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Direct and residual effects of lime on peanut performance on an acid soil of West Sumatra

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DIRECT AND RESIDUAL EFFECTS OF LIME ON PEANUT PERFORMANCE

ON AN ACID SOIL OF WEST SUMATRA

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ABSTRACT

Acid soils are the largest available lands for peanut cultivation expansion in Indonesia. This study was undertaken to determine the effects of lime on peanut growth on an acid soil of West Sumatra. In the first experiment eight peanut cultivars were grown in plots with 0, 500 and 2000 kg lime/ha. Lime reduced soil Al saturation and increased peanut yields. Pelanduk and Rusa cultivars were the least sensitive to Al saturation and Banteng was the most.

In the another experiment Tapir, Tupai, Florunner and Kelinci cultivars were grown under six combinations of lime rate (0, 375 and 1000 kg/ha) and methods of application (surface broadcast, shallow and deeply incorporated). The plots received 375, 2250 and 6500 kg lime/ha 29 months earlier. The plots then were planted with Srondol and Danau Dibawah rice followed by Kelinci and Tapir peanuts.

Lime increased soil pH, exchangeable Ca, Mg and K but reduced extractable Al, P and SO_4^{2-}. In about a year, the effects of lime extended to deeper soil layers. Roots that ceased to grow when near harvest contributed about 0.5 ton organic matter/ha.

Peanut yields increased with lime and with higher rainfall. In the drier season peanut pod yields ranged from 240 kg/ha for Florunner at low lime to 1660 kg/ha for Kelinci with the high lime treatment. In the higher rainfall the yields ranged from 800 kg/ha for Tapir to 1960 kg/ha for Kelinci. In a dry period shallow incorporation of lime increased the yields over broadcast.

Critical Al saturation was approximately 22 % for Florunner and Tapir cultivars, 35 % for Kelinci and 46 % for Tupai. The critical values increased to about 56 % for Kelinci and Tapir in the higher rainfall season. Florunner and Tapir yield responded

almost linearly to Ca saturation. Kelinci and Tupai maximum yields were obtained at Ca saturation of 74 % and 65 %, and 50 % for both cultivars in the second crop.

Peanut seedlings were grown in solution with low Ca and high Al at initial pHs 4 and 5. Root growth was enhanced by low-level Al, but reduced by initial concentration of 15 lM Al at initial pH 4 and by 50 lM Al at initial pH 5. Ca was essential for root growth but the requirement seemed low. Concentration of 150 lM reduced the toxic effect of Al.

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INTRODUCTION

As sources of protein and oil in the diet, grain legumes are indispensable crops in many developing countries. Dry legume seeds are often the most practical source of storable and transportable protein in the regions lacking refrigeration facilities. Their ability to grow vigorously in diverse environments and especially on poor, N deficient soils is particularly advantageous in subsistence agriculture (Rachie, 1978). They also enrich the soil by fixing nitrogen from the atmosphere. Grain legumes form a major component of cropping systems in the lowland tropics.

Peanut and soybean are the most important legumes cultivated in the world. According to FAO statistics, in 1987 there were about 11,177,000 ha of peanut and 12,049,000 ha of soybean in Asia alone. The average yield was 1144 and 1304 kg/ha, respectively. India, China and the United States are the largest producers of peanut in the world. Indonesia, the third largest country in Asia and also the third largest producer, was a net exporter in the early 1970s. However, while rice production has exceeded the country's need, Indonesia is now a net importer of peanut (BPS, 1984).

Of the two grain legume, peanut is better adapted to environmental stress than is soybean (Gibbon, 1980; Somaatmadja and Siwi, 1983; Weiss, 1983). Peanut is also reported to be tolerant to soil fertility problems associated with soil acidity. Peanut is moderately tolerant of solution Mn (Morris and Pierre, 1949) and solution Al (Adams and Pearson, 1970). Adams and Hartzog (1980) summarized 78 field experiments in the southeastern United States and found that peanut response to liming correlated more highly with exchangeable calcium than with soil pH.

In Indonesia peanuts are cultivated mainly in Java, South Sulawesi and Nusa Tenggara on slightly over 500,000 ha of land, or about 4% of the total area in cereals cultivation (BPS, 1988; Baharsyah, 1978; FAO, 1987). Most of this is established agricultural land which is intensively utilized throughout the year. Therefore, to expand the area for peanut cultivation, Indonesia has to look to newly opened agricultural land in transmigration areas.

The air temperature in the transmigration areas is suitable for peanut growth year round. Rainfall is sufficient to support at least two crops a year. However, almost all the soils of these new lands are acid, low in base cations and often have toxic aluminum concentrations. Recently a massive program was started to encourage transmigrant farmers to grow soybean. Free lime is provided for the homestead field along with an intensive extension effort to the farmers. To date there has been little such encouragement for peanut.

Studies in transmigration areas of Sitiung, West Sumatra have shown encouraging performances of peanut on acid soils. Tuban, a local peanut cultivar yielded more than 2 tons peanut pods /ha with 375 kg lime (Gill and Kamprath, 1985). However, due to water stress in the early growth stage in another experiment the yield was only about 1 ton pod (Wade and Santoso, 1985).

The study of crop production systems is complicated by many interactions between the crop and its environment. The traditional approach of multiyear experiments or field trials is expensive. Moreover, the results of such trials are usually specific to location, season, cultivar and management. The objective of agricultural research is to be able to prescribe appropriate technology at the level of the farmer and his farm. This objective can be achieved only if there is a shift in emphasis from reductionist and analytical research to holistic and system-based research. A system-based research strategy centers on balanced development of two interactive components: (a) crop model and expert systems, and (b) resource database (Nix, 1984; IBSNAT, 1987; Uehara, 1988).

Crop modeling is used to simulate and test hypothetical plant performance. Where several relationships exist, a model can be used to rationalize or resolve conflicting hypotheses regarding cause and effect. With accurate prediction of plant growth the research area with the greatest potential to improve plant performance can be identified. Coupled with a resource database, a crop model can be used to make predictions of system performance under a specific set of environmental conditions.

However, in many cases such crop simulation models are not available. Expert systems are tools which make the best of currently available knowledge based on field experience. Expert systems is a branch of artificial intelligence that the computer solves problems in a way that would be considered intelligent if done by a human (Waterman, 1986). An expert system is a computing system which uses organized knowledge about some specific problem area to solve a problem.

The most innovative part of an expert system is the ease with which a variety of information can be represented and used in decision making. This information ranges from quantitative information, including statistical relationships such as regression equations and physical or chemical laws, to less precise general rules of thumb or hunches that have been developed from hard gained experience in the field. The first type of information referred to as 'algorithmic' and the second as 'heuristic' information. The latter type of information can now be preserved and utilized in a more systematic way (Yost *et al.*, 1986).

OBJECTIVES

The objectives of this research are to:

(a) evaluate and rank the adaptability of several peanut cultivars to an acid tropical soil.

(b) quantify the effect of lime rate, and depth of incorporation and cropping on soil pH, exchangeable cations, aluminum saturation, P and sulfate-S on an acid tropical soil.

(c) correlate calcium and aluminum saturation percentage resulted from liming to root growth, pod and grain yields of different peanut cultivars.

(e) find the functional relationships between soil aluminum and calcium saturations with peanut growth and yield.

(d) characterize the performance of different peanut cultivars under different lime treatments at two different water supplies.

(f) evaluate the influence of varying levels of Ca and Al in solution at different pH on the root growth of different peanut cultivars, and

(g) determine the degree of tolerance to solution aluminum and minimum Ca requirement for the root growth of the peanut cultivars.

LITERATURE REVIEW

Acid Tropical Soils

The largest reserves of potentially arable land in the world are in the humid tropics. But most tropical soils are very poor and the equilibrium between plant-soil-climate that supports the amazing performance of the tropical rain forest is extremely fragile. Under the forest, fertility will accumulate at the surface. The exchange capacity of the subsoil is low because the small amount of well-balanced nutrients selected by the vegetation is rapidly and efficiently circulated by the turnover of organic matter. Efficient, because relatively large amount of organic matter is produced per unit nutrient taken up. Compared to its temperate counterpart, lowland tropical forest have more nitrogen but lower phosphorus return in the litterfall (Vitousek, 1983). Once this cycle is broken by clearing the forest, the disadvantages of highly-weathered tropical soil may become evident. Organic matter as an important structural element, buffering agent and main source of exchange capacity and plant nutrient will rapidly disappear (Von Uexkull, 1986).

In expanding agricultural areas for the transmigrants from Java, Bali and Lombok to the Other Islands most of the available soils are acid soils. To ensure the improvement of the transmigrant living standard and the sustainability of the new agricultural lands, the lands must be utilized properly. When the land is improperly utilized, productivity rapidly decreases and the ecosystem is jeopardized. Proper land use not only beneficial now but it ensures that the resources will still be available for future generations.

Selection of farming systems on acid tropical soils for transmigrant farmers need also to be reconsidered because two important development in recent years. First, the instability of oil prices had forced Indonesia to diversify her foreign earning by boosting non oil export and the self sufficiency in rice as staple food has been attained and maintained in the last six years make cash crop consequential alternative.

Extent and Problems of Acid Soils

Acid mineral soils which occur naturally as a result of intense weathering and are formed from acid parent materials, are widespread throughout the world. In the tropics, highly leached, low base acid soils of the Oxisol and Ultisol Orders comprise about 1675 million ha or 38% of the total land (IBSRAM, 1987). In Indonesia alone it was estimated that 48 million ha belong to these two soil Orders (Muljadi and Soepraptohardjo, 1975).

The extent of acid soils is also being increased by human activity through agricultural practices such as fertilization and basic cation removal in harvested crops. Application of synthetic fertilizers in six years of continuous cropping had reduced the pH of a Dystropept of Lampung, Indonesia by 0.5 units. While a negligible decrease occurred in the control plot, mixing the synthetic fertilizers with animal manure slightly increased soil pH (Santoso and Sibuea, 1982). Cultivation of leguminous crops and pasture is also reported to cause soil acidification (Haynes, 1983).

Acidification to below pH 5.5 resulted in large increases in the amount of exchangeable Al in the soil. With increasing soil acidification, increasing amount of cations were leached. The magnitude of leaching loss was of the same order as the cations were present in the soil. Soil acidification also appeared to inhibit nitrification (Haynes and Swift, 1986).

Acid soil infertility commonly results in crop growth being limited by one or more interacting factors, including low pH, toxicity of aluminum and manganese, deficiencies in calcium, magnesium, phosphate or molybdenum, and changes in microbiological activity (Foy, 1984). A further constraint to plant growth in these soils may arise from water stress resulting from restriction of root development in acid subsurface horizons (Adams, 1984).

Utilization and Development

The objective of much of the research conducted on acid tropical soils is to develop a highly productive and sustainable agriculture appropriate to the lands and the people. The utilization of acid tropical soil for arable food crops has developed with increasing intensity.

Shifting Cultivation

Traditional agriculture on much of the land is shifting cultivation which has low productivity and somewhat higher sustainability. The soils are grown with upland rice along with various types of annual food crops. This type of agriculture could support the subsistence living of many indigenous people in the past. This low intensity utilization relies on long fallow periods for regeneration.

The regeneration time for most acid tropical soils can be very long. Studying 20 years shifting cultivation cycle on Oxisols of Sarawak, Malaysia, Andriesse (1980) found that the soil surface nutrients increase on felling and burning but drop to relatively low level within 8 months. Allowing the land to fallow for 20 years enhanced the organic matter build up but did not always enhance the fertility. But when continuously cultivated the organic matter will dramatically reduced. Driessen *et al.* (1976) reported a decline in organic carbon of cultivated acid soil of Central Kalimantan to about a half in two years and to about a third in 7 years.

Annual Crops Cultivation

With increasing population and limited available land, more intensive agricultural developement will alter the productivity and the sustainability. The introduction of new high yielding cultivars, which require high chemical inputs in the last decades, has increased the productivity but reduced the sustainability. Liming is commonly practiced to alleviate acid soil problems. Recently, however, growing more tolerant crops has become an attractive option. Different options to serve as transition technology between shifting and continuous cultivation for acid soils of the tropics have been developed and tested.

Continuous cultivation of annual food crops with low inputs will collapse in relatively short time, mainly due to weed infestation. Although apart from decline in topsoil organic matter little change was observed in soil fertility even after 34 months (Sanchez *et al.*, 1987). A managed fallow with Kudzu crop cover for a year has improved the top soil fertility and the rice yield in subsequent cropping.

Continuous production of three annual crops per year in rotation of upland rice-maize-soybean or upland rice-peanut-soybean with high chemical inputs on infertile acid soils of Amazon Basin has given sustainable yield and improved soil fertility. But continuous monoculture of the same crops, has not produced sustained yield because of pathogen buildups (Valverde and Bandy, 1982). Further, it is unwise to assume this technology is directly applicable to million of hectares of Ultisols and Oxisols in the humid tropics (Sanchez *et al.*, 1982, Sanchez, 1987). Level lands like where the research had been conducted are already scarce. The relatively high capital requirement to purchase the chemical inputs, poor infrastructure and the uncertainty of the market made it less suitable for many small scale transmigrant farmers. Further, still unanswered is the question how it will perform in longer time. However, low input management can serve as precursor to establish legume-based pasture and agroforestry (Benites and Sanchez, 1989).

Alley Cropping

Several ways have been suggested to maintain the productivity of acid tropical soils used for annual food crops farming. Von Uexkull (1982, 1984) suggested a low-cost management system based on the establishment of a leguminous cover crop and adoption of a variant of shifting cultivation within the cover crop area. Another way to restore and maintain the soil fertility is 'alley cropping'. This system, based on perennial trees or hedges, usually uses legumes as a source of green manure as well as feed for livestock in the farming system. Trees or hedges are grown along the contour lines between the food crop fields. Roles of leguminous trees are to recycle the leached nutrients that cannot be reached by shallow-rooted food crops and to prevent erosion. Nevertheless, the long time lapse from planting the trees until they can be pruned for manure, and labor needed for the application made it less attractive to transmigrants. It is also unclear, whether the trees or hedges can be effective in recycling the leached nutrient after being pruned.

Perennial Crops

Perennial crops, grown with association with forestry plantation, are considered the most appropriate type of land use for tropical regions, where rainfall is high and soils are mostly infertile. From ecological point of view, they have some obvious advantages over annual crops. They offer good protection against soil degradation caused by leaching, erosion and soil compaction, and relatively lower demand for soil nutrients which often coupled with higher tolerance to soil acidity and aluminum toxicity (Alvim, 1982).

Indeed, with proper management many perennial crops like cocoa, oil palm and rubber are highly productive on acid soils. Now this still widely practiced, by both smallholders and big companies in utilization of the logging deforested lands in Indonesia. Smallholder plantations of both rubber and oil palm have increased from 2,154,900 hectares in 1983 to 2,700,600 hectares in 1987 while the estate type has increase from 852,600 hectares to 999,800 hectares (BPS, 1988).

Agroforestry

Agroforestry is the term given to any type of farming involving trees. Although agroforestry is widely practiced by the indigenous farmers, it is the least studied of all tropical agricultural systems. Research in agroforestry will require an interdisciplinary, ecological approach that must include agronomists of all kinds, anthropologists, geographers, rural sociologists as well as economists. It is also implies a perceptual change, for a sustained yield agriculture necessitates an integrative approach rather than a substitutive orientation (Hecht, 1982). Much still has to be learned on the basic technique like the best plant combinations and their geometric arrangements which probably vary for the different set of environments. Interaction between different plant species are usually site specific, making it difficult to generalize from isolated studies. As the problem stands today, agroforestry is then to be regarded as a promising field of research in the humid tropics, but by no means a system ready to be widely recommended for promoting agricultural development (Alvim, 1982).

Cropping before Permanent Crops Establishment

During the early stages of development of tree crops, sufficient light reaches the interrow spaces and this area can be intercropped with food crops to cater to the needs of the early settlers. These crops can also prevent the growth of weeds and reduce erosion on sloping lands. However, without proper soil management, certain food crops like upland rice, maize or cassava can deplete soil fertility rapidly.

Legume cover crops have showed benefit in improving soil fertility, and this effect on the trees planted could persist as long as 10 years after establishment (Pushparajah and Bachik, 1987). Legumes, however, rarely thrive in acid soils because of their relatively high Ca and P requirements and the sensitivity of Rhizobia to acidity. Slow growing *Bradyrhizobium* of peanut and cowpea is known to thrive in acid soil (Munns, 1986).

Both peanut and cowpea are relatively tolerant of acid soils. Both crops also relatively tolerant of water stress that might happen during prolonged dry season. Cowpea leaves were also a better source of organic manure to detoxify aluminum in acid soils compared to leucaena or grass (Hue and Amien,1989). The detoxification effect of cowpea can persist until at least six month after application (Hansen, 1989). This opens the possibility that the acid soil problem can be alleviated by cropping the soils several time with cowpea and leaving the plant residue in the field before cultivation of other less acid tolerant crops.

Although wild pigs that can damage peanuts, transmigrant farmers still prefer peanut over cowpea. Peanut, beside being an important source of protein and oil in the diet, can improve the soil fertility as a legume cover crop before permanent crops are established in the interrow of the tree crops. Benites *et al.* (1989) working in Yurimaguas, Peru, estimated contribution of 54 kg N/ha from a good peanut crop but only 12 kg N/ha from a poor one.

People Perceptions of Soils

Different perceptions of soils in farming system practices were observed among the ethnic groups in Sitiung transmigration area. The Javanese and Sundanese transmigrants lean toward more intensive soil management while the indigenous Minang focuses more on low labor crops and management strategies. The indigenous emphasis on tree crops is consistent with scientific consensus about appropriate crops for rolling land such as one finds in the area. However, given the small overall land holding of the transmigrant farmers, it is unlikely to use the extensive management method of the Minang (Colfer *et al.*, 1989). In their study of Sitiung area, Kan and Colfer (1989) found that transmigrant farmers showed strong interest in tree crops. Transmigrant farmers usually have little experience with perennial crop cultivation, but the frequent lack of funds to buy agricultural inputs suggests that the Minang strategy may have important hints to us to develop usable agricultural strategies for acid tropical soils.

Peanut Performance on Acid Soils

The lack of response by peanut to normal fertilization and cultural practices has been ascribed to the toxic presence of Al, low level of Ca and Mg (Coleman and Thomas, 1967) and poor nodulation of peanut crop, indicating poor 'legume-rhizobium' symbiosis (Graham and Donawa, 1981). Liming will supply Ca, increase soil pH and reduce aluminum in soil solution. Soil pH was reported to affect the Ca requirement of soybean for maximum root growth. Greater amount of Ca is needed is higher when the pH is low and a far higher amount is needed in the presence of aluminum (Lund, 1970). For peanut, however, soil pH *per se* was not a good criterion for liming. Adams and Hartzog (1980) found no correlation between soil pH and yield response of peanut to liming in Alabama. Instead, yield response was highly correlated with exchangeable Ca. Lime and gypsum applications in field trials gave equal results on soils with pH ranging from 4.3 to 4.9 in Malawi (Laurence, 1973).

Change in Soil pH

Plant roots are reported to induce pH changes in the rhizosphere. Acid-base changes in the rhizosphere are affected more by cation-anion imbalance than CO_2 production, excretion of organic acids or microbial production of acids from root carbon release. If plants absorb more anions than cations the roots must release HCO_3^- to maintain electrical neutrality in the root-soil interface. In legumes, the methods of nitrogen acquisition determines the pH changes. Rhizosphere pH is increases when the plants are fertilized with nitrate but if the nitrogen is obtained symbiotically, the uncharged di-nitrogen molecule crossing the root-nodule-soil boundary means fewer anions are absorbed by the plant. If cations exceed the intake of anions, the root will lower the soil pH (Nye, 1986).

Peanut is one of the Al tolerant legumes that have pH increasing ability. Peanut roots absorbed ions at lower cation/anion ratio than cotton, thus creating a less acid rhizosphere and a lower Al concentration. Peanut roots also showed a greater propensity for preferential absorption of lower valency ions and exclusion of higher valency ions (Adams and Pearson, 1970). The ability to increase or decrease pH in the rhizosphere of legumes is also associated with the type of *Rhizobia*. Slow-growers like *Bradyrhizobia* commonly raise pH and fast-growers acidify it (Munns, 1986).

Symbiotic N fixation and N fertilization

Growth of legumes on acid soils normally depends upon the establishment and functioning of an effective legume-*Rhizobium* symbiosis. Legumes and *Rhizobia* vary in their tolerance to soil acidity. Slow-growing *Bradyrhizobia* and the legume hosts tend to be less sensitive than fast growing *Rhizobia* and their hosts. Peanut and *Bradyrhizobia* formed one of the most acid tolerance associations found on an Oxisol (Munns and Fox, 1977).

Rhizobia also function independently of the plant, both as minor constituents of the general heterotrophic soil population and as non-specific colonizers of the rhizosphere. Legumes themselves obviously can function successfully without *Rhizobia* in soils that supply sufficient ammonium and nitrate.

In terms of energy requirement, nitrogen fixation is an expensive process whether carried out by petrochemical industry or by living organisms. Chemical fixation of nitrogen uses expensive non-renewable fossil energy and additional energy is required for its transportation and application in the field. Biological nitrogen fixation uses solar energy collected through photosynthesis and produces N_2 at the site where it is needed. In the case of rhizosphere and symbiotic N_2-fixing microorganisms, the carbon substrate is provided directly by the host plant (Neves, 1982).

There is good evidence that photosynthate supplied to nodules is a major limitation to symbiotic fixation (Hardy and Havelka, 1975). The carbon cost of 6.5 g C/g N estimated by Ryle *et al.* (1979) and Mahon (1979) suggests that fixation of a kg of NH_3 would cost the plant 15-20 kg dry weight.

Although the peanut-Rhizobia association in various degrees will increase nitrogen uptake by the plant, it does not always increase plant yield (Ball *et al.*, 1983). A common observation is that on soils very low in available N effective nodulation increases yield compared to uninoculated control. In soils of very high fertility, soil N suppresses nodulation and fixation and yield are generally equal. In soils of intermediate fertility, the energy cost of nodule formation and fixation might lower the yield of a crop obtaining some of its N via the symbiotic process (Larue and Patterson, 1983). Gardini *et al.* (1985) working in Brazil, reported that although peanut accumulated higher N in the shoots with 3 strains of inoculant, higher pod yield was obtained from fertilization with 30 kg N/ha in the wet season. In the dry season, when more photosynthate was produced no yield difference was observed.

The presence of Al and low pH can inhibit the growth of *Rhizobia* while manganese toxicity and calcium deficiency are less important inhibitors in soils (Keyser and Munns, 1979a; 1979b). Molybdenum deficiency is the most widely reported micronutrient deficiency in N_2 dependent legumes on acid soils.

Peanut is cultivated for two distinct markets: oil and edible peanut. End usage has a basic influence on nitrogen fertilizer policy. Excess N usually depresses oil content and increases protein content of the kernel. Kernel destined for eating should therefore receive more nitrogen than those for oil (Weiss, 1983).

Soils Fertility and Peanut Nutrition

Phosphate

Acid soils have a high P-fixing capacity. The principal factors affecting P fixation are clay mineralogy, clay content, exchangeable Al, and organic matter. Soils with amorphous minerals were reported to fix P the most, followed by oxides and hydroxides. The less crystalline the oxides the higher the fixation capacity because of greater surface area (Fox and Searle, 1978).

Considerable controversy exists regarding whether or not liming decreases P fixation. Part of the problem is the difficulty in separating direct and indirect effects of liming using only plant data. The effect of liming on P fixation depends on soil properties such as pH and Al content. Liming high aluminum acid soils to pH 5.5 decreases P fixation but does not have any influence on low Al saturated soils. Liming soil to pH above neutrality may increase rather than decrease P fixation because of the formation of insoluble Ca-phosphates (Sanchez and Uehara, 1980).

Haynes (1983) observed that when an acid soil with high exchangeable Al was incubated with lime, then the moist soil was reacted with phosphate, liming increased phosphate adsorption. In contrast, if the limed soil was air dried before reacting with phosphate, the liming decreased phosphate adsorption. Apparently, drying alters the surface characteristics of limed soil. Haynes (1983) speculated that drying causes the crystallization of hydroxy-Al polycations as gibbsite. The area of amphoteric surfaces on crystalline gibbsite would be small in comparison with the surface area of amorphous hydroxy-Al polycations. With increasing time after liming the phosphate adsorption capacity of the soil may decrease (Haynes, 1984).

Inadequate P may be the most common nutritional problem for peanuts. Phosphate is essential for root and kernel development, increases the number, density and efficiency of nodules and can also significantly increase the uptake of other nutrients. Phosphorus fertilization was reported to increase oil and protein content, decrease total soluble carbohydrate but have no effect on free fatty acids (Arora *et al.*, 1970).

Concentration of P in plant parts was highest in kernels followed by leaflets, roots, stems, petioles and shells (Reddy and Murthy, 1985) . The approximate P concentrations in the haulms, shells and kernels of peanuts at harvest are 0.07, 0.03, and 0.36%, respectively. The values for stems and shells are most variable while the value for the kernel is reasonably constant (Nelson, 1980). The P concentration in all plant parts decreases linearly during plant growth as result of the dilution effect and translocation to reproductive parts. However, when the soil was well supplied with P and S was not limiting, the plant was able to take up P from the soil to supply the need of developing fruit. Loss of P from the vegetative portion did not occur (Nelson, 1980).

Plant analysis may be used to determine if peanuts are deficient in P. Leaf P at flowering may be the most standard plant part and stage for plant analysis (Cox *et al.*, 1982).

Peanut reportedly needs high P fertilizization, seldom less than 20 kg P/ha (Weiss, 1983). In high P-adsorbing soils even higher amounts are needed. Fertilization of 30 kg P/ha applied to peanut experiments in Sitiung gave a good yield (Gill and Kamprath, 1985).

Calcium

Because of its ability to increase pH of the rhizosphere, peanut response to liming is mainly due to Ca increase in the pegging zone. Calcium is known to increase shelling percentage and yield. Working on an acid low-Ca Ultisol in Venezuela, Sanchez (1977) found that the highest yield was obtained with 0.5 ton $CaCO_3$/ha which also reduced the Al saturation to 30%. Mathur *et al.* (1983) found that liming the soil with more than the Ca requirement reduced the yield gain. Working with soil which had 3.7 $cmol_c$ Ca/kg Ca, they recorded the highest yield from 200 kg $CaCO_3$ /ha for each crop in 3 consecutive years.

Application of 1723 kg $CaCO_3$ /ha increased soil exchangeable Ca from 0.44 to 1.97 $cmol_c$ Ca/kg and gave the highest peanut yield on acid laterite soil of South Arcot of Tamil Nadu, India. Further increments of lime reduced the yield to nearly that of the no lime treatment. Increasing lime increased nodulation but reduced the aluminum content of the plant that is associated with reduced yield at high lime levels (Anandan *et al.*, 1984). Residual effect of 2000 kg lime (75% $CaCO_3$ equivalent) produced the highest peanut yield on acid soil with 0.08 $cmol_c$ Ca/kg after 3 maize and 1 sorghum crops were harvested in Kano, Nigeria (Adeoye and Singh, 1985).

The response to Ca differs among peanut cultivars. Hobman (1984) reported that lime did not increase the yield of 'Red Spanish' cultivar on acid soil with a Ca level of 1.21 $cmol_c$/kg, but significantly increased the yield of 'White Spanish' and 'Virginia Bunch' cultivars. His results agree with early workers (Colwell and Brady, 1945; Walker *et al.*, 1976; Balasubramanian and Yayock, 1981) conclusions that large-seeded cultivars have higher Ca requirement than small-seeded cultivars. Application of 375 kg $CaCO_3$ /ha on a high aluminum soil of Sitiung reduced aluminum saturation to about 70% and gave a satisfactory yield for a small-seeded local cultivar (Gill and Kamprath, 1985).

Calcium concentration was highest in the leaflet; followed in order by petiole, stem, root, shell and kernel. Calcium content of peanut could yield as high as 2.41% in the leaflet at 45 days after sowing and as low as 0.07 in the kernel at harvest. The pod yield was significantly correlated with Ca content of the leaflet at 25, 45 and 65 days after sowing (Reddy and Murthy, 1985). Enrichment of plant tissue with calcium resulted in maintenance of a higher water status under moisture stress associated with low proline accumulation (Chari *et al.*, 1986).

Magnesium

Exchangeable Mg is the most important source of plant available Mg (Christenson and Doll, 1978). When the pH in KCl of 5 South African soils were raised to 5 exchangeable Mg were reduced. Grove *et al.*, (1981) speculated that the reduction caused by adsorption and possible diffusion of soluble Mg into newly precipitated amorphous-hydroxy Al polymers created when acid soils were limed. The incidence of

Mg deficiency was increased by liming an acid soil with Mg-free lime and fertilizing with KCl at an excessive rate. Grove and Sumner (1985) found that increasing lime decreased extractable soil Mg, tissue Mg and tissue dry matter of maize in two green house trials.

Peanut response to Mg fertilization is rarely reported. Peanut certainly requires Mg, but compared to soybean, peanut is more efficient at extracting it from the soil. It seems probable that Mg requirements can be met by the subsoil supply (Cox *et al.*, 1982). Working on low Mg soil of Sitiung, West Sumatra, Gill *et al.* (1986) reported that corn-soybean rotation with higher inputs of lime and fertilizers were more responsive to Mg fertilization as compared to rice-peanut albeit higher yield given by the peanut.

Magnesium deficiency is expected to occur when soil exchangeable Mg is about 0.1 $cmol_c$ Mg/kg or less (Adams, 1984). Application of Mg on soil with 0.04 $cmol_c$ Mg/kg increased peanut yield and oil content at Yangambi, Zaire (Lumpugu and Mutera, 1983). Residual effects of 900 kg dolomite still gave 3.25 ton/ha of peanut pods on an acid soil of Yurimaguas, Peru (Wade and Sanchez, 1984).

Magnesium content of peanut was highest in the petiole followed by the stem, leaflet, root, kernel and shell. Magnesium concentrations in peanut were found to be as high as 0.85% in the petiole at 85 days after sowing and as low as 0.09% in the shell at harvest. There was no significant correlation between Mg content in leaflet with pod yield (Reddy and Murthy, 1985). Mg concentration of 0.3% in leaves of a 12 week-old Florunner from a field experiment did not show any evidence of Mg deficiency (Cox *et al.*, 1982).

Potassium

Most tropical upland soils are very low in mineral reserves as a source of potassium. Graham and Fox (1971) working with 11 Hawaiian soils reported that labile pool K which indicated K availability to corn had high correlation with rainfall. Small K pool was found in soils subjected to high rainfall and intense leaching.

Liming acid soils can further decrease the availability of K. Goedert *et al.* (1975) working with acids soils of Brazil reported that liming decreased the K intensity factor that might contribute to K deficiency. This is caused by the relatively high proportion of pH-dependent CEC that results in an important shift of solution K to exchangeable K as pH increases. However, peanut could tolerate a high Ca:K ratio and possessed an ability for luxury absorption of K in excess of that required for normal growth (Rogers, 1948). Working with Spanish and Runner peanuts in Alabama Rogers (1948) found that liming decreased the percentage of K in peanut vines, he attributed in part to increased growth and efficiency of utilization of applied K. Tamimi *et al.* (1974), reported that application of lime as high as 53.76 tons/ha on a Hydric Dystrandept of Hawaii did not decrease K uptake by corn. Liming allows variable charge soils to retain more fertilizer K against leaching losses. Peanut was reported to be less responsive to K fertilizer than maize. Applying 20 kg K/ha was sufficient for the local peanut on a Haplorthox of Sitiung that had 0.1 $cmol_c$/kg exchangeable K (Gill and Kamprath, 1985). The same rate of K fertilization was considered sufficient in the United States when lime-induced K deficiency was striking (Adams, 1984).

Potassium concentration in peanut was reported to be highest in the stem followed by the petiole, leaflet, root, kernel and shell. The highest concentration was 2.3% at 25 days after sowing. The potassium content in the leaflet at this time was significantly correlated to pod yield (Reddy and Murthy, 1985). Potassium concentration in the plant shoot was high in early growth then decreased drastically at 100 days after sowing. In contrast, in the root it was as low as 0.6% at 25 days after sowing then increased to 1.4% at 50 days after sowing (Polara *et al.*, 1984).

Aluminum

Aluminum toxicity is the most important factor limiting plant growth on acid soils. Recent research in solution culture has shown that only monomeric solution aluminum is phytotoxic and that the sum of the activity of monomeric species provides the best index of toxicity. Concentration of total and monomeric Al in solution decreased with increasing P/Al ratio, but Ca concentration had no significant effect on Al concentration. Instead, Ca significantly affected the sum of activities of monomeric Al (Alva *et al.*, 1986).

With the exception of particular bean cultivars, nodulation in legumes was more sensitive to solution aluminum than plant growth. Root infection and/or nodule initiation appear more sensitive to aluminum than subsequent nodule development. Aluminum solution concentrations which have strong inhibitory effects on nodulation, show no effect on the functioning of nodules in nitrogen fixation. Carvalho *et al.* (1982) showed that nitrogen fixation by well-nodulated plants of three *Stylosanthes* species was independent of solution aluminum concentration as high as 100 lM, both when measured by an increase in total nitrogen content of plants and by acetylene reduction assay on roots of plants harvested at 10 and 20 days after imposition of aluminum treatments. Franco and Munns (1982) working with *Phaseolus vulgaris* also failed to find any effect of aluminum concentration up to 83 lM on the growth of nodules already initiated in the absence of aluminum or on acetylene reduction activity.

Peanut nodulation and growth seem to be more affected by the sum of activities of monomeric Al than the concentration of total Al or monomeric Al. The sum of activities of monomeric aluminum necessary for 10% reduction of peanut nodulation and plant growth were 7.3 and 31.0 uM respectively (Bell and Edwards, 1986). This might explain why peanut response to liming is more closely related to Ca than acidity, Al or Al saturation.

Aluminum is generally regarded as non-essential for plant growth, but under some conditions low concentrations can increase growth or produce other desired effects (Foy and Fleming, 1978). In an experiment mentioned previously, Anandan *et al.* (1985) found that in excessively limed soil peanut absorbed half the amount of aluminum in the root and a quarter in the shoot of treatment that gave highest yield. This opens the possibility that aluminum might have a stimulating effect on peanut.

Manganese

Excessive quantities of Mn that are toxic to plants commonly occur in very acid, waterlogged where the acidic and reducing environment favors the solubilization of the Mn ion. High Mn concentration decreased nodulation of tropical legumes, but Al toxicity and soil acidity are probably more important than Mn toxicity and Ca deficiency in restricting nitrogen fixation (Foy, 1984).

The highest concentration of manganese was found in the leaflet followed by the petiole, stem, root and shell of the peanut plant. The concentration increased in all above ground parts of the plant until 45 days after sowing then decreased sharply by 85 days and harvest (Reddy and Murthy, 1985). Since peanut is commonly grown on well aerated soil, incidence of Mn toxicity is rare.

Manganese deficiency in acid soil is unusual, but can occur where large amounts of lime have been applied. The usual foliar symptoms of a Mn deficiency is interveinal chlorosis, with the vein remaining green. In sand culture trials, peanut had greater uptake of manganese than other species which accumulated mostly in leaves and little in roots (Weiss, 1983).

Sulfur

In highly leached acid soils of the tropics, sulfur may be deficient in the topsoil. Sulfur deficiency in peanut has been observed in India and Africa. The increased response to high sulfur containing phosphates has been well established. In some instances the apparent response to phosphate has been due to the sulfur content, where lower yield was obtained with phosphatic fertilizer with lower sulfur content. Plants receiving sulfur produced larger kernels of better quality. There are indications that sulfur may affect nodulation (Weiss, 1983; Norman *et al.*, 1984).

Liming acid soils can be expected to increase sulfur availability. It accelerates organic matter decomposition, thereby increasing the rate at which organic S is mineralized and the increased pH reduces the soil capacity to retain S in solid phase (Adams, 1984).

Peanut Root Growth

The shape and extent of root system are known to influence the rate and pattern of nutrient and water uptake from soil (Russell, 1977; Taylor and Klepper, 1978). Rooting characteristics differ greatly among species (Robertson *et al.*, 1979) and variation within peanut species has been reported (Ketring *et al.*, 1982; Ketring 1984). The anatomy of the peanut root has been studied by Yarbrough (1949).

Lea (1961) studied the depth of root penetration on sandy and clayey soils of Africa. Obviously, peanut is not a tree, but grown in loose soil peanut roots can penetrate to a depth of more than 2 meters in a relatively short period (Lea, 1961; Robertson *et al.*, 1980). Larger primary lateral roots originating from the top 15 cm often descend to the same depth as the tap root on sandy soil of Kongwa, Tanzania (Lea, 1961). During drought periods, lower roots continue to grow downward to unrestricted moist soil even though top growth may appear to stop (Allen *et al.*, 1976). Frequently greater rooting depth was found in water stressed peanut than in irrigated peanuts (Lenka and Misra, 1973; Narasimham *et al.* 1977). Taylor and Ratliff (1969) demonstrated that peanut taproots could grow into relatively dry soil as long as soil strength was low. Peanuts appear to have genetic ability for deep rooting and deep water extraction if grown in barrier free soil. Such a trait would postpone desiccation during extended droughts, although yield would probably be reduced because the water uptake from greater depths may not sufficient to supply all transpiration needs (Boote *et al.*, 1982).

Because of the thick taproot most of peanut roots were found in the top 15 cm of the soil. Lenka and Misra (1973) reported this to be 76% at 80 days and 85% at harvest. Highest proportion of roots in the deeper layers was found at 105 days after sowing. At harvest root component of the total crop dry weight was very small in peanut. At harvest peanut roots accounted for only 1.5% of the total dry matter (McCloud, 1973). For comparison, the root fraction of soybean at harvest was about 5.8% (IITA, 1972).

The detrimental effects of Al on root growth of various plant species has been well documented. The beneficial effects of increased Ca levels on peanut root has been indicated by Wolt and Adams (1979). Calcium is required on the exterior surface of the plasmalemma and also plays a structural role in cell membranes where it prevents membrane damage and leakiness (Clarkson and Hanson, 1980). Soepardi (1979) reported that lateral roots of 3 peanut cultivars were found abundant to 15 cm on limed and unlimed acid Latosol. More roots were found when lime was incorporated deeper. The effect of varying levels of Al and Ca on soybean roots has been reported by Noble *et al.* (1988). Peanut genotypes however, differ greatly in both root volume and dry weight among and within virginia, spanish and valencia botanical types of the subspecies of *hypogaea* Krap and Rig (Ketring, 1984).

Peanut Fruiting Habit and Seed Ca Requirement

Peanut has a unique fruiting habit. Six hours after pollination, fertilization is normally completed before midday and within 5-6 hours the flower may wither. After the flower droops, peg, a stalk like structure that bears the fertilized ovules, grows geotropically and penetrate the soil surface to a maximum depth of 7 cm. If the peg fails to contact and enter the soil after it expands to about 15 cm, it will die (Ramanatha Rao, 1988).

Soil surface moisture content is critical to peg penetration. Pegs frequently fail to penetrate effectively into air-dry soil, thus preventing pod development (Undewood *et al.*, 1971; Boote *et al.*, 1976). There are significant differences in the proportion of pegs developing into pods (Seshadri, 1962; Shingh *et al.*, 1981).

When peg has reached the maximum depth it becomes diageotropic and start to develop. Underwood *et al.*, (1971) found that if pegs penetrated to 1-1.5 cm depth, some pod development occured, but the development was slower near the surface. Further development of the pod is dependent on soil calcium. Calcium defficiency will cause aborted, shriveled fruit or darkened plumule. Germination of dark-plumule seed is poor and seedling survival is even worse (Cox and Reid, 1964; Harris and Brolmann, 1966). Low Ca seed content also cause poor germination. The critical Ca level for maximum germination of Florigiant peanut was 0.042 % Ca (Cox *et al.*, (1976) and between 0.045 to 0.068 % for NC5 peanut (Sullivan *et al.*, 1974). Since Ca is not translocated from vegetative plants parts to subterranean fruit calcium requirement of peanut must be obtained by the fruit itself (Sketon and Shear, 1971).

Peanut Growth Model

Crop simulation models consider explicitly processes at plant and organ levels. The process can be conveniently divided at the soil surface into aereal processes, which are mostly concerned with crop physiology and morphology, and soil processes (Whisler *et al.*, 1986). Better understanding of crop physiology and morphology led into more development of crop models that dealing better or primarily with the top part of the crops.

There are several existing models which simulate peanut growth and yield. An unpublished model was described in Duncan *et al.*, (1978). This model considers individual fruit growth rate and duration and cohorts of new fruit each day. Although this model has a simple soil water balance it does not consider water limitations or pests. Young *et al.* (1979) published a peanut growth and development model based on photosynthesis, growth and respiration in response to the daily environment. This model was developed from single plant phytotron data and certain factors were later calibrated in the field. This model does not consider pests nor does it have soil water balance.

Because peanut has phenological stages similar to soybean, Jones *et al.* (1984) felt that the model structure of SOYGRO, the soybean growth model, could be used for peanut with only minor changes. They modeled the partitioning of CH_2O to various plant parts as a function of crop development phenological growth phases. Since protein, oil and structural carbohydrate compositions of peanut plant parts differed slightly from those of soybean, the effectiveness of converting CH_2O into seeds, leaves, stems, roots and shells was changed. The algorithms for pod initiation, potential seed growth rates and potential seed sizes were changed as well.

Daily canopy photosynthesis rate (PG) was represented as a multiplicative function (PGMULT) similar to the one in SOYGRO.

$$PG = PGMULT * PTMAX * f_L * f_H * f_N * f_T \qquad (1)$$

where PTMAX is a function of daily radiation influx at optimal values of L (leaf area index), T (temperature), N (nitrogen concentration of leaves) and fraction of available soil water (J). In Florida, maximum photosynthesis of peanut was 24% higher than soybean. This was consistent with greater peanut growth and a greater single leaf photosynthesis rate (Boote *et al.* 1986).

Vegetative growth consists of leaf, stem plus petiole, and root growth from emergence to maturity. Partitioning of assimilate to these tissues depends on the stage of growth but also varies with water stress. New growth of leaves, stems, and roots was calculated by the equation.

$$G = X_i * E (P_g - R_m) \qquad (2)$$

where G represents new growth, X_i represents partitioning factors for leaves, stems and roots, E is the conversion for photosynthate, P_g is gross photosynthesis rate and R_m is the maintenance respiration rate. As pods develop, the fraction of assimilate going to vegetative growth is progressively reduced. Unlike soybean, peanut continues some vegetative growth even after full pod. For Florunner peanut maximum assimilate partitioning to the seed was 0.83 at which point no further pods were added. The maximum value of partitioning to fruits varies considerably among peanut cultivars.

Boote *et al.* (1986) further adapted the soil water balance of Ritchie (1985) for the peanut soil water model, where the soil was divided into up to 10 layers. Each layer contains soil water and root densities which change with time. Water content in each layer varies between a lower limit and saturated upper limit. Drainage occurs if water content is above the drained upper limit.

Total root length was determined by carbohydrate partitioning to roots and the same length to weight parameter as in SOYGRO, 9500 cm root length/g, but with a different partitioning factor. The distribution of roots in the soil layers depends on current root depth, soil water and an empirical weighting function (WR(L)) that represents the probability distribution of roots growing in each layer until late in the season if well watered. The rate of root depth increase continues until reaching the maximum depth specific to the cultivar and the soil.

Several improvements have been made to this peanut model to the standard input and output formats for climate and soil, so it can be validated in various soils and climates around the world. The improvements include the addition of: 1) temperature and radiation effects on specific leaf area, 2) effects of specific leaf area on photosynthesis, 3) possibility of allowing effects of temperature, radiation and photoperiod on root:shoot partitioning, 4) ability to allow for determinate and indeterminate vegetative growth, 5) use of cohorts of pegs, shell, and seeds with peg addition starting earlier in the growth stage, 6) soil water in fruiting zone affects rate of peg and early fruit formation and 7) improvement of soil water balance (Boote *et al.* 1988).

Almost all of the peanut modeling work has been done in Florida and has been primarily weather oriented on the assumption that only soil water will limit root growth. To date little has been done on modeling of peanut growth on acid tropical soils where soil chemical characteristics might also limit root growth. Chemical inputs as well as pH and other nutrients in the soil surely will determine the performance of the crop.

Expert Systems

The Agriculture Research Service of the USDA has developed the Crop Management Expert System (COMAX) which for cotton is called COMAX/GOSSYM. This Expert System gives advices to cotton growers regarding the application of nitrogen, irrigation and growth regulator (McKinion and Lemmon, 1985). There is no expert system of this type, however, has been done on peanut.

A more general expert system on acid soil management has been developed by the TropSoils research program of the University of Hawaii. This Acidity Decision Support System (ADSS) expert system consists of four modules: soil database, crop management, soil management and economic analysis. Crop management information will give the users the options in selecting crops that are more appropriate to the soil conditions based on the crops tolerance to acidity where peanut is considered relatively tolerant. In the soil management module, information on the amount of lime required to reduce soil aluminum saturation to a level that will not reduce crop yield will be provided based on an equation developed by Cochrane *et al.* (1980). The system considers critical aluminum saturation for peanut to be 40%. Lime is required when soil aluminum saturation exceeds that value. The profitability of liming can be analysed further of in partial-budget economic analysis module (Yost *et al.*, 1989).

MATERIALS AND METHODS

Field Experiments

Cultivar Screening Experiment

Eight cultivars from Indonesia were planted to test their tolerance of soil acidity and toxic aluminum. These included seven improved cultivars from Indonesia: Anoa, Banteng, Gajah, Pelanduk, Rusa, Tapir and Tupai (Somaatmadja and Siwi, 1983) and a local cultivar Tuban. The Tuban cultivar from Java is very popular among transmigrant farmers. Another spanish cultivar from Peru, Blanco Tarapoto, that was reported to be acid tolerant (Wade and Sanchez, 1984) was included for comparison. However, because of poor seed quality very few germinated. This cultivar seems to be morphologically similar to the Kelinci, a recently introduced cultivar from South America.

The peanut cultivars were planted on an acid soil of Sitiung, West Sumatra on a field next to the area that later became the site of the main experiment. Topsoil of the site had been removed for construction of an irrigation canal nearby. The plots were amended with 3 different rates of lime which were 0, 0.5 and 2 tons/ha lime. Ground limestone with 85 % $CaCO_3$ equivalent and 50 % passing a 60 mesh sieve, typical of that used in Indonesian liming program, was applied 2 weeks before planting. The lime rates provided an aluminum saturation of about 80, 60 and 20 %. Each treatment was replicated three time and arranged in a split plot design with lime as the main plot and peanut cultivars as subplots. Some chemical characteristics of the soil after peanut harvest are presented in Table 1.

The peanuts were planted using a dibble stick, with 2 seeds per hill at 25 cm x 25 cm spacing. All plots received basal fertilizers of 40 kg P as TSP, 30 kg K as KCl and 16 kg Mg as kieserite given prior to planting. *Rhizobia* inoculum was applied with the seed.

Table 1: Some Chemical Characteristics of the Soil after Peanuts Harvest (April,1987), Sitiung I

Depth	pH	C	Exchangeable Ca	Mg	K	Na	Al	H	SO_4
(cm)		(%)	$cmol_c/kg$						mg/kg
			No Lime						
0-7.5	4.7	1.73	0.22	0.19	0.32	0.35	3.45	0.25	84.8
7.5-15	4.7	0.87	0.22	0.17	0.32	0.11	3.45	0.20	82.5
15-30	4.8	0.40	0.22	0.15	0.32	0.12	3.44	0.18	80.2
30-50	4.8	0.41	0.16	0.15	0.31	0.11	3.53	0.31	142.9
			500 kg Lime/ha						
0- 7.5	4.8	1.63	1.28	0.22	0.34	0.10	2.79	0.17	91.2
7.5-15	4.7	1.05	1.01	0.24	0.43	0.12	3.09	0.20	132.4
15-30	4.7	0.54	0.55	0.17	0.39	0.13	3.34	0.18	85.8
30-50	4.7	0.41	0.22	0.15	0.31	0.11	3.50	0.19	84.0
			2000 kg Lime/ha						
0- 7.5	4.9	1.27	3.72	0.28	0.40	0.23	0.82	0.03	109.4
7.5-15	4.8	1.23	2.92	0.21	0.37	0.15	1.20	0.26	104.0
15-30	4.7	0.67	0.88	0.19	0.45	0.13	3.24	0.18	91.4
30-50	4.7	0.41	0.25	0.15	0.31	0.11	3.45	0.19	85.6
$LSD_{0.05}$(lime)	0.4	0.16	0.22	0.05	0.08	0.08	0.12	0.05	18.9

Lime Rate and Depth of Incorporation Experiment

A field experiment was conducted in Sitiung transmigration area from April 1987 to July 1988. The site was rain forest which was cleared by bulldozers 10 years earlier. The plot area had been cropped for a period of time and then abandoned.

Table 2: Selected Initial Chemical and Physical Characteristics of the Experiment Plot

Depth	Organic C	clay	bulk density	pH	Exchangeable Ca	Mg	K	Al
(cm)	g/kg	(%)	g/cm^3		-----------$cmol_c/kg$----------			
0- 15	30	72	0.94	4.1	0.5	0.1	0.14	3.1
15- 37	10	75	1.04	4.9	0.4	0.1	0.10	2.9
37- 68	5	83	0.98	5.0	0.3	0.1	0.05	2.7
68-100	5	68	0.97	4.9	0.3	0.1	0.05	2.9

Source : Gill, 1988

From 1984 to 1986 the plot was used as an experiment with three levels of lime (375, 2250 and 6500 kg/ha) as main plots and six levels of K (0, 20, 40, 80, 120 and 240 kg/ha) as subplots and cropped with two rotations of maize-peanut-mungbean/cowpea before left fallow for a brief time. The potassium fertilizers were applied for each corn and peanut crops. A total of 230 kg P as TSP, 600 kg Urea and 525 kg kieserite were applied as basal fertilizers for both crops. Ten kg/ha each of $CuSO_4$, $ZnSO_4$ and borax was applied only before the first maize crop (Gill, 1988). Some chemical and physical characteristics of the soil before the earlier experiment started are presented in Table 2.

This plot was used on consideration that the site was fenced to keep away wild pigs, which remain a serious problem in this area. By applying sufficiently high level of K the residual effect of K is expected to be equalized. In the earlier experiment, the effect of K did not seem to be significant on peanut (Gill, 1988).

In this experiment six combinations of lime levels and depth of incorporation were applied on the former K subplots. These lime treatments were: (1) control; (2) 375 kg/ha surface broadcast; (3) 375 kg/ha shallow incorporation; (4) 1000 kg/ha broadcast; (5) 1000 kg/ha shallow incorporation and (6) 1000 kg/ha deep incorporation. The broadcast treatment was applied after the plot was rototilled. The lime in the shallow application was incorporated by rototiller to about 10 to 15 cm depth. A fork was used to incorporate the deep application to about 20 to 25 cm depth. Each plot was 7 m long and 4.5 m wide and treatments were replicated four time.

The plot then was planted with four peanut cultivars, Florunner, Kelinci, Tapir and Tupai in 15 by 35 cm spacing from April to August 1987. The last two cultivars were selected by their performance in a cultivar screening experiment conducted earlier in an adjacent plot. Florunner, a widely grown cultivar from Florida, was chosen as a standard for comparison. As a typical cropping sequence in this area, two rice cultivars, Danau Dibawah and Srondol were planted from September 1987 to January 1988 after the first peanut crop. After the rice harvest the plots were planted again with Kelinci and Tapir peanuts. The second peanuts crop was planted in February and harvested in June 1988.

To overcome possible yield limitations by other nutrients, basal fertilizers of 24 kg Mg/ha as kieserite were applied before the first peanut crop along with 30 kg P/ha as TSP and 40 kg K/ha as KCl. The same rate of P and 20 kg K/ha were also applied before planting the second peanut crop. Higher K rate was applied in the first peanut crop to eliminate possible variability due to K treatments in Gill (1988) experiment. For the rice crop, only 20 kg P/ha was applied before planting and urea were broadcast at the rate of 30 kg N/ha at both 3 and 7 week after planting.

Observations were focused on the lowest lime mainplot (375 kg/ha) of the previous experiment, because soil analyses showed that the residual effect of neither lime nor K was significant. For comparison soil samples were taken from several treatments in the medium and high lime treatments considering the K fertilization in the earlier experiment. Soil samples from medium and high lime treatments of Gill (1988) experiment were taken only from those plots with no or a low level of K in the earlier experiment.

At harvest the haulms and pods were weighed. From samples in each treatment number and weight of pod and grain were recorded.

Root Sampling and Measurement

Several methods of studying root systems were described by Bohm (1979). Recently more sophisticated methods of root measurement using a mini-rhizotron have been developed. This method involves lowering a small video camera into small acrylic tubes that are buried in the soil and observing the roots that intersect the tubes on a video monitor (Upchurch and Ritchie, 1983; 1984). Viable plant roots were also measured with an image analyzing computer (Ottman and Timm, 1984). None of these facilities were available in the Sitiung area, therefore the root study was done using more crude methods by taking root samples using either soil augers or cylindrical cores.

For root study purposes, plots in the liming experiments were weeded every five days so that no roots other than peanut roots were taken. In the first peanut crop, the root samples were taken from the plant base. Root samples were taken from the top 60 cm of soil surface at 60, 85 and 100 days after planting (dap) in 20 cm increments.

Because very few roots were obtained when using a soil auger in the first peanut crop, in the second peanut crop 13.6 cm diameter and 10 cm height cylindrical cores were used. In the second peanut crop the root samples were also taken at the plant base in 10 cm increments. Root samples were taken from the top 20 cm at 25 days after planting (dap); from the top 30 cm at 50 dap and from the top 50 cm at 75 and 100 dap. The roots were separated from soil in a stream of water on a 0.85 mm screen and transferred into jars of clear water. The weight of cleaned root samples was determined after drying in an oven for 24 hours at 70^{o} C.

Root length/gram of fresh weight of soybean was determined by the procedure of Newman (1966) as modified by Sartain and Kamprath (1975). Instead of using a microscope as suggested by Newman procedure, a rectangle of known area (23 x 30 cm) with a perforated bottom and an acetate sheet with 80 lines randomized within columns, was used for root length measurement. This method was used by Gonzalez-Erico *et al.* (1979) on corn roots. The total root length was calculated using the Newman equation :

$$R = \pi NA / 2H \qquad (3)$$

where R is the total length of root, N is the number of intersections between root and the straight line, A is the area of the rectangle, and H is the total length of straight lines.

Much of the time required for this method is occupied by ensuring a uniform root dispersal throughout a finite area (A) and the repetitive use of a short line (H) for intercept counts. Because there was a simple relationship between A and H, Marsh (1971) argued that the formula could be simplified to

$$R = 11/14\ N \qquad (4)$$

for a grid of indeterminate dimensions. N comprised all intercepts of roots with the total length of vertical and horizontal grid lines and R was measurable in term of grid units; for 1/2 x 1/2 cm grid squares, equation (4) is multiplied by 1/2 to give centimeter measurement. This method was tested with almost perfect relationship with actual length of cotton thread and very good relationship with wheat roots by Tenant (1975).

The length of 120 root samples of the second peanut crop, selected randomly within the cultivars, time of sampling and soil depth was measured using this method. The samples were composed primarily of lateral roots after removal of nodules.

Root nodule numbers were counted at every sampling but nodule weight was recorded only at 75 and 100 days after planting. Nodule number and weight per m^2 were obtained by multiplication of the samples mean by number of plants per m^2.

Soil Analyses

Soil samples were taken from 0 to 7.5 cm; 7.5 to 15 cm; 15 to 30 cm and 30 to 45 cm before the new lime was applied and after each harvest. The samples then were analyzed for organic carbon, pH, Al, H, Ca, Mg, K, Na, P and S. Soil pH was determined in distilled water and 1 N KCl in 1:2.5 soil to solution ratio. Exchangeable

Al and H were extracted by leaching after equilibration using 1 N KCl extractant (Lin and Coleman, 1960). Exchangeable Ca, Mg, K and Na were extracted with 1 N CH_3COONH_4 at pH 7 and measured by atomic absorption spectrophotometry and flame photometry. P was analyzed using the Bray-1 method (Bray and Kurtz, 1945) and inorganic sulfate was extracted using 0.02 *M* $Ca(H_2PO_4)_2$ introduced by Fox *et al.* (1964) and determined by methylene blue colorimetric method developed by Johnson and Nishita (1952). Soil effective cation exchange capacity (ECEC) was calculated by the sum of extractable Al and H and exchangeable Ca, Mg, K and Na. Aluminum and Ca saturation percentage are the percentage of the ECEC which is extractable Al and exchangeable Ca, respectively.

After the experiment soil samples from selected treatments were again taken for soil solution analyses. A centrifugation procedure was used to collect soil solutions (Adams *et al.*, 1980). In this method approximately 250 g of soil at field water holding capacity was packed into a modified plastic Buchner funnel lined with Whatman no. 42 filter paper. The whole assembly was centrifuged at 500 g for 30 minutes, pH and soluble oxidizable carbon of the soil solution was immediately measured before significant CO_2 might be lost. Soluble oxidizable carbon was determined by the Mn(III)-pyrophosphate method (Bartlett and Ross, 1988). The other analyses were for soil solution Al and basic cations. Al was analyzed using a pyrocatechol method as described by Dougan and Wilson (1974). While Mg and Ca was measured with atomic absorption spectrophotometer after $LaCl_3$ addition.

Solution Culture Experiments

Three peanut cultivars Kelinci, Tapir and Tupai were grown in a dilute nutrient solutions with varying concentrations of Al and Ca at two different pH's. Two sets of treatments were applied after finding there were no significant differences among Ca levels and yet significant detrimental effects of Al from the first treatments. The first set of treatments comprised ten combinations of partial factorial of three initial levels of Ca (50, 150, and 250 lM) as $CaSO_4$ and four initial levels of Al (0, 50, 100 and 200 lM Al) as $AlCl_3.6H_2O$. The second set of treatments was comprised of lower levels of Ca (0, 25, and 50 lM) and lower levels of Al (0, 7.5, 15, and 30 lM). Both set of treatments were started at pH 4 and 5.

No nutrient was added to avoid the effect of the nutrient on both pH and Al except for the 0 Ca 0 Al solution where NaCl was added to the give an ionic strength similar to that of other treatments. In a short period of 4 days, sufficient nutrient is expected to be supplied by the seed. In all cases reagent grade chemicals were used. The pH of the solution was adjusted using either 0.05 M NaOH or 0.05 M HCl. The solutions were transferred to 1 L glass jars. The pH was measured again after 2 days and 4 days, at the end of the experiment.

Peanut seeds were placed on moistened paper towels and allowed to germinate in distilled water. After three days, 5 peanut seedlings with approximately 15 mm radicles were transplanted into their respective solutions. The growth chambers had 30^0 C day and 25^0 C night temperature, 12 hours photoperiod and 70 to 80 % relative humidity. After another 4 days, the peanut tap root length and weight were measured. Solution Al was analyzed in the beginning, after 2 days and at the end of the experiment using the pyrocatechol method as described by Dougan and Wilson (1974). Calcium was also analyzed using an Atomic Absorption Spectrophotometer. The jars were randomly placed in the growth chamber and the experiments were replicated twice over time.

RESULTS AND DISCUSSION

Performance of Some Improved Peanut Cultivars on An Acid Tropical Soil

The Rainfall

Rainfall distribution during the crop growing period is critical to rainfed agriculture. During the experiment the rainfall fluctuated poorly, thus hampered the peanut performance. The low rainfall soon after-planting probably delayed germination. A sharp decrease in rainfall occurred during peanut flowering, peg formation and pod development, but rainfall increased greatly in the later stage of growth (Figure 1).

Su *et al.* (1964) reported that the period from 50 to 69 days after planting was the most critical for water deficit for spanish cultivars followed by the 30 to 49 days period. As seen in Figure 1, the lowest rainfall was recorded during these periods. Soil surface moisture is critical for peg entrance into the soil. Pegs frequently failed to penetrate effectively into air dry-soil, thus preventing fruit growth (Boote *et al.*, 1976). Ono *et al.* (1974) observed that adequate moisture in the pegging zone was critical for pod development and that adequate soil moisture in the root zone did not compensate for the lack of moisture in the pegging zone for the first 30 days of pod development. The high rainfall in later phases of fruit growth probably reduced photosynthesis and peanut pod filling. This decreased yield particularly in heavy textured soils (Boote *et al.*, 1982). The yield decrease was associated with weakened peg attachment and a subsequent loss of pods due to detachment. Due to the unfavorable rainfall distribution relatively low yields were harvested from all the peanut cultivars.

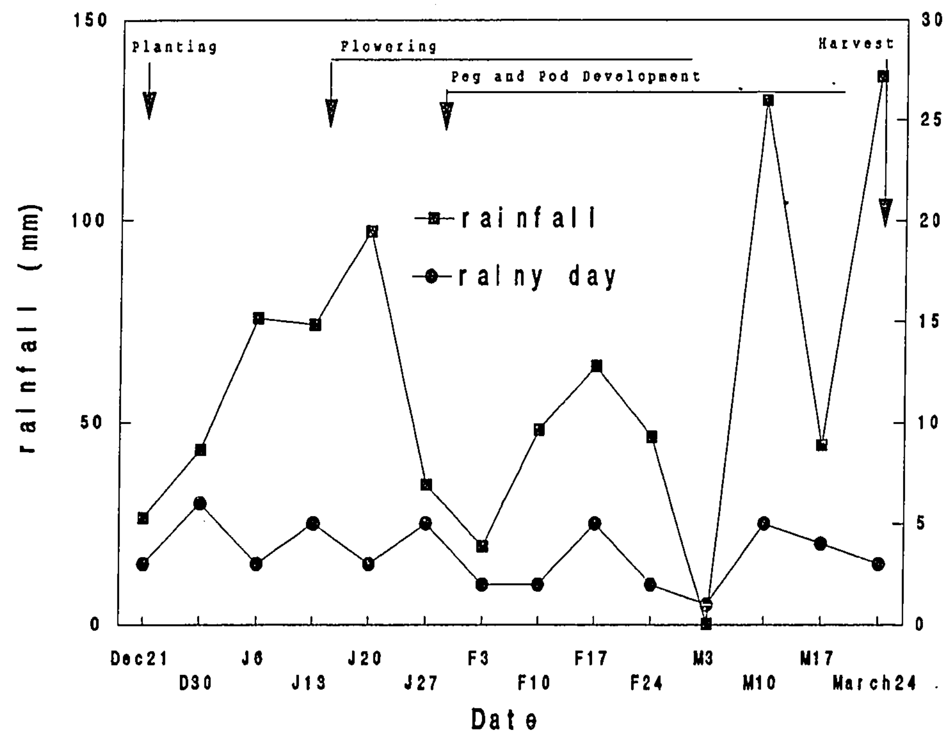


Figure 1: Weekly Rainfall Distribution at Gunung Medan, Sitiung during Peanut Screening Experiment

Soil Calcium

Peanut yield on acid soil is often limited by the lack of Ca rather than by the lack of other plant nutrients (Cox *et al.*, 1982). Lime did not increase soil pH significantly. At 2000 kg lime/ha the soil pH was still less than 5. However, lime had improved the soil condition by significantly increasing surface soil Ca and reducing surface soil Al. At

500 kg lime/ha the topsoil Al saturation was reduced from about 75 % to about 58 %. Soil exchangeable Ca increased from 0.22 to 1.28 $cmol_c$/kg, a level more than twice the critical Ca level for Florunner peanut (Adams and Hartzog, 1980). The application of 2000 kg lime/ha reduced top soil Al saturation further to 23 % and increased exchangeable Ca to 3.72 $cmol_c$/kg (Table 1).

Small seeded spanish cultivars would probably require less Ca (Middleton *et al.*, 1945; Hobman, 1984). However, the drought conditions during pegging and pod development probably prevented the plant from absorbing the soil Ca when it was needed most. Calcium is passively absorbed by plants, the amount absorbed not only depends upon its concentration in the soil but also upon the amount of water absorbed by the plant (Mengel and Kirkby, 1982). Peanut absorbs Ca by both peg and root, but since Ca ions are transported almost exclusively in xylem tissue, once the developing peg penetrates the soil surface it loses access to Ca absorbed by the root.

Although lime has significantly increased surface soil Ca to the level considered more than sufficient for peanut reproductive development, the relatively low soil water during pod filling had inhibited its absorption. In the relatively low rainfall, higher Ca was probably required in the soil surface to compensate the low absorption due to the limited soil moisture.

The Peanut Yield

Low yield of crops on acid soil has been ascribed to toxic levels of Al and low levels of Ca (Coleman and Thomas, 1967). By increasing soil Ca and reducing soil Al, liming significantly improved growth and yield of all the peanut cultivars. However, probably due to the poor rainfall distribution, relatively low pod and grain yields were harvested from all the peanut cultivars. Only Tuban, Tupai, Banteng and Gajah produced more than 1000 kg dry pod/ha, all at 2000 kg lime per ha (Figure 2). At this lime rate Tupai produced the highest pod yield, while Anoa and Rusa produced the lowest. The highest grain yield was produced by Tuban followed by Gajah, Tupai and Tapir. At the high lime level only Banteng produced less than 590 kg grain/ha.

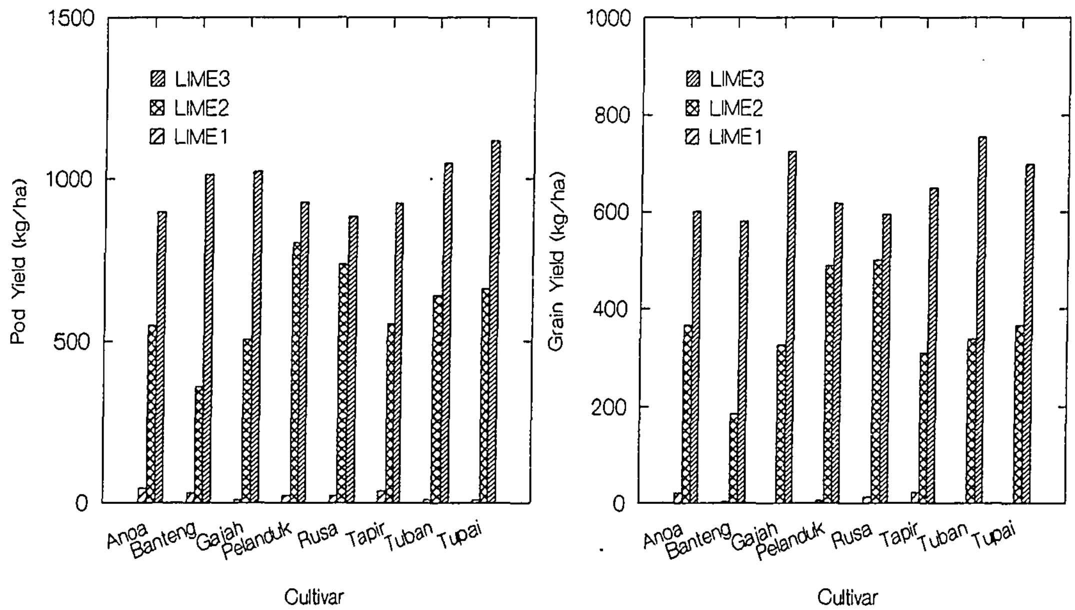


Figure 2: Pod and Grain Yields of the Peanut Cultivars

The application of 500 kg lime increased the yield by both improvement in number and quality of pods, grain and the number of seeds per pod. Increasing the lime rate to 2000 kg improved the mean dry weights of pod, except for the Rusa cultivar. The mean grain dry weight at 14 % moisture only increased in Pelanduk, Tuban and Tupai (Table 3). The yield increase obtained from lime was mainly due to increasing number of pods and number of grains per pod. This confirms the finding of Cox *et al.* (1976) that soil moisture and soil Ca interact to improve peanut quality and yield.

Without lime, Gajah, Tuban and Tupai cultivars produced no pods while the others produced very few. The pods of Banteng and Pelanduk had only one grain per square meter (Table 3). Among the cultivars Banteng produced the fewest pods at the

Table 3: Means Grain Weight, Grain Number / m^2, and Grain / Pod

Cultivar	Grain			Grain Number/m^2			Grain/Pod		
	lime (kg/ha)								
	0	500	2000	0	500	2000	0	500	2000
	(g/grain)								
Anoa	0.2	0.3	0.3	7	97	151	0.7	1.3	1.5
Banteng	0.2	0.4	0.4	1	48	138	0.1	1.2	1.8
Gajah	*	0.4	0.4	*	66	132	*	1.3	1.6
Pelanduk	0.1	0.4	0.5	1	86	111	0.3	1.2	1.4
Rusa	0.1	0.3	0.2	5	154	232	0.9	1.5	1.7
Tapir	0.1	0.4	0.4	6	72	139	1.1	1.1	1.5
Tuban	*	0.3	0.4	*	96	156	*	1.3	1.9
Tupai	*	0.4	0.5	*	73	134	*	1.1	1.3

* no pod was obtained from these treatments.

highest lime level, while the Gajah cultivar produced the least grain. The reproductive ability of Banteng peanut seemed to be the most sensitive to drought-induced Ca deficiency while Rusa was the least sensitive. Among the cultivars Rusa produced the most pod and grain per square meter in the low Ca and drought conditions of the experiment (Table 4). At 500 kg lime/ha Rusa produced the most pods and grain while Banteng produced the least. Rusa also produced the highest numbers of pods and grain at 2000 kg lime/ha.

All the peanut cultivars produced more haulm with increasing lime (Table 5). At the no lime and 500 kg rates Pelanduk produced the highest haulm, but at 2000 kg Banteng yielded more. Except for Anoa peanut, at 500 kg lime/ha, haulm increased significantly with increasing lime. Higher lime rates further increased the haulm of all cultivars except for the Tuban cultivar which was slightly decreased. With these two exceptions there was no significant difference in the haulm production among the

Table 4: Means Fresh and Dry Weight of Pod and Pod Number per Square Meter

Cultivar	Fresh pod			Dry pod			Pod number/m^2		
	lime (kg/ha)								
	0	500	2000	0	500	2000	0	500	2000
		(g)							
Anoa	0.8	1.2	1.3	0.3	0.6	0.7	10	73	102
Banteng	2.0	1.8	2.0	0.8	0.8	1.0	4	39	78
Gajah	*	1.6	1.7	*	0.8	1.0	nil	52	85
Pelanduk	0.5	1.9	1.8	0.2	0.9	1.0	4	70	81
Rusa	0.3	1.2	1.1	0.1	0.6	0.5	5	102	137
Tapir	0.5	1.5	1.6	0.2	0.7	0.9	5	66	91
Tuban	*	1.7	1.9	*	0.7	1.1	nil	72	83
Tupai	*	1.8	1.7	*	0.8	0.9	nil	67	100

cultivars within the same lime rate. However, there seemed to be different lime requirements among the cultivars for maximum vegetative growth. Haulm yield of the Pelanduk, Rusa, Tapir and Tuban cultivars did not increase significantly when lime was increased from 500 kg/ha to 2000 kg/ha, but still increased significantly for the cultivars Anoa, Banteng, Gajah and Tupai.

Although no significant pod or grain yield was produced at no lime treatment, Anoa, Rusa and Tapir had significantly higher shelling percentage of 49.6 %, 55.3 % and 57.4 %, respectively. These three cultivars also had the highest number of pods per square meter. With only 0.22 $cmol_c/kg$ exchangeable Ca on this treatment and the

Table 5: Peanuts Haulm and Shelling Percentage

Cultivar	Dry haulm			Shelling Percentage		
	lime (kg/ha)					
	0	500	2000	0	500	2000
	(kg/ha)			(%)		
Anoa	861	882	1281	49.6	66.9	66.4
Banteng	795	954	1663	22.0	51.3	53.7
Gajah	580	909	1491	0.0	64.6	70.8
Pelanduk	913	1255	1533	21.1	60.9	66.9
Rusa	550	938	1129	55.3	67.8	67.4
Tapir	621	1135	1416	57.4	55.4	70.2
Tuban	476	1112	1033	0.0	52.8	72.0
Tupai	479	814	1648	0.0	55.1	62.2

$LSD_{0.05}$ for main effects:
(lime) 316 (Cultivar) 398 (lime) 23.0 (cultivar) 29.6

drought condition the three cultivars probably require less Ca for pod filling. Wolt and Adams (1979) reported that higher Ca was required for pod filling than for flowing and vegetative growth.

Yield Response to Al Saturation

Exchangeable Ca and Al, Ca and Al saturation as well as Ca+Mg saturation were significantly correlated with grain and pod (data not shown). Increasing soil Ca increased peanut haulm while soil Al had adverse effects. Aluminum saturation, Ca saturation or Ca+Mg saturation produced the highest R^2 when regressed against pod or grain yields (data not shown).

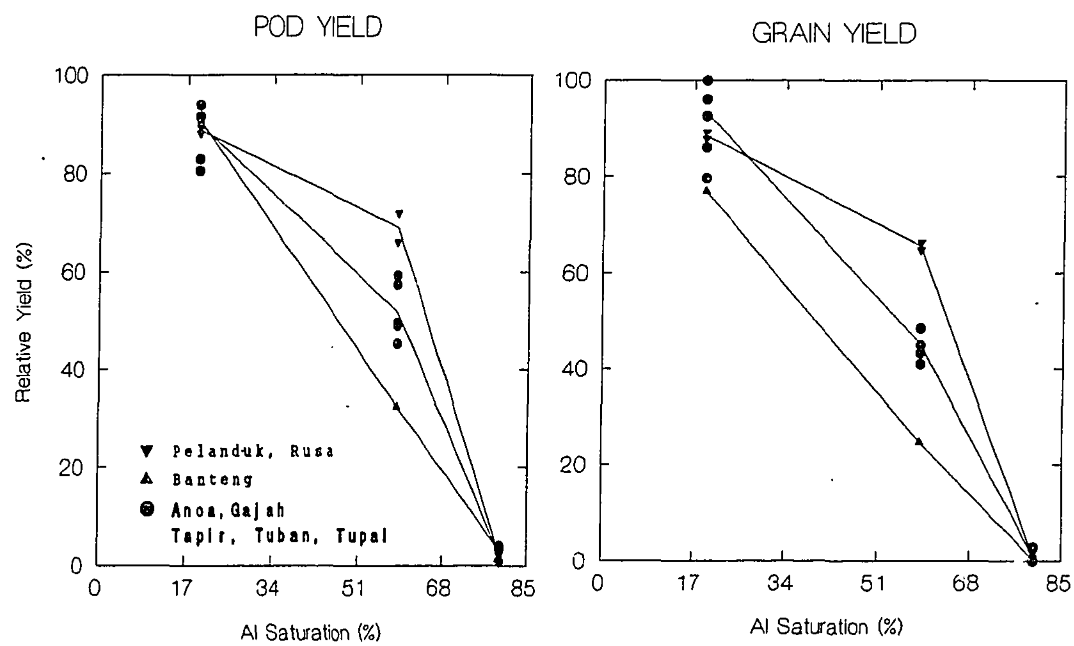


Figure 3: Relative Pod and Grain Yields as Affected by Al Saturation

The critical Al saturation for peanut has been estimated to be 40% (Yost *et al.*, 1987). But since in the earlier experiments only Tuban or Gajah cultivars were tested

(Agus *et al.*, 1985; Wade and Santoso, 1985; Gill and Kamprath, 1985; Gill *et al.*, 1986; Evensen, 1989), it is interesting to see the relation of Al saturation to the performance of the other cultivars.

At a 5% significant difference level of the relative yields, the cultivars can be grouped into 3 distinct responses. Cultivar Banteng was the most acid sensitive, while Pelanduk and Rusa were the least sensitive. The other five cultivars including Tuban and Gajah were intermediate. In Figure 3, relative yield of pod and grain was plotted against topsoil Al saturation. The smoothed lines in the figure were obtained by using Robust locally weighted regression method (Cleveland, 1979). As seen in the figure the critical Al saturation of Banteng at this drought stress condition was probably less than 40 % while for Pelanduk and Rusa it was probably far higher. These critical Al saturations will certainly differ when soil moisture is more favorable for peanut pegging and pod development. More precise critical Al saturations for those peanut cultivars that lay between 20 and 60 % can be determined if more points were available.

Effects of Lime and Cropping on Selected Soil Chemical Properties

Residual Lime

Soil pH and Aluminum

Because of high rainfall, lime applied to acid soils in the humid tropics is not expected to last long. Yet, soil data taken 29 months after lime application indicated that the lime continued to have positive effects. The higher the rate of the lime applied previously, the higher the soil pH and exchangeable Ca and the lower the extractable Al. Soil pH, extractable aluminum and exchangeable Ca of the top 30 cm of different lime rates for periods between 11 to 42 months after lime application are presented in Table 6. The 0-15 cm layer data taken at 29 to 42 months are average values of 0-7.5 and 7.5-15 cm layers.

For all treatments soil pH varied very little when measured 29 months after lime application. Forty two months after the lime was applied only the pH in surface 0-15 cm layer of the high lime treatment remained above 5. The pH of the medium lime treatment was still slightly higher than the pH of the low lime treatment.

Soil extractable Al increased with time but the increase was higher after the rice crop compared to after the peanut crops. The increase was particularly high in the low lime plot after rice harvest. In the medium and high lime treatments the increase in extractable Al was always higher in the top 0-15 cm than in the 15-30 cm layer. After almost four years, the medium lime rate of 2.25 ton/ha maintained relatively low extractable aluminum. But in the low lime treatment the extractable aluminum already exceeded the initial value.

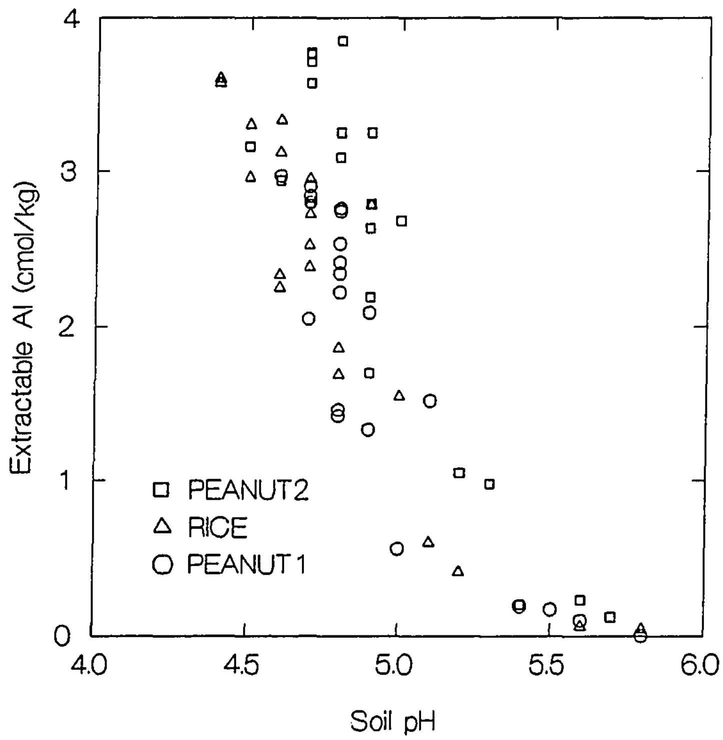


Figure 4. Relationship between Topsoil pH and Extractable Al

Soil pH and extractable Al negatively correlated particularly in the surface soil as shown in Figure 4. At soil pH above 5.0 extractable Al was about 1.00 $cmol_c/kg$ or less and above pH 5.5 the value was less than 0.30 $cmol_c/kg$. Soil pH can be a good indicator on the aluminum status of this soil. It seems aluminum will rarely become a problem to plants when the soil pH is 5.5 or higher.

Table 6: Soil pH, aluminum and calcium at two depths as affected by lime and cropping, at Sitiung I

Lime Rate	Soil Depths	Months after lime application 11*	29	33	38	42
		-----previous crop-----				
			fallow**	peanut	rice	peanut
(kg/ha)	(cm)					
			pH			
375	0-15	4.4	4.73	4.73	4.50	4.70
	15-30		4.74	4.60	4.58	4.60
2250	0-15	4.7	5.00	5.05	4.80	4.85
	15-30		4.80	4.80	4.70	4.70
6500	0-15	5.0	5.32	5.15	4.95	5.10
	15-30		4.81	4.90	4.70	4.75
$LSD_{0.05}$	(lime)		0.23	0.40	0.32	0.50
		Extractable Al ($cmol_c$/kg)				
375	0-15	2.29	2.72	2.91	3.55	3.86
	15-30	2.33	2.44	2.76	3.12	3.62
2250	0-15	1.33	1.74	1.76	1.91	2.06
	15-30	2.21	2.25	2.29	2.37	2.38
6500	0-15	0.31	0.73	0.83	1.43	1.51
	15-30	1.85	2.02	2.12	2.00	2.07
$LSD_{0.05}$	(lime)		0.36	0.62	1.24	1.50
		Exchangeable Ca ($cmol_c$/kg)				
375	0-15	1.02	0.92	0.77	0.73	0.60
	15-30	0.47	0.55	0.50	0.50	0.43
2250	0-15	2.28	1.99	1.87	1.84	1.63
	15-30	0.57	0.77	0.76	0.71	0.64
6500	0-15	5.09	4.51	4.08	4.00	3.85
	15-30	0.61	1.15	1.54	1.55	1.59
$LSD_{0.05}$	(lime)		0.40	0.48	0.27	0.60

* Data from Gill (1988)

** the plots were planted with maize,peanut,cowpea and mungbean then left fallow for several months. Soil samples were taken before planting each crop.

Soil Calcium

Surface soil exchangeable Ca decreased steadily with time. In the high lime treatment there was indication of Ca movement from the 0-15 cm layer to 15-30 cm layer (Table 6). This was more pronounced during the first peanut crop where exchangeable Ca in 15-30 cm layer increased from 1.15 $cmol_c/kg$ before planting to 1.54 $cmol_c/kg$ after harvest. The application of kieserite probably supplied the soil with SO_4^{2-} that formed uncharged ion pairs with Ca (Adams, 1971). These uncharged ion pairs may have facilitated Ca movement by moving down with percolated water. In the last sampling 42 months after lime application the exchangeable Ca in the 15-30 cm layer of the high lime plot was 1.59 $cmol_c/kg$, an increase of almost four-fold from its initial 0.4 $cmol_c/kg$ before the lime was applied (Table 2).

The medium rate of 2.25 ton lime/ha maintained relatively high exchangeable Ca. The high lime treatment further improved the subsoil by increasing exchangeable Ca and reducing extractable Al. Where the lowest amount of lime (375 kg/ha) was applied exchangeable Ca returned to the initial values. As presented in Table 2, the exchangeable Ca was initially 0.5 and 0.4 $cmol_c/kg$ in the 0-15 cm and 15-37 cm layers, respectively.

Effective Cation Exchange Capacity

Highly weathered mineral soils in the tropics commonly have low effective cation exchange capacity (ECEC), therefore increasing the ECEC is an important management goal. Because of the predominant pH dependent charge, ECEC can be increased by liming through deprotonation of surface hydroxyls. Phosphate or silicate amendments also increase the negative charge thus shifting the zero point of charge to lower pH values (Keng and Uehara, 1974).

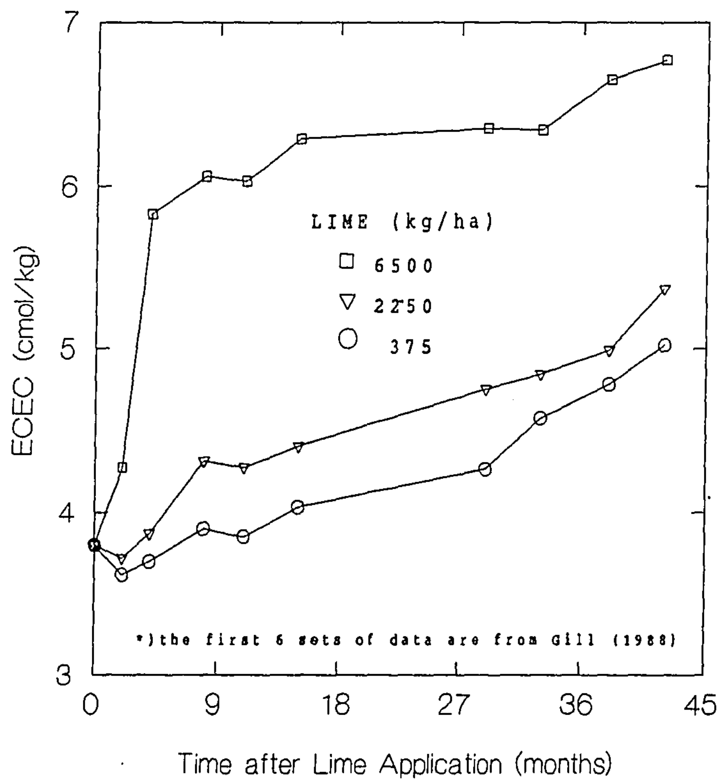


Figure 5. Changes in Effective Cation Exchange Capacity with Time after Lime Application

Effective cation exchange capacity (ECEC) in the 0-15 cm layer of the soil surface was increased by lime treatment and with time (Figure 5). But relatively little increase was observed in low and medium lime treatments. Juo and Balloux (1977) working with Nigerian soil, reported that most of the applied lime below 3 ton/ha was consumed in neutralizing the exchangeable Al and thus had little effect in increasing charge.

Long after lime application, even in the low lime treatment, the ECEC continued to increase. Continuous application of phosphate along with other highly sulfated fertilizers may have contributed to this improvement (Mekaru and Uehara, 1972; Wann and Uehara, 1978: Bolan *et al.*, 1988; Marcano-Martinez and McBride, 1989). In the low lime plot ECEC increased from initial 3.84 $cmol_c/kg$ before the lime was applied to 5.02 $cmol_c/kg$ 42 months later. While in the medium and high lime plots the ECEC increased to 5.37 and 6.77 $cmol_c/kg$, respectively.

Soil Potassium

Soil potassium was low initially. Only 0.14 $cmol_c/kg$ was found in the 0-15 cm layer and 0.05 $cmol_c/kg$ in the 36-68 cm layer (Table 2). The application of different rates of K and lime in the previous experiment increased exchangeable K. But K removal by the crops confounded the effect of lime on soil K.

Where 0 and 20 kg/ha of K was applied, exchangeable K in the 0-15 cm layer decreased to less than the initial value, but increased slightly in the 30-50 cm layer. Probably more K was removed by the previous crops than that applied. Application of 20 kg/ha K for each maize and peanut crop seemed inadequate when followed with unfertilized mungbean and cowpea crops.

At 80 kg K/ha a substantial increase of in the topsoil exchangeable K was observed in the high lime treatment. Almost no change was seen in the medium lime. Exchangeable K in the low lime treatment decreased to less than the initial value. The exchangeable K in the 0-15 cm layer of the 240 kg K/ha treatment increased to about twice the initial value in the low lime treatment and to about three times in the high lime treatment.

The greatest changes in K due to liming were a decrease in intensity factor and an increase in buffer capacity. A decrease in intensity is due to both a decrease in activity of K and an increase in activity of Ca+Mg while an increase in buffer capacity may be due to replacement of Al by Ca and Mg with later replaced by K, and an increase in the net charge due to increasing pH (Goedert *et al.*, 1975).

The relatively high yield of maize on the high lime treatment probably removed more K from the soil than the low lime treatment. Maize grain in two harvests removed about 21 kg K/ha compared to only 12 kg/ha in the low lime treatment. Potassium concentration was higher in the stovers of the high lime treatments. Maize stover in the low lime treatment contained 4.3 and 7.7 g K/kg in the first and second crop respectively as compared to 6.3 and 8.5 g K/kg in the high lime treatment. At higher lime rates, K uptake was less limited by Al and the crop was able to utilize soil K more efficiently. However, in contrast to maize there was no difference in the K uptake by peanut crops for the different rates of lime. Although the yield was lower in the low lime treatment the K content in both pod and grain was higher resulting in similar K uptake (Gill, 1988).

Although more K was removed by the plant with the higher lime rates, when K fertilizer was applied, the medium and high lime treatments retained more K in the top 15 cm layer but less in the subsoil. However, as shown in Figure 6, in all K rates the exchangeable K of the 30-50 cm layer exceeded the initial value. This suggests that K leaching occurred. The leaching was apparently reduced in the medium and high lime treatments. The high rainfall in the Sitiung area probably has promoted K leaching.

Increasing cumulative rainfall from 25 to 150 mm reduced exchangeable K in the top 0-5 cm of high K fertilized pasture (Ayarza *et al.*, 1987).

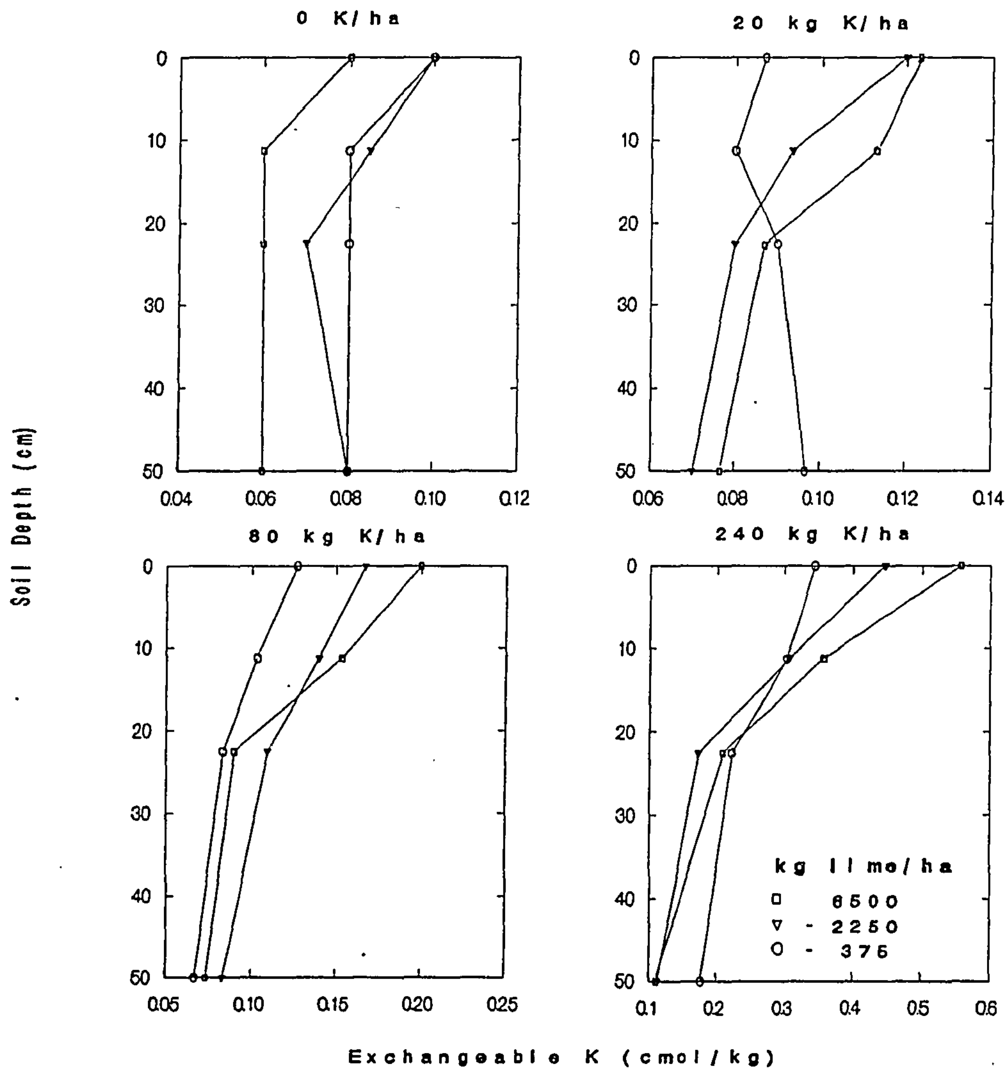


Figure 6: Soil Exchangeable K within the Top 50 cm as Affected by Liming

Peanut roots are highly efficient in utilizing K from subsoil (Cox *et al.*, 1982). This also might have contributed to the lower exchangeable K of the subsoil in the higher lime treatments. Peanut response to K fertilization is unlikely, unless the previous crop had exhausted the subsoil K (Cox *et al.*, 1982). Gill (1988) reported no yield response to K in the first peanut crop but observed yield response in the second peanut crop, which was the fifth in the crop rotation. Considerable quantities of K were extracted from the soil because all crop residues were removed at harvest.

Soil Phosphorus

There was no soil phosphorus data collected before the application of P fertilizer. But P of Sitiung soils are generally very low. Wade *et al.* (1987) reported that native available P of Sitiung soils as determined by modified Olsen was less than 5 mg/kg. While McIntosh *et al.* (1982) reported the value of 2 mg/kg using the Bray-2 P method. A total of 230 kg P/ ha as Treble Super Phosphate (TSP) was applied during the previous experiment. Twenty kg P was last applied about a year before soil samples were taken.

Extractable P remained high in the soil even after six crops had been harvested during a little over 2 years. On higher lime treatments, extractable P remained lower P throughout the profile. The differences were more pronounced in the surface 0-15 cm.

Liming acid soil to pH above 6.0 may increase P fixation because of formation of insoluble Ca-phosphates (Sanchez and Uehara, 1980). Even in the high lime treatment the soil pH was not high enough to suspect lime-induced P fixation. Higher yields of the previous crops in the high lime treatment has removed more P. Consequently the extractable P in the 0-15cm was lower.

The levels of extractable P in the top 7.5 cm layer were 16; 33 and 42 mg/kg from high, medium and low lime treatments respectively. These values were well above the critical level of 7 mg/kg for peanut response to P fertilization as suggested by Cox and coworkers (1982).

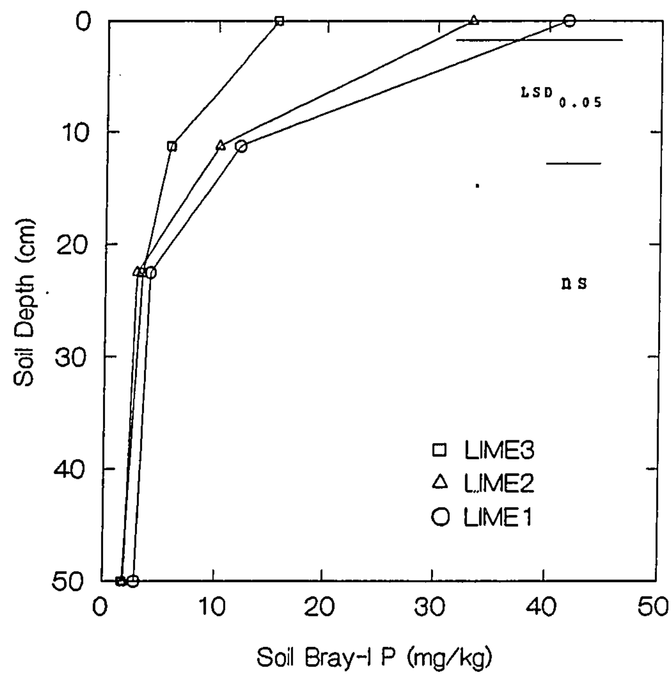


Figure 7: Soil Bray-1 P as Affected by Liming

Soil Sulfate-S

Applying TSP and kieserite adds considerable SO_4^{2-} to the soil. But unlike phosphate, sulfate ion is weakly held on the soil surface, and, therefore, more susceptible to leaching (Barrow, 1978). In both medium and high lime treatments a significant decrease was observed in surface soil SO_4^{2-} S and a significant increase in the subsoil SO_4^{2-} S from 29 months to 42 months after lime application. After the second peanut harvest (42 months) the surface soil SO_4^{2-} S was almost zero in the higher lime treatments although 150 kg/ha kieserite had been applied 12 months earlier. But in the low lime treatment the SO_4^{2-}-S level remained about the same. This indicates that higher sulfate movement occurred in the higher lime treatments. Therefore, the higher the lime rate, the less SO_4^{2-}-S was found in the surface soil but more in the subsoil.

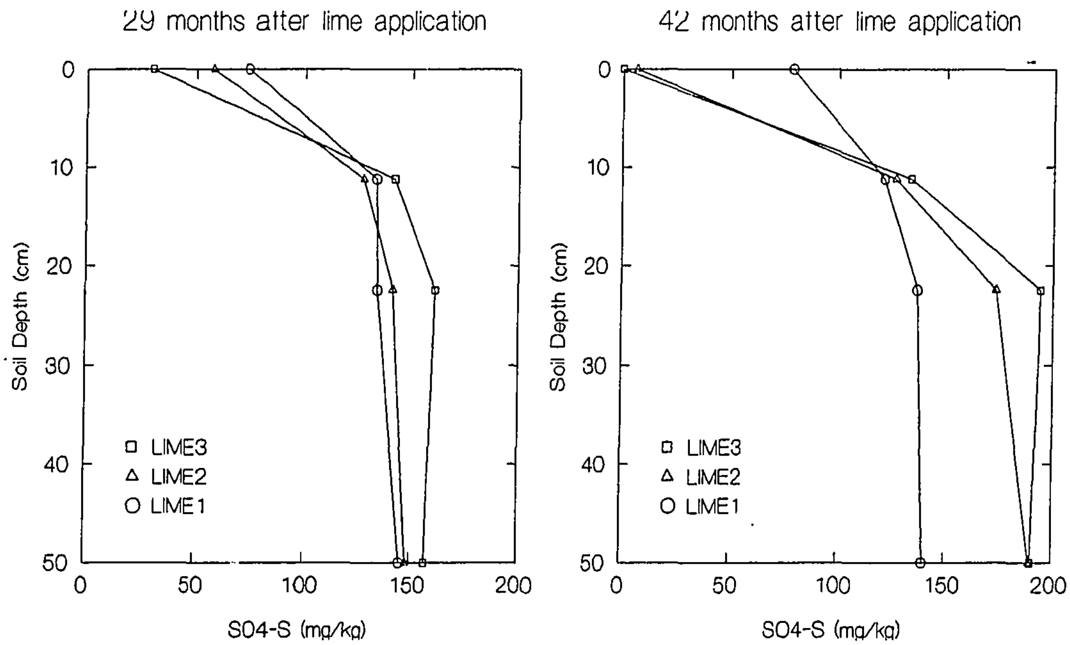


Figure 8: Soil SO_4^{2-}-S as Affected by Liming

Sulfate mobility in soils is affected by several factors that include 1) solution concentration of sulfate, 2) time of contact between sulfate solution and adsorbent, 3) temperature, 4) solution pH, 5) other ionic species present and 6) type of adsorbent (Gaston *et al.*, 1986). The first three and the last of these factors in the experiment soil initially were similar in all lime treatments because the same amount of TSP and kieserite were applied as basic fertilizers. But higher soil pH and soil calcium (Couto *et al.*, 1979; Edmeades, 1982; Marsh *et al.*, 1987) and lower Al (Chao *et al.*, 1963) due to liming apparently reduced sulfate sorption. Bolan *et al.* (1988) reported that lime induced the leaching of sulfur by desorption of absorbed sulfate or by the mineralization of organic sulfur. By increasing both soil pH and soil Ca and also reducing extractable Al both medium and high lime treatments probably enhanced the sulfate leaching.

Peanut response to S fertilization has been reported when the soil total sulfur was lower than 75 mg/kg (Laurence *et al.*, 1976). Application of sulfur as fertilizer or fungicide has increased both grain yield and protein content. The availability of sulfate presumably has lifted constraints upon S-amino acid production. Because the soil SO_4^{2-}-S in all lime treatments exceeded 75 mg/kg, sulfur was probably not limiting to either peanut crops.

Exchangeable Magnesium

Soil exchangeable Mg, which was initially only 0.1 $cmol_c/kg$, increased after heavy application of kieserite in the earlier experiment (Gill, 1988). Exchangeable Mg remained high when another 150 kg kieserite was applied in April 1987. This last application increased the exchangeable Mg, which later decreased after the rice and second peanut harvests (Figure 9).

The previously applied lime seemed to result in increased Mg retention in the surface horizon after the first cropping cycle despite low level of Mg of the lime material (Gill, 1988). As presented in Figure 9, exchangeable Mg in the surface horizon was significantly lower in low lime plots as compared to the medium and high lime plots in the second crop rotation. After the second cropping cycle the difference between

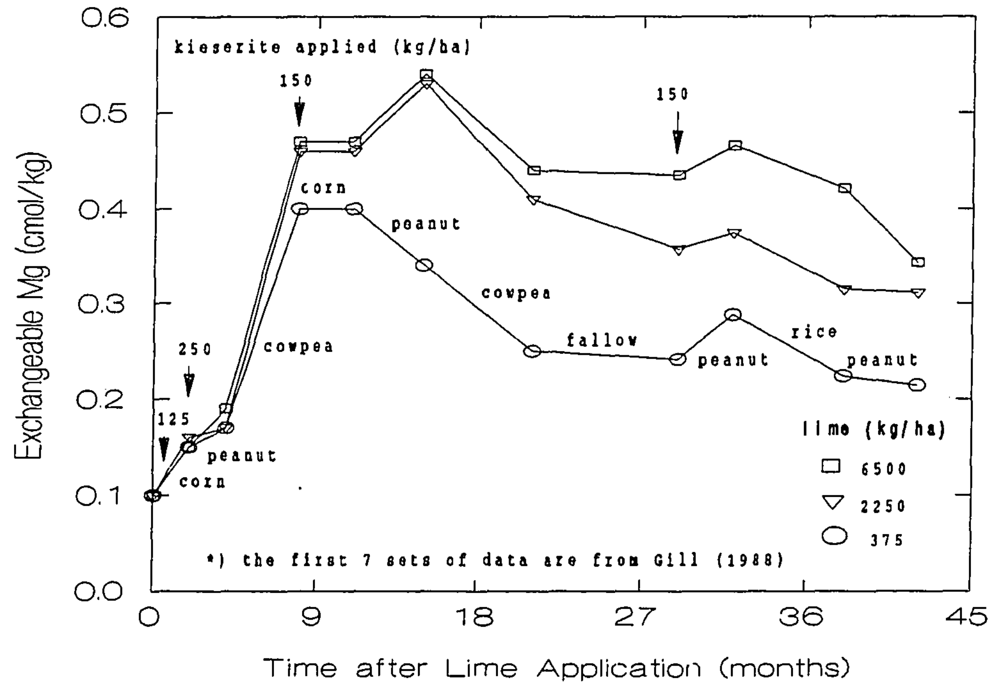


Figure 9: Changes in Soil Exchangeable Mg in 0-15 cm Layer

medium and high lime became more pronounced. Prior to the last application of kieserite, the high and medium lime treatments retained 0.19 $cmol_c/kg$ and 0.13 $cmol_c/kg$ more Mg respectively, as compared to the low lime treatment.

The higher crop yields of the higher lime treatments would be expected to remove more Mg from the soil. Calculation from Gill (1988) experiment shows that two crops of maize and peanut took up about 10 kg Mg/ha in the grain of the high lime plots as compared to only about 5 kg of the low lime plots. Since the same amount of kieserite was applied and there was little Mg in the lime material, the lower values of exchangeable Mg in the lower lime treatments was probably due to loss of Mg by leaching.

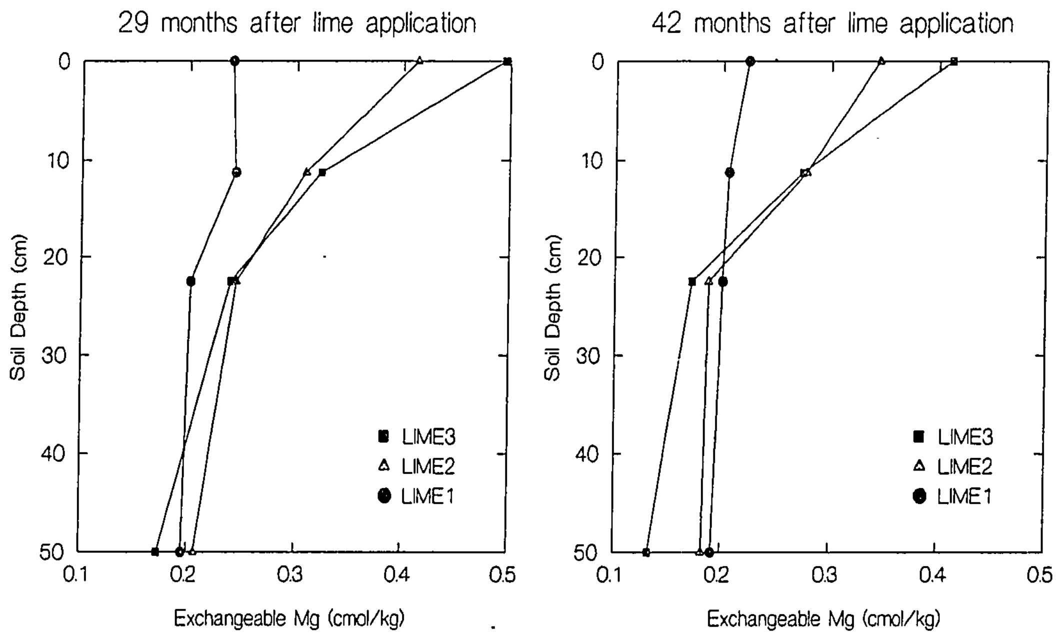


Figure 10: Soil Exchangeable Mg in the Top 50 cm as Affected by Lime

Measurement of exchangeable Mg within the top 50 cm also suggested the movement of Mg from topsoil to subsoil layers. As can be seen in Figure 10, by 29 months after lime application and where 525 kg/ha kieserite had been applied, the exchangeable Mg in the 15-30 cm and 30-50 cm layers in all residual lime treatments already exceeded the initial 0.1 $cmol_c$/kg before kieserite was applied. In some cases applied Mg has apparently moved down. The lower the lime application the more Mg was moved to the subsoil.

The application of 24 kg Mg/ha before the first peanut crop seemed to be sufficient to supply the Mg requirement of one rice and two peanut crops. Very little decrease in the surface soil exchangeable Mg was observed in the low lime treatment from prior to the first peanut crop planting to the harvest of the second peanut crop. However, a greater decrease in Mg was found in the higher lime treatments (Figure 10). The higher yields in the higher lime treatments apparently absorbed more Mg.

The topsoil exchangeable Mg remained sufficiently high for crop nutrient requirements during the rice and last peanut crops. In all lime rates the value was over 0.21 $cmol_c/kg$. This value was suggested as a critical value for peanut response to Mg fertilization on Sitiung soils (Gill *et al.,* 1985). Working with local peanut in two rice-peanut crop rotations Gill *et al.,* (1985) concluded that the critical level of exchangeable Mg for peanut was around 0.21 $cmol_c/kg$. They also found that maize-soybean cropping sequence requires higher Mg than a rice-peanut sequence even though the peanut produced a higher grain yield than the soybean. Peanut is thought to be very efficient in extracting Mg from the soil, and consequently, response to Mg fertilization was rarely reported (Cox *et al.*, 1982).

Freshly Applied Lime

Soil Calcium

The second lime application in April 1987 significantly increased Ca (Table 7) but did not seem to affect the soil pH (data not shown). The soil exchangeable Ca in the 0-

7.5 cm layer increased with increasing rate of lime (Table 7). When the lime was applied deeper the exchangeable Ca at 7.5 to 15 cm layer was also increased. Slightly higher Ca was observed in the 15 to 30 cm layer of the deep incorporated lime treatment. With the 1000 kg/ha rate, the surface broadcast application resulted in higher Ca in the 0-7.5 layers but lower Ca in the 7.5-15 cm layer. However, there seemed to be no difference between the exchangeable Ca in the deep and shallow incorporated lime.

Table 7: Soil Exchangeable Ca ($cmol_c/kg$) as Affected by Fresh Lime Ttreatments after Each Crop Harvest

Soil Depth	New lime applied (kg/ha) 0	375b*)	375s*)	1000b*)	1000s*)	1000d*)
(cm)	After First Peanut Harvest					
0-7.5	0.93	1.54	1.22	2.44	1.78	1.69
7.5-15	0.82	0.85	0.93	0.98	1.60	1.54
15-30	0.75	0.77	0.77	0.75	0.81	0.97
30-50	0.71	0.63	0.62	0.53	0.50	0.59
$LSD_{0.05}$	(lime)	0.35		(depth)	0.31	
	After Rice Harvest					
0-7.5	0.85	1.14	1.07	1.90	1.50	1.23
7.5-15	0.69	0.81	0.69	1.10	1.50	1.53
15-30	0.56	0.59	0.61	0.73	0.80	0.81
30-50	0.44	0.53	0.70	0.60	0.44	0.74
$LSD_{0.05}$	(lime)	0.14		(depth)	0.33	
	After Second Peanut Harvest					
0-7.5	0.70	0.99	0.96	1.80	1.31	0.92
7.5-15	0.44	0.74	0.62	1.14	0.94	1.16
15-30	0.52	0.69	0.55	0.64	0.64	1.04
30-50	0.41	0.51	0.46	0.38	0.59	0.65
$LSD_{0.05}$	(lime)	0.47		(depth)	0.27	

*) b=surface broadcast, s=shallow (10-15 cm), d=deep (20-25 cm)

The soil exchangeable Ca in the top 15 cm layer decreased after the rice and the second peanut harvest. The Ca depletion was probably due to plant uptake during the three croppings. The haulm of peanut harvested in 1985 on this soil contained 15.8 kg/ha Ca on the low lime treatment and as high as 41.7 kg/ha in the high lime treatment. But only 5.3 kg/ha Ca and 18.5 kg/ha Ca was removed from low and high lime treatments, respectively, in the haulm of 1986 peanut harvest (Gill, 1988). However, a slight increase was observed in the 7.5 to 15 cm layer of the surface broadcast 1000 kg/ha treatment. The increased Ca in the 7.5 to 15 cm layer was probably because of Ca movement from the 0-7.5 cm to 7.5-15 cm layer.

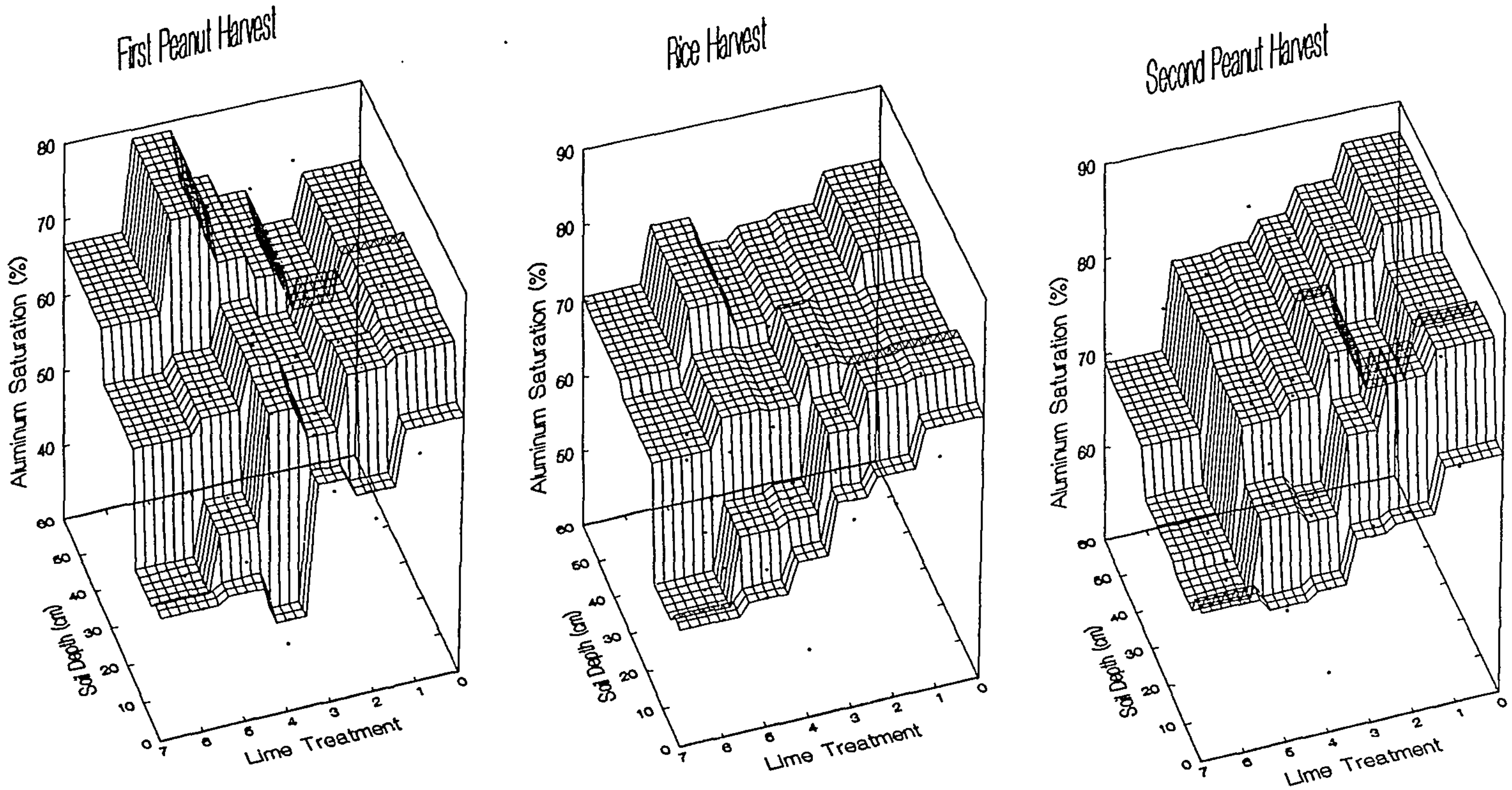
Evidence of Ca leaching to the deeper layer was only seen where 1000 kg/ha was deeply incorporated 15 months after lime application. On this same soil Gill (1988) earlier reported that after 11 months Ca in the medium lime rate treatment moved down to 30 cm depth, while in the high lime treatment the Ca moved further down to 50 cm depth. A similar observation was reported when 1 or 2 ton lime/ ha were applied on Typic Acrorthoc at Manaus, Brazil (Cravo and Smyth, 1987).

Movement of Ca into the subsoil has been reported to occur within several years when high rates of lime have been combined with high rates of fertilizers on highly weathered, low base soils (Pearson *et al.*, 1962; Ritchey *et al.*, 1980; Farina and Chanon, 1988). However, moderate levels of lime were found to improve subsoil acidity on an Ultisol of the Amazon Basin after eight years continuous cultivation (Sanchez *et al.*, 1982). Friesen and coworkers (1982) reported a movement of Ca downward to 90 cm depth 3 years after application of the more soluble $Ca(OH)_2$ on an Ultisol of Nigeria. High rainfall in the Sitiung area coupled with soil tillage and application of high sulfated kieserite fertilizer probably facilitated Ca movement in the soil. Juo and Ballaux (1977) in a leaching experiment reported 1% of added Ca to a Nigerian Ultisol had moved beyond 30 cm depth in 10 weeks when watered with an equivalent to 455 to 860 mm rainfall. Soil tillage enhanced downward movement of Ca on dolomitic limestone and gypsum treated Ultisol at Yurimaguas, Peru (Gichuru *et al.*, 1987).

Aluminum Saturation

The fresh lime also reduced soil Al saturation. The reduction of soil Al saturation by the freshly applied lime in plots that previously received only 375 kg lime/ha is presented in Figure 11. After the first peanut harvest Al saturation in the surface 0-7.5 cm layer ranged from 39 % from the surface broadcast 1000 kg lime/ha plot to 64 % in the control plot. Lime reduced Al saturation considerably at least in the 0-7.5 cm layer when surface applied and further to 7.5 to 15 cm layer when incorporated. But 9 months after application the surface broadcast 1000 kg lime/ha also reduced Al saturation in the 7.5-15 cm layer. When 1000 kg lime/ha was incorporated either shallow or deep, the Al saturation in the 15-30 cm layer was also decreased.

The depth of incorporation probably affected Al saturation within this layer as seen in the higher exchangeable Ca with the deeply incorporated lime compared to shallow incorporation (Table 6), however, the difference may not be reflected in the data because the soil samples were taken in 15 cm increments. The application of 1000 kg lime/ha either surface broadcast or incorporated, maintained a relatively low Al saturation in the soil surface at least 13 months after application. However, the Al saturation of the 375 kg lime/ha treatments returned to or exceeded the value before the fresh lime was applied.



1 = no lime 2 = 375 surface broadcast 3 = 375 shallow
4 = 1000 surface broadcast 5 = 1000 shallow 6 = 1000 deep

Figure 11: Soil Aluminum Saturation at Residual of 375 kg/ha Lime Plots after Each Crop Harvest

Exchangeable Potassium

Considerable residual K remained in the soil after the first peanut crop. Exchangeable K in the surface 7.5 cm of soil varied from 0.36 $cmol_c/kg$ in the surface broadcast of 1000 kg lime/ha to 0.43 $cmol_c/kg$ in the control plot. In the 30-50 cm layer K varied from 0.17 $cmol_c/kg$ in the shallow incorporated 1000 kg lime/ha to 0.25 $cmol_c/kg$ in the deeply incorporated 1000 kg lime/ha. Contrary to the first lime treatments, no significant effect of the second lime application was seen on soil exchangeable K probably due to the lower rate .

The relatively high K application before peanut planting eliminated the range of soil K due to K treatments in Gill (1988) experiment (data not shown). As expected there was no significant difference in the exchangeable K of the plots that previously received a low rate of lime, although the plots were fertilized 4 times with KCl that ranged from 0 to 240 kg K/ha. Prior to K application the exchangeable K in the plots that previously received 240 kg K/ha was significantly higher than those received 80 kg K/ha or less (Figure 6).

The residual K after the first peanut harvest was sufficiently high for the following rice crop. Although no K was applied before planting, relatively high yields were obtained by the following rice crop. Gill (1988) reported that critical exchangeable K for rice was between 0.16 to 0.20 $cmol_c/kg$. After the first peanut harvest the exchangeable K of the top 7.5 cm layer in all lime treatments was about twice these critical values.

The rice crop extracted substantial K from the soil. Except in the shallow incorporated, 375 kg/ha lime treatment, after the rice harvest the topsoil exchangeable K was about one half the value before planting. Sentani rice grown in Sitiung contained between 2.6 to 3.0 g K/kg grain and between 14.7 to 15.9 kg K/kg straw (Gill, 1988). The exchangeable K in the subsoil was also decreased which was probably due to K leaching.

Table 8: Soil Exchangeable Potassium ($cmol_c/kg$) after Each Crop Harvest

Soil Depth	Fresh lime applied (kg/ha)					
	0	375b*)	375s*)	1000b*)	1000s*)	1000d*)
(cm)						
			After the First Peanut Harvest			
0-7.5	0.43	0.42	0.40	0.36	0.41	0.40
7.5-15	0.26	0.30	0.38	0.27	0.27	0.38
15-30	0.20	0.27	0.23	0.21	0.19	0.25
30-50	0.20	0.22	0.22	0.18	0.17	0.25
	$LSD_{0.05}$	(lime)	0.24	(depth)	0.07	
			After Rice Harvest			
0-7.5	0.18	0.20	0.28	0.17	0.21	0.20
7.5-15	0.13	0.15	0.20	0.12	0.14	0.11
15-30	0.11	0.15	0.15	0.10	0.12	0.08
30-50	0.10	0.15	0.23	0.11	0.11	0.10
	$LSD_{0.05}$	(lime)	0.27	(depth)	0.07	
			After the Second Peanut Harvest			
0-7.5	0.24	0.18	0.23	0.15	0.22	0.17
7.5-15	0.12	0.12	0.13	0.11	0.15	0.10
15-30	0.08	0.06	0.10	0.07	0.10	0.05
30-50	0.06	0.05	0.14	0.03	0.07	0.04
	$LSD_{0.05}$	(lime)	0.24	(depth)	0.10	

*) b=surface broadcast, s=shallow (10-15 cm), d=deep (20-25 cm)

No significant change was noted in residual K in the topsoil after the second peanut harvest although 20 kg K/ha had been applied before planting. However, in the 15 to 50 cm layer the exchangeable K decreased in all lime treatments. The decrease could be due to both the efficient K utilization of the deep-rooted peanut (Cox *et al.*, 1982) and K leaching. Gill (1988) reported that each ton of peanut contained 6.3 kg and

15.0 kg of K in the fruit and haulm, respectively. If the second peanut crop contained a similar amount of K, an application of 20 kg K/ha was insufficient for the peanut in this soil because some of the haulm yields were as high as 8 tons.

Exchangeable Magnesium

A relatively high level of Mg remained in the soil after the first peanut harvest. The application of 24 kg Mg/ha as basal fertilizer before planting supplied the peanut with sufficient Mg and increased the soil Mg as well. In all lime treatments, the topsoil exchangeable Mg increased from 0.24 $cmol_c/kg$, the value before kieserite was applied, to as high as 0.35 $cmol_c/kg$ in the surface broadcast 375 kg lime/ha and shallow incorporated 1000 kg lime/ha. The exchangeable Mg in the top 7.5 cm was significantly higher than the exchangeable Mg in all the lower layers except in the deeply incorporated 1000 kg/ha lime treatment. The relatively low rainfall during the first peanut crop probably did not leach much Mg from the surface soil.

Exchangeable Mg in the topsoil decreased after the rice crop and but very little decrease after the second peanut crop. An increase of exchangeable Mg in the subsoil was observed in some of the treatments after rice harvest indicating that leaching might have occured. But, after the peanut harverst the subsoil exchangeable Mg decreased in all treatments. This probably indicated that the shallow-rooted rice absorbed most of the Mg from the topsoil but the deep-rooted peanut absorbed more Mg from the subsoil.

Gill (1988) reported that peanut fruit contained higher Mg compared to rice grain but about the same content in peanut haulm and rice straw. Higher yields of rice grain and straw probably removed more Mg from the soil. The topsoil exchangeable Mg after the second peanut harvest was slightly lower than the value before kieserite was applied to the first peanut crop. This probably indicates that the soil will require another Mg fertilization after about three crops have been harvested.

Table 9: Soil Exchangeable Mg ($cmol_c/kg$) after Each Crop Harvest

Soil Depth	Lime Applied (kg/ha)					
	0	375b	375s	1000b	1000s	1000d
(cm)						
	After First Peanut Harvest					
0-7.5	0.34	0.35	0.30	0.32	0.35	0.31
7.5-15	0.22	0.25	0.24	0.20	0.30	0.28
15-30	0.19	0.21	0.23	0.19	0.28	0.24
30-50	0.18	0.20	0.22	0.18	0.21	0.20
$LSD_{0.05}$	(lime)	0.12		(depth)	0.05	
	After Rice Harvest					
0-7.5	0.24	0.21	0.20	0.23	0.24	0.28
7.5-15	0.22	0.22	0.23	0.24	0.26	0.26
15-30	0.23	0.20	0.18	0.22	0.23	0.25
30-50	0.22	0.16	0.17	0.21	0.21	0.23
$LSD_{0.05}$	(lime)	0.15		(depth)	0.06	
	After Second Peanut Harvest					
0-7.5	0.22	0.18	0.20	0.23	0.20	0.26
7.5-15	0.21	0.18	0.19	0.21	0.20	0.22
15-30	0.20	0.18	0.17	0.21	0.19	0.22
30-50	0.20	0.17	0.17	0.20	0.16	0.22
$LSD_{0.05}$	(lime)	0.13		(depth)	0.03	

*) b=surface broadcast, s=shallow (10-15 cm), d=deep (20-25 cm)

Soil Sulfate-S

A significant increase in soil SO_4^{2-} S was observed after the first peanut harvest. The application of kieserite and sulfate containing Treble Super Phosphate increased soil SO_4^{2-} S in all soil layers. In the top 7.5 layer it increased SO_4^{2-} S from an average value of 74.1 mg/kg before kieserite was applied (Figure 9) to as high as 248 mg/kg in the control plot after the first peanut harvest.

Table 10: Soil SO_4^{2-} S (mg/kg) after Peanut Hrvest

Soil	Lime Applied (kg/ha)					
Depth	0	375b	375s	1000b	1000s	1000d
(cm)						
	After First Peanut Harvest					
0-7.5	248	166	145	142	108	185
7.5-15	171	220	188	173	151	208
15-30	175	169	185	172	134	168
30-50	206	190	214	180	165	219
$LSD_{0.05}$		(lime)	83	(depth)		71
	After Second Peanut Harvest					
0-7.5	51	77	94	90	51	69
7.5-15	93	131	115	111	118	123
15-30	122	153	144	121	142	168
30-50	102	159	149	156	144	187
$LSD_{0.05}$		(lime)	54	(depth)		56

*) b=surface broadcast, s=shallow (10-15 cm), d=deep (20-25 cm)

In the 30-50 cm layer SO_4^{2-} increased from average value of 145 mg/kg to as high as 219 mg/kg in the deep incorporated 1000 kg/ha lime treatment. Substantial SO_4^{2-} decrease occurred in all layers after the second peanut harvest. Higher losses were observed from the top 15 cm layers. After three crops, soil SO_4^{2-} S decreased to the value before kieserite was applied. The rate and method of the second lime application did not seem to affect soil SO_4^{2-} S (Table 10).

Soil Solution

The concentration of nutrients in the soil solution is an indicator of potential nutrient mobility in the soil. The nutrients in the soil solution are readily available to the plant roots as well as susceptible to leaching in high rainfall areas.

Relatively high pH and consequently low Al concentrations were found in all the samples. The soluble oxidizible carbon of the 0-15 cm layer ranged from 4.00 mM to 4.58 mM (Table 11). Subsoil of an acid Ultisol of Kaneohe, Hawaii had 0.8 mM but increased to 8.5 mM when 20 g/kg of ground cowpea leaves was applied (Hue and Amien, 1989). The relatively high soluble oxidizable carbon may be part of the reason for the low Al and high pH. The role of organic matter in reducing aluminum toxicity in acid soils has been well documented (Hoyt and Turner, 1975; Asghar and Kanehiro, 1980; Hue *et al.*, 1988; Hue and Amien, 1989; Hansen, 1989). This is attributed primarily to its role in increasing pH and consequently reducing aluminum concentration (Hue and Amien, 1989; Hansen, 1989).

Four crops of peanut and two crops of mungbean and cowpea as well as two maize and one rice crop were grown in the soil before the samples were taken. Although all the crop tops were removed during harvest, considerable crop residue such as fallen leaves and roots remain and were decomposed in the soils. This may have played an important role in reducing soil solution Al. Approximately one-third of the organic inputs to the soil in a variety of tropical cropping systems originates from dead roots (Scholes and Salazar (1989). Root production of organic matter near anthesis in

Table 11: Soil Solution pH and Concentration of Selected Elements after the Second Peanut Harvest

Soil Depth	Lime Applied (kg/ha) 0	375	1000	2250*)	6500*)	$LSD_{0.05}$ (lime)
(cm)						
			Oxidizable C (mM)			
0-15	4.07	4.58	4.30	4.03	4.00	0.59
15-30	2.35	2.58	2.13	2.55	2.71	
			pH			
0-15	5.02	5.43	5.49	5.48	5.81	0.31
15-30	5.61	5.65	5.59	5.89	5.83	
			Al (mg/L)			
0-15	0.56	0.55	0.46	0.52	0.42	0.17
15-30	0.49	0.49	0.49	0.47	0.50	
			Ca (mg/L)			
0-15	4.90	6.15	21.50	12.14	21.20	9.37
15-30	2.40	2.90	6.40	3.20	4.70	
			Mg (mg/L)			
0-15	6.35	5.25	3.50	3.18	3.20	2.03
15-30	2.05	3.60	1.20	1.85	2.05	
			K (mg/L)			
0-15	2.24	1.97	1.49	1.56	1.12	0.60
15-30	0.67	1.08	0.87	0.49	0.89	
			Na (mg/L)			
0-15	1.27	1.12	0.64	0.63	0.70	0.66
15-30	0.41	0.83	0.30	0.37	0.49	

*) applied 29 months earlier

the depth of 30 cm on acid soil of Yurimaguas, Peru for cowpea, corn and upland rice were estimated to be 1.03, 0.97 and 0.62 ton/ha, respectively (*ibid*).

In some cases the beneficial effect of organic matter can remain for a relatively longer time. Hansen (1989) reported that the effectiveness of cowpea in protecting plant from Al damage did not diminish even after 6 months of application. This study, however, was an incubation study and not a field trial.

Lime treatments slightly increased soil solution pH in the soil surface but had a marked effect on soil solution Ca. Even four years after the application 2250 and 6500 kg/ha lime treatments maintained a higher Ca concentration in soil solution. The Ca concentration of the top 0-15 cm layer was over twice of the control plot in the 2250 kg/ha lime and more than four-fold higher in the 6500 kg/ha lime treatments. Only a slight increase was observed in the soil solution Ca concentration in the 375 kg lime/ha treatment of the second applied lime over the control, but more than four-fold in the 1000 kg/ha treatment.

Regardless of the time of lime application, higher solution Mg and K and Na were found in the low lime treatments compared to the high lime treatments particularly in the surface 0-15 cm. Lime has been reported to reduce the intensity of K (Goedert *et al.*, 1975).

Peanut Root Distribution and Nodulation

The First Peanut Crop

A small diameter auger had been successfully used to sample plant root (Gonzalez-Erico *et al.*, 1979 ; Robertson *et al.*, 1979). But the soil auger used to sample peanut root in this experiment did not give satisfactory results. Very small amounts of root were obtained from the samples, particularly in deeper layers, although the auger was placed directly on the plant base. With auger of about 20 cm deep and 6 cm diameter in the top an average of 5 cm of the tap root were found in the samples from the 20-40 cm layer. This indicated that the tap root did not always go straight downward.

At no depth nor time of sampling was there a significant difference in the root weight among the lime treatments. At the level of lime applied, neither rate nor method of application seemed to affect root weight. However, a substantial difference in the root mass was observed between the peanut botanical types. The spreading type Florunner had less root compared to the erect Spanish cultivars, particularly in the first two samplings. Soil conditions were probably unfavorable to the root growth of Florunner cultivar. In a non-restricting medium, Florunner had more root than most of the Spanish cultivars tested (Ketring *et al.*, 1982). Peanut root elongation rate was not affected by soil moisture but was decreased to about one half when penetration resistance was increased to 19.1 bars (Taylor and Ratliff, 1969). The warm temperature in Sitiung may also contributed to less root growth. Wood (1975) reported that peanut root growth was responsive to temperature treatments. At constant night temperature of

25^0 C the root of Spantex, a Spanish peanut, at 35 ^{0} C day temperature was about 35 % of that at 20 ^{0} C.

Table 12: Peanut Root Weight from the Top 20 cm in the First Crop

Lime	Florunner	Kelinci	Tapir	Tupai
(kg/ha)	------------(g)------------------			
		50 dap		
0	0.86	1.02	0.98	0.97
375 b	0.90	1.17	0.96	1.20
375 s	0.77	1.17	1.49	1.45
1000 b	0.82	1.12	1.26	1.22
1000 s	0.91	1.19	1.23	1.32
1000 d	0.90	1.10	1.10	1.30
		75 dap		
0	1.24	1.52	1.62	1.13
375 b	1.22	1.45	1.65	1.35
375 s	1.26	1.42	2.05	1.60
1000 b	1.36	1.38	1.69	1.45
1000 s	1.33	1.60	2.06	1.74
1000 d	1.39	1.45	1.39	1.44
		100 dap		
0	1.25	1.89	1.36	1.06
375 b	1.36	1.99	1.36	1.12
375 s	1.35	1.72	1.60	1.52
1000 b	1.64	1.76	1.44	1.33
1000 s	1.70	1.69	1.53	1.59
1000 d	1.58	1.73	1.28	1.42

b=surface broadcast s=shallow (10-15 cm) d=deep (20-25 cm)

Table 13: Relative Root Weight in the 20-40 cm and 40-60 cm Layers Expressed as % of Root Weight in the Top 0-20 cm Layer in the First Peanut Crop

Lime	Sampling Time ----50 dap-----		-----75 dap----		----100 dap----	
	Depth (cm)					
	20-40	40-60	20-40	40-60	20-40	40-60
(kg/ha)			(%)			
			Florunner			
0	3.6	0.8	5.6	1.4	3.6	0.5
375 b	5.8	0.6	7.1	1.1	3.4	0.6
375 s	5.6	0.5	6.1	0.7	4.7	0.4
1000 b	4.9	0.8	4.2	1.0	3.3	0.6
1000 s	5.8	0.5	6.9	1.5	4.2	0.9
1000 d	5.9	0.7	7.9	1.4	4.6	0.9
			Kelinci			
0	4.7	0.5	6.5	0.7	3.5	0.4
375 b	5.4	0.6	4.9	0.5	2.9	0.4
375 s	4.4	0.5	4.6	0.6	3.7	0.4
1000 b	4.3	0.9	6.0	0.8	3.6	0.5
1000 s	3.5	0.7	4.9	0.8	3.6	0.7
1000 d	4.4	0.7	6.2	0.7	2.7	0.6
			Tapir			
0	2.3	0.9	4.5	0.7	2.3	0.4
375 b	1.5	0.9	3.0	0.7	3.1	0.5
375 s	2.5	0.6	2.6	0.9	2.6	0.5
1000 b	4.0	0.8	3.8	0.9	4.0	0.7
1000 s	3.1	0.7	4.0	0.9	3.5	0.8
1000 d	5.2	0.9	5.5	1.1	4.4	0.8
			Tupai			
0	1.9	0.3	4.0	0.4	3.7	0.4
375 b	2.2	0.3	3.4	0.6	3.6	0.5
375 s	2.1	0.4	2.8	0.5	2.8	0.6
1000 b	2.6	0.4	3.2	0.7	3.7	0.9
1000 s	2.9	0.6	4.3	0.6	3.0	0.6
1000 d	3.3	0.5	6.7	0.8	3.7	0.7

b=surface broadcast s=shallow d=deep

At all dates of sampling and for all the peanut cultivars, the root weight declined with depth. Because of the finer roots only a very small proportion of the root weight was found in the deeper layer. The lowest proportion was for Tupai, with about 3% of the root weight in the 20 to 60 cm layer at 50 days after planting. Florunner had the highest proportion with about 7% at 75 day after planting. Lenka and Misra (1973) reported the root mass in the top 15 cm layer was 77% of the total when grown on loamy sand to sandy loam soil, presumably with no chemical restriction in the subsoils.

As in the top 20 cm, there was no significant effect of lime on the root weight in the 20-40 cm and 40-60 cm layers. However, at 100 days after planting the four cultivars had a higher proportion of root weight in the 40-60 cm layer in the higher lime treatments as compared to no lime and low lime treatments. Because the second lime application probably did not move to this layer even after the first peanut was harvested, this could be due to an indirect effect of lime. The high lime treatments had better top growth that produced more photosynthate that probably partitioned to the root. For Florunner and Kelinci cultivars the root weight was increasing until the last sampling at 100 days after planting but for Tapir and Tupai it was decreasing after the third sampling at 75 days after planting. In the last sampling Tapir and Tupai were near maturity while the Florunner and indeterminant Kelinci still grew another four weeks.

The Second Peanut Crop

At 25 days after planting all the peanut root was found within the top 20 cm of the soil surface and very few if any roots penetrated beyond 50 cm depth even at the peak of the growth at 75 or 100 days after planting. This was much shallower than reported by Lea (1961) and Robertson *et al.* (1979) but close to that reported by Lenka and Misra (1973), who found that semi-erect AK peanut tap root was 20 cm long at 28 days after planting that penetrated to 45 cm at 80 days after planting. Their experiment

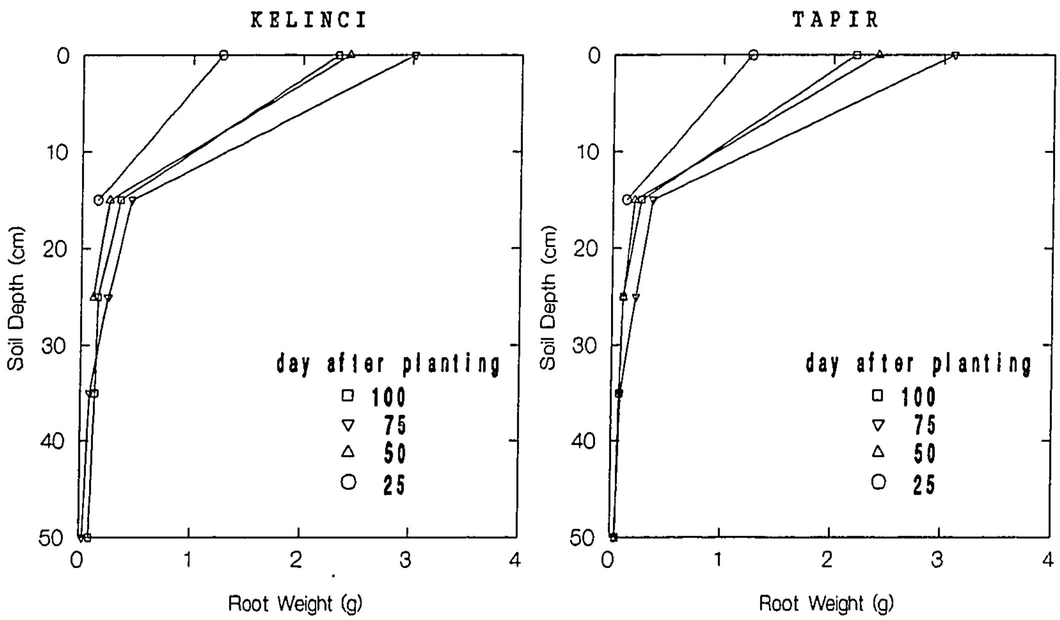


Figure 12: Root Mass of Kelinci and Tapir Peanut in the Second Crop

also indicated that peanut tap root grew to different depths in different soils and in different seasons. The tap roots in their study did not go beyond 56 cm depth at harvest even though the soil was not irrigated until depletion of 75 % of available water. As the case in the first crop, lime did not seem to affect the root weight of the second peanut crop (Appendix 1 and 2). Although slightly more root was measured in the deeper soil layer for Kelinci there was no significant difference between the cultivars (Figure 12). Most of the root was found in the surface soil layer. The percent root in the 0-10 cm layer was 88% at 25 days after planting and decreased to 78% at 100 days after planting for Kelinci cultivar. With the Tapir cultivar the percentage decreased from 90% to 83%.

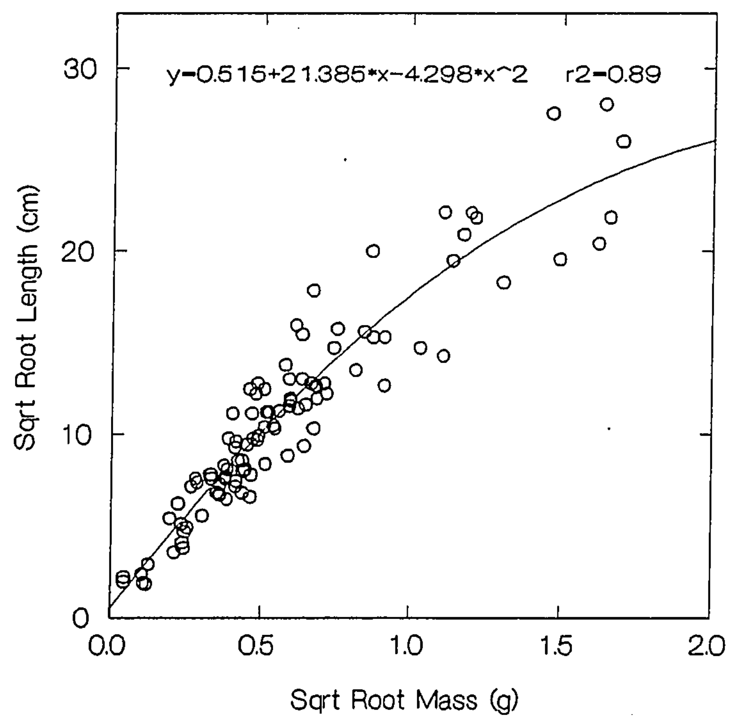


Figure 13: Relation between Root Length and Root Mass

In the top 20cm layer, the proportion of root at the peak of root growth was over 90 % for both Kelinci and Tapir. This was far higher than AK peanut as reported by Lenka and Misra (1977).

For the second peanut crop, the organic matter contribution of peanut root at the peak of growth was about 0.52 ton/ha. Peanut root mass was less than other grain legume such as cowpea and soybean (Mc Cloud, 1974; Scholes and Salazar, 1989). Peanut root length density was also the second lowest after sorghum among the field crops studied by Robertson *et al.* (1979).

Visual examination of scatter plots suggested that the fit of the equation improved after square root transformation (Figure 13). Nageswara Rao *et al.* (1989) also reported that the square root transformation had substantially reduced the residual when predicting root length from root mass of TMV2 peanut grown at ICRISAT, India.

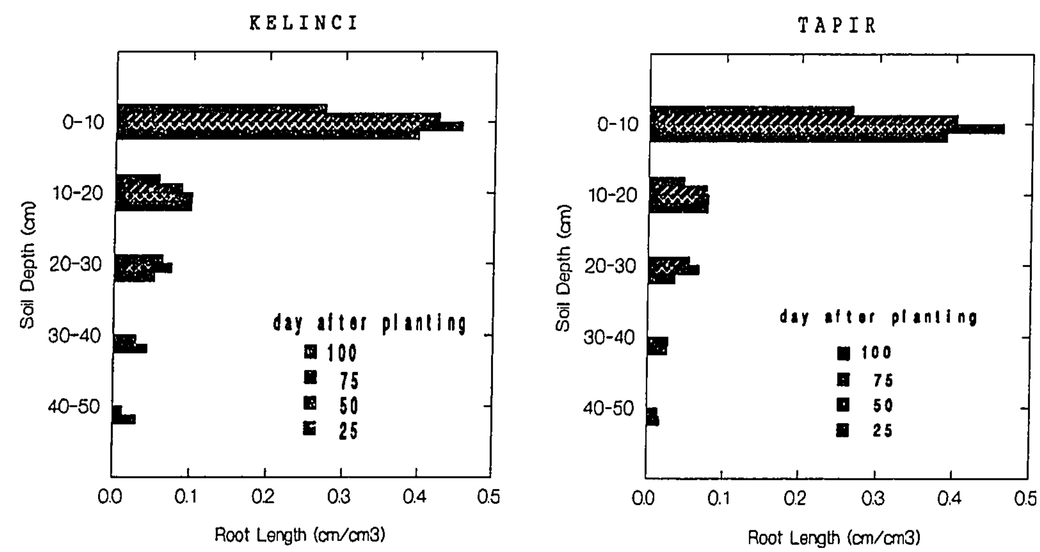


Figure 14: Root Length Distribution of Kelinci and Tapir Cultivars

The root length of the remaining samples were calculated using the regression equation. The root length for both Kelinci and Tapir (Figure 14) cultivars were less than root length of Florunner on sandy soils of Florida as reported by Robertson at al. (1979)

but similar to the root length of the erect bunch TMV2 cultivar grown on Alfisol (Nageswara Rao *et al.*, 1989).

Root Nodules

A substantial number of nodules were found in the root even at 25 days after planting. The nodule numbers increased until maxima at 75 and 100 days after planting. By measuring haemoglobin in peanut nodule and nitrogen content of peanut leaves, Shiffmann and Lobel (1973) suggested that nitrogen fixation started early in the growth cycle, reached the peaks at 2.5 and 3 months of growth, and then declined, although remained high until harvest. The numbers of nodules in this experiment indicated the same trend.

Lime did not seem to affect peanut nodulation. At no time of sampling and in neither cultivar was there a significant difference in the nodule numbers and weight as affected by lime treatments. Munns *et al.*, (1977) also reported that liming Hawaiian Oxisol up to 22.6 tons/ha, which increased the soil pH from 4.7 to 7.1, did not increase the peanut nodule number and size although peanut yield increased by one-third.

Graham and Donawa (1981) and Chong *et al.* (1987) however, reported that liming acid soil had increased nodulation and subsequent nitrogen fixation. Chong *et al.* (1987) attributed the lack of nodulation in acid soil to root damage by Al. However, the adverse effects of soil acidity on nodulation, in one case were overcome the by increasing the inoculum (Robson and Loneragan, 1970). In the present experimental plot, rhizobium inoculum was applied when the first peanut crop was planted (Gill and Kamprath, 1985). Two other legumes, cowpea and mungbean were grown twice on the soil may have maintained high population of acid tolerant rhizobium. Certain strains of cowpea rhizobia were reported to tolerate soil acidity stresses of 50 lM Al at pH 4.5 (Keyser and Munn, 1979b). Both the relatively high initial population and the tolerant nature to acidity of slow growing peanut-cowpea *rhizobia* probably contributed to the lack of nodulation response to liming.

Table 14: Nodule Number and Weight of Kelinci and Tapir Cultivars in the Second Crop

Lime	Nodule Number/m2				Nodule Weight	
	25 dap	50 dap	75 dap	100 dap	75 dap	100 dap
(kg/ha)					—(g/m2)—	
			Kelinci			
0	601	981	1362	1362	6.60	6.61
375 b	495	800	1171	1695	5.62	6.39
375 s	505	781	1019	1219	4.30	5.01
1000 b	743	1038	1486	1495	5.91	5.57
1000 s	495	876	1229	1133	6.03	5.67
1000 d	552	990	1429	1219	7.03	5.89
6500 *	743	1105	1724	1410	8.76	7.17
			Tapir			
0	1076	1448	1810	1648	7.58	7.06
375 b	552	1133	1314	1143	5.34	5.32
375 s	895	1514	1867	1438	8.70	7.08
1000 b	810	1448	2000	1914	7.93	8.01
1000 s	886	1229	1714	1305	7.04	5.11
1000 d	667	1057	1305	1057	6.01	6.13
6500 *	1114	1638	1914	1533	7.48	6.19
$LSD_{0.05}$ lime	377	565	729	897	3.74	1.54
cultivar	514	162	312	493	2.79	2.63

b=surface broadcast s=shallow d=deep *lime was applied 29 months earlier

Effect of Lime Treatments on Peanut Yields

Weather conditions contrasted sharply between the two peanut growing periods. The first peanut crop received a total of 555 mm rainfall while the second peanut crop received a total of 1095 mm (Figure 15). Pan evaporation exceeded the rainfall in several occasions during the first crop but only once in the second crop. In the first crop water deficits occurred intermittently during much of the reproductive growth stage, which probably reduced peanut yields.

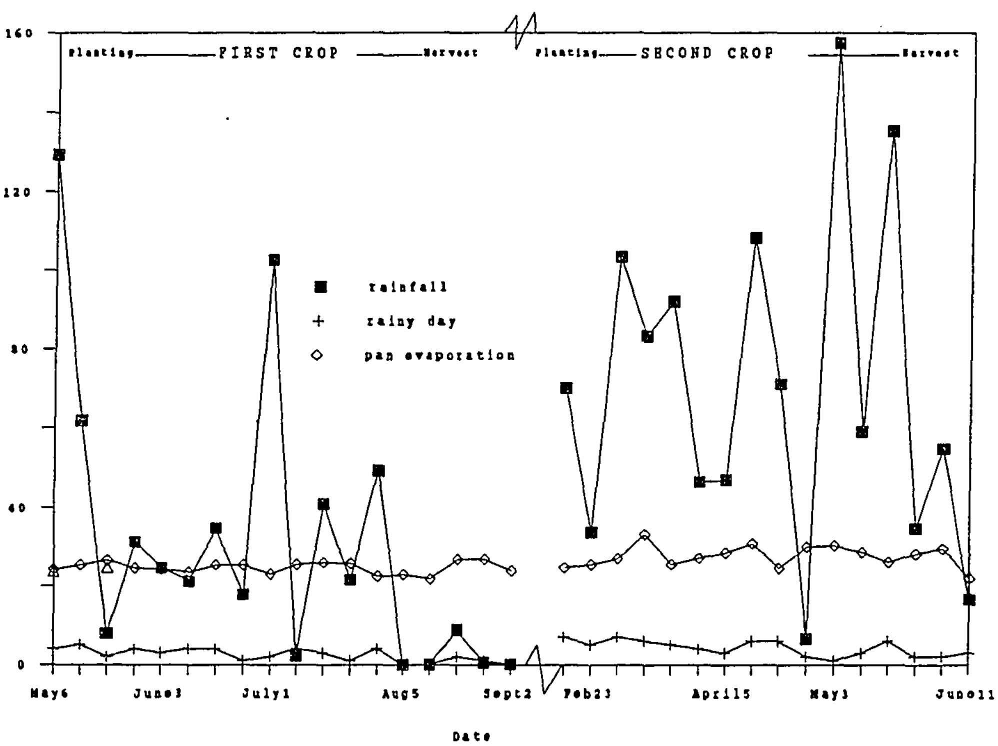


Figure 15: Weekly Rainfall, Pan Evaporation (mm) and Rainy Days during the Two Peanut Growing Periods, 1987-1988 at Sitiung.

Yields of the First Peanut Crop

In spite of peanut's reputed drought tolerance (Pandey *et al.*, 1984), the relatively low rainfall in the first crop has probably reduced peanut yields. Low rainfall together with unfavorable soil conditions resulted in poor yields. Of the four cultivars Florunner seemed to suffer most. The three Spanish cultivars produced the highest yield, with Kelinci producing the highest pod yield followed by Tapir and Tupai. Peanut haulm, pod and grain yields were increased by the lime applied 29 months earlier (residual) and the freshly applied lime. Residual lime from the 2250 and 6500 kg lime/ha application still increased peanut yields after two sequences of a maize, peanut and cowpea/mungbean rotation (Figures 16 to 19).

Response to Previously Applied Lime

The haulm yields of the four cultivars were significantly higher in plots where 6500 kg/ha lime were applied 29 months earlier than in plots where 375 or 2250 kg/ha was applied. For the Tapir cultivar, haulm yields of the 2250 kg/ha plots were also significantly higher than those of the 375 kg lime/ha plots. However, the differences were not significant for Florunner, Kelinci and Tupai (Table 15).

Very low pod and grain yields were harvested in the plots that previously received 375 kg lime/ha. Dry pod yields of Florunner was only 236 kg/ha. Tupai and Tapir cultivars yielded slightly more with 425 and 525 kg/ha respectively. While Kelinci had the highest yield of 705 kg/ha. The grain yields on this treatment were 155; 199; 258 and 299 kg/ha for Florunner, Tupai, Tapir and Kelinci respectively.

Table 15: Peanut Haulm Yield and Shelling Percentage of Four cultivars, First Peanut Crop, August 1987

Applied Lime		Haulm Yield				Shelling Percentage		
		Residual Lime (kg/ha) 1)						
		375	2250	6500		375	2250	6500
(kg/ha)			(kg/ha)				(%)	
				Florunner				
0		4220	5113	7478		65.8	74.4	70.8
375 b 2)		5394	5628	7022		71.4	76.7	72.0
375 s		5018	5480	7636		72.2	71.7	73.3
1000 b		5319	6099	7128		72.3	75.4	74.7
1000 s		5216	6356	6963		72.3	72.5	70.5
1000 d		5685	6502	6560		71.2	69.5	71.4
$LSD_{0.05}$	(rl)3)	1451	(al)	931	(rl)	10.9	(al)	4.7
				Kelinci				
0		7365	7243	8234		42.5	63.2	61.5
375 b		7191	7942	8682		48.8	63.0	65.1
375 s		7226	8133	8304		51.8	63.7	63.6
1000 b		7537	7918	8663		53.6	62.8	67.0
1000 s		7168	8133	8930		62.5	63.3	67.5
1000 d		7787	8110	8750		58.0	63.1	66.2
$LSD_{0.05}$	(rl)	980	(al)	916	(rl)	9.6	(al)	4.7
				Tapir				
0		5862	7232	8191		49.7	64.0	66.2
375 b		5641	6804	8398		59.1	61.5	68.3
375 s		5582	6973	8200		59.7	63.0	66.9
1000 b		6549	7196	8511		64.6	64.0	66.1
1000 s		6319	7985	8503		69.0	66.2	68.4
1000 d		6861	7923	8173		59.1	68.0	65.4
$LSD_{0.05}$	(rl)	633	(al)	995	(rl)	7.3	(al)	6.2
				Tupai				
0		6132	6426	8259		47.2	61.2	66.4
375 b		6162	7016	8561		56.9	63.1	66.6
375 s		6281	6891	8354		56.6	63.2	66.5
1000 b		6626	6928	8789		62.6	61.7	64.3
1000 s		6708	7244	8313		63.3	60.6	65.6
1000 d		7575	8049	8243		55.9	63.1	61.9
$LSD_{0.05}$	(rl)	1357	(al)	710	(rl)	8.4	(al)	5.6

1) the residual lime was applied 29 months earlier
2) b=surface broadcast s=shallow d=deep
3) (rl)=residual lime (al)=applied lime

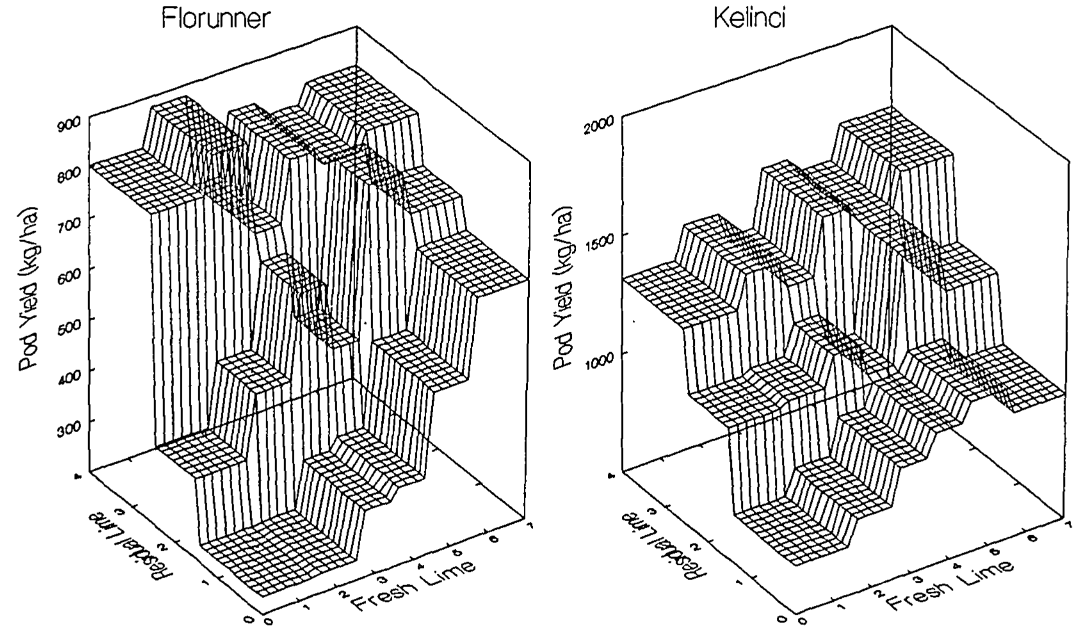
The medium and high lime treatments applied 29 months earlier still increased pod and grain yields significantly over the low lime treatment. The pod yield in the medium lime treatment was over 50% higher for Florunner, Kelinci and Tapir and more than 100% higher for Tupai compared to the low lime treatment. While the increase in grain yields ranged from 72% for Florunner to 165% for Tupai. For Florunner the pod and grain yields of the high lime treatment were more than twice of the yields of the medium lime plot. Response to lime was less for the other three cultivars.

Although Florunner produced the least dry pod yields, it had the highest shelling percentage, which was not not affected by lime treatments. Contrary to Florunner, the shelling percentages of the three other cultivars were improved by both lime treatments. However, there was no significant difference between the shelling percentage of the 2250 kg/ha and 6500 kg/ha lime treatments.

In all the lime treatments Florunner produced the lowest pod and grain yields followed by Tupai and Tapir and Kelinci, which produced the highest. The yields of the four peanut cultivars still increased where lime had been applied 29 months before. Florunner seemed to be the most responsive to the residual lime followed by Tupai and Tapir and Kelinci.

Response to Freshly Applied Lime

The freshly applied lime did not increase haulm production of the Kelinci cultivar. It also did not increase the haulm yields of the other three cultivars in the plots where 6500 kg/ha of lime was applied earlier. Where 2250 kg/ha of lime was applied earlier, the fresh lime did not increase the haulm yield of Tapir. But the high rate of fresh lime treatments increased the haulm yield of Florunner and Tupai. In the plots where only 375 kg lime/ha was applied earlier, the fresh lime treatments increased the haulm yield of Florunner, but only the high rate of fresh lime increased the haulm yields of Tapir and Tupai.

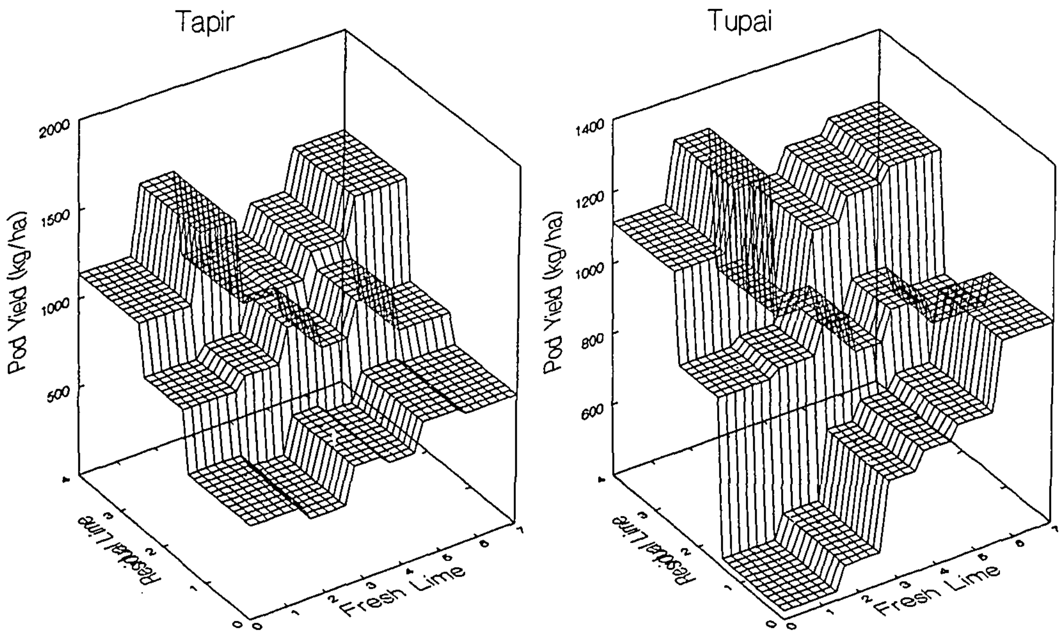


residual lime (kg/ha) 1=375 2=2250 3=6500
new lime (kg/ha) 1=0 2=375 surface broadcast 3=375 shallow incorporated
4=1000 surface broadcast 5=1000 shallow incorporated 6=1000 deep incorporated

Figure 16: Effect of Residual Lime (applied 29 months earlier) and Freshly Applied Lime on Pod Yield of Florunner and Kelinci Peanut Cultivars

Peanut requires less Ca for vegetative growth than reproductive growth (Wolt and Adams, 1979). But there seemed to be different requirements of Ca among the cultivars for vegetative growth. In water-stress conditions of the first peanut crop, 0.77

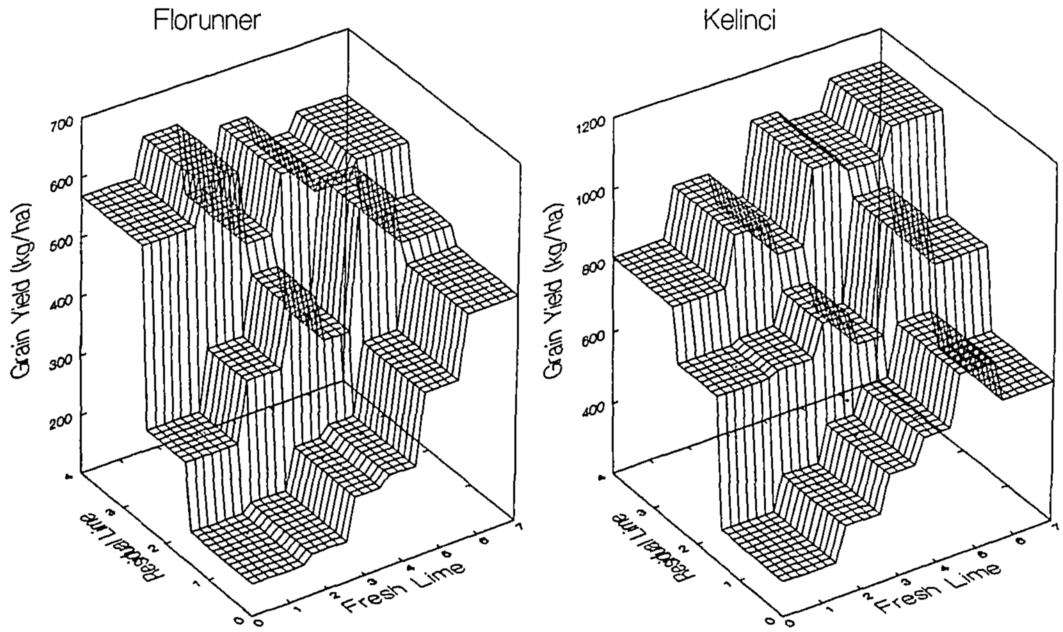
cmol$_c$/kg exchangeable Ca in the soil surface was sufficient for Kelinci but inadequate for Florunner. Florunner seemed to be the more sensitive to low available Ca for haulm production in this year of low rainfall.



residual lime (kg/ha) 1=375 2=2250 3=6500
new lime (kg/ha) 1=0 2=375 surface broadcast 3=375 shallow incorporated
4=1000 surface broadcast 5=1000 shallow incorporated 6=1000 deep incorporated

Figure 17: Effect of Residual Lime (applied 29 months earlier) and Freshly Applied Lime on Pod Yield of Tapir and Tupai Peanut Cultivars

The fresh lime did not increase pod and grain yields significantly when applied to plots that previously received 6500 kg lime/ha. When the fresh lime was applied to plots that previously received 2250 kg lime/ha it also did not increase the yields of the three Spanish cultivars, but increased pod and grain yields of Florunner. When the fresh lime was applied to plots that previously received 375 kg lime/ha, the pod and grain yields increased with increasing lime rate. However, the yield in the low lime rate treatment was only significantly higher for Kelinci and Tupai when incorporated. The yields of the



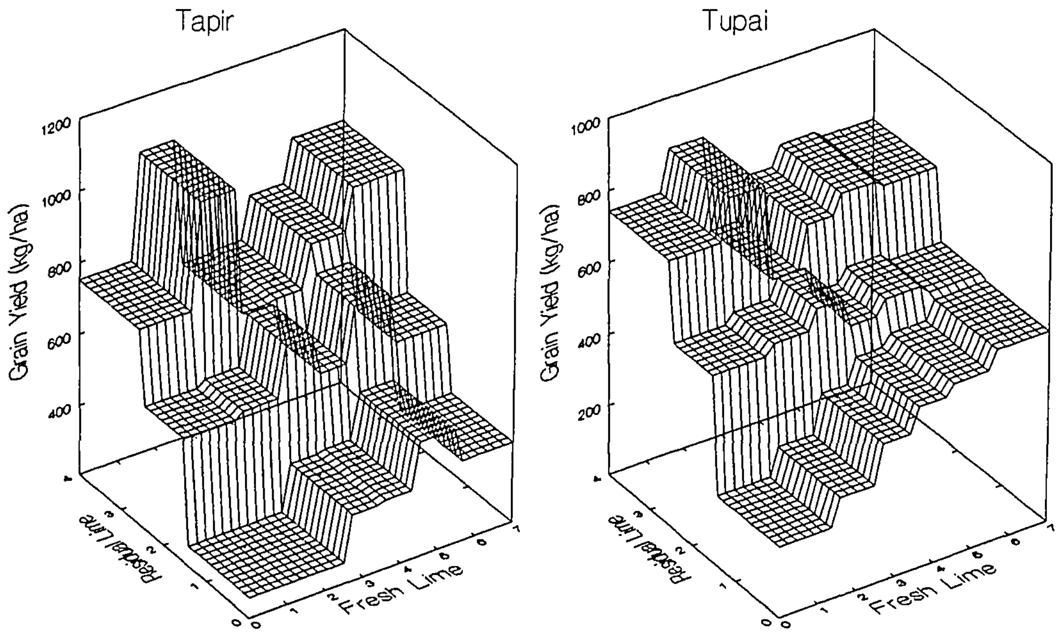
residual lime (kg/ha) 1=375 2=2250 3=6500
fresh lime (kg/ha) 1=0 2=375 surface broadcast 3=375 shallow incorporated
4=1000 surface broadcast 5=1000 shallow incorporated 6=1000 deep incorporated

Figure 18: Effect of Residual Lime (applied 29 months earlier) and Freshly Applied Lime on Grain Yield of Florunner and Kelinci Peanut Cultivars

high lime rate treatments were significantly higher than the yield of no lime plot in all methods of application for Kelinci and Tupai and only when incorporated for Florunner and Tapir.

Effect of Lime Placement

Calcium requirement for fruit development of peanut must be obtained by the fruit itself since Ca is not translocated from vegetative plant parts to subterranean fruit (Bledsoe *et al.*, 1949; Skelton and Shear, 1971). But although higher Ca was observed in the 0-7.5 cm layer, when lime was surface broadcast (Table 6), interestingly the peanut yields were lower compared to when the lime was incorporated. Surface soil dryness



residual lime (kg/ha) 1=375 2=2250 3=6500
fresh lime (kg/ha) 1=0 2=375 surface broad cast 3=375 shallow incorporated
4=1000 surface broadcast 5=1000 shallow incorporated 6=1000 deep incorporated

Figure 19: Effect of Residual Lime (applied 29 months earlier) and Freshly Applied Lime on Grain Yield of Tapir and Tupai Peanut Cultivars

probably prevented the plant from absorbing the broadcast Ca in the soil surface. Incorporating the lime deeper, probably increased peanut yield by providing more Ca for absorption by fruit due to the higher soil moisture in the deeper layer. Higher Ca was found in the 7.5-15 cm layers of all incorporated lime treatment compared to the surface broadcast treatment (Table 6). Wright (1989) reported that surface soil dryness reduced the yield of Gajah and McCubbin peanuts but did not affect the yield of Robut 33-1 although high Ca was applied in the podding zone and unlimited water was available in the root zone. Surface soil dryness reduced the Ca content of the seed to about one half of the Ca content in the wet treatment. However, higher Ca was found in Robut 33-1 seed both in wet and dry soil surface treatments than in seed of McCubbin and Gajah cultivars. Wright (1989) suggested that more pod hairs of Robut 33-1 may have increased the effective pod absorption area and facilitated Ca uptake under drought conditions.

Incorporating the lime deeper however, showed mixed results. Deeper incorporation of lime reduced the yields of the four cultivars in the plots that previously received 2250 kg lime/ha. But in plots where 375 kg of lime was applied previously, deep incorporation of lime increased the yields of Florunner and Tupai but reduced the yields of Tapir and Kelinci. Shallow incorporation of lime may have improved the availability of Ca in the relatively moist layer when prolonged drought occurred.

The yield gain of peanut due to liming in the first crop occurred mainly due to the increased number of seed per area. Except for the Florunner cultivar, the seed number increased mainly due to the lime applied 29 months before. Pod number increased slightly in the residual of 375 kg/ha lime treatment for Florunner and Tapir but no significant increase was observed for Kelinci and Tupai. Both residual and freshly applied lime increased the pod number of Florunner but only the residual lime increased the pod number of Tapir. Substantial increase in numbers of seed per pod was observed for Kelinci cultivar in the higher rates of the previously applied lime treatment.

Table 16: Pod and Seed Numbers per m^2 and Seed Weight of Four Cultivars, First Peanut Crop, August 1987

Applied Lime	Pod Number			Seed Number			Seed Weight		
	Residual Lime (kg/ha) 1)								
	375	2250	6500	375	2250	6500	375	2250	6500
	m^{-2}						(gram)		
				Florunner					
0	95	75	148	126	120	185	0.31	0.37	0.36
375 b	88	81	176	121	128	248	0.35	0.38	0.37
375 s	94	118	173	134	180	233	0.35	0.37	0.38
1000 b	95	119	133	128	182	197	0.36	0.39	0.39
1000 s	118	128	114	173	200	164	0.36	0.36	0.37
1000 d	123	157	151	182	229	213	0.38	0.34	0.38
$LSD_{0.05}$	(rl) 51	(al) 33		(rl) 32	(al) 47		(rl) 0.16	(al) 0.05	
				Kelinci					
0	213	188	196	332	478	477	0.18	0.24	0.24
375 b	188	171	238	357	477	489	0.22	0.25	0.28
375 s	193	194	165	343	467	405	0.24	0.28	0.26
1000 b	207	199	192	387	493	432	0.27	0.26	0.29
1000 s	196	234	192	367	477	476	0.28	0.26	0.28
1000 d	217	153	219	361	424	515	0.27	0.26	0.27
$LSD_{0.05}$	(rl) 79	(al) 53		(rl) 128	(al) 106		(rl) 0.03	(al) 0.05	
				Tapir					
0	120	162	165	153	223	240	0.31	0.34	0.36
375 b	152	162	170	197	245	285	0.29	0.33	0.36
375 s	128	177	165	181	237	292	0.35	0.36	0.38
1000 b	151	201	163	206	267	285	0.35	0.35	0.38
1000 s	162	184	180	234	295	296	0.36	0.35	0.38
1000 d	128	184	193	203	292	292	0.36	0.32	0.38
$LSD_{0.05}$	(rl) 53	(al) 45		(rl) 96	(al) 63		(rl) 0.11	(al) 0.05	
				Tupai					
0	148	143	159	170	213	240	0.29	0.36	0.39
375 b	114	166	182	152	245	277	0.38	0.34	0.40
375 s	115	152	149	159	239	244	0.36	0.37	0.38
1000 b	116	144	153	171	231	256	0.36	0.36	0.36
1000 s	151	145	183	198	209	273	0.34	0.36	0.37
1000 d	122	152	165	157	272	285	0.36	0.36	0.35
$LSD_{0.05}$	(rl) 39	(al) 40		(rl) 81	(al) 53		(rl) 0.08	(al) 0.06	

1) the 'residual lime' was applied 29 months earlier
2) b=surface broadcast s=shallow d=deep
3) (rl)=residual lime (al)=applied lime

Freshly applied and residual lime also significantly increased seed weight of the Florunner, Kelinci and Tupai cultivars. But for Florunner the increase in seed weight by fresh applied lime was observed only when 1000 kg lime/ha was applied. For Tapir cultivar lime did not seem to increase seed weight.

Yields of the Second Peanut Crop

Haulm Yield

Haulm yields of the second peanut crop were much higher than those from the first crop, particularly in the low lime treatments. Haulm of Kelinci ranged from 7550 kg/ha to 9200 kg/ha from plots where 375 kg lime/ha was shallow incorporated and 375 kg/ha of lime applied earlier and where 1000 kg of lime/ha was shallow incorporated and 6500 kg/ha of lime were applied earlier. For the Tapir cultivar the lowest haulm yield was recorded in plots receiving no fresh lime and 375 kg/ha was applied earlier. The highest was in the plot receiving 375 kg/ha surface broadcast in the plot where 6500 kg were applied three years before.

Higher rainfall in the second peanut crop was more favorable for vegetative growth and resulted in increased haulm yield. For the Tapir cultivar higher haulm yields were harvested in all treatments of the second crop compared to the first crop. While for Kelinci higher haulm yields were harvested in low and medium lime treatments of the first applied lime. Although it has been suggested that leaf 'water storage' of peanut and folding of the leaves play an important role in water stress avoidance (Allen *et al.*, 1976), prolonged drought may also reduce the leaf number and size (Ong *et al.*, 1985). Water stress has a major influence in partitioning dry matter because vegetative growth is more sensitive to stress than reproductive growth (Ong, 1984). Hsiao, (1973) reported that leaf expansion and leaf growth are highly sensitive to water stress. Florunner peanut haulm was not affected when irrigation was withheld for 35 days, but greatly reduced when it was withheld for 70 days (Pallas *et al.*, 1979). For Spanish peanut

Table 17: Haulm and Shelling Percentage of Two Peanut Cultivars in the Second Crop, June, 1988

Second Lime	Haulm			Shelling Percentage		
	First Lime (kg/ha)					
	375	2250	6500	375	2250	6500
(kg/ha)	(kg/ha)			(%)		
	Kelinci					
0	8417	8148	8022	35.4	47.9	58.6
375 b	7649	7947	8662	47.7	57.1	63.7
375 s	7547	8020	8982	53.3	59.2	59.1
1000 b	8609	8872	8817	53.7	60.0	59.9
1000 s	7884	8503	9199	62.1	54.6	59.9
1000 d	7917	8375	8756	57.6	62.9	61.1
$LSD_{0.05}$	(rl) 769	(nl) 1278		(rl) 6.4	(nl) 6.5	
	Tapir					
0	6657	8569	8598	50.8	57.7	60.2
375 b	7376	8021	8740	58.0	55.6	58.1
375 s	7107	8505	8892	58.9	58.5	58.3
1000 b	8104	8195	8891	59.0	60.9	60.9
1000 s	7346	8070	8654	58.3	59.4	54.3
1000 d	8021	8824	8818	58.5	57.0	62.7
$LSD_{0.05}$	(rl) 660	(nl) 1548		(rl) 6.5	(nl) 5.7	

b=surface broadcast s=shallow d=deep rl)=residual lime (al)=applied lime
*) first lime was applied three and a half years and second lime ten months earlier

withholding water until relative water content dropped to 0.5 at early flowering and pod formation did not reduce plant height and numbers of leaves and branches (Ike, 1986). Except in the first two weeks after planting, the first peanut crop probably suffered from water stress throughout the growing period. In the first peanut crop, the extended drought probably reduced haulm yield particularly in the low lime plots.

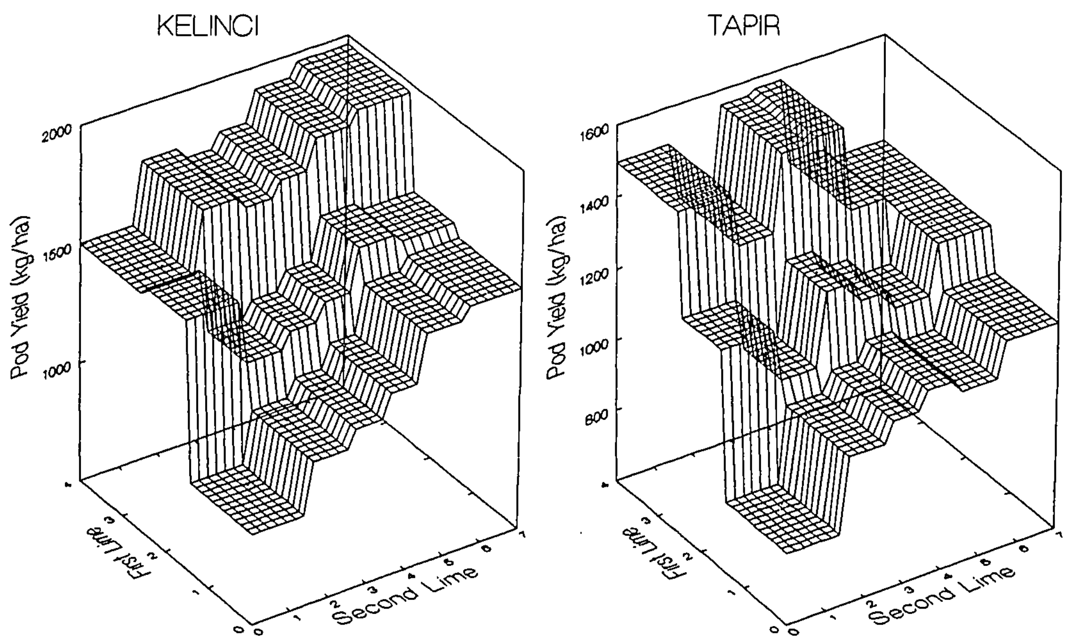
In the plots where 6500 kg lime/ha were applied earlier, the haulm yields of Kelinci and Tapir cultivars did not differ significantly with the haulm yields of the first crop. Sufficient Ca was reported to enhance water status of peanut by lower proline accumulation and less membrane damage (Malathi Chari *et al.*, 1985). Peanut grown on higher Ca in nutrient solution also exuded less sugar than those with low Ca (Shay and Hale, 1973).

Lime applied 10 months earlier did not appear to increase the haulm yield of either cultivar in the second crop (Table 17). But lime applied three and a half years earlier still increased the haulm yields. For both cultivars the haulm yield of the plots that received 6500 kg lime three and a half years earlier was significantly higher than from plots receiving 375 kg lime/ha. No significant difference were observed, however, between the haulm yields of the plots limed with 6500 kg/ha and those with 2250 kg/ha. For Kelinci, the difference between the haulm yield of the plots with 2250 kg/ha and 375 kg/ha was also not significant. But for Tapir cultivar, significant differences in haulm yields were observed between the the plots receiving 2250 kg lime/ha and those receiving 375 kg/ha. Although applied 29 months earlier, because of the higher rates, the earlier lime treatments still increased haulm yield. This suggests that the residual of 6500 kg lime/ha maintained high yield at least 3 years.

Dry Pod Yield

Pod yields harvested from both cultivars were higher in the more favorable weather conditions of the second crop. Dry pod yields of Kelinci ranged from 880 to

1960 kg/ha from plot where 375 kg lime was broadcast on plots that previously had 375 kg/ha lime and where 1000 kg lime was deeply incorporated on plots previously treated with 6500 kg/ha lime, respectively. For Tapir the lowest pod yield was 799 kg/ha from control treatment on the plots that previously had 375 kg/ha lime and the highest was



First Lime (kg/ha) 1=375 2=2250 3=6500 Second Lime (kg/ha) 1=0 2=375 broadcast 3=375 shallow incorporated 4=1000 broadcast 5=1000 shallow incorporated 6=1000 deep incorporated
*)First Lime applied three and a half years and Second Lime applied ten months earlier

Figure 20: Dry Pod of Kelinci and Tapir Cultivars in the Second Peanut Crop

1570 kg/ha from the surface broadcast 1000 kg treatment on the plot previously had 6500 kg/ha lime. The pod yield from the residual of high lime rate applied either 10 months or three and a half years earlier was about that expected from improved peanut cultivar in the peanut growing area in Indonesia. Gajah, the most popular peanut grown in Indonesia, has a potential dry pod yield of 1200 to 1800 kg/ha (Hidayat and Purboyo, 1983).

Dry pod yield still increased with increasing lime rate, applied over three years earlier. For Kelinci cultivar the pod yields from the plots that previously received 6500 kg lime were significantly higher than the yields from plots that previously had 375 kg lime. The pod yield also significantly higher than the plots that previously had 2250 kg kg lime except in the control plot of the fresh lime treatment. When no fresh lime was applied, the pod yield was somewhat lower than the yield from the plots that previously had 2250 kg lime but significantly higher than the yield from the plots that had 375 kg lime. However, 2250 kg lime/ha applied three years earlier increased pod yields significantly more than the plots with 375 kg lime/ha only when no lime or a low level of fresh lime was applied.

For the Tapir cultivar, no significant difference was observed between the dry pod yield in the plots that previously received 2250 kg lime/ha and 375 kg lime/ha. The plots that had 6500 kg lime/ha 3 years earlier also did not differ significantly from those receiving 2250 kg lime/ha. However, the plot that receiving 6500 kg lime 3 years earlier produced higher pod yields compared to that receiving 375 kg lime/ha but a significant increase was only observed in the control, and when fresh lime was applied either 375 kg/ha incorporated or 1000 kg surface broadcast.

Where only 375 kg/ha lime was applied earlier, the lime applied prior to planting of the first peanut crop also increased dry pod yields of both cultivars. But for the Tapir cultivar a significant yield increase was only observed in the plots where 1000 kg/ha lime was deeply incorporated. For Kelinci significant yield gains were observed in both shallow and deep incorporated 1000 kg lime/ha treatments.

Shelling Percentage

Peanut pods often fail to fill properly in unfavorable conditions such as low available calcium or water stress, which results in low shelling percentage. The shelling percentage of both peanut cultivars, particularly in the higher lime rates, wëre generally lower in the second crop (Table 17). The higher rainfall in the later period of the growth of the second peanut crop probably reduced the photosynthesis and pod filling due to less sunlight. For the Kelinci cultivar the shelling percentage varied from 35.4 % in plots where lime was not re-applied to the 375 kg/ha earlier lime treatment to 63.7 % in the broadcast 375 kg of the 6500 kg/ha of the earlier lime treatment. For Tapir the shelling percentage ranged from 50.8 % to 62.7 %. Both residual of the earlier and later applied lime seemed to increase the shelling percentage of both peanut cultivars.

For the Kelinci cultivar, in the plots where no lime or only 375 kg/ha lime was re-applied, increasing rate of previously applied lime significantly increased the shelling percentage. The lime applied 10 months before planting also increased shelling percentage of Kelinci peanut. But a significant difference was only observed in the low and medium lime treatments applied three and a half years earlier.

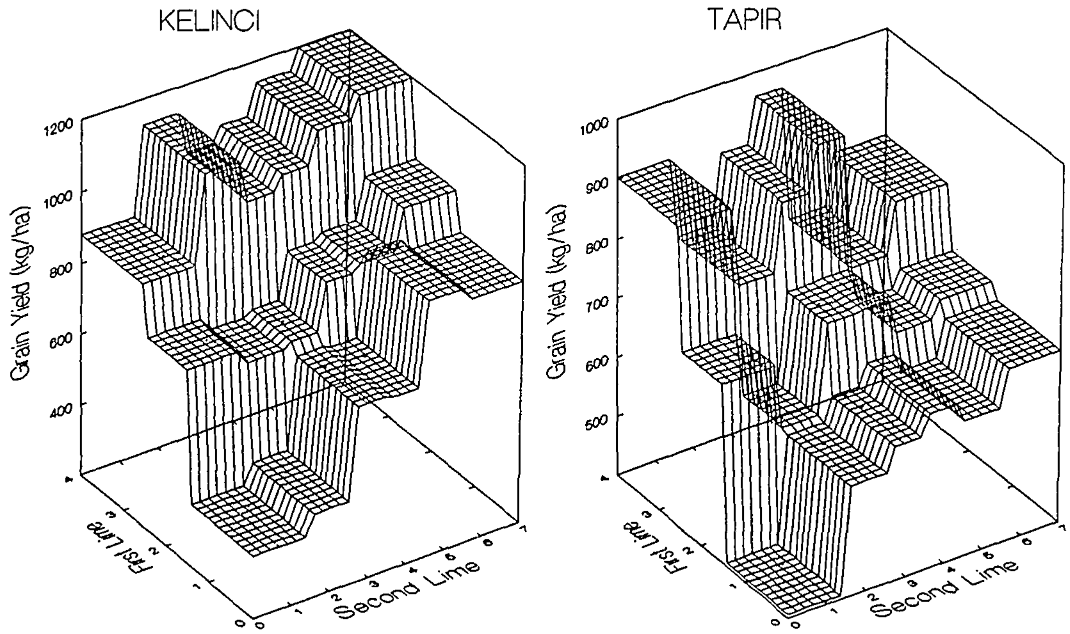
For the Tapir cultivar, the medium and high lime rates applied three and a half years earlier significantly increased the shelling percentage. The lime applied 10 months earlier also increased the shelling percentage, but no significant difference was observed between the different rate of the latter lime treatments.

Lime, at rates of 2250 and 6500 kg/ha, still increased the shelling percentage of peanut significantly in the second crop or three and a half years after lime application. Lower rates of 375 and 1000 kg/ha still increased the shelling percentage of peanut 10 months after application.

Grain Yield

The grain yield of Kelinci ranged from 380 kg/ha in the plots where lime was not re-applied but 375 kg/ha had been initially applied to 1200 kg/ha in the plots where 1000 kg of lime was deeply incorporated and 6500 kg/ha had been applied earlier. The grain yield of Tapir varied from 410 kg/ha in the plot where lime was not re-applied but 375 kg/ha had been initially applied to 960 kg/ha in plots where 1000 kg/ha of lime was broadcast and 6500 kg/ha had been applied.

The residual lime from the first and second applications still increased grain yields of the two peanut cultivars. With one exception, the higher the lime applied three and a half years before, the higher the grain yield of Kelinci cultivar. The lime applied 10 months before also increased grain yield of Kelinci peanut in the plots where 375 and 6500 kg/ha of lime were applied three and a half years earlier. But in the plots where 2250 kg/ha of lime was applied before only the application of 1000 kg/ha additional lime increased grain yield. However, for the Tapir cultivar, significant grain yield gains were observed only



First Lime (kg/ha) 1=375 2=2250 3=6500
Second Lime (kg/ha) 1=0 2=375 surface broadcast 3=375 shallow incorporated
4=1000 surface broadcast 5=1000 shallow incorporated 6=1000 deep incorporated
*)First Lime applied 3½ years and Second Lime applied 10 months earlier

Figure 21: Grain Yields of Kelinci and Tapir Cultivars in the Second Peanut Crop

where 1000 kg/ha lime was deeply incorporated but 375 kg/ha had been initially applied and where no lime was re-applied and 6500 kg/ha had been applied (Figure 21).

From the rainfall distribution it can be seen that the first peanut crop had probably suffered from water stress since the early stages of growth. This extended drought likely reduced the peanut yields particularly in the low lime plots. However, when sufficient Ca was available in the soil, for example in the residual of high lime plots, the different effect of the two seasons and the effect of water stress seemed to be diminished (Figure 19).

Better rainfall distribution during the second peanut crop probably resulted in higher haulm and pod yields. Although pod yields from the high initial lime rates were higher in the second crop than in the first crop, the grain yields were about the same. This greater grain yield was due a higher shelling percentage in the first crop. A higher shelling percentage was recorded in all treatments for Tapir cultivar and in the higher lime treatments for Kelinci. In the lower rainfall first crop, peanut probably had more photosynthesis which improved pod filling.

Higher pod and seed numbers per area from both cultivars were observed in the second crop. However, no significant increase was observed in the seed weight and number of seeds per pod. As in the first crop, only for Kelinci cultivar, the medium and high lime rates of the initial lime seemed to increased the number of seeds per pod (Table 18).

Peanut response to drought varies among cultivars (Gillier, 1978). Dry surface soil can reduce yield by affecting either development of pegs into full grown pods and/or by influencing seed abortion. Wright (1989), working with three peanut cultivars, found that surface soil dryness reduced yield of McCubbin peanut by reducing the number of pods and seed but for the Gajah cultivar drought reduced yield mostly by seed abortion. For another cultivar, Robut, the surface soil dryness did not affect either pod or seed (Wright, 1989). For Florunner peanut a 35 day moisture stress in the early season only reduced seed weight slightly but did not reduce the number of sound mature seeds (Pallas *et al.*,

Table 18: Pod and Seed Numbers per m^2 and Seed Weight of Two Cultivars, Second Peanut Crop, June 1988

Applied Lime	Pod Number			Seed Number			Seed Weight		
	Residual Lime (kg/ha) [1]								
	375	2250	6500	375	2250	6500	375	2250	6500
								(gram)	
				Kelinci					
0	177	248	282	298	562	663	0.19	0.25	0.26
375 b [2]	291	252	309	443	582	688	0.22	0.22	0.25
375 s	271	258	302	463	531	678	0.21	0.26	0.28
1000 b	272	245	263	483	545	631	0.23	0.23	0.25
1000 s	265	251	268	522	576	691	0.24	0.23	0.21
1000 d	256	249	315	493	529	718	0.27	0.25	0.23
$LSD_{0.05}$	(rl) [3] 170	(al) 68		(rl) 263	(al) 135		(rl) 0.07	(al) 0.05	
				Tapir					
0	203	301	232	213	503	417	0.35	0.32	0.33
375 b	251	184	314	350	317	460	0.30	0.30	0.38
375 s	229	164	274	360	296	396	0.28	0.32	0.41
1000 b	247	248	318	432	433	560	0.30	0.31	0.33
1000 s	242	275	162	392	505	285	0.31	0.30	0.35
1000 d	248	220	273	432	366	510	0.32	0.29	0.33
$LSD_{0.05}$	(rl) 62	(al) 78		(rl) 210	(al) 144		(rl) 0.25	(al) 0.11	

[1] the 'residual lime' was applied 3½ years earlier, 'applied lime' was applied 10 months before planting

[2] b=broadcast s=shallow d=deep [3] (rl)=residual lime (al)=applied lime

1979; Stansell and Pallas, 1985). However, a 70 day drought reduced the number of sound mature seed and greatly reduced seed weight.

The more favorable soil water conditions in the second crop increased the yields of Kelinci and Tapir cultivars mainly by increasing the number of pods and seeds. In the relatively low rainfall first crop, both peanut cultivars had fewer pods and seeds but had about equal individual seed weight and number of seeds per pod.

Yield Response to Aluminum and Calcium Saturation

Topsoil extractable Al, exchangeable Ca as well as Ca and Al saturation all correlated significantly with haulm, grain and pod yields. However, there was a big gap in the values of extractable Al and exchangeable Ca in both samplings. Higher coefficients of determination were obtained from the relationship of peanut yields with either Al or Ca saturations rather than with extractable Al or exchangeable Ca. Ca and Al saturation also correlated significantly with the shelling percentage except for the Florunner cultivar (data not shown). In the first peanut crop the haulm yields correlated better with Ca saturation than with Al saturation.

The responses of peanut pod and grain yields to Al saturation were described by a linear response plateau (Anderson and Nelson, 1981) while the responses to Ca saturation were described by a quadratic response. The models agree with the general concept that absence or lack of Al, an unessential element, will not harm crop performance. Yield reduction from excess lime has often been reported thus perhaps justifying the curvilinear response to Ca saturation (Mathur *et al.*, 1983; Anandan *et al.*, 1984).

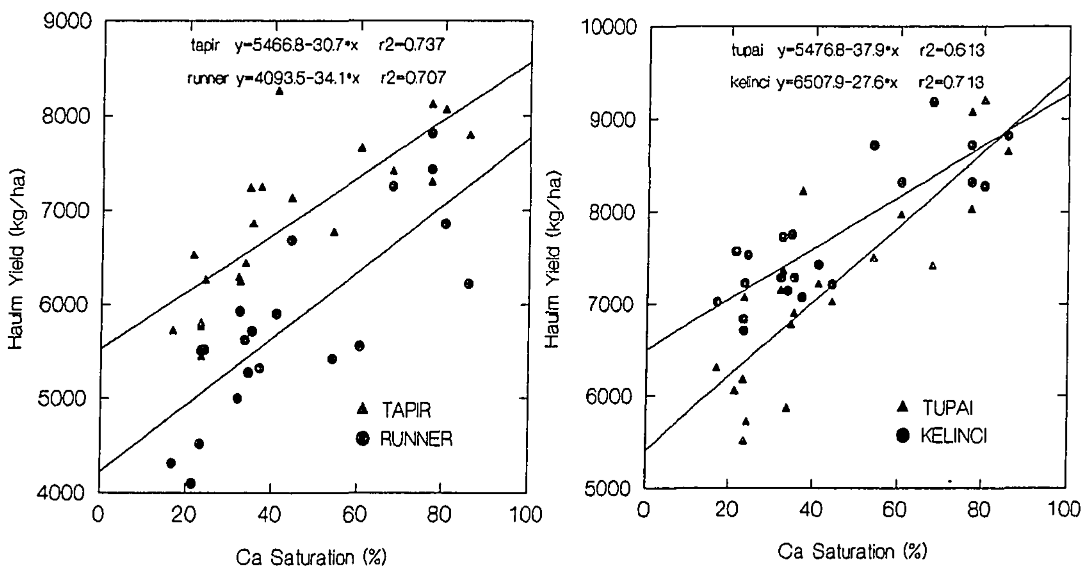


Figure 22: Effect of Ca Saturation on Haulm Yields of Four Peanut Cultivars

The coefficient of determination (R^2) of the linear-response-plateau and quadratic models were calculated using the equation described by Kvalset (1985). In the first crop both linear-response-plateau and quadratic models had equally high coefficients of determination. Based on the R^2 values, the pod and grain yields of Kelinci cultivar correlated better with Ca saturation than with Al saturation but the pod yield of Tupai cultivar seemed to correlate better with Al saturation (Figure 23, 24, 27 and 28). The pod and grain yields of Florunner and

Tapir as well as grain yield of Kelinci correlated equally well with either Al or Ca saturation. In the second crop, peanut yields responses to Al saturation were not as closely related as in the first crop. The pod and grain yields were more closely related to Al saturation than to Ca saturation (Figure 25, 26, 29 and 30).

Aluminum Saturation

The critical Al saturation for the various cultivars was estimated using a Quasi-Newton, nonlinear least square estimation procedure (NONLIN) in the SYSTAT statistical analysis package (Wilkinson, 1988). The following equation was fitted using this procedure:

$$\text{Yield} = A + B * (\text{ALS-C}) * (\text{ALS} > C) \qquad (6)$$

where: A = linear plateau yields

B = regression coefficient of linear response

C = critical aluminum saturation (intersection point)

ALS = percent aluminum saturation of the soil

Starting estimates for the linear plateau (A) and regression coefficient (B) as well as the critical Al saturation were made from a scatter diagram of the data. The model was fit and was then tested by varying estimated critical Al saturation values up and down 5 %. The model fitting was finalized when parameter estimates did not change and a graph of residuals showed no systematic trend.

Different levels of critical Al saturation were suggested for each cultivar. In the first crop when water stress may have occurred, Florunner and Tapir were the most sensitive, with a critical Al saturation 22 % for both pod and grain yields and Tupai was the most tolerant, with critical Al saturation 47 % for pod yield. The critical Al saturation for Tupai grain yield was a little lower at 44 %. For Kelinci cultivar the critical level was estimated at 34 % and 38 % for pod and grain yield respectively (Figure 23 & 24).

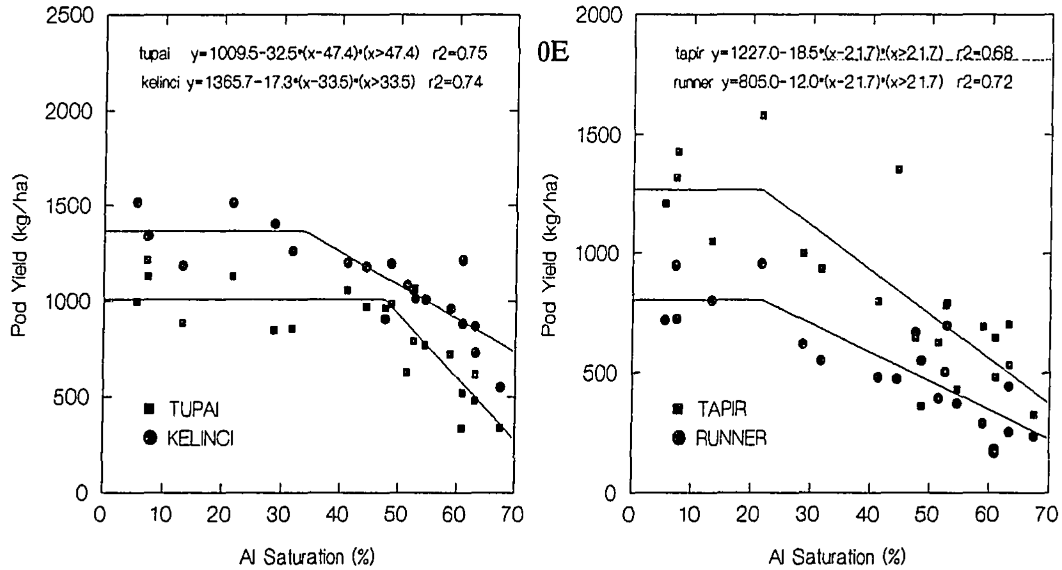


Figure 23: Pod Yields as Affected by Al Saturation in the Low Rainfall First Season

The critical Al saturation for Tapir was lower in the low rainfall first season than in earlier experiment, while it was about the same for Tupai (Figure 3). In the second crop, the critical Al saturation for both cultivars was higher than in the first crop. For Kelinci the critical value for pod yield was shifted from 34 in the first crop to 56 % in the second crop with predicted maximum yield increasing from 1390 kg to 1600 kg/ha. While for Tapir the critical Al saturation increased from 22 to 55 % with predicted maximum yield increasing from 1270 kg to 1340 kg. The critical Al saturation for Kelinci grain yield also changed from 38 % to 54 % with predicted maximum yield increasing from 870 kg to 960 kg (Figure 24).

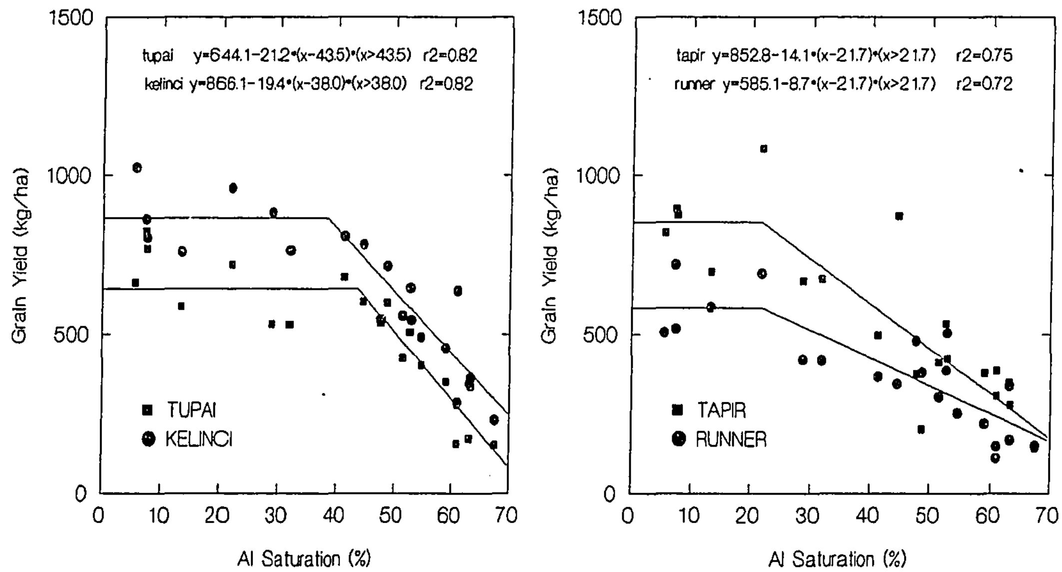


Figure 24: Grain Yields as Affected by Al Saturation in Low Rainfall First Season

The seed used for the second crop was that harvested from the first crop. New introduced cultivars sometimes perform better and are more adapted to the environment in the second generation. However, for the peanut cultivars in this experiment, that did not seem to be the case because the germination rate was lower in the second crop. The more favorable rainfall seemed to reduce the cultivars susceptibility to toxic Al. The critical Al saturation for Tapir increased from 22 when the rainfall was 555 mm to around 40 % when the rainfall was 905 mm and 63 % when the rainfall was 1095 mm. The grain yield of Tapir cultivar seemed to be the most sensitive to water stress. A comparison of yield response to Al saturation for the different seasons is presented in Figure 25 and 26.

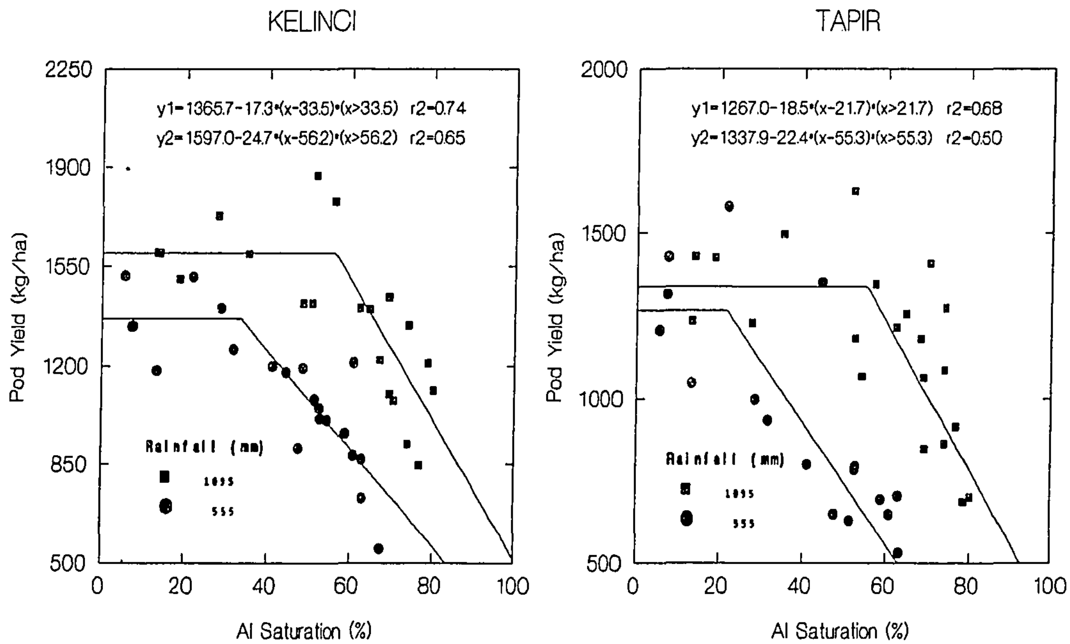


Figure 25: Comparison of Peanut Pod Yield Response to Al Saturation for the Different Seasons

Krizek and Foy (1988) reported that drought and Al have interacted in acid soils. Al toxicity became more apparent when plant were suffering from water stress. They speculate that the reduction of Al toxicity by supplying adequate soil moisture could be due to: (a) increased accessibility of Al-injured root to water and/or (b) increased uptake and transport of nutrients such as Ca, P and Mg. Peanut leaves contain less Ca when imposed to water stress if Ca is limited, but will have similar or even higher Ca when adequate Ca is available (Malathi Chari *et al.*, 1986). High Ca levels in leaves apparently helped the plant to cope with water stress.

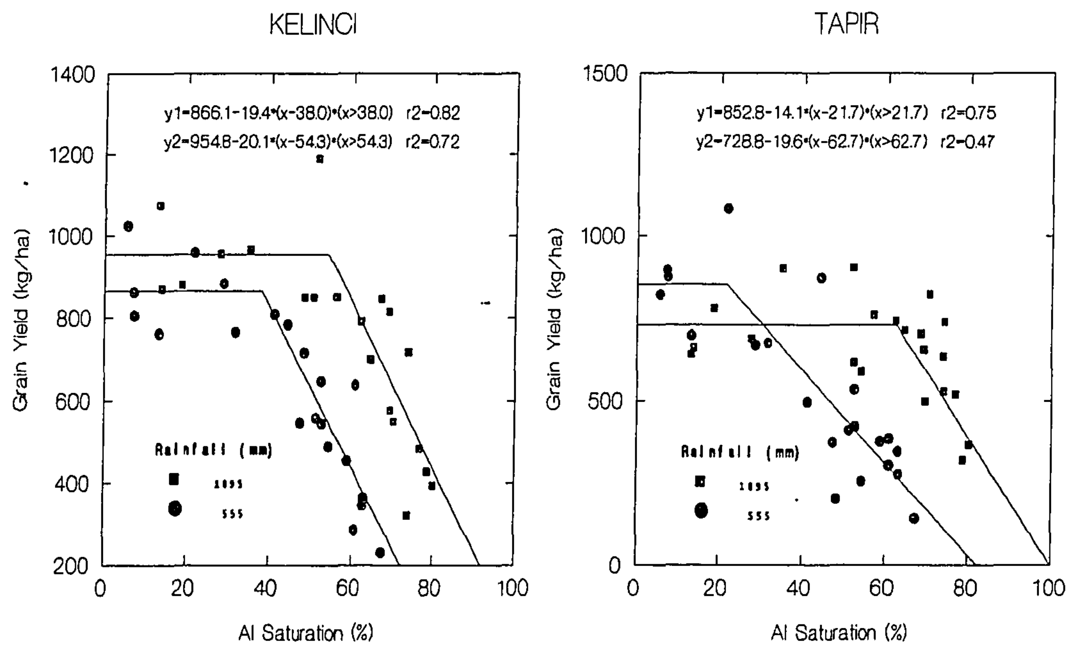


Figure 26: Comparison of Peanut Grain Yield Response to Al Saturation for the First (555 mm) and Second (1095 mm) Crops

Calcium Saturation

Peanut 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 (Cox *et al.*, 1982). This is because of the inherent thriftiness of the peanut plant in obtaining soil nutrient for its vegetative growth and because of it unique fruiting habit. Ca deficiency is common problem in acid soils, thus Ca saturation is sometimes used to express soil acidity.

The quadratic equations relating pod and grain yield responses to Ca saturation were also estimated using Quasi-Newton least square estimation procedure (NONLIN). The following equation was fitted using the procedure:

$$Yields = A + B * CAS + C * CAS^2 \qquad (7)$$

where: A = Yields at no Ca,

B = regression coefficient of linear response

C = regression coefficient for quadratic response and

CAS = percent calcium saturation percentage of the soil.

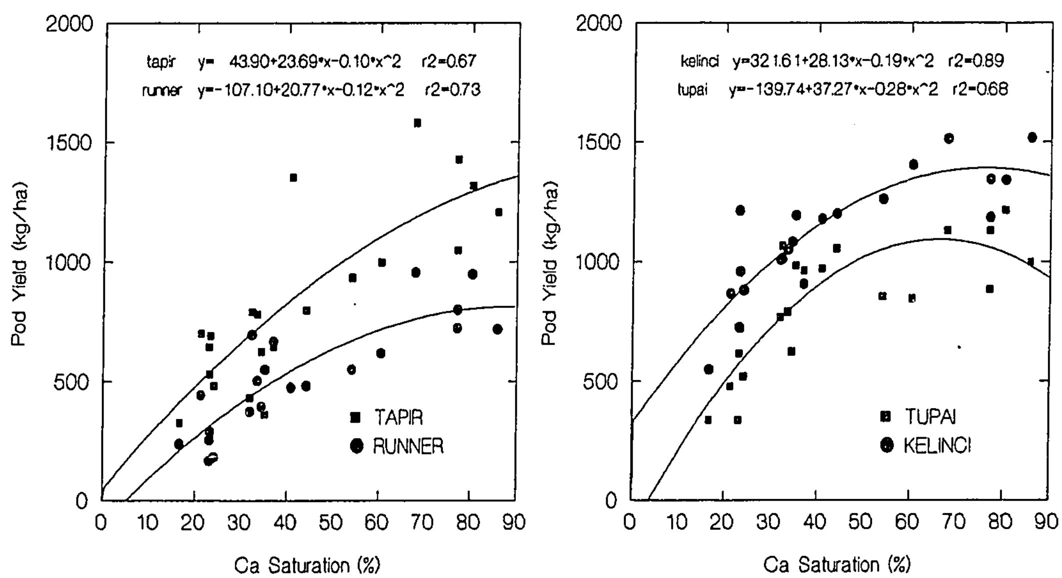


Figure 27: Relation of Peanut Pod Yield with Ca Saturation in the First Crop

The yield response of peanut to Ca saturation in the first crop is presented in Figure 27 and 28. Kelinci and Tupai pod yields declined after reaching maximum yields at 76 % and 66 %, respectively. While Tapir pod yield response was almost linear, Florunner maximum pod yield occurred at a higher level of 89 % Ca saturation. Except for Florunner, peanut grain yields correlated better with Ca saturation than did pod

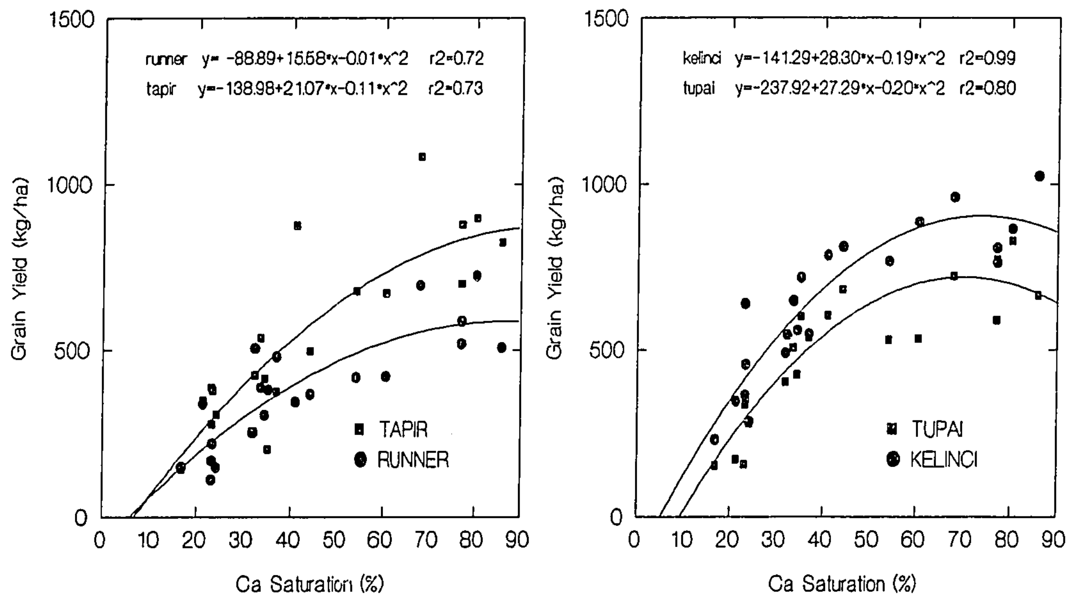


Figure 28: Relation of Peanut Grain Yield with Ca Saturation in the First Crop

yields. Maximum grain yields were also obtained at lower Ca saturation than were pod yields, except for Tapir cultivar in the first crop.

As the case of extractable Al and exchangeable Ca, Ca saturation values in the second sampling had a gap in Ca percentage between 39 and 58 %. Therefore, it was difficult to predict whether the relationship with peanut yields was quadratic or linear plateau. However, for comparison with the yield response of the first crop, quadratic models were fit. The Ca saturation for 90 % maximum yield was around 35 % and 45 % for Tapir and Kelinci, respectively, with slightly less for grain yield. In the more favorable weather the Ca saturation requirement for maximum yields for both cultivars was considerably less. The Ca saturation requirement for 90 % maximum yield decreased from about 90 % in the first crop to about 50 % in the second crop (Figure 29 and 30).

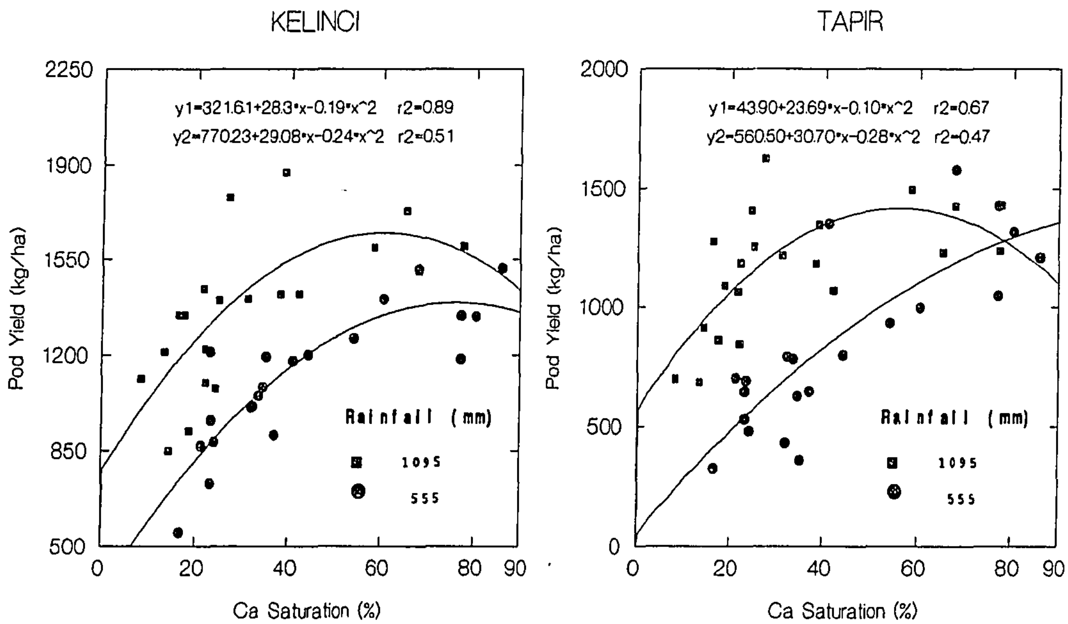


Figure 29: Comparison of Pod Yield with Responses to Ca Saturation for the First Crop (555 mm) and Second Crop (1095 mm)

Based on studies in solution culture, Wolt and Adams (1979) used the activity ratio of Ca to total cation in soil solution to express critical Ca levels for vegetative and reproductive growth of Florunner peanut. The critical levels for flower fertility and pod filling was corresponding to around 40 % or more soil Ca saturation. This value is in agreement with the Ca saturation for maximum yields of the second crop but far less than the value of the first crop. Because Ca is passively absorbed by the plant, higher soil moisture usually facilitates absorption of both Ca and water (Mengel and Kirkby, 1982). Drought has been reported to induced Ca deficiency (Gillier, 1969; Rajendrudu and William, 1987). Water stress greatly reduced the Ca content of peanut leaves (Malathi Chari *et al.*, 1986) and seed (Stansel and Pallas , 1985; Wright, 1989). Higher soil exchangeable Ca therefore appears to be generally required to satisfy the plant requirement in soil with less available water.

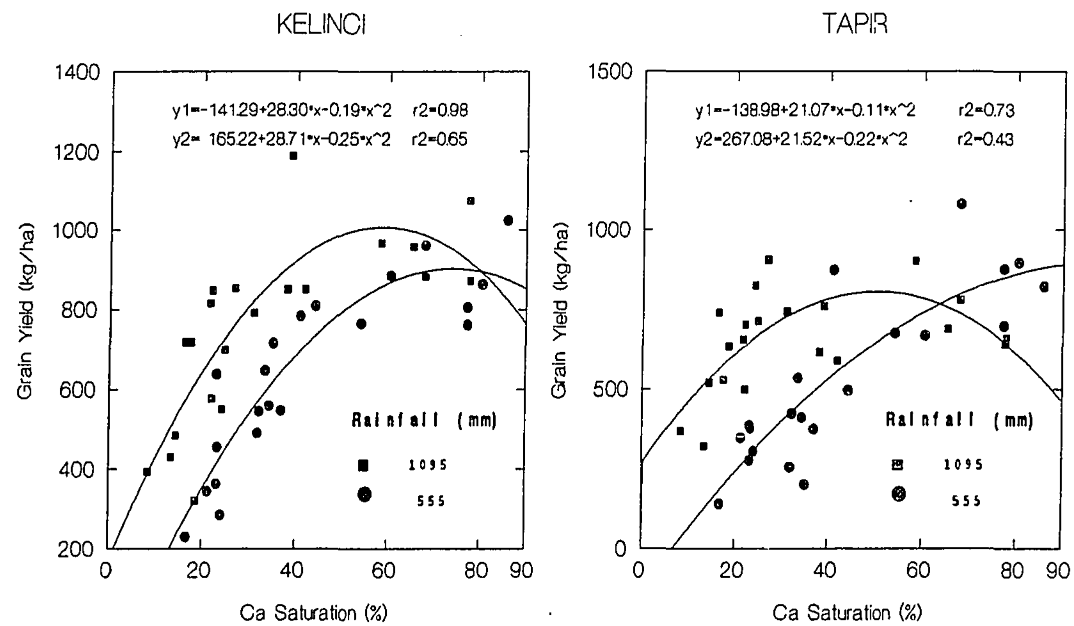


Figure 30: Comparison of Grain Yield Response to Ca Saturation for the Different Seasons

Yields of the second crop were higher, particularly in the lower lime treatments, probably due to increasing numbers of pods and grain per unit area. This probably reflects the more favorable soil water conditions during the second crop, and more Ca available for pegging and fruiting. Calculated from Wright's (1989) experiment the seed of McCubin and Gajah peanut cultivars contained more than three times higher Ca when grown in field capacity (13 % gravimetric water content) than in air dry (3 % gravimetric water content) of coarse sand podding zone fertilized with the rate equivalent to 4 tons gypsum/ha. While the seed of Robut cultivar contained more than twice higher Ca in the more favorable soil moisture, although the seed number and weight were not significantly different.

Yield Response to Soil Solution Calcium

The soil samples for soil solution analysis were taken after the second peanut crop was harvested. Consequently, solution concentration may have been lower than those occurring during the crop growth with possible exception of Al. Almost 4 years after lime application, the soil solution Ca of the samples was higher with the increasing rate of lime treatments. In the sample from the high lime plot the soil solution Ca was over 4 times higher than that in the low lime plot (Table 11).

Both pod and grain yield increased with increasing soil solution Ca. Although the data are sparse, the pod yield of Kelinci increased until the highest soil solution Ca level but reached a plateau for Tapir cultivar. The critical level for maximum grain yield of both cultivars seemed to be between 10 and 20 mg Ca/L. Solution Ca concentration *per se* was not an adequate parameter for describing plant growth response to Ca level (Wolt and Adams, 1979). These workers observed that vegetative growth and pod filling of Florunner peanut correlated better with activity ratio of Ca and total cation than Ca *per se*.

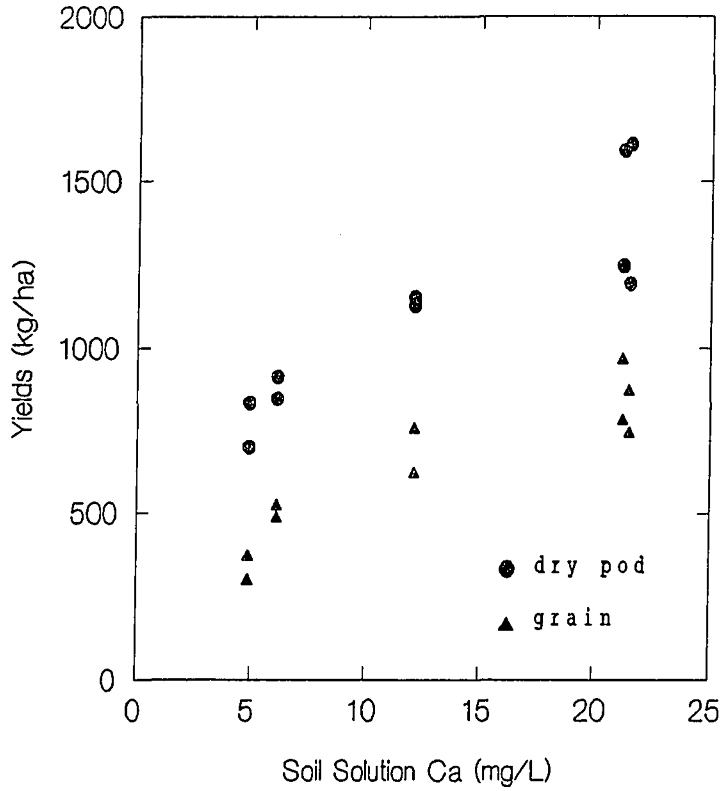


Figure 31: The Relation between Soil Solution Ca with Pod and Grain Yields

Possible Expansion of the Knowledge Base of Acidity Decision Support System (ADSS)

In the Acididy Decision Support System (ADSS) peanut is considered to be less sensitive to soil acidity than other grain legumes such as soybean or mungbean. The critical Al saturation was estimated to be 40 % where soil amelioration such as liming is required for peanut cultivation on soil with higher Al saturation percentage. The recommendation for peanut lime requirement when grown on acid soil is based on the soil Al saturation percentage, effective cation exchange capacity, depth of lime incorporation, soil bulk density and quality of liming materials (Yost *et al.*, 1987). Although peanut response to liming could well be expressed in term of Al saturation percentage, there are strong indications that Ca plays a crucial role, particularly when water stress occurs. Aluminum concentration to the extent of that found in the experiment soil at Sitiung did seem to hamper peanut root growth.

Calcium levels, although present in levels considered more than sufficient for peanut, may be limiting when the soil water is inadequate. The Tapir cultivar, on the high lime treatment, produced a higher yield in the lower rainfall first crop than in the second season with a more favorable water supply. This indicates that a high lime treatment could compensate the yield reduction due to water stress.

Because rainfall is the only source of water in rainfed agriculture, the rainfall during the peanut growing period is another qualifier in determining lime requirement that should be included in ADSS. The water supply not only will affect the amount of lime to be applied but also the method of application. Broadcasting the lime on the soil surface or deep application produced less yield compared to shallow incorporation when a mild water stress occur. Incorporating the lime to moist soil within the reach of peanut peg helps the plant to cope with the dry soil surface.

The weather in the future growing seasons is very difficult to predict. Knowing the common pattern of rainfall distribution in Sitiung area, the rainfall can be inferred through the time or month of planting or even as the order of the crops grown after the commence of rainy season. The common cropping pattern in the area is upland rice followed by secondary crops. If peanut is planted after the upland rice harvest, a favorable weather can be expected, but if it is planted as the third crop there is possibility of a water stress.

In soils where Al is not hampering peanut growth, lime requirement is more as source of Ca nutrient than amelioration of soil acidity. Therefore, it is not necessary to apply lime deeper than the podding zone. Broadcasting lime later after peanut flowering as stated in the note of one of the rule of the ADSS is an appropriate strategy. Because the amount required is not as high as for soil amelioration the more soluble gypsum can be considered as another source of liming materials.

Large-seeded cultivars were reported to require more Ca than small seeded cultivars (Colwell and Brady, 1945; Walker *et al.*, 1976; Balasubramanian and Yayock, 1981; Hobman, 1984). Although only small seeded cultivars were tested in the cultivar screening experiment, there were three distinct responses of peanut cultivars to liming. The experiment provided some hints that peanut cultivars of the similar seed size can differ in Ca requirement. This was probably due to the different ability of the peanut pod and peg to absorb Ca from relatively dry soil as reported by Wright (1989). As more information is collected on the different cultivar's response to different rates of lime, the peanut cultivar should be added as another qualifier in the expert system.

Peanut Root Growth in Solution Culture

In the field experiment, neither the first or second peanut crops showed any symptoms of root growth reduction due to soil acidity. This could be because of the relative tolerant nature of peanut to soil acidity or because the toxic level of Al in the soil was not sufficiently high to cause damage. To determine which was the main factor affecting the plant root response in the field, the peanut cultivars were grown in growth chamber experiment in solution with high Al and low Ca.

Solution pH

The pH change in solutions are likely to be greater than in soils because of the lack of an exchange complex to absorb and desorb hydrogen ions. The solution pH of all treatments with initial pH 4.0 increased at both the second and last measurements (Figure 32). The pH increases were greater with no Al treatment and least with the higher Al levels. Solutions with an initial pH of 5.0 increased by the second measurement and decreased by the last measurement with no or low levels of Al. When no Ca was added, the pH of the solution increased and remained higher than the initial pH until harvest. The pH of solution with high Al concentration decreased after the first measurement.

The direction of pH shift is thought to be affected by unequal absorption of anions and cations by the root (Nye, 1986). More anion absorption should lead to a pH increase and more cation absorption should lead to a pH decrease. However, species differences in nutrient absorption and assimilation may be important, since it has been consistently observed in non-nodulated jackbean (*Canavalia ensiformis*) that the pH of the nutrient solution decreased markedly with time even when all the nitrogen was supplied by nitrate (Asher and Edward, 1983). In the present experiment no nutrient was applied to the solution other than Al and Ca in form of $CaSO_4$ and $AlCl_3$.

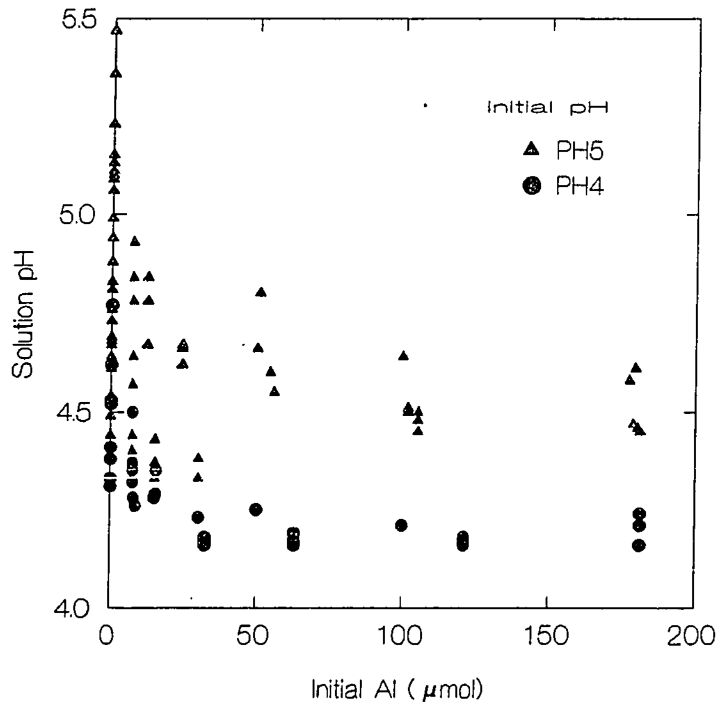


Figure 32: Changes in Solution pH after 4 Days

Because most plants, particularly legumes, require more Ca than both S and Cl, peanut probably absorbed more cations than anions from the solution. The pH shift of the solution was also affected by the initial pH. The solution pH decreased where initial pH was 5.0 but increased where it was 4.0.

Aluminum and Calcium

At initial pH 4.0 and 5.0 both Al and Ca concentrations decreased with time. There were no significant differences in the changes of Al and Ca concentrations between replications and among peanut cultivars. At an initial pH 5.0, the Al decreased more rapidly than when the initial pH was 4.0 (Appendix 3). A calculation of solubility indicated that some of the Al in the solution may have precipitated at pH 5.0.

The depletion of Ca was greater in solutions with initial pH of 4.0 compared to solutions with initial pH of 5.0. The Ca requirement for sustained growth has been reported to be higher in low pH solution because its role as a detoxicant to acidity (Burstorm, 1952). Albeit not statistically significant, the Ca reduction may have been greater at lower Al levels. This probably due the better root growth and more Ca absorption.

The decrease in Ca was greater in the first two days in Al treated solution than in no Al solutions. Where no Al was added a greater reduction occurred in the last two days. This probably indicates that Ca uptake was greater when the plants were larger.

Monomeric Aluminum Species

Ion activity is often a better indicator of plant response to particular element compared to its activity (Wolt and Adams, 198.; Noble *et al.*, 1988). The activity and species of monomeric Al in the solution was calculated using 'Alcal program' developed by Dr. N. V. Hue of the University of Hawaii. The program written in FORTRAN uses pK values of 34.31 for $Al(OH)_3$, 120.44 for $(Al(_4(OH)_{10}SO_4$, and 30.63 for

$Al(OH)_2H_2PO_4$. To run the program, P concentration in the solution may not be 0, therefore although no P was applied to the solution, a very low concentration of 0.001 mg/L of P was given at every run.

In the solution with initial pH of 4.0, Al^{3+} was the dominant Al species followed by $Al(OH)_2^+$ and $Al(OH)^{2+}$ (Appendix 3). The activity of these Al species decreased by time at second and fourth days measurement. There was no $Al(OH)_3$ species was measured initially but a very low activity was in the higher Al treatments in the last measurement.

In solution with initial pH 5.0 the dominant Al species was $Al(OH)_2^+$ that activity decreased by time in accord with decreasing pH (Appendix 4). The activity of Al^{3+} and $Al(OH)^{2+}$ were relatively low which increased by time. Substantial $Al(OH)_3$ activity was calculated since the 0 day but also decreased by time. Lower $AlSO_4$ activity was measured compared to the solution with initial pH 4.0 but the activity was increased by time.

The Plant Response to Aluminum

All the peanut cultivars had better root growth in solutions with initial concentration of 7.5 μM Al or activity of 7.1 to 8.2 μM than in solutions without Al. Root weight, length of taproot and lateral roots were higher with 7.5 μM Al compared to no Al for all cultivars. In solutions with an initial pH of 5.0, Kelinci and Tupai cultivars produced longer tap and lateral roots at initial concentration of 15 μM or activity between 11.8 to 14.9 μM Al than the lower Al concentrations. At low levels Al seemed to stimulate the root growth particularly in solutions with initial pH 4.0 (Table 19).

Table 19: Root Weight, Lateral and Tap Root Length of the Three Cultivars

	0 μM Ca			25 μM Ca		
Initial Al Activity	Root weight	Lateral Root	Tap Root	Root Weight	Lateral Root	Tap Root
(μM)	(gram)	(mm)		(gram)	(mm)	
			INITIAL pH 4.0			
			KELINCI			
0	1.50	17	53	2.19	30	98
8.3	1.71	25	63	2.49	55	107
14.9	1.31	22	48	1.79	45	88
LSD $_{0.05}$	(rw) 0.90	(tr) 25	(lr) 20			
			TUPAI			
0	1.32	19	46	1.61	29	67
7.1	1.51	29	70	2.21	40	92
13.8	1.13	13	51	1.73	36	79
LSD $_{0.05}$	(rw) 0.75	(tr) 21	(lr) 17			
			TAPIR			
0	1.36	24	56	2.00	41	80
6.6	1.59	30	66	2.36	61	93
13.1	1.27	18	47	2.35	50	84
LSD $_{0.05}$	(rw) 0.81	(tr) 30	(lr) 14			
			INITIAL pH 5.0			
			KELINCI			
0	2.19	76	40	2.94	87	65
7.4	1.26	49	21	2.80	89	82
12.1	1.15	48	26	2.57	99	95
LSD $_{0.05}$	(rw) 0.88	(tr) 14	(lr) 10			
			TUPAI			
0	0.91	37	20	3.08	79	55
7.2	0.95	38	21	2.26	75	63
12.0	1.39	42	21	1.88	80	74
LSD $_{0.05}$	(rw) 0.50	(tr) 17	(lr) 11			
			TAPIR			
0	1.09	56	29	2.12	91	45
7.2	0.79	42	17	2.26	88	70
11.9	1.36	56	17	1.56	84	45
LSD $_{0.05}$	(rw) 1.15	(tr) 13	(lr) 10			

rw=root weight tr=tap root lr=lateral root

Aluminum is generally regarded as non-essential for plant growth, but low concentrations can increase growth or produce other desired effects (Foy and Fleming, 1978). Higher Al concentrations both in shoot and root were associated with higher yield of peanut (Anandan *et al.*, 1985). In an over limed soil, peanut absorbed half the amount of Al in the root and a quarter in the shoot compared to the treatment that produced highest yield.

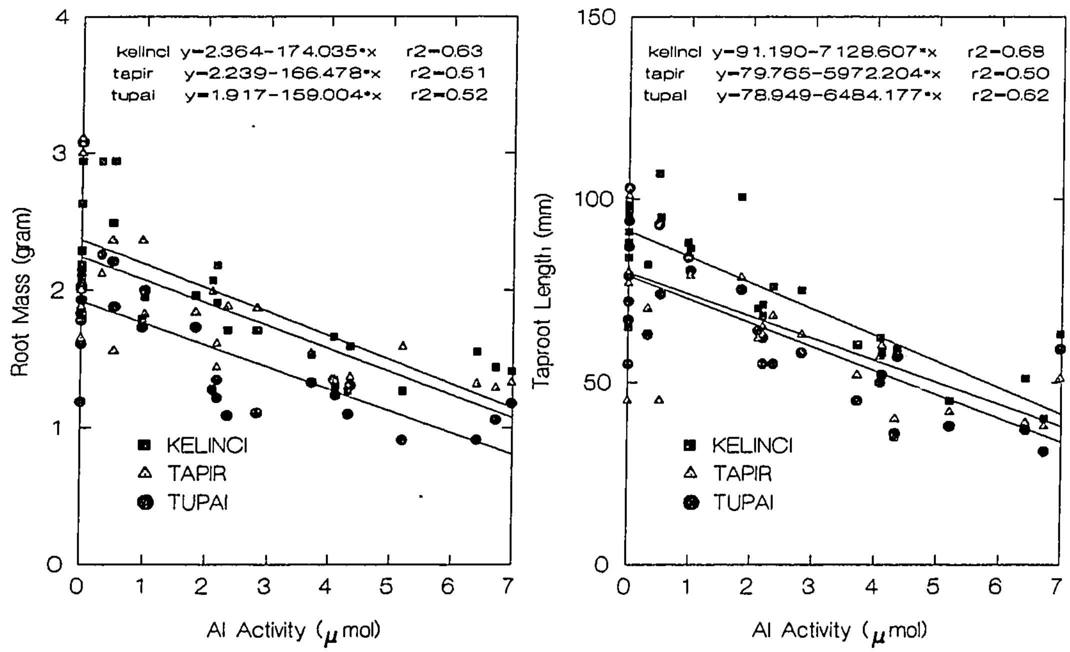


Figure 33: Root Weight and Taproot Length in Solution as Affected $Al(OH)^{2+}$ Activity

In solutions with initial pH 4.0, Al began reducing root weight and tap root length at the 15 μM initial treatment while in solutions with initial pH 5.0 root growth began to decline at the higher initial level of 50 μM Al (Table 20 and 21). When Al concentration in solution was increased, the roots became stiff and tips were distorted.

Of all the monomeric Al species $Al(OH)^{2+}$ seemed to affect the peanut root mass and tap root length most, with coefficient of determination ranged from 0.509 for the root mass of Tapir to 0.634 for root mass of Kelinci and 0.503 for the taproot length of Tapir to 0.684 for the taproot length of Kelinci. For Tupai cultivar the coefficient of determination were 0.523 and 0.617 for root mass and taproot length, respectively. Both root mass and taproot length have poor correlation with $Al(OH)_2^+$ but have relatively good correlation with sum of activity of monomeric Al. Aluminum did not seem to affect the weight of the top part of the three peanut cultivars. No significant differences were observed in the top weights of the three peanut cultivars.

The Plant Response to Calcium

Solutions without Ca had very poor root growth, even in solutions with initial pH 5.0 (Table 19). Some of the root tips were appeared dead and rotted. The peanuts developed a few short lateral roots, which probably kept the plant alive. Calcium is necessary for sustained root growth (Rios and Pearson, 1964).

The increase in root weight and length of Tupai cultivar in the 25 μM (1 mg/L) initial Ca treatment was not as high as with the Kelinci and Tapir cultivars. This may indicate that Tupai requires more Ca than Kelinci and Tapir. The Ca requirement for root systems was apparently very low if other essential ions were in balance and no toxic ions were present. For wheat root systems, only 1 μM or 0.04 mg/L was required for cell division and 10 μM or 0.40 mg/L for cell elongation (Burstorm, 1952). Lund (1970) reported no differences in soybean root lengths in solutions containing 0.25 to 156 mg/L

Table 20. Root Weight and Tap Root Length of the Peanut at Higher Al and Ca Levels

Initial Al Activity	Solution Calcium (lM) 50	150	250	50	150	250
	Root Weight			Tap Root Length		
(lM)		(gram)			(mm)	
			INITIAL pH 4.0			
			KELINCI			
0	2.28	2.08	2.29	96	84	95
57.4	1.53	1.71	1.71	60	75	76
90.8	1.44	1.27	1.27	40	45	36
148.3			1.55			51
	$LSD_{0.05}$	0.65		$LSD_{0.05}$	26	
			TUPAI			
0	2.01	1.93	1.78	103	94	87
55.4	1.33	1.11	1.09	45	58	55
101.2	1.06	0.91	1.10	31	38	36
154.3			0.91			37
	$LSD_{0.05}$	0.62		$LSD_{0.05}$	20	
			TAPIR			
0	3.00	3.07	3.11	103	100	101
54.9	1.54	1.87	1.88	52	63	68
100.3	1.29	1.59	1.30	38	42	40
149.5			1.32			39
	$LSD_{0.05}$	0.99		$LSD_{0.05}$	25	
			INITIAL pH 5.0			
			KELINCI			
0	2.63	2.14	2.07	98	91	88
49.1	2.07	2.18	1.91	70	71	68
101.4	1.59	1.66	1.30	59	62	58
168.0			1.41			63
	$LSD_{0.05}$	0.53		$LSD_{0.05}$	18	
			TUPAI			
0	2.03	1.19	1.83	79	72	79
51.8	1.28	1.35	1.22	64	55	62
96.7	1.31	1.35	1.24	57	50	52
169.2			1.48			59
	$LSD_{0.05}$	0.46		$LSD_{0.05}$	19	
			TAPIR			
0	1.88	2.16	1.65	80	77	65
52.6	1.99	1.44	1.61	62	65	63
98.8	1.37	1.35	1.34	59	57	60
171.2			1.33			51
	$LSD_{0.05}$	0.49		$LSD_{0.05}$	8	

(39 mM) Ca. But growth was slightly reduced at the 0.05 mg/L (1.25 μM) level. Howard and Adams (1965) however, reported that the Ca requirement for cotton root penetration into subsoil was dependent upon the Ca/total cation ratio rather than Ca concentration *per se*. Ca/total cations ratio of 0.10 and 0.15 was apparently required in soil solution *in situ* and in nutrient solution. In the present study increasing solution Ca from 50 to 150 μM reduced the toxic effect of Al when the Al level was 50 μM at initial pH 4.0. There was no further reduction of toxic effect of Al when solution Ca increased from 150 to 250 μM either at initial pH 4.0 or 5.0 (Table 20).

GENERAL SUMMARY AND CONCLUSIONS

As sources of protein and oil in the diet, grain legumes are indispensable crops in many developing countries. Peanut and soybean are the most important legumes cultivated in the world. Of the two grain legume peanut is better adapted to environmental stress than is soybean. Peanut is also reported to be relatively tolerant to soil fertility problems associated with soil acidity.

Indonesia was a net exporter of peanut in early 1970s. Although rice production has exceeded the country's need, Indonesia is now a net importer of peanut. Peanuts are cultivated mainly in established agricultural land which is intensively utilized throughout the year. Therefore, to increase peanut production by expanding the area of cultivation, Indonesia has to look to newly opened agricultural land in transmigration areas. Recently a massive program was started to encourage transmigrant farmers to grow soybean. To date there has been little such encouragement for peanut, partly due to its susceptibility to wild pigs that damage crops in most of transmigration areas.

Most of the soils in the new agricultural lands of Indonesia are acid, low fertility and often with toxic levels of Al. Liming is commonly practiced to alleviate soil problems associated with soil acidity. The direct and residual effects of lime applications and the effect of depth of incorporation on selected soil chemical properties and peanut performance were studied in field experiments on an acid soil of Sitiung, West Sumatra.

In the first field experiment, 8 bunch peanut cultivars were tested on plots with 0; 500 and 2000 kg lime /ha, which reduced the soil Al saturation from about 80 % to about 60 and 20 %. Poor yields were harvested from all the cultivars, probably due to the low rainfall during flowering and pod-filling stages that might have hampered Ca absorption. Of the cultivars, Pelanduk and Rusa were the least sensitive to Al saturation and Banteng was the most sensitive. Anoa, Gajah, Tapir, Tuban and Tupai were intermediate in sensitivity as measured by pod and grain yields.

In the second field experiment, 6 combinations of lime rate and depth of incorporation (control; 375 kg/ha broadcast; 375 kg/ha shallow incorporated; 1000 kg/ha broadcast; 1000 kg/ha shallow incorporated and 1000 kg/ha deeply incorporated) were re-applied into plots that had been limed with 375; 2250 and 6500 kg/ha, respectively, 29 months earlier. The plots were planted with Florunner, Kelinci, Tapir and Tupai peanut cultivars. In the following rainy season, following the local cropping pattern, the plots were planted with Danau Dibawah and Srondol rice and then planted again with Kelinci and Tapir peanut. A total of 24 kg Mg/ha, 80 kg P/ha and 60 kg K/ha were applied for the three crops as basal fertilizers. Peanut roots were sampled from different depths at 25, 50, 75 and 100 days after planting.

The higher rates of lime (2.25 and 6.5 ton/ha) applied 29 months earlier still maintained relatively high exchangeable Ca and low extractable Al as well as higher soil pH. Lime also increased the soil effective cation exchange capacity (ECEC), and with continuous intensive cultivation the soil ECEC increased until 42 months after lime application. With increasing ECEC the surface soil retained more potassium (K) and magnesium (Mg) but somewhat less phosphate and sulfate. The increase in ECEC and surface soil Mg retention were more pronounced a year after lime application. One ton of lime/ha applied 29 months later did not change the soil pH significantly but increased exchangeable Ca and reduced Al saturation. In about a year after application the beneficial effects of lime extended to deeper soil layers as indicated by increasing Ca and decreasing Al saturation at the 15 to 30 cm depth.

Although the Al saturation was relatively high, low Al was measured in the soil solution which probably due to the relatively high soluble oxidizable carbon that could have increased the soil solution pH. Application of 24 kg Mg/ha seemed to be adequate only for 3 crops. The 20 kg K/ha seemed to be inadequate for the second peanut crop because the soil exchangeable K after harvest was less than the value before K application.

In both peanut crops and for all samplings, over 90 % of the root mass was found in the top 20 cm of the surface. At 100 days after planting about 80 % of the root mass of the second peanut crop were found in the top 10 cm of the soil surface. Lime treatments did not seem to affect the peanut root growth and distribution in either season. Neither did the lime improve peanut nodulation. Peanut root mass and length started to decline between 75 to 100 days after planting when nearing harvest. Peanut contributed about 0.5 ton organic material/ha in each crop by the roots left in the soil after harvest.

Both lime treatments have increased haulm, pod and grain yields of the first peanut crop but only the earlier applied lime increased the haulm yield of the second crop. Application of 2.25 and 6.5 ton lime/ha still increased peanut pod and grain yields as the seventh and ninth crops in the rotation. Application of 375 and 1000 kg lime/ha also increased peanut pod and grain yields as the first and third crop.

In all lime treatments of the first crop, Florunner produced the least yield, while Kelinci produced the most followed by Tapir and Tupai. With more rainfall in the second crop, higher yields were harvested from Kelinci and Tapir cultivars. There was no significant difference in yield between the two cultivars.

In the relatively dry period of the first peanut crop, the shallow incorporation of lime increased the peanut yield over the broadcast treatment. However, incorporating the lime even deeper might have reduced the yield. The relatively moist subsoil probably facilitated Ca absorption by peanut pegs during reproductive stage.

The peanut yields were correlated significantly with topsoil Al and Ca saturations. Weather conditions contrasted sharply between the two periods and probably changed the responses to Al and Ca saturations. The coefficient of determinations of peanut yield responses were higher for Ca saturation than Al saturation for the low rainfall season (555 mm). In the higher rainfall season (1095 mm), however the coefficient of determination was higher with Al saturation than with Ca saturation.

In the drier conditions during the first crop, the critical Al saturation values for Florunner and Tapir peanut cultivars was about 20 % for pod and grain yields, while the critical Al saturation for Kelinci was over 30 % and over 40 % for Tupai. The higher rainfall of the second crop apparently shifted the critical Al saturation of Kelinci and Tapir cultivars to over 50 %.

In the first crop Florunner and Tapir yield responses to Ca saturation were almost linear, but Kelinci yields started to decline at a Ca saturation of 74 % and Tupai at about 65 %. In the second crop the yield of both Tapir and Kelinci cultivars declined at a lower Ca saturation of 50 %. Except for Tapir cultivars in the second crop, the regression equation developed in this study predicted no peanut yield without Ca.

In growth chamber experiments, Kelinci, Tapir and Tupai peanut cultivars were planted in solution with excessively low Ca and high Al at initial pH of 4.0 and 5.0. After 4 days the solution pH with initial pH 4.0 increased, but those with initial pH 5.0 decreased. Both Al and Ca concentrations in solution decreased with time. The reduction in Al was greater where the initial pH was 5.0 but Ca reduction was greater in solutions with initial pH 4.0. Calcium reduction was also greater at lower Al concentrations and in the last two days. These data suggest that there is a higher Ca requirement at lower pH and that there was more absorption with larger plants.

Although root growth ceased in solutions without Ca, the Ca requirement for peanut root growth was relatively low. About 25 μM Ca was adequate to sustain root growth until eight days after germination. A relatively low concentration of Al enhanced peanut root growth. But at an initial pH of 4.0, Al began reducing root weight and tap root length at 15 μM, while at initial pH 5.0 root growth only began to decline at an Al level of 50 μM. Peanut root growth correlated better with $Al(OH)^{2+}$ or sum of monomeric Al species than other individual monomeric Al species. Increasing the Ca concentration from 50 μM to 150 μM reduced the toxic effect of Al but further increase to 250 μM did not change the peanut root growth response to Al.

APPENDIX 1

Kelinci peanut root mass at Sitiung, 1988

Lime	25 dap		50 dap		
	Soil Depth (cm)				
Rate	0-10	10-20	0-10	10-20	20-30
		(gram)			
0	1.087	0.181	2.587	0.273	0.169
375 B	0.942	0.106	2.445	0.278	0.164
375 S	1.512	0.135	2.492	0.142	0.130
1000 B	1.282	0.173	3.261	0.324	0.172
1000 S	1.330	0.258	2.607	0.555	0.239
1000 D	1.030	0.184	2.536	0.183	0.254
6500 *	1.030	0.108	2.675	0.257	0.200
$\text{LSD}_{0.05}$	0.386	0.178	1.217	0.342	0.159
		75 dap			
	0-10	10-20	20-30	30-40	40-50
0	2.869	0.699	0.185	0.107	0.021
375 B	2.548	0.425	0.152	0.064	0.019
375 S	2.929	0.363	0.213	0.094	0.037
1000 B	1.940	0.313	0.198	0.083	0.040
1000 S	3.060	0.394	0.076	0.057	0.020
1000 D	3.119	0.353	0.167	0.069	0.026
6500 *	2.635	0.190	0.078	0.092	0.058
$\text{LSD}_{0.05}$	0.981	0.443	0.178	0.097	0.046
		100 dap			
	0-10	10-20	20-30	30-40	40-50
0	1.930	0.175	0.113	0.096	0.066
375 B	2.831	0.541	0.194	0.115	0.075
375 S	2.189	0.309	0.144	0.068	0.054
1000 B	2.318	0.436	0.131	0.173	0.120
1000 S	2.345	0.346	0.167	0.124	0.040
1000 D	2.144	0.222	0.105	0.076	0.049
6500 *	2.191	0.349	0.157	0.068	0.046
$\text{LSD}_{0.05}$	1.056	0.225	0.113	0.097	0.067

*) applied 29 months earlier

APPENDIX 2

Tapir peanut root mass at Sitiung, 1988

Lime Rate	25 dap 0-10	25 dap 10-20	50 dap 0-10	50 dap 10-20	50 dap 20-30
	Soil Depth (cm)				
	(gram)				
0	1.550	0.231	2.960	0.209	0.197
375 B	1.047	0.110	3.274	0.224	0.151
375 S	1.083	0.142	3.356	0.258	0.183
1000 B	1.100	0.181	3.038	0.376	0.176
1000 S	1.401	0.232	3.768	0.221	0.117
1000 D	1.369	0.081	2.714	0.299	0.109
6500 *	1.138	0.089	2.750	0.249	0.192
LSD $_{0.05}$	0.668	0.238	1.070	0.211	0.159
	75 dap				
	0-10	10-20	20-30	30-40	40-50
0	2.937	0.396	0.260	0.091	0.028
375 B	2.789	0.233	0.194	0.193	0.051
375 S	2.370	0.142	0.073	0.052	0.024
1000 B	2.593	0.372	0.121	0.050	0.021
1000 S	2.520	0.276	0.088	0.058	0.021
1000 D	3.331	0.305	0.329	0.090	0.036
6500 *	1.735	0.250	0.063	0.046	0.027
LSD $_{0.05}$	1.217	0.393	0.292	0.069	0.039
	100 dap				
	0-10	10-20	20-30	30-40	40-50
0	2.327	0.114	0.052	0.076	0.037
375 B	2.198	0.184	0.155	0.123	0.080
375 S	2.466	0.339	0.087	0.050	0.025
1000 B	2.344	0.333	0.140	0.072	0.037
1000 S	2.329	0.299	0.071	0.038	0.030
1000 D	2.013	0.344	0.086	0.056	0.036
6500 *	1.859	0.198	0.115	0.065	0.046
LSD $_{0.05}$	0.651	0.203	0.113	0.062	0.052

*) applied 29 months earlier

APPENDIX 3

Solution Aluminum and Calcium at 0; 2 and 4 days

Intended Treatment		Aluminum			Calcium		
		day after start					
Al	Ca	0	2	4	0	2	4
				(mg/L)			
				Initial pH 4			
0	0	0.00	0.00	0.00	0.00	0.00	0.00
0	1	0.00	0.00	0.00	1.01	0.83	0.07
0	2	0.00	0.00	0.00	1.92	1.61	0.89
0	6	0.00	0.00	0.00	5.89	5.52	3.91
0	10	0.00	0.00	0.00	10.01	9.40	7.25
0.2	0	0.23	0.19	0.15	0.00	0.00	0.00
0.2	1	0.21	0.19	0.15	0.98	0.59	0.14
0.2	2	0.20	0.20	0.15	1.79	1.49	1.04
0.4	0	0.42	0.34	0.28	0.00	0.00	0.00
0.4	1	0.41	0.36	0.26	0.87	0.51	0.31
0.4	2	0.40	0.35	0.28	1.78	1.47	1.12
0.8	2	0.87	0.67	0.54	1.93	1.61	1.44
1.35*	2	1.79	1.72	1.69	2.01	1.68	1.41
1.35*	6	1.79	1.76	1.65	6.02	5.72	5.11
1.35*	10	1.79	1.76	1.72	10.12	9.84	9.13
2.7*	2	3.29	3.22	3.18	2.02	1.72	1.59
2.7*	6	3.29	3.18	3.15	6.03	5.78	5.07
2.7*	10	3.39	3.32	3.29	10.11	9.94	9.51
5.4	10	4.89	4.78	4.78	10.01	9.60	9.51
				Initial PH 5			
0	0	0.00	0.00	0.00	0.00		0.00
0	1	0.00	0.00	0.00	1.02		0.49
0	2	0.00	0.00	0.00	2.01		1.23
0	6	0.00	0.00	0.00	5.96		5.23
0	10	0.00	0.00	0.00	10.01		9.21
0.2	0	0.20	0.12	0.08	0.00		0.00
0.2	1	0.20	0.12	0.08	1.04		0.54
0.2	2	0.20	0.12	0.08	2.03		1.25
0.4	0	0.33	0.18	0.14	0.00		0.00
0.4	1	0.33	0.18	0.14	1.04		0.56
0.4	2	0.33	0.18	0.14	2.11		1.24
0.8	2	0.65	0.38	0.37	2.14		1.36
1.35	2	1.37	1.06	0.82	2.17		1.80
1.35	6	1.47	1.22	0.89	6.12		5.58
1.35	10	1.51	1.12	0.92	10.04		9.71
2.7	2	2.84	2.37	2.41	2.19		1.95
2.7	6	2.75	2.37	1.80	6.20		5.73
2.7	10	2.84	2.37	2.13	10.02		9.71
5.4	10	4.84	2.81	2.07	10.07		9.87

* possibly error in preparation

APPENDIX 4

Intended Concentration and Activity of Calcium and Aluminum Species in the Solution with Initial pH 4.0 (μM)

Intended Concentration Ca	Al	Activity Ca	Al^{3+}	$Al(OH)^{2+}$	$Al(OH)_2^+$	$Al(OH)_3$	$AlSO_4$
				0 day			
25	0	2.36	0.00	0.00	0.00	0.00	0.00
50	0	4.34	0.00	0.00	0.00	0.00	0.00
150	0	12.17	0.00	0.00	0.00	0.00	0.00
250	0	19.32	0.00	0.00	0.00	0.00	0.00
0	7.5	0.00	0.64	0.06	0.13	0.00	0.00
25	7.5	2.28	0.50	0.05	0.10	0.00	0.05
50	7.5	4.06	0.44	0.04	0.09	0.00	0.09
0	15	0.00	1.15	0.11	0.23	0.00	0.00
25	15	2.03	0.99	0.10	0.20	0.00	0.10
50	15	4.03	0.88	0.09	0.18	0.00	0.17
50	30	4.34	1.87	0.18	0.37	0.00	0.39
50	50	4.49	3.79	0.37	0.76	0.00	0.82
150	50	12.33	2.91	0.28	0.58	0.00	1.77
250	50	19.42	2.41	0.24	0.48	0.00	2.36
50	100	4.47	6.88	0.67	1.37	0.00	0.15
150	100	12.29	5.31	0.52	1.06	0.00	3.23
250	100	19.33	4.41	0.43	0.88	0.00	4.30
250	200	19.28	6.56	0.64	1.31	0.00	6.31
				2 days after start			
25	0	1.95	0.00	0.00	0.00	0.00	0.00
50	0	3.68	0.00	0.00	0.00	0.00	0.00
150	0	11.49	0.00	0.00	0.00	0.00	0.00
250	0	10.88	0.00	0.00	0.00	0.00	0.00
0	7.5	0.00	0.35	0.07	0.27	0.00	0.00
25	7.5	1.40	0.32	0.06	0.26	0.00	0.02
50	7.5	3.41	0.31	0.06	0.25	0.00	0.05
0	15	0.00	0.61	0.12	0.49	0.00	0.00
25	15	1.21	0.61	0.12	0.49	0.00	0.04
50	15	3.37	0.55	0.11	0.44	0.00	0.09
50	30	3.66	1.04	0.20	0.83	0.01	0.18
50	50	3.79	2.64	0.51	2.10	0.01	0.48
150	50	11.78	2.19	0.43	1.74	0.01	1.27
250	50	18.96	1.88	0.37	1.50	0.09	1.80
50	100	3.84	4.87	0.95	3.87	0.02	0.90
150	100	11.84	3.93	0.77	3.12	0.02	2.29
250	100	19.06	3.53	0.69	2.81	0.02	3.39
250	200	18.43	5.12	9.90	4.07	0.03	4.74

Intended Concentration Ca	Al	Activity Ca	Al^{3+}	$Al(OH)^{2+}$	$Al(OH)_2^+$	$Al(OH)_3$	$AlSO_4$
				4 days after start			
25	0	0.17	0.00	0.00	0.00	0.00	0.00
50	0	2.09	0.00	0.00	0.00	0.00	0.00
150	0	8.41	0.00	0.00	0.00	0.00	0.00
250	0	14.62	0.00	0.00	0.00	0.00	0.00
0	7.5	0.00	0.17	0.05	0.33	0.00	0.00
25	7.5	0.34	0.16	0.05	0.32	0.00	0.00
50	7.5	2.42	0.15	0.05	0.31	0.00	0.02
0	15	0.00	0.31	0.09	0.61	0.01	0.00
25	15	0.75	0.28	0.09	0.55	0.01	0.01
50	15	2.60	0.28	0.09	0.57	0.01	0.04
50	30	3.29	0.54	0.17	1.08	0.01	0.09
50	50	3.20	1.68	0.52	3.34	0.03	0.26
150	50	10.64	1.43	0.44	2.85	0.03	0.75
250	50	17.78	1.33	0.41	2.66	0.03	1.19
50	100	3.56	3.10	0.96	6.19	0.06	0.53
150	100	10.51	2.72	0.84	5.42	0.05	1.40
250	100	18.35	2.52	0.78	5.03	0.05	2.32
250	200	18.28	3.65	1.13	7.28	0.07	3.35

APPENDIX 5

Intended Concentration and Activity of Calcium and Aluminum Species in the Solution with Initial pH 5.0 (μM)

Intended Concentration Ca	Al	Activity Ca	Al^{3+}	$Al(OH)^{2+}$	$Al(OH)_2^+$	$Al(OH)_3$	$AlSO_4$
				0 day			
25	0	2.38	0.00	0.00	0.00	0.00	0.00
50	0	4.54	0.00	0.00	0.00	0.00	0.00
150	0	12.30	0.00	0.00	0.00	0.00	0.00
250	0	19.32	0.00	0.00	0.00	0.00	0.00
0	7.5	0.00	0.03	0.03	0.65	0.02	0.00
25	7.5	2.42	0.03	0.03	0.64	0.02	0.00
50	7.5	4.57	0.03	0.03	0.63	0.02	0.01
0	15	0.00	0.05	0.05	1.07	0.03	0.00
25	15	2.42	0.05	0.05	1.05	0.03	0.01
50	15	4.74	0.05	0.05	1.04	0.03	0.01
50	30	4.79	0.10	0.10	2.04	0.06	0.02
50	50	4.83	0.22	0.21	4.30	0.14	0.05
150	50	12.53	0.22	0.22	4.46	0.14	0.14
250	50	19.30	0.22	0.22	4.46	0.14	0.22
50	100	4.84	0.45	0.43	8.88	0.28	0.10
150	100	12.62	0.42	0.41	8.32	0.26	0.26
250	100	19.21	0.42	0.41	8.38	0.26	0.41
250	200	19.20	0.71	0.70	14.25	0.45	0.69
				4 day after start			
25	0	1.17	0.00	0.00	0.00	0.00	0.00
50	0	2.85	0.00	0.00	0.00	0.00	0.00
150	0	10.94	0.00	0.00	0.00	0.00	0.00
250	0	17.99	0.00	0.00	0.00	0.00	0.00
0	7.5	0.00	0.04	0.02	0.22	0.00	0.00
25	7.5	1.29	0.04	0.02	0.22	0.00	0.00
50	7.5	2.89	0.04	0.02	0.21	0.00	0.01
0	15	0.00	0.08	0.04	0.39	0.01	0.00
25	15	1.33	0.08	0.04	0.38	0.01	0.00
50	15	2.87	0.07	0.04	0.37	0.01	0.01
50	30	3.12	0.20	0.10	0.98	0.02	0.03
50	50	4.07	0.43	0.21	2.14	0.03	0.08
150	50	11.56	0.42	0.21	2.12	0.03	0.02
250	50	18.78	0.41	0.20	2.07	0.03	0.39
50	100	4.34	1.24	0.61	6.23	0.10	0.27
150	100	11.80	0.86	0.42	4.31	0.07	0.50
250	100	18.73	0.95	0.47	4.78	0.08	0.90
250	200	19.00	0.92	0.45	4.64	0.07	0.88

APPENDIX 6

Performance of Two Upland Rice Cultivars on an Acid Soil

Only small fraction of rice production in Indonesia from upland rice. In West Sumatra in 1988 upland rice crop was about 4% of the total rice cultivated area, but due to the lower yield contributed only 2 % to the total rice production (BPS, 1988). However, since rice is the main food for most Indonesian upland rice is still a very important crop particularly for local consumption in newly open settlement like transmigration area.

Productivity of rice in general and upland rice in particular has long been known to be limited by inadequate water. In a well distributed rainfall both the upland rice cultivars performed relatively well. The cumulative rainfall during the rice growing period was 999 mm. Pan evaporation exceeded the rainfall in a couple of times, but because of the high rainfall in the previous day this hardly caused water deficit (Figure 34).

Rice, more than any other major food crops has critical requirement for high and regular water availability. The water required is total lost through evapotranspiration, seepage and percolation since very little is actually retained by the plant. High temperature and solar radiation increase evapotranspiration and water requirements but favor growth and yield (Lawson and Alluri, 1980).

However, rats had attacked some of the treatments of Danau Dibawah cultivar, but interestingly did not attack Srondol cultivar. The rat damage ranged from 2 to 35 % which higher damage in the plots that close to the border. The yield of these plots were estimated by the number hills harvested. Rat still serious problem to upland agriculture in the area. In the area where many place are uncultivated the rat problem is very difficult to control. The tall Srondol cultivar gave higher yield compared to the semi-dwarf Danau Dibawah. The grain yield of Srondol ranged from 2109 kg/ha to 2688

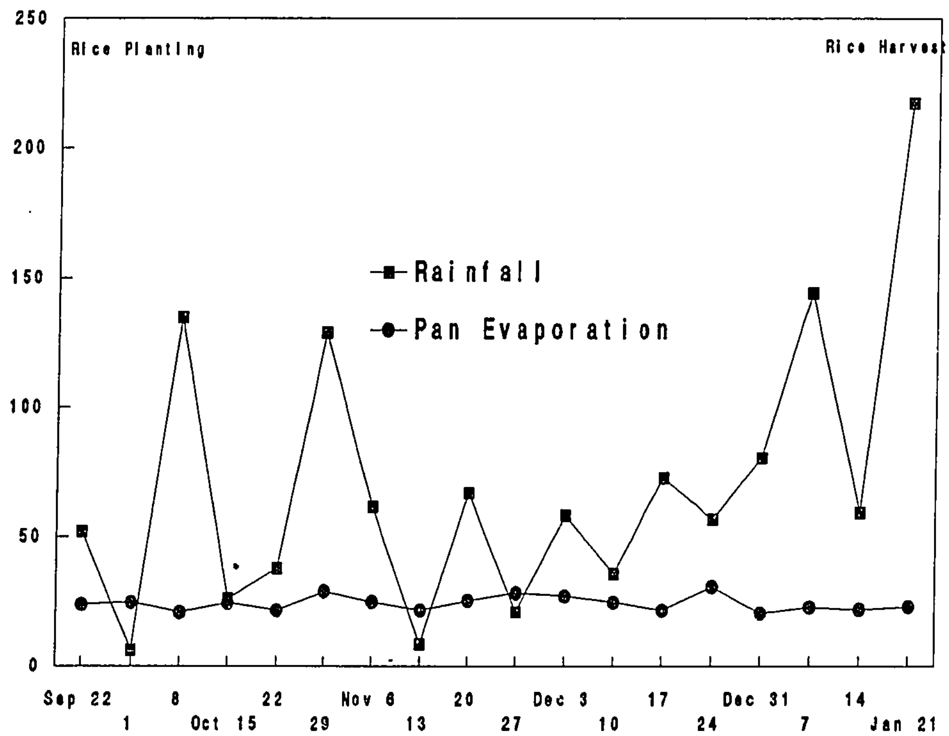


Figure 34: Weekly Rainfall and Pan Evaporation (mm) during Rice Growing Season

kg/ha while for Danau Dibawah ranged from 1426 kg/ha to 1874 kg/ha. The grain yield of Srondol was higher than national average but the yield of Danau Dibawah was slightly lower. Srondol also produced higher straw yield that ranged from 2449 kg/ha to 4058 kg/ha. The straw yield of semi-dwarf Danau Dibawah was varied from 1938 kg/ha to 3119 kg/ha.

No significant difference in grain and straw yields due to residual or fresh lime treatments. Different responses of upland rice to liming were reported in Sitiung area.

Table 21: Rice Grain and Straw Yields as Affected by Lime Treatments

Applied Lime	Grain			Straw		
	Residual Lime (kg/ha)					
	375	2250	6500	375	2250	6500
			(kg/ha)			
			SRONDOL			
0	2262	2438	2440	2969	3495	3178
375 B	2417	2688	2503	3088	4321	2915
375 S	2377	2571	2499	3356	2940	4058
1000 B	2416	2299	2561	2749	3331	3544
1000 S	2403	2468	2345	3114	3506	3387
1000 D	2109	2578	2419	2646	3367	3211
$LSD_{0.05}$	(rl) 283	(al) 138		(rl) 162	(al) 368	
			DANAU DIBAWAH			
0	1629	1452	1674	2150	2205	2325
375 B	1607	1406	1874	2463	2442	2194
375 S	1683	1500	1635	2587	2149	2416
1000 B	1482	1598	1852	1938	2802	3119
1000 S	1637	1426	1446	2179	2589	2244
1000 D	1782	1464	1570	2432	2238	2345
$LSD_{0.05}$	(rl) 277	(al) 153		(rl) 301	(al) 175	

B=broadcast S=shallow D=deep rl=residual lime al=applied lime

Rice did not grow without lime application when planted on bulldozed field (Makarim, 1985). Earlier Rumawas (1984) reported that increasing lime rate to 8 ton/ha had increased rice yield. However, Wade *et al.*, (1987) found no response to lime when low P was applied, but responded to 1 ton lime/ha when the rice was fertilized with 50 kg P. Later, Gill (1988) reported no difference in rice yield due to different lime rates that ranged from 375 kg/ha to 6500 kg/ha. Similar result was reported from another location in Sitiung area. Application of 375 kg lime/ha had increased rice yield but increasing the lime rate further did not increased rice yield (Evensen, 1989). Upland rice is found to be the most tolerant food crop to acid soil condition of Sitiung (Wade *et al.*, 1987). The critical acid saturation for Sentani rice was estimated to be between 67 to 70% (Evensen, 1989). The aluminum saturation of surface soil of the control plot was 66 % before planting the rice and increased to 75 % after harvest. At this level the grain and straw yields of Srondol and Danau Dibawah rice were not different with the yield of the high lime treatments. Tall traditional cultivars were found to be more tolerant to acidity and high aluminum compared to the new semi-dwarf cultivars (Howeler and Cadavid, 1976). The tall Srondol probably has a higher critical acid saturation than Sentani.

LITERATURE CITED

Adams, F. 1971. Ionic concentrations and activities in soil solutions. Soil Sci. Soc. Am. Proc. 35:420-426.

Adams, F. and D. Hartzog. 1980. The nature of yield response of Flowrunner peanuts to lime. Peanut Sci. 7: 120-123.

Adams, F. 1984. Crop responses to lime in the southern United States. *in* F. Adams (ed.) Soil Acidity and Liming. Agronomy Monograph 12. ASA.

Adams, F., C. Burmester, N. V. Hue, and F. L. Long. 1980. A comparison of column-displacement and cenrifuge methods for obtaining soil solutions. Soil Sci. Soc. Am. J. 44:733-735.

Adams, F. and R. W. Pearson. 1970. Differential response of cotton and peanut to subsoil acidity. Agron. J. 62: 9-12.

Adeoye, K. B. and L. Singh. 1985. The effect of bulk application of lime under two tillage depth on soil pH and crop yields. Plant and Soil 85: 295-297.

Agus, F., M. K. Wade and J. Prawirasumatri. 1985. Effects of post clearing methods and crop production. Tropsoils-Indonesia, Field Research Brief 18.

Allen, L. H., Jr., K. J. Boote and L. C. Hammond. 1976. Peanut stomatal diffusion resistence affected by soil water and solar radiation. Proc. Soil and Crop Sci. Fla. 35:42-46.

Alva, A. K., D. G. Edwards, C. J. Asher and F. P. C. Blamey. 1986. Effect of phosphorus/aluminum molar ratio and calcium concentration on plant response to aluminum toxicity. Soil Sci. Soc. Am. J. 50: 133-137.

Alvim, P. de T. 1982. A perspective appraisal of perennial crops in the Amazon Basin. *in* S. B.Hecht (ed.) Amazonia: Agriculture and Land Use Research. p 311-328. CIAT, Cali, Colombia.

Anandan, K. M. S., S. Chandrasekaran and G. Aranuchalam. 1984. Effect of lime on exchangeable aluminum, nodulation and yield of peanut (*Arachis hypogaea* L.) in an acid Oxisol. Trop. Agric. (Trinidad) 62: 38-40.

Anderson, R. L. and L. A. Nelson. 1981. A family of models and experimental designs for evaluation response to fertilizers nutrients when the true model is not known. *in* J. A. Silva (ed.) Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs for Agrotechnology Transfer. HITAHR Paper no. 49, University of Hawaii.

Andriesse, J. P. 1980. Nutrient level change during a 20 years shifting cultivation cycle in Sarawak (Malaysia). *in* K. T. Joseph (ed.), Proc. Conf. on Classification and Management of Tropical Soils (CLAMATROPS). Malaysian Soc. Soil Sci. Kuala Lumpur. p 479-491.

Arora, S. K., J. S. Saini, R. C. Gandhi and R. S. Sandhu. 1970. Study of chemical composition and yield of groundnut as affected by *Rhizobium* inoculation. Oleagineux 25: 274-280.

Asghar M. and Y. Kanehiro. 1980. Effects of sugar cane trash and pineapple residue on soil pH, redox potential, extractable Al, Fe and Mn. Trop. Agric. (Trinidad) 57:245-258.

Asher, C. J. and D. G. Edward. 1983. Modern solution culture techniques. *in* (eds. A. Lauchli and R. L. Bieleski) Encyclopedia of Plant Physiology New Series 15A: Inorganic Plant Nutrition. Springer-Verlag, Berlin p 94-119.

Ayarza, M., P. A. Sanchez and R. Dextre. 1987. Potassium dynamics in legume-based pastures. *in* N. Caudle and C. B. McCants (eds.) Tropsoils Technical Report, 1985-1986. p15-17.

Baharsyah, J. 1982. Country report: Indonesia. In Grain Legumes Production in Asia. Asian Productivity Organization, Tokyo.

Balasubramanian, V. and J. Y. Yayock. 1981. Effect of gypsum and moisture stress on growth and pod-fill of groundnut (*Arachis hypogaea* L.). Plant and Soil 62: 209-219.

Ball, S. T., J. C. Wynne, G. H. Elkan and T. J. Scheneeweis. 1983. Effect of inoculation and applied nitrogen on yield, growth and nitrogen fixation of two peanut cultivars. Field Crops Res. 6: 85-91.

Barrow, N. J. 1978. The description of phosphate adsorption curves. J. of Soil Sci. 29 (4): 447-442.

Bartlett, R. J. and D. S. Ross. 1988. Colorimetric determination of oxidizable carbon in acid soil solutions. Soil Sci. Soc. Am. J. 52: 1191-1192.

Bell, L. C. and D. G. Edwards. 1986. The role of aluminum in acid soil infertility. *in* M. Latham (ed.) p 201-223. Soil Management under Humid Conditions in Asia and Pacific. IBSRAM Proc. no. 5. Bangkok, Thailand.

Benites, J. R. and P. A. Sanchez. 1989. Central Experiment: Transition to other technologies. *in* N. Caudle and C. Levesque (eds.) Tropsoils Technical Report, 1986-1987. p 44-51.

Benites, J. R., R. E. McCollum and M. C. Scholes. 1989. Nitrogen carryover in rotation and strip-intercropping systems. *in* N. Caudle and C. Levesque (eds.) Tropsoils Technical Report, 1986-1987. p 88-91.

Bledsoe, R. W., C. L. Comar and H. W. Harris. 1949. Absorption of radioactive calcium by peanut fruit. Science 109: 329-330.

Bohm, W. 1979. Methods of Studying Root Systems. Springer-Verlag, Berlin.

Bolan, N. S., J. K. Syers, R. W. Tillman and D. R. Scotter. 1988. Effect of liming and phosphate additions on sulphate leaching in soils. J. Soil Sci. 39: 493-504.

Boote, K. J. , R. J. Varnell and W. G. Duncan. 1976. Relationship of size, osmotic concentration, and sugar concentration of peanut pods to soil water. Proc. Soil and Crop Sci. Fla. 35: 47-50.

Boote, K. J., J. R. Stansell, A. M. Schubert and J. F. Stone. 1982. Irrigation, water use and water relations. *in* H. E. Pattee and C. T. Young (eds.) Peanut Science and Technology. p 164-205. American Peanut Research and Education Society, Inc. Yoakum, Texas, USA.

Boote, K. J., J. W. Jones, J. W. Mishoe and G. G. Wilkerson. 1986. Modeling growth and yield of groundnut. *in* M. V. K. Sivakumar and S. M. Virmani (eds.) Agrometeorology of groundnut. Proc. of Int. Symposium. ICRISAT Sahelian Center, Niamey, Niger.

Boote, K. J., J. W. Jones, G. Hoogenboom, G. G. Wilkerson and S. S. Jagtap. 1988. Peanut Crop Growth Simulation Model: User's Guide. Florida Agric. Exp. Sta. J. No. 8420.

BPS (Biro Pusat Statistik). 1984. Statistik Import Ekspor. BPS, Jakarta.

BPS (Biro Pusat Statistik). 1988. Statistik Indonesia. BPS, Jakarta.

Bray, R. H. and L. T. Kurtz. 1945. Determination of total and, available forms of phosphorus in soils. Soil Sci.59:39-45.

Burstorm, H. 1952. Studies on growth and metabolism of roots. VIII. Calcium as a growth factor. Physiol. Plant. 5:391-402.

Carvalho, M. M. de, C. J. Asher, D. G. Edwards and C. S. Andrew. 1982. Lack of effect of toxic aluminum concentrations on nitrogen fixation by nodulated *Stylosanthes* species. Plant and Soil 64: 141-152.

Chao, T. T., M. E. Harward and S. C. Fang. 1963. Cationic effect on sulfate adsorption by soils. Soil Sci. Soc. Am. Proc. 27: 35-38.

Chong, K., J. C. Wynne, G. H. Elkan and T. J. Schneeweis. 1987. Effects of soil acidity and aluminum content on *Rhizobium* inoculation, growth and nitrogen fixation of peanuts and other grain legumes. Trop. Agric. (Trinidad) 64: 97-104.

Christenson, D. R. and E. C. Doll. 1978. Magnesium uptake from exchangeable and non-exchangeable sources in soils as measured by intensive cropping. Soil Sci. 126: 166-168.

Clarkson D. T. and J. B. Hanson. 1980. The mineral nutrition of higher plants. Annu. Rev. Plant Physiol. 31: 239-298.

Cleveland, W. S. 1979. Robust locally weighted regression and smoothing scatterplots. J. Amer. Stat. Assoc. 74(368): 829-836.

Cochrane, T. T, J. G. Salinas and P. A. Sanchez. 1980. An equation for liming acid mineral soils to compensate crop aluminum tolerance. Trop. Agric. (Trinidad) 57(2): 133-140.

Coleman, N. T. and G. W. Thomas. 1967. The basic chemistry of soil acidity. *in* R. W. Pearson and F. Adams (eds) Soil Acidity and Liming. Agronomy Monograph Series 12:1-41.

Colfer, C. J. P., D. W. Gill, B. Newton and H. Soedjito. 1989. Indigenous knowledge systems related to soil management. *in* N. Caudle and C. Levesque (eds.) Tropsoils Technical Report, 1986-1987. p202-230.

Colwell, W. E. and N. C. Brady. 1945. The effect of calcium on certain characteristics of peanut fruit. J. Amer. Soc. Agron. 37: 696-708.

Couto, W., D. J. Lathwell and D. R. Bouldin. 1979. Sulfate sorption by two oxisols and an alfisol of the tropics. Soil Sci. 127: 108-116.

Cox, F. R. and P. H. Reid. 1964. Calcium-boron deficiency as related to cocealed damage in peanuts. Agron. J. 56: 173-176.

Cox, F. R., G. A. Sulivan and C. K. Martin. 1976. Effect of calcium and irrigation treatments on peanut yield, grade and seed quality. Peanut Sci. 3: 81-85.

Cox, F. R., F. Adams and B. B. Tucker. 1982. Liming, fertilization and mineral nutrition. *in* H. E. Pattee and C. T. Young (eds.) Peanut Science and Technology. p 139-163. American Peanut Research and Education Society, Inc. Yoakum, Texas, USA.

Cravo, M. and T. J. Smyth. 1987. Lime requirement and downward movement of Ca and Mg. *in* N. Caudle and C. B. McCants (eds.) Tropsoils Technical Report, 1985-1986. p102-106.

Dougan, W. K. and A. L. Wilson. 1974. The absorptiometric determination of aluminum in water. A comparison of some chromogenic reagents and the development of an improved method. Analyst 99:413-430.

Driessen, P. M., P. Buurman and S. Permadhy. 1976. The influence of shifting cultivation on a 'podzolic' soil from Central Kalimantan. Bull. 3. Soil research Institute, Bogor p. 95-114.

Duncan, W. G., D. E. McCloud, R. L. McGraw and K. J. Boote. 1978. Physiological aspects of peanut yield improvement. Crop Sci. 18: 1015-1020.

Edmeades, D. C. 1982. Effects of lime on effective cation exchange capacity of and exchangeable cations in a range of New Zealand soils. New Zealand J. Agric. Res. 25: 27-33.

Evensen, C. L. I. 1989. Alley Cropping and Green Manuring for Upland Crop Production in West Sumatra. Ph. D. Dissertation. University of Hawaii.

FAO. 1987. FAO Production Yearbook. FAO, Rome.

Farina, M. P. W. and P. Channon. 1988. Acid-subsoil amelioration: II. Gypsum effect on growth and subsoil properties. Soil Sci. Soc. Am. J. 52: 175-180.

Fox, R. L. and G. P. E. Searle. 1978. Phosphate adsorption in the Tropics. ASA Special Publication 35: 97-119.

Foy, C. D. 1984. Physiological effects of hydrogen, aluminum and manganese toxicity in acid soils. In F. Adams (ed.) Soil Acidity and Liming. ASA Monograph 12.

Foy, C. D. and A. L. Fleming. 1978. The physiology of plant tolerance to excess available aluminum and manganese in acid soils. In Crop Tolerance to Suboptimal Conditions. ASA Monograph.

Franco, A. A. and D. N. Munns. 1982. Acidity and aluminum restraints on nodulation, nitrogen fixation and growth of *Phaseolus vulgaris* in solution culture. Soil Sci. Soc. Am. 46: 296-300.

Friesen, D. K. ; A. S. R. Juo and M. H. Miller. 1982. Residual value of lime and leaching of calcium in a kaolinitic Ultisol in the high rainfall tropics. Soil Sci. Soc. Am. J. 46: 1184-1189.

Gardini, A. R. , E. S. Lopez, A. Savy Filho and A. M. L. Neptune. 1985. *Rhizobium* inoculation and nitrogen application to groundnuts. Braganta 44(1): 27-39.

Gaston, L. A, R. S. Mansell and R. D. Rhue. 1986. Sulfate mobility in acid soils and implications with respect to cation leaching: A Review. Soil and Crop Sci. Fla. Proc. 45: 67-72.

Gibbon, R. W. 1980. The ICRISAT groundnut program. In Proc. Int. Workshop on groundnut. ICRISAT, India.

Gichuru, M. P., P. A. Sanchez and J. R. Benites. 1987. Calcium and magnesium movement in low-input cropping system. *in* N. Caudle and C. B. McCants (eds.) Tropsoils Technical Report, 1985-1986. p9-10.

Gill, D. W. and E. J. Kamprath. 1985. Response of peanut on soil base level to applied K and three lime levels in Sitiung 1. Tropsoils-Indonesia, Field Research Brief 12.

Gill, D. W., I. B. Aribawa, M. K. Wade. 1986. Mg fertilization for annual crops. Tropsoils-Indonesia, Field Resesearch Brief no. 31.

Gill, D. W. 1988. Response of Upland Crops to Potassium at Three Levels of Aluminum Saturation in the Humid Tropics of West Sumatra. Ph. D. Dissertation, North Caroline State University.

Gillier, P. 1969. Secondary effects of drought on groundnut. Oleagineux 24: 79-81.

Giliier, P. 1978. Nouvelles limites des cultures d' arachides resistantes a la secherresse et a la rosette. Oleagineux 33:25-28.

Goedert, W. J., R. B. Corey and J. K. Syers. 1975. Lime effect on potassium equilibria in soils of Rio Grande do Sul, Brazil. Soil Sci. 120: 107-111.

Gonzalez-Erico, E. J. Kamprath, G. G. Naderman and W. V. Soares. 1979. Effect of depth of lime incorporation on the growth of corn on Oxisol of Central Brazil. Soil Sci. Soc. J. 43: 1155-1158.

Graham, E.R. and R. L. Fox. 1971. Tropical soil potassium as related to labile pool and calcium exchange equilibria. Soil Sci. 111: 318-322.

Graham, R. A. and A. L. Donawa. 1981. Effect of soil pH and inoculum rate on shoot weight, nitrogenase activity and competitive nodulation of groundnut (*Arachis hypogaea* L.). Trop. Agric. (Trinidad) 58: 337-340.

Grove, J. H. and M. E. Sumner. 1985. Lime induced magnesium stress in corn: Impact of magnesium and phosphorus availability. Soil Sci. Soc. Am. J. 49: 1192-1196.

Grove, J. H., M. E. Sumner and J. K. Syers. 1981. Effect of lime on exchangeable magnesium in variable surface charge soils. Soil Sci. Soc. Am. J. 45: 497-500.

Hale, M. G. 1977. Calcium concentration and fruit exudation of sugars from pegs and fruits of axenic peanut plants. Soil Biol. Biochem. 10: 67-69.

Hansen, J. M. 1989. Influence of Decomposing Organic Material on Aluminum Chemistry and Phytotoxicity. M. Sc. Thesis. University of Hawaii.

Hardy, R. W. F. and U. D. Havelka. 1975. Photosynthate as major factor limiting nitrogen fixation by field-ground legumes with emphasis on soybean. In P. Nutman (ed.) Symbiotic Nitrogen Fixation in Plants. Cambridge University Press, London.

Harris, H. C. and J. B. Brolmann. 1966. Comparison of calcium and boron deficiencies of peanut. II. Seed quality in relation to histology and viability. Agron J. 58: 578-582.

Haynes, R. J. 1983[a]. Soil acidification induced by leguminous crops. Grass Forage Sci. 38: 1-11.

-----------------. 1983[b]. Effect of lime and phosphate application on adsorption of phosphate,sulfate and molybdate by a Spodosol. Soil Sci. 135: 221-227.

-----------------. 1984. Lime and phosphate in soil-plant system. Advances in Agronomy 37: 249-315.

Haynes, R. J. and R. S. Swift. 1986. Effect of soil acidification and subsequent leaching on level of extractable nutrient in a soil. Plant and Soil 95: 327-336.

Hecht, S. B. 1982. Agroforestry in the Amazon Basin: Practice, theory and limits of a promising lands. *in* S. B.Hecht (ed.) Amazonia: Agriculture and Land Use Research. p 331-371. CIAT, Cali, Colombia.

Hidayat, O. O and I. Purboyo. 1984. Groundnut production, utilization and future research needs in Indonesia. Indon. Agric. Res. Dev. J. 6(3&4): 29-33.

Hobman, F. R. 1984. Evaluation of groundnut (*Arachis hypogaea* L.) for wet tropical coast of Queensland, Australia. Trop. Agric. (Trinidad) 63(3):217-221.

Howard, D. D. and F. Adams. 1965. Calcium requirement for penetration of subsoil by primary cotton roots. Soil Sci. Soc. Amer. Proc. 29:558-562.

Howeler, R. H. and L. F. Cadavid. 1976. Screening of rice cultivars for tolerance to Al-toxicity in nutrient solutions as compared with a field screening method. Agron. J. 68: 551-555.

Hoyt, P. B. and R. C. Turner. 1975. Effect of organic materials added to very acid soils on pH, aluminum, exchangeable NH_4, and crop yield. Soil Sci. 119: 227-237.

Hsiao, T. C. 1973. Plant response to water stress. Annual Rev. Plant Physiology 24: 519-570.

Hue, N. V., I. Amien and J. Hansen. 1988. Aluminum detoxification with green manures and sewage sludge in strongly acid Ultisols of the tropics. Agron. Abstr. p 237.

Hue, N. V. and I. Amien. 1989. Aluminum detoxification with green manures. Comm. in Soil Sci. and Plant Anal. 20(15&16): 1499-1511.

IBSNAT. 1987. A Systems-based Decision-support System for Agrotechnology Transfer. A summary of IBSNAT phase II plans. USAID, CTAHR, University of Hawaii.

IBSRAM. 1987. Management of Acid Tropical Soil for Sustainable Agriculture. Proc. of an IBSRAM Inaugural Workshop. April 24-May 3, 1985. Yurimaguas, Peru and Manaus and Brasilia, Brazil.

IITA, 1972. Grain Legume Improvement Report, IITA, Ibadan, Nigeria.

Ike, I. F. 1986. Effects of soil moisture stress on the growth and the yield of Spanish variety peanut. Plant and Soil 96: 297-298.

Johnson, C. M. and H. Nishita. 1952. Microestimation of sulfur in plant material, soils and irrigation waters. Anal. Chem. 24:736-742.

Jones, J. W., J. W. Mishoe and K. J. Boote. 1984. SOYGRO: Soybean crop growth model. In Proc. Int. Symposium at ICRISAT. ICRISAT, India.

Juo, A. S. R. and J. C. Ballaux, 1977. Retention and leaching of nutrients in a limed Utisol under cropping. Soil Sci. Soc. Am. J. 41: 757-761.

Kan, S. and C. J. P. Colfer. 1989. Farmer resource allocation in Sitiung, West Sumatera. *in* N. Caudle and C. Levesque (eds.) Tropsoils Technical Report, 1986-1987. p 231-232.

Keng, J. C. W and G. Uehara. 1974. Chemistry, mineralogy and taxonomy of Oxisols and Ultisols. Soil and Crop Sci. Soc. Fla. 33: 119-126.

Ketring, D. L., W. R. Jordan, O. D. Smith and C. E. Simpson. 1982. Genetic variability in root and shoot growth characteristics of peanut. Peanut Sci. 9: 68-72.

Ketring, D. L. 1984. Root diversity among peanut genotypes. Crop Sci. 24: 229-232.

Keyser, H. H. and D. N. Munns. 1979a. Effect of Ca, Mn and Al on growth of *Rhizobia* in acid media. Soil Sci. Soc. Am. J. 43: 500-503.

--. 1979b. Tolerance of *Rhizobia* to acidity, aluminum and phosphate. Soil Sci.Soc.Am. 43: 519-523.

Krizek, D. J. and C. D. Foy. 1988. Role of water stress in differential aluminum tolerance of two barley cultivars grown in an acid soil. J. Plant Nutrition 11(4): 351-367.

Kvalseth, T. O. 1985. Cautionary note about R^2. The American Statistician 39(4): 279-285.

Larue, T. A. and T. G. Patterson. 1983. How much nitrogen do legumes fix? Advances in Agronomy 35: 15-38.

Laurence, R. C. N. 1973. Improvements of groundnut pod-filling by lime and gypsum application to some soils in northern Malawi. Expl. Agric. 9: 353-360.

Laurence, R. C. N, R. W. Gibbons and C. T. Young. 1976. Changes in yield, protein, oil and maturity of groundnut with the application of sulphur fertilizers and fungicides. J. Agric. Sci. Camb. 86: 245-250.

Lawson, T. L. and K. Alluri. 1980. Maximum water requirement of upland rice variety OS6 in the humid/subhumid zone of West Africa. Proc. Symposium Agrometeorology of Rice Crop. WMO-IRRI Los Banos, the Philippines. p 181-185.

Lea, J. D. 1961. Studies on depth and rate of root penetration of some annual tropical crops. Tropical Agric. 38: 93-105.

Lenka, D., and P. K. Misra. 1973. Response of groundnut (*Arachis hypogaea* L.) to irrigation. Indian J. Agron. 18:492-497.

Lin, C. and N. T. Coleman. 1960. The measurement of exchangeable aluminum in soils and clays. Soil Sci. Soc. Am. Proc. 24:444-446.

Lumpugu, K. and B. T. Mutera. 1983. Effect of Mg and minor elements on the yield and kernel oil content of groundnut (*Arachis hypogaea* L.). Trop. Grain Legume Bull. 27: 33-35.

Lund, Z. 1970. Effect of calcium and other cations in soybean root growth. Soil Sci. Soc. Am. J. 34: 456-459.

Mahon, J. D. 1979. Environmental and genotype effects on the respiration associated with symbiotic nitrogen fixation. Plant Physiol. 63: 892-897.

Makarim, A. K. 1985. Effects of land reclamation management practices on crop production and physical and chemical properties on a tropical soil. Ph. D. Dissertation. North Caroline State Univ. Raleigh.

Malathi Chari, K. Gupta, T. G. Prasad, K. S. Krishna Sastry and M. Udaya Kumar. 1986. Enhancement of water status by calcium pretreatment in groundnut and cowpea plants subjected to moisture stress. Pland and Soil 91: 109-114.

Marsh, B. a'B. 1971. Measurement of length in random arrangements of lines. J. Applied Ecology 8: 265-267.

Marsh, K. B., J. K. Syers and R. W. Tilman. 1987. Charge relationships of sulfate sorption in soils. Soil Sci. Soc. Am. J. 51:318-323.

Mathur, B. S., H. Sinha, N. K. Rana and S. Lall. 1983. Use of calcium as a nutrient for legume crops in acidic red loam soils of Ranchi. J. Indian Soc. Sci. 31: 334-336.

McCloud, D. E. 1974. Growth analysis of high yielding peanuts. Proc. Soil Crop Sci. Soc. Fla. 33: 24-26.

McIntosh J. L., I. G. Ismail, S. Effendi and M. Sudjadi. 1982. Cropping sytems to preserve fertility of red-yellow podsolic soils in Indonesia. Proc. Symposium Trop. Agric. Res. Tsukuba, Japan October 19-26. p 297-320.

McKinion, K. J. and H. E. Lemmon. 1985. Expert systems for agriculture. Computers and Electronics in Agric. 1:31-40.

Mekaru, T. and G. Uehara. 1972. Anion adsorption in ferruginous tropical soils. Soil Sci. Soc. Amer. Proc. 36: 296-300.

Mengel, K. and E. A. Kirkby. 1982. Principles of Plant Nutrition. International Potash Institute. Bern, Switzerland.

Middleton, G. K. , W. E. Colwell, N. C. Brady and E. F. Shultz. 1945. The behavior of four varieties of peanuts as affected by calcium and potassium variables. J. Amer. Soc. Agron. 37: 443-457.

Morris, H. D. and W. H. Pierre. 1949. Minimum concentration of manganese necessary for injury to various legumes in culture solutions. Agron. J. 41: 107-112.

Muljadi, D. and M. Soepraptohardjo. 1975. Masalah data dan penyebaran tanah-tanah kritis. Simposium Pencegahan dan Pemulihan Tanah-tanah Kritis dalam rangka Pengembangan Wilayah, Jakarta, 27-29 Desember 1875.

Munns, D. N. , R. L. Fox and B. L. Koch. 1977. Influence of lime on nitrogen fixation by tropical and temperate legumes. Plant and Soil 46: 591-601.

Munns, D. N. 1986. Acid tolerance in legume and *Rhizobia*. *in* Tinker and Lauchli (eds.) Advances in Plant Nutrition Vol. 2. Praeger, New York.

Nageswara Rao, R. C., L. P. Simmonds, S. N. Azam-Ali and J. H. Williams. 1989. Population, growth and water use of groundnut maintained on stored water. I. Root and shoot growth. Expl. Agric. 25: 51-61.

Narasimham, R. L., I. V. Subba Rao and M. Singa Rao. 1977. Effect of moisture stress on response of groundnut to phosphate fertilization. Indian J. Agric. Sci. 47:573-576.

Nelson, L. E. 1980. Phosporus nutrition of cotton, peanuts, rice, sugarcane and tobacco. *in* F. E. Khasawneh, E. C. Sample and E. J. Kamprath (eds.) The Role of Phosporus in Agriculture. p 693-736. Am Soc. Agron. Madison, Wisconsin, USA.

Neves, M. C. P. 1982. Energy cost of biological nitrogen fixation. *in* P. H. Graham and S. C. Harris (eds.) Biological Nitrogen Fixation Technology for Tropical Agriculture. CIAT, Colombia.

Newman, E. I. 1966. A method of estimating the total length of root in a sample. J. Applied Ecology 3: 136-145.

Nix, H. A. 1983. Minimum data set for Agrotechnology transfer. *in* Proc. Int. Symposium at ICRISAT. ICRISAT, India.

Noble, A. D. , M. V. Fey and M. E. Sumner. 1988. Calcium-aluminum balance and the growth of soybean roots in nutrient solutions. Soil Sci. Soc. Am. J. 52: 1651-1656.

Norman, M. J. T., C. J. Pearson and P. G. E. Searle. 1984. The Ecology of Tropical Food Crops. Cambridge University Press, Cambridge.

Nye, P. H. 1986. Acid-base changes in the rhizosphere. Advances in Plant Nutrition 2: 129-153.

Ong, C. K. 1984. The influence of temperature and water deficit on partitioning of dry matter in groundnut (*Arachis hypogaea* L.). J. of Experimental Botany 35: 746-755.

Ong, C. K., C. R. Black, L. P. Simmmonds and R. A. Saffel. 1985. Influence of saturation deficit on leaf production and expansion in stands of groundnut (*Arachis hypogaea* L.). grown without irrigation. Annals of Botany 56: 523-536.

Ono, Y., K. Nakayama and M. Kubota. 1974. Effect of soil temperature and soil moisture in the podding zone on pod development of peanut plants. Proc. Crop Sci Soc. Jap. 43: 247-251.

Ottman, M. J. and H. Timm. 1984. Measurement of viable plant roots with the image analyzing computer. Agron. J. 76: 1018-1020.

Pallas, J. E. Jr., J. R. Stansell and T. J. Koske. 1979. Effect of drought on Florunner peanuts. Agron. J. 71: 853-857.

Pandey, R. K. , W. A. T. Herrera and J. W. Pendelton. 1984. Drought responses of grain legumes under an irrigation gradient : I. Yield and yield components. Agron. J. 76: 549-553.

Pearson, R. W. F. Abruna and J. Vicente-Chandler. 1962. Effect of lime and nitrogen applications on downward movementof calcium and magnesium in two humid tropical soils of Puerto Rico. Soil Sci. 93: 77-82.

Polara, K. B., C. L. Patel and S. R. Pathak. 1984. Pattern of N, P and K accumulation in groundnut varieties as influenced by soil moisture stress at different stages of growth. Legume Res. 7(2): 95-100.

Puspharajah, E. and A. T. Bachik. 1987. Management of acid tropical soils in Southeast Asia. *in* P. A. Sanchez, E. R. Stoner and E. Pushpararajah (eds.) Management of Acid Tropical Soils for Sustainable Agriculture. IBSRAM Proc. no.2. Bangkok, Thailand.

Rachie, K. O. 1978. Productivity potentials of edible legumes in the lowland tropics. *in* G. A. Jung (ed.) Crop Tolerance to Suboptimal Land Conditions. ASA Special Publication no. 32.

Rajendrudu G. and J. H. William. 1987. Effect of gypsum and drought on pod initiation and crop yield in early maturing groundnut (*Arachis hypogaea*) genotypes. Expl. Agric. 23: 259-271.

Ramanatha Rao, V. 1988. Botany. *in* P. S. Reddy (ed.) Groundnut. Indian Council of Agricultural Research. p. 24-64

Reddy, K. C. and P. K. Murthy. 1985. Distribution of N, P, K, Ca, Mg, S, Zn. Fe, Mn and Cu in groundnut. Plant and Soil 84: 269-273.

Rios, M. A. and R. W. Pearson. 1964. The effect of some chemical environmental factors on cotton root behaviour. Soil Sci. Soc. Amer. Proc. 28:232-235.

Ritchey, K. D., D. M. G. Souza, E. Lobato and D. Correa. 1980. Calcium leaching to increase rooting depth in a Brazilian savannah Oxisol. Agron. J. 72: 40-44.

Ritchie, J. T. 1985. A user-oriented model of the soil water balance in wheat. In W. Day and R. K. Atkin (eds.) Wheat Growth and Modeling. Plenum Publishing Corporation, NATO-ASI Series.

Robertson, W. K., L. C. Hammond, J. T. Johnson and G. M. Prine. 1979. Root distribution of corn, soybeans, peanuts, sorghum and tobacco in fine sand. Soil and Crop Sci. Soc. Florida 38: 54-59.

Robertson, W. K., L. C. Hammond, J. T. Johnson and K. J. Boote. 1980. Effect of plant-water stress on root distribution of corn, soybeans and peanuts in sandy soil. Agron. J. 72: 548-550.

Robson A. D. and J. F. Loneragan. 1970. Nodulation and growth of *Medicago tumcatula* on acid soils. I. Effect of $CaCO_3$ and nodulation level on the nodulation of *Medicago tumcatula* on moderately acid soil. Aust. J. Agric. Res. 21: 203-208.

Rogers, H. T. 1948. Liming for peanuts in relation to exchangeable soil calcium and effect on yield, quality, and uptake of calcium and potassium. Soil Sci. 40 : 15-31.

Rumawas, F. 1984. Beberapa hasil percobaan tahap akhir pada tanah bukaan bekas hutan didaerah transmigrasi Sitiung II dan Pamenang. Proc. Pertemuan Tehnis Penelitian Usaha Tani Menunjang Transmigrasi. Cisarua, Bogor, 27-29 February 1984.

Russell, E. W. 1977. Soil Conditions and Plant Growth. Second Edition. Longmans, London

Ryle, G. J. A., C. E. Powell and A. J. Gordon. 1979. The respiratory costs of nitrogen fixation in soybean, cowpea and white clover. J. Exp. Bot. 30: 135-154.

Sanchez, C. 1977. Ecolamiento de Ultisols de Sabana. Univ. de Oriente, Jusepi, Monagas, Venezuela.

Sanchez, P. A. and G. Uehara. 1980. Management consideration for acid soils with high phosphorus fixation capacity. In Khasawneh (ed.) The Role of Phosphorus in Agriculture. ASA.

Sanchez, P. A., D. E. Bandy, J. H. Villachica and J. J. Nicholaides. 1982. Amazon Basin Soils: Management for continous Crop Production. Science 216:821-827.

Sanchez, P. A. 1987. Management of acid soils in the humid tropics of Latin America. *in* P. A. Sanchez, E. R. Stoner and E. Pushpararajah (eds.) Management of Acid Tropical Soils for Sustainable Agriculture. p 63-107. IBSRAM Proc. no.2. Bangkok, Thailand.

Sanchez, P. A., J. Benites and D. Bandy. 1987. Low-input systems and managed fallows for acid soils in the humid tropics. *in* M. Latham (ed.) p 353-360. Soil Management under Humid Conditions in Asia and Pacific. IBSRAM Proc. no. 5. Bangkok, Thailand.

Santoso, D. and L. H. Sibuea. 1982. Penelitian pengelolaan tanah masam di Tanjung Iman, Lampung. Laporan, LPT, Bogor.

Sartain, J. B. and E. J. Kamprath. 1975. Effect of liming a high Al-saturated soil on the top and the root of growth and soybean nodulation. Agron. J. 67: 507-510.

Scholes, R. J. and A. Salazar. 1989. Root production turnover in different management options. *in* N. Caudle and C. Levesque (eds.) Tropsoils Technical Report, 1986-1987. p111-113.

Seshadri, C. R. 1962. Groundnut. The Indian Cental Oilseeds Commitee, Hyderabad, A. P. India.

Shay, F. J. and M. G. Hale. 1973. Effect of low levels of calcium and exudation of sugars and sugar derivatives from intact peanut root under axenic conditions. Plant Physiol. 51: 1061-1063.

Singh, H., A. K. Yadav, T. P. Yadapa and M. L. Chabra. 1981. Genetic variability and heritability for morpho-physiological attributes in groundnut. Indian J. Agric. Sci. 52: 322-324.

Shiffmann J. and R. Lobel. 1973. Seasonal changes in symbiotic nitrogen fixation and haemoglobin content in nodules of peanuts. Plant and Soil 39: 329-340.

Skelton, B. J. and G. M. Shear. 1971. Calcium translocation in the peanut (*Arachis hypogaea* L.). Agron. J. 63: 409-412.

Soepardi, G. 1979. Effect of moisture regime, fertilizer and lime on growth and yield of peanut grown on acid mineral soils. Contributions 55. CRIA, Bogor.

Somaatmadja, S. and B. H. Siwi. 1983. Development of grain legumes in Indonesia. In Grain Legumes in Asia. ICRISAT. India.

Stansell, J. R. and J. E. Pallas Jr. 1985. Yield quality response of Florunner peanut to applied drought at several growth stage. Peanut Sci. 12: 64-70.

Su, K. C., T. R. Chen, S. C. Hsu and M. T. Tseng. 1964. Studies on the processing of water absorption and economized irrigation of peanuts. (Chinese, Eng. summary). J. Agric. Assoc. China 45: 31-40.

Sullivan, G. A. , G. L. Jones and R. P. Moore. 1974. Effects of dolomitic limestone, gypsum and potassium on yield and seed quality of peanuts. Peanut Sci. 1: 73-77.

Tamimi, Y. N., R. S. Uchida and D. T. Matsuyama. 1974. The importance of the pH dependency of charge in tropical soils on crop fertilizer management. Proc. Planning and Organization Meeting Fertilizer INPUTS (Increasing Productivity under Tight Supplies. East West Center, Honolulu, Hawaii.

Taylor, H. M. and R. F. Ratliff. 1969. Root elongation rate of cotton and peanuts as a function of soil strength and soil water content. Soil Sci. 108:113-119.

Taylor, H. M. and B. Klepper. 1978. The role of root characteristics in supply of water to plants. Adv. Agron. 30: 99-127.

Tenant, D. 1975. A test of modified line intersect method of estimating root length. J. of Ecology 63 (3): 995-1001.

Uehara, G. 1989. Technology transfer in the tropics. Outlook in Agriculture 18(1):38-242.

Underwood, C. V. , H. M. Taylor and C. S. Hoveland. 1971. Soil physical factors affecting peanut pod development. Agron. J. 53: 953-954.

Upchurch, D. R. and J. T. Ritchie. 1983. Root observations using a video recording system in mini-rhizotrons. Agrron. J. 75: 1009-1015.

--. 1984. Battery-operated color video camera for root observations in mini-rhizotrons. Agron. J. 76: 1015-1017.

Valverde, C. S. and D. E. Bandy. 1982. Production of annual food crops in the Amazon. *in* S. B.Hecht (ed.) Amazonia: Agriculture and Land Use Research. p 243-280. CIAT, Cali, Colombia.

Vitousek, P. M. 1984. Litterfall, nutrient cycling, and nutrient limitation in tropical forests. Ecology 65(1): 285-298.

Von Uexkull, H. R. 1982. Problem soils for food crops in the humid tropics. Proc. Int. Symp. Distribution Characteriristics and Utilization of Problem Soils. p 139-152. Trop. Agric. Res. Centre., Min. Agric. For. Fish., Tsukuba, Japan. Trop. Agric. Res. Series no. 15.

Von Uexkull, H. R. 1984. Managing acrisols in the humid tropics. *in* Ecology and Management of Problem Soils in Asia. Food and Fertilizer Technology Centre, Taiwan, Book Series no 27: 382-396.

Von Uexkull, H. R. 1986. Efficient Fertilizer Use in Acid Upland Soils of the humid Tropics. FAO Fertilizer and Plant Nutrient Bulletin 10, FAO Rome.

Wade, M. K. and P. A. Sanchez. 1984. Productive potential of an annual intercropping scheme in the Amazon. Field Crop Res. 9: 253-263.

Wade, M. K. and D. Santoso. 1985. Phosphorus rates and methods of application. Tropsoils-Indonesia, Field Research Brief 14.

Wade, M. K. Heryadi and D. W. Gill. 1987. Effect of green manure applications on soil fertility and crops. *in* N. Caudle and C. B. McCants (eds.) Tropsoils Technical Report, 1985-1986. p134-137.

Wade, M. K., D. Santoso, M. Al-Jabri and I. P. Gedjer. 1987. Phosphorus management in transmigration area. *in* N. Caudle and C. B. McCants (eds.) Tropsoils Technical Report, 1985-1986. p131-134.

Wade, M. K., D. W. Gill, H. Subagyo, M. Sudjadi and P. A. Sanchez. 1987. Overcoming soil fertility constraints in transmigration area of Indonesia. Tropsoils Bull. No. 88-01. N. C. State Univ. Raleigh.

Walker, M. E., T. C. Kiesling and J. S. Drexler. 1976. Response of three peanut cultivars to gypsum. Agron. J. 68:527-528.

Waterman, D. A. 1986. A Guide to Expert Systems. Addison Wesley Publishing Company, Reading, MA, USA.

Weiss, E. A. 1983. Oilseed Crops. Longman, London and New York.

Whisler, F. D., B. Acock, D. N. Baker, R. E. Fye, H. F. Hodges,J. R. Lambert, H. E. Lemmon, J. M. McKinion and V. R. Reddy. 1986. Crop simulation models in agronomic systems. Adv. in Agron. 40:141-208.

Wilkinson, L. 1988. SYSTAT: The System for Statistics. Systat, Inc. Evanston, Illinois.

Wolt, J. D. and F. Adams. 1979. Critical levels of soil- and nutrient-solution calcium for vegetative growth and fruit development of Florunner peanut. Soil Sci. Soc. Am. J. 43: 1159-1164.

Wood, I. M. W. 1968. The effect of temperature at early flowering on the growth and development of peanut (*Arachis hypogaea*). Aust. J. Agric. Res. 19: 241-251.

Wright, G. C. 1989. Effect of pod zone moisture content on reproductive growth in three cultivars of peanut (*Arachis hypogaea*). Plant and Soil 116: 111-114.

Yarborough, J. A. 1949. *Arachis hypogaea* : The seedling, its cotyledons, hypocotyl and roots. Am. J. Botany 36: 758-772.

Yost, R. S., G. Uehara, M. K. Wade, M. Sudjadi, I. P. G. Widjaja-Adhi and Zhi-Cheng Li. 1986. Expert Systems in Agriculture : Determining Lime Recommendations for Soils of the Humid Tropics. CTAHR, University of Hawaii.

Yost, R.S., S. Itoga, Zhi-Cheng Li and P. Kilham. 1987. Soil acidity management with expert systems. *in* M. Latham (ed.) Soil Management under Humid Conditions in Asia and Pacific. p 225-236. IBSRAM Proc. no. 5. Bangkok, Thailand.

Yost, R.S., S. Itoga, Zhi-Cheng Li, C. Colfer, L. I. Amien, P. Kilham and J. Hansen. 1989. Expert systems for soil and crop management information transfer in developing countries. (*in press*)

Young, J. H., F. R. Cox and C. K. Martin. 1979. A peanut growth and development model. Peanut Sci. 6: 27-36.