This is to certify that the

thesis entitled

ROOT AND SHOOT RESPONSES OF
(Zea mays L.) AND LEUCAENA LEUCOCEPHALA
TO SUBSOIL ALUMINUM TOXICITY AND pH
VARIATIONS USING CALCIUM SULPHATE AND
CALCIUM CARBONATE

presented by

Bernard Mdoka Mtonga

has been accepted towards fulfillment
of the requirements for

Masters degree in Crop & Soil Sci.

Boyd G Ellis
Major professor

Date September 23, 1991

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.

DATE DUE	DATE DUE	DATE DUE

ROOT AND SHOOT RESPONSES OF CORN (*Zea mays* L.) AND *LEUCAENA LEUCOCEPHALA* TO SUBSOIL ALUMINUM TOXICITY AND pH VARIATIONS USING CALCIUM SULPHATE AND CALCIUM CARBONATE

By

Bernard Mdoka Mtonga

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Sciences

1991

ABSTRACT

ROOT AND SHOOT RESPONSES OF CORN (*Zea mays* L.) AND *LEUCAENA LEUCOCEPHALA* TO SUBSOIL ALUMINUM TOXICITY AND pH VARIATIONS USING CALCIUM SULPHATE AND CALCIUM CARBONATE

By

Bernard M. Mtonga

Soil acidity and aluminum toxicity are known to affect root growth with subsequent decreases in plant yield. However, little is known about the effects of soil acidity and aluminum toxicity on the growth of corn (*Zea mays* L. *Var* Great lakes 450) and *Leucaena leucocephala.* This study, using two sources of Ca, was designed to investigate the chemical, biological and physical responses of both corn and Leucaena to soil acidity and aluminum toxicity. This was achieved by measuring their effects on the growth of corn and Leucaena roots and shoots. Leucaena and corn treatments were established in the greenhouse. In both treatment types, natural acidic soil was used as a control treatment.

Data collected included weekly measurements of plant heights, and at harvest shoot and root dry weight, and root length and diameter. The data indicate that corn is more responsive to soil acidity than Leucaena. Both shoot and root dry weights were significantly different in corn in response to liming but not in Leucaena. However most of this difference in corn was due to the smaller root diameter range (0.00-0.55mm). Liming did not significantly cause any differences in the growth rate and maximum heights of both corn and Leucaena. There were no significant difference in shoot to root ratios in corn or Leucaena, but there was a trend for liming to decrease the ratio in Leucaena. Overall dry weight data showed an increase in total dry weight in corn when the soil was treated with either $CaSO_4$ or $CaCO_3$. Liming Leucaena showed that calcium sulphate is more effective in increasing total dry weight than calcium carbonate.

Soil data indicated that of the two liming sources, calcium carbonate had a more negative effect on root weight that shoot weight. The water and KCl extracted pH's decreased after cropping. Both liming sources were effective in reducing the aluminum level from an initial content of 2.95 milliequivalents (meq) to less than 1 meq with calcium carbonate being more effective than calcium sulphate. Coefficients of variation ranged from 5 to 40%. Root growth was greatest when the subsoil was treated with calcium sulphate.

Dedicated to

Judith and Emmanuel

for their encouraging companionship.

ACKNOWLEDGEMENTS

I wish to humbly express my heartfelt and sincere appreciation to my major Professor, Dr. B. G. Ellis for his excellent guidance and patience throughout my entire academic stay at Michigan State University. His outstanding wisdom, counsel and understanding in directing my research and course work cannot be equalled.

Furthermore, I would like to particularly thank all the other members of my Guidance Committee, Dr. A. J. Smucker, Dr. E. Foster and Dr. M. Gold for their valuable advice and willingness to direct my research studies. The diverse nature of my committee was a valuable contribution to my studies. I also greatly appreciate the valuable technical assistance that Rosamond Soanes provided in my data collection and processing. Special thanks to my wife Judith and my son Emmanuel for providing an encouraging friendship and company as I pursued my studies. I will remain eternally grateful to my mother, brothers and sisters for their patience to allow me to complete my advanced studies at Michigan State University. Special appreciation is extended to my Sponsors for the adequate financial support they provided through the Zambian Government.

Finally, glory to God in the highest for His Grace to successfully see me through my studies. To Him be the glory forever and ever, AMEN.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

It is well known that soil is the natural matrix for plant root growth as well as the primary natural agricultural resource. Any unfavorable soil condition may place a stress on plant growth and yield. The vast majority of soils of the tropics, including the cultivated soils, are acid. This study was developed to focus on tropical soils because of the serious nature of soil acidity and liming problems in the tropics. The well established practice of liming temperate-region soils to neutrality has not been effective in most of the highly weathered soils of the tropics. More often than not, liming to pH 7 has caused more harm than good, especially since most of tropical crops are well adapted to acid soil conditions. Such crops do not respond to liming in the same manner as temperate zone crops.

Poor crop growth in acid soils can also be directly correlated with aluminum (Al) saturation (Sanchez, 1976). It is well known that pH per se has little direct effect on plant growth, except at pH values below 4.2, where the hydrogen ion (H^+) concentration may stop or even reverse cation uptake by roots (Black, 1967). According to Jackson (1967), Al toxicity, calcium (Ca) and/or magnesium (Mg) deficiency are some of the major factors responsible for acid soil infertility. Aluminum tends to accumulate in the roots and impede the uptake and translocation of Ca and phosphorus (P) to the tops (Foy, 1974). Thus Al toxicity may produce or accentuate Ca and P deficiencies.

It is admittedly true that many studies have been done on the effect of various adverse soil factors on the performance of many crops. But little if any has been done to investigate the response of *Leucaena leucocephala* and corn to soil acidity and Al toxicity using Ca materials. Thus, the main purpose of this study was to investigate the primary effects of soil acidity and Al toxicity on the growth of corn and *Leucaena leucocephala* which are important for alley cropping in tropical Africa.

CHAPTER 1

LITERATURE REVIEW

Of the two environments for plant growth, the soil is more complicated than the atmosphere (Russell, 1977). Between the two parts of the plant, the root and the shoot, the root, which grows below the soil surface, seems more complex than the shoot. Any chemical, physical and biological stress in the environment of the soil may inhibit or reduce root growth and plant productivity. Soil acidity and Al toxicity are two adverse environmental conditions which reduce the growth and dynamics of root systems of both agronomic crops and tree species.

LIMING AND ALUMINUM TOXICITY.

The purpose of liming is primarily to neutralize exchangeable Al which is normally accomplished by raising the soil pH to 5.5. The factors which need to be considered include the amount of lime needed to decrease the percent saturation to a desired level at which the particular crop and variety will grow, the quality of lime and the placement method (Sanchez, 1976). Much effort has been devoted to finding the best methods for estimating lime needs in the tropics. Kamprath (1970) and Reeve and Summer (1970) suggested that lime recommendations be based on the amount of exchangeable Al in the topsoil. This would be achieved by multiplying the milliequivalents (meq) of Al by 1.5 to give the meq of Ca needed to be applied as lime. This implies that for every meq of exchangeable Al present, 1.5 meq of Ca or 1.65 tons/ha of $CaCO_3$-equivalent should be added. In soils with high organic matter, the factor has to be raised to 2 or 3 because of the presence of exchangeable H^+. This method has been used very successfully in Brazil and other parts of the tropics since 1965.

Alleviation of Aluminum Toxicity by Calcium Sulphate.

According to Noble et al., 1988, the alleviation of Al toxicity by $CaSO_4$ is partly due to an increase in the formation of less phytotoxic $AlSO_4^+$ species. They found that the magnitude of alleviation of Al toxicity by $CaSO_4$ was smaller at pH 4.8 than at pH 4.2. They suggested that this pH dependency is due to lesser formation of $AlSO_4^+$ at pH 4.8 than pH 4.2, together with an increase in formation of $Al(OH)_2^+$ at pH 4.8. Addition of Ca ameliorates acid soil infertility factors by the fact that this treatment mechanistically results in the precipitation, complexation, polymerization or chelation of Al thereby reducing the levels of phytotoxic Al in solution (Hoyt and Turner, 1975; Hue et al., 1986). However not all acid soils restrict plant growth through Al toxicity. Adams and Moore (1983) clearly demonstrated that certain acid subsoils suffered from Ca deficiency rather than Al toxicity.

The ameliorating effect of Ca on Al toxicity can be attributed to either a reduction in the activity of phytotoxic Al species, through an increase in the ionic strength of the solution or a direct physiological effect of the added Ca on the root surface (Alva et al., 1986; Clarkson and Sanderson, 1971; Rhue and Grogan, 1977). Furthermore, the associated carrier anion, which depends on the source of Ca applied, may result in the formation of less phytotoxic species. Such an effect has been demonstrated for SO_4^{2-} when Ca was applied as $CaSO_4$ (Kinraide and Parker, 1987). The relationship between tap root length of soybean and the activity of $AlSO_4^+$ has been reported to be relatively poor. This observation adequately supports the lesser phytotoxicity of $AlSO_4^+$ species and strongly suggests the need to modify solution Al indices to account for the SO_4^{2-} complexation of Al in a form that is less phytotoxic. Since increasing activity of $AlSO_4^+$ was obtained by an increase in $CaSO_4$, there was a confounding effect of improved root length at the higher $CaSO_4$ additions due to Ca alleviation of Al toxicity (Noble et al., 1988). Thus, increasing Ca in the root environment has been reported to play a physiological role in alleviation of Al toxicity.

Response of Corn to Liming and Aluminum Toxicity

According to Sanchez (1976), corn is sensitive to 40 to 60 percent Al saturation. Although liming to zero Al saturation might be beneficial, lowering the Al saturation level to 20 percent could be more economical. When extremely acid Oxisols have their topsoil limed to pH 5.5, most of the root development of corn occurs in the topsoil. The high subsoil Al saturation prevents deeper root penetration. For this reason, Gonzalez and Kamprath (1973) compared incorporating lime at two depths, 0 to 15 cm and 0 to 30 cm in an Oxisol using a rototiller. They found that deeper applications produced higher yields. Root studies showed that higher yields were associated with deeper root development in the 0 to 30 cm layer which also diminished water stress during short term water deficits. The feasibility of deep lime incorporation in the field depends largely on soil structural properties and available equipment.

Prior to 1950, literature from tropical soil regions is full of reports citing the lack of response of crops when tropical soils are limed to near neutrality. This has created the general idea that liming does not work in the tropics (Richardson, 1951). Kamprath (1971) reviewed the reasons for the lack of positive lime responses when highly leached soils are limed to neutrality. He found that overliming caused yield reduction, soil structure deterioration, and decreased availability of P, boron (B), zinc (Zn) and manganese (Mn). The review indicated that liming to neutrality promotes the formation of smaller aggregates, thus reducing infiltration rates and making some Oxisols and Ultisols more susceptible to erosion (Peele, 1936; Schuffelen and Middleburg 1954; Ghani et al., 1955). Furthermore, overliming induces P deficiency in soils with high P fixation capacity. The bulk of the evidence suggests that highly weathered soils should not be limed to pH values greater than 5.5 since beyond that level yield decreases can occur. However, overliming oxides and oxide-coated layer silicate systems with little pH-dependent charge produces no yield decreases (McLean, 1971).

Corn management, especially in the tropics, should be aimed at determining the minimum level of lime needed, selecting species and varieties more tolerant to Al, and following practices that promote deeper root development in the acid subsoils. Mahilum et al., (1970), studied the residual effects of liming in Hawaii and found that after 5 years, a rate of 2 tons lime/ha kept the Al level at about 1 meq (from an original value of 3 meq), even though most of the Ca was leached to lower levels. Apparently Al ions did not readily reoccupy the exchange sites even when Ca leached to lower depths such that after 5 years, the residual effect of liming at the rate of 5 tons/ha had completely disappeared. In sharp contrast, De Freitas and Van Raij (1975) obtained a positive corn response to lime in a sandy Oxisol of Brazil, that response was still apparent 6 years after lime application. They observed increasing yield responses with time and attributed them to the dissolution of the coarser lime particles.

According to Rhue (1979), some plants have the ability to accumulate enormous amounts of Al in their foliage without evidence of injury or toxicity. In a review article on the effects of Al on plant growth, Jackson (1967) concluded that correlations between Al contents in the foliage of crop plants and Al toxicity are more the exception than the rule. He stated that toxic effects of Al may result from excess Al in the growth medium (soil) with little or no change in Al content in the foliage. Jackson further reported that in some situations the Al contents in the foliage of crop plants were either unaffected or actually increased with the addition of lime or P. Various mechanisms have been proposed to explain the differential Al tolerance of plant species. Mussel and Staples (1979) suggested that plants that are able to maintain sizeable concentrations of Al within their tissues while at the same time maintaining adequate P levels, must possess a mechanism whereby Al is prevented from precipitating with P at physiological pH's. Varietal differences in Al tolerance have also been reported in corn (Clark, 1974).

As a species, corn is fairly tolerant of Al. Using nutrient solutions containing a range in Al concentrations, Foy and Brown (1964) showed that corn was more tolerant to Al than barley. Of six species tested, corn gave the least response to lime when grown on acid soil which had an initial pH value of 4.6. In field studies, Kamprath (1970) observed that liming consistently increased the growth of corn only when the Al saturation was greater than 70%. In another study, Clark and Brown (1974) have shown differences in Al tolerance within and among different varieties of corn. They reported marked differences among inbred lines in their ability to take up P from acid, Bladen soil (pH 4.3).

Using a Ca variable to control the degree of Al toxicity showed that a wide range in tolerance to Al exists among corn inbreds. Roots of one inbred (ND408) showed symptoms of severe Al toxicity at all levels of stress (swelling, stunting and discoloration), while those of another inbred (Va 17) were fairly tolerant even at the lowest level of Ca (Mussel and Staples, 1979). They further reported that the response of corn to Ca in the presence of 0.25 mM Al is not a direct response to Ca *per se*, but is a response to the ameliorating effect of Ca on Al toxicity.

Genetic control of Al tolerance in corn has also been suggested in which the hypothesis of a multiple series of factors controlling tolerance in corn has been obtained from two composites, one of temperate and the other of tropical origin. The study indicated that rapid progress could be made in developing Al tolerant corn populations in only one or two cycles of selection starting with the original composites (Mussel and Staples, 1979).

Response of Leucaena to Ca Addition and Al Toxicity.

While the humid tropics are viewed as areas of high potential productivity, production on many humid tropical soils is constrained by many factors such as low nutrient reserves, Al toxicity, high P fixation, soil acidity, steep slopes, low cation exchange capacity and shallow organic soils.

These limitations adversely affect the performance of both trees and agronomic crops that are grown in an intercropping system. Climatic characteristics often limit tree growth. Moisture stress, seasonal temperature fluctuations, poor soil drainage and infiltration, soil acidity and soil infertility also limit tree and agronomic crop growth.

Establishment of *Leucaena leucocephala* is often nutritionally constrained by low P levels in tropical soils (Benge, 1982). But its principal limitations are that it prefers a tropical lowland area, requires a reasonable mineral balance (Ahmad and Ng, 1981) and specific rhizobia in the soil (Halliday, 1981; Sanginga, et al., 1988; Trinick, 1980). Low fertility diminishes its performance. Furthermore, Sanginga, et al., (1988), reported that most tropical soils are deficient in P such that fertilization with P becomes necessary for Leucaena growth. *Leucaena leucocephala* needs P for vigorous growth and N fixation (Benge, 1982; Hu and Chang, 1981; National Academy of Sciences,1977). In another study, Melo et al., (1987), showed that shoot height, shoot dry weight and nutrient accumulation were increased significantly in the Al-intolerant cultivar when inoculated with the mycorhizal fungus *Glomus* *leptotichum*. They also found non significant difference between seedlings given Al treatments.

Leucaena is reported to have grown poorly on acid soils. However among the genetic introductions, variety K-636 showed the best growth at one site (IITA Annual Report, 1986). According to Fox et al., (1985), growth of Leucaena on an acidic Oxisol increased with increasing lime until a pH in excess of 7 was attained. The beneficial effects of liming on Leucaena growth were linear from pH 4.8 to 7.0. Liming the Oxisol depressed Al concentration in the pH range 4.8 to 5.5 and Mn in the pH range 4.8 to 5.7. They found that liming did not change solution Ca until pH 5.7 was reached, after which solution Ca contents of saturation extracts increased exponentially with increasing pH. They suggested that improved Ca nutrition may have been responsible for increased growth of Leucaena that was associated with increasing soil pH in the range 6 to 7 and beyond. Although Al toxicity rather than Mn toxicity was believed to be a major factor causing infertility of the Ultisol from one site, the Leucaena growth response curve was substantially the same as on the manginiferous Oxisol, including increased production with increasing pH in the range 5.8 to 7.1. These data suggest that Mn toxicity, Al toxicity, and at least one other factor including Ca deficiency, all interacting at the low pH, were responsible for growth responses associated with liming.

Furthermore, they argue that an important factor in liming soils of the humid tropics is the small quantity of lime required to effect pH changes at low end of the lime curve and the relatively large quantity of lime required to effect a change in Ca concentration. This is due to the fact that mineral soils with variable charge colloids are poorly buffered when soil pH is <5.3 (Fox, 1981). Relatively little lime was required to increase the pH of the Oxisol to 5.5, a pH at which Al toxicity is unlikely. Starting at a pH at which net charge of the soil is zero, an increase in pH of variable-charge soils is accompanied by an increase in effective cation exchange capacity (ECEC). In another study Juo and Uzu (1977), observed that Ca deficiency is a real possibility even for plants that have low Ca requirements if the plants are growing at a pH where liming produces little change in Ca concentration.

Root dynamics studies have shown that Leucaena is generally deep rooted having both deep penetration and horizontal extension thereby exhibiting best root development both in the topsoil and subsoil (Hairiah and Van Noordwijk, 1986). In addition, Kang et al., (1985), have shown that corn and Leucaena have different root feeding zones, with Leucaena extracting moisture from deeper soil layers. Prunings added as mulch substantially increased moisture retention in the topsoil. This is why maize is often grown in alley cropping system intercropped with *Leucaena leucocephala*.

LITERATURE CITED

Almad, N. and Ng, F.S.P. 1981. Growth of *Leucaena leucocephala* in relation to soil pH, nutrient levels and rhizobia concentration. Leucaena Research Reports 2:5-10.

Alva, A.K., C.J. Asher and D,G. Edwards. 1986. The role of calcium in alleviating aluminum toxicity. Aust. J. Agric. Res. 37:373-382.

Benge, M.D. 1982. The miracle tree: Reality or myth? In: Leucaena Research in the Asian-Pacific Region. IDRC pp 95-98. Ottawa. Ontario. Canada.

Black, C. A. 1967. Soil plant relationships, 2nd ed. Wiley, N.Y.

Clark, R.B., and J.C. Brown. 1974. Intraspecific differences in Al tolerance in corn. Comm. Soil Science Plant Anal. 5: 213-227.

Clarkson, D.T., and J. Sanderson. 1971. Inhibition of the uptake and long-distance transport of calcium by aluminum and other polyvalent cations. J. Exp. Bot. 22:837-851.

De Freitas, L. M. M., and B. Van Raij. 1975. Residual effects of liming a sandy clay loam Latosol. pp. 300-307. In E. Bornemisza and A. Alvarado (eds.), Soil management in Tropical America. North Carolina State University. Raleigh.

Fox, R.L. 1981. Soils with variable charge: Agronomic and fertility aspects. pp.195-224. *In* B.K.G. Theng (ed) Soils with variable charge.New Zealand Society of Soil Science, Soil Bureau, DSIR, Lower Hutt, N.Z.

Fox, R.L., Yost, R.S., Saidy, N.A., and B.T. Kang. 1985. Nutritional Complexities with pH Variables in Humid Tropical Soils. Soil Sci. Soc. of Ame. J. 49: 1475-1480.

Foy, C.D., and J.C. Brown. 1964. Toxic factors in acid soils. II. Differential Aluminum tolerance of plant species. Soil Sci. Soc. Amer. Proc. 28: 27-32.

Foy, C.D. 1974. Effects of aluminum on plant growth. pp. 601-642. In E.W. Carson (Ed.), The plant root and its environment. University Press of Virginia, Charlottesville.

Ghani, M.O., K.A. Hassan, and M.F.A. Kahn. 1955. Effects of liming on aggregation, non-capillary pore space and permeability of laterite soils. Soil Sci. 80: 469-478.

Hairiah, K. and M. Van Noordwijk. 1986. Root studies on a Tropical ultisol in relation to nitrogen management. Report of field work at IITA's high rainfall sub-station at Onne (Port Harcourt, Nigeria) in 1985. CODEN; IBBRAH (7-86) pp. 75-91.

Halliday, J. 1981. Nitrogen fixation by Leucaena in acid soils. Leucaena Research Reports 2: 71-73.

Hoyt, P.B., and R.G. Turner. 1975. Effects of organic materials added to very acid soils on pH, Aluminum, exchangeable NH_4, and crop yields. Soil Sci. 119:227-237.

Hu Ta-Wei and Chang, W. E. 1981. Growth and nutrient levels of *Leucaena leucocephala*: Response to lime and phosphorus on acid soil. Leucaena Research Reports 2: 48-49.

IITA (International Institute Of Tropical Agriculture, 1986. Farming Systems Program Annual Report, 1985. Ibadan Nigeria. 119-120.

Jackson, W.A. 1967. Physiological effects of soil acidity. In Soil acidity and Liming (R.W. Pearson and F. Adams eds) Am. Soc. Agron. NO. 12:43-124.

Juo, A.S.R., and F.O. Uzu. 1977. Liming and nutrient interactions in two Ultisols from southern Nigeria. Plant Soil 47:419-430.

Kamprath, E.J. 1970. Exchangeable Aluminum as a criterion for liming leached mineral soils. Soil Sci. Soc. of Amer. Proc. 34:252-254.

Kamprath, E.J. 1971. Potentially detrimental effects of liming highly weathered soils to neutrality. Proc. Soil Crop Sci. Soc. Fla. 31:200-203.

Kamprath, E.J. 1973. Soil acidity and Liming. pp126-128. In P.A Sanchez (ed.), "A Review of Soils Research in Tropical America." North Carolina Agr. Exp. Sta. Tech. Bull. 219.

Kang, B.T., Grimme, H., and Lawson, T.L. 1985. Alley cropping sequentially cropped maize and cowpea with Leucaena on a sandy soil in southern Nigeria. Plant Soil 85: 267- 277.

Kang, B.T.,Wilson, G, F. and Lawson, T.L. 1986. Alley cropping: A stable alternative to shifting cultivation. IITA. Ibadan, Nigeria. 8-21. May.

Kinraide, T.B., and D.R. Parker. 1987. Non-phytotoxicity of the aluminum sulfate ion, $AlSO_4^+$. Physiol. Planta. 71:207-212.

Mahilum, B. C., R. L. Fox, and J. A. Silva. 1970. Residual effects of liming volcanic ash soils in the tropics. Soil Sci. 109:102-109.

McLean, E.O. 1971. Potentially beneficial effects of liming: chemical and physical. Proc. Soil Crop Sci. Fla. 31: 189-199.

Melo, I.S., Silveria, A. P. D. DA; Maluf, A. M. 1987. Effect of aluminum and Glomus leptotichum on the development of cultivars of *Leucaena leucocephala* tolerant and intolerant of aluminum. Superior agric. 44: 1365-1380.

Mussel, H., and R.C. Staples. 1979. Stress Physiology in crop plants. John Wiley and Sons, Inc. Wiley-Interscience Publication. New York. pp. 61-106.

National Academy of Sciences. 1977. Leucaena: Promising forage and tree crop for the tropics. Washington, DC. U.S.A. NAS. pp115.

Noble, A.D., M.E. Summer, and A.K. Alva. 1988. The pH dependency of Aluminum phytotoxicity alleviation by calcium sulfate. Soil Sci. J. 53:1398-1402.

Peele, T.C. 1936. The effects of calcium on the erodibility of soils. Soil Sci. Soc. Amer. Proc. 1: 47-58.

Rhue, R.D., and C.O Grogan. 1977. Screening corn for aluminum tolerance using different Ca and Mg concentrations. Agron. J. 69:755-760.

Rhue, R.D. 1979. Differential Aluminum Tolerance in Crop Plants. Contribution from the Department of Agronomy, Cornell University, Ithaca, New York as Agronomy Paper N0. 1212. *In* Mussel, H., and R.C. Staples. 1979. Stress Physiology in crop plants. John Wiley and Sons, Inc. Wiley-Interscience Publication. New York. pp. 62-80.

Richardson, H. L. 1951. Soil acidity and Liming with tropical crops. World Crops 3: 339-340.

Russell, R.S. 1977. Plant Root System: Their function and interaction with the soil. Mc Graw-Hill Book Co. (UK) pp. 1.

Sanchez, P.A. 1976. Properties and management of soils in the tropics. John Wiley and Sons, Inc. N.Y. pp 224 - 253.

Sanchez, P.A., Palm, C.A., Davey, C.B., Szcott, L.T., and Russell, C.E. 1985. Tree crops as soil improvers in the humid tropics? In: Cannel, M.G.R. and Jackson, J.E. Attributes of trees as crop plants. Institute of Terrestrial Ecology, Huntington, England.

Sanginga, N., Mulongoyi, K., and Ayanaba, A. 1988. Response of Leucaena/Rhizobia symbiosis to mineral nutrients in southwestern Nigeria. Plant and Soil 112: 121-127.

Schuffelen, A. C. and H. A. Middleburg. 1954. Structural deterioration of lateritic soils through liming. Trans. Fifth Int. Congr. Soil Sci. 2:158-165.

Trinick, M.J. 1980. Relationships among the fast growing rhizobia of *Lablab purpureus, Leucaena leucocephala*, Mimosa spp., *Acacia farnesiana* and *Sesbania grandiflora* and their affinities with other rhizobial groups. J. Appl. Bacteriol. 49:39-53.

CHAPTER 2

ROOT AND SHOOT RESPONSES OF CORN (*Zea mays* L.) AND *LEUCAENA LEUCOCEPHALA* TO SUBSOIL ALUMINUM TOXICITY AND pH VARIATIONS USING CALCIUM SULPHATE AND CALCIUM CARBONATE.

INTRODUCTION

Aluminum (Al) toxicity and soil acidity are serious causes of poor plant growth and low yields due to the fact that they impair proper root growth and development. This problem is more common in the tropics than temperate regions (Sanchez, 1976) and the subsoil is the primary zone of soil acidity and Al toxicity. In normal circumstances, lime should be applied to the subsoil for effective reduction of Al toxicity and soil infertility due to soil acidity. But physically incorporating lime in subsoils is difficult. On the other hand $CaSO_4$ is sufficiently soluble to allow the movement of significant quantities of Ca and SO_4 into the subsoil with water, when $CaSO_4$ is applied to the top soil.

Previous studies have recorded that inhibition of root growth is one of the first observable symptoms of Al toxicity in plants (Scott et al., 1991). But a differential response exists between Al-tolerant germplasm and Al-sensitive germplasm. Briggs et al., (1989) have shown in wheat that Al-tolerant germplasm had greater root weight index than Al-sensitive germplasm in response to pH change.

The objective of this study was to investigate the response of a grain crop (corn) and a N fixing multipurpose leguminous tree (Leucaena) to soil acidity and Al toxicity. The sources of Ca used were $CaSO_4$ and $CaCO_3$. The primary idea was to see the difference and effectiveness of these materials in neutralizing soil acidity and Al toxicity. Soil chemistry data, shoot and root dynamics were the major focus of interest to evaluate their effectiveness and response of corn and Leucaena to variation in soil pH and Al.

MATERIALS AND METHODS

This study was conducted in the greenhouse due to logistical considerations because naturally acidic soils were not located near Michigan State University Campus. The soil, with initial average topsoil and subsoil pH values (1N KCl 1:1 soil to solution) of 4.6 and 3.9, respectively was collected from Kellogg Biological Station. The soil was air-dried for 5-6 days, screened and thoroughly mixed. Initial water and KCl measurements of pH, KCl extracted exchangeable Al, Ca, and P contents were done on the soil before planting using the methods of analysis outlined in the Agronomy Procedure N0.9 Part 2 (Page et al., 1982).

The subsoil weight per container was 4,000 g while the top soil weight was 4,200 g per container. The sub-soils were prepared for planting by adding either 43.35 g of $CaSO_4.2H_2O$ or 9.63 g of $CaCO_3$ to the subsoil in separate cans. Each can was 15.5 cm in diameter and 17.5 cm high. In order to ensure even distribution of the chemicals, the soil was spread on a flat plastic onto which either of the substances were evenly distributed and mixed about 50 times. The bottom can was then packed half full with the subsoil after which 450 ml of de-ionized water was added. After filling the can completely with the subsoil an additional 840 ml of distilled water was added. Then a can with bottom removed was placed above the container and sealed on top of it. Potassium phosphate (KH_2PO_4) was added and mixed to the topsoil as a source of K and P at the rate of 1.04 g per can. After almost filling the top can with surface soil, more distilled water was added to bring the soil to field capacity. The seeds were then sown into the surface soil after which the rest of the topsoil was added to the top can. The procedure was similar for establishing Leucaena seedlings. The soil packing procedure aimed at reaching a field capacity of 18% moisture and a bulk density of 1.4 g/cm^3.

Leuceana leucocephala seeds were germinated in petri dishes in the dark and then transplanted after 3 days. Two seedlings were initially transplanted and then thinned to 1 seedling per can after 2 weeks. Corn (*Zea mays* L. *var:* Great Lakes 450) was directly seeded. Four seeds were sown after which the seedlings were thinned to 2 seedlings per can 2 weeks after planting. The cans were placed on a bench in a randomized complete block design (RCBD), with four replications. The treatments were:

1. Corn planted in untreated soil.
2. *Leucaena leucocephala* transplanted into untreated soil.
3. Corn planted in soil to which $CaSO_4$ was added to the subsoil.
4. *Leucaena Leucocephala* transplanted into soil to which $CaSO_4$ was added to the subsoil.
5. Corn planted in soil with the subsoil limed with $CaCO_3$.
6. *Leucaena leucocephala* planted in soil with the subsoil limed with $CaCO_3$.

Every day throughout the growing period, the soil was returned to field capacity by adding appropriate amounts of distilled water. Plant heights were measured weekly. Nitrogen was applied to corn twice during the growing period using NH_4NO_3 solution at the rate of 10g of N per container.

Corn was harvested after 9 weeks (the plants had just tasselled). The harvested plants were immediately weighed then dried and reweighed to determine shoot fresh and dry matter content. The roots were harvested from the top and subsoils separately then removed from the soil by washing with the hydropneumatic elutriation system (Smucker et al., 1982) after which they were stained and stored in the cooler at 4^oC in readiness for processing with the Robotic camera system (Smucker, 1989) which was used to take video images of the roots. Root length and diameter were determined by computer image processing (Smucker et al., 1987). This procedure was repeated for Leucaena plant shoots and roots which were harvested 15 weeks after planting. Further data analysis was done with LOTUS 123 and MSTAT C. Post harvest measurements of soil pH, Al, Ca and P contents were also determined for the soil after harvesting.

RESULTS

From the results of shoot and root dynamics obtained in this study, it is obvious that corn responded more to lime and gypsum additions than did Leucaena. Leucaena may be more Al-tolerant than corn because it evolved in tropical areas.

Responses of Plant Tissue Dry Weights and Root to Shoot Ratios to Lime and Gypsum Addition.

Table 1 shows that root and shoot dry weights of corn were significantly increased by both $CaSO_4$ and $CaCO_3$. But with Leucaena, plant tissue dry matter (roots and shoots) was not significantly increased by application of $CaSO_4$ or $CaCO_3$ but both sources did increase the shoot weights. In general, $CaSO_4$ caused higher plant root dry weights in both corn and Leucaena than did $CaCO_3$. The root to shoot ratios of corn and Leucaena were not significantly affected by $CaSO_4$ or $CaCO_3$ application. But there was a trend of decrease in root to shoot ratios with $CaSO_4$ or $CaCO_3$ additions in Leucaena. The plants had an increased shoot dry weight than root weight when either $CaSO_4$ or $CaCO_3$ was added. However, the decrease in the ratios was not significant.

Table 1. Plant tissue dry weight and root to shoot ratios of corn and Leucaena as affected by lime and gypsum.

TREATMENTS	Plant tissue dry weight			
	Roots	Shoots	Root:shoot ratio*	Total dry wgt
	grams			
Corn.				
Control	0.65	45.2	0.014	45.9
$CaSO_4$	1.33	54.3	0.024	56.6
$CaCO_3$	1.08	54.7	0.018	55.8
$LSD_{0.05}$	0.37	4.41	n.s.	4.7
Leucaena.				
Control	1.02	4.51	0.23	5.53
$CaSO_4$	1.21	6.03	0.20	7.27
$CaCO_3$	0.87	5.25	0.16	6.15
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.

* Subsoil Root to Shoot ratios.

Furthermore, the results indicate that addition of $CaSO_4$ or $CaCO_3$ increased the growth rates of corn (Figure 1a) and Leucaena (Figure 1b) as well as the maximum plant heights attained by both corn and Leucaena after 9 and 15 weeks of growth respectively (Figure 1c). Of the two sources of Ca, $CaSO_4$ generally gave higher values in both corn and Leucaena in terms of root and shoot dry weights, root to shoot ratios and the total dry matter content of the plants.

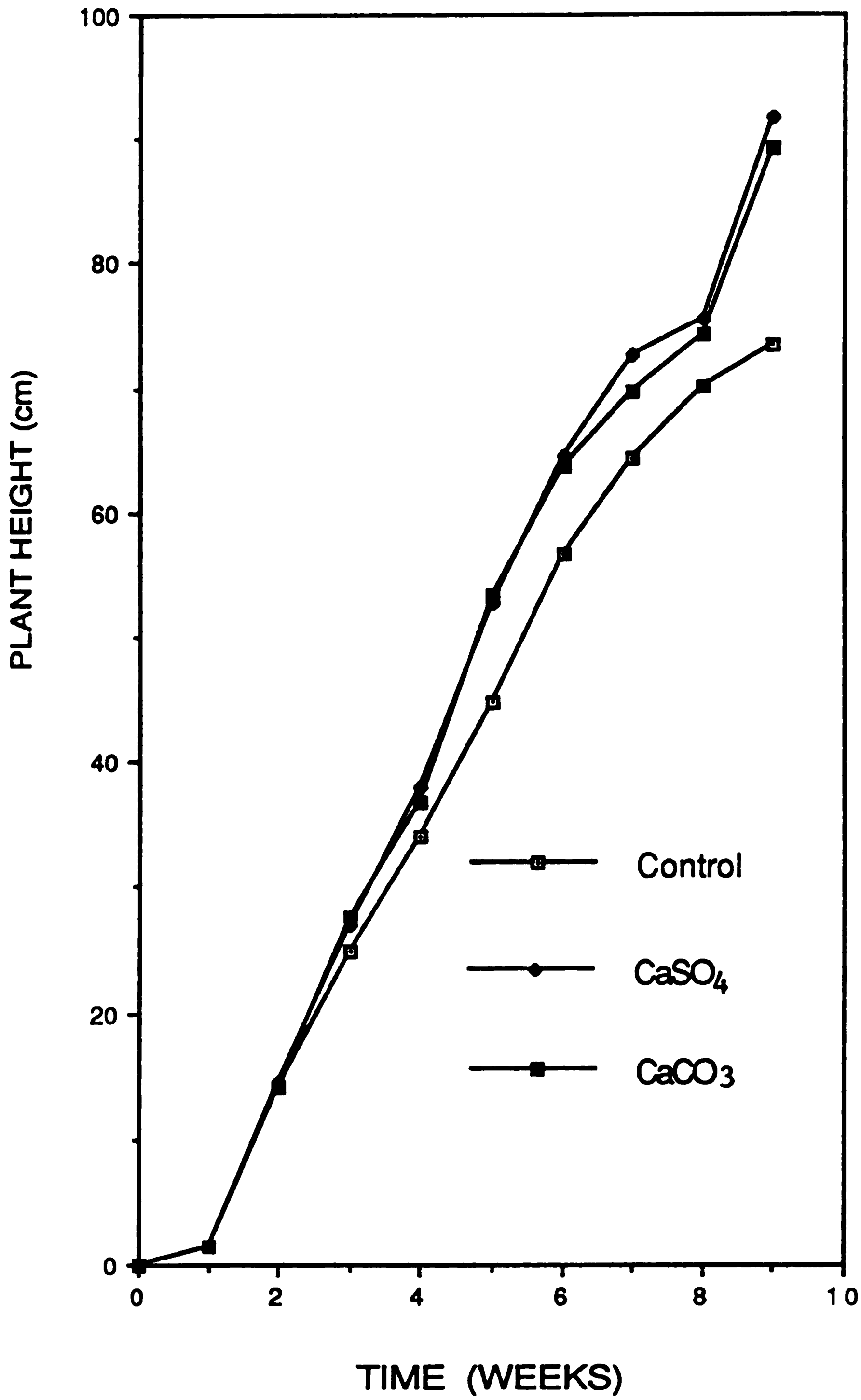

Figure 1a: Effects of $CaSO_4$ and $CaCO_3$ on the plant height of corn.

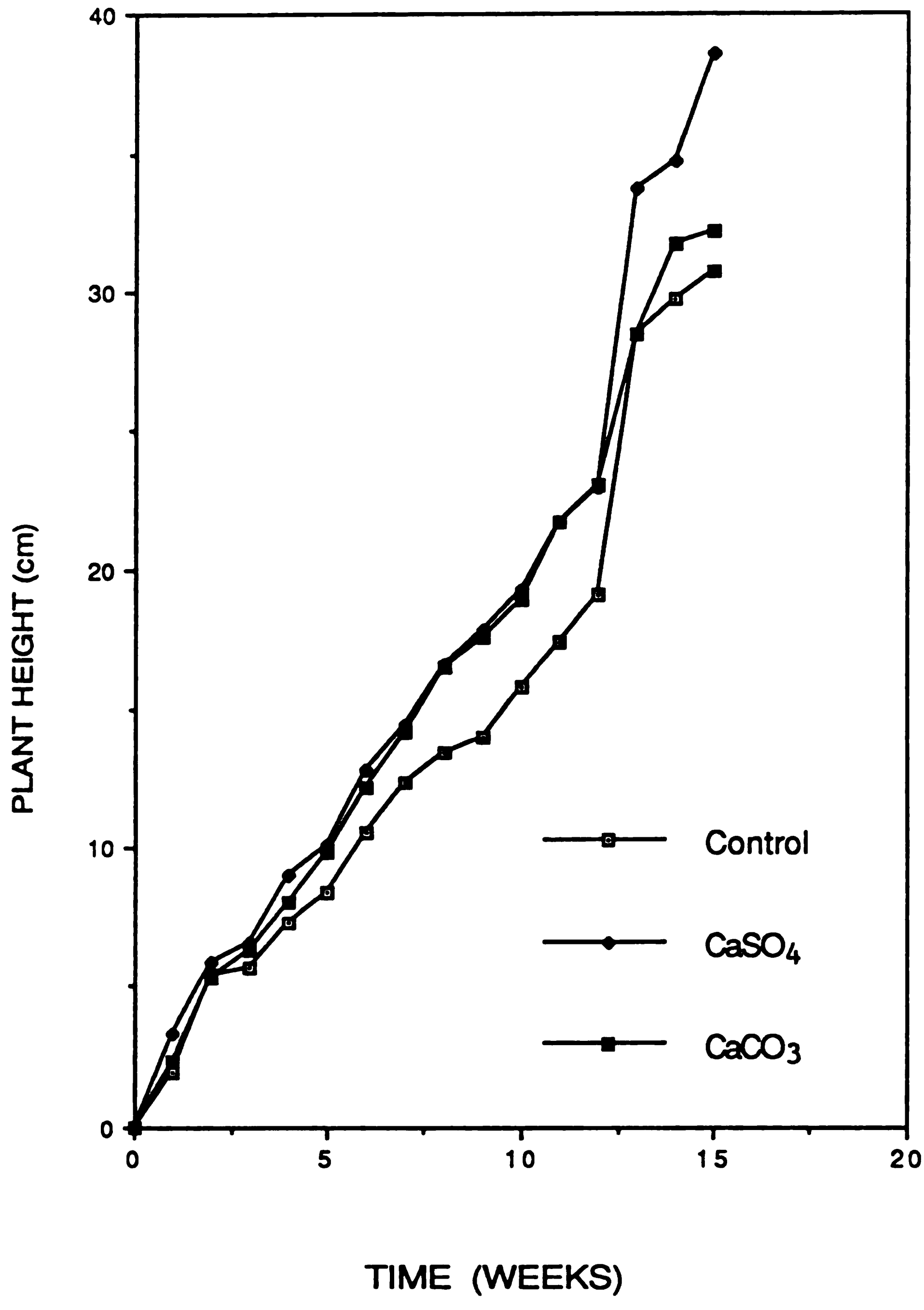

Figure 1b: Effects of $CaSO_4$ and $CaCO_3$ on the plant height of Leucaena.

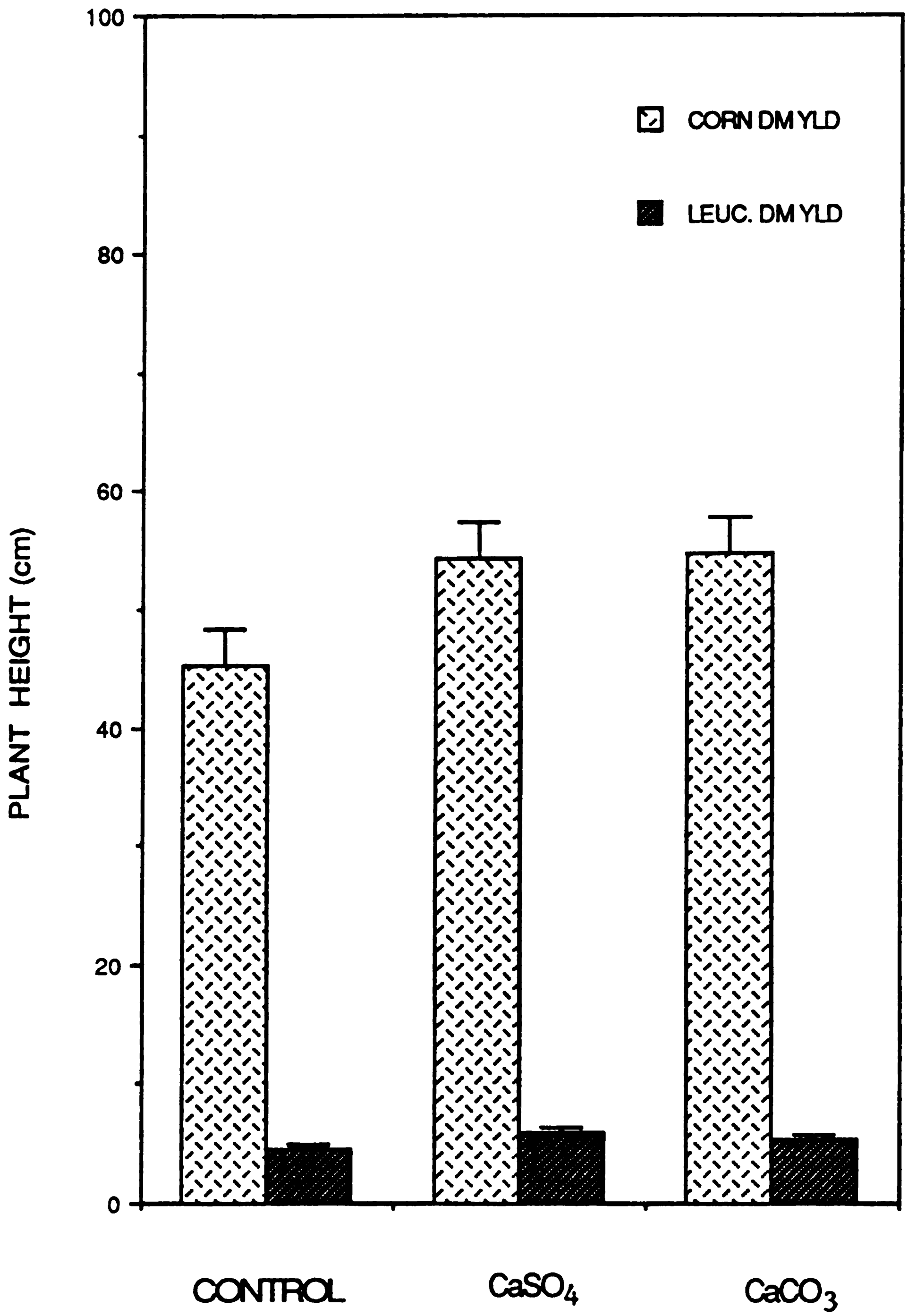

Figure 1c: Effects of $CaSO_4$ and $CaCO_3$ on the maximum plant heights of corn and Leucaena.

Responses of Root Length and Density to Lime and Gypsum.

Root length and density responses of corn and Leucaena to $CaCO_3$ and $CaSO_4$ addition are tabulated in Table 2. Root length results are similar to those of plant tissue dry matter. The root densities of corn or Leucaena were not increased by additions of $CaCO_3$ or $CaSO_4$. Total root length is significantly increased in corn when $CaCO_3$ or $CaSO_4$ is added. However, adding $CaSO_4$ or $CaCO_3$ to the subsoil did not cause significant increases in root length of Leucaena. The significant increase in root length of corn in response to $CaCO_3$ and $CaSO_4$, is primarily and significantly contributed by the smallest diameter range of root sizes (0-0.25mm) which account for 74.9 to 81.6% of the total root length (Figure 2a). Furthermore, the figure shows that the medium diameter range of root size (0.25-0.55mm), contributes 15.4 to 20.5% of the total root length of corn whereas 2.2 to 4.6% of the total root length of corn is contributed by the largest diameter range sizes (0.55-0.90mm).

In Leucaena, 42.5 to 46.2% of the observed differences in total root length is due to the smallest diameter root range sizes. The medium sized roots contained 46.5 to 48.1% of the total root length while the largest roots contribute only 7.2 to 9.9% of the total root length of Leucaena (Figure 2b). It is clear from this study that in both corn and Leucaena, the total root length is principally that of the small roots. But the medium sized roots contribute more towards the total root length in Leucaena than in corn. In both corn and Leucaena, the largest roots gave insignificant contributions towards the total root length.

Table 2. Root length and density of corn and Leucaena as affected by lime and gypsum.

TREATMENTS	Root length diameter classes (Millimeters)			Total root length	Root density
	0-0.25	0.25-0.55	0.55-0.90	(cm)	(g/cm3)
Corn.		(cm)			
Control	59.2	15.7	1.8	76.7	0.17
$CaSO_4$	123.8	34.0	7.2	165.0	0.13
$CaCO_3$	132.3	24.9	4.9	162.2	0.14
$LSD_{0.05}$	53.9	12.2	3.2	65.5	n.s.
Leucaena.					
Control	32.6	34.7	5.1	72.4	0.12
$CaSO_4$	24.9	30.4	5.8	61.2	0.20
$CaCO_3$	33.5	33.5	5.2	72.2	0.11
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	n.s.

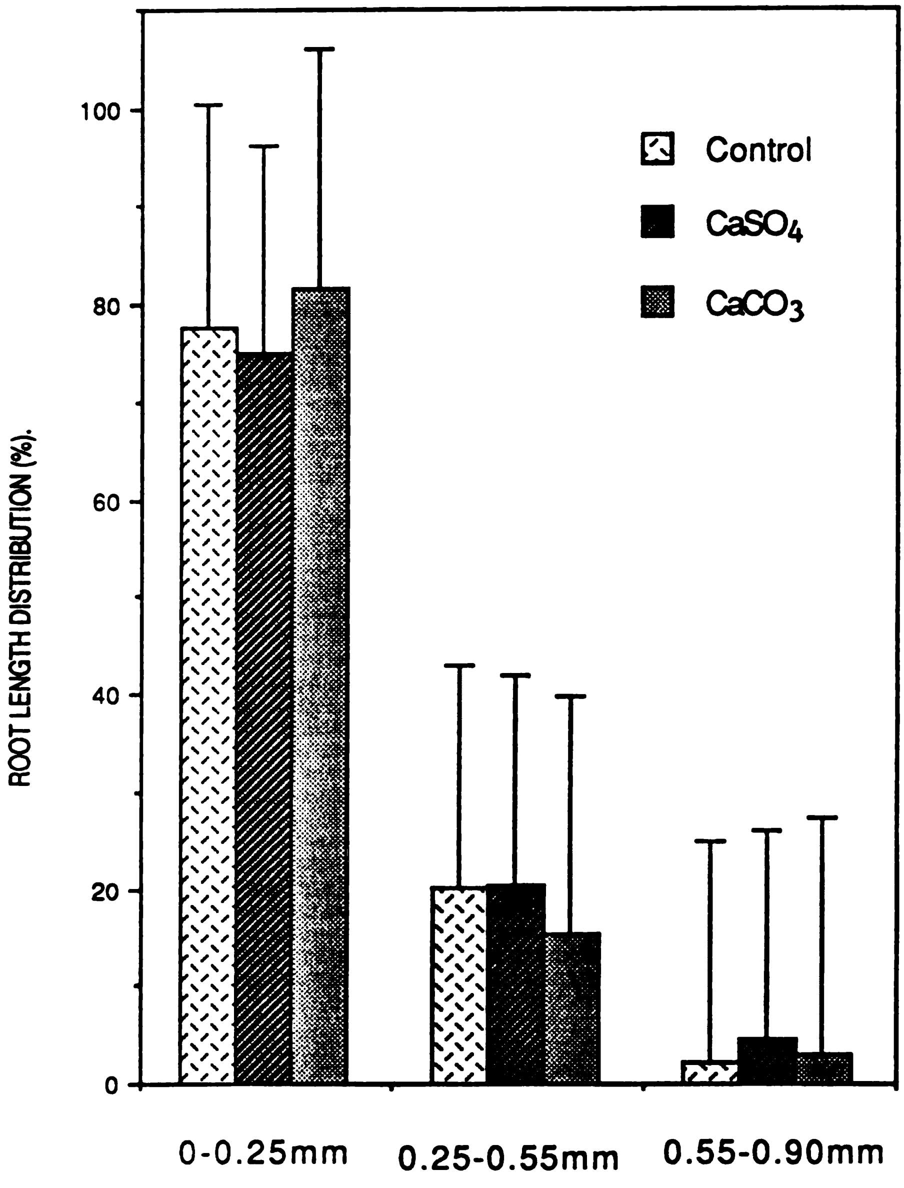

Figure 2a: Effects of $CaSO_4$ and $CaCO_3$ on the percent distribution of root length of corn.

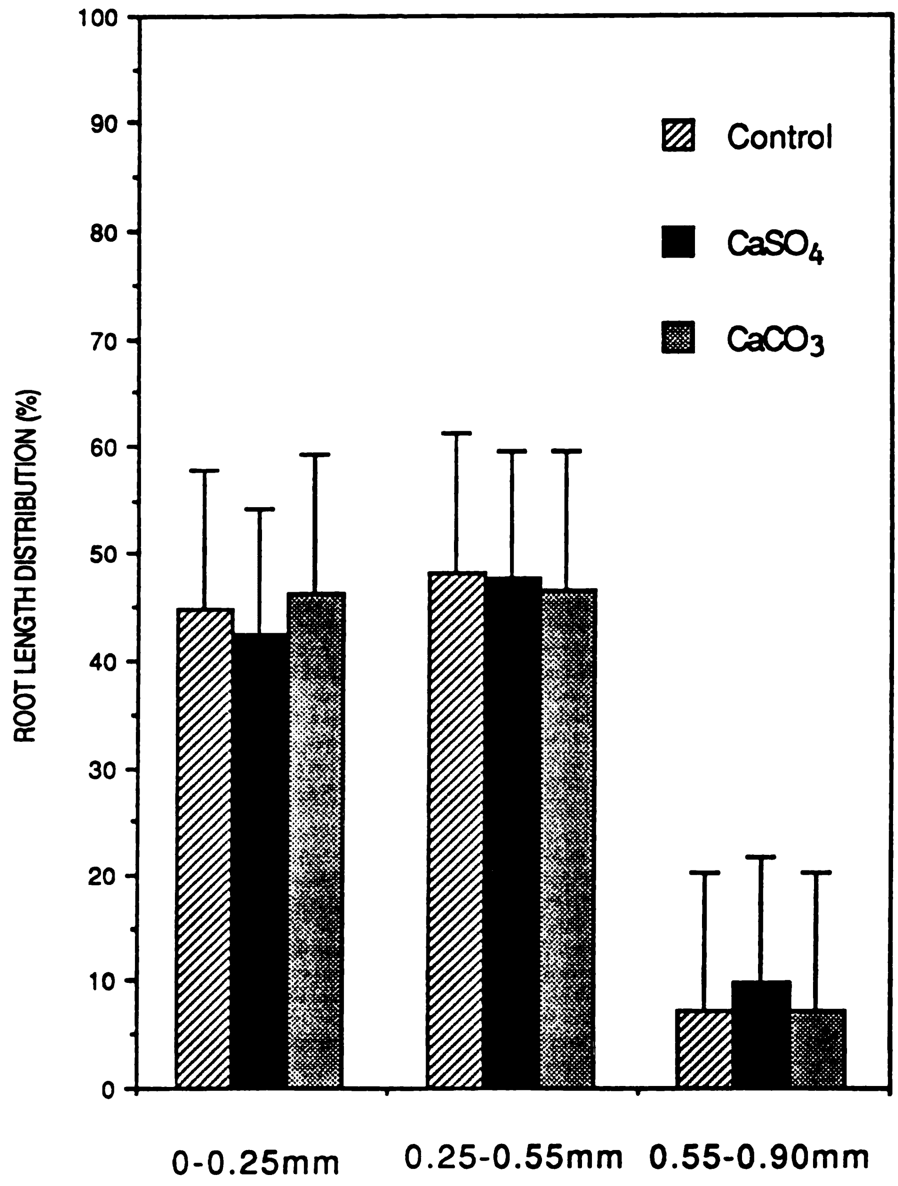

Figure 2b: Effects of $CaSO_4$ and $CaCO_3$ on the percent distribution of root length of Leucaena.

Responses of Root Surface Area to Lime and Gypsum Additions.

Table 3 indicates that the total root surface area of corn is significantly increased when $CaCO_3$ or $CaSO_4$ is added, with $CaSO_4$ giving the highest increase. The total root surface area of corn is almost equally contributed by the smallest and medium sized roots which account for 45 to 55% and 33 to 42% of the total root surface area, respectively. The largest roots contribute only 8 to 17% of the total root surface area (Figure 3a).

Notably, $CaSO_4$ caused a decrease in the individual root diameter sizes as well as total root surface area in Leucaena but the differences were not significant. There are more medium sized roots in Leucaena than in corn. They contribute 60 to 64% of the total root surface area of Leucaena. The smallest and largest roots are responsible for 17 to 20% and 17 to 23% of the total root surface area of Leucaena, respectively (Figure 3b).

Reported in Table 4 is the response of total root volume of both corn and Leucaena to $CaCO_3$ or $CaSO_4$ addition. The increase in root volume of corn and Leucaena in response to $CaCO_3$ or $CaSO_4$ addition is non-significant. However, the medium sized roots contributed 54 to 66% of the total root volume in corn (Figure 4a) and 64 to 70% in Leucaena (Figure 4b). In corn, the smallest and largest roots are responsible for 14 to 21% and 16 to 30% of the total root volume, respectively. The contribution (4.1 to 5%) of the smaller roots of Leucaena towards the total root volume is almost negligible compared to that of larger roots which caused 25 to

32% increase in root volume of the total volume (Figure 4b).

Table 3. Root surface area of corn and Leucaena as affected by lime and gypsum.

TREATMENTS	Root length diameter classes (Millimeters) 0-0.25	0.25-0.55	0.55-0.90	Total root surface area
		cm^2		
Corn.				
Control	23.2	19.7	4.08	47.0
$CaSO_4$	48.6	42.7	16.4	107.8
$CaCO_3$	51.9	31.4	11.2	94.5
$LSD_{0.05}$	21.17	15.39	7.39	37.35
Leucaena.				
Control	12.8	43.6	11.7	68.1
$CaSO_4$	9.8	38.2	13.3	61.3
$CaCO_3$	13.2	42.1	11.9	67.1
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.

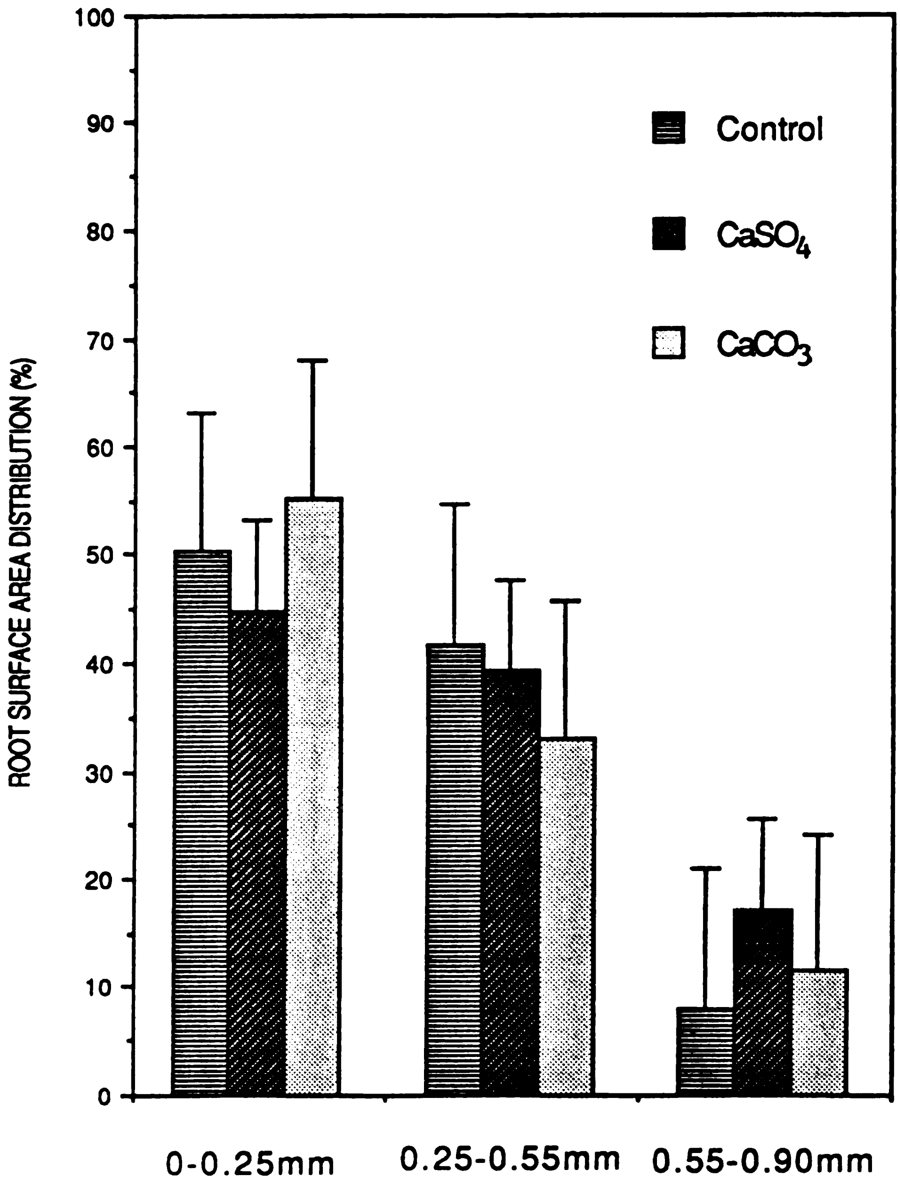

Figure 3a: Effects of $CaSO_4$ and $CaCO_3$ on the percent distribution of root surface area of corn.

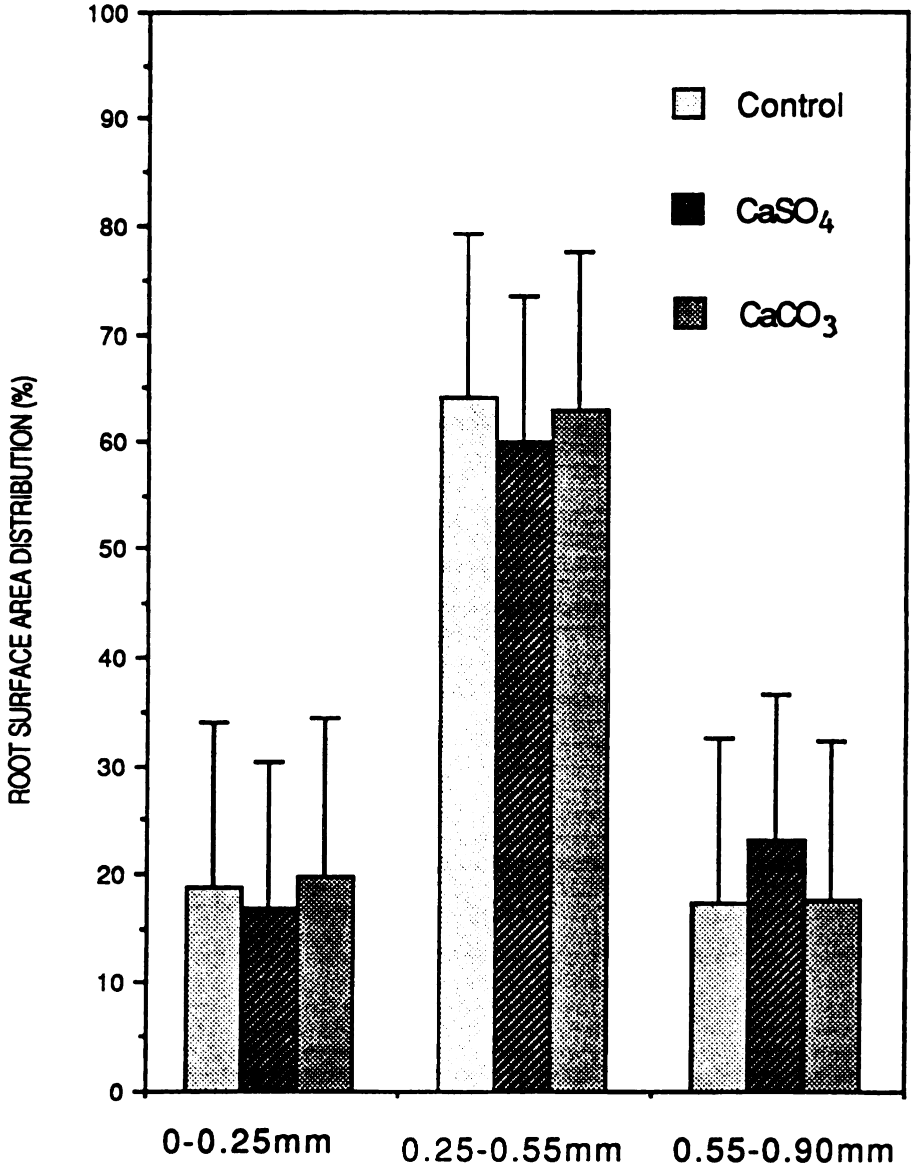

Figure 3b: Effects of $CaSO_4$ and $CaCO_3$ on the percent surface area distribution of Leucaena.

Table 4. Root volume of corn and Leucaena as affected by lime and gypsum.

TREATMENTS	Root length diameter classes (Millimeters)			Total root volume
	0-0.25	0.25-0.55	0.55-0.90	
		cm^3		
Corn.				
Control	1.40	3.86	2.26	7.51
$CaSO_4$	1.17	4.04	1.75	6.96
$CaCO_3$	1.54	5.90	2.19	9.62
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.
Leucaena.				
Control	0.35	5.67	2.13	8.15
$CaSO_4$	0.38	4.45	1.65	6.54
$CaCO_3$	0.35	5.77	2.52	8.65
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.

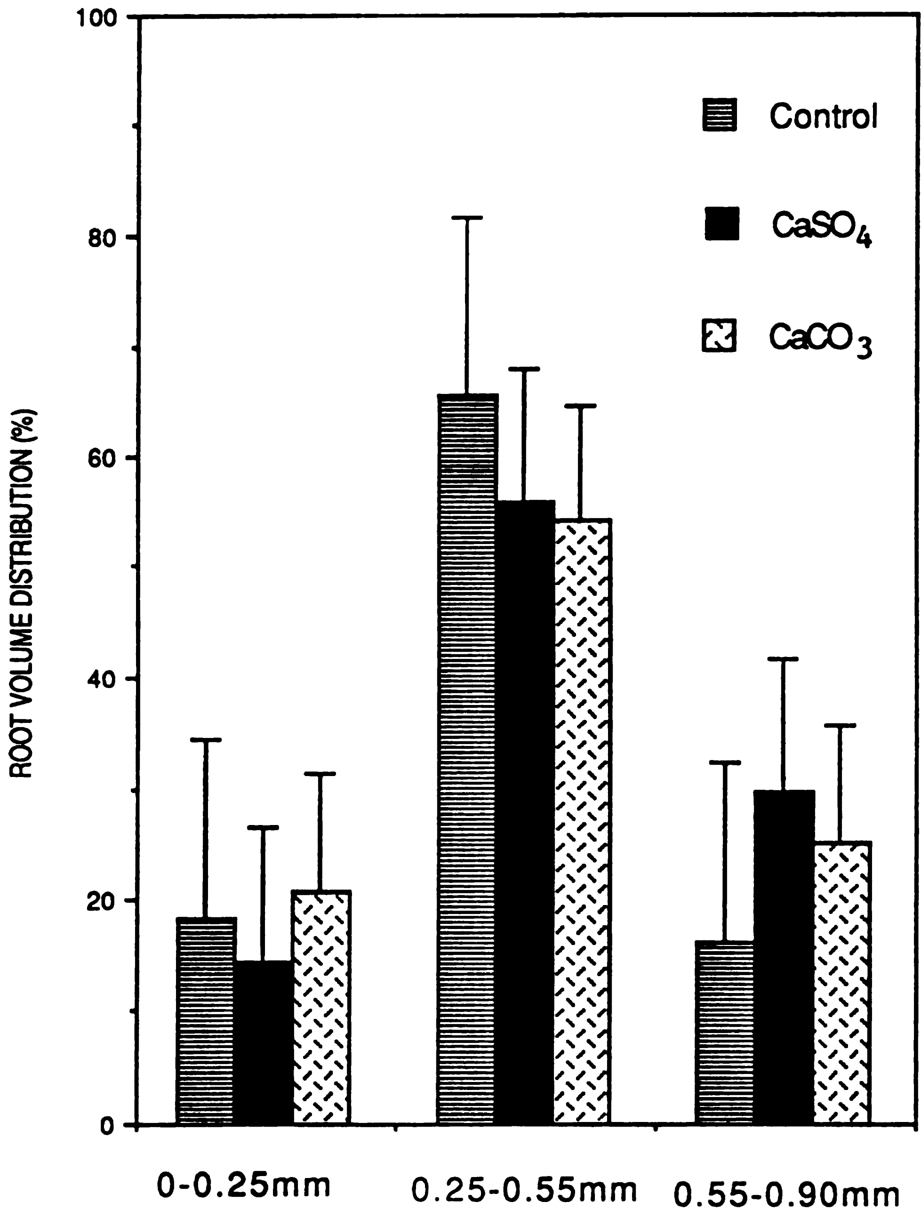

Figure 4a: Effects of $CaSO_4$ and $CaCO_3$ on the percent of root volume of corn.

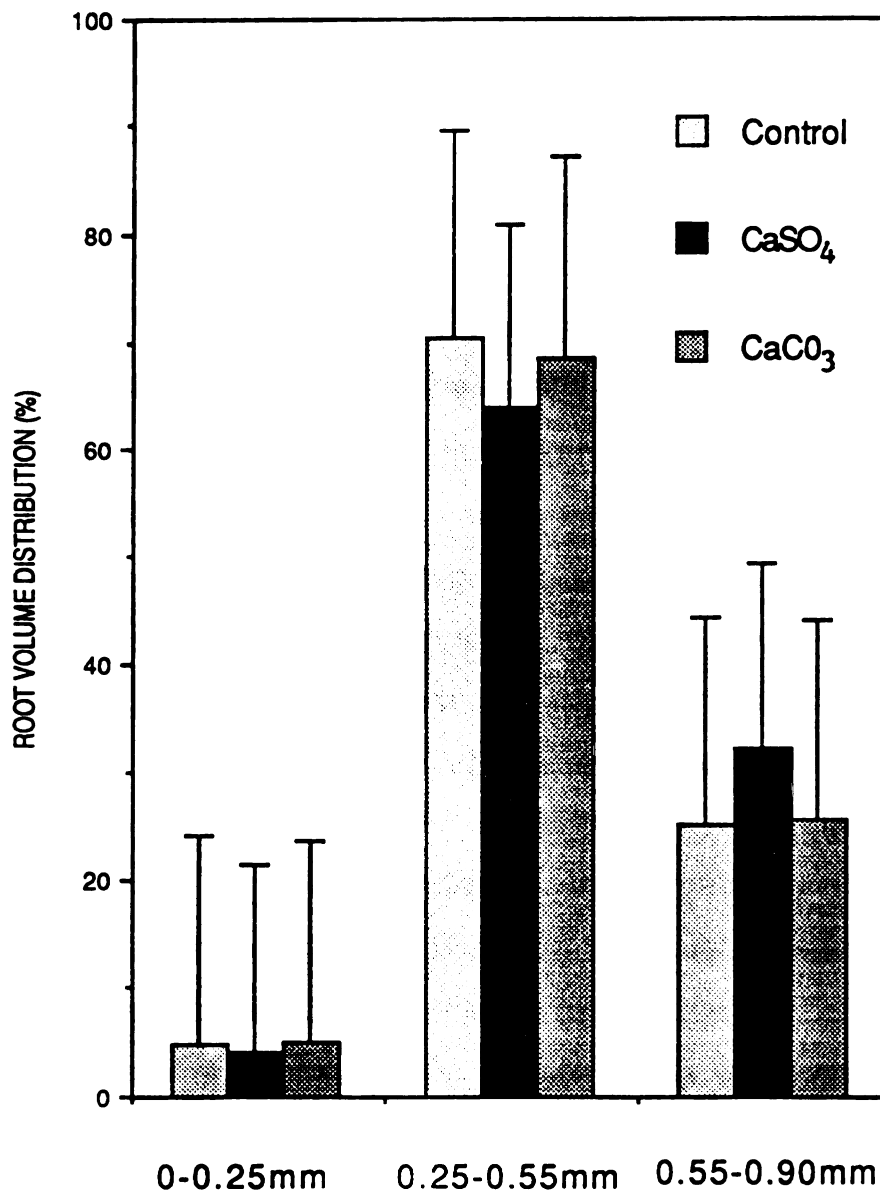

Figure 4b: Effects of $CaSO_4$ and $CaCO_3$ on the percent distribution of root volume of Leucaena.

Pre-plant and Post-harvest Subsoil pH and Al Content in Response to Ca Addition.

Results of the initial site, pre-plant and post-harvest soil analyses of top and subsoil pH, exchangeable Al and Ca, and extractable P are presented in Tables 5, 6, and 7. The initial pH in water and KCl of the subsoil were 4.97 and 3.91 respectively (Table 5).

Pre-plant Al concentration levels range from 3.99 to 6.75 cmol per Kg (cmol (P^+) Kg^{-1}). For the control and $CaSO_4$ treatments, the Al was reduced to about half the original values after plant growth. With both corn and Leucaena, there were no significant changes in P and Ca contents with plant growth and soil treatment. The post-harvest subsoil levels of Ca were relatively lower than expected (Table 6). A comparison of post harvest top and subsoil pH is given in Table 7. The soil analysis data shows that with both corn and Leucaena, there is a decrease in subsoil pH (H_2O and KCl) after plant growth. In both crops, $CaSO_4$ incorporation into the subsoil and the control resulted in a pH drop in the subsoil; whereas $CaCO_3$ increased the subsoil KCl pH. Of the two sources of Ca, $CaCO_3$ was more effective in reducing the Al level from an initial content of 6-7 to <0.2 cmol (P^+) Kg^{-1}.

Table 5. Pre-plant top and subsoil data.

	$pH(H_2O)$	pH(KCl)
TOPSOIL	5.62	4.61
SUBSOIL	4.97	3.91

Table 6. Pre-plant and post-harvest subsoil characteristics analysis data.

	Ex. Al (CEC) $cmol(P^+)Kg^{-1}$		Ex. P(Conc.) ppm	Ex.Ca (Conc.) ppm
	(Pre)	**(Post)**	**(Post)**	**(Post)**
Corn.				
Control	5.91	3.65	56.25	286.0
$CaSO_4$	6.75	2.99	55.25	295.5
$CaCO_3$	6.27	0.12	56.25	267.0
$LSD_{0.05}$	n.s.	0.59	n.s.	32.87
Leucaena.				
Control	7.31	2.48	62.33	276.5
$CaSO_4$	6.27	2.48	59.33	324.0
$CaCO_3$	3.99	0.10	59.00	267.0
$LSD_{0.05}$	n.s.	1.14	n.s.	45.18

Table 7: Post-harvest top and subsoil characteristics analysis data.*

	TOP-SOIL		SUB SOIL	
	pH(H_2O)	pH(KCl)	pH(H_2O)	pH(KCl)
Corn.				
Control	4.90	3.73	5.25	3.75
$CaSO_4$	4.50	3.70	4.43	3.78
$CaCO_3$	4.80	3.70	5.88	4.80
$LSD_{0.05}$	0.14	n.s.	0.46	0.17
Leucaena.				
Control	4.93	3.80	5.55	3.80
$CaSO_4$	4.90	3.80	4.43	3.80
$CaCO_3$	4.85	3.85	5.80	4.93
$LSD_{0.05}$	n.s.	n.s.	0.32	0.09

* Ca treatments were applied to the subsoil only.

DISCUSSION

Plant Growth Changes Following Addition of $CaSO_4$ and $CaCO_3$.

According to Scott et al., (1991), the greatest effect of Al is on root growth. Therefore it is common to see a decreased root to shoot ratio with decreasing Al. In the absence of reduced photosynthesis, this would imply that a smaller proportion of the assimilated carbon is translocated to the roots, resulting in accumulations of carbon within the shoot. This is in agreement with the root to shoot ratios obtained in this study. But, of the two sources of Ca, $CaSO_4$ caused a greater change in root to shoot ratio than did $CaCO_3$ with the greatest effect seen in corn (Table 1). Since corn responded more to Al alleviation than Leucaena, it is likely that corn is more Al-sensitive than Leucaena.

Furthermore, in other studies, it has been shown that Al affects the concentrations of organic acids in a variety of plant species, and could play a role in detoxification of Al in the cytoplasm (Suhayda and Haung., 1986). They suggest that if accumulation of organic acids permits detoxification of Al ions by chelation, then concentrations should be higher in the Al-tolerant than Al-sensitive germplasm. In this study, this effect could be assumed to explain differences between Al-tolerant Leucaena and Al-sensitive corn. This is because when the plants were exposed to toxic levels of Al, the rate of photosynthesis in the primary leaves may have increased on a dry weight basis while the rate of translocation from primary leaves may have declined as Hoddinott and Richter (1987) have reported for beans (*Phaseolus vulgaris*). Thus, the photosynthetically fixed carbon must have been diverted into a metabolite pool other than starch. This shift in patterns of carbon allocation could represent an energetic cost of Al toxicity or metabolic cost of Al-tolerance mechanism which may require carbon skeletons for their action. For example, chelation of Al by carboxylic acids in the cytoplasm or rhizosphere have been postulated as tolerance mechanisms, and roots of Al-tolerant cultivars often have higher concentrations of carboxylic acids than Al-sensitive cultivars under conditions of Al-stress (Taylor, 1988).

The effects of Al on the function of root cap and primary root meristem have been previously reported (Bennet et al., 1985; and Bennet et al., 1987) where the action of Al is considered to be primarily directed at the morphologically distinctive activities of the peripheral cap cells (Bennet and Breen, 1991). They argue that since the cells are not mitotically active, Al-induced changes in root growth rates are directed through naturally occurring regulators present in the cap. This concept is also supported by the studies of Bennet et al., (1987). Other studies have shown a regenerative capacity in primary roots which may permit their recovery from Al. Such results revealed the reactivation of physiological mechanisms during recovery. They also provide information not only on how plant roots may recover from the unfavorable conditions associated with Al, but also indicate some of the cellular interrelationships within the root apex which are involved in regulating root growth responses (Bennet and Breen., 1989) This is also likely to explain the plant growth changes observed in this study.

Predicted Speciation of Al as Affected by Subsoil Lime and Gypsum Additions.

The addition of lime to very acid subsoils is expected to reduce the Al^{3+} activity in the soil solution by increasing soil pH. This effect can be quantified by the use of thermodynamic constants and known soil chemical conditions. The speciation program called Minequal (Allison, et al., 1990) was used for this purpose to predict treatment effects on the activity of Al^{3+} under the experimental conditions of this study (Table 8).

The addition of lime increased the subsoil pH to 5.8 in water and 4.8 in KCl. The pH in KCl was used for purposes of speciation since this more nearly approximates the ionic strength expected at field capacity where lime was applied. The predicted speciation given in Table 8 shows that the concentration of Al^{3+} decreased from 5.32×10^{-3} to 6.12×10^{-6} moles per liter as the pH was increased from 3.91 to 4.8. Other species of Al ($Al(OH)_2^+$ and $Al(OH)_3$) became appreciable as the pH increased and accounted for 39% of the Al in solution as compared to 7% at pH 3.91. It should also be noted that the total Al in solution decreased by nearly 1000 fold as soil pH changed from 3.91 to 4.8.

TABLE 8: Predicted speciation of Al as affected by subsoil pH and $CaSO_4$.

SPECIES	CONTROL	$CaSO_4$ (No re-disol. of $Al(OH)_3$)	$Al(OH)_3 + CaSO_4$
		Moles/Liter	
		pH 3.91	
Al^{3+}	$5.32X10^{-3}$ (92.8%)	$2.84X10^{-3}$ (51.6%)	$9.65X10^{-3}$ (66.6%)
$AlSO_4^+$	$2.18X10^{-4}$ (3.8%)	$2.01X10^{-3}$ (36.6%)	$3.80X10^{-3}$ (26.2%)
$AlSO_4^{2-}$	$2.75X10^{-6}$ (<1%)	$5.60X10^{-4}$ (10.2%)	$7.84X10^{-4}$ (5.4%)
		pH 4.2	
Al^{3+}	$4.16X10^{-4}$ (82.6%)	$1.63X10^{-4}$ (39.2%)	$8.32X10^{-4}$ (42.7%)
$AlSO_4^+$	$4.54X10^{-5}$ (9.1%)	$1.77X10^{-4}$ (42.5%)	$7.93X10^{-4}$ (40.8%)
$AlSO_4^{2-}$	$9.43X10^{-7}$ (<1%)	$6.49X10^{-5}$ (15.6%)	$2.66X10^{-4}$ (13.7%)
		pH 4.4	
Al^{3+}	$9.88X10^{-5}$ (77.1%)	$7.63X10^{-5}$ (38%)	$2.01X10^{-4}$ (38.7%)
$AlSO_4^+$	$1.22X10^{-5}$ (9.5%)	$8.44X10^{-5}$ (42%)	$2.16X10^{-4}$ (41.7%)
$AlSO_4^{2-}$	$2.71X10^{-7}$ (<1%)	$3.14X10^{-5}$ (15.7%)	$7.9X10^{-5}$ (15.2%)
		pH 4.6	
Al^{3+}	$2.45X10^{-5}$ (70.2%)	$7.41X10^{-5}$ (36.9%)	$4.99X10^{-5}$ (36.8%)
$AlSO_4^+$	$3.11X10^{-6}$ (8.9%)	$8.2X10^{-5}$ (40.9%)	$5.56X10^{-5}$ (40.9%)
$AlSO_4^{2-}$	$7.06X10^{-8}$ (<1%)	$3.06X10^{-5}$ (15.3%)	$2.08X10^{-5}$ (15.3%)

The addition of gypsum produced a pH in water of 4.43 (Table 7) by the end of the growing season. Since the subsoil should still contain gypsum, this is likely to be the ionic strength that would exist at field capacity. Therefore, a series of pH runs were made with increasing pH's from 3.91 to 4.6 to examine the change in Al^{3+} with increasing pH and in the presence of saturated $CaSO_4$. The speciation was also accomplished assuming that gibbsite did not redisociate at a rate sufficiently rapid to react with all of the sulphate and also assuming that equilibrium was reached in which the gibbsite finally reached equilibrium with the solution. In a practical situation where gypsum is added to soils, the reaction with Al^{3+} would be expected to be very rapid but the redisolution of gibbsite would be expected to take from a few months to several years depending upon the crystallinity of the gibbsite.

The addition of gypsum had significantly reduced the Al^{3+} in solution at all pH's that were examined If gibbsite rapidly dissociates, the addition of gypsum causes the formation of $Al(SO_4)^+$ without lowering Al^{3+} for a given pH. But in practice where excess gypsum is applied, gibbsite is expected to dissolve much more slowly than gibbsite. Under these conditions the Al^{3+} content of the soil solution is reduced at any pH with the formation of $Al(SO_4)^+$ complexes. The reduction from pH 3.91 without gypsum to 4.6 with gypsum was seven fold. The use of gypsum, therefore, offers a practical method of modifying the environment of acid subsoils without the expense of deep tillage. This is particularly important since many of the areas in the tropics have no opportunity of deep tillage.

The Role of $CaSO_4$ and $CaCO_3$ in Tropical Soils

The application of lime to temperate acid soils is commonly aimed at raising the pH to near neutrality in the belief that effects such as low base status, Al toxicity, and P fixation will be eliminated or at least favorably affected (Reeve and Summer., 1970). But two earlier surveys (Adams and Pearson, 1967; Fisher, 1969) have indicated that it is unnecessary to lime to pH 6.5 or above while several other authors had already reported depressed yields as a result of heavy lime applications (Pierre and Browning, 1935, Hourigan et al., 1961; Shoop et al., 1961; Reeve and Summer, 1970). Liming to neutrality has proved almost always ineffective in the tropics. It is better to apply sufficient lime to alleviate Al toxicity than attaining near neutrality soil status.

Lime and gypsum are two fundamental and cheaply available sources of Ca in the tropics. The cost of these materials may vary depending upon transportation costs. Hence their utilization in this study. A detailed and comprehensive representative of the acidity status of tropical soils such as Oxisols, Ultisols, Alfisols, and Inceptisols profiles are documented by Sanchez, (1976). Oxisols usually have a high percentage of Al saturation throughout their profiles (Guerrero, 1971). Some Ultisols also have high Al saturation, particularly in the subsoil. The Al status of other Inceptisols and Entisols is quite variable. Most vertisols, Mollisols and Aridsols are essentially 100 percent base saturated while most Spodosols and Histosols are acid. Some organic soils have high exchangeable hydrogen contents (Sanchez, 1976). This state of tropical soils requires the use of cheap Ca materials to improve the status of soils for better plant growth and higher yields.

This study showed that both $CaSO_4$ and $CaCO_3$ alleviate Al toxicity when applied to the subsoil (Table 6). To find lime sources of sufficient fineness and purity is a major practical problem in the tropics. The selection of sources must take into account the Ca and Mg contents of the liming material and the Ca and Mg status of the soil. Fineness is crucial for faster reaction. A good grade of fineness is more than 60 mesh; a better grade, 100 mesh (Sanchez, 1976). Subsoil application of Ca was undertaken in this study to exploit the beneficial effects of deep incorporation. When extremely acid Oxisols have their topsoil limed to pH 5.5, most of the root development of corn occurs in the topsoil. The high subsoil Al saturation prevents deeper root penetration. This was also observed in this study in both corn and Leucaena. Of the total root length of corn in the subsoil, most of it was contributed by the smallest root sizes (Figure 2a) which was also true for Leucaena (Figure 2b).

In the tropics, Al toxicity is the most common cause of acid soil infertility. This can be corrected by $CaSO_4$ and $CaCO_3$ addition to precipitate the exchangeable Al as Aluminum Hydroxide ($A(OH)_3$) and other Al complexes. Ca and Mg deficiencies are also important causes of acid soil infertility. Tropical crops differ widely in their ability to tolerate acid soil infertility conditions. Important varietal differences also exist in corn (Sanchez, 1976). The results obtained in this study support the hypothesis that $CaSO_4$

and $CaCO_3$ may play an important role in alleviating Al toxicity in tropical acid soils.

LITERATURE CITED

Adams, F., and R.W. Pearson. 1967. Crop responses to lime in the United states and Puerto Rico. Soil acidity and liming. Agr. 12:161-206.

Allison, J.D., D.S. Brown, and K.J. Novo-Gradac. 1990. Ninteqa2/Prodefa2, A geographical assessment model for environmental systems: Version 3.0 Users manual. Environmental Research Laboratory. USEPA. Athens, Georgia.

Bennet, R.J. and C.M. Breen. 1989. Towards understanding root growth responses to environmental signals: the effect of Al on maize. S. Afr. J. Sci. 85:9-12.

Bennet, R.J. and C.M. Breen. 1991. The recovery of roots of *Zea mays* L. from various Al treatments: Towards elucidating the regulatory processes that underlie root growth control. Envir. Exp. Bot. 31:153-163.

Bennet, R.J., Breen, C.M., and M.V. Fey. 1985. The primary site of Al injury in root of *Zea mays* L. S. Afr. J. Pl. Soil 2: 8-17.

Bennet, R.J., Breen, C.M., and M.V. Fey. 1987. The effects of Al on root cap function and root development in *Zea mays* L. Envir. Exp. Bot 27: 91-104.

Briggs, K.G., Taylor, G.J., Sturges, I., and J. Hoddinott. 1989. Differential Al-tolerance of high-yielding, early-maturing Canadian wheat cultivars and germplasm. Can. J. Plant Sci. 69:61-69.

Fisher, T.R. 1969. Crop yields in relation to soil pH as modified by liming acid soils. Research Bulletin 947. Univ. of Missouri-Columbia College of Agr. Exp. Sta.

Guerrero, R. 1971. Soils of the Colombian Llanos Orientals. Composition and classification of selected soil properties. Ph.D. Thesis, North Carolina State University, Raleigh.

Hoddinott, J., and C. Richter. 1987. The influence of Al on photosynthesis and translocation in french bean. J. Plant Nutr. 10:443-454.

Hourigan, W.R., R.E. Franklin, E.O. McLean and L.R. Bhumla. 1961. Growth and Ca uptake by plants as affected by rate of liming. Soil Sci. Soc. Amer. Proc. 7: 491-494.

Page, A.L., R.H. Miller and D.R. Keeney. 1982. Methods of soil analysis. Agronomy N0. 9 Part 2 2nd Edition. Chemical and microbiological properties. ASA, SSSA.

Pierre, W.H., and G.M Browning. 1935.The temporary and injurious effect of excessive liming of acid soils and the relation to the phosphate nutrition of plants. J. Amer. Soc. Agron. 27:742-759.

Reeve, R.G., and M.E. Sumner. 1970. Lime requirements of Natal Oxisols based on exchangeable Aluminum. Soil Sci. Soc. Amer. Proc. 34:595-598.

Sanchez, P.A. 1976. Properties and management of soils in the tropics. John Wiley and Sons, Inc. N.Y. pp 224 - 253.

Scott, R., J, Hoddinott., G. J. Taylor and K. Briggs., 1991. The influence of Aluminum on growth, carbohydrates and organic acid content of an Al-sensitive cultivar of wheat. Can. J. Bot. 69:711-716.

Shoop, G.J., C.R. Brooks., R.E. Brazer, and G.W Thomas. 1961. Differential responses of grasses and legumes to liming and phosphorus fertilization. Agron. J. 53:111-123.

Smucker, A.J.M., A.L. McBurncy and A.K. Srivastava.1982. Quantitative separation of roots from compacted soil profile by the hydropneumatic elutriation system. Agron. J. 74:500-503.

Smucker, A.J.M., J.C. Ferguson, W. Debruyn, R.K. Belford, and J.T. Ritchie. 1987. Image analysis of video-recorded root systems. In: ASA Special Publication 50:67-80. ASA Madison, WI.

Smucker, A.J.M.,1989. Operation manual for staining, preparation and video recording of washed root systems by the Robotic camera method.

Suhayda, C.G., and A. Haug. 1986. Organic acids reduce Al toxicity in maize root membranes. Physiol. Plant. 68:189-195.

Taylor, G.J. 1988. The physiology of Al tolerance. *In* Metal ions in biological systems. Vol. 24. Edited by H. Sigel. Marcel Dekker, New York. pp. 165-260.

CHAPTER 3

SUMMARY AND CONCLUSIONS

Lime and gypsum incorporation caused a significant increase in total root length and shoot dry weight in corn. Leucaena was less responsive to lime and gypsum than corn due to the fact that Leucaena is more Al-tolerant than corn. Calcium carbonate was generally less effective as a source of Ca. The study of soil acidity and Al toxicity on young plants of corn and Leucaena roots and shoots has great importance as far as the future life of the plants is concerned. The seedling stage is the beginning of the developmental stages of growth which will have a sequential influence on the final yield.

The fact that both corn and Leucaena are able to successfully grow in acidic soils is an important conclusion to draw from this study. Both species are grown in the tropics with an ever-increasing demand and use in alley cropping systems. This study was focussed on the response of corn and Leucaena when Ca is added to the subsoil using two affordable sources of Ca. The study offers sufficient support to justify the use of corn and Leucaena in an intercropping system in the acidic regions of the world as long as Ca incorporation is included for better Al alleviation and yield results.