1965), 2 mg B/kg soil (Golakiya and Patel, 1986), 1.9 kg H_3BO_3/ha (Harris and Gilman, 1957), 6 kg Borax or H_3BO_3/ha (Asokan and Raj, 1974), 9 kg B/ha (Ganesan and Sundararajan, 1972), and even 15 kg Borax/ha (Muthuswamy and Sundararajan, 1973). Application of fertilizer B nearly eliminated hollow heart in South Africa (Snyman, 1972), Oklahoma (Morrill *et al.*, 1977), and Virginia (Hallock, 1966). Yields in an experiment in China (Zhang *et al.*, 1986) were increased by up to 11.5% by application of B (as borax). Boron application may also increase oil content of peanut fruit (Sankaran *et al.*, 1977).

In other cases, B application had no effect on yield or grade. In Alabama, Hartzog and Adams (1968) determined that topdressing 1.1 kg B/ha had no effect on yield and increased grade in only one out of five experiments. Cope *et al.* (1984) reported no effect of application of B (in combination with Zn, Mn, Cu, and Mo) on peanut yields, and B spray had no yield effect in a test in India (Swamy and Reddy, 1983). Hill and Morrill (1974) found B deficiency in 50% of their field locations but reported that B application did not affect yield or market grade. Hartzog and Adams (1973a) again reported no yield or grade effect of B fertilization but determined that B could be applied preplant in a herbicide tank mixture or sprayed on with a fungicide mixture without damaging plants. Application of a total of 0.6 kg B/ha is commonly tank mixed with and split equally between the first two fungicide applications (Walker, 1967).

Harris (1963, 1965) stated that B-deficiency symptoms were similar for runner, spanish, and virginia-type peanuts. He also noted that spanish- and runner-type peanuts developed B-deficiency symptoms earlier than virginia-type peanuts and that the virginia types recovered more quickly after B application. Harris and Gilman (1957) also noted differences in B response among runner cultivars.

Boron deficiency is more common in sandy, droughty soils (Hallock, 1966; Anonymous, 1972). Walker (1967) stated that 0.6 kg B/ha applied as a foliar spray increased peanut yields on Ruston and Tifton soils (sandy loams) but not on Greenville soil (a finer textured soil). In India, Saxena and Mehrotra (1985) found a significant response in yield to the application of 1 kg B/ha on a loam soil, but on a sandy loam they found yield response to only 0.5 kg B/ha. Boron leaches out of sandy soils, thus requiring more frequent applications than clay soils. However, sandy soils also have less adsorption capacity and, therefore, require lower application rates to be effective.

Harris and Brolmann (1966c) showed that applying a complete fertilizer without B accentuated B-deficiency symptoms. Hill and Morrill (1975) found that B application improved peanut grade, except when soil potassium levels were high. Cox and Reid (1964) showed that liming increased soil available B but did not increase B content in peanut kernels. Pod yield was highest when Ca:B ratio in pods was 218 to 224 (Golakiya, 1989).

Diagnosis of B nutritional problems can be either by soil or plant analysis but neither has been entirely satisfactory. Reliability of soil B tests have been considered rather low due mostly to the lack of correlation data. Harris (1968) indicated that, if soil B $\leq$0.2 mg/kg, then B should be applied. Hartzog and Adams (1971) reported that in eight experiments with hot water-extractable soil B <0.07 mg B/kg, hollow-heart failed to develop, and yield and grade was unaffected by B fertilization. Application of 5 kg B/ha increased yield on a soil in India with 0.16 mg B/kg (Jadhao *et al.*, 1989). The critical values by the hot water-soluble method, above which there should be no deficiency, are estimated to be 0.05 mg B/kg for acid soils (Cox and Reid, 1964) and 0.2 mg B/kg for calcarous soils (Hill and Morrill, 1974). In the Southeastern U.S., 0.6 kg B/ha is recommended for peanut when soil B <0.2 mg/kg.

Very little B-related peanut research has been reported in the past decade. There is a need for studies to evaluate diagnostic B concentrations in plant tissue using modern testing methods such as inductively coupled plasma (ICP) and/or direct current plasma (DCP) emission spectroscopy methods which are less laborious than commonly used colorimetric methods. Gopal and Rao (1972) reported a critical level of 25 mg/kg in middle leaves. Research on spanish-type peanuts in Oklahoma suggested a critical level of 30 mg B/kg in young peanut leaves (Chrudimsky, 1970). The critical leaf B concentration, below which the spanish-type peanut is deficient, is in the range 26 to 30 mg/kg (Morrill *et al.*, 1977). In the southeastern U.S., 0.6 kg B/ha is recommended if leaf B <30 mg/kg (young leaves).

Toxicity. Boron can be toxic to peanuts; therefore, B should be applied at the recommended rate only. Perry (1971) recommended 0.6 kg B/ha for sandy soils and 1.1 kg/ha for heavy soils, but warned against over application due to potential B toxicity. McGill and Bergeaux (1966) warned of exceeding 0.6 kg B/ha, and Morrill *et al.* (1977) stated that 1 to 1.5 kg B/ha caused toxicity and reduced yields. Application of 1 kg B/ha also reduced yields in Australia (Blamey *et al.*, 1981). Boron application at >6 kg Borax/ha gave an adverse effect (Asokan and Raj, 1974), and 5 kg Borax/ha resulted in toxic symptoms (Reddy and Patil, 1980). Care should be taken not to overapply B to peanut.

Research in India has shown that B toxicity results in chlorosis of leaf tips which extends marginally and interveinally, followed by marginal necrosis (Harigopal and Rao, 1964). Chlorosis was related to decreased leaf chlorophyll, protein N, and Fe (Gopal, 1975). Boron toxicity decreased yield, and leaching was recommended as an ameliorative method (Harigopal and Rao, 1967). Gopal (1969) showed that B interfered with the ability of iron to complex with proteins; however, iron addition made no difference to B nutrition (Gopal, 1970a). Boron also decreased leaf Cu (Gopal, 1970b). Boron toxicity decreased total and protein N in chlorotic leaves, but increased soluble N and free amino acids (Gopal, 1971a). Boron concentration in nutrient solution has resulted in B toxicity at levels >3 mg B/L (Lauter *et al.*, 1989) and 10 mg B/L (Gopal, 1968). In soil, 3 mg B/kg was reported as a toxic level by Gopal (1971b). However, soil critical level will vary with soil texture. Critical tissue B estimates range from 58 mg B/kg in young leaves (Blamey *et al.*, 1981), to 85 mg B/kg in leaves (Gopal, 1968), 100 mg B/kg in shoots (Stoller, 1966), and 140 mg B/kg in middle leaves (Gopal and Rao, 1972). There is a wide variation in reported toxic critical levels for B, so it is important to follow local B application recommendations without exceeding them to avoid yield reduction due to B toxicity.

Chlorine

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

Schilling and Hirsch (1974) found no correlation between leaf Cl and peanut yield in a study in Senegal. Addition of Cl to soil increased Cl concentration in Florunner peanut leaves in 1984 in Georgia, but there was no significant effect on dry matter production (greenhouse) or pod yield (field) (M. B. Parker, pers. commun.). There are no data that would warrant fertilizer Cl recommendations for peanuts.

Copper

Copper is seldomly applied to peanut as a nutrient but is commonly applied in the form of pesticides, particularly fungicides. Harris and Bledsoe (1949) reported that application of 11 kg $CuCl_2$/ha increased the proportion of sound to shriveled fruits for runner peanuts. Three years after application, the residual effect of Cu on peanut quality was maintained. Harris (1952) described Cu-deficiency symptoms as mostly affecting the bud area and as causing small, irregular leaflets with marginal necrosis and mild chlorosis and small yellow-white spots on the foliage. He found that the spanish type is more sensitive to Cu deficiency than the runner type but that yields for all three cultivars studied (two runners and one spanish) were increased more than 300% by applying 11 kg/ha Cu (as $CuCl_2$) to an Arredondo loamy fine sand (pH 5.7). Copper application also decreased seed shriveling and increased the percentage of sound mature kernels. The residual effect of soil Cu application (11 kg/ha) to oats, wheat, rye, or cotton in rotation with peanuts was found to be equally effective as peanut foliar applications (0.2 kg $CuCl_2$ /ha). Boswell (1964) found no definite pattern between Cu application and peanut yields in Georgia. Harris (1952) concluded that, in general, peanut yields in Florida had not been increased by Cu applications (though yields were increased on the Gainesville experimental farm), and, therefore, Cu application was not recommended.

Iron

Iron deficiency in peanut can be a serious problem in calcareous soils, but no problems have been reported on acidic soils. Perkins (1964) stated that the total Fe content of most acidic soils in Georgia is greater than 1%; therefore, he assumed that Fe is available in sufficient amounts for agronomic crop production. Iron deficiency in peanut results in interveinal chlorosis (starting in the youngest leaves), followed by chlorosis of the entire leaf (whitish-yellow) and brown spots leading to marginal necrosis. Lachover and Ebercon (1972b) showed that yield response to Fe application is related to $CaCO_3$ concentration in the soil. Papastylianou (1989) surveyed 35 peanut fields in Cyprus and determined that plants were chlorotic when $CaCO_3$ >20-25% and Fe content was <2.5 kg/ha. To prevent iron chloresis in peanut, Dungarwal *et al.* (1974) applied 500 kg S/ha to a clay loam of pH 8.4. This application increased peanut yields by 197%.

Lachover *et al.* (1970) applied an Fe chelate (FeEDDHA) to a soil in Israel with pH 7.9 and 15% $CaCO_3$ and measured a 50% increase in pod yield and a 40% increase in hay yield. Lachover and Ebercon (1971) showed that Fe chelate applied to a soil of pH 7.9 and 11% $CaCO_3$ caused leaves to green-up and increased yield. Foliar-applied Fe chelate increased greenness and yield, but Fe polyflavenoid and Fe acetate increased greenness without improving yield (Hartzook *et al.*, 1971). Yields were increased 359% by application of 10 kg Fe/ha (as FeEDDHA) to a loamy clay with pH 7.9 and 31% $CaCO_3$ (Lachover and Ebercon, 1972a).

Reddy and Patil (1980) applied $FeSO_4$ spray to spanish-type peanuts grown on an Indian soil with pH 7.5 (2.5% $CaCO_3$ and 9 mg/kg Fe) and measured no yield increase. Hallock (1964) applied Fe chelates to peanuts grown in Virginia and found no yield effect. Schneider and Anderson (1972) measured yield response to FeEDDHA in Texas.

Patil *et al.* (1979) determined that foliar application of $FeSO_4$ produced greater yields than soil-applied $FeSO_4$ on a black clay soil with pH 7.7 (2.5% $CaCO_3$ and 1.26 mg/kg available Fe). They also noted that high phosphorus fertilization was related to chlorosis and diminished yields.

Nitrogen fertilizers did not improve leaf color in peanuts with Fe chlorosis, and N levels in green and chlorotic leaves were not different (Lachover and Ebercon, 1971). Kafkafi and Neumann (1985) showed that no Fe chlorosis was observed when NH_4-N was 20% or greater of the total soil N. They suggested that NH_4^+ uptake resulted in H^+ efflux from roots which lowered pH and made soil Fe more available. Kafkafi and Neumann (1985) recommended the use of a nitrification inhibitor in addition to ammonium fertilizers. Iron stress was found to be greater in nodulated than in non-nodulated plants, and high plant Fe levels enhanced N fixation by peanuts (Terry *et al.*, 1988).

Zaharieva *et al.* (1988) showed that high soil Mn levels can be related to

Fe deficiency. Iron and Mn do not compete for absorption sites; Mn actually inactivates Fe metabolic activity by decreasing the Fe^{2+} concentration in peanut plants. Zaharieva *et al.* (1988) also stated that Fe-efficient cultivars can overcome Fe chlorosis without additional Fe supply. Hartzook *et al.* (1974a,b) determined that yield of untreated Fe efficient cultivars was roughly equal to the yield of inefficient cultivars which were fertilized with an Fe chelate (Hartzook *et al.*, 1974a).

Iron deficiency cannot be determined by plant analysis since chlorotic leaves may contain more Fe than healthy leaves (Papastylianou, 1989). Rao *et al.* (1987) stated that total Fe is unsatisfactory as a measure of Fe status in plant tissue and that Fe status was better assessed from an estimate of ferrous-Fe (by extraction with *o*-phenanthroline). They determined that the critical level for ferrous-Fe in the youngest fully opened leaf was 6 mg/kg. Rao *et al.* (1987) showed that chlorotic leaves had lower extractable Fe but higher total Fe and, therefore, Fe deficiency is due to poor utilization of Fe within a leaf, not due to absorption or translocation problems. Estimated critical levels are <2.5 mg Fe/kg in soil and <6 mg/kg ferrous-Fe in leaves.

Manganese

Deficiency. Manganese deficiency is a problem only on high pH soils. Rich (1956) stated Mn deficiency is a problem for peanut in Virginia. He reported that Mn concentration in the plant was inversely related to soil pH, calcium, and magnesium levels, in a study using 32 Coastal Plain soils. Visual Mn deficiency symptoms were evident when leaf Mn was below 10 mg/kg (Rich, 1956). Manganese deficiency in peanut has been observed on soils with pH values as low as 5.8. Anderson (1964) reported that no yield effect was observed for $MnSO_4$ addition (10 to 50 kg/ha) to a Tifton loamy sand, a Norfolk sandy loam or a Greenville clay loam in Georgia. Hickey *et al.* (1974) recorded a significant yield increase for peanut grown on a Lakeland sand (pH 6.3, extractable soil Mn 0.67 mg/kg) due to addition of 40 kg Mn/ha ($MnCl_2$). Foliage Mn levels were also increased from 59 to 155 mg/kg. The recommendation from the 1980 Virginia Peanut Production Guide is to apply foliar Mn at a rate of 0.8 to 1.1 kg/ha. The application may need to be repeated up to three times when interveinal chlorosis (symptomatic of Mn deficiency) is evident (Allison, 1980).

Hallock (1979) showed that soil Mn treatments did not yield significantly less than spray treatments for virginia-type peanuts, but deficiency symptoms were greater for soil-applied treatments. Parker and Walker (1986) studied the interaction of Mn response with soil pH on a Pelham sand. Manganese deficiency occurred only on plots with pH levels near 6.8 (Mehlich 1 extractable soil Mn = 3.3 mg/kg), not in plots with pH levels of 5.2 (soil Mn = 2.1 mg/kg) or 6.0 (soil Mn = 2.5 mg/kg). At pH 6.8, soil application of Mn at 0, 10, 20, and 40 kg/ha resulted in yields of 3.41, 5.40, 5.73, and 6.37 Mg/ha, respectively. Critical Mn levels in the leaves were 13, 15, 15, 15, 13, and 12 mg/kg at 7, 9, 11, 13, 15, and 17 weeks after planting respectively. Parker and Walker (1986) concluded that maintaining a soil pH near 6.0 was optimal for peanut production.

Soil Mn applications can be used to prevent Mn deficiency when the soil pH is known to be >6.0. Foliar Mn applications can correct Mn deficiency more rapidly than soil Mn applications.

Toxicity. Manganese toxicity can be a problem in low pH soils. Morris and Pierre (1949) reported that a concentration of 10 mg Mn/L in a nutrient solution reduced peanut growth to 76% of the control and resulted in chlorosis of leaf margins. Plant Mn concentration was 1245 mg/kg. Peanuts were the least sensitive (of five legumes studied) to Mn toxicity and had the lowest plant Mn concentrations. Boyd (1971) described Mn toxicity symptoms for peanuts as interveinal leaf chlorosis followed by marginal leaf necrosis. Boyd (1971) found that soil Mn (NH_4OAc extractable) was well correlated with leaf necrosis. Severe symptoms occurred when soil Mn was greater than 10 mg/kg and foliar Mn was greater than 50 mg/kg.

Benac (1976) found that a nutrient solution with Mn concentration $\geq$20 mg/kg caused stunting of peanut plants. Tissue Mn of plants with leaf necrosis was $\geq$4000 mg/kg, and the highest Mn concentration was found in the leaves. Nambiar and Anjaiah (1989) found that peanut plants with Mn toxicity symptoms had between 1040 and 3070 mg/kg Mn in the plant tissue in a nutrient solution test. High Mn levels decreased dry matter accumulation and nitrogen uptake.

High Mn levels may magnify Fe deficiency in peanuts. Zaharieva (1986) found that the $Mn:Fe^{2+}$ ratio was greater than 1:1 in chlorotic plants. Zaharieva *et al.* (1988) stated that peanut plants with Mn toxicity (dark brown marginal leaf spotting) had >450 mg/kg Mn in the leaves. Application of Fe as FeEDDHA eliminated leaf spotting. Zaharieva *et al.* (1988) also suggested that Fe application could induce Mn deficiency.

It is difficult to relate nutrient solution tests to field situations. More research is needed in the area of Mn toxicity in peanuts.

Molybdenum

Molybdenum is essential for nitrogen fixation, and is therefore recommended for some legumes (e.g., soybeans, alfalfa). However, it is currently not recommended for peanuts.

Plot trials in Senegal showed that Mo has a harmful effect on peanuts (Bouyer and Collot, 1952). Molybdenum deficiency symptoms were not attained in a sand culture experiment, though slight chlorosis was evident late in the growing season (Reid and York, 1958). Harris (1959) stated that Mo application caused peanut foliage to be a darker green and frequently increased the size of the foliage, but it has never caused a significant increase in peanut yield in research in Florida.

Walker (1967) found that 200 g Mo/ha increased yield by 224 kg/ha on a Tifton soil but had no effect on yield on a Greenville soil. Welch and Anderson (1962) found that Mo availability was increased by liming and that Mo application increased its concentration in peanut leaves but that no deficiency symptoms were evident in areas which received no Mo. They stated that Mo concentration in germinating peanut seed is high enough to provide the plant's Mo requirement even in a low Mo soil. Sellschop (1967) stated that Mo deficiency is best corrected by liming. Parker (1964) reported that in Georgia experiments, Mo often improved plant color but gave a yield response in only one of 15 experiments conducted. Boswell *et al.* (1967) showed that peanut yield was not well correlated with leaf or soil Mo content and that Mo addition increased nitrogen content of peanut foliage. However, the yield effect of Mo was inconsistent.

Heinis (1972) determined that Mo fertilization increased N and methionine contents in peanut leaves. Graham (1979) stated that Mo is essential for nodule formation and function and that Mo deficiency, which is more common on acid soils, can cause nitrogen deficiency. However, Kiat (1979) reported that Mo application had no significant influence on yield, nitrogen fixation or Mo concentration in peanut tissue.

In research studies in India, it was found that 1 kg/ha NH_4 molybdate increased yield of a spanish peanut (Reddy and Patil, 1980). The soil test level was 0.5 mg/kg available Mo, and pH was 7.5. The authors suggested that this beneficial effect may be due to increased N availability which resulted in increased protein in peanut kernels. Kene *et al.* (1988) found that Mo increased nodulation and nodule N content for peanut.

Most of the literature agrees that Mo increases greenness and N content of peanut leaves, but yield increases due to Mo application are rare. More research is required to determine under what conditions Mo fertilizers may be beneficial. Currently, there are no consistent data to recommend Mo fertilization of peanuts.

Zinc

Deficiency. Zinc deficiency is rare in peanut, except when grown on high pH soils. In addition, phosphorus application can show an antagonistic effect on Zn uptake (Chahal and Ahluwalia, 1977). Zinc deficiency is associated with high soil pH and high available P levels (Graham, 1979). However, Patil *et al.* (1979) applied $ZnSO_4$ to peanuts with severe chlorosis which was attributed to high soil pH and heavy phosphorus fertilization, but there was no yield response to either soil or foliar applications. In other research on a calcareous soil with <0.3 mg/kg soil Zn, applications of $ZnSO_4$ from 10 to 60 kg/ha had no significant yield effect (Lakshminarasimhan *et al.*, 1977). However, spraying 0.8% ZnO on peanuts grown on a calcareous Vertisol soil increased yield of a valencia-type peanut (Mupawose, 1978). Sellschop (1967) stated that Zn insufficiency was less conspicuous in peanut than in maize and recommended soil application of 16 to 22 kg Zn/ha where the problem exists. Schneider and Anderson (1972) found that a Zn application of 0.1 kg Zn/ha gave a positive yield response for spanish peanut but that 90 kg/ha reduced yield. Carter (1964) concluded that zinc fertilization can either increase or decrease yield but, generally, differences were insignificant.

Since response to Zn fertilization is variable, it is important to be certain of the diagnostic criteria for Zn deficiency. Bell *et al.* (1990) described Zn deficiency symptoms in peanut as decreased internode length and restricted development of new leaves. They also found that Zn-deficient plants accumulated reddish pigments in stems, petioles, and leaf veins. Bell *et al.*

(1990) stated that 20 mg/kg in upper stems and leaves and 25 mg/kg in recently matured leaves (at early pegging) had been used previously as critical levels for Zn deficiency diagnosis. They recommended that the blade of the youngest fully expanded leaf be used for diagnosis with 8 to 10 mg/kg Zn as its critical value. Reddy and Patil (1980) stated that 0.5 mg/kg Zn in soil and 22 mg/kg Zn in leaves at flowering were the critical levels for Zn deficiency in peanut. Rhoads *et al.* (1989) suggested a critical soil Zn level of 2.5 mg/kg when soil Ca >400 mg/kg. Soil critical level varies with pH, and leaf critical level is estimated to be 20 to 25 mg/kg. Foliar application of $ZnSO_4$ or Zn chelate is probably the best way to correct Zn deficiency.

Toxicity. Zinc toxicity was first reported by Quintana (1972) who noted that application of 90 kg Zn/ha as $ZnSO_4$ decreased yields and resulted in 67 mg Zn/kg in plant tissue. Keisling *et al.* (1977) described Zn toxicity symptoms as chlorosis, stunting, purple coloration of the main stem and petioles, usually a lesion at the base of the plant (stem splitting), and premature necrosis. Tentative Zn toxicity critical values were set at 12 and 220 mg/kg for soil (Mehlich 1-extractable) and tissue, respectively. Tissue Zn concentration increased 15 mg/kg for each 1 mg/kg increase in soil Zn. Liming reduced Zn uptake and stunting but did not change the soil extractable Zn level. Davis and Parker (1993) showed that leaf chlorosis (Davis-Carter *et al.*, 1990) and stem purpling were not well correlated with leaf Zn levels and described new symptoms of horizontal leaf growth and leaflet folding which appear at approximately 6 weeks of age, several weeks prior to development of split stems. Davis and Parker (1993) also confirmed the critical tissue Zn level, found to be 220 mg Zn/kg by Keisling *et al.* (1977); as all plants exhibiting toxicity symptoms in their study had tissue Zn levels >240 mg Zn/kg.

Rhoads *et al.* (1989, 1991b) also noted cultivar differences in tolerance to Zn toxicity. Southern Runner had greater dry matter yield and lower plant Zn concentration than Sunrunner at the same soil Zn level. Davis-Carter *et al.* (1990) illustrated the influence of soil texture on critical levels. Zinc toxicity symptoms of peanut grown on clayey soils required lower soil pH and higher soil Zn levels than peanut grown on sandy soils. On clayey soils, leaf Zn >470 mg/kg induced Zn toxicity symptoms. However, on sandy soils, plants with leaf Zn >350 mg/kg exhibited Zn toxicity symptoms.

Rhoads *et al.* (1989) stated that peanut response to Zn appeared to be more dependent on soil Ca level than on soil pH. Up to 23 kg Zn/ha did not affect plant growth when soil Ca >400 mg/kg and soil pH was 6.5 to 6.8, but 8.1 kg Zn/ha reduced plant growth when soil Ca ranged from 150 to 200 mg/kg and pH was $\leq$6.6. Rhoads *et al.* (1991a) showed that increasing Zn rates in greenhouse studies decreased Ca concentration in peanut tissues. In two greenhouse tests, the Ca:Zn ratio in tissue proved to be a good diagnostic tool for predicting dry matter yield; in one test, the critical ratio was 140:1, and in another it was 78:1. Parker *et al.* (1990) studied data from growers' fields which indicated that a leaf Ca:Zn ratio $\leq$50 was required for Zn toxicity of peanut, but Davis and Parker (1993) reported a critical Ca:Zn ratio of 35. The Ca:Zn ratio can be helpful but is not a definitive diagnostic tool.

Leaf Zn is affected more by soil pH than by soil Zn (Parker *et al.*, 1990). Liming redistributes Zn from the exchangeable fraction to less soluble fractions, thus reducing plant availability without changing the total amount of Zn present (Davis-Carter and Shuman, 1993). A regression equation, including both factors, showed that an increase in Mehlich 1-extractable soil Zn from 1 to 10 mg/kg increased leaf Zn by 202 mg Zn/kg at soil pH 4.6 but only by 9 mg Zn/kg at pH 6.6 (Parker *et al.*, 1990). Cox (1990) used data from North Carolina and Georgia to predict plant Zn concentration from soil pH and soil Zn. Davis-Carter *et al.* (1991) stated, that since Mehlich 1 extraction of Zn from soil is not pH sensitive, it is necessary to include soil pH in any regressions predicting leaf Zn. They used such equations to calculate the probabilities for the development of Zn toxicity symptoms in peanuts as a function of soil pH and soil Zn. From this research, a table was developed which gives the minimum soil pH required for peanut production depending on soil Zn concentration (Table 4).

Table 4. Minimum soil pH to avoid zinc toxicity in peanuts (from Davis and Rhoads, 1994).

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

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