EXCHANGEABLE ALUMINIUM AS AN INDEX OF LIMING FOR THE ACIDIC UPLAND SOILS OF KERALA

By

MEENA, K.

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT
FOR THE DEGREE OF
MASTER OF SCIENCE IN AGRICULTURE
(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, TRIVANDRUM

1987

DECLARATION

I hereby declare that this thesis entitled "Exchangeable aluminium as an index of liming for the acidic upland soils of Kerala" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Meena K

(MEENA, K.)

Vellayani,
November 1987.

CERTIFICATE

Certified that this thesis entitled "Exchangeable aluminium as an index of liming for the acidic upland soils of Kerala" is a record of research work done independently by Miss. Meena, K. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Alice Abraham

(Alice Abraham),
Chairman,
Advisory Committee,
Professor of Soil Science &
Agricultural Chemistry.

Vellayani,
November 1987.

Approved by:

Chairman

Dr. Alice Abraham Alice Abraham
24-12-87

Members

1. Dr. M.M. Koshy M.M. Koshy
24.12.87

2. Sri. P.R. Ramasubramaniam Ramasubramaniam
4.1.88.

3. Sri. K.P. Madhavan Nair Madhavan Nair
24/12/87.

External Examiner

ACKNOWLEDGEMENT

I wish to express my heartfelt gratitude and indebtedness to Dr. Alice Abraham, Professor of the Department of Soil Science and Agricultural Chemistry and Chairman of the Advisory Committee for the inspiring and critical guidance offered to me during the course of my studies and in the preparation of this thesis.

I gratefully acknowledge the valuable help rendered during the course of the study and preparation of thesis by Dr. M.M. Koshy, Dean i/c, College of Agriculture, Sri. P.R. Ramasubramaniam, Professor of the Department of Soil Science and Agricultural Chemistry and Sri. K.P. Madhavan Nair, Professor of the Department of Agronomy, members of the Advisory Committee.

I express my heartfelt thanks to Dr. R.S. Aiyer, Professor and Head of the Department of Soil Science and Agricultural Chemistry for his valuable suggestions and for providing necessary laboratory facilities.

My sincere thanks are also due to Sri. Abdul Hameed, Professor of the Department of Soil Science and Agricultural

Chemistry for his help in the analytical aspect.

I am extremely grateful to Sri. P.V. Prabhakaran, Professor and Head of the Department of Agricultural Statistics, and Smt. P. Saraswathi, Associate Professor of the Department of Agricultural Statistics for the help offered by them in the statistical analysis.

I also wish to place on record my sincere thanks to all the staff members of the Department of Soil Science and Agricultural Chemistry and to my fellow students for their co-operation and help throughout the course of investigation.

I am extremely grateful to the Indian Council of Agricultural Research for the fellowship awarded to me during the course of my post graduate studies.

My grateful acknowledgement is also due to the Kerala Agricultural University for the laboratory and library facilities and the funds provided during the course of the investigation.

I also like to record my boundless gratitude

and indebtedness to my family members for their constant inspiration and help.

Last but not least, I thank God for all help and courage given to me for completing the investigation.

(MEENA, K.)

Vellayani,
November 1987.

LIST OF TABLES

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

INTRODUCTION

The acidity of the humid tropical soils is primarily associated with the presence of hydrogen and aluminium in exchangeable forms. Acid soils are also characterised by a deficiency and toxicity of several elements related to plant nutrition. Eventhough aluminium toxicity is one of the major problems confronted by the plants in acid soils, it is not fully recognised.

Poor crop growth in acid soils can be directly correlated with the aluminium saturation of soils and it was shown as early as in 1942 that hydrogen ion concentration as indicated by pH value has no direct effect on plant growth except at values below 4.2.

Although aluminium is not an essential element, an appreciable amount of this element is often present in most plants. High aluminium levels in soil solution is known to cause direct harm to roots and decrease root growth and translocation of minerals especially calcium and phosphorus to the tops (Jarvis and Hatch, 1986). Aluminium toxicity may not often be simply diagonised either from visual symptoms or from the aluminium content of the plants. However, the aluminium in soil sollution has been considered to be a real measure of aluminium toxicity potential. Concentration of soil solution aluminium even above 1 ppm has been reported to cause yield reduction and legumes in general are considered to be highly sensitive.

Liming is the widely used practice followed to correct plant stress caused by soil acidity. The purpose of liming is primarily to neutralise the exchangeable aluminium (Martini et al. 1974) and it is usually achieved when the soil pH is raised to about 5.5. Lime application based on pH values alone is both uneconomical and unnecessary and it may lead to several undesirable effects from the point of view of plant nutrition.

Many workers have proved in recent years that the aluminium removed from the soil by N KCl, designated as exchangeable aluminium gives a more reliable and realistic estimate of lime needed to neutralise reactive aluminium and to make a favourable soil condition for plant growth. Kamprath (1970) and Sanchez (1976) have considered the aluminium saturation of the effective CEC of soils based on the content of exchangeable aluminium to be a more reliable and accurate parameter for defining lime requirement rather than the actual estimate of exchangeable aluminium.

Sanchez (1976) has considered an aluminium saturation of more than 20% of the effective CEC of soils as critical for many of the sensitive plants. Cochrane et al. (1980) have proposed the use of minimum amount of lime on acid soils so as to decrease the percentage aluminium saturation to levels that do not affect production and compensate crop aluminium tolerance. The concept of use of lime levels only upto the point of elimination of aluminium toxicity has been developed in the light of these.

In the light of the growing recognition of aluminium saturation of soils as a more realistic criteria for liming acid soils, the use of lime based on this principle ensures the maintenance of a slightly acidic soil condition where the aluminium may not be toxic to crop plants and at the same time permit a better utilization of unavailable plant nutrients like phosphorus from the soil.

More than 70 percent of the upland soils of Kerala are acidic. There is no systematic liming practice to suit the needs of various crops grown in these soils. Toxicity by aluminium, eventhough is not recognised as an important factor, is likely to be one of the main constraints of crop production in them. The inhibition of root growth which is the primary effect of aluminium toxicity to plants is most likely to go unnoticed in view of its subterranean charcter. At the same time, poor crop growth resulting from a restricted absorption of nutrients especially phosphorus and calcium is very much evident also. The non availability of phosphorus and calcium in acid soils coupled with a poorly developed root system of the plant which cannot ensure a satisfactory state of nutrient absorption may be responsible for the poor crop production. Application of lime to suppress exchangeable aluminium to below critical level for each crop may ensure better crop growth and response to added nutrients in such soils.

In the light of these considerations, the present study has been undertaken with the following objectives.

i. To study the pattern of distribution of water soluble and exchangeable aluminium in the acidic upland soils of Kerala and to compute the percentage aluminium saturation (PAS) in them.

ii. To test the response of two acid sensitive crops (cowpea and fodder maize) to different levels of exchangeable aluminium in soils maintained by the addition of different quantities of lime.

iii. To study the influence of the above on the plant characters yield and nutrient content of cowpea and fodder maize.

iv. To correlate exchangeable aluminium and percentage aluminium saturation of soil with the nutrient content, nutrient uptake, plant characters and yield of the two crops.

Results obtained from this study will help to identify the minimum level of exchangeable aluminium that can be tolerated by these crops and the lime requirement thereof.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The vast majority of the humid tropical soils of the world are acidic due to the direct and indirect influence of high temperature and heavy rainfall. Soil acidity, leading to deficiency and toxicity of elements has been identified as a major limiting factor in boosting agricultural production in many of the tropical countries. Eventhough, both exchangeable hydrogen and aluminium, present in soils are considered to be mainly responsible for soil acidity, exchangeable aluminium is identified as the chief factor limiting the growth and productivity of crop plants in acid soils.

Many scientists have considered that bringing down the aluminium saturation of acid soils to below critical levels is the ultimate end to be attained in all liming operations to ameliorate acid soils. Considerable amount of work has been undertaken all over the tropical countries on this subject. Some of the more important work in this direction is reviewed and summarised below.

Aluminium as a potential source of acidity in acid soils

Breakdown of clay colloids during weathering releases aluminium from the aluminosilicate layers. The aluminium ions so released remain either attached to the colloidal particles by replacing hydrogen ions or are released into the soil solution. In the soil solution each trivalent aluminium ion reacts with water to form hydroxy aluminium compounds, yielding three hydrogen ions which further increases soil acidity (Black, 1973). In addition to this, the free aluminium ions (which are not hydroxylated) present in highly acidic soil solutions act as a direct toxicant for several crops.

Magistad (1925) was the first one to report on aluminium toxicity symptoms in barley, corn and soybean and he related concentration of aluminium in soil solution as a function of soil pH. He has also reported that the solubility of (Al^{3+}) increased from 0.3 to 76.4 ppm when the soil pH was shifted from 4.5 to 3.1.

Ragland and Coleman (1959) have related poor growth of sorghum roots in unlimed soil to the amount of exchangeable aluminium and they observed an increase in root growth when lime sufficient to cause hydrolysis of the exchangeable aluminium was added.

According to Deewan (1966) exchangeable aluminium is the predominant source of acidity in soils containing Kaolinite and Vermiculite clay minerals.

Kamprath (1970) has pointed out that at a pH below 5.4, the buffer capacity of the soils was primarily due to exchangeable aluminium and that soils with high exchangeable aluminium possessed only a comparatively lower CEC.

Tripathi and Pande (1971), Andrew and Vandenberg (1973) and Goswami et al. (1976) have given convincing evidences to show that at low pH values, uptake of nutrients, particularly P, Ca, Mg and K were reduced due to the presence of an excess of soluble aluminium.

Poor crop growth in acid soils has been indirectly correlated with aluminium saturation of soils by Black

(1973). He has shown that pH had no direct effect on plant growth except at values below pH 4.2. Frink (1973) has related the amount of exchangeable aluminium in soil to the concentration of exchangeable hydrogen. His study has also pointed to the existence of exchangeable hydrogen in the acid sulphate soils at its usual pH.

Bloom et al. (1979) considered the activity of (Al^{3+}) in soil solution as a function of soil pH and stated that this relationship depended on the exchange of aluminium ions from the organic matter to the exchange sites on the clay surfaces.

Saigura et al. (1980), Franco and Munns (1982) and Adams and Hatchcock (1984) have proposed exchange acidity as a realistic measure of the aluminium toxicity potential of a soil.

Shamshuddin and Tessens (1983) have indicated the significance of aluminium in controlling the acidity of acid soils. They considered that the buffering action of soils is dominated by aluminium below pH 5.5.

James and Riha (1984) have shown that a decrease of 0.1 to 0.2 units in solution pH in the range of pH 2.4 to 4.5 has resulted in increases and decreases in the concentration of labile aluminium. An increase in the solubility of aluminium consequent to increase in soil acidity has been reported by Bache (1985).

Gillman and Sumpler (1986) have attributed the additional lime consumption in the upper horizons of some soils to the replacement of non-exchangeable aluminium associated with the organic matter. Khanna et al. (1986) in a study on the exchange characteristics of some acid organic forest soils found that most of the exchange sites were occupied by aluminium.

Toxic level of aluminium in the soil

The aluminium concentration of soil solution has been considered to be a real measure of aluminium toxicity potential. Blair and Prince (1923) have identified soluble aluminium compounds as one of the causes of toxicity in acid soils. Lockard and Mc Walter

(1956) showed that aluminium toxicity occurs at concentrations between 6.7 and 40.5 ppm in rice plants. Tomlinson (1957) has reported an aluminium level higher than 250 ppm might be harmful to plants.

Hortenstine and Fiskell (1961) have observed that aluminium concentrations above 4 ppm drastically decreased height and weight of tops and roots of sunflower plants.

Nye et al. (1961) and Evans and Kamprath (1970) have reported that the aluminium concentration in the soil solution was generally less than 1 ppm. When the aluminium saturation increased beyond 60%, aluminium in the soil solution also recorded a correspondingly sharp increase. Presence of organic matter however was found to reduce aluminium concentration in soil solution.

Cate and Sukhai (1964) have shown that water soluble aluminium concentrations as low as 1 to 2 ppm markedly inhibited the growth of roots while leaf symptoms occurred only at a concentration of 25 ppm.

Higher concentrations inhibited root growth and produced green and yellow spots on the leaves.

Adams and Lund (1966) have reported that critical levels of aluminium vary for different crops and soils.

According to Tanaka and Navasero (1966) critical concentrations of aluminium in culture solution was 25 ppm for the rice plant.

Hutchinson and Hunter (1970) have observed a reduced dry matter production in lucerne, clover and barley when aluminium concentration was higher than 100 kg/ha and Lee (1971) reported a reduction in the yield of roots of potato crops when the level of aluminium reached 20 ppm. Further increase in aluminium concentration in growth medium, according to him reduced plant growth and tuber yield, but favourably contributed to tuber quality.

Brenes and Pearson (1973) have observed that root growth in corn was not seriously affected unless aluminium saturation exceeded 60 percent. About

80 percent of aluminium saturation reduced corn root growth by 50 percent of the maximum.

Abruna et al. (1974(b)) have found that the critical limit of aluminium saturation for corn production was approximately 15 percent for ultisols and 35 percent for oxisols.

Pieri (1974) observed a reduction in nodulation of groundnut when the aluminium saturation of the exchange complex exceed 30 percent.

Velly (1974) recognised different critical levels for different plants. Cotton seemed to be damaged at 25 ppm of exchangeable aluminium, groundnut at 50 to 60 ppm and maize only at about 120 to 130 ppm.

An inverse relationship was observed between Kikuyu grass growth and aluminium concentrations when present in excess of 1.5 $\mu g/g$ in the soil and 90 $\mu g/g$ in the tops (Awad et al., 1976).

Alley (1981) found that aluminium saturation of 18, 11 and 3 percent of the effective CEC decreased corn, barley and alfalfa yields.

Franco and Munns (1982) have stated that aluminium concentrations upto 83 µg did not affect root dry weight, nodule growth and nitrogenase activity of bean cultivar. They have also reported a beneficial effect of low level of aluminium (19 µg) on tap root elongation. However, root colonization of rhizobia was reduced at > 33 µg.

According to Keefer et al. (1983) plant growth was limited wherever the soils contained > 2 me/100 g of exchangeable aluminium.

Zaini and Mercado (1984) have shown that in susceptable varieties a high concentration of aluminium reduced phosphorus mobility.

Jarvis and Hatch (1986) have reported a reduction in dry weight of roots and shoots of white clover at 50 to 100 µ m levels of soluble aluminium. Less than 10 percent of the aluminium absorbed from the solution was transported to shoots.

Aluminium toxicity in Cereals and Pulses

Several crop plants such as rice, wheat, barley, oats, sorghum, legumes, potato, tobacco etc. are reported to be adversely affected by aluminium toxicity. Some of the important work on aluminium toxicity on cereals and pulses are summarised below.

<u>Cereals</u>

Discolored and malformed roots and root-lets and morphological abnormalities of roots and reduced uptake of nutrients have been reported to be the general symptoms of aluminium toxicity in cereals.

Ligon and Pierre (1932) have noted that even 1 ppm of aluminium in solution produced apparent root injury in corn after three days. However, the toxicity symptoms in shoots became apparent only after 2 weeks which was characterised by leaf chlorosis and reduced yield. Hutton and Fiskell (1965) and Juste (1966) have reported on aluminium toxicity in maize.

Mac Lean and Chiasson (1966) demonstrated an inhibitory effect of aluminium on the translocation of phosphorus and calcium in barley. They also observed chlorosis of leaves, dieback of leaf tips and purple discoloration of the leaves resembling that of phosphorus deficiency.

Cruz et al. (1967) have pointed out that concentration of 0.2 to 6 ppm aluminium in the nutrient solution had no effect on the translocation of radioactive phosphorus (P^{32}) to young leaves of wheat, but the phosphorus/aluminium ratio in leaves, stems and roots was different.

Ota (1968) and Long and Foy (1970) have came across the same type of leaf chlorosis, bronzing and petiole collapse in rice and barley respectively, and they attributed this condition to aluminium induced calcium deficiency.

Fox (1979) observed 90 percent yield reduction in corn when the aluminium saturation of the soil exceeded 12 percent.

According to Foy et al. (1980), aluminium toxicity resulted in a shallow rooting pattern in cotton making the plant more susceptable to drought since such plants can use subsoil water and nutrients less effectively.

Mugwira et al. (1980) have shown that 0 to 6 ppm aluminium increased the concentration of phosphorus in the roots, and of potassium in the roots and tops, but reduced the concentrations of calcium and magnesium in the tops of triticale wheat, rye and barley. Fageria and Carvalho (1982) have reported differential behaviour of rice cultivars to aluminium levels and showed that level of aluminium in the tops of a 21 day old rice plant varied from 100 to 417 ppm.

Abraham (1984) has reported that 20 ppm of aluminium in nutrient solution suppressed root elongation of rice, and more than 30 ppm of aluminium reduced the number of productive tillers as well as yield of grain and straw. Aluminium toxicity also caused a reduction in the uptake of all nutrients in rice.

Bennet et al. (1985) conducted an experiment on the primary site of aluminium injury on the root of *Zea mays*, and they have noticed a rapid inhibitory effect on the metabolic activity of root cells. Aluminium was shown to affect the pattern and intensity of respiratory activity in the root apex.

Fageria (1985) has reported that increased aluminium concentration in nutrient solutions inhibited the uptake of N, P, K, Ca, Mg, S, Fe, B, Cu, Zn and Mn in rice.

Legumes

Poor growth of pulses in acid soils has been directly correlated with aluminium saturation of soils. Among the different legumes, cowpea and pigeon peas seem to be more tolerant to aluminium toxicity. Many of these species have been evolved in acid soils and possess genes responsible for tolerating conditions associated with high aluminium levels.

Ruschel et al. (1968) studied the effect of excess aluminium on the growth of beans and found that nutrient solution containing 3 ppm of aluminium decreased plant growth and >7 ppm significantly increased aluminium content of roots and aerial parts.

Abruna et al. (1974 (a)) have reported a decreased yield of beans due to a high percentage of aluminium saturation. Sartain and Kamprath (1975) and Zakaira et al. (1977) have reported reduced growth of roots and tops and a reduction in nodule count in legumes due to high aluminium saturation of soils.

Malavolta et al. (1981) studied the relationship between aluminium tolerance, and total dry matter, plant height and root length in different legumes. According to him total dry matter production of young plants gave the highest correlation with aluminium tolerance.

Franco and Munns (1982) identified aluminium toxicity as the main reason for the frequent failure of beans in acid soils. Nodulation, nitrogen fixation, shoot and root growth etc. were adversely affected by the aluminium present in soil solution.

An appreciable difference among cowpea and blackgram varieties towards tolerance of aluminium toxicity was noted during screening trials carried out by Sudharmai Devi (1983). Rechcigl et al. (1986) have reported that in the absence of aluminium, root and shoot growth of alfalfa were not affected by a low pH of 4.5. Increasing aluminium concentration in the soil solution from 0 to 0.2 mM caused a reduction in root and shoot growth at the same pH. Suthipradit and Alva (1986) found that neither germination percent nor radicle length were influenced by varying aluminium concentrations in soybean.

Effect of liming on aluminium content of soil

Use of lime as an ameliorant for reducing aluminium toxicity and reclamation of acid soils has been reported by Blair and Prince (1923), Coleman et al. (1958), Abruna et al. (1964), Foy and Brown (1964), Reid et al. (1969), Helyar and Anderson (1974), Sartain and Kamprath (1975), Awad et al. (1976), Goswami et al. (1976), Horsnell (1985) and several others.

Evans and Kamprath (1970) showed that small increments of lime resulted in relatively rapid decrease in soil solution aluminium.

Reeve and Sumner (1970) and Reid et al. (1971) have reported growth response to lime upto the point of elimination of exchangeable aluminium after which a significant reduction in yield occurred.

Kabeerathumma and Nair (1973) and Abraham (1984) have reported a reduction in exchangeable aluminium and hydrogen content of the acid soils of Kerala as a result of liming.

Pearson (1975) based on his studies on soil acidity and liming in the humid tropics reported that corn yields may be increased by liming when the soil pH is below 5.0 or when the aluminium saturation exceeds 15 percent.

Martini et al. (1977) have suggested that liming to bring soil pH from 4.8 to 5.7 so as to reduce exchangeable aluminium to 1.5 me/100 g was a more valid means of increasing yield than raising the pH to neutrality.

Cochrane et al. (1980) recommended the use of minimum amount of lime in acid soils so as to decrease the aluminium saturation to levels that do not affect the economy of crop production.

Bache and Crooke (1981) concluded that exchangeable and soluble aluminium in acid soils were reduced by liming.

According to Hargrove and Thomas (1981), lime application increased plant yield by neutralizing aluminium toxicity rather than by increasing solution phosphorus

Haynes and Ludecke (1981) found out a negative but linear relationship between exchangeable calcium and aluminium. Jones et al. (1982) observed that eventhough there was no significant effect in increasing the yield, lime decreased the exchangeable aluminium from 0.12 to 0.01 me/100 g.

Mukhopadhyay et al. (1984) have suggested that increasing the rate of application of $CaCO_3$ decreased exchangeable aluminium content of soils.

Recently Curtin and Smillie (1986) have reported that soil concentrations of free Al can be decreased by liming.

Lime requirement of acid soils in relation to controlling of aluminium toxicity

Clark and Nichol (1966) have explained the necessity of considering pH and solubility of aluminium while estimating lime requirement of organic soils. Concentration of aluminium on which lime requirement is based depend on pH, clay (type and amount) and organic matter present.

Evans and Kamprath (1970) related soil solution aluminium to the percentage aluminium saturation of the effective CEC in mineral soils, but it was more related to the amount of exchangeable aluminium in organic soils. They reported that lime response is related to percentage aluminium saturation, solution aluminium and organic matter content.

Ekpete (1972) found that lime requirement is influenced by pH, exchangeable aluminium, soil organic matter, clay content, but the buffer capacity of the soils was greatly influenced by soil organic matter.

Oates and Kamprath (1983) have shown that the amount of aluminium removed from the exchange sites depend on the nature of exchanging cation and the pH of the extracting solution.

Halder and Mandal (1985) have shown that lime requirement is negatively correlated with pH and positively correlated with exchange acidity, extractable acidity, and exchangeable aluminium. Lime requirement was found to be strongly influenced by the combined effect of all these parameters.

Pal and Mandal (1985) reported that lime requirement was significantly correlated with exchange, residual and total acidity and exchangeable aluminium.

According to Gillman and Sumpler (1986) lime requirement depend on CEC, exchangeable aluminium, type of soil, base saturation, organic matter content, pH etc.

Khanna et al. (1986) showed that when exchange sites are occupied by aluminium and associated with high organic matter, unbuffered salt solutions extracted more aluminium than could be associated with exchange sites, which will over estimate the lime requirement values.

Exchangeable aluminium as a criterion for lime requirement

Pavar and Marshal (1934) considered exchangeable aluminium as the criterion of soil acidity rather than hydrogen ion concentration.

Mc Lean et al. (1964) concluded that exchange acidity is a poor index for lime requirement and that the amount of soluble aluminium was not closely related to base unsaturation or pH.

Kamprath (1970) has proposed lime application based on exchangeable aluminium to be a realistic approach for leached mineral soils. He found that lime rates equivalent to the amount of exchangeable aluminium reduced the aluminium saturation of the effective CEC to <30 percent. Lime rates greater than this equivalent amount resulted in neutralization of non-exchangeable acidity and is generally uneconomical.

Since the principal function of lime in an acid soil is to eliminate aluminium toxicity, Reeve and Sumner (1970) considered exchangeable aluminium status as a more suitable criterion for the measurement of lime requirement. The amount of lime thus calculated was only approximately 1/6th of the amount required to raise the soil pH to 6.5.

Hoyt and Nyborg (1971) have suggested that extractable aluminium could be a valuable supplement to soil pH in assessing the need for lime application or for growing aluminium tolerant varieties.

Amedee and Peech (1976) have pointed out that lime requirement based on exchangeable aluminium concentration was less than the estimate of lime based on the neutralization value.

Sanchez (1976) considered soil acidity as a poorly defined parameter and recommended that percentage aluminium saturation of the effective CEC should be taken as a useful measure of soil acidity.

Martini et al. (1977) have suggested liming rates to bring soil pH from 4.8 to 5.7 and to reduce exchangeable aluminium to 1.5 me/100 g soil as a more valid means of increasing yield than the raising of soil pH to neutrality.

Mendez and Kamprath (1978) have demonstrated that liming rates equivalent to 1.5 times of the exchangeable aluminium content of a soil can neutralize most of the exchangeable aluminium and adjust the pH satisfactorily for plant growth. Such liming rates were considerably lesser than those required to raise the pH to 7.0.

Cochrane et al. (1980) have proposed the use of minimum amount of lime on acid soils so as to decrease the percentage aluminium saturation to levels that do not affect production and compensate crop aluminium tolerance.

Farina et al. (1980) have concluded that because of considerable variation in the optimum pH requirements of the different soils, pH proved to be a poor measure of lime requirement. But both highly weathered and less weathered soils behaved similarly when assessed on the basis of aluminium saturation.

Saigura et al. (1980) conducted experiments on exchange acidity and aluminium toxicity potential and showed that exchange acidity was a useful realistic measure of aluminium toxicity potential. Manrique (1986) has found that a pH value <4.0 in 1 M KCl should indicate an aluminium saturation less than 15 percent.

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study entitled "Exchangeable aluminium as an index of liming for the acidic upland soils of Kerala" was carried out by studying the pattern of distribution of water soluble and exchangeable aluminium in the acidic upland soils of Kerala, and by comparing the response of two acid sensitive crops to levels of lime as determined by conventional methods and that required to lower the percentage of aluminium saturation (PAS) of soils to levels below the tolerance limit for most crops.

The study included the collection and analysis of acidic upland soils and conduct of a pot culture experiment to compare the effectiveness of levels of lime based on conventional lime requirement methods and that based on percentage of aluminium saturation values of soils.

Collection of soil samples.

A total number of 80 soil samples representing the five major acid soil types of Kerala were collected.

They included the laterite, alluvial, red loam, sandy and forest soils. The types of soil and the location from which they were collected are given in Table 1.

Table 1 Details of soil samples collected

Sl. No.	Soil types	Location	Total number of samples in each type
1	2	3	4
1	Laterite	Anchal	
2	"	Kallayam	
3	"	Kulathupuzha	
4	"	Neyyattinkara	
5	"	Ottasekharamangalam	
6	"	Palode	
7	"	Punalur	
8	"	Thalavoor	
9	"	Uzhamalakkal	
10	"	Vellarada	
11	"	Vembayam	
12	"	Vithura	
13	"	Pennukkara	

Table 1 (contd.)

1	2	3	4
14	Laterite	Chengannoor	
15	"	Kadakkamon	20
16	"	Pathanapuram	
17	"	Varkala (3 samples) (17-19)	
20	"	Poojappura	
21	Alluvial	Karumady	
22	"	Edathwa (7 samples) (22-28)	15
29	"	Thalavadi (5 samples) (29-33)	
34	"	Neerettupuram	
35	"	Kalangera	
36	Red loam	Vizhinjum (5 samples) (36-40)	
41	"	Thekkerkonam	
42	"	Kottappuram	
43	"	Mulloor (7 samples) (43-49)	
50	"	Kadakulam (2 samples) (50-51)	25

Table 1 (contd.)

1	2	3	4
52	Red loam	Azhakulam (2 samples) (52-53)	
54	"	Muttakadu (2 samples)	
56	"	Panangodu	
57	"	Venganoor (3 samples) (57-59)	
60	"	Kalliyoor	
61	Sandy	Karuvatta	
62	"	Karumady	
63	"	Thiruvizha	
64	"	Shertallay	
65	"	Pattanakad	5
66	Forest soil	Anchal (5 samples) (66-70)	
71	"	Arippa (2 samples) (71-72)	
73	"	Pottamavu (2 samples) (73-74)	
75	"	Onnamkurukku (2 samples) (75-76)	15

Table 1 (contd.)

1	2	3	4
77	Forest soil	Sastanada	
78	"	Valiyathodu-Thavarna	
79	"	Santhimathi Estate	
80	"	Muthoot Estate	

<u>Collection of soil samples.</u>

Soil samples were collected from a depth of 6" after making a "V" shaped cut with a sharp spade. The fresh soil was packed in polythene bags, labelled and transported to the laboratory. In the laboratory these samples were dried in shade, powdered with a wooden mallet and sieved through 2 mm sieve. The sieved soil samples were stored in air tight containers after proper labelling.

<u>Analysis of the soil samples</u>

The chemical analysis of these samples was carried out by the methods described.

Sl. No.	Soil property	Extraction method
1	2	3
1	pH (water)	1:2.5 soil water suspension
2	pH (0.01 M $CaCl_2$)	1:2.5 soil $CaCl_2$ solution
3	Electrical conductivity	1:2.5 soil water suspension
4	Organic carbon	Walkley and Black's rapid titration method
5	Water soluble aluminium	1:10 soil water extract
6	CEC	Neutral normal NH_4O AC method

Instrument	Reference
4	5
Perkin Elmer pH meter	Jackson (1973)
"	"
Solu Bridge	"
-	"
P.E. 3030 AAS - Wave length - 309.3 nm	Chenery (1948)
-	Jackson (1973)

Sl. No.	Soil property	Extraction method
1	2	3
7	Lime requirement	1:2.5 soil buffer suspension
8	Exchangeable bases	
	a) Potassium	Neutral normal ammonium acetate extraction method
	b) Calcium	"
	c) Magnesium	Neutral normal ammonium acetate extraction method
9	Exchangeable Al and H	Titration method
10	Exchangeable Fe	KCl extract

Instrument	Reference
4	5
Perkin Elmer pH meter	Shoemaker et al. (1961)
EEL flame-photometer	Jackson (1973)
P.E. 3030 AAS Wave length - 422.7 nm	"
P.E. 3030 AAS Wave length - 285·2nm [illegible]	Yuan (1959)
P.E. 3030 AAS Wave length - 248.3 nm	

From the above datas, percentage base saturation and percentage aluminium saturation were computed as follows.

$$\text{Percentage base saturation (PBS)} = \frac{\text{Exchangeable K} + \text{Exchangeable Ca} + \text{Exchangeable Mg}}{\text{CEC}} \times 100$$

$$\text{Percentage aluminium saturation (PAS)} = \frac{\text{Exchangeable aluminium}}{\text{CEC}} \times 100$$

<u>Pot culture experiment</u>.

From the 80 samples of acidic upland soils studied, one soil containing the maximum amount of exchangeable aluminium and the highest percentage aluminium saturation was selected for the conduct of the pot culture study. This sample was located at Vembayam in Trivandrum district, from where bulk samples were collected and brought to the laboratory. The soil was dried in the shade, the larger clods were broken and filled in earthenware pots of 13 cm diameter. The data on the physico-chemical analysis of the soil used in the pot culture experiment are given in Table 2.

Table 2 Physico-chemical characteristics of the soil used in the pot culture experiment

Location : Vembayam

Type : Laterite

pH in water (1:2.5 soil water suspension)	- 4.2
pH in 0.01 M $CaCl_2$ (1:2.5 soil solution)	- 3.8
EC (m mhos/cm)	- 0.2
Total nitrogen (%)	- 0.095
Total phosphorus (%)	- 0.043
Total potassium (%)	- 0.116
Available nitrogen (kg/ha)	- 183.4
Available phosphorus (kg/ha)	- 9.0
Available potassium (kg/ha)	- 19.2
Lime requirement (t/ha)	- 7.7
Organic carbon (%)	- 0.99
Exchangeable aluminium (me/100 g)	- 2.48
Water soluble aluminium (ppm)	- 28.4
Exchangeable hydrogen (me/100 g)	- 0.47
Exchangeable bases (me/100 g) (Ca+Mg+K)	- 1.982
Cation Exchange Capacity (me/100 g)	- 5.3
Percent aluminium saturation	- 46.79
Percent base saturation	- 37.39

Determination of lime required to reduce percentage aluminium saturation to different levels.

The amount of lime required to reduce the percentage aluminium saturation of the soil to different levels was determined by mixing 200 g of the moistened soil with 10, 25, 50, 100, 150 and 200 mg of lime, keeping overnight, and then estimating the content of exchangeable aluminium and exchangeable hydrogen in the treated samples by titration method after extracting with N KCl (Yuan, 1959). The results obtained are given in Table 3.

Table 3 Changes in percentage aluminium saturation with different levels of lime

Treatment	Quantity of lime applied (mg/200 g soil)	Total acidity me/100 g	Exch. Al^{3+} me/100 g	Exch. H^+ me/100 g	PAS %
1	2	3	4	5	6
1	0	2.94	2.45	0.49	46.26
2	10	2.68	2.20	0.48	41.55
3	25	2.47	1.98	0.49	37.78
4	50	1.73	1.25	0.48	23.65
5	100	1.35	0.89	0.46	16.70
6	150	0.90	0.44	0.46	1.36
7	200	0.45	-	0.45	-

Based on these results, the 4th treatment (50 mg of lime/200 g soil) which worked out to 500 kg/ha was selected as the lime required for reducing percentage aluminium saturation to < 30 and the 3rd treatment (25 mg of lime/200 g soil) which worked out to 250 kg/ha were selected as lime required to reduce percentage aluminium saturation to < 40.

Lime requirement based on conventional method.

Lime requirement by this method was determined according to the SMP buffer method using the glass electrode of Perkin Elmer pH meter. Ten grams of soil was mixed with 25 ml of buffer solution having a pH of 7.5 and shaken continuously for 10 minutes. The pH of the suspension was immediately read using the glass electrode. From the table given by Shoemaker et al. (1961) the amount of lime required to bring the soil to an indicated pH of 6.4 was determined. This was found to be 7.7 t/ha.

Experiment I.

Response of Cowpea to different levels of exchangeable aluminium.

Layout of the experiment

Experimental design : CRD

Four levels of lime treatment were given as follows

1	T_1	No lime	control
2	T_2	lime based on conventional lime requirement methods	7.7 t/ha
3	T_3	lime to reduce PAS to <30	500 kg/ha
4	T_4	lime to reduce PAS to <40	250 kg/ha

Number of replications - Four

N, P and K fertilizers at 20:30:10 kg of the respective nutrient/ha were uniformly applied to all the pots as urea (46% N), superphosphate (16% P_2O_5) and muriate of potash (60% K_2O) as prescribed in the package of practice recommendations of the KAU (Anon., 1984) for cowpea.

Earthen pots of 13 cm diameter were filled each with 10 kg of the soil type selected for this study and mixed with fully burned lime (CaO) as per the treatment schedule. The required doses of fertilizers were applied and thoroughly mixed with the soil after two days.

Soil samples were collected from a depth of three inches from each pot and analysed for pH, exchangeable H, Al, Fe, Ca, Mg and K. PAS and PBS were computed from the data by the methods described earlier after the application of lime (S_{00}) as well as after fertilizer application (S_0).

Sowing of seeds.

Seeds of cowpea Var. Krishnamony were sown at the rate of six seeds per pot. After complete germination and establishment, thinning was done to maintain three seedlings in each pot. The plants were irrigated every day. There was no serious attack of pests and diseases in the initial growth phase, but after flowering, aphid attack was a major problem. Roger (0.03 percent) was sprayed for the control of aphids.

Biometric observations.

Biometric observations of the plants were recorded at three stages of growth viz. maximum flowering (S_1), mid pod filling (S_2) and grain stage (S_3) ie. at harvest. Individual plants from each pot were pulled out carefully at each of the above stages and the following characters were determined.

Height of the plant.

Height of the plant was measured from the base of the stem to the tip of the youngest leaves using a metre scale and expressed in centimetres.

Root length.

Length of the root was measured in centimetres, from the base of the stem to the tip of the longest root.

Nodule count.

The roots of the uprooted plants were washed carefully in running water and all the soil particles adhering to the root system were removed using a jet of water. The root nodules were separated by a pair of forceps and classified into three groups based on the visual observation of their size. The number of small, medium and large sized nodules was recorded.

Fresh weight.

Fresh weight of plants was recorded and expressed in grams.

Dry weight.

The plants were dried in the shade and then dried in an air oven at 80 ± 5°C until constant weight was obtained. The weight in gram was recorded.

Yield

Dried pods were collected potwise, as and when matured and kept in labelled paper packets. The total weight of the air dried pods from each pot was recorded. These pods were later separated into grain and husk and their separate weights were also recorded.

Plant analysis

The different plant parts viz. tops, roots, grain and husk collected at the three stages of the plant were dried in an air oven at 80 ± 5°C, powdered and analysed for total N, P, K, Ca, Mg, Fe, Al, Zn and Cu in sulphuric acid extract as described by Jackson (1973).

Soil analysis

Soil samples collected at the three stages from a depth of three inches were analysed for various factors such as pH exchangeable Al, H, Ca, Mg and K by methods described earlier. PAS and PBS were computed from the data.

Experiment II.

Response of fodder maize to different levels of exchangeable aluminium

The layout of the experiment and different treatments of lime were the same as in the previous experiment.

Fertilizers were applied as per the package of practice recommendations of the KAU (Anon., 1984) for fodder maize at the rate of 120:60:40 Kg/ha of N, P, and K. The fertilizers were applied as urea (46% N), superphosphate (16% P_2O_5) and muriate of potash (60% K_2O).

Raising of the crop

Medium sized earthen pots (13 cm diameter) were filled with 10 kg of the soil selected and the calculated quantity of lime was incorporated into the soil. The fertilizers were applied after two days.

Soil samples were collected from a depth of three inches from each pot after the application of lime (S_{00}) as well as after the application of fertilizers (S_0), and analysed for pH, exchangeable Al, Fe, H, Ca, Mg and K by the methods described earlier. PAS and PBS were computed from the data as described earlier.

Sowing of seeds.

Three maize seeds of variety Ganga-5 were sown in a triangular manner in each pot. After complete germination of seeds, thinning was done at four leaf stage to maintain a single healthy plant in each pot.

Biometric observations

The following biometric observations were made at 30 (S_1), 65 (S_2) and 90 (S_3) days after sowing.

Height of the plant

Height of the plant was measured from the base of the plant to the tip of the youngest fully opened leaf after 30 and 65 days and from the base of the plant to the tip of the tassel at 90th day and recorded in centimetres.

Root length

Length of the root was measured from the base of the stem to the tip of longest root and expressed in cm.

Fresh weight of tops and roots

At fodder harvest stage, each plant was pulled out with utmost care and washed carefully in running water. Soil particles adhering to the roots were removed with the help of a jet of water. The plants were separated into roots and tops which were weighed separately.

Dry weight of tops and roots

Separated root and top samples were first air dried and then oven dried in an air oven at 80 ± 5°C till constant weight was obtained. The dry weight of tops and roots were recorded.

Chemical analysis of plants

Oven dried top and root samples were powdered separately and analysed for N, P, K, Ca, Mg, Fe, Al, Mg, Zn and Cu in sulphuric acid extract (Jackson, 1973).

Soil analysis

Soil samples collected at the three stages were analysed for various factors such as pH, exchangeable Al, H, Ca, Mg and K by methods described earlier.

Statistical analysis.

The data obtained from the different estimates of laboratory and pot culture studies were analysed by appropriate statistical methods to bring out the comparative effect of different treatments on plant characters as well as the relationship between levels of exchangeable aluminium and growth, yield and nutrient uptake in cowpea and maize.

RESULTS

RESULTS

The results of chemical analysis of 80 soil samples representing the five major soil types of Kerala are given in Table 4.

The mean value for pH in water recorded a minimum of 4.2 in the laterite soil of Vembayam and in the alluvial soil collected from Kalangara. Maximum pH of 7.9 was shown by the red loam soil collected from Thekkerkonam. The pH of all the soils showed a reduction of 0.2 to 2.9 units when taken in 0.01 M $CaCl_2$.

Lime requirement values also showed wide variation among the soils. The value for lime requirement was minimum in the sandy soil of Thiruvizha and some red loam soils of Vizhinjum area. The lime requirement value was maximum (7.7 t/ha) in the laterite soil of Vembayam which has recorded the lowest value for pH also. Most of the soils collected from Vizhinjum and nearby areas had a neutral reaction and were devoid of any exchangeable aluminium.

Table 4 Chemical analysis of Soil Samples

No.	pH (H_2O)	pH 0.01M $CaCl_2$	LR t/ha	EC	OC Percent	K me/100 g	Ca me/100 g	Mg me/100 g	PBS	Fe ppm	Total acidity (me/100 g)	Exchange-able hydrogen (me/100 g)	Exchange-able aluminium (me/100 g)	Percentage aluminium saturation (PAS)	Water soluble aluminium ppm	CEC (me/100 g)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	5.0	4.3	4.7	0.05	0.30	0.14	0.99	0.81	60.13	1	1.47	0.50	0.97	30.30	8	3.2
2	5.3	4.5	2.7	0.08	0.18	0.18	1.71	0.97	75.12	5	0.98	0.98	–	–	trace	3.8
3	5.6	4.5	3.7	0.08	1.11	0.23	1.75	0.85	74.24	1	0.49	0.01	0.49	12.76	3	3.8
4	5.8	4.7	2.2	0.04	0.15	0.19	0.83	0.67	75.21	2	0.49	0.49	–	–	trace	2.4
5	5.2	4.0	5.7	0.03	0.36	0.20	0.83	0.78	51.65	1	1.47	0.22	1.26	35.85	11	3.5
6	5.2	4.0	5.2	0.03	0.27	0.08	0.58	0.25	45.35	1	1.47	0.99	0.49	24.25	3	2.0
7	5.1	3.9	5.7	0.04	0.51	0.45	0.91	0.82	64.15	9	1.47	0.50	0.97	28.53	5	3.4
8	5.8	4.8	3.7	0.23	0.69	0.14	0.72	0.80	44.62	13	0.49	0.01	0.49	13.11	4	3.7
9.	5.0	4.1	4.7	0.06	0.30	0.12	0.84	0.77	57.50	16	1.47	0.57	0.90	39.13	6	2.3
10	5.9	4.5	2.2	0.09	0.36	0.18	0.86	1.02	64.13	14	0.49	0.49	–	–	trace	3.3
11	4.2	3.2	7.7	0.02	0.36	0.55	0.35	1.08	37.39	13	2.94	0.47	2.48	46.70	28.4	5.3
12	6.9	4.0	–	0.03	0.27	0.17	0.86	0.32	53.64	14	0.49	0.49	–	–	trace	2.5
13	5.6	4.3	4.2	0.05	0.66	0.31	0.75	0.85	40.60	14	0.98	0.50	0.49	10.32	5	4.7
14	5.6	4.2	4.7	0.03	0.09	0.33	1.67	0.54	51.83	14	0.98	0.50	0.49	9.90	6	4.9
15	5.0	4.0	7.2	0.03	1.02	0.14	0.86	0.56	56.96	13	1.47	0.52	0.96	31.83	9	3.0
16	5.6	4.0	5.7	0.03	1.11	0.20	0.83	0.73	40.83	14	1.47	0.50	0.97	31.29	10	3.1
17	5.3	3.9	3.7	0.06	0.03	0.17	1.79	0.36	59.31	14	1.47	0.52	0.96	22.74	4	4.2
18	5.9	4.6	1.7	0.08	0.06	0.18	2.06	0.95	65.04	15	0.49	0.49	–	–	trace	4.9
19	5.5	4.2	2.2	0.05	0.27	0.19	1.91	0.58	59.13	5	0.98	0.53	0.46	10.11	5	4.5
20	6.8	5.4	–	0.12	0.33	0.16	2.40	1.37	63.37	44	0.49	0.49	–	–	trace	6.2
21	5.4	4.8	2.2	0.14	0.57	0.21	1.09	0.83	41.82	28	1.79	0.57	1.22	23.92	12	5.1
22	5.4	4.5	2.7	0.05	0.48	0.19	1.60	0.88	50.38	26	1.79	0.57	1.22	23.02	11	5.3
23	5.3	4.2	3.7	0.04	0.27	0.16	1.64	1.40	61.48	25	0.45	0.45	–	–	trace	5.2
24	5.1	4.3	3.2	0.08	0.33	0.21	1.85	1.12	55.79	22	1.30	0.82	0.48	8.40	4	5.7
25	4.7	4.2	5.2	0.06	0.45	0.21	1.82	1.28	56.81	31	0.90	0.42	0.48	8.25	5	5.8
26	5.0	4.0	4.2	0.16	0.45	0.20	1.80	1.67	69.04	23	0.98	0.50	0.49	9.15	3	5.3
27	5.2	3.9	3.7	0.03	0.12	0.19	1.81	1.63	65.85	23	0.98	0.50	0.49	8.82	4	5.5

Table 4 (Contd..)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
28	5.8	4.5	2.2	0.04	0.24	0.22	1.68	2.79	75.61	17	0.49	0.49	-	-	trace	6.2
29	5.5	4.0	5.2	0.05	0.33	0.20	1.20	1.38	52.51	22	0.49	0.14	0.31	5.79	2	5.3
30	5.5	5.0	2.7	0.11	1.11	0.21	2.45	2.64	72.56	25	0.90	0.28	0.61	8.39	5	7.3
31	5.4	4.7	4.7	0.27	0.84	0.20	2.24	1.93	67.15	40	0.45	0.44	0.01	-	trace	6.5
32	5.5	4.7	4.7	0.22	0.75	0.22	2.24	1.77	66.94	30	0.45	0.43	0.02	-	trace	6.3
33	5.5	4.6	4.7	0.26	0.90	0.24	1.92	1.58	65.37	30	0.98	0.50	0.49	8.51	5	5.7
34	4.5	4.3	6.7	0.04	1.11	0.22	1.19	1.91	55.23	27	0.90	0.47	0.43	7.17	3	6.0
35	4.2	3.7	5.7	0.18	0.95	0.23	3.17	0.88	35.61	26	2.94	0.48	2.46	38.40	24	6.4
36	6.3	4.9	1.2	0.03	0.99	0.14	2.87	1.57	76.17	17	0.45	0.45	-	-	trace	6.0
37	6.6	5.0	-	0.04	0.90	0.16	2.49	1.08	60.97	17	0.45	0.45	-	-	"	6.1
38	6.1	5.1	-	0.04	0.90	0.17	2.73	0.98	61.59	19	0.45	0.45	-	-	"	6.3
39	6.1	4.8	1.7	0.07	1.02	0.18	2.01	1.58	61.72	16	0.45	0.45	-	-	"	6.1
40	7.0	5.2	-	0.15	0.99	0.14	2.73	1.62	72.23	15	0.90	0.66	0.24	3.87	1	6.2
41	7.9	5.3	-	0.10	0.87	0.23	1.25	1.87	52.31	20	0.45	0.45	-	-	-	6.4
42	5.9	5.7	1.2	0.15	0.48	0.12	1.43	1.88	57.70	16	0.45	0.45	-	-	-	6.5
43	6.1	5.2	-	0.03	0.63	0.10	2.00	1.47	72.69	19	0.49	0.49	-	-	trace	4.9
44	6.0	5.0	-	0.02	0.45	0.06	1.89	1.48	71.27	16	0.49	0.49	-	-	trace	4.8
45	6.7	5.6	-	0.06	0.66	0.12	1.90	1.96	82.93	2	0.49	0.49	-	-	"	4.8
46	7.4	5.7	-	0.02	0.90	0.09	1.61	1.50	67.98	2	0.49	0.49	-	-	"	4.7
47	6.5	5.4	-	0.02	0.57	0.09	1.97	1.77	76.38	2	0.49	0.49	-	-	"	5.0
48	7.6	5.9	-	0.13	0.99	0.08	1.76	1.27	70.66	2	0.49	0.49	-	-	"	4.4
49	7.0	6.0	-	0.09	0.57	0.12	2.30	2.10	79.19	2	0.49	0.49	-	-	"	5.7
50	6.6	5.1	-	0.15	1.08	0.08	1.77	2.19	82.41	17	0.49	0.49	-	-	"	4.9
51	7.1	5.5	-	0.03	0.54	0.07	1.93	1.57	71.28	2	0.49	0.49	-	-	"	5.0
52	7.2	5.9	-	0.09	0.90	0.20	2.15	1.80	76.85	1	0.49	0.49	-	-	"	5.4
53	6.5	5.9	-	0.09	0.87	0.34	1.48	1.78	76.57	1	0.49	0.49	-	-	"	4.7
54	5.7	5.9	-	0.09	0.90	0.11	1.69	1.78	72.92	2	0.49	0.49	-	-	"	4.9

Table 4 (Contd...)

1	2	3	4	5	6	7	8	9	10
55	6.1	4.9	-	0.07	1.14	0.10	1.27	0.80	80.19
56	6.5	4.2	-	0.04	0.93	0.97	1.67	0.84	77.44
57	5.5	5.0	1.2	0.03	0.60	0.05	0.99	1.13	74.79
58	5.5	4.1	2.2	0.04	0.48	0.05	2.00	1.40	75.28
59	5.8	4.2	1.2	0.04	0.66	0.07	1.19	1.25	73.74
60	5.1	4.1	2.2	0.07	0.39	0.11	1.60	0.27	70.43
61	5.2	4.0	3.7	0.04	0.54	0.05	0.71	1.11	66.57
62	6.0	3.8	2.2	0.08	1.11	0.03	1.26	0.92	58.03
63	6.5	5.2	1.2	0.09	0.84	0.05	0.89	0.27	42.96
64	5.6	4.4	2.2	0.05	0.39	0.07	0.23	0.76	55.53
65	5.5	4.1	3.7	0.04	0.45	0.06	0.25	0.69	66.20
66	5.1	4.0	5.2	0.03	2.43	0.05	0.92	0.43	66.00
67	5.5	4.1	4.7	0.04	2.46	0.07	1.00	0.49	67.87
68	5.6	4.3	3.7	0.04	2.01	0.09	1.24	0.40	59.66
69	5.8	4.5	4.7	0.05	2.19	0.10	0.82	0.58	60.04
70	4.9	4.0	5.2	0.02	2.43	0.03	0.85	0.54	59.04
71	5.1	4.1	5.2	0.02	0.45	0.22	1.03	0.46	42.75
72	5.2	3.8	4.7	0.01	1.17	0.12	1.55	0.99	45.55
73	5.0	4.0	5.2	0.01	0.62	0.15	1.21	0.66	46.67
74	6.4	4.0	-	0.09	0.63	0.40	1.82	0.41	54.79
75	5.6	4.8	3.7	0.07	1.62	0.51	1.69	0.88	54.04
76	4.8	4.1	3.2	0.01	0.90	0.25	1.46	0.32	41.43
77	4.9	4.2	3.7	0.02	0.48	0.05	0.99	0.02	42.40
78	4.5	4.0	3.7	0.01	1.23	0.16	1.35	0.46	37.16
79	5.4	4.1	1.7	0.04	1.67	0.32	1.57	0.26	50.00
80	6.1	4.7	-	0.08	2.24	0.28	1.16	0.95	59.75

11	12	13	14	15	16	17
6	0.49	0.49	-	-	trace	2.7
2	0.49	0.49	-	-	"	4.5
1	0.49	0.49	-	-	"	2.9
2	0.49	0.49	-	-	"	3.2
2	0.49	0.49	-	-	"	3.4
1	0.98	0.50	0.25	8.85	2	2.8
1	0.98	0.50	0.25	8.85	2	2.8
15	0.98	0.98	-	-	trace	3.8
1	0.49	0.49	-	-	"	2.8
9	0.49	0.49	-	-	"	1.9
10	0.49	0.49	-	-	"	1.5
5	1.47	0.99	0.49	23.09	4	2.1
1	1.47	0.99	0.49	21.08	5	2.3
4	0.98	0.50	0.49	16.72	3	2.9
5	1.47	0.99	0.49	19.40	1	2.5
3	1.95	0.98	0.77	32.17	3	2.4
1	2.45	0.51	1.49	37.12	3	4.0
3	1.47	0.99	0.49	25.60	1	5.8
1	2.94	1.00	0.97	23.10	4	4.2
0	1.47	0.50	0.97	20.20	1	4.8
1	1.49	0.49	1.00	17.59	1	5.7
0	1.47	0.50	0.97	19.80	2	4.9
1	0.98	0.50	0.49	19.40	3	2.5
3	2.45	0.57	1.94	36.60	4	5.3
1	1.96	0.48	0.49	11.28	4	4.3
4	0.98	0.09	0.90	22.25	6	4.0

The maximum value for exchangeable aluminium was recorded in the laterite soil of Vembayam (2.48 me/100 g) which has incidentally recorded the lowest pH value of 4.2.

The percentage aluminium saturation was highest in the laterite soil of Vembayam while this value was almost negligible in red loam soils. The status of bases like K, Ca & Mg was moderately high in various soils and the percentage base saturation of soils ranged from 35.61 in alluvial soil collected from Kalangara to 82.93 in red loam soils of Mulloor area.

Sandy soils of Pattanakad recorded the lowest value for cation exchange capacity (1.5 me/100 g) and the highest value of 6.4 me/100 g was obtained in an alluvial soil of Kalangara.

Experiment I.

Pot culture studies with cowpea

Influence of different levels of lime on soil properties

Soil reaction

The mean values of pH of the soils in the different pots treated with lime at different stages of growth of cowpea is presented in Table 5 and the analysis of variance in appendix 1(a).

Application of different levels of lime as per the treatments has resulted in a significant shift in pH from 4.4 to 6.2 compared to the value of 4.1 in the control. Rise in pH was maximum in T_2 where 7.7 t/ha of lime was applied, and minimum in T_4 where only 250 kg/ha of lime was applied. T_3 receiving 500 kg/ha recorded a pH of 4.7.

After the application of fertilizers a rise in pH was observed in all the treatments where it ranged from 4.6 in control to 6.3 in T_2. T_2 recorded a significantly higher pH than T_3, T_4 and T_1.

At maximum flowering stage of cowpea, all the treatments showed an increase in pH ranging from 4.8 in control to 6.3 in T_2, which was significantly superior to the other treatments. At the mid pod filling stage of cowpea, pH was higher than that at the maximum flowering stage and it ranged from 5.0 in

Table 5 Influence of different levels of lime on soil properties (crop-cowpea)

Soil reaction (pH)

Treatments	S_{00}	S_0	S_1	S_2	S_3
T_1	4.1	4.6	4.8	5.0	4.8
T_2	6.2	6.3	6.3	6.4	6.3
T_3	4.7	4.9	5.7	5.9	5.2
T_4	4.4	4.7	5.2	5.3	4.9
CD	0.11	0.16	0.23	0.29	0.31

Total acidity (me/100 g soil)

Treatments	S_{00}	S_0	S_1	S_2	S_3
T_1	2.94	2.33	1.47	0.49	0.98
T_2	0.49	0.40	0.28	0.16	0.22
T_3	1.73	0.98	0.55	0.31	0.49
T_4	2.45	1.96	0.98	0.49	0.92
CD	0.21	0.19	0.10	0.11	0.11

Table 5 (contd.)

Exchangeable aluminium (me/100 g soil)

Treatment	S_{00}	S_0	S_1	S_2	S_3
T_1	2.45	1.86	0.74	0.30	0.50
T_2	0.09	0.05	0.03	0.01	0.01
T_3	1.26	0.50	0.31	0.20	0.25
T_4	1.98	0.98	0.62	0.25	0.50
CD	0.22	0.19	0.15	0.01	0.01

Exchangeable hydrogen (me/100 g soil)

Treatment	S_{00}	S_0	S_1	S_2	S_3
T_1	0.49	0.47	0.73	0.20	0.48
T_2	0.40	0.36	0.25	0.15	0.21
T_3	0.47	0.49	0.25	0.11	0.25
T_4	0.47	0.98	0.36	0.24	0.42
CD	0.04	0.04	0.12	0.11	0.11

Table 5 (contd.)

Exchangeable potassium (me/100 g soil)

Treatments	S_{00}	S_0	S_1	S_2	S_3
T_1	0.58	0.61	0.39	0.29	0.28
T_2	0.48	0.61	0.46	0.33	0.32
T_3	0.46	0.58	0.43	0.26	0.30
T_4	0.46	0.61	0.47	0.25	0.24
CD	0.10	NS	NS	NS	0.05

Exchangeable calcium (me/100 g soil)

Treatments	S_{00}	S_0	S_1	S_2	S_3
T_1	0.31	0.40	0.95	1.11	0.87
T_2	11.35	8.45	7.27	5.64	6.64
T_3	0.79	0.73	1.37	1.35	1.24
T_4	0.61	0.43	1.02	1.11	0.77
CD	0.39	0.49	1.25	0.76	0.60

Table 5 (contd.)

Exchangeable magnesium (me/100 g)

Treatment	S_{00}	S_0	S_1	S_2	S_3
T_1	1.05	0.93	0.63	0.69	0.60
T_2	1.16	1.00	0.84	0.81	0.80
T_3	1.09	0.95	0.75	0.74	0.67
T_4	1.05	0.94	0.65	0.75	0.62
CD	NS	NS	0.12	NS	0.120

Exchangeable iron (ppm)

Treatment	Before cultivation	After cultivation
T_1	13	< 1
T_2	5	Nil
T_3	8	< 1
T_4	11	< 1
CD	0.937	0.382

control (T_1) to 6.4 in T_2. At the harvest stage, however, there was a slight decreasing tendency for this value compared to the previous stages, pH at this stage ranged from 4.8 in T_1 to 6.3 in T_2; T_2 being significantly superior to T_1, T_3 and T_4.

Total acidity.

The effect of different levels of lime on the estimate of total acidity of the soil is given in Table 5 and analysis of variance in Appendix I(b).

The total acidity ranged from the lowest value of 0.49 me in T_2 to the highest value of 2.94 me in T_1. Application of lime at the rate of 7.7 t/ha has significantly reduced the total acidity compared to the other treatments.

The application of fertilizers, resulted in a further lowering of total acidity in all the treatments. The lowest value 0.40 me was recorded for T_2 and the highest value 2.33 me was recorded for T_1. Total acidity in T_2 was significantly lower than T_3, T_4 and T_1.

At the maximum flowering stage of cowpea, values for the total acidity ranged from 0.28 in T_2 to 1.47 me/100 g in T_1. Total acidity in T_2 was significantly lower than that of T_3, T_4 and T_1.

The values for total acidity showed a decreasing trend towards the mid pod filling stage, showing a minimum value of 0.16 me in T_2 and a maximum of 0.49 me/100 g in the control and in T_4. Total acidity value in T_2 was significantly lower than that of T_3, T_4 & T_1.

Unlike the other stages, at the harvest stage, the soils showed an increasing trend in the content of acidity. It was minimum (0.22 me) in T_2 and maximum (0.98 me) in T_1. Here also, T_2 was significantly superior to T_3, T_4 and T_1.

Exchangeable aluminium

The effect of different levels of lime on the exchangeable aluminium content of the soil is given in Table 5 and analysis of variance in Appendix I(c).

lower value (0.20 me) compared to T_4 and T_1.

Exchangeable aluminium content and the corresponding value for percentage aluminium saturation of the soil increased towards the harvest stage. Recorded value for exchangeable aluminium at this stage ranged from 0.01 in T_2 to 0.50 me in T_1 and T_4. Exchangeable aluminium content was lowest in T_2 and it was significantly lower than T_3, T_4 and T_1.

Exchangeable hydrogen.

Mean values for the exchangeable hydrogen content of the soil due to treatment with different levels of lime are given in Table 5 and analysis of variance in Appendix I(d).

The values for exchangeable hydrogen in the soil ranged from 0.40 in T_2 to 0.49 me/100 g of soil in T_1. Application of lime at the rate of 7.7 t/ha significantly reduced the level of exchangeable hydrogen compared to the other treatments. After the application of fertilizers the value of exchangeable hydrogen changed from 0.36 in T_2 to 0.98 me in T_4. T_2 recorded a significantly lower value than T_1, T_4 and T_3.

At the maximum flowering stage of cowpea all treatments except T_1 showed a decrease in exchangeable hydrogen. The values for exchangeable hydrogen at this stage ranged from 0.25 in T_2 and T_3 to 0.73 me in T_1. Treatments T_2, T_3 and T_4 were equally effective in reducing exchangeable hydrogen content of the soil.

The values for exchangeable hydrogen showed a decreasing trend towards the mid pod filling stage, showing a minimum value of 0.11 me in T_3 and a maximum value 0.24 me in T_4. The value for exchangeable hydrogen in T_3 was significantly lower than that of T_4, but the effectiveness of T_2 and T_3 were almost similar in reducing the exchangeable hydrogen content of the soil.

At the harvest stage, exchangeable hydrogen showed an increasing trend. The values ranged from 0.21 me in T_2 to 0.48 me in T_1. T_2 and T_3 were significantly superior to T_1 and T_4 in reducing exchangeable hydrogen content of the soil.

Exchangeable potassium

The mean values of exchangeable potassium content of the soils in the different treatments at different stages of growth of cowpea are given in Table 5 and analysis of variance in Appendix I(e).

Decreased level of exchangeable aluminium in soil due to liming has resulted in a slight decrease in the content of exchangeable potassium. The values ranged from 0.58 in T_1 to 0.46 me in both T_3 and T_4. T_1 recorded a significantly higher amount of exchangeable potassium than T_3 and T_4.

After the application of fertilizers all the treatments showed an increase in the content of exchangeable potassium. This increase in the different treatments was not statistically significant and the mean values for exchangeable potassium ranged from 0.58 in T_3 to 0.61 me in T_1, T_2 and T_4.

At the maximum flowering stage of cowpea, a reduction in the exchangeable potassium content was noticed in all the treatments. However, it was not statistically significant. The values ranged from 0.39 in T_1 to 0.47 me in T_4.

The values for exchangeable potassium further showed a reduction at the mid pod filling stage where it ranged from 0.25 in T_4 to 0.33 me in T_2. The difference between various treatments was not significant.

At the harvest stage, the values of exchangeable potassium content was minimum and ranged from 0.24 in T_4 to 0.32 me in T_2. T_2 was found to contain a significantly higher amount of exchangeable potassium than T_4.

Exchangeable calcium

The mean values of exchangeable calcium at different stages of growth of cowpea in the pots receiving different levels of lime are given in Table 5 and the analysis of variance in Appendix I(f).

Application of different levels of lime has resulted in a reduction in the level of exchangeable aluminium in soil and a significant increase in the exchangeable calcium ranging from 0.31 in T_1 to 11.35 me in T_2. T_2 was found to contain a significantly higher amount of exchangeable calcium compared to treatments T_3, T_4 and T_1.

After the application of fertilizers, a slight decrease in exchangeable calcium was observed in all the treatments except in the control. The values for exchangeable calcium ranged from 0.40 in T_1 to 8.45 me in T_2 which maintained a significantly higher level compared to the other treatments T_3, T_4 and T_1.

At the maximum flowering stage of cowpea, exchangeable calcium showed an increasing trend in all the treatments except in T_2 where the value decreased a little. Exchangeable calcium content of the soil at this stage ranged from 0.95 in T_1 to 7.27 me in T_2.

The values for exchangeable calcium varied from 1.11 in T_1 and T_4 to 5.64 me in T_2 at the mid pod filling stage of the crop. Exchangeable calcium content in T_2 was significantly higher than that in T_1, T_3 and T_4.

At harvest stage, the values for exchangeable calcium showed a marked decrease compared to the other two stages, in all treatments except in T_2 where a slightly higher content of exchangeable calcium was noticed. Exchangeable calcium ranged from 0.77 in T_4 to 6.64 me in T_2 at this stage.

Exchangeable magnesium

The mean values for exchangeable magnesium content of the soil receiving different treatments are given in Table 5 and the analysis of variance in Appendix I(g).

Exchangeable magnesium content of the soil increased with lime application and the values ranged from 1.05 in T_1 to 1.16 me in T_2. This variation was, however, not statistically significant.

Exchangeable magnesium content of the soil showed a decreasing trend after the application of fertilizers and the values ranged from 0.93 in T_1 to 1.00 me in T_2.

The values for exchangeable magnesium declined at the maximum flowering stage and ranged from 0.63 in T_1 to 0.84 me in T_2. Exchangeable magnesium content in T_2 was significantly higher than T_1 and T_4. The content of exchangeable magnesium at the mid pod filling stage ranged from 0.69 in T_1 to 0.81 me in T_2. The difference between these was not statistically significant.

At the harvest stage, exchangeable magnesium showed a decreasing trend and it ranged from 0.62 in T_1 to 0.80 me in T_2. Exchangeable magnesium content in T_2 was significantly higher than that in T_1, T_3 and T_4.

Exchangeable iron

The mean values of exchangeable iron content of soils before and after cowpea cultivation are presented in Table 5 and the analysis of variance in Appendix I(h).

Exchangeable iron content in the soils before cultivation showed a significant difference, where it ranged from 5 ppm in T_2 to 13 ppm in T_1. But after the cultivation the exchangeable iron content in the soil decreased drastically and it was nil in T_2, and in the other three treatments, it was only less than one ppm.

Biometric Observations

The mean values on the various plant characters of cowpea are given in Table 6 and the analysis of variance in Appendix II.

Height of the plant

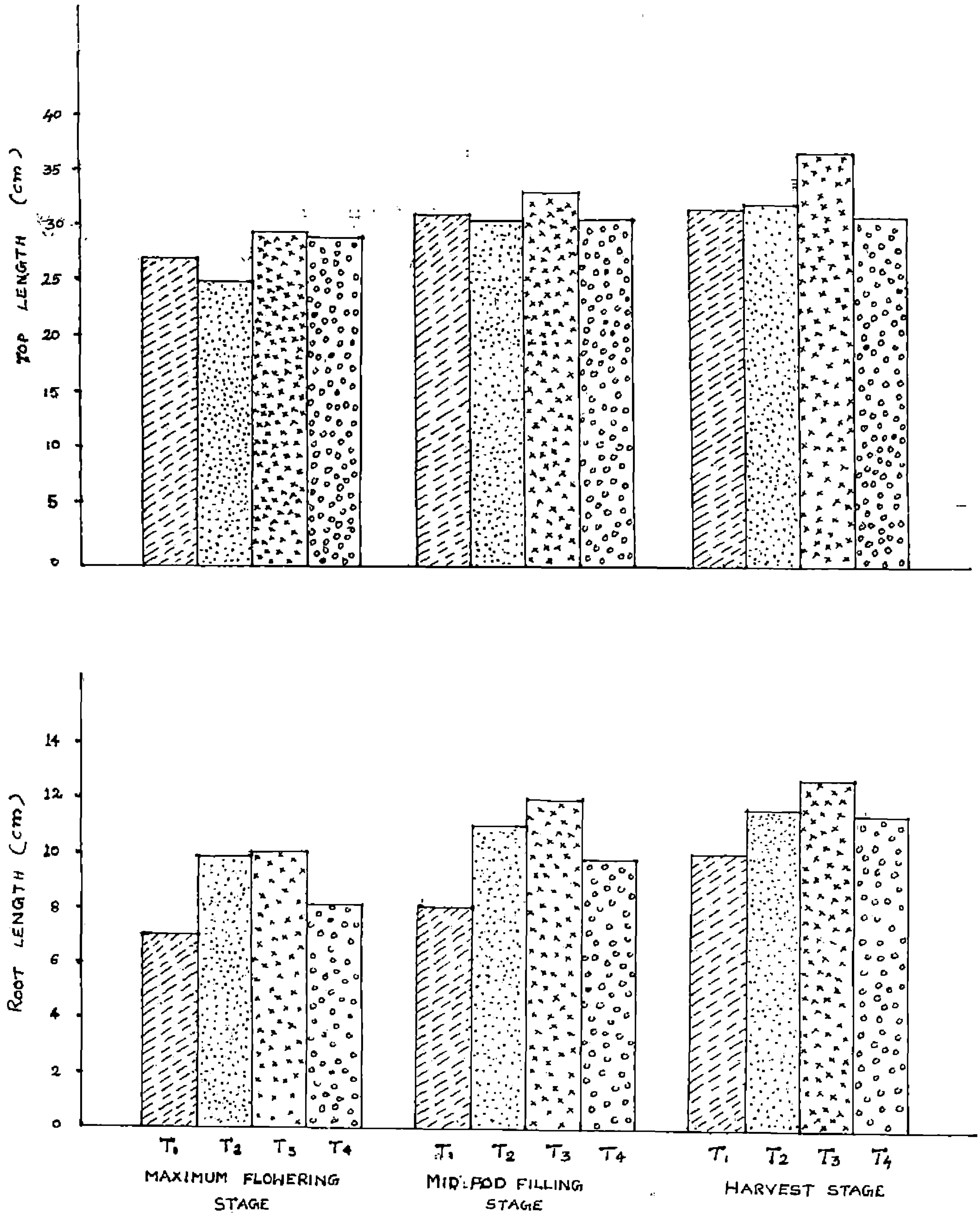
Influence of different levels of exchangeable aluminium on plant height is given in Fig.1. No significant relationship was obtained between the height of the plant and the different treatments at the maximum flowering stage. However, the mean height of the plant increased with an increase in lime levels with a corresponding decrease in exchangeable aluminium. The treatment T_2 which showed the least amount of exchangeable aluminium recorded the lowest height of 25.2 cm. In the other treatments the mean height of

Table 6 Biometric observations

Influence of different levels of lime on the plant characters of cowpea

Treatment	Height of the plant (cm)			Root length (cm)			Number of nodules			Grain weight (g)/pot	Husk weight (g)	Total pod weight (g)	Dry weight		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3				S_1	S_2	S_3
T_1	27.1	32.0	33.0	7.0	8.4	10.8	2	4	2	0.90	0.35	1.25	1.03	1.47	2.35
T_2	25.2	31.5	33.3	10.0	11.5	11.5	4	7	4	1.63	0.73	2.35	1.03	2.20	2.95
T_3	29.3	34.9	37.4	10.5	12.0	13.3	4	6	6	2.63	1.28	3.98	1.74	2.87	3.88
T_4	29.0	32.0	31.0	8.5	11.4	11.4	3	3	3	0.80	0.45	1.23	1.03	1.83	2.55
CD	NS	NS	NS	1.61	NS	NS	1.3	2.8	2.45	0.71	0.29	0.83	0.27	0.76	NS

FIG. 1. INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON THE TOP AND ROOT LENGTH OF COWPEA AT DIFFERENT STAGES OF GROWTH



the plants ranged from 27.1 cm in T_1 to 29.3 cm in T_3.

At the mid pod filling stage, the height of the plants varied from 31.5 in T_2 to 34.9 cm in T_3. None of the treatments was found to alter the height of the plant significantly.

At the harvest stage, the minimum height recorded was 31.0 cm for T_4 and the maximum was 37.4 cm for T_3. But no significant differentc in height was noticed between the different treatments. Plants grown in soils having a high exchangeable aluminium and percentage aluminium saturation of > 40 showed leaf curling and chlorosis which are typical symptom of aluminium toxicity.

Root length

Influence of different levels of exchangeable aluminium on root length is given in Fig.1 and Plate 1.

An increase in the length of roots was observed due to a decrease in the exchangeable aluminium content of the soil by liming. But the increase in length was

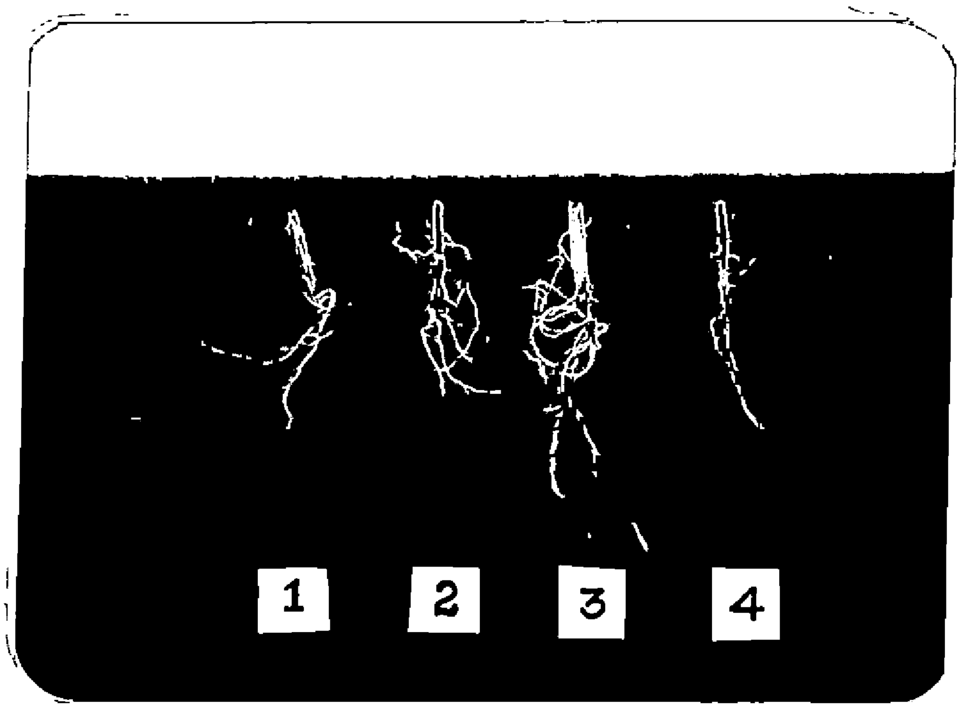


PLATE.1. — INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON ROOT GROWTH OF COWPEA.

significant only at the maximum flowering stage after which the plants in the different treatments did not show any appreciable variation.

At the maximum flowering stage, the length of roots varied from 7.0 in T_1 to 10.5 cm in T_3. It was significantly higher than the length of root in treatments T_1 and T_4.

At the mid pod filling stage, the root length varied from 8.4 cm in T_1 to 12.0 cm in T_3. Eventhough the length of roots showed an increasing trend due to a decreased exchangeable aluminium compared to the control, the difference was not significant and at harvest it ranged from 10.8 in T_1 to 13.3 cm in T_3.

Number of nodules.

A significant increase in nodule count was obtained with the reduction of exchangeable aluminium content in the soil by liming as compared to the control. At the maximum flowering stage, the number of nodules per plant varied from 2 in T_1 to 4 in T_2 and T_3. T_2 and T_3 were significantly superior to

T_1 and T_4.

Nodule count at the mid pod filling stage showed an increase and it ranged from 3 in T_4 to 7 in T_2. T_2 recorded a significantly higher number of nodules compared to T_1 and T_4. At the harvest stage there was a reduction in the number of nodules per plant and it varied from 2 in T_1 to 6 in T_3. The number of nodules per plant in T_3 was significantly higher compared to T_1 and T_4.

Grain yield

Influence of different levels of exchangeable aluminium on grain yield is shown in Fig.2.

The weight of grain was significantly higher in T_3, compared to T_1, T_2 and T_4. It ranged from 0.80 in T_4 to 2.68 g/pot in T_3.

An increase in weight of husk was also noticed in all the three treatments receiving lime as compared to the control. The minimum weight of husk was noticed in T_1 (0.35 g/pot) and the maximum in T_3 (1.28 g/pot)

FIG. 2. INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON GRAIN YIELD OF COWPEA

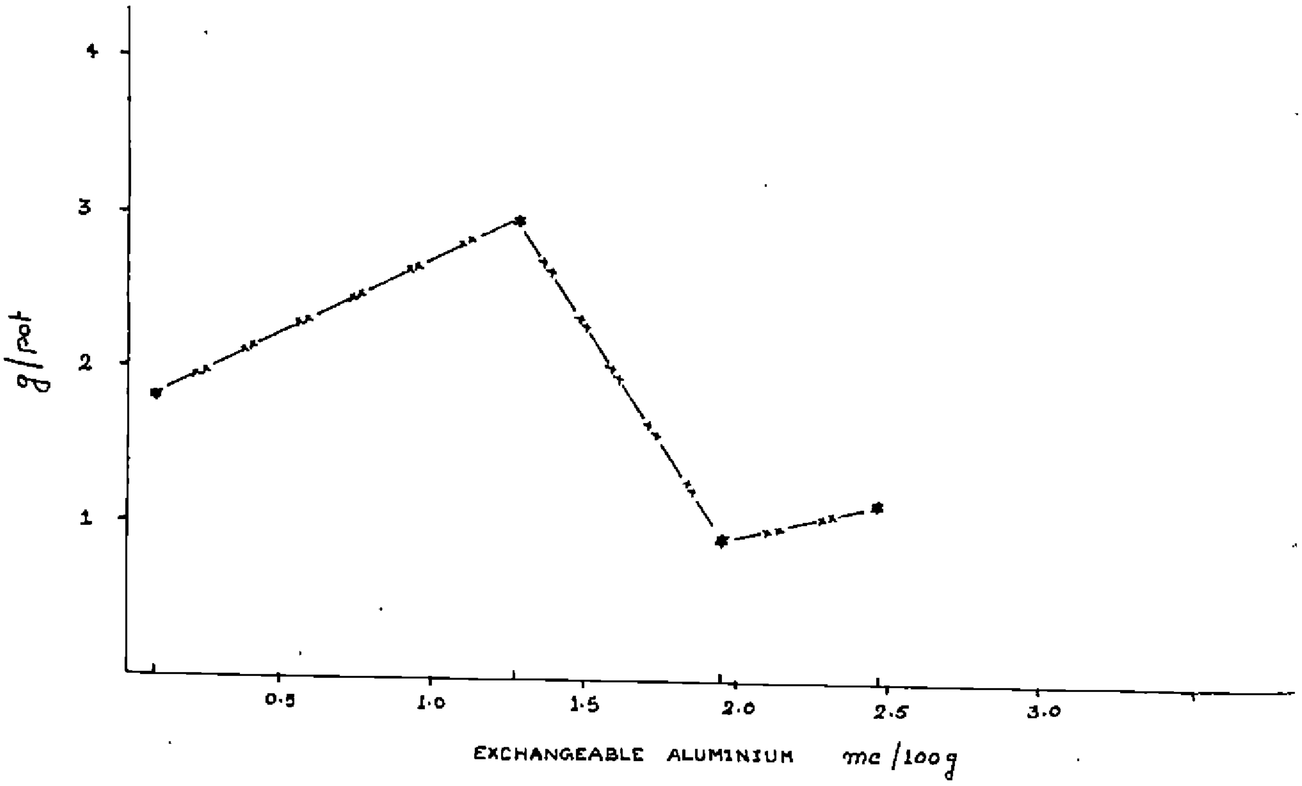
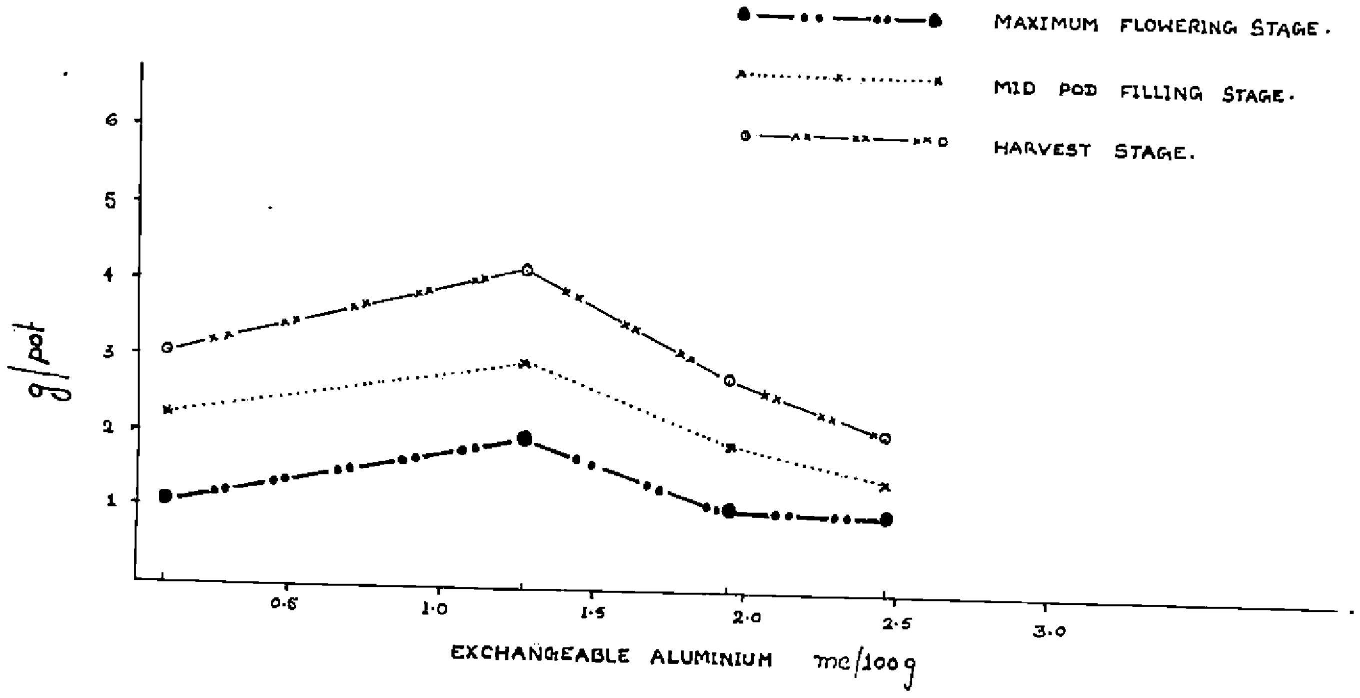


FIG. 3. INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON TOTAL DRY WEIGHT OF COWPEA



which was significantly higher compared to T_1, T_2 and T_4.

Total dry weight

Influence of different levels of exchangeable aluminium on total dry matter production is given in Fig.3.

At the maximum flowering stage of cowpea, maximum dry weight of 1.74 g was recorded in T_3 compared to other treatments T_1, T_2 and T_4 which were on par (1.03 g/plant).

At the mid pod filling stage, the total dry weight ranged from 1.47 in T_1 to 2.87 g/plant in T_3. T_3 recorded a significantly higher dry weight compared to T_1 and T_4.

The total dry weight from different treatments at harvest ranged from 3.60 in T_1 to 7.86 g/plant in T_3. T_3 recorded the highest value for total dry weight production compared to T_1, T_2 & T_3.

Nutrient composition

The data on the nutrient composition of cowpea at different stages of growth are presented in Table 7, Fig.4 and analysis of variance in Appendix II(a) and II(b).

Tops and roots.

Nitrogen

The nitrogen content of cowpea tops showed an increase with a decrease in exchangeable aluminium content at the maximum flowering stage. It ranged from 2.08 in T_1 to 3.20 percent in T_2. Nitrogen content in T_2 was significantly higher than in T_3, T_4 and T_1. But the nitrogen content in the root at the maximum flowering stage was significantly higher in T_3 when compared to T_1 and T_2. It was minimum (1.21 percent) in T_1 and T_2 and maximum (1.87 percent) in T_3.

The nitrogen content decreased at the mid pod filling stage where it ranged from 1.88 percent in T_1 to 2.54 percent in T_2. Plants receiving higher

Table 7 Influence of different levels of lime on nutrient composition of cowpea

Percent nitrogen

Treatment	Tops			Roots			Grain	Husk
	S_1	S_2	S_3	S_1	S_2	S_3		
T_1	2.08	1.88	1.78	1.21	1.22	0.96	3.22	0.54
T_2	3.20	2.54	1.99	1.21	1.51	1.09	3.50	1.02
T_3	2.31	2.53	1.81	1.87	1.40	1.03	3.77	1.33
T_4	2.10	2.18	1.78	1.74	1.33	1.02	3.48	0.78
CD	0.35	NS	NS	0.42	NS	NS	NS	0.25

Percent phosphorus

Treatment	Tops			Roots			Grain	Husk
	S_1	S_2	S_3	S_1	S_2	S_3		
T_1	0.21	0.22	0.17	0.33	0.28	0.29	0.53	0.22
T_2	0.22	0.28	0.23	0.43	0.28	0.35	0.57	0.31
T_3	0.23	0.23	0.20	0.38	0.35	0.29	0.68	0.40
T_4	0.22	0.20	0.19	0.38	0.32	0.29	0.55	0.34
CD	NS	0.03	0.02	NS	NS	NS	0.09	0.11

Table 7 (contd.)

Percent potassium

Treatment	Tops			Roots			Grain	Husk
	S_1	S_2	S_3	S_1	S_2	S_3		
T_1	2.29	3.07	2.86	0.09	0.13	0.18	1.59	1.79
T_2	3.62	2.88	2.78	0.10	0.12	0.16	1.45	1.54
T_3	2.88	2.53	2.66	0.10	0.11	0.18	1.71	1.65
T_4	2.67	2.98	2.78	0.09	0.08	0.18	1.39	1.79
CD	NS	NS	NS	NS	NS	NS	NS	NS

Percent calcium

Treatment	Tops			Roots			Grain	Husk
	S_1	S_2	S_3	S_1	S_2	S_3		
T_1	0.17	0.25	0.20	0.006	0.008	0.021	0.14	0.04
T_2	0.53	0.84	0.54	0.008	0.019	0.038	0.28	0.05
T_3	0.24	0.39	0.36	0.030	0.022	0.036	0.30	0.04
T_4	0.19	0.29	0.23	0.160	0.010	0.033	0.14	0.04
CD	0.03	0.13	0.09	0.006	0.005	0.012	0.05	0.01

Table 7 (contd.)

Percent magnesium

Treatment	Tops			Roots			Grain	Husk
	S_1	S_2	S_3	S_1	S_2	S_3		
T_1	0.20	0.23	0.24	0.07	0.08	0.07	0.11	0.22
T_2	0.22	0.24	0.25	0.11	0.09	0.12	0.14	0.20
T_3	0.22	0.24	0.26	0.08	0.09	0.09	0.15	0.27
T_4	0.20	0.23	0.25	0.08	0.08	0.08	0.12	0.25
CD	NS	NS	NS	0.02	NS	0.02	0.02	0.04

Iron content (ppm)

Treatment	Tops			Roots			Grain	Husk
	S_1	S_2	S_3	S_1	S_2	S_3		
T_1	3330	1920	820	2110	3330	2030	72	144
T_2	2160	1850	780	2570	4010	3270	98	175
T_3	980	990	510	3450	6140	2110	70	132
T_4	1190	1190	600	2430	7700	2860	120	299
CD	1260	NS	230	380	1590	1010	34	88

Table 7 (contd.)

Aluminium content (ppm)

Treatment	Tops			Roots			Grain	Husk
	S_1	S_2	S_3	S_1	S_2	S_3		
T_1	1170	1260	850	2093	4060	2695	189	355
T_2	830	1090	550	1236	3640	1180	140	256
T_3	800	1020	490	1273	3650	1260	113	238
T_4	840	1040	600	1327	3870	1720	186	318
CD	NS	NS	250	155	249	298	39	45

Zinc content (ppm)

Treatment	Tops			Roots			Grain	Husk
	S_1	S_2	S_3	S_1	S_2	S_3		
T_1	71	71	74	50	60	98	65	34
T_2	59	52	48	54	64	102	67	44
T_3	61	56	54	92	95	216	68	40
T_4	62	69	72	85	65	124	55	37
CD	NS	NS	18	NS	NS	66	NS	NS

Table 7 (contd.)

Copper content (ppm)

Treatment	Tops			Roots			Grain	Husk
	S_1	S_2	S_3	S_1	S_2	S_3		
T_1	15	15	14	9	9	15	5	10
T_2	15	12	15	10	8	15	16	12
T_3	16	12	15	7	12	11	15	12
T_4	14	15	15	9	12	14	11	11
CD	NS	NS	NS	NS	NS	NS	4	NS

levels of lime showed a comparatively higher amount of nitrogen. A similar trend was observed in the nitrogen content of root at this stage. It ranged from 1.22 in T_1 to 1.51 percent in T_2.

At harvest, compared to the other stages, the nitrogen content of cowpea (tops and roots) still decreased though the values for the different treatments did not differ significantly. The values ranged from 1.78 percent both in T_1 and T_4 to 1.99 percent in T_2 for tops and from 0.96 percent in T_1 to 1.09 percent in T_2 for roots.

Phosphorus

At the maximum flowering stage, values for phosphorus content in cowpea (tops) ranged from 0.21 percent in T_1 to 0.23 percent in T_3. The content of phosphorus in the various treatments was not much different. At this stage, the phosphorus content of the roots showed an increase with a reduction in exchangeable aluminium levels in soil, the maximum being 0.43 percent in T_2 and the minimum 0.33 percent in T_1.

At the mid pod filling stage, the phosphorus content of cowpea (tops) ranged from 0.20 in T_4 to 0.28 percent in T_2. T_2 recorded a significantly higher level of phosphorus compared to T_4, T_1 and T_3. The level of phosphorus in roots was maximum in T_3 (0.35 percent) and minimum in T_1 and T_2 (0.28 percent).

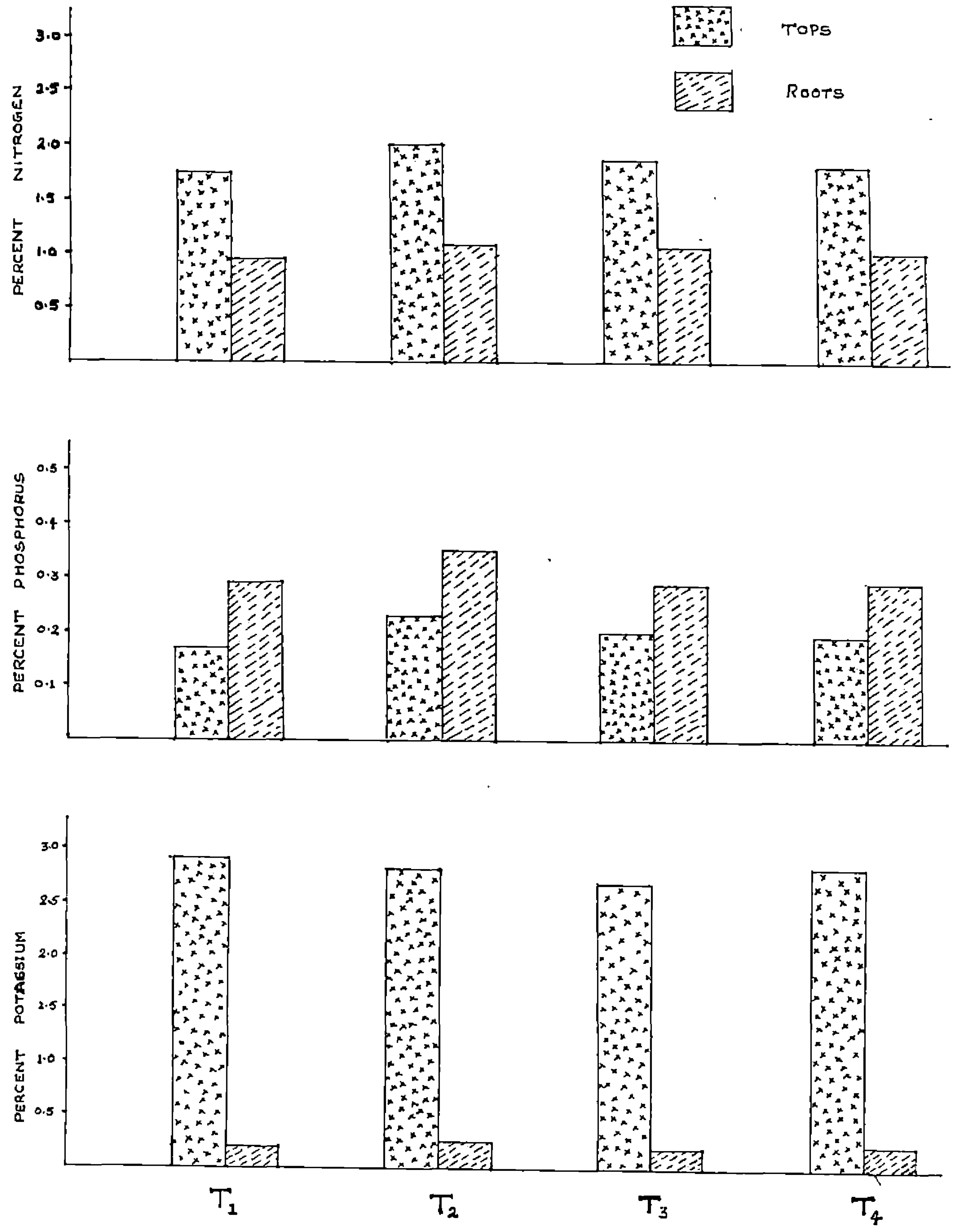
The phosphorus content of cowpea tops was minimum at harvest while the content of phosphorus in cowpea roots recorded an increase at this stage. Content of phosphorus in cowpea (tops) ranged from 0.17 in T_1 to 0.23 percent in T_2. T_2 recorded a significantly higher phosphorus content compared to T_3, T_4 and T_1. In roots the phosphorus content ranged from 0.29 percent in T_1, T_3 and T_4 to 0.35 percent in T_2.

Potassium

The content of potassium in both cowpea tops and roots at different stages did not show any significant variation between treatments.

At the maximum flowering stage, the level of potassium in tops varied from 2.29 in T_1 to 3.62 percent

FIG. 4 INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON NUTRIENT CONTENT OF COWPEA AT HARVEST



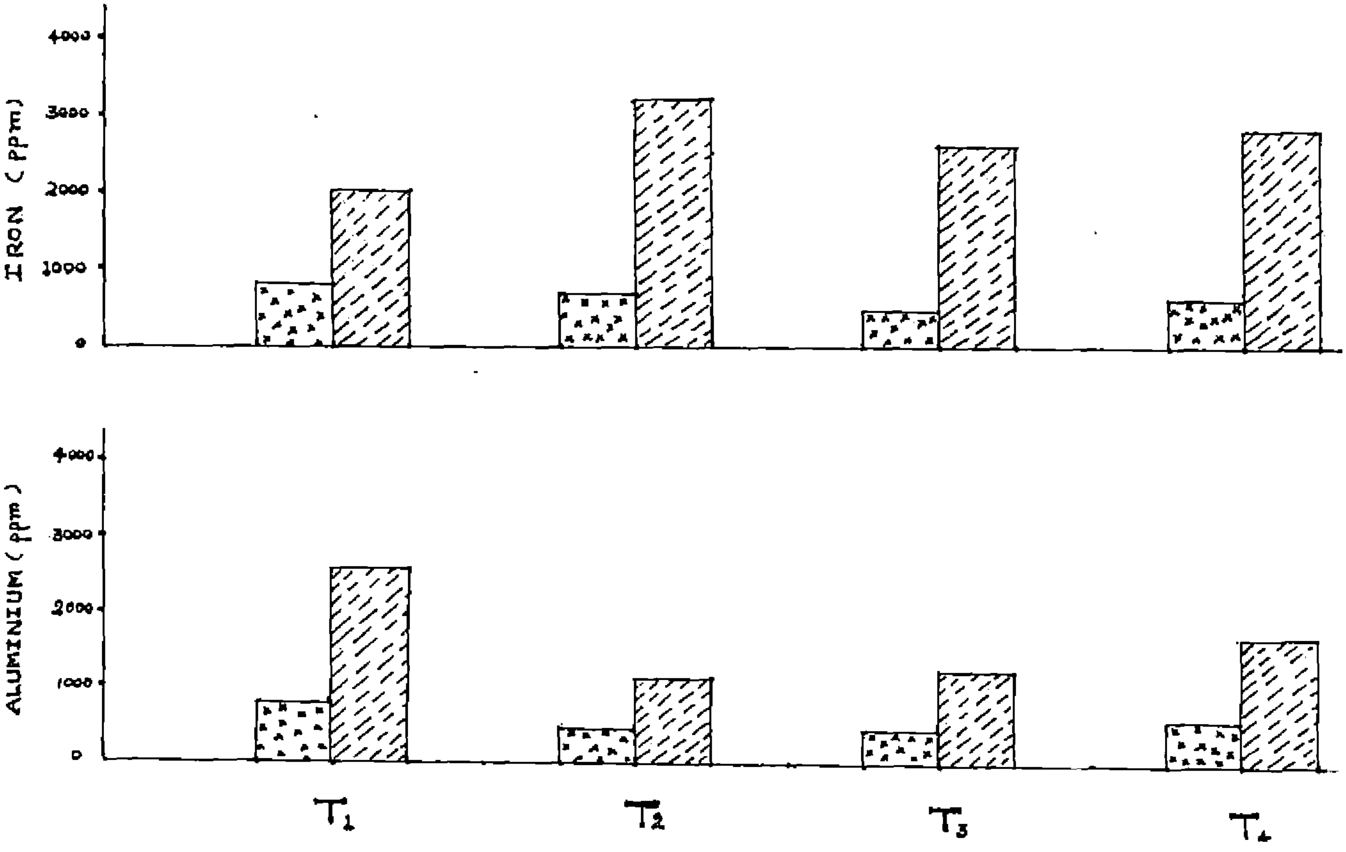
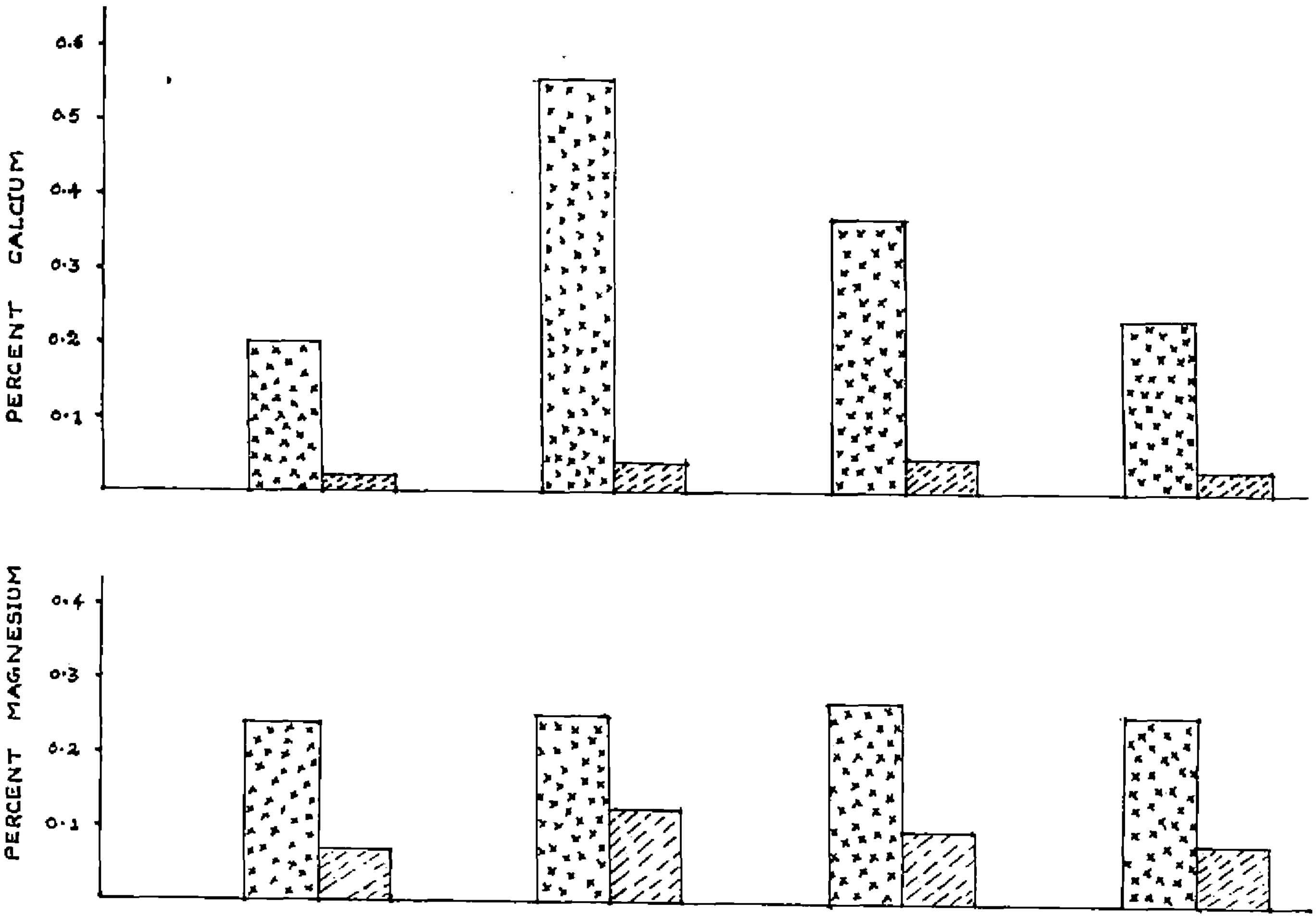

IRON (ppm)
4000
3000
2000
1000
0
ALUMINIUM (ppm)
4000
3000
2000
1000
0
T_1
T_2
T_3
T_4

FIG-4 contd..


PERCENT CALCIUM
0.6
0.5
0.4
0.3
0.2
0.1
PERCENT MAGNESIUM
0.4
0.3
0.2
0.1

in T_2 and the corresponding values in the roots varied from 0.09 in T_1 and T_4 to 0.10 percent in T_2 and T_3.

At the mid pod filling stage, the content of potassium ranged from 2.53 in T_3 to 3.07 percent in T_1 in tops and from 0.08 percent in T_4 to 0.13 percent in T_1 in roots.

At harvest, the highest value noted in tops was 2.86 percent for T_1 and lowest for T_3 being 2.66 percent. For roots the values ranged from 0.16 in T_2 to 0.18 percent in T_1, T_4 and T_3.

Calcium

A highly significant increase in calcium content was noticed in cowpea tops at all the three stages with a corresponding decrease in exchangeable aluminium and an increase in the lime levels. At the maximum flowering stage, the content of calcium ranged from 0.17 in T_1 to 0.53 percent in T_2 which has recorded a significantly higher value for calcium. However calcium content in roots at this stage ranged from

0.006 in T_1 to 0.03 percent in T_3. Content of calcium in T_3 was found to be significantly higher than the other treatments T_2, T_4 and T_1.

The content of calcium in the cowpea tops further showed an increasing trend towards the mid pod filling stage, the maximum being recorded in T_2 (0.84 percent) and the minimum in T_1 (0.25 percent). The level of calcium in roots at this stage ranged from 0.008 in T_1 to 0.022 percent in T_3.

At harvest, the content of calcium in tops showed a tendency to decrease compared to that at the mid pod filling stage. It ranged from 0.20 in T_1 to 0.54 percent in T_2. T_2 was found to be significantly superior compared to T_3, T_4 and T_1. The content of calcium in roots at this stage ranged from 0.021 in T_1 to 0.038 percent in T_2 which was significantly higher than T_1.

Magnesium

The content of magnesium in cowpea tops at different stages did not show any marked variation between treatments. It ranged from 0.20 in T_1 and T_4 to 0.22 percent in T_3 and T_2 at the maximum flowering stage, 0.23 in T_1 and T_4 and 0.24 percent in T_2 and T_3 at the mid pod filling stage and 0.24 in T_1 to 0.26 percent in T_3 at harvest whereas in cowpea roots a significantly high content of magnesium was recorded in T_2 (0.11 percent) at the maximum flowering stage. The level of the nutrient at this stage varied from 0.07 percent in T_1 to 0.11 percent in T_2. At the mid pod filling stage, the magnesium content of roots varied from 0.08 in T_1 and T_4 to 0.09 percent in T_2 and T_3. The variation between treatments was not significant.

At harvest a significantly higher content of magnesium was noticed in roots of treatment T_2 (0.12 percent) compared to T_3, T_4 and T_1. At this stage, T_1 recorded the lowest value of 0.07 percent magnesium.

Iron

At the maximum flowering stage, the content of iron in cowpea tops ranged from a minimum of 930 in T_3 to a maximum of 3330 ppm in T_1. The treatment T_3 has significantly reduced the iron content in cowpea tops compared to T_1, T_4 and T_2. But it may be noted that a reduction in exchangeable aluminium content in soil by liming has resulted in an accumulation of more iron in the roots of plants in the limed pots than in control. The level of iron in cowpea roots varied from 2110 in T_1 to 3450 ppm in T_3. T_3 showed a significantly higher amount of iron in the roots than in T_1, T_2 and T_4.

At the mid pod filling stage, eventhough the level of iron in cowpea tops registered a decrease, compared to the previous stage, it was not appreciably different in the different treatments. It ranged from the lowest value of 990 in T_3 to the highest value of 1920 ppm in T_1. At this stage, the value for iron in the roots varied from 3330 in T_1 to 7700 ppm in T_4 which was significantly higher than that in T_1, T_2 and T_3.

The content of iron in both cowpea tops and roots decreased further at harvest. A minimum value of 510 ppm in T_3 and a maximum of 820 ppm in the control was observed in tops. In roots the maximum content of iron was noticed in T_2 (3270 ppm) which was significantly higher than that in T_1, T_2 and T_3. The lowest value recorded was 2030 ppm in T_1.

Aluminium

The content of aluminium in the top at the maximum flowering stage was lowest (800 ppm) in T_3 and highest (1170 ppm) in T_1. None of the treatments could produce a significant reduction in aluminium concentration. A low level of exchangeable aluminium in the soil, reduced the accumulation of aluminium in the top. However, at this stage, the content of aluminium in roots showed a significant linear reduction with a reduction in aluminium content in soil. The values ranged from 1236 in T_2 to 2093 ppm in T_1.

At the mid pod filling stage the content of aluminium slightly increased in both tops and roots. Aluminium content in tops ranged from 1020 ppm in T_3 to 1260 ppm in T_1. None of the treatments could produce a significant reduction in aluminium content of the top at this stage also. The different lime levels among themselves also did not show any significant difference in reducing the accumulation of aluminium in roots. The treatment T_4 accumulated almost equal amount of aluminium (3870 ppm) in root compared to control.

The level of aluminium in the plant tops and roots further decreased and was minimum at harvest. It may be noted that the content of aluminium in tops was highest in T_1 (850 ppm) and lowest in T_3 (490 ppm). Significant reduction in aluminium content was noticed in T_3 alone compared to the control (T_1).

A drastic and significant reduction in the build up of aluminium in the roots was observed at harvest. A low level of exchangeable aluminium in the soil has significantly reduced the accumulation of aluminium in root. Values for aluminium content in root of this stage ranged from 1180 in T_2 to 2695 ppm in T_1.

Zinc

Generally the content of zinc in cowpea tops showed a reduction due to the lowering of exchangeable aluminium level in soil. The content ranged from 59 in T_2 to 71 ppm in T_1 at the maximum flowering stage, from 52 in T_2 to 71 ppm in T_1 at the mid pod filling stage and at harvest T_2 recorded a significantly lower value of 43 compared to 74 ppm in control.

In the case of cowpea roots, the level of zinc ranged from 50 in T_1 to 92 ppm in T_3 at the maximum flowering stage and from 60 in T_1 to 95 ppm in T_3 at the mid pod filling stage. But the content of zinc in the different treatments did not show any appreciable difference. The zinc content increased towards harvest and the maximum amount of 216 ppm was observed in T_3, and the lowest content of 93 ppm in T_1.

Copper

The content of copper in cowpea tops and roots did not show any marked difference between treatments and between stages. The value in cowpea tops varied between 12 and 16 ppm in the different treatments at different stages. In cowpwa roots also it was more or less uniform (7 to 15 ppm) at the three stages in all the treatments.

b) Grain and husk

The data on the nutrient composition of grain and husk are given in Table 7, Fig.5 and analysis of variance in Appendix II(c).

Nitrogen

The nitrogen content of the grain was not significantly affected by the different treatments (eventhough it showed a variation in the different treatments). It ranged from the lowest value of 3.22 in T_1 to 3.77 percent in T_3. But the nitrogen content of the husk showed a difference in the different treatments. The level of nitrogen in the husk ranged from the lowest value of 0.54 in T_1 to the highest value of 1.33 percent in T_3. Treatment T_3 recorded a significantly higher content of nitrogen compared to T_1, T_2 and T_4.

Phosphorus

The phosphorus content of the grain in the different treatments ranged from 0.53 in T_1 to 0.68 percent in T_3 and was significantly higher than that in

T_1, T_2 and T_4.

The content of phosphorus in the husk was comparatively lower and it ranged from 0.22 percent in T_1 to 0.40 percent in T_3 which was significantly higher than in other treatments.

Potassium

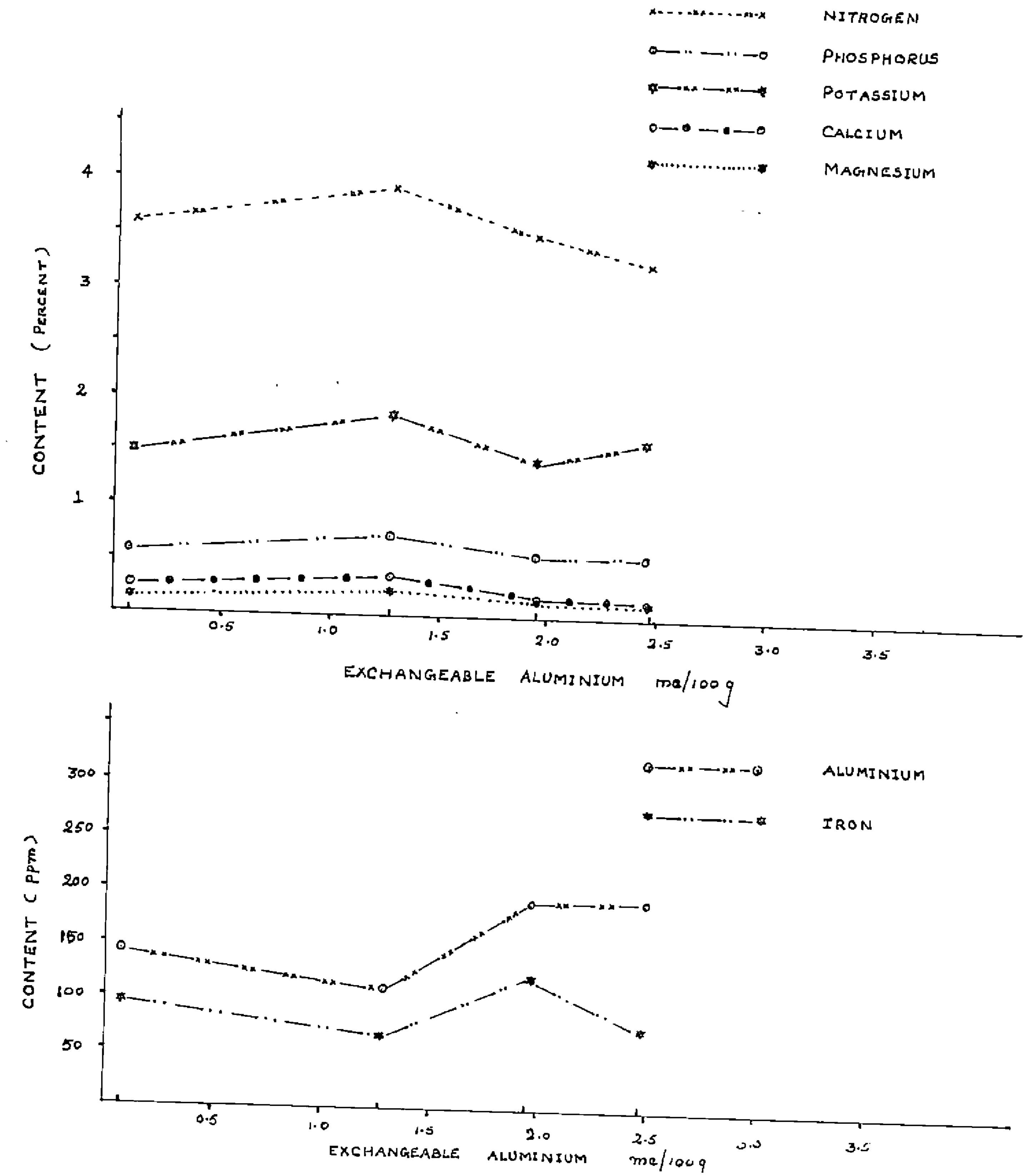
The content of potassium in both grain and husk did not show any marked variation due to the different treatments. The value of potassium in the grain ranged from 1.39 in T_4 to 1.71 percent in T_3.

In the husk, the lowest value of potassium was noted for T_2 (1.54 percent) and the highest for T_1 and T_4 (1.79 percent).

Calcium

A clear and significant difference in the calcium content of grain was noted in all the treatments. The amount of calcium present in the grain in the differently treated pots ranged from 0.14 percent in T_1 and T_4 to 0.30 percent in T_3 which recorded a significantly

FIG.5. INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON NUTRIENT CONTENT OF COWPEA GRAINS.



higher value when compared to T_1 and T_4. The level of calcium in the husk ranged from 0.04 percent in T_1, T_3 and T_4 to 0.05 percent in T_2 which was significantly higher than other treatments.

Magnesium

A significantly higher amount of magnesium was present in the grain in T_3, compared to T_1 and T_4 and the values ranged from 0.11 percent in T_1 to 0.15 percent in T_3.

The magnesium content of husk was highest in T_3 (0.27 percent) and lowest in T_2 (0.20 percent). A significantly higher content of magnesium was present in the treatment T_3 compared to T_1 and T_2.

Iron

The level of iron in cowpea grains ranged from 70 ppm in T_3 to 120 ppm in T_4. It was significantly lower in the treatment T_3 compared to T_4.

The content of iron in the husk ranged from 132 ppm in T_3 to 299 ppm in T_4. Here also the iron content was significantly lower in T_3 compared to T_4.

Aluminium

The content of aluminium in grain in the different treatments showed a reduction with a decrease in exchangeable aluminium content in the soil. The level of aluminium in the grain recorded the lowest value of 113 ppm in T_3 and the highest value of 189 ppm in T_1. Significant reduction in the aluminium content was observed in T_3 compared to T_1 and T_4.

The aluminium content in the husk from the different treatments also showed a similar trend. It was highest in the control (355 ppm) and in the other treatments it ranged from 238 ppm in T_3 to 318 ppm in T_4. T_3 was found to be significantly effective in reducing the aluminium content of the husk compared to T_1 and T_4.

Zinc

The content of zinc in the grain did not exhibit any significant variation between the different treatments. The values ranged from 55 ppm in T_4 to 68 ppm in T_3.

In the husk also, the zinc content did not show any significant difference between treatments, while it showed an increasing trend with a decrease in exchangeable aluminium brought about by higher levels of lime. The levels of zinc ranged from 34 ppm in T_1 to 44 ppm in T_2.

Copper

The copper content in the grain ranged from 5 ppm in T_1 to 16 ppm in T_2. The content of copper in the husk in the different treatments did not show any significant variation. However, it showed an increasing trend with an increase in levels of lime and a consequent decrease in exchangeable aluminium. The values ranged from 10 ppm in control (T_1) to 12 ppm in T_2 and T_3.

Experiment II.

Pot culture studies with fodder maize.

Influence of different levels of lime on soil properties

Soil reaction

The mean values of the pH of the soils at different stages of sampling in the different treatments are given in Table 8 and analysis of variance in Appendix III(a).

After the application of fertilizers a rise in pH was noticed and the pH ranged from 4.5 in T_1 to 6.3 in T_2. pH in T_2 was found to be significantly higher than the pH in T_1, T_3 and T_4.

At thirty days after planting the pH of the soil increased further and the values ranged from 5.1 in T_1 to 6.4 in T_2. The pH in T_2 was significantly higher than T_1, T_3 and T_4.

At sixty five days after sowing, not much change in pH was noticed compared to previous stage. The pH at this stage ranged from 5.2 in T_1 to 6.4 in T_2.

At fodder harvest, after ninety days of sowing, the values for pH showed a decreasing trend in all the treatments compared to the other two stages. The pH at this stage ranged from 5.0 in T_1 to 6.3 in T_2 and it was significantly higher compared to the other treatments T_1, T_3 and T_4.

Table 8 Influence of different levels of lime on soil properties (crop-fodder maize)

Soil reaction (pH)

Treatment	S_{00}	S_0	S_1	S_2	S_3
T_1	4.1	4.5	5.1	5.2	5.0
T_2	6.2	6.3	6.4	6.4	6.3
T_3	4.7	5.3	5.4	5.5	5.2
T_4	4.4	4.9	5.2	5.3	4.9
CD	0.11	0.22	0.26	0.25	0.54

Total acidity (me/100 g soil)

Treatment	S_{00}	S_0	S_1	S_2	S_3
T_1	2.94	2.29	1.47	0.57	0.93
T_2	0.49	0.41	0.34	0.23	0.29
T_3	1.73	1.16	0.49	0.49	0.57
T_4	2.45	1.80	0.98	0.49	0.92
CD	0.21	0.46	0.05	0.14	0.33

Table 8 (contd.)

Exchangeable aluminium (me/100 g soil)

Treatments	S_{00}	S_0	S_1	S_2	S_3
T_1	2.45	1.65	0.74	0.25	0.50
T_2	0.08	0.04	0.03	0.02	0.02
T_3	1.26	0.50	0.25	0.19	0.25
T_4	1.98	0.99	0.49	0.25	0.41
CD	0.27	0.27	0.01	0.01	0.15

Exchangeable hydrogen (me/100 g soil)

Treatments	S_{00}	S_0	S_1	S_2	S_3
T_1	0.49	0.64	0.73	0.32	0.49
T_2	0.40	0.45	0.31	0.21	0.19
T_3	0.47	0.66	0.24	0.29	0.35
T_4	0.47	0.81	0.49	0.25	0.41
CD	NS	NS	0.05	NS	0.20

Table 8 (contd.)

Exchangeable potassium (me/100 g soil)

Treatments	S_{00}	S_0	S_1	S_2	S_3
T_1	0.48	0.59	0.44	0.26	0.23
T_2	0.49	0.58	0.51	0.27	0.25
T_3	0.44	0.61	0.45	0.27	0.30
T_4	0.45	0.67	0.43	0.27	0.27
CD	NS	NS	NS	NS	NS

Exchangeable calcium (me/100 g soil)

Treatments	S_{00}	S_0	S_1	S_2	S_3
T_1	0.35	0.42	1.32	1.37	0.82
T_2	11.92	8.74	6.82	5.49	6.61
T_3	0.88	0.93	1.66	1.45	1.37
T_4	0.53	0.55	1.40	1.62	1.08
CD	0.24	0.78	0.62	0.56	0.71

Table 8 (contd.)

Exchangeable magnesium (me/100 g soil)

Treatment	S_{00}	S_0	S_1	S_2	S_3
T_1	1.02	0.93	0.67	0.72	0.55
T_2	1.16	0.95	0.74	0.67	0.65
T_3	1.10	0.97	0.75	0.62	0.72
T_4	1.07	0.90	0.75	0.75	0.71
CD	NS	NS	NS	NS	0.11

Exchangeable iron (ppm)

Treatments	Before cultivation	After cultivation
T_1	13	4
T_2	6	0
T_3	10	2
T_4	11	3
CD	1	1

Total acidity

The total acidity as influenced by the different levels of lime is given in Table 8 and analysis of variance in Appendix III(b).

A reduction in total acidity was observed in all the treatments due to the application of fertilizers. The values ranged from 0.41 in T_2 to 2.29 me/100 g of the soil in T_1. Total acidity in T_2 was significantly lower than that in T_3, T_4 and T_1.

At thirty days after sowing, the total acidity was lowered and recorded a minimum value of 0.34 in T_2 and a maximum of 1.47 me/100 g in T_1. Total acidity was reduced to a significantly lower value in the treatment T_2. Sixty five days after sowing, the values for the total acidity showed a decreasing trend and it ranged from 0.23 in T_2 to 0.57 me in T_1. Total acidity in the soil was reduced to a significantly lower level in T_2 compared to T_1, T_3 and T_4.

At fodder harvest, the values for total acidity in the soil showed an increasing trend against the decreasing trend observed in the previous stages. The total acidity varied between 0.20 in T_2 and 0.98 me/100 g of the soil in T_1. Total acidity in T_2 was significantly lower compared to T_3, T_4 and T_1.

Exchangeable aluminium

The influence of different levels of lime on the exchangeable aluminium content of the soil is given in Table 8 and analysis of variance in Appendix III(c).

The exchangeable aluminium content was maximum in T_1 (2.45 me/100 g) and was minimum in T_2 (0.03 me). Percentage aluminium saturation at this stage ranged from 1.64 in T_2 to the highest value of 46.28 in T_1. Exchangeable aluminium content and the percentage aluminium saturation values were lowest in T_2 compared to T_3, T_4 and T_1. A reduction in the exchangeable aluminium content was observed after the application of fertilizers and the values ranged from 0.04 in T_2 to 1.65 me in T_1. Percentage aluminium saturation at this stage was negligible in T_2 while it was 31.13 in T_1.

A decreasing trend was observed for both exchangeable aluminium and percentage aluminium saturation at thirty and sixty five days after sowing.

Exchangeable aluminium content and percentage aluminium saturation showed a slight increase towards the harvest stage. The values for exchangeable aluminium ranged from 0.02 in T_2 to 0.50 me in T_1. The exchangeable aluminium content and percentage aluminium saturation values in T_2 was much lower compared to T_3, T_4 and T_1.

Exchangeable hydrogen

The mean values of the exchangeable hydrogen content of the soil at different lime level is presented in Table 8 and analysis of variance in Appendix III(d).

The variation in exchangeable hydrogen in the different treatments was not found to be significant although it varied from 0.40 in T_2 to 0.49 me/100 g in T_1.

After the application of fertilizers the values for exchangeable hydrogen showed a slight increase and it varied from 0.45 in T_2 to 0.81 me in T_4.

At thirty days after sowing the values for exchangeable hydrogen still decreased in the lime treated soils and the values ranged from 0.24 in T_3 to 0.73 me/100 g in T_1. Exchangeable hydrogen content was significantly lower in T_3 than in T_1, T_2 and T_4.

With the progressive increase in the growth of maize (after 65 days) the exchangeable hydrogen decreased to a lower value in the limed pots than in unlimed pots. The values ranged from 0.21 in T_2 to 0.32 me in T_1. However, this reduction was not significant.

At fodder harvest, exchangeable hydrogen values ranged from 0.18 in T_2 to 0.49 me/100 g in T_1 and the treatment T_2 recorded a significantly lower content of exchangeable hydrogen than the treatments T_3, T_4 and T_1.

Exchangeable potassium

The mean values for the exchangeable potassium content in soil are given in Table 8 and analysis of variance in Appendix III(e). Different levels of lime did not produce any significant change in the exchangeable potassium content of the soil. It ranged from 0.44 in T_3 to 0.49 me/100 g of the soil in T_2. Higher amount of exchangeable potassium was noticed in all treatments after the application of fertilizers, where the values varied from 0.58 in T_2 to 0.67 me/100 g in T_4.

At thirty days after sowing, a reduction in the exchangeable potassium content of soils was observed. But this reduction was not significant in any of the treatments. The content of exchangeable potassium in the soil at this stage ranged from 0.43 in T_4 to 0.51 me/100 g in T_2.

At 65 days after sowing the exchangeable potassium content still exhibited a decreasing trend and it ranged from 0.26 in T_1 to 0.27 me/100 g in T_3, T_2 and T_4.

At fodder harvest, the content of exchangeable potassium in the soil recorded values varied from 0.23

in T_1 to 0.30 me in T_3.

Exchangeable calcium

The mean values for exchangeable calcium in soils at different lime levels are given in Table 8 and the analysis of variance in Appendix III(f).

Application of lime resulted in a significant increase in the content of exchangeable calcium of the soil. It recorded a maximum value of 11.92 in T_2 and a minimum of 0.35 me in T_1. A significantly higher amount of exchangeable calcium was present in T_2 than in T_3, T_4 and T_1.

Exchangeable calcium recorded a slight increase after the application of fertilizers in all the treatments except in T_2 where it was reduced to 8.74 me/100 g from the original value of 11.92.

At thirty days after sowing, exchangeable calcium content of all the soils showed a further increase except in the treatment T_2 where it was reduced to 6.82 me. In the other treatments, it was much lesser and ranged from 1.32 in T_1 to 1.66 in T_3.

At 65 days after sowing, the level of exchangeable calcium was significantly higher in T_2. It showed a slight decrease in treatments T_3 and T_2. The values ranged from 1.37 in T_1 to 5.49 me in T_2. At fodder harvest stage, the exchangeable calcium content of the soil showed a reduction in T_1, T_3 and T_4 while a slight increase was observed in the case of T_2. The values for exchangeable calcium at this stage varied from 0.82 in T_1 to 6.61 me/100 g of soil in T_2.

Exchangeable magnesium

The mean values for the content of exchangeable magnesium in the soil are presented in Table 8 and the analysis of variance in Appendix III(g).

Exchangeable magnesium content of the soil showed an increase with increase in levels of lime and the values ranged from 1.02 in T_1 to 1.16 me/100 g of soil in T_2. The exchangeable magnesium of the different treatments was not significantly different.

It showed a decrease after the application of fertilizers as well as with the progress in the growing period of fodder maize. The values ranged from 0.67 in T_1 to 0.75 me/100 g in T_3 at 30 days after sowing, from 0.62 in T_3 to 0.75 in T_4 at 65 days after sowing and from 0.55 in T_1 to 0.72 me/100 g in T_3 at the time of harvest.

Exchangeable iron

The mean values of exchangeable iron content in the soil before and after cultivation of fodder maize are given in Table 8 and the analysis of variance in Appendix III(h).

It may be seen that considerable reduction in exchangeable iron occurred due to the application of different levels of lime. It was significantly different among the different treatments and T_2 recorded the minimum of 6 ppm iron.

After cultivation of fodder maize, the level of exchangeable iron decreased considerably and it was completely absent in T_2.

Biometric observations

The mean values of plant characters as influenced by different levels of exchangeable aluminium in the soil are presented in Table 9 and the analysis of variance in Appendix IV.

Height of the plant

Influence of different levels of exchangeable aluminium on plant height is shown in Fig.6.

Different levels of lime did not show any significant effect in increasing the height of plant over the control. However, the height of fodder maize plants at thirty days after sowing ranged from 36.0 in T_2 to 57.7 cm in T_4.

Height of the plants showed an increasing trend at the 65th day after sowing and the average height at this stage varied from 83.7 in T_2 to 91.7 cm in T_3. The difference between various treatments was not significant.

Plant height was maximum at 90th day after sowing and it ranged from 104.3 cm in T_2 to 118.0 cm

Table 9 Influence of different levels of lime on plant characters of fodder maize

Treatment	Height of the plant (cm)			Weight of tops (g)	Root length (cm)	Root weight (g)	Total dry weight (g)
	30 DAS	65 DAS	90 DAS				
T_1	45.7	83.7	105.7	40.40	26.5	32.80	73.20
T_2	36.0	85.0	104.3	94.63	41.7	58.03	152.47
T_3	56.7	91.7	118.0	64.93	41.4	51.73	116.67
T_4	57.7	90.7	116.7	64.77	31.8	37.47	102.13
CD	NS	NS	NS	29.58	7.7	17.17	30.27

FIG. 6. INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON FODDERMAIZE AT HARVEST

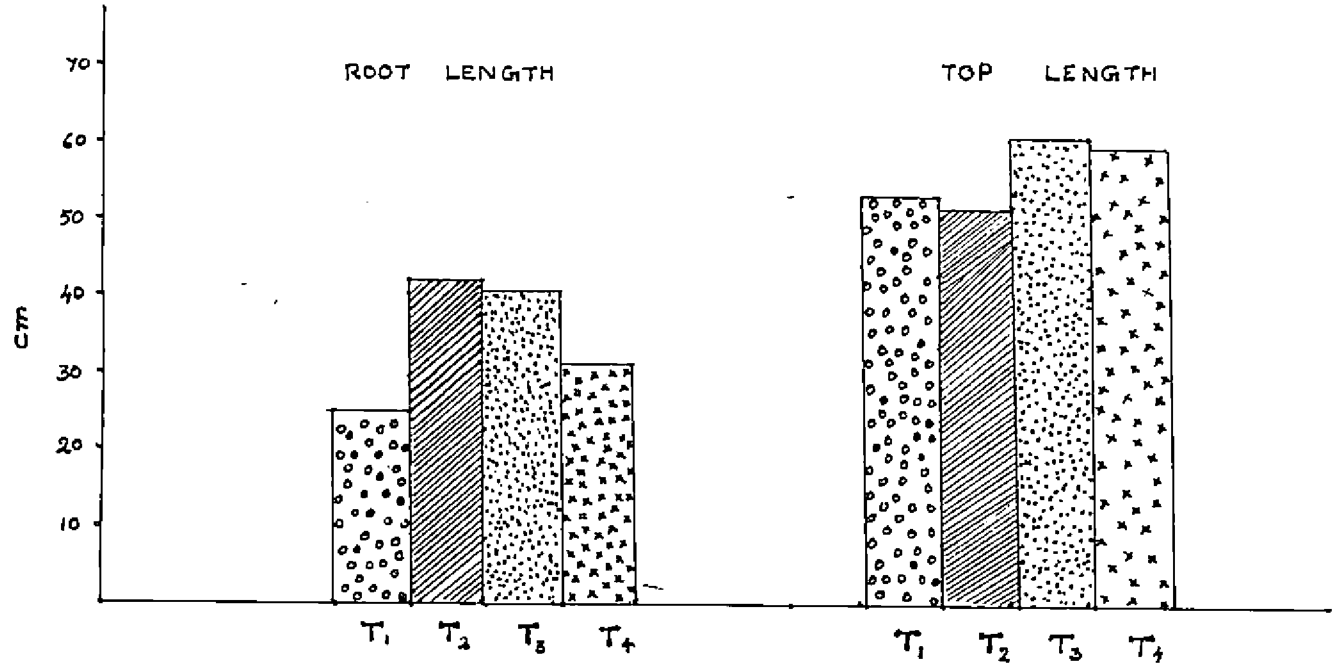
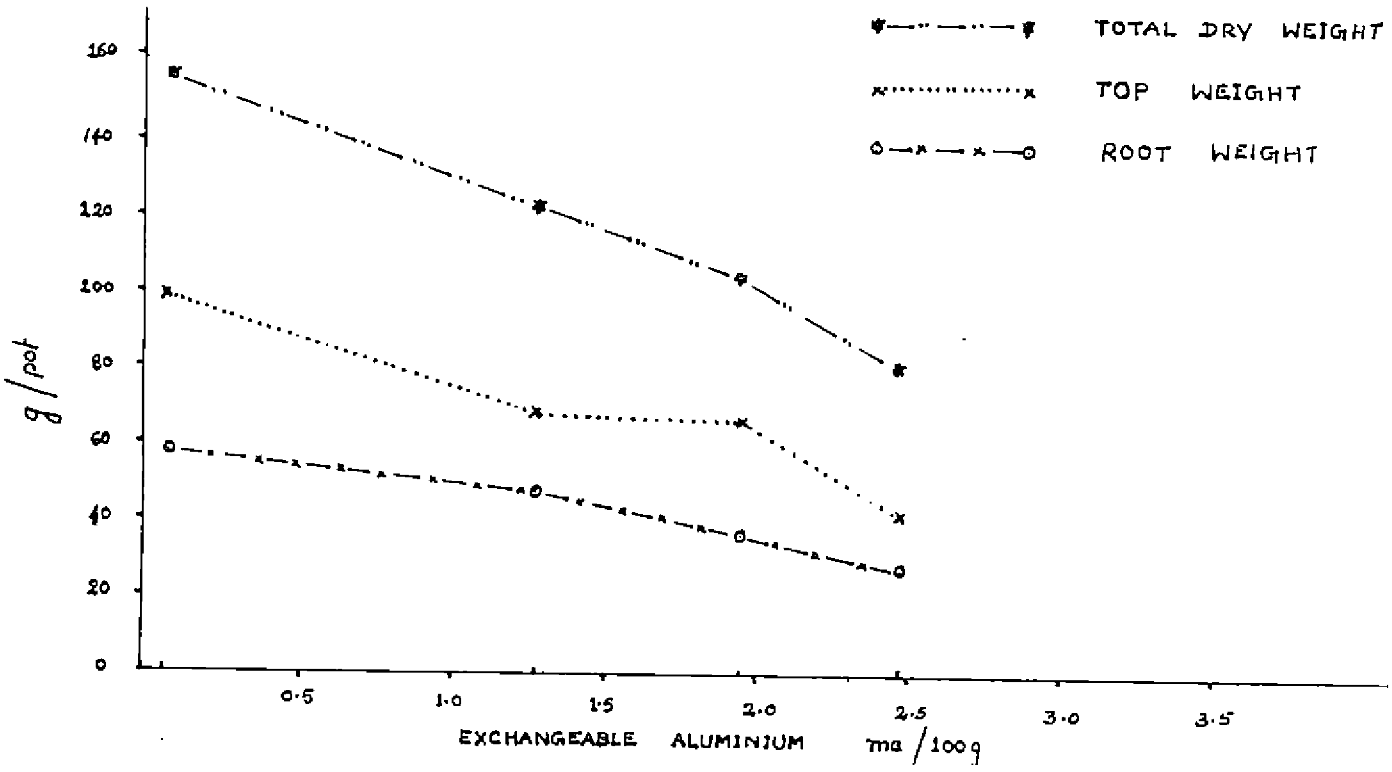


FIG. 7. INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON THE FODDER YIELD OF MAIZE.



in T_3. But none of the treatments could produce a significant increase in height of the plants over the control. Plants in T_1 and T_4 where a higher level of exchangeable aluminium was present showed interveinal chlorosis and at later stages dark brown streaks were found along the margins of the outer leaf.

Root length

Influence of different levels of exchangeable aluminium on root length is shown in Fig.6 and Plate 2.

At the time of fodder harvest a significant increase in the length of root was observed in the treatment T_2 (41.7 cm) and T_3 (41.4 cm) compared to the control (26.5 cm). The length of root recorded in T_4 was 31.8 cm which was on par with T_1.

Weight of tops and roots

Influence of different levels of exchangeable aluminium on the weight of tops and roots are shown in Fig.7.

Decreased exchangeable aluminium content in the

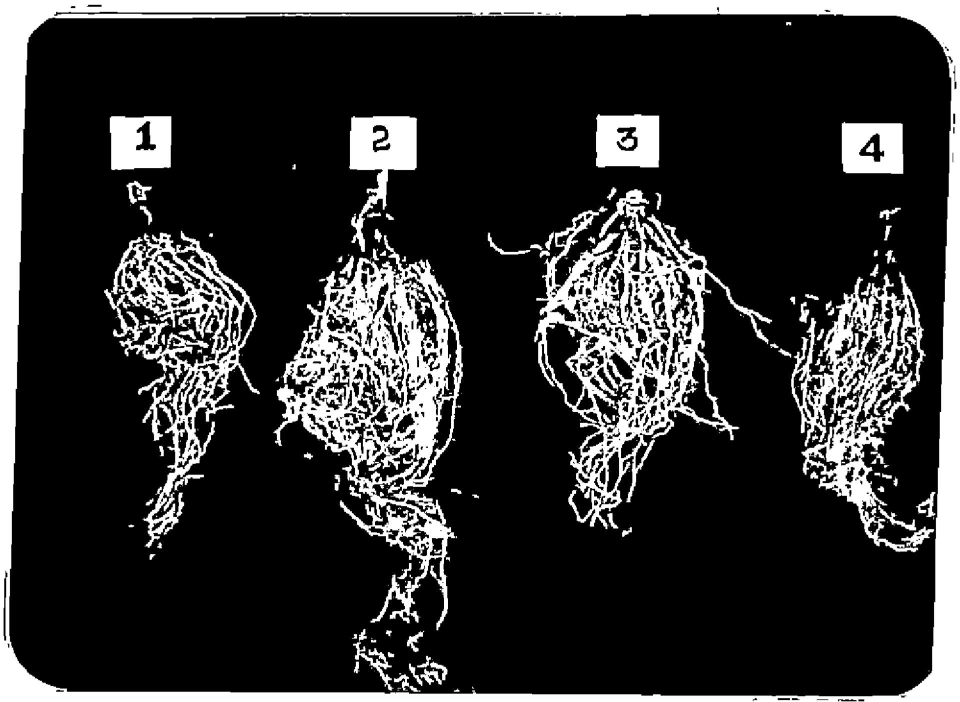


PLATE. 2. INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON ROOT GROWTH OF FODDER MAIZE

soil has increased the weight of tops in fodder mai at harvest stage. The values ranged from 40.40 in T_1 to 94.63 g in T_2. A significantly higher top weight was observed in T_2 compared to T_1, T_3 and T_4.

A significantly higher root weight was recorded with T_2 (58.03 g) and T_3 (51.73 g) over the control (32.80 g). The treatment T_4 produced roots weighing 37.47 g per plant which was on par with T_1.

Total dry weight production

Influence of different levels of exchangeable aluminium on total fodder yield of maize is shown in Fig.7.

Significant increase in the total dry matter production at harvest on 90th day after sowing was observed with a decrease in exchangeable aluminium content of soil due to liming. The total dry matter ranged from 73.20 g in control to 152.47 g in T_2, where T_2 recorded a significantly higher value compared to T_1, T_3 and T_4.

Nutrient composition

The data on the nutrient composition of fodder maize is given in Table 10 and Fig.8 and analysis of variance in Appendix V.

Nitrogen

No significant effect on the nitrogen content in the maize top was observed between treatments eventhough the values varied from 0.69 in T_4 to 0.82 percent in T_3. A similar trend was noticed in roots also where the values varied from 0.77 in T_1 to 0.88 in T_3.

Phosphorus

No significant difference between treatments was observed for the phosphorus content in the tops and roots of fodder maize. Treatments T_2 and T_3 recorded the highest value (0.20 percent) and T_1 the lowest (0.18 percent). In roots the values varied from 0.19 in T_1, T_2 and T_4 to 0.20 percent in T_3.

Potassium

The content of potassium in fodder maize top

Table 10 Influence of different levels of lime on nutrient composition of fodder maize

Treatments	N		P		K		Ca		Mg		Fe		Al		Zn		Cu	
	Tops %	Roots %	Tops %	Roots %	Tops %	Roots %	Tops %	Roots (ppm)	Tops %	Roots (ppm)	Tops (ppm)	Roots (ppm)	Tops (ppm)	Roots (ppm)	Tops (ppm)	Roots (ppm)	Tops (ppm)	Roots (ppm)
T_1	0.76	0.77	0.18	0.19	1.07	0.45	0.16	9	0.12	200	2360	2280	850	3610	26	43	6	12
T_2	0.77	0.78	0.20	0.19	1.49	0.85	0.35	46	0.13	484	1170	2940	690	2920	16	42	4	13
T_3	0.82	0.88	0.20	0.20	1.38	0.67	0.29	28	0.13	216	740	3480	600	3060	36	43	6	14
T_4	0.69	0.82	0.19	0.19	1.28	0.46	0.21	19	0.12	202	760	2760	690	3160	28	53	7	12
CD	NS	NS	NS	NS	0.23	0.25	0.07	6	NS	96	260	NS	150	47	13	NS	2	NS

FIG. 8. INFLUENCE OF DIFFERENT LEVELS OF EXCHANGEABLE ALUMINIUM ON NUTRIENT CONTENT OF FODDER MAIZE.

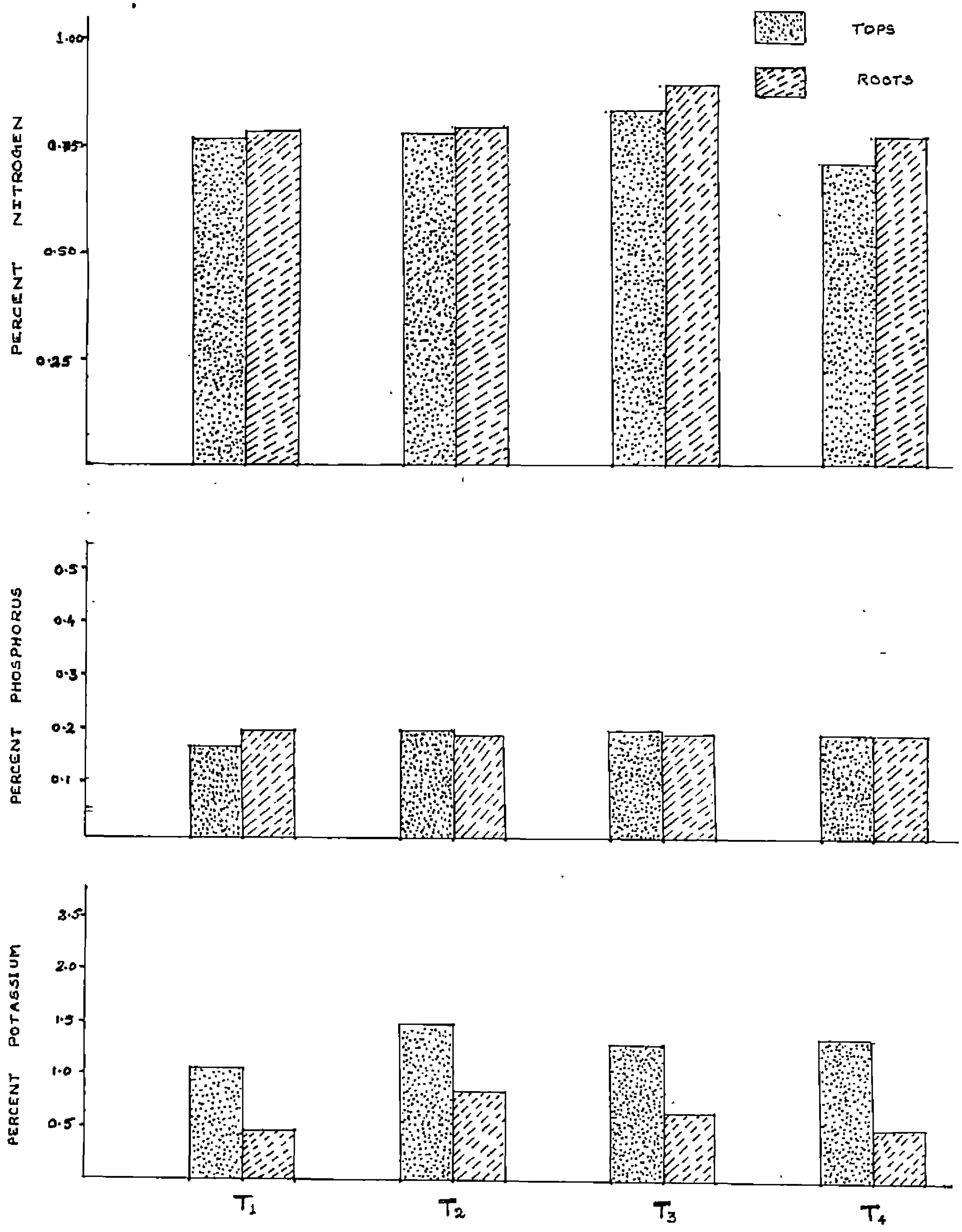
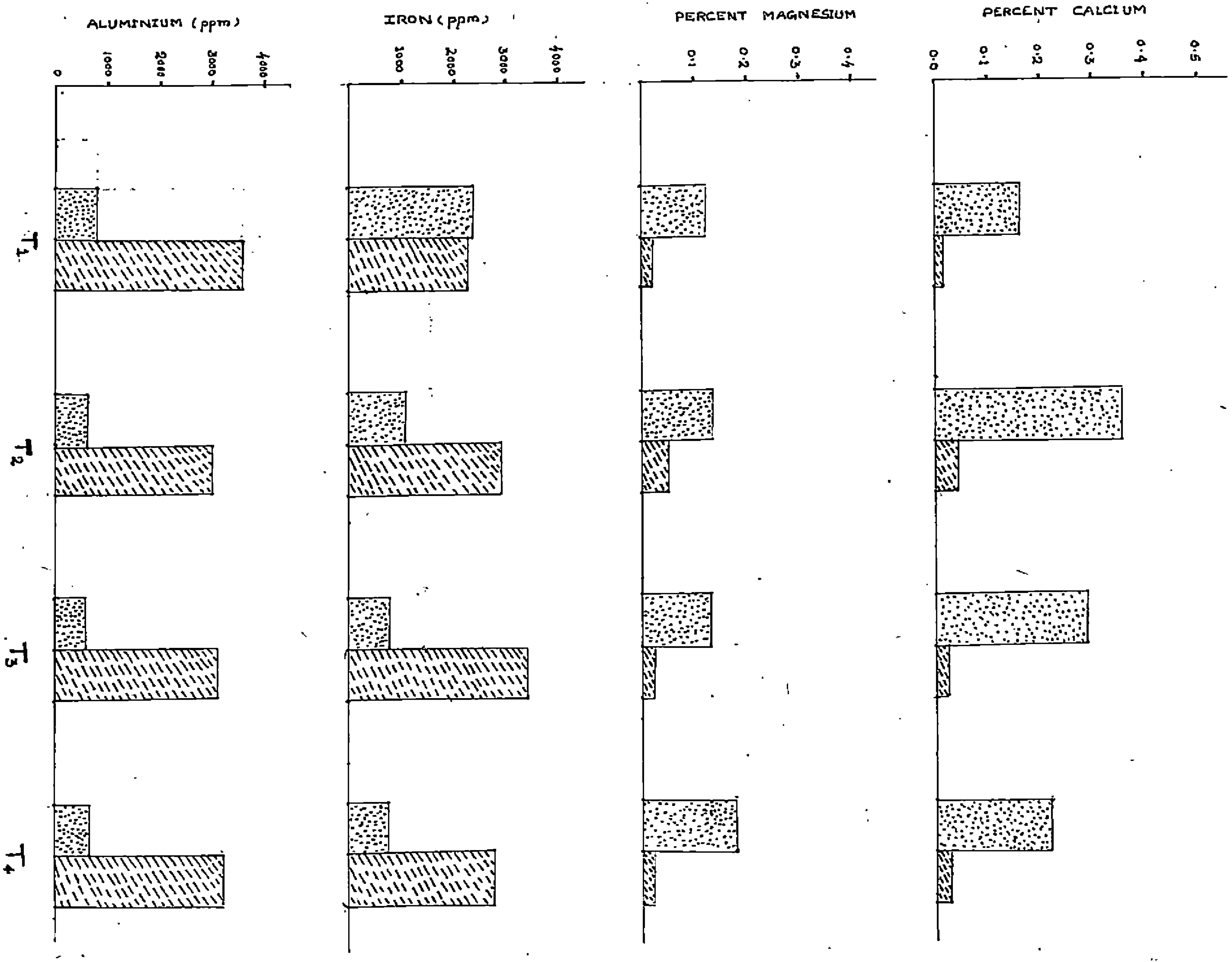


FIG. 6. Contd.



ALUMINIUM (ppm)
0
1000
2000
3000
4000
IRON (ppm)
1000
2000
3000
4000
PERCENT MAGNESIUM
0.1
0.2
0.3
0.4
PERCENT CALCIUM
0.0
0.1
0.2
0.3
0.4
0.5
T1
T2
T3
T4

ranged from 1.07 percent in T_1 to 1.49 percent in T_2. A significantly higher amount of potassium was found in T_2 than in T_3. In the roots it showed an increasing trend with a decrease in the content of exchangeable aluminium in the soil, and the values ranged from 0.45 in T_1 to 0.85 percent in T_2.

Calcium

The level of calcium in the tops and roots increased with increasing lime levels. The values ranged from 0.16 in T_1 to 0.35 percent in T_2 in maize tops. T_2 recorded a significantly higher calcium content compared to T_4 and T_1. In roots, the value of calcium content varied from 9 ppm in T_1 to 46 ppm in T_2. Calcium content in T_2 was found to be significantly higher than T_1, T_3 and T_4.

Magnesium

The content of magnesium in the maize tops did not show any significant variation due to different treatments, and the values ranged from 0.12 in T_1 and T_4 to 0.13 percent in T_3 and T_2. However treatment T_2 has significantly increased the magnesium content in fodder maize roots compared to T_1, T_4 and T_3. Magnesium content in roots ranged from 200 ppm in T_1 to 484 ppm in T_2.

Iron

The level of iron in the fodder maize top was significantly reduced by the treatment T_3 when compared to T_1 and T_2 and the values ranged from 740 ppm in T_3 to 2360 ppm in T_1.

The content of iron in fodder maize roots recorded the lowest value of 2280 ppm in T_1 and the highest value of 3480 ppm in T_3. More of iron accumulated in the maize roots in T_3 than in T_1, T_2 and T_4. But the difference was not significant.

Aluminium

The content of aluminium in the fodder maize tops reduced significantly by the reduction of exchangeable aluminium content in the soil brought about by liming. The content of aluminium in the top ranged from 600 ppm in T_3 to 850 ppm in T_1. T_3 was found to be significantly effective in reducing the aluminium content of the tops compared to T_1.

Aluminium content of the roots was also reduced significantly by the reduction in exchangeable aluminium content of soil. Reduction in the concentration of aluminium in root was linear with the reduction of exchangeable aluminium in soil and it ranged from 2920 in T_2 to 3610 ppm in T_1.

Zinc

A significantly higher amount of zinc was present in the tops in T_3 than in T_2. The values ranged from 16 ppm in T_2 to 36 ppm in T_3. However, no significant difference was observed in the content of zinc in roots, where the values ranged from 42 ppm in T_2 to 53 ppm in T_4.

Copper

The content of copper in the tops ranged from 4 ppm in T_2 to 7 ppm in T_4, and in the roots it varied from 12 ppm in T_1 to 14 ppm in T_3. In maize tops, treatment T_2 has significantly reduced the copper content compared to T_1, T_3 and T_4.

Correlation Studies

I. Cowpea

A. Soil properties and nutrient uptake

1. PAS and nutrient uptake

Results of this correlation is given in Appendix VI(a).

The percentage aluminium saturation of the soil at the maximum flowering stage and at the mid pod filling stage were found to have a negative effect on N, P, K, Ca, Mg and Fe uptake. However, the correlation was significant only in the case of calcium uptake $r = {}^{-}0.909^{xx}$ and $r = {}^{-}0.919^{xx}$respectively at the two stages). A significant positive correlation was obtained between percentage aluminium saturation and aluminium content in the root at maximum flowering ($r = 0.673^{x}$) and at mid pod filling ($r = 0.665^{x}$) stage respectively. But the correlation between percentage aluminium saturation and aluminium content of top and aluminium uptake were positive but non significant.

At the harvest stage a significant negative correlation existed between percentage aluminium saturation and the uptake of phosphorus ($r = {}^{-}0.521^{x}$) and calcium uptake ($r = {}^{-}0.657^{xx}$), N, K, Mg and Fe uptake recorded a negative correlation with percentage aluminium saturation but they were not significant. Aluminium content of the root was positively and significantly correlated with percentage aluminium saturation ($r = 0.739^{xx}$), and correlations between percentage aluminium saturation and aluminium uptake and aluminium content of top were found to be positive.

2. Exchangeable aluminium and nutrient uptake

The results of correlation analysis is given in Appendix VI(b).

The exchangeable aluminium content of the soil at the maximum flowering stage and at the mid pod filling stage was found to be negatively correlated with the uptake of N, P, K, Ca, Mg and Fe but the correlation was significant only in the case of calcium uptake in both the stages ($r = {}^{-}0.909^{xx}$, $r = {}^{-}0.912^{xx}$ respectively). A positive significant correlation existed between exchangeable aluminium and aluminium content in the root ($r = 0.679^{x}$) at maximum flowering and mid pod filling stages ($r = 0.661^{x}$). Though a positive correlations existed between exchangeable aluminium and aluminium uptake by plants, it was not significant.

At the harvest stage, the exchangeable aluminium content showed a significant and negative correlation with the uptake of phosphorus ($r = {}^{-}0.533^{x}$) and calcium ($r = {}^{-}0.663^{xx}$). A negative but non significant correlation existed between N, K, Mg and Fe uptake. A positive and significant relation was observed between exchangeable aluminium content of the soil and the aluminium content of the root ($r = 0.744^{xx}$). Correlation between exchangeable aluminium and aluminium uptake and aluminium content of the tops also followed the same pattern, as above.

B. Soil properties and plant characters

1. Percentage aluminium saturation and plant characters

Results of the correlation analysis are given in Appendix VII(a).

A significant and negative correlation existed between percentage of aluminium saturation and nodule count ($r = {}^{-}0.618^{x}$) as well as root length ($r = {}^{-}0.750^{xx}$) at maximum flowering stage. Percentage aluminium saturation though had a negative effect on total dry matter production in cowpea but it was not significant.

At the mid pod filling stage also, a strong negative correlation was noticed between percentage aluminium saturation and the nodule count ($r = {}^{-}0.697^{x}$). Percentage aluminium saturation was negatively correlated with the root length and total dry matter. However it is not significant.

At the harvest stage, husk, grain and total yield were found to have a significant and negative correlation with the percentage aluminium saturation ($r = {}^{-}0.491^{x}$, $r = {}^{-}0.508^{x}$, $r = {}^{-}0.518^{x}$ respectively). A negative but non significant correlation was observed between percentage aluminium saturation and nodule count, root length and dry weight at this stage.

2. Exchangeable aluminium and plant characters

The correlation results are presented in

Appendix VII(b).

Exchangeable aluminium content of the soil exhibited a significant negative correlation with the nodule count ($r = {}^{-}0.623^{x}$) and the root length ($r = {}^{-}0.759^{xx}$) at the maximum flowering stage. A negative correlation was also observed between exchangeable aluminium and dry weight which was not significant.

At the mid pod filling stage also exchangeable aluminium was negatively correlated with nodule count, root length and total dry matter. But the relationship was significant only in the case of nodule count ($r = {}^{-}0.688^{x}$).

At the harvest stage, husk, grain and total yield were significantly and negatively correlated to the exchangeable aluminium content of the soil ($r = {}^{-}0.501^{x}$, $r = {}^{-}0.520^{x}$, $r = {}^{-}0.589^{x}$). Exchangeable aluminium in the soil had a negative effect on nodule count, root length and total dry matter but none of them were significant.

C. Aluminium content of tops

1. Aluminium content of tops and nutrient composition of tops

Results of the correlation study at the three stages of growth of cowpea are given in Appendix VIII(a).

The aluminium content of the tops at the maximum flowering stage exhibited a negative influence on N, P, K, Ca, Mg and Cu and a positive relation with the contents of Fe and Zn in the plant top.

At the mid pod filling stage, the aluminium content of the top was found to be negatively correlated with N, P, K, Ca, Mg and Cu. Fe and Zn content at this stage was positively correlated to the aluminium content of the tops. But none of them were significant.

At harvest also, the same trend was found and N, P, K, Ca and Mg content of tops were negatively influenced by the aluminium content. Aluminium content was positively correlated to Fe, Zn and Cu content of the plant, but the correlation was significant only in the case of Zn ($r = {}^{+}0.584^{x}$).

2. Aluminium content of tops and plant characters

Results of the correlation study at the three stages of growth of cowpea are given in Appendix VIII(b).

The aluminium content of the tops at all the three stages exhibited a negative influence on characters like nodule count, root length and total dry weight. A significant negative correlation was evident between aluminium content of the tops at the maximum flowering stage and the root length ($r = {}^{-}0.727^{xx}$). A significant negative correlation was also exhibited between aluminium content of the tops at harvest and grain yield ($r = {}^{-}0.597^{x}$).

3. Aluminium content of tops and nutrient content of roots

Details of the correlation study are given in Appendix VIII(c).

A significant positive correlation existed between the content of aluminium in the tops and roots at the maximum flowering stage ($r = {}^{+}0.638^{x}$). However, the correlations obtained between aluminium and N, P, K, Ca, Mg, Fe and Cu in the roots were non-significant and negative. At this stage, a positive relation was obtained between contents of aluminium in the tops and zinc content of roots.

At the mid pod filling stage a significant negative correlation is seen between the level of aluminium in tops and phosphorus content in the root (r = $^{-}0.700^{XX}$). At this stage aluminium content in the tops was negatively correlated to N, Ca, Mg, Fe, Zn and Cu and positively correlated to K.

At the harvest stage, aluminium content in the tops showed a significant negative correlation with the content of calcium (r = $^{-}0.769^{XX}$) and magnesium (r = $^{-}0.552^{X}$) in the roots. However, the correlations between the aluminium in tops and N, P, Fe and Zn in the roots were negative and non-significant. Aluminium content in the tops showed correlation with potassium and aluminium.

4. Aluminium content of tops and nutrient uptake

Results of the correlation analysis are given in Appendix VIII(d).

At all the three stages, aluminium content in the tops exhibited a negative correlation with the uptake of N, P, K, Ca, Mg & Fe. The correlation between aluminium content of the tops and the uptake of nitrogen and potassium at the maximum flowering stage and that of phosphorus at harvest alone were significant.

D. Aluminium content of roots

1. Aluminium content of roots and nutrient composition of tops

Results of the correlation analysis are given in Appendix IX(a).

Aluminium content of the roots at the maximum flowering stage had a negative effect on the content of N, P, K, Ca & Mg. Aluminium content of the roots at this stage also exhibited a significant positive correlation with the Fe ($r = {}^{+}0.741^{x}$) and Al content ($r = {}^{+}0.638^{x}$) of the tops. The correlation between Al content of roots with Zn and Cu was found to be positive and non-significant.

There was a significant and negative correlation between aluminium content in roots and nitrogen (r = $^{-}0.634^{x}$) and calcium content (r = $^{-}0.645^{x}$) in tops at the mid pod filling stage. The negative correlation between aluminium content of roots and phosphorus content in tops as well as the positive correlation between aluminium content of roots and K, Mg, Fe, Al, Zn and Cu content of tops were not significant.

Aluminium content of roots at harvest showed a strongly adverse effect on phosphorus (r = $^{-}0.545^{x}$) and calcium contents (r = $^{-}0.748^{xx}$) of tops and to a lesser extent on the content of nitrogen and magnesium. Al and Zn content in tops exhibited a highly significant positive relationship with Al content in roots (r = $^{+}0.736^{xx}$ and r = $^{+}0.594^{x}$ respectively).

2. Aluminium content of roots and plant characters

Results of this correlation analysis are given in Appendix IX(b).

From the results of correlation analysis it may be seen that the aluminium content of roots at the maximum flowering stage exhibited a highly significant negative influence on nodule count ($^{-}0.597^{x}$) and root length (r = $^{-}0.710^{xx}$) while it was non significantly and negatively correlated to the plant height and total dry weight. The correlation between the level of aluminium in root and various growth parameters were negative both at mid pod filling stage and at harvest. Nodule count (r = $^{-}0.822^{xx}$) and total dry weight (r = $^{-}0.624^{x}$) at the mid pod filling stage were found to be significantly and negatively correlated to aluminium content in roots. Similarly aluminium content in roots at harvest exhibited significant negative correlations with nodule count (r = $^{-}0.514^{x}$), husk (r = $^{-}0.607^{x}$), grain (r = $^{-}0.568^{x}$) and total pod yield (r = $^{-}0.601^{x}$) and root length (r = $^{-}0.529^{x}$).

3. Aluminium and nutrient content of roots

Results of the correlation study are given in Appendix IX(c).

Content of aluminium in the plant root exhibited a negative correlation with most of the other nutrients. Among the negative correlations, the relation between aluminium and iron contents in roots ($r = {}^{-}0.586^{x}$) at the maximum flowering stage, and calcium and magnesium contents in roots at mid pod filling ($r = 0.643^{x}$, $r = {}^{-}0.670^{x}$) and harvest stage ($r = {}^{-}0.681^{xx}$, $r = {}^{-}0.737^{xx}$) were significant.

4. Aluminium content of roots and nutrient uptake

Results of the correlation analysis are given in Appendix IX(d).

Results of correlation analysis have shown that the aluminium content in roots at maximum flowering stage was negatively correlated to N, P, K, Ca & Mg uptake. A positive correlation was observed between aluminium content in root and iron and aluminium uptake.

At the mid pod filling stage, a strong and significant negative correlation was evident between aluminium content in roots and uptake of nitrogen ($r = {}^{-}0.625^{x}$), phosphorus ($r = {}^{-}0.717^{xx}$), calcium ($r = {}^{-}0.747^{xx}$) and magnesium ($r = {}^{-}0.644^{x}$). Aluminium content in roots at harvest showed a significant negative correlation with phosphorus ($r = {}^{-}0.596^{x}$) and calcium uptake (r = $^{-}0.499^{x}$). A highly significant and positive correlation was also observed between aluminium content in root and aluminium uptake (r = $^{-}0.636^{xx}$).

II. Fodder Maize

A. Soil properties and nutrient uptake

1. Percentage aluminium saturation and nutrient uptake

The results of the study are presented in Appendix X(a).

The percentage aluminium saturation of the soil at harvest is found to have a significant negative correlation with the uptake of N, P, K, Ca, Mg and Fe (r = $^{-}0.774^{xx}$, r = $^{-}0.855^{xx}$, r = $^{-}0.833^{xx}$, r = $^{-}0.904^{xx}$, r = $^{-}0.797^{xx}$, r = $^{-}0.767^{xx}$ respectively) by the plant. The percentage aluminium saturation showed a significant positive correlation with aluminium content in roots (r = $^{+}0.799^{xx}$) and positive but non significant correlation with that in fodder maize tops.

2. Exchangeable aluminium and nutrient uptake

Results of this study are presented in Appendix X(a).

A strong significant negative correlation was obtained between exchangeable aluminium content of the soil at the harvest and uptake of N, P, K, Ca, Mg and Fe ($r = {}^{-}0.768^{xx}$, $r = {}^{-}0.853^{xx}$, $r = {}^{-}0.823^{xx}$, $r = {}^{-}0.898^{xx}$, $r = 0.791^{xx}$, $r = 0.763^{xx}$).

3. Percentage base saturation and nutrient uptake

Results of the correlation study are given in Appendix X(a).

A significant and positive correlation was obtained between percentage base saturation and uptake of N, P, K, Ca and Mg ($r = 0.805^{xx}$, $r = 0.850^{xx}$, $r = 0.953^{xx}$, $r = 0.938^{x}$, $r = 0.886^{x}$ respectively).

B. <u>Soil properties and plant characters</u>

1. Percentage aluminium saturation and plant characters

The details of the correlation study are presented in Appendix X(b).

The percentage aluminium saturation of the soil at harvest was found to exert a significant negative effect on root length ($r = {}^{-}0.676^{x}$), weight of roots

$(r = {}^{-}0.690^{x})$, weight of tops $(r = {}^{-}0.767^{xx})$ and total dry matter yield $(r = {}^{-}0.816^{xx})$.

2. Exchangeable aluminium and plant characters

The exchangeable aluminium content of the soil at harvest was also significantly and negatively correlated to the plant characters like length of root $(r = {}^{-}0.681^{x})$, weight of root $(r = {}^{-}0.773^{xx})$, top weight $(r = {}^{-}0.680^{xx})$ and total dry matter yield $(r = {}^{-}0.811^{xx})$.

3. Percentage base saturation and plant characters

A significant and positive correlation was obtained between percentage base saturation and yield parameters like length $(r = {}^{+}0.656^{x})$ and weight $(r = {}^{+}0.682^{x})$ of root, weight of top $(r = {}^{+}0.778^{x})$ and total dry matter production $(r = {}^{+}0.847^{xx})$.

C. Aluminium content of tops

1. Aluminium content and nutrient composition of tops

The results of the correlation study is presented in Appendix XI(a).

A significant negative correlation is observed between aluminium and the content of phosphorus ($r = {}^{-}0.642^{x}$) and calcium ($r = {}^{-}0.598^{x}$) in the plant tops, and a not significant but negative effect on the N, Mg, Zn and Cu contents in the tops.

A significant and positive correlation was evident between aluminium and iron content ($r = {}^{+}0.746^{xx}$) in the tops and a positive but not significant relation obtained with potassium.

2. Aluminium content of tops and plant characters

Results are shown in Appendix XI(b).

A negative correlation was obtained between the content of aluminium in the maize tops and the different characters like root length, weight of tops and roots and total dry matter. But none of them were significant.

3. Aluminium content of tops and nutrient content of roots

Results are given in Appendix XI(c).

A significant negative correlation was noticed between aluminium content in tops and iron content in the roots ($r = {}^{-}0.632^{x}$) while the negative correlations between aluminium content in the tops and content of other nutrients (N, P, K, Ca & Mg) in the roots were non-significant. Zinc content in the roots was found to be positively correlated to the aluminium content in the tops, and aluminium content in tops positively and significantly related to the aluminium content of roots ($r = {}^{+}0.700^{x}$).

D. Aluminium content of roots

1 Aluminium content of roots and nutrient composition in the tops

Results obtained from the correlation studies are presented in Appendix XII(a).

It was observed from the results that a strong negative correlation existed between aluminium content in roots and phosphorus ($r = {}^{-}0.803^{xx}$) and calcium ($r = {}^{-}0.882^{xx}$) content in tops.

A significant positive correlation was found between the contents of aluminium in the roots with that of iron ($r = +0.816^{xx}$) and aluminium ($r = +0.700^{x}$) in the tops. However the negative correlation observed between aluminium content of roots and N, K and Mg contents of tops is not significant.

2. Aluminium content of roots and plant characters

Results of the correlation analysis is presented in Appendix XII(b).

Aluminium content in roots of fodder maize exhibited a significant negative correlation with root length ($r = -0.764^{xx}$), weight of tops ($r = -0.749^{xx}$), weight of roots ($r = -0.735^{xx}$) and total dry matter yield ($r = -0.845^{xx}$).

3. Nutrient content in the root

Results are presented in Appendix XII(c).

The level of aluminium in the roots of fodder maize plant had a negative influence on N, P, K, Ca, Mg, Fe, Zn and Cu content in the roots, but the relationship was significant only between the contents of aluminium in roots and potassium ($r = -0.620^{x}$), calcium (r = $^{-}0.849^{xx}$), magnesium (r = $^{-}0.610^{xx}$) and iron (r = $^{-}0.624^{x}$).

<u>Nutrient uptake</u>

Results of correlation analysis are presented in Appendix XII(d).

Aluminium content in roots was significantly and negatively correlated to the uptake of nutrients like nitrogen (r = $^{-}0.826^{xx}$), phosphorus (r = $^{-}0.882^{xx}$), potassium (r = $^{-}0.771^{xx}$), calcium (r = $^{-}0.838^{xx}$), magnesium (r = $^{-}0.684^{x}$) and iron (r = $^{-}0.601^{x}$).

DISCUSSION

DISCUSSION

Numerous studies in recent years have revealed that exchangeable aluminium in acid soils is mainly responsible for crop failure and other harmful effects associated with acidity. Eventhough the pH of the soil has been widely used as an index to find out the amount of lime required to neutralise the acidity and produce a good crop, this practice may lead to the use of a large amount of lime which is both uneconomical and unnecessary. Complete neutralization of acidity is often not necessary to bring about significant improvement in the economy of crop production. Yield response to lime is found to be more related to the reduction of exchangeable acidity and exchangeable aluminium in soil rather than to complete neutralization of total acidity. Hence liming upto the point of elimination of aluminium toxicity in soils is considered to be enough for producing a good crop.

Effect of different levels of lime on parameters of acidity

An increase in pH and a reduction in total acidity and exchangeable aluminium have been observed as the most important and immediate effects consequent to liming. Thus, soils treated with lime at the rate of 250, 500 kg/ha and 7.7 t/ha record an increase of 0.3, 0.6 and 2.1 units of pH respectively. Total acidity is also correspondingly reduced to 0.49, 1.73 and 2.45 me/100 g soil in these treatments compared to the initial level of 2.94 me.

Higher levels of lime also reduce the exchangeable hydrogen and aluminium content of the soil. But the extent of reduction in exchangeable hydrogen is much less compared to that of total acidity and exchangeable aluminium. A maximum difference of only 0.09 me of exchangeable hydrogen is observed as against 1.96 me of total acidity and 2.39 me of exchangeable aluminium. Treatment with lime appears to be more effective in controlling total acidity and exchangeable aluminium rather than exchangeable hydrogen. Probably the calcium in lime is not able to fully replace the hydrogen ions strongly held in the exchange complex while it has reacted with exchangeable aluminium and changed it into a non-extractable form. It also shows that total acidity of the soil is mostly contributed by exchangeable aluminium rather than by exchangeable hydrogen.

A marked decrease in levels of exchange acidity and exchangeable aluminium, concomitant with higher lime level has been reported by Haynes and Ludecke (1981). Kabeerathumma and Nair (1973) and Abraham (1984) have also reported a reduction in exchangeable aluminium and hydrogen content of the acid soils of Kerala as a result of liming. Cochrane et al. (1980), Bache and Crooke (1981), Hargrove and Thomas (1981), Mukhopadhyay et al. (1984) and more recently Curtin and Smillie (1986) have also found that exchangeable and soluble aluminium in acid soils could be reduced by liming. According to them, lime levels sufficient to reduce the aluminium saturation to limits that do not affect the economy of crop production is more important. The results of this experiment have shown that application of lime to raise the soil pH to 6.4 has resulted in almost complete neutralization of exchangeable aluminium in the soil. The variation in exchangeable aluminium content in the other treatments is also significant and has helped to maintain a level of 1.26 and 1.98 me of aluminium/100 g soil with corresponding percentage aluminium saturation values of 23.75 and 37.78 respectively. The ability of different levels of lime in reducing the exchangeable aluminium content and decreasing percentage aluminium saturation has been considered to be the most significant consequence of liming of acid soils.

The favourable effect of liming in increasing yield has been correlated to the reduction of toxic levels of aluminium than to an increase in soil pH (Martini et al., 1977). Similarly, Reeve and Sumner (1970) and Reid et al. (1971) have obtained a better response of lime only upto the point of elimination of aluminium toxicity. Kunshi (1982) has also given more stress on the reduction of extractable aluminium rather than an increase in pH for getting a greater response.

Application of fertilizers to the limed soils before cultivation has resulted in a further rise in pH in all the treatments. Increase in pH is maximum

(0.5 pH units) in unlimed and minimum (0.1 pH unit) in pots which receive the highest amount of lime. This increase in pH may be associated with a corresponding reduction in total acidity contributed by both exchangeable hydrogen and aluminium. A similar reduction in exchangeable aluminium content in soils following phosphate application has been reported by Awad et al. (1976), Bache and Crook (1981) and Haynes and Ludecke (1981).

Despandae (1976) has found that application of phosphoric acid to acid soils with very low pH resulted in the fixation of aluminium as aluminium phosphate. An increase in pH of 0.1 to 0.2 units has been observed in some soil samples due to the addition of phosphates. Bache and Crooke (1981) have attributed the increase in pH after the application of fertilizers to a reduction in exchangeable and soluble aluminium by reaction with the phosphorus present in the fertilizer.

Changes in acidity parameters during growth of plants

Cultivation of cowpea as well as fodder maize has caused an increase in pH and a decrease in total acidity, exchangeable aluminium and exchangeable hydrogen both in limed and unlimed soils at the early stages of growth. However, at harvest the pH values showed a slight decrease and the other values a tendency to increase. The increase in pH and a decrease in the exchangeable hydrogen and aluminium at the early stages of growth of both cowpea and fodder maize may be indicative of a mechanism of tolerance to aluminium exhibited by these plants. Foy et al. (1964, 1965 and 1967) have reported a lowering of pH in nutrient solutions by sensitive varieties and a raising of pH around the roots in the case of plants tolerant to aluminium. They were of the view that aluminium tolerant plants may produce some exudates which immobilize the soluble aluminium in the vicinity of growing roots. The complexing of soluble aluminium can also result in an increase in pH.

The slight decrease in pH and increase in total acidity, exchangeable hydrogen and aluminium towards the harvest stage might be due to an increased rate of production of acidity through plant excretions or due to the production of organic acids through the action of soil microbes.

A slight reduction in pH (by about 0.3 units) observed in barley has been attributed to the nitrification process in the root zone (Bache and Crooke, 1981). A decrease in exchangeable aluminium in the vicinity of plant roots may arise due to the formation of complexes of iron or aluminium with organic matter and their subsequent removal from the soluble pool. Reid et al. (1982) have observed such processes of removal of exchangeable aluminium from the vicinity of roots.

Effect of exchangeable aluminium on plant characters

Cowpea

It may be seen from Table 6 and from the results presented earlier that the height of cowpea show a tendency to increase in treatments where the exchangeable aluminium levels have been lowered by liming. However, the plants in the pots treated with the highest level of lime which has lead to the complete elimination of exchangeable aluminium showed only the least height indicating the depressing effect of overliming.

The length of roots in cowpea also exhibit a negative relation with exchangeable aluminium content of the soil as evidenced from Fig.1 and Plate 1. The treatment with an exchangeable aluminium level of 1.26 me/100 g and percentage of aluminium saturation around 30 recorded the maximum value for length of root. The other treatments where either the exchangeable aluminium level is negligible or where it is more than 1.26 me recorded only a lower length of roots. This is suggestive of the harmful effects of both overliming as well as underliming. Aluminium is observed to be more harmful to roots than tops and an inhibition of root development has been identified as one of the first observable symptoms of aluminium toxicity in plants (Abraham [illegible], 1984; Bennet et al., 1985; Kim et al., 1985; Alva et al., 1986 and Rechcigl et al., 1986).

It is observed from the results of the present study that the elongation of cowpea roots are adversely affected by exchangeable aluminium and it is negatively correlated to percentage aluminium saturation and exchangeable aluminium throughout its growth period. The reduced length of roots at high aluminium saturation may be due to the irreversible inhibition of root growth correlated with high aluminium content (Aniol et al., 1979 and Mugwira et al., 1980).

A reduction in exchangeable aluminium brought about by liming has resulted in an increase in the number of nodules indicating the specific effect of aluminium on suppression of root nodule formation in cowpea. A similar reduction in nodule formation due to high aluminium saturation has been reported earlier (Pieri, 1974; Malavolta, 1981 and Franco and Munns, 1982).

The beneficial effects imparted by pulses in general depend on the gain in soil nitrogen through symbiotic nitrogen fixation, which inturn is related to the number of nodules formed by the rhizobia on the roots. The highest number of nodules is obtained at the maximum flowering stage which slowly decreases towards the harvest stage. A decline in the number of nodules as the plant reaches maturity has been generally observed (Indira, 1985).

The correlation between exchangeable aluminium and percentage aluminium saturation with nodule count is negative and significant both at the maximum flowering and at the mid pod filling stage. This correlation eventhough continued to be negative became non-significant at the harvest stage. Excessive aluminium has been considered to be a severe stress to rhizobia than free acidity measured in terms of pH values (Keyser and Munns, 1979).

Total dry matter production

A comparison of the total dry matter production by cowpea shown in Table 6 reveals that the suppressing effect of exchangeable aluminium is more prominent at the early stages of growth than at the later stages. But in the treatment where the PAS is maintained at around 30, the dry matter content is highest at all the three stages of growth. Neither the lime levels which maintain the percentage aluminium saturation around 40 nor that which raise the pH to neutrality leading to a percentage aluminium saturation of less than 1 could produce a significant increment in dry matter production. The reduction in dry matter in these treatments may be attributed to the adverse effect of exchangeable aluminium in influencing nutrient absorption (Lee, 1971; Sanchez, 1976; Jarvis and Hatch, 1986) which is essential for maintaining a higher rate of carbohydrate synthesis.

The antagonistic relation existing between dry matter production and exchangeable aluminium supports this view.

Grain yield

It may be seen from the results in Table 6 that the maximum grain yield is produced by the treatment where the percentage aluminium saturation is less than 30. In the other treatments which have maintained a higher level of exchangeable aluminium as well as percentage aluminium saturation, the yield is significantly lower. Similarly in the treatment where the percentage aluminium saturation is only less than one and exchangeable aluminium 0.09 me/100 g, there also the grain yield is comparatively lower than the treatment where the exchangeable aluminium content is

1.26 me but higher than the treatments where the exchangeable aluminium contents are 1.98 and 2.45 me. The attainment of a maximum yield at around 30 percent aluminium saturation of the soil is significant and clearly indicates the possibility of getting a higher yield at this level of exchangeable aluminium. Eventhough a pH of 4.7 in the soil where the PAS is around 30 suggests a strongly acidic condition, cowpea has been able to produce a higher yield compared to a situation in the treatment where the pH is near neutrality. This observation points to the fact that it is sufficient to reduce the percentage aluminium saturation to values around 30 to obtain a better yield. Instead of taking pH as a criteria for liming, the exchangeable aluminium values and corresponding percentage aluminium saturation values may be looked upon as better indicators for the need of lime in highly acid soils.

A reduction in grain yield noted at the highest lime level (Table 6) though not significant, might be due to the undesirable effects like phosphorus and micronutrient deficiency consequent to overliming

(Holford, 1985 and Timmer, 1985). It is possible that the strong negative influence exerted by exchangeable aluminium on root elongation and nodulation might have adversely affected the availability and uptake of nitrogen as well as most other nutrients in the treatments where there is a high level of exchangeable aluminium in the soil. It appears that a certain amount of exchangeable aluminium which maintain a moderately acidic state of soil has promoted plant growth by indirectly influencing the release of more of the fixed nutrients into the available pool. This might have led to greater absorption, resulting in a higher yield of grain as well as total dry matter production.

It is evident from the present study that a percentage aluminium saturation of above 30 has considerably reduced the weight and length of root, nodule count, height of plant as well as yield. Such instances of lower crop yield, reduced nodulation and root growth and poor nutrient uptake associated with aluminium toxicity in soils have been amply reported in literature (Abruna et al., 1974; Sartain and Kamprath, 1975;

Dionne and Pesant, 1985). However, Andrew et al. (1973) have reported an increase in yield of pasture legumes at 0.5 ppm aluminium. Beneficial effects of low concentration of aluminium (19 µM) on tap root elongation in phaseolus and the non inhibitory effect of aluminium upto 83 M on root dry weight, nodule growth and nitrogenase activity in beans are also reported (Franco and Munns, 1982).

Fodder Maize

Plant characters such as weight of tops and roots, length of roots and total dry matter production exhibit a linear; negative relationship with exchangeable aluminium content. However, plant height alone is higher at an exchangeable aluminium level of 1.26 me and percentage aluminium saturation around 30. The favourable effect on all the other plant characters at the highest level of lime may be due to the beneficial effects imparted by the reduction of toxic levels of exchangeable aluminium in the soil (Table 9).

A comparison of the response by cowpea and fodder maize to various levels of exchangeable aluminium resulting from the use of different levels of lime, reveals a greater tolerance of cowpea to aluminium than fodder maize. It is clearly evident from the results that while yield and other plant characters are better at 30 percent aluminium saturation in cowpea, such a situation is attained in fodder maize only by the use of a higher level of lime which can reduce the percentage aluminium saturation to a minimum. Various scientists have proposed different limits of tolerance of aluminium saturation of soils for cereal crops such as wheat, barley and corn. Kamprath (1970) has found that an aluminium saturation of more than 45 percent reduced corn yield while Alley (1981) observed an unfavourable effect on corn yields at an aluminium saturation of 18 percent of the effective CEC. Fox (1979) on the other hand obtained 90 percent yield reduction in corn when the aluminium saturation exceeded 12 percent.

Liming to reduce the aluminium saturation to 40 percent is not that much effective in increasing the yield of cowpea compared to the levels of lime needed to reduce the percentage aluminium saturation to 30. At the same time, lime levels to raise the pH to around 6.4 and reduce percentage aluminium saturation to < 1 is uneconomical in view of the huge quantity of lime required. The yield of grain as well as the total dry matter production in cowpea attained at this level of liming may not commensurate with the cost involved. It is clear that since cowpea can perform well at a percentage aluminium saturation of 30, there is no further need to reduce it to less than 30 by applying more of lime. The optimum level of lime to attain this condition is found to be 500 kg/ha. But in the case of fodder maize, almost all the growth characters except the height of the plant recorded maximum values in the treatment T_2 where the pH is 6.4 and effect of aluminium in soils is negligible. The other two treatments which reduce the aluminium saturation to 30 and 40 percent are found to be not as effective in increasing the yield parameters. From these results it appears that a better performance with fodder maize may be expected in soils which are either limed to the point of complete elimination of exchangeable aluminium or a particular level which may be tolerated by the crop.

A comparison of the performance of fodder maize and cowpea under different levels of exchangeable aluminium brings out the fact that fodder maize is highly sensitive to aluminium toxicity while cowpea is somewhat tolerant to it.

Influence of different levels of exchangeable aluminium on the nutrient content of cowpea and fodder maize

It may be seen from the results that the nitrogen content in tops and roots show a linear increase with a decrease in exchangeable aluminium content of soil throughout the growth of cowpea. Nitrogen content is highest in the treatment where the exchangeable aluminium is minimum.

The higher content of nitrogen in cowpea grown in soils of lowest exchangeable aluminium content may be the consequence of a higher rate of nitrogen absorption which has been made available through a better association between the macro and micro symbionts. This is evidenced by the higher nodulation of cowpea in treatments giving a low level of exchangeable aluminium.

A negative correlation is also found to exist between aluminium content in tops and nitrogen content, eventhough it is not significant at any of the growth stages of cowpea. The adverse effect of aluminium on the absorption of nitrogen by the plant is thus reflected in this relationship. The effect seems to be more prominent at the mid pod filling stage as indicated by the significant and negative correlation existing between aluminium content in roots and nitrogen content in the tops at the mid pod filling stage.

The adverse effect of excessive aluminium on nodulation and nitrogen fixation as reported in many instances (Malavolta et al., 1981; Franco and Munns, 1982) may be the reason for this negative correlation between aluminium concentration and nitrogen content in cowpea.

Nitrogen content in the tops and roots of fodder maize also shows an increase due to a reduction in the exchangeable aluminium content of the soil. However, maximum content of nitrogen is observed in the treatment with a percentage aluminium saturation of 30 which contain a higher level of exchangeable aluminium than in the treatment where the exchangeable aluminium is minimum. The lower content of nitrogen in the treatment where exchangeable aluminium is minimum may be attributed to the adverse effects of overliming.

A negative correlation also exists between aluminium content in soil and nitrogen content of tops and roots. A similar relationship between these two elements in rice roots has been observed by Fageria and Carvalho (1982).

In general a higher content of phosphorus in the tops and roots of plants is noticed at the lower levels of exchangeable aluminium and percentage aluminium saturation values. But the different treatments are not significant in increasing the phosphorus content in tops and roots over unlimed treatments except at the mid pod filling stage and at harvest. At higher percentage aluminium saturation values, the concentration of phosphorus in tops show a reduction probably due to the strong antagonistic relation which is believed to exist between aluminium and phosphorus (Zaini and Mercado, 1984; Fageria, 1985).

A decrease in the phosphorus content of both tops and roots has been observed with an increase in the aluminium content of the soil. However, the correlation between aluminium and phosphorus in tops and roots is not constant always. This finding is in agreement with the observations made by Mugwira et al. (1980) and Fageria and Carvalho (1982) on the relationship between aluminium and phosphorus. However, Sartain and Kamprath (1975) did not observe any relation between aluminium content of soil and plant phosphorus concentration.

Eventhough a reduction in percentage aluminium saturation of soils has resulted in an increase in the content of phosphorus, the phosphorus in the treatment where the percentage aluminium saturation is 30 is found to be equal to that in the treatment where exchangeable aluminium is minimum. A greater absorption of phosphorus in the treatment where exchangeable aluminium content is 1.26 me. inspite of a higher exchangeable aluminium and acidity than in the treatment where exchangeable aluminium is minimum, points to a greater solubilization of phosphorus in these soils. The rhizosphere of fodder maize plants which has become more acidic towards the harvest stage might have helped in the greater absorption of phosphorus in this treatment.

Reduction of exchangeable aluminium in soils by liming has not produced any marked increase in the potassium content of roots and tops of cowpea. However, potassium content at the maximum flowering stage records highest value in heavily limed treatments with lowest aluminium saturation.

However, at the mid pod filling stage and at harvest, potassium in roots and tops is maximum in plants grown in the presence of the highest concentration of exchangeable aluminium. Mugwira et al. (1980) and Fageria and Carvalho (1982) have reported a favourable effect of higher concentration of aluminium on potassium absorption while Mac Leoad and Jackson (1967) have reported an opposite effect.

Aluminium content of tops show a negative correlation to potassium in tops at all the three stages and at mid pod filling stage aluminium in tops is found to be positively correlated to potassium content in roots. Thus the effect of aluminium either in the soil or plant appears to be inconsistent and it appears that a high aluminium content is not likely to reduce potassium absorption and translocation in cowpea. In fact, low levels of aluminium have been reported to act as a stimulant for potassium absorption (Andrew et al. 1973; Fageria and Carvalho, 1982).

A general increase in potassium content in both roots and tops of fodder maize is obtained due to a reduction in exchangeable aluminium status indicating a greater sensitiveness of fodder maize to absorb potassium in the presence of high levels of aluminium. The highest level of lime has produced the maximum content of potassium in tops (1.49 percent) as well as in roots (0.85 percent).

Calcium content in plant tops and roots also show a linear increase with a decrease in exchangeable aluminium and percentage aluminium saturation values at all the three stages of growth of cowpea. Eventhough the calcium content in tops record a maximum value in the treatment having the least content of exchangeable aluminium, its content in the roots record a maximum value in the treatment where the exchangeable aluminium in soil amounts to 1.26 me and percentage aluminium saturation is <30. The strong antagonistic effect prevailing between these two elements (Mugwira et al. 1980) may lead to a lesser uptake of calcium in the presence of aluminium. The treatment where exchangeable aluminium is minimum has increased the calcium content of the soil to a considerable level may also account for the highest content of calcium observed in the plants in this treatment. The decrease in the content of calcium in tops towards harvest may be due to a greater accumulation of calcium in the roots at this stage as evidenced from Table 7 compared to the other two stages. The reduction in calcium content in tops at harvest may also be attributed to the dilution effect in the plant as proposed by Martini and Mutters (1985).

Aluminium content in tops and roots reveal a consistent negative correlation with calcium content in tops and roots throughout the growing period.

However, correlation between aluminium content in tops and calcium content in roots is significant only at harvest. This behaviour may be explained in the light of the strong negative correlation that exists between aluminium content in roots and calcium content in tops and roots as well as aluminium and calcium content in tops. The results also indicate the greater sensitiveness of fodder maize compared to cowpea in absorbing calcium in the presence of aluminium.

An increase in magnesium content in tops and roots with a reduction in the percentage aluminium saturation and exchangeable aluminium is also evident from the results. A higher content of magnesium in plant tops and roots as a result of liming may be attributed to the increased absorption and translocation of the element at reduced percentage aluminium saturation and exchangeable aluminium values (Mac Leoad and Jackson, 1967; Mugwira et al. 1980). These findings also indicate a greater sensitiveness of fodder maize to aluminium than cowpea.

The content of iron in the tops of cowpea and fodder maize show a tendency to decrease with decreasing levels of exchangeable aluminium in the soil. A lowering of the exchangeable iron in soil due to the treatment with lime has naturally resulted in a lower uptake of this element by both the plants. A decrease in the status of exchangeable iron in the soil due to lime application is evident from the results presented earlier. Iron content in the roots of cowpea and fodder maize show a negative relationship indicating the ability of these plants to prevent the translocation of toxic levels of iron to the tops.

A higher content of zinc is noticed in fodder maize due to a reduction in exchangeable aluminium by liming. However, inspite of the use of a very high level of lime leading to the complete suppression of exchangeable aluminium, this treatment has recorded the lowest content of zinc. The precipitation of zinc in the presence of a very high amount of lime might have led to a greater unavailability of zinc to the plant. A decrease in the availability of zinc at high lime levels has been reported in many instances (Lee, 1971; Fageria and Carvalho, 1982).

But in the case of cowpea, the availability of zinc does not seem to be much affected by the application of lime, eventhough the observed tendency is for a lesser uptake of zinc in the presence of lime. Here also the plants in the treatment where exchangeable aluminium is minimum, record the lowest content of zinc suggesting a situation where the availability of zinc has been reduced due to overliming.

Copper content in both tops and roots of cowpea and maize are not much affected by a reduction in exchangeable aluminium content in the soil.

It may be noted from the results presented in Table 7 that the content of aluminium in both tops and roots decrease with a decrease in the percentage aluminium saturation and exchangeable aluminium content of the soil. The content of aluminium in cowpea tops record the lowest value in the treatment with percentage aluminium saturation around 30 and exchangeable aluminium 1.26 me/100 g soil.

Aluminium content in roots also exhibit a linear decrease with a reduction in exchangeable aluminium content of the soil. The content of aluminium in both tops and roots record maximum values at the mid pod filling stage and then decrease as the crop attain maturity. Martini and Mutters (1985) have observed a similar reduction in the content of aluminium in soybean after four weeks.

Eventhough the treatment with percentage aluminium saturation value around 30 has recorded the least amount of aluminium in the tops, the other two treatments with a higher percentage aluminium saturation and exchangeable aluminium value than the treatment with percentage aluminium saturation around 30 maintain a higher level of aluminium in tops. The treatment with the lowest percentage aluminium saturation and exchangeable aluminium show only the minimum content of aluminium in the roots at all the three stages.

Aluminium content in roots is found to be significantly higher than that in the tops. The accumulation of more aluminium in roots compared to tops may be due to a lesser degree of transport of the absorbed aluminium to the tops in order to maintain a non toxic level of aluminium in the tops. Accumulation of aluminium in the roots has been observed as a mechanism exhibited by plants tolerant to aluminium toxicity. A higher content of aluminium in roots of plants grown in highly acidic soils has been reported (Andrew et al. 1973). Jarvis and Hatch (1986) have observed that only less than 10 percent of aluminium absorbed from solution alone is transported to shoots.

It may be noted that a strong positive correlation exists between aluminium content of tops and roots at the maximum flowering stage and at harvest. Inspite of the retention of appreciable amounts of aluminium in the roots of cowpea, translocation to the aerial parts seem to have taken place as suggested by the strong positive correlation between the aluminium content of tops and roots. This indicates the plant's inability to prevent translocation from roots beyond a certain limit, which may result in an expression of aluminium toxicity symptoms in the leaves. The marginal leaf chlorosis and leaf curling observed in plants in the control and in the treatment with a percentage aluminium saturation of more than 40 support this finding. Recently Truman et al. (1986) have obtained a similar type of positive relation between aluminium content in tops and roots.

A reduction in the exchangeable aluminium content and percentage aluminium saturation values bring about a decrease in the content of aluminium in the tops of fodder maize. Here also the treatment with a percentage aluminium saturation of around 30 is found to be more effective in reducing the level of aluminium in plant tops than in the treatment with a negligible percentage aluminium saturation value or the treatment with a percentage aluminium saturation around 40. The content of aluminium in the roots also decreases linearly with a corresponding decrease in the percentage aluminium saturation values. The treatment with the lowest level of percentage aluminium saturation is observed as the most effective in reducing aluminium content in roots. A strong significant positive correlation between the content of aluminium in the tops and roots is obtained as in the case of cowpea. As mentioned earlier, the accumulation of aluminium in the roots is indicative of a tolerant mechanism exhibited by plants growing in soils with high exchangeable aluminium values.

Nutrient content in grain and husk of cowpea

A reduction in the exchangeable aluminium content of the soil has resulted in an increase in concentration of N, P, Ca and Mg in both grain and husk. Treatment with an exchangeable aluminium level of 1.26 me and percentage aluminium saturation around 30 record the highest value for all these nutrients in grain and husk compared to the treatments where the level of exchangeable aluminium is either lesser or greater than this treatment. Neither the lime levels to bring the percentage aluminium saturation to around 40 nor that caused a reduction of percentage aluminium saturation to less than one could increase the content of N, P and Mg in grain and husk compared to the treatment with an exchangeable aluminium level of 1.26 me. But calcium content of both grain and husk is highest in the treatment where exchangeable aluminium content and percentage aluminium saturation is minimum. This may be explained in the light of a greater amount of calcium available in the treatment where exchangeable aluminium is minimum. Potassium contents in the grain and husk do not show any variation due to the reduction in percentage aluminium saturation or exchangeable aluminium content of the soil.

Aluminium content in grain and husk is reduced to a considerable extent by a reduction in exchangeable aluminium and percentage aluminium saturation of the soil. The treatment where the exchangeable aluminium content is 1.26 me has accumulated the least content of aluminium in grain and husk compared to the treatment where exchangeable aluminium is minimum and in the control. Zinc content in the grain and husk also register an increase with a decrease in exchangeable aluminium.

From these results it may be concluded that reducing the percentage aluminium saturation to around 30 by the application of 500 kg/ha lime is most optimum to increase the content of nutrients like N, P, Mg and Zn in the grain. Treatments with percentage aluminium saturation around 40 and the treatment with negligible percentage aluminium saturation have produced grains of much lower nutrient value in terms of their content of N, P, Mg and Zn. The content of calcium in grain is, however, maximum in the treatment with minimum exchangeable aluminium and percentage aluminium saturation, which may be attributed to a comparatively higher content of calcium in the soil due to the application of a very high level of lime.

Pulses are the most important source of proteinaceous food and the nutritive value of this diet mainly depends on the protein content of the grain which in turn depends on its content of nitrogen. Lime level which reduce the percentage aluminium saturation to 30 has helped to accumulate more of nitrogen as well as other nutrients in the grain. This in turn will improve its quality.

Influence of exchangeable aluminium on nutrient uptake

It may be noted that the inhibitory effect of aluminium is more prominent on calcium and phosphorus uptake in cowpea compared to the other elements as seen from the significant negative correlation that exists between exchangeable aluminium content and percentage aluminium saturation of soils and uptake of phosphorus and calcium. Guerrier (1977) has observed a similar effect of aluminium on the uptake of calcium and phosphorus in pulses.

A higher content of exchangeable aluminium in the soil adversely affects the uptake of N, P, K, Ca, Mg and Fe in fodder maize. Such an appreciable reduction in the uptake of nutrients under aluminium toxic conditions in several cereals have been reported (Fageria and Carvalho, 1982; Abraham [illegible], 1984).

<u>Influence of aluminium content in plant on growth and nutrient uptake</u>

A significant negative correlation is observed between aluminium content in plant and total pod as well as grain yield in cowpea. The concentration of aluminium in plants seems to exert a depressing effect on other plant characters such as root length, nodule count, dry weight etc. as seen from the negative correlation between these characters and aluminium.

In the case of fodder maize also aluminium content is negatively correlated to nutrient uptake and various yield parameters. This may be attributed to the direct toxic effects of aluminium on nutrient uptake and yield in fodder maize.

Such undesirable effects produced by high levels of aluminium on the growth of root and its elongation, nodulation, dry matter production etc. are evident from the reports of Franco and Munns (1982); Kim et al. (1985) and Alva et al. (1986).

It may be noted from the results discussed here that aluminium can reduce the uptake of many of the nutrients essential for plant growth as well as for maintaining the nutritive quality of the produce. Possibly, the reduced absorption of many of the nutrients might be due to the competition of aluminium for common binding sites at or near root surface thereby reducing the uptake of calcium, potassium, magnesium and copper.

A reduced nutrient uptake in rice due to similar competition has been observed by Fageria and Carvalho (1982).

A strong negative relationship is noted between aluminium content of root and its length, weight of tops and total dry matter production. The unfavourable influence of aluminium on these plant characters may possibly be related to a reduced nutrient uptake resulting from a higher content of aluminium in the root. The antagonistic influence of aluminium on nutrient uptake is further supported by the significant and negative correlation that exists between the uptake of nitrogen, phosphorus, potassium, calcium, magnesium and iron and the aluminium content of roots.

In the light of the results obtained from the present study, it may be concluded that exchangeable aluminium in the soil which contributes to the percentage aluminium saturation exhibits a strong antagonistic influence on the growth and yield as well as nutrient uptake in cowpea and fodder maize.

Control of exchangeable aluminium to tolerant limits is thus imminent and it is only a matter of identifying and fixing the liming rates to achieve this. It is imperative that liming is done only upto the point of elimination of aluminium toxicity for various crops. Plants differ in their capacity to tolerate levels of exchangeable aluminium in the soil and cowpea is seen to tolerate a higher level of exchangeable aluminium (1.26 me/100 g) while fodder maize is not. Thus it follows that the same level of liming cannot be recommended for cowpea and fodder maize. A better criteria in this respect will therefore, be to determine the level of lime that may reduce the exchangeable aluminium to 1.26 me/100 g soil in the case of cowpea and its complete elimination in the case of fodder maize. Since fodder maize is more sensitive to aluminium, a better performance is possible only in soils limed upto the point of total elimination of exchangeable aluminium. Liming to reduce percentage aluminium saturation to around 20, 30 or 40 has recorded only a poor response compared to the complete elimination of exchangeable aluminium. While 500 kg lime/ha is sufficient to bring down the exchangeable aluminium to a tolerable limit for cowpea, this is not enough for fodder maize which needs a higher level of lime to completely eliminate exchangeable aluminium. At the same time the use of 7.7 t/ha of lime to raise the pH to near neutrality is also unnecessary since a much lower amount alone would be needed to nullify the effect of exchangeable aluminium. Computation based on exchangeable aluminium content of soil at different liming rates indicate that 544 kg/ha would be the minimum amount of lime needed to achieve this

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A study has been undertaken to find out the suitability of using exchangeable aluminium as an Index of liming for the acidic upland soils of Kerala. The investigation was carried out on the following aspects.

A total number of 80 soil samples representing the five major upland soil types of Kerala viz. laterite, alluvial, red loam, sandy and forest soils were collected and chemical nature of these soils was determined with a view to find out the status of exchangeable aluminium and other factors contributing to soil acidity. One soil sample containing the highest amount of exchangeable aluminium and highest percentage aluminium saturation was selected for a pot culture experiment. The growth, yield and nutrient uptake of two acid sensitive crops namely cowpea and fodder maize were studied in this soil after maintaining different levels of exchangeable aluminium by applying different levels of lime. The levels of lime based on conventional lime requirement method and that required to bring down the exchangeable aluminium content of the soil to tolerant limits for the two crops was also selected. The performance of the crops in the presence of different levels of exchangeable aluminium was compared by making biometric observations and by chemically analysing the plant and soil samples at different stages of their growth and at harvest.

From the results obtained, the effect of different levels of exchangeable aluminium on the growth and nutrient uptake of these plants could be brought out and the comparative sensitivity of cowpea and fodder maize to exchangeable aluminium content in soil could be revealed.

The important findings from this investigations are summarised below.

1. The pH of the upland soils varied from 4.2 to 7.2 and was lowest in laterite and alluvial soil and highest in red loam soils. pH when determined in 0.01 M $CaCl_2$ solution recorded a lowering of 0.2 to 2.9 units compared to pH in water.

2. Lime requirement and cation exchange capacity were

minimum in sandy soil. Lime requirement was maximum in the laterite soil and CEC was maximum in alluvial soil, Exchangeable aluminium content and PAS were maximum in laterite soil while a few of the red loam soils recorded almost nil values.

3. Application of different levels of lime as per the treatments resulted in a significant rise in pH and a significant lowering of total acidity, exchangeable aluminium and exchangeable hydrogen content of the soil. Addition of fertilizers to the limed soils also lead to an increase in pH and a corresponding reduction in total acidity as well as both exchangeable aluminium and hydrogen.

4. Cultivation of fodder maize and cowpea has resulted in an increase in pH and a decrease in total acidity and exchangeable aluminium and hydrogen content of the soil at their early stages of growth. But at harvest, both these plants slightly reduced the pH of the soil leading to a corresponding rise in acidity, exchangeable aluminium and hydrogen content.

5. Maximum height of plant as well as length of root in cowpea is observed in soils with an exchangeable aluminium level of 1.26 me/100 g. Complete elimination of exchangeable aluminium showed a depressing effect on both these characters. A reduction in exchangeable aluminium brought about by liming has also resulted in a linear increase in the number of root nodules. The number of nodules in plants in all the treatments decreased towards harvest.

6. Maximum dry matter production and grain yield in cowpea were recorded at an exchangeable aluminium content of 1.26 me/100 g. A further increase or decrease in exchangeable aluminium showed a depressing effect on both these characters.

7. Correlation between exchangeable aluminium content of soils and characters like height of the plant, root length, nodule count, grain yield, total pod yield and total dry matter production in cowpea were negative and significant. Maintenance of exchangeable aluminium at 1.26 me/100 g with a corresponding percentage aluminium saturation value of around 30 appeared

to be the optimum for maximising the yield in cowpea. Complete elimination of exchangeable aluminium appears to be unnecessary and uneconomical as indicated from the negative effect of this treatment on the growth and yield of cowpea.

8. The fodder maize also showed an increase in height with a reduction in exchangeable aluminium content of the soil. The maximum height was recorded when the exchangeable aluminium was 1.26 me with percentage aluminium saturation value around 30.

9. Other plant characters of fodder maize such as weight of tops and roots, length of roots and total dry matter production etc. exhibited a linear negative relationship with exchangeable aluminium content, maximum values for each of these characters being recorded at the minimum level of exchangeable aluminium. The suppressing effect of aluminium on root growth was evident from the negative and significant correlation that existed between exchangeable aluminium and root length of fodder maize.

10. The nutrient uptake in both cowpea and fodder maize

showed a similar behaviour towards levels of exchangeable aluminium in soils. Among the different nutrients, the nitrogen content in tops and roots showed a linear increase with a decrease in exchangeable aluminium content of the soil throughout the growth of cowpea and fodder maize. Aluminium content in tops and roots was adversely related to the nitrogen content in tops and roots.

11. At higher values of exchangeable aluminium in soil the concentration of phosphorus in tops showed a reduction due to the strong antagonistic relation between aluminium and phosphorus. Aluminium content in the tops and roots of cowpea and fodder maize recorded a negative correlation to phosphorus content in tops and roots.

12. A reduction in exchangeable aluminium in soils did not produce any marked difference in the potassium content of roots and tops of cowpea. However, a general increase in potassium content in fodder maize has been obtained due to a reduction in exchangeable aluminium. A high aluminium content was not found to inhibit the absorption

and translocation of potassium in cowpea, eventhough in fodder maize a strong negative correlation prevailed between aluminium and potassium content in roots.

13. Calcium content in tops of cowpea recorded the highest value with the complete elimination of exchangeable aluminium content in soil, but the content in root was maximum when soils contained about 1.26 me exchangeable aluminium. Thus, fodder maize was found to be more sensitive compared to cowpea in the absorption of calcium in the presence of aluminium. A strong negative relation was also found to exist between aluminium content and calcium content in tops of fodder maize.

14. Magnesium content in the tops and roots of both cowpea and fodder maize increased with a reduction in the level of exchangeable aluminium in the soil. Cowpea was found to be more tolerant in absorbing magnesium in presence of aluminium than fodder maize as evident from the higher magnesium content at a higher level of exchangeable aluminium in cowpea compared to fodder maize which recorded the highest value for magnesium only after complete elimination of exchangeable aluminium in the soil.

15. A reduction in the level of exchangeable aluminium in soil has reduced the content of iron in the tops of cowpea and fodder maize. Iron content in roots of cowpea and fodder maize exhibited a negative relationship with the iron content in the tops.

16. The uptake of zinc by cowpea was not much affected due to a reduction in the exchangeable aluminium content. But a higher content of zinc is noticed in fodder maize, where the exchangeable aluminium has been completely reduced by liming. However in both plants, the uptake of zinc has been reduced due to over liming. But copper content in cowpea and fodder maize was not affected by a reduction in exchangeable aluminium in soil.

17. Aluminium content in both tops and roots of cowpea and fodder maize decreased with a reduction in the exchangeable aluminium content of soil. Aluminium concentration in root was found to be significantly higher than that in tops and a strong positive correlation between aluminium content in tops and roots was evident.

18. A reduction in exchangeable aluminium and percentage aluminium saturation values has resulted in an increased uptake of N, P, Ca and Mg in both grain and husk of cowpea. Soils having an exchangeable aluminium content of 1.26 me/100 g recorded the highest value for all these nutrients. The inhibitory effect of aluminium appears to be more prominent on the uptake of calcium and phosphorus compared to other elements in both cowpea and fodder maize.

19. The content of aluminium in the grain and husk recorded the lowest value in soils with an exchangeable aluminium of 1.26 me/100 g.

20. Reducing the exchangeable aluminium level to 1.26 me/100 g by the application of 500 kg lime has helped to increase the yield and nutrient uptake in cowpea. But in fodder maize this level of lime has been found to be insufficient and complete elimination of aluminium toxicity appears to be essential.

From the results of the present investigation it may be concluded that higher levels of exchangeable aluminium adversely affect the growth and yield of cowpea and fodder maize. It can adversely affect their quality by influencing the uptake of nutrients and their content in roots, tops and grains. It appears that cowpea can be cultivated profitably in presence of 500 kg lime/ha which permits to maintain a certain amount of exchangeable aluminium level in soils, while fodder maize is more sensitive to exchangeable aluminium than cowpea and performed better only when the excess aluminium was completely eliminated. Cowpea exhibited a greater tolerance to aluminium at 1.26 me of exchangeable aluminium.

It follows from the results that a level of lime higher than 500 kg/ha may practically effective in completely eliminating the level of exchangeable aluminium in the soil. This level of lime has been arrived by calculation as 544 kg/ha which is very much less than the lime requirement based on conventional methods to bring the soil pH to neutrality. Application of 544 kg lime/ha which can completely suppress the exchangeable aluminium instead of full lime requirement values of the soil may therefore be considered to be optimum for fodder maize in producing maximum drymatter and permit a greater uptake of nutrients.

Since the critical levels of exchangeable aluminium appears to be different for different crops, it is desirable that lime levels to reduce exchangeable aluminium to such a critical level alone be applied. The results of the present study thus point to the advantage in adopting the exchangeable aluminium level of soil as a better index of liming for various crops grown in the upland acidic soils of Kerala.

REFERENCES

REFERENCES

Abraham Alice. 1984. The release of aluminium in soils under submerged conditions and its effect on rice. Ph.D. Thesis, Kerala Agricultural University.

Abruna, R.F., Chandler, V.J. and Pearson, R.W. 1964. Effects of liming on yields and composition of heavy fertilized grasses on soil properties under humid tropical conditions. Proc. Soil Sci. Soc. Am., 28: 657-661.

Abruna, R.F., Escolar, P.R., Chandler, V.J., Figarella, J. and Silva, S. 1974(a). Response of green beans to acidity factors in six tropical soils. J. Agric. Uni. Peurto Rico, 58: 44-57.

Abruna, R.F., Escolor, P.R., Chandler, V.J., Pearson, R.W. and Silva, S. 1974(b). Response of corn to acidity factors in eight tropical soils. J. Agri. Uni. Puerto Rico, 58: 57-59.

Adams, F. and Lund, Z.F. 1966. Effect of chemical activity of soil solution aluminium on cotton root penetration of ecid sub soils. Soil Sci., 101: 193-198.

Adams, F. and Hatchcock, P.J. 1984. Aluminium toxicity and Ca deficiency in acid sub soil horizons of two coastal plains soil series. Soil Sci. Soc. Am. J., 48: 1305-1309.

Alley, M.M. 1981. Short term soil chemical and crop yield response to lime stone application. Agron. J., 73: 687-689.

Alva, A.K., Asher, C.J. and Edwards, D.G. 1986. The role of Ca in alleviating aluminium toxicity. Aust. J. Agri. Res., 37: 375-382.

Amedee, G. and Peech, M. 1976. The significance of KCl-extractable Al (III) as an index to lime requirement of soils of the humid tropics. *Soil Sci.*, **121**: 227-233.

Andrew, C.S. and Vandenberg, P.J. 1973. The influence of aluminium on phosphate sorption by whole plants and excised roots of some pasture legumes. *Aust. J. Agric. Res.*, **24**: 341-351.

Andrew, C.S., Johnson, A.D. and Sandland, R.L. 1973. Effect of aluminium on the growth and chemical composition of some tropical and temperate pasture legumes. *Aust. J. Agri. Res.*, **24**: 325-339.

Aniol, A., Hill, R.D. and Larter, E.N. 1979. Al tolerance of spring rye inbred lines. *Crop Sci.* **20**: 205-208.

Anonymous. 1984. The package of practice recommendations of the Kerala Agricultural University.

Awad, A.S., Edwards, D.G. and Milham, P.J. 1976. Effect of pH and phosphate on soluble soil aluminium and on growth and composition of Kikuyu grass. *Plant soil*, **45**: 531-542.

Bache, B.W. 1985. Soil acidification and aluminium mobility. Soil use and management, **1**: 10-14.

Bache, B.W. and Crooke, W.M. 1981. Interaction between Al, P and pH in the response of barley to soil acidity. *Plant Soil*, **61**: 365-375.

*Bennet, R.J., Breen, C.M. and Fey, M.V. 1985. The primary site of aluminium injury in the root of *Zea mays* L. *South African J. of Plant and Soil*, **2**: 8-17.

Black, C.A. 1973. Soil plant relationships, Wiley Eastern Private Limited, New Delhi, 273-355.

Blair, A.W. and Prince, A.L. 1923. Studies on the toxic properties of soils. Soil Sci., 15: 109-129.

Bloom, P.R., Mc Bride, M.B. and Weaver, R.M. 1979. Aluminium and organic matter in acid soils. Buffering and solution aluminium activity. Soil Sci. Soc. Am. J., 43: 488-493.

Brenes, E. and Pearson, R.W. 1973. Root responses of three graminae species to soil acidity in an oxisol and ultisol. Soil Sci., 116: 295-302.

Cate, R.B. and Sukhai, A.P. 1964. A study of aluminium in rice soils. Soil Sci., 98: 85-93.

Chenery, E.M. 1948. Thioglycolic acid as an inhibitor for iron in the calorimetric determination of aluminium by means of aluminon. Analyst, 73: 501-502.

Clark, J.S. and Nichol, W.E. 1966. The lime potential percent base saturation relations of acid surface horizon of mineral and organic soils. Can. J. Soil Sci., 46: 281-285.

Cochrane, T.T., Salinas, J.G. and Sanchez, P.A. 1980. An equation for liming acid mineral soils to compensate crop Al tolerance. Tropical Agric., 57: 113-140.

Coleman, N.T., Kamprath, E.J. and Weed, S.B. 1958. Liming. Adv. Agron., 10: 475-517.

*Cruz, A.D., Haag, H.P. and Sarruge, J.R. 1967. P and Al interactions in two wheat varieties (Triticum vulgare) grown in nutrient solution. Anais. ESC. Sup. Agric. Luiz Queivoz., 24: 119-129.

Curtin, D. and Smillie, G.W. 1986. Effects of liming on soil chemical characteristics and grass growth in laboratory and long term field amended soils. Plant Soil, 95: 15-22.

Desapandae, T.L. 1976. Acid soils of Maharashtra. Bull. Indian Soc. Soil Sci., 11: 47-53.

*Dewan, H. 1966. Acidity of certain Virginia soil as related to their minerology and chemistry. Diss. Abstr., 26: 3575.

Dionne, J.L. and Pesant, A.R. 1985. Effects of application of Mn and Al, soil pH and moisture regimes on alfalfa yields and the availability of Mn and Al. Can. J. Soil Sci., 65: 269-282.

Ekpete, D.M. 1972. Assessment of the lime requirement of Eastern Nigeria soils. Soil Sci., 113: 363-372.

Evans, C.E. and Kamprath, E.J. 1970. Lime response as related to percent aluminium saturation, solution aluminium and organic matter content. Proc. Soil Sci. Soc. Am. 34: 893-896.

Fageria, N.K. 1985. Influence of aluminium in nutrient solutions on chemical composition in two rice cultivars at different growth stages. Plant Soil, 85: 423-429.

Fageria, N.K. and Carvalho, J.R.P. 1982. Influence of aluminium in nutrient solutions on chemical composition in upland rice cultivars. Plant Soil, 69: 31-44.

Farina, M.P.W., Sumner, M.E., Plank, C.O. and Letzsch, W.S. 1980. Exchangeable aluminium and pH as indicators of lime requirement for corn. Soil Sci. Soc. Am. J., 44: 1036-1041.

Fox, R.H. 1979. Soil pH, aluminium saturation and corn grain yield. *Soil Sci.*, **127**: 330-334.

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

Foy, C.D., Burns, G.R., Brown, J.C. and Fleming, A.L. 1965. Differential aluminium tolerance of two wheat varieties associated with plant induced pH changes around their roots. *Proc. Soil Sci. Soc. Am.* **29**: 64-67.

Foy, C.D., Fleming, A.L., Burns, G.R. and Armiger, W.H. 1967. Characterisation of differential aluminium tolerance among varieties of wheat and barley. *Proc. Soil Sci. Soc. Am.*, **31**: 513-521.

Foy, C.D., Jones, J.E. and Webb, H.W. 1980. Adaptation of cotton genotypes to an acid, aluminium toxic soil. *Agron. J.*, **72**: 833-839.

Franco, A.A. and Munns, D.N. 1982. Acidity and aluminium restraints on nodulation, nitrogen fixation and growth of *Paseolus vulgaris* in solution culture. *Soil Sci. Soc. Am. J.*, **46**: 296-301.

Frink, C.R. 1973. Aluminium chemistry in acid sulphate soils. *Proc. Int. Sym. Acid sulphate Soils*, Wageningen, 1: 131-168.

Gillman, G.P. and Sumpler, E.A. 1986. Surface charge characteristics and lime requirement of soils derived from Basaltic, Granitic and Metamorphic rocks in high rainfall tropical Queensland. *Aust. J. Soil Res.*, **24**: 173-192.

Goswami, N.N., Leelavathi, L.R. and David, M.S. 1976. Response of cereals to lime as affected by its rate of application and fertilizer treatments in acid soils. Bull. Indian Soc. Soil Sci., **11**: 238-245.

Guerrier, G. 1977. Absorption of mineral elements in presence of aluminium. Plant Soil, 51: 275-278.

Halder, B.R. and Mandal, M. 1985. Lime requirement of acid soils in relation to pH, exchange acidity, extractable acidity and exchangeable Al content of the soils. J. Indian Soc. Soil Sci., **33**: 528-535.

Hargrove, W.L. and Thomas, G.W. 1981. Titration properties of aluminium organic matter. Soil Sci. **134**: 216-225.

Haynes, R.J. and Ludecke, T.E. 1981. Effect of lime and phosphorus application on the concentrations of available nutrients and on P, Al and Mn uptake by two pasture legumes in an acid soil. Plant Soil, **62**: 117-128.

Helyar, K.R. and Anderson, A.J. 1974. Effect of Calcium Carbonate on the availability of nutrients in an acid soil. Proc. Soil Sci. Soc. Am., **38**: 341-346.

Holford, I.C.R. 1985. Effects of lime on yields and phosphate uptake by clover in relation to changes in soil phosphate and related characteristics. Aust. J. Soil Res., **23**: 75-83.

Horsnell, L.J. 1985. The growth of improved pastures on acid soils. 1. The effect of superphosphate and lime on soil pH and on the establishment and growth of phalaris and lucerne. Aust. J. Expt. Agric., **25**: 149-156.

Hortenstine, C.C. and Fiskell, J.G.A. 1961. Effects of aluminium on sunflower growth and uptake of boron and calcium from nutrient solution. Proc. Soil Sci. Soc. Am., 25: 304-307.

Hoyt, P.B. and Nyborg, M. 1971. Toxic metals in acid soil 1. Estimation of plant available aluminium. Proc. Soil Sci. Soc. Am., 35: 236-240.

Hutchinson, F.E. and Hunter, A.S. 1970. Exchangeable aluminium levels in two soils as related to lime treatment and growth of six crop species. Agron. J., 62: 702-704.

*Hutton, C.E. and Fiskell, J.G.A. 1965. Soil acidity factors affecting corn production in West Florida. Proc. Soil Crop Sci. Soc. Fla., 25: 36-46.

Indira, M. 1985. Nitrogen fixation by cowpea as influenced by the stage of growth and duration of crop. M.Sc.(Ag) Thesis, Kerala Agricultural University.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India (P) Ltd., New Delhi.

James, B.R. and Riha, S.T. 1984. Soluble aluminium in the acidified organic horizons of forest soils. Can. J. Soil Sci., 64: 637-646.

Jarvis, S.C. and Hatch, D.J. 1986. The effects of low concentrations of aluminium on the growth and uptake of nitrate-nitrogen by white clover. Plant Soil, 95: 43-45.

Jones, U.S., Samonte, H.P. and Jariel, D.M. 1982. Response of corn and inoculated legumes to urea, lime, P and S on Guadalupe clay. Soil Sci. Soc. Am. J., 46: 296-301.

*Juste, C. 1966. Contribution to the study of the aluminium cycle in the acid soils of the South West Atlantic area. II. Application to their reclamation. *Annls. agron.*, **17**: 251-341.

Kabeerathumma, S. and Nair, C. 1973. Effect of liming on exchangeable cations and pH of acid soils of Kuttanad. *Agri. Res. J. Kerala*, **11**: 9-13.

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

*Keefer, R.F., Singh, R.N., Bennett, O.C. and Horvath, D.J. 1983. Chemical composition of plants and soils from revegetated mine soils. In proceeding 1983. Symposium on surface mining, hydrology, sedimentology and reclamation; 155-161.

Keyser, H.H. and Munns, D.N. 1979. Tolerance of Rhizobia to acidity, aluminium and phosphate. *Soil Sci. Soc. Am. J.*, **43**: 519-523.

Khanna, P.K., Raison, R.J. and Falkiner, R.A. 1986. Exchange characteristics of some acid organic rich forest soils. *Aust. J. Soil Res.*, **24**: 67-80.

Kim, M.K., Edwards, D.G. and Asher, C.J. 1985. Tolerance of *Trifolium subterranium* cultivars to low pH. *Aust. J. Agri. Res.*, **36**: 569-578.

Kunishi, H.M. 1982. Combined effects of lime, phosphate fertilizer and aluminium on plant yield from an acid soil of the South-eastern United States. *Soil Sci.*, **134**: 233-238.

Lee, C.R. 1971. Influence of aluminium on plant growth and tuber yield of potatoes. *Agron. J.*, **63**: 363-364.

Ligon, W.S. and Pierre, W.H. 1932. Soluble aluminium studies - II. Minimum concentrations of aluminium found to be toxic to corn, sorghum and barley in the culture solution. Soil Sci., 34: 307-321.

Lockard, R.G. and Mc Walter, A.R. 1956. Effect of toxic levels of Sodium, Arsenic, Iron and Aluminium on the rice plants. Malayan Agric. J., 39: 256-267.

Long, F.L. and Foy, C.D. 1970. Plant varieties as indicators of aluminium toxicity in the A2 horizon of a Norfolk soil. Agron. J., 62: 679-681.

Mac Lean, A.A. and Chiasson, T.C. 1966. Differential performance of two barley varieties to varying aluminium concentrations. Can. J. Soil Sci., 46: 147-153.

Mac Leod, L.B. and Jackson, L.P. 1967. Aluminium tolerance of two barley varieties in nutrient solution, peat and soil culture. Agron. J., 59: 359-363.

Magistad, O.C. 1925. The aluminium content of the soil solution and its relation to soil reaction and plant growth. Soil Sci., 20: 181-226.

Malavolta, E., Nogueira, F.D., Oliveira, I.P., Nakayamma, L. and Elmori, I. 1981. Aluminium tolerance of sorghum and bean-Methods and results. J. Plant Nutr., 3: 687-694.

*Manrique, L.A. 1986. The relationship of soil pH to Al saturation and exchangeable aluminium in Ultisols and Oxisols. Commun. In. Soil Sci. Plant Anal., 17: 439-455.

Martini, J.A. and Mutters, R.G. 1985. Effect of lime rates on nutrient availability, mobility and uptake during the soybean - growing season. 1. Aluminium, Manganese and Phosphorus. Soil Sci., 139: 219-226.

Martini, J.A., Kochhan, R.A., Siqueira, O.J. and Borket, C.M. 1974. Response of soybeans to liming as related to soil acidity, Al and Mn toxicities, and P in some Oxisols of Brazil. Soil Sci. Soc. Am. Proc., 38: 616-620.

Martini, J.A., Kochhann, R.A., Gomes, E.P. and Langer, F. 1977. Response of wheat cultivars to liming in some high Aluminium Oxisols of Rio Grande do Sul, Brazil. Agron. J. 69: 612-616.

Mc Lean, E.O., Hourigan, W.R., Shoemaker, H.E. and Bhumbla, D.R. 1964. Aluminium in soils V Forms of aluminium as a cause of soil acidity and a complication in its measurement. Soil Sci., 97: 119-126.

Mendez, J. and Kamprath, E.J. 1978. Liming of latosols and the effect on phosphorus response. Soil Sci. Soc. Am. J., 42: 86-88.

Mugwira, L.M., Patel, S.U. and Fleming, A.L. 1980. Aluminium effects on growth and Al, Ca, Mg, K and P levels in Triticale, Wheat and Rye - Plant Soil, 57: 467-470.

*Mukhopadhyay, P., Haldar, M. and Mandal, L.N. 1984. Effect of Calcium carbonate on the availability of Al, Mo, P, Ca and Mg in waterlogged acidic rice soils. Agro. Chemica, 28: 125-132.

Nye, P., Craig, D., Coleman, N.T. and Ragland, J.L. 1961. Iron exchange equilibria involving aluminium. Proc. Soil Sci. Soc. Am., 25: 14-17.

Oates, K.M. and Kamprath, E.J. 1983. Soil acidity and liming. I. Effect of extracting solution cation and pH on the removal of aluminium from acid soils. Soil Sci. Soc. Am. J., 47: 686-689.

Ota, Y. 1968. Mode of occurrence of bronzing in rice plant. *Jap. Agric. Res. Q.*, **3**: 1-5.

Pal, A.K., and Mandal, L.N. 1935. Lime requirement of alluvial acid soils in relation to buffer pH acidity measured by different methods. *J. Indian Soc. Soil Sci.*, 33: 271-277.

Pavar, H. and Marshall, C.E. 1934. The role of aluminium in the reaction of the clays. *J. Soc. Chem. Ind.*, **53**: 750-760.

*Pearson, R.W. 1975. Soil acidity and liming in the humid tropics. *Cornell Intl. Agric. Bull.* 30. Cornell Univ. Itbaca, N.Y.

*Pieri, C. 1974. Preliminary experimental studies on the sensitivity of ground to aluminium toxicity. *Agronomic Tropicale*, **29**: 685-696.

Ragland, J.L. and Coleman, N.T. 1959. The effect of soil solution aluminium and calcium on root growth. *Proc. Soil Sci. Soc. Am.*, **23**: 355-360.

Rechcigl, J.E., Reneau, R.W., Wolf, D.D.Jr., Kroontje, W. and Van Scoyoe, S.W. 1986. Alfalfa seedling growth in nutrient solutions as influenced by Al, Ca and pH. *Commun. in Soil Sci. plant anal.*, **17**: 27-44.

Reeve, N.G. and Sumner, M.E. 1970. Effects of aluminium toxicity and P fixation on crop growth on oxisols in Natal. *Proc. Soil Sci. Soc. Am.*, **34**: 263-267.

Reid, D.A., Jones, G.D., Armiger, W.H., Foy, C.D., Koch, E.J. and Sturling, T.M. 1969. Differential Al tolerance of winter barley varieties and selection in associated green house and field experiments. *Agron. J.*, **61**: 218-222.

Reid, D.A., Fleming, A.L. and Foy, C.D. 1971. A method of determining aluminium response of barley in nutrient solution in comparison to response in aluminium toxic soils. *Agron. J.*, *63*: 600-603.

Reid, J.B., Goss, M.J. and Robertson, P.D. 1982. Relationship between the decrease in soil stability effected by the growth of maize roots and change in organically bound Fe and Al. *J. Soil Sci.*, 33: 397-410.

*Ruschel, A.P., Alvahydo, R. and Sampaio, I.B.M. 1968. Effect of excess aluminium on growth of beans (*Phaseolus vulgaris* L) in nutrient culture. *Pesq. agropec. bras.*, *3*: 229-235.

Saigura, M., Shoji, S. and Takahashi, T. 1980. Plant root growth in acid andosols from north eastern Japan. Exchange acidity Y, as a realistic measure of aluminium toxicity potential. *Soil Sci.*, *130*: 242-280.

Sanchez, P.A. 1976. Properties and management of soils in the tropics. John Wiley & Sons, New York.

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

*Shamshuddin, J. and Tessens, E. 1983. Potentiometric titration of acid soils from Penninsular Malasia. Pertanika, *6*: 71-76.

Shoemaker, H.E.O., Mc Lean, E.O. and Pratt, P.F. 1961. Buffer methods for determining lime requirement of soils with appreciable amounts of extractable aluminium. *Proc. Soil Sci. Soc. Am.*, *25*: 274-277.

Sudharmai Devi, C.R. 1983. The nature of acidity in upland and rice fallows in relation to response of pulse crop to liming. M.Sc. Thesis, Kerala Agricultural University.

Suthipradit, S. and Alva, S.K. 1986. Aluminium and pH limitations for germination and radicle growth of soybean. *J. of Plant Nutr.*, **9**: 67-73.

Tanaka, A. and Navasero, S.A. 1966. Growth of rice plant on acid sulphate soils. *Soil Sci. Pl. Nutr.* **12**: 23-30.

Timmer, V.R. 1985. Response of hybrid poplar clone to soil acidification and liming. *Can. J. Soil Sci.*, **65**: 727-735.

Tomlinson, T.E. 1957. Relationship between mangrove vegetation soil texture and reaction of surface soil. *Tropic. Agrl.*, **34**: 41-50.

Tripathi, R.S. and Pande, H.K. 1971. Studies on toxicity factors and nutritional imbalance in soil for wheat culture in acid lateritic soil. *Int. Symp. Soil Fert. Evaluation*, 1: 821-830.

Truman, R.A., Humphreys, F.R. and Ryan, P.J. 1986. Effect of varying solution ratios of aluminium to calcium and magnesium on the uptake of phosphorus by *Pinus radiata*. *Plant Soil*, **96**: 109-123.

*Velly, J. 1974. Observations on the acidification of some soils of Madagascar. *Agronomie Tropicale*, **29**: 1249-1262.

Yuan, T.L. 1959. Determination of exchangeable hydrogen in soil by titration method. *Soil Sci.*, **88**: 164-167.

*Zakaria, Z.Z., Schroder, V.N. and Boota, K.J. 1977. Soybean response to calcium and phosphorus under aluminium saturation. Proc. Soil Crop Sci. Soc. Flor., **36**: 178-181.

*Zaini, Z. and Mercado, B.T. 1984. Phosphorus nutrition and phosphate activity of young rice plants grown in culture solution - II Phosphorus - aluminium interaction and phosphatase activity of roots. Philippine Agriculturist, **68**: 217-224.

* Originals not seen

APPENDICES

Appendix I(a)

Influence of different levels of lime on the soil reaction at different stages of growth of cowpea

Source	df	SS	MSS	F
1. After application of different levels of lime				
Total	15	11.0200		
Treat	3	10.9569	3.6523	689.1132^{xx}
Error	12	0.0631	0.0053	
2. After application of fertilizers				
Total	15	8.1644		
Treat	3	8.0319	2.6773	242.472^{xx}
Error	12	0.1325	0.0110	
3. At the maximum flowering stage				
Total	15	5.7494		
Treat	3	5.4919	1.8306	85.3335^{xx}
Error	12	0.2575	0.0215	
4. At the mid pod filling stage				
Total	15	5.2975		
Treat	3	4.8725	1.6242	45.8804^{xx}
Error	12	0.4250	0.0354	
5. At the harvest				
Total	15	6.4940		
Treat	3	6.0165	2.0055	50.3894^{xx}
Error	12	0.4775	0.0398	

xx Significant at 1% level

Appendix I(b)

Influence of different levels of lime on the total acidity of the soil at different stages of growth of cowpea

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	15	13.8629		
Treat	3	13.6449	4.5483	
Error	2	0.2179	0.0182	250.4526^{xx}
2. After the application of fertilizers				
Total	15	9.5386		
Treat	3	9.3531	3.1177	201.7092^{xx}
Error	2	0.1855	0.0155	
3. At the maximum flowering stage				
Total	15	3.2959		
Treat	3	3.2457	1.0818	258.5981^{xx}
Error	12	0.0502	0.0042	
4. At the mid pod filling stage				
Total	15	0.3758		
Treat	3	0.3111	0.1037	19.2268^{xx}
Error	12	0.0647	0.0054	
5. At the harvest stage				
Total	15	1.6205		
Treat	3	1.5633	0.5210	109.386^{xx}
Error	12	0.0572	0.0048	

xx Significant at 1% level

Appendix I(c)

Influence of different levels of lime on the exchangeable aluminium content of the soil at different stages of growth of cowpea

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	15	13.1831		
Treat	3	12.9314	4.3105	
Error	12	0.2518	0.0209	205.4557^{xx}
2. After the application of fertilizers				
Total	15	7.3850		
Treat	3	7.1991	2.3997	
Error	12	0.1859	0.0155	154.9488^{xx}
3. At the maximum flowering stage				
Total	15	1.3297		
Treat	3	1.2205	0.4068	
Error	12	0.1092	0.0091	44.6996^{xx}
4. At the mid pod filling stage				
Total	15	0.1837		
Treat	3	0.1836	0.0612	
Error	12	0.0002	0.00001	4250.69^{xx}
5. At the harvest stage				
Total	15	0.6451		
Treat	3	0.6450	0.2150	
Error	12	0.0001	0.00001	24169.34^{xx}

xx Significant at 1% level

Appendix I(d)

Influence of different levels of lime on exchangeable hydrogen content of the soil at different stages of growth of cowpea

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	15	0.0263		
Treat	3	0.0177	0.0059	
Error	12	0.0086	0.0007	8.2044^{x}
2. After the application of fertilizers				
Total	15	0.9361		
Treat	3	0.9281	0.3094	
Error	12	0.0080	0.0007	462.29^{xx}
3. At the maximum flowering stage				
Total	15	0.6924		
Treat	3	0.6252	0.2083	
Error	12	0.0672	0.0056	37.2154^{xx}
4. At the mid pod filling stage				
Total	15	0.1024		
Treat	3	0.0406	0.0135	
Error	12	0.0618	0.0005	2.6239^{NS}
5. At the harvest				
Total	15	0.2768		
Treat	3	0.2164	0.0721	
Error	12	0.0605	0.0050	14.3168^{xx}

x Significant at 5% level

xx Significant at 1% level

Appendix I(e)

Influence of different levels of lime on exchangeable potasium content of the soil at different stages of growth of cowpea

Source	df	SS	MSS	F
1. After application of different levels of lime				
Total	15	0.0403		
Treat	3	0.0353	0.0119	
Error	12	0.0050	0.0004	28.94^{XX}
2. After the application of fertilisers				
Total	15	0.0152		
Treat	3	0.0029	0.0009	
Error	12	0.0123	0.0010	0.9404^{NS}
3. At the maximum flowering stage				
Total	15	0.0958		
Treat	3	0.0165	0.0055	
Error	12	0.0793	0.0066	0.8325^{NS}
4. At the mid pod filling stage				
Total	15	0.0421		
Treat	3	0.0144	0.0079	
Error	12	0.0277	0.0023	2.0720^{NS}
5. At the harvesting stage				
Total	15	0.0269		
Treat	3	0.0161	0.0054	
Error	12	0.0108	0.0009	5.9596^{NS}

xx Significant at 1% level

Appendix I(f)

Influence of different levels of lime on exchangeable Ca content of the soil at different stages of growth of cowpea

Source	df	SS	MSS	F
1. After application of different levels of lime				
Total	15	349.0777		
Treat	3	348.3272	116.1091	
Error	12	0.7498	0.0625	1858.1432^{xx}
2. After the application of fertilizers				
Total	15	190.3120		
Treat	3	189.0846	63.0282	
Error	12	1.2274	0.1022	616.1930^{xx}
3. At the maximum flowering stage				
Total	15	122.1967		
Treat	3	114.2743	38.0914	
Error	12	7.9224	0.6602	57.6969^{xx}
4. At the mid pod filling stage				
Total	15	62.4647		
Treat	3	59.5158	19.8386	
Error	12	2.9489	0.2457	80.7299^{xx}
5. At the harvest stage				
Total	15	98.9967		
Treat	3	97.1773	32.3924	
Error	12	1.8194	0.1516	213.6477^{xx}

xx Significant at 1% level

Appendix I(g)

Influence of different levels of lime on exchangeable magnesium content of the soil at different stages of growth of cowpea

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	15	0.0726		
Treat	3	0.0296	0.0099	
Error	12	0.0430	0.0036	2.7600^{NS}
2. After the application of fertilizers				
Total	15	0.0496		
Treat	3	0.0011	0.0035	
Error	12	0.0390	0.0033	1.0939^{NS}
3. At the maximum flowering stage				
Total	15	0.1957		
Treat	3	0.1204	0.0401	
Error	12	0.0753	0.0063	6.3901^{x}
4. At the mid pod filling stage				
Total	15	0.1137		
Treat	3	0.0301	0.0100	
Error	12	0.0836	0.0070	1.4400^{NS}
5. At the harvest				
Total	15	0.1699		
Treat	3	0.0970	0.0324	
Error	12	0.0729	0.0061	5.3272^{x}

x Significant at 5% level

Appendix I(h)

Influence of different levels of lime on exchangeable iron content of the soil before and after cowpea cultivation

Source	df	SS	MSS	F
1. Before cultivation				
Total	15	143.5844		
Treat	3	139.1619	46.3873	
Error	12	4.4225	0.3685	125.8814^{xx}
2. After cultivation				
Total	15	2.8966		
Treat	3	2.1600	0.7200	
Error	12	0.7367	0.0061	11.7282^{xx}

xx Significant at 1% level

Appendix II

Influence of different levels of lime on the plant characters of cowpea at different stages of growth of cowpea

Height of the plant

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	15	114.52		
Treat	2	44.56	14.852	2.547^{NS}
Error	13	69.965	5.830	
2. At the mid pod filling stage				
Total	15	130.86		
Treat	2	29.38	9.792	1.158^{NS}
Error	13	101.49	8.457	
3. At the harvest				
Total	15	290.124		
Treat	2	84.652	28.217	1.648^{NS}
Error	13	205.473	17.123	

Root length

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	28.52		
Treat	3	22.61	7.536	
Error	8	5.91	0.739	10.19^{xx}
2. At the mid pod filling stage				
Total	11	45.747		
Treat	3	22.76	7.587	2.64^{NS}
Error	8	22.986	2.873	
3. At the harvest				
Total	15	70.03		
Treat	3	13.95	4.648	0.995^{NS}
Error	12	56.09	4.674	

xx Significant at 1% level

Appendix II (contd.)

Number of nodules

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	8.366		
Treat	3	4.552	1.517	3.580^{NS}
Error	8	3.814	0.477	
2. At the mid pod filling stage				
Total	11	46.842		
Treat	3	29.054	9.685	4.35^{x}
Error	8	17.787	2.223	
3. At the harvest				
Total	15	56.089		
Treat	3	25.569	8.523	3.355^{NS}
Error	12	30.486	2.541	

Grain yield

Source	df	SS	MSS	F
1. Grain yield				
Total	15	11.5		
Treat	3	8.985	2.995	14.29^{xx}
Error	12	2.515	0.2096	
2. Husk yield				
Total	15	2.529		
Treat	3	2.117	0.7056	20.5273^{xx}
Error	12	0.413	0.0344	
3. Total pod yield				
Total	15	23.56		
Treat	3	20.11	6.702	23.2764^{xx}
Error	12	3.455	0.283	

xx Significant at 1% level

x Significant at 5% level

Appendix II (contd.)

Total dry weight

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	1.269		
Treat	3	1.103	0.368	17.643^{xx}
Error	8	1.667	0.021	
2. At the mid pod filling stage				
Total	11	4.509		
Treat	3	3.209	1.070	6.580^{x}
Error	8	1.300	0.1625	
3. At the harvest				
Total	15	39.274		
Treat	3	5.497	1.832	0.651^{NS}
Error	12	33.777	2.815	

xx Significant at 1% level

x Significant at 5% level

Appendix II(a)

Influence of different levels of lime on nutrient composition of cowpea tops at different stages of growth of cowpea

Nitrogen

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	2.7807		
Treat	3	2.5033	0.8344	24.064^{xx}
Error	8	0.2774	0.0368	
2. At the mid pod filling stage				
Total	11	1.7486		
Treat	3	0.9095	0.3032	2.890^{NS}
Error	8	0.8391	0.1049	
3. At the harvest				
Total	15	0.3540		
Treat	3	0.1184	0.0395	2.011^{NS}
Error	12	0.2355	0.0196	

Phosphorus

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	0.0038		
Treat	3	0.0002	0.00005	0.1235^{NS}
Error	8	0.0036	0.0005	
2. At the mid pod filling stage				
Total	11	0.0113		
Treat	3	0.0094	0.0031	12.712^{xx}
Error	8	0.0020	0.0002	
3. At the harvest				
Total	15	0.0090		
Treat	3	0.0060	0.0020	7.9677^{x}
Error	12	0.0030	0.0003	

xx Significant at 1% level

x Significant at 5% level

Appendix II(e) contd.

Potassium

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	8.6319		
Treat	3	2.7986	0.9329	1.2794^{NS}
Error	8	5.8333	0.7292	
2. At the mid pod filling stage				
Total	11	1.0047		
Treat	3	0.4908	0.1636	2.5465^{NS}
Error	8	0.5139	0.0642	
3. At the harvest				
Total	15	2.8656		
Treat	3	0.0816	0.0272	0.1172^{NS}
Error	12	2.784	0.232	

Calcium

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	0.2587		
Treat	3	0.2570	0.0086	404.06^{xx}
Error	8	0.0017	0.0002	
2. At the mid pod filling stage				
Total	11	0.6978		
Treat	3	0.6599	0.2200	46.361^{xx}
Error	8	0.0380	0.0047	
3. At the harvest				
Total	15	0.3343		
Treat	3	0.2929	0.0976	28.136^{xx}
Error	12	0.0414	0.0035	

xx Significant at 1% level

Appendix II(a) contd.

Magnesium

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	0.0016		
Treat	3	0.0006	0.0002	1.7437^{NS}
Error	8	0.0009	0.0001	
2. At the mid pod filling stage				
Total	11	0.0032		
Treat	3	0.000008	0.000003	0.0063^{NS}
Error	8	0.0032	0.0004	
3. At the harvest				
Total	15	0.0140		
Treat	3	0.0010	0.0003	0.2943^{NS}
Error	12	0.0130	0.0011	

Iron

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	139837		
Treat	3	104057	34685.667	7.755^{xx}
Error	8	35779	4472.375	
2. At the mid pod filling stage				
Total	11	518606.6		
Treat	3	195886.6	65295.5	1.61863^{NS}
Error	8	322720	40340	
3. At the harvest				
Total	15	528192.75		
Treat	3	261068.75	87022.92	3.9093^{x}
Error	12	267125.00	22260.42	

xx Significant at 1% level

x Significant at 5% level

Appendix II(a) contd.

Aluminium

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	527291.67		
Treat	3	268491.67	89497.2	2.7665^{NS}
Error	8	258800	32350	
2. At the mid pod filling stage				
Total	11	223625		
Treat	3	106691	35563.667	2.433^{NS}
Error	8	116933	14616.625	
3. At the harvest				
Total	15	614943.8		
Treat	3	305918.8	101972.93	3.95^{x}
Error	12	309025	25752.1	

Zinc

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	1592.667		
Treat	3	246.00	82	0.487^{NS}
Error	8	1346.66	168.33	
2. At the mid pod filling stage				
Total	11	1840.916		
Treat	3	784.250	261.416	1.979^{NS}
Error	8	1056.666	132.083	
3. At the harvest				
Total	15	3551.75		
Treat	3	1972.25	657.42	4.995^{x}
Error	12	1579.5	131.625	

x Significant at 5% level

Appendix II(a) contd.

Copper

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	32		
Treat	3	6.67	2.22	0.702^{NS}
Error	8	25.33	3.167	
2. At the mid pod filling stage				
Total	11	96.667		
Treat	3	33.333	11.111	1.40^{NS}
Error	8	63.333	7.916	
3. At the harvest				
Total	15	93.438		
Treat	3	2.1875	0.7291	0.096^{NS}
Error	12	91.25	7.6041	

Appendix II(b)

Influence of different levels of lime on the nutrient composition of cowpea roots at different stages of growth of cowpea

Nitrogen

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	1.4904		
Treat	8	1.0844	0.3614	7.1209^{x}
Error	3	0.4061	0.0508	
2. At the mid pod filling stage				
Total	11	0.7135		
Treat	8	0.1351	0.0450	0.6229^{NS}
Error	3	0.5783	0.0723	
3. At the harvest				
Total	15	0.7463		
Treat	3	0.0344	0.0115	0.1931^{NS}
Error	12	0.7119	0.0593	

Phosphorus

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	0.0438		
Treat	3	0.0156	0.0052	1.46^{NS}
Error	8	0.0282	0.0035	
2. At the mid pod filling stage				
Total	11	0.0200		
Treat	3	0.0097	0.0032	2.5164^{NS}
Error	8	0.0102	0.0013	
3. At the harvest				
Total	15	0.07432		
Treat	3	0.01090	0.0036	0.687^{NS}
Error	12	0.0634	0.0053	

x Significant at 5% level

Appendix II(b) contd.

Potassium

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	0.0027		
Treat	3	0.0002	0.00006	0.2033^{NS}
Error	8	0.0025	0.00031	
2. At the mid pod filling stage				
Total	11	0.0094		
Treat	3	0.0046	0.0015	2.48^{NS}
Error	8	0.0049	0.0006	
3. At the harvest				
Total	15	0.0484		
Treat	3	0.0005	0.0002	0.0415^{NS}
Error	12	0.0479	0.0040	

Calcium

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	1.15128		
Treat	3	1.06843	0.35614	
Error	8	0.08285	0.01356	34.388^{xx}
2. At the mid pod filling stage				
Total	11	0.52744		
Treat	3	0.46458	0.15486	19.7066^{xx}
Error	8	0.06286	0.00785	
3. At the harvest				
Total	15	1.39011		
Treat	3	0.65724	0.21908	3.587^{x}
Error	12	0.73286	0.06107	

xx Significant at 1% level

x Significant at 5% level

Appendix II(b) contd.

Magnesium

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	0.0031		
Treat	3	0.0026	0.0009	12.826^{xx}
Error	8	0.0005	0.00007	
2. At the mid pod filling stage				
Total	11	0.0014		
Treat	3	0.0004	0.00012	0.8908^{NS}
Error	8	0.0010	0.00013	
3. At the harvest				
Total	15	0.0066		
Treat	3	0.0049	0.0016	12.90^{xx}
Error	12	0.0016	0.0001	

Iron

Source	df	SS	MSS	F
1. At the maximum flower stage				
Total	11	326389.2		
Treat	3	293549.2	97849.72	23.8367^{xx}
Error	8	32840	4105	
2. At the mid pod filling stage				
Total	11	417796.6		
Treat	3	360539.3	120179.777	16.7915^{xx}
Error	8	57257	7157.125	
3. At the harvest				
Total	15	94839.75		
Treat	3	43539.25	14513.1	3.391^{NS}
Error	12	51300	4275	

xx Significant at 1% level

Appendix II(b) contd.

Aluminium

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	1558825		
Treat	3	1504758.3	501586.1	
Error	8	54066.67	6758.33	74.47^{xx}
2. At the mid pod filling stage				
Total	11	510000		
Treat	3	371400	123800	
Error	8	140000	17500	7.074^{xx}
3. At the harvest				
Total	15	6270000		
Treat	3	5820000	1940000	
Error	12	450000	37800	51.73^{xx}

Zinc

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	11627		
Treat	3	3369	1123	
Error	8	8258	1032.25	1.0879^{NS}
2. At the mid pod filling stage				
Total	11	8162.92		
Treat	3	2342.92	780.97	
Error	8	5820	727.5	1.073^{NS}
3. At the harvest				
Total	15	58677.75		
Treat	3	36464.25	12154.5	
Error	12	22213.5	1851.125	6.5661^{xx}

xx Significant at 1% level

Appendix II(b) contd.

Copper

Source	df	SS	MSS	F
1. At the maximum flowering stage				
Total	11	94.66		
Treat	3	8.67	2.889	0.268^{NS}
Error	8	86	10.75	
2. At the mid pod filling stage				
Total	11	114.91		
Treat	3	37.583	12.5277	1.296^{NS}
Error	8	77.333	9.667	
3. At the harvest				
Total	15	631.75		
Treat	3	38.25	12.75	0.2577^{NS}
Error	12	593.5	49.458	

Appendix XI(a)

Influence of different levels of lime on the nutrient composition of grain and husk of cowpea

Nitrogen

Source	df	SS	MSS	F
1. Grain				
Total	15	2.0227		
Treat	3	0.6021	0.2007	1.696^{NS}
Error	12	1.4203	0.1183	
2. Husk				
Total	15	1.6695		
Treat	3	1.3667	0.4553	18.066^{xx}
Error	12	0.3028	0.0252	

Phosphorus

Source	df	SS	MSS	F
1. Grain				
Total	15	0.0911		
Treat	3	0.0547	0.0182	6.016^{xx}
Error	12	0.0364	0.0030	
2. Husk				
Total	15	0.1230		
Treat	3	0.0669	0.0223	4.7522^{xx}
Error	12	0.0562	0.0047	

xx Significant at 1% level

Appendix II(c) contd.

Potassium

Source	df	SS	MSS	F
1. Grain				
Total	15	1.0396		
Treat	3	0.2476	0.0825	1.205^{NS}
Error	12	0.7920	0.0660	
2. Husk				
Total	15	0.4002		
Treat	3	0.1779	0.0593	3.1996^{HS}
Error	12	0.2224	0.0185	

Calcium

Source	df	SS	MSS	F
1. Grain				
Total	15	0.00064		
Treat	3	0.00057	0.00019	35.39^{xx}
Error	12	0.00007	0.000006	
2. Husk				
Total	15	0.1010		
Treat	3	0.0890	0.0297	29.585^{xx}
Error	12	0.0120	0.0010	

xx Significant at 1% level

Appendix II(c) contd.

Magnesium

Source	df	SS	MSS	F
1. Grain				
Total	15	0.00479		
Treat	3	0.00268	0.000894	5.095^{x}
Error	12	0.00211	0.000176	
2. Husk				
Total	15	0.3826		
Treat	3	0.3726	0.1242	148.93^{xx}
Error	12	0.0100	0.0008	

Iron

Source	df	SS	MSS	F
1. Grain				
Total	15	12692.94		
Treat	3	6768.19	2256.06	4.569^{x}
Error	12	5924.75	493.729	
2. Husk				
Total	15	109653		
Treat	3	70374.5	23458.17	7.1667^{xx}
Error	12	39278.5	3273.21	

x Significant at 5% level

xx Significant at 1% level

Appendix II(c) contd.

Aluminium

Source	df	SS	MSS	F
1. Grain				
Total	15	23870.44		
Treat	3	16225.69	5408.56	8.49xx
Error	12	7644.75	637.06	
2. Husk				
Total	15	45951.7		
Treat	3	35717.2	11905.733	13.95xx
Error	12	10234.5	852.875	

Zinc

Source	df	SS	MSS	F
1. Grain				
Total	15	1518.687		
Treat	3	460.187	153.395	1.739NS
Error	12	1058.5	88.208	
2. Husk				
Total	15	893.75		
Treat	3	202.25	68.4167	1.1924NS
Error	12	688.5	57.375	

xx Significant at 1% level

Appendix II(c) contd.

Copper

Source	df	SS	MSS	F
1. Grain				
Total	15	389.438		
Treat	3	289.688	96.563	11.617^{xx}
Error	12	99.75	8.313	
2. Husk				
Total	15	53		
Treat	3	7.5	2.5	0.65^{NS}
Error	12	45.5	3.792	

Xx Significant at 1% level

Appendix III(a)

Influence of different levels of lime on soil reaction at different stages of growth of fodder maize

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	11	8.6892		
Treat	3	8.6625	2.8875	866.249^{xx}
Error	8	0.0267	0.0033	
2. After the application of fertilizers				
Total	11	5.6292		
Treat	3	5.5225	1.8408	138.06^{xx}
Error	8	0.1067	0.0133	
3. 30 days after sowing				
Total	11	3.38		
Treat	3	3.226	1.0755	56.135^{xx}
Error	8	0.153	0.01916	
4. 65 days after sowing				
Total	11	2.9692		
Treat	3	2.8292	0.9431	53.8895^{xx}
Error	8	0.1400	0.0175	
5. 90 days after sowing (at harvest)				
Total	11	4.290		
Treat	3	3.636	1.2122	14.8447^{xx}
Error	8	0.6533	0.08166	

xx Significant at 1% level

Appendix III(b)

Influence of different levels of lime on the total acidity of soil at different stages of growth of fodder maize

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	11	10.4327		
Treat	3	10.2720	3.4240	170.489^{xx}
Error	8	0.1607	0.0201	
2. After the application of fertilizers				
Total	11	6.4285		
Treat	3	5.9617	1.9872	34.0540^{xx}
Error	8	0.4668	0.0584	
3. 30 days after sowing				
Total	11	2.3557		
Treat	3	2.3509	0.7836	1301.006^{xx}
Error	8	0.0048	0.00006	
4. 65 days after sowing				
Total	11	0.2477		
Treat	3	0.2015	0.0672	11.614^{xx}
Error	8	0.0463	0.0058	
5. 90 days after sowing				
Total	11	1.2578		
Treat	3	1.0509	0.3503	13.546^{xx}
Error	8	0.2069	0.0259	

xx Significant at 1% level

Appendix III(c)

Influence of different levels of lime on the exchangeable aluminium content of the soil at different stages of growth of maize

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	11	10.0047		
Treat	3	9.8365	3.2788	155.956^{xx}
Error	8	0.1683	0.0210	
2. After fertiliser application				
Total	11	4.4372		
Treat	3	4.2737	1.4246	69.711^{xx}
Error	8	0.1635	0.0204	
3. 30 days after sowing				
Total	11	0.84601		
Treat	3	0.84588	0.2820	16266.92^{xx}
Error	8	0.00013	0.00002	
4. 65 days after sowing				
Total	11	0.1037		
Treat	3	0.1036	0.0345	2301.49^{xx}
Error	8	0.0001	0.000015	
5. 90 days after sowing				
Total	11	0.4336		
Treat	3	0.3937	0.13124	26.299^{xx}
Error	8	0.0399	0.00499	

xx Significant at 1% level

Appendix III(d)

Influence of different levels of lime on exchangeable hydrogen content of the soil at different stages of growth of fodder maize

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	11	0.0257		
Treat	3	0.0072	0.0024	1.041^{NS}
Error	8	0.0185	0.0023	
2. After the fertilizer application				
Total	11	0.6586		
Treat	3	0.1928	0.0643	1.1039^{NS}
Error	8	0.4658	0.0582	
3. 30 days after sowing				
Total	11	0.4277		
Treat	3	0.4213	0.1404	175.01^{xx}
Error	8	0.0064	0.0008	
4. 65 days after sowing				
Total	11	0.0705		
Treat	3	0.0234	0.0078	1.3260^{NS}
Error	8	0.0471	0.0059	
5. 90 days after sowing (at harvest)				
Total	11	0.2449		
Treat	3	0.1588	0.0529	4.9209^{x}
Error	8	0.0861	0.0108	

x Significant at 5% level

xx Significant at 1% level

Appendix III(e)

Effect of different levels of lime on exchangeable potassium content of the soil at different stages of growth of fodder maize

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	11	0.0264		
Treat	3	0.0044	0.00145	0.5275^{NS}
Error	8	0.0220	0.00275	
2. After the application of fertilizers				
Total	11	0.0231		
Treat	3	0.0135	0.00449	3.7112^{NS}
Error	8	0.0097	0.00121	
3. 30 days after sowing				
Total	11	0.0328		
Treat	3	0.0090	0.00299	1.0027^{NS}
Error	8	0.0239	0.002982	
4. 65 days after sowing				
Total	11	0.0108		
Treat	3	0.0002	0.00006	0.045^{NS}
Error	8	0.0107	0.0013	
5. 90 days after sowing (at harvest)				
Total	11	0.0251		
Treat	3	0.0082	0.0027	1.28^{NS}
Error	8	0.0170	0.0021	

Appendix III(f)

Influence of different levels of lime on exchangeable calcium content of the soil at different stages of growth of fodder maize

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	11	289.744		
Treat	3	289.615	96.538	5949.20^{xx}
Error	8	0.130	0.0163	
2. After the application of fertilisers				
Total	11	149.762		
Treat	3	148.403	49.468	291.244^{xx}
Error	8	1.359	0.170	
3. 30 days after sowing				
Total	11	65.659		
Treat	3	64.794	21.598	199.775^{xx}
Error	8	0.865	0.1081	
4. 65 days after sowing				
Total	11	36.994		
Treat	3	36.276	12.092	134.769^{xx}
Error	8	0.718	0.090	
5. 90 days after sowing (at harvest)				
Total	11	70.132		
Treat	3	69.008	23.0025	163.690^{xx}
Error	8	1.1242	0.1405	

xx Significant at 1% level

Appendix XII(g)

Influence of different levels of lime on exchangeable magnesium content of the soil at different stages of growth of fodder maize

Source	df	SS	MSS	F
1. After the application of different levels of lime				
Total	11	0.0831		
Treat	3	0.0300	0.0100	1.501^{NS}
Error	8	0.0531	0.0066	
2. After the application of fertilisers				
Total	11	0.0236		
Treat	3	0.0027	0.0009	0.338^{NS}
Error	8	0.0209	0.0026	
3. 30 days after sowing				
Total	11	0.0849		
Treat	3	0.0122	0.0041	0.4478^{NS}
Error	8	0.0727	0.0091	
4. 65 days after sowing				
Total	11	0.0576		
Treat	3	0.0317	0.0106	3.259^{NS}
Error	8	0.0259	0.0032	
5. 90 days after sowing				
Total	11	0.0814		
Treat	3	0.0542	0.0181	5.3099^{x}
Error	8	0.0272	0.0034	

x Significant at 5% level

Appendix III(h)

Influence of different levels of lime on exchangeable iron content of the soil before and after fodder maize cultivation

Source	df	SS	MSS	F
1. Before cultivation				
Total	11	90.9467		
Treat	3	88.9000	29.6333	115.846^{xx}
Error	8	2.0467	0.2558	
2. After cultivation				
Total	11	25.6225		
Treat	3	21.7492	7.2497	14.974^{xx}
Error	8	3.8733	0.4842	

xx Significant at 1% level

Appendix IV

Influence of different levels of exchangeable aluminium on plant characters of fodder maize

Height of the plant

Source	df	SS	MSS	F
1. 30 days after sowing				
Total	11	1634		
Treat	3	942	314	3.63^{NS}
Error	8	692	86.5	
2. 65 days after sowing				
Total	11	1172.25		
Treat	3	144.25	48.083	3.74^{NS}
Error	8	1028.00	128.500	
3. 90 days after sowing (at the harvest)				
Total	11	2715.667		
Treat	3	416.667	153.889	0.5462^{NS}
Error	8	2254.0	281.75	

Root length

Source	df	SS	MSS	F
Total	11	638.889		
Treat	3	503.709	167.9030	9.9365^{xx}
Error	8	135.180	16.8975	

xx Significant at 1% level

Appendix IV contd.

Weight of tops

Source	df	SS	MSS	F
Total	11	6408.169		
Treat	3	4434.129	1478.04	5.990*
Error	8	1974.04	246.755	

Weight of roots

Source	df	SS	MSS	F
Total	11	1927.689		
Treat	3	1262.389	420.7963	5.0600*
Error	8	665.3	83.1625	

Total dry weight

Source	df	SS	MSS	F
Total	11	11844.117		
Treat	3	9776.997	3258.999	12.6127*
Error	8	2067.12	258.39	

* Significant at 5% level

Appendix V

Influence of different levels of exchangeable aluminium on nutrient composition of fodder maize

Nitrogen

Source	df	SS	MSS	F
Top-Total	11	0.1727		
Treat	3	0.0257	0.0086	0.467^{NS}
Error	8	0.1470	0.0184	
Root-Total	11	0.2244		
Treat	3	0.0214	0.0072	0.282^{NS}
Error	8	0.2020	0.0025	

Phosphorus

Source	df	SS	MSS	F
Top-Total	11	0.00449		
Treat	3	0.00083	0.00028	0.600^{NS}
Error	8	0.00367	0.00046	
Root-Total	11	0.00149		
Treat	3	0.00003	0.000008	0.0455^{NS}
Error	8	0.00147	0.00018	

Appendix V contd.

Potassium

Source	df	SS	MSS	F
Top - Total	11	0.41387		
Treat	3	0.29867	0.09956	6.9135^{x}
Error	8	0.1152	0.0144	
Root-Total	11	0.4704		
Treat	3	0.3296	0.1099	6.2398^{x}
Error	8	0.1408	0.0176	

Calcium

Source	df	SS	MSS	F
Top - Total	11	0.07144		
Treat	3	0.06174	0.0206	16.979^{xx}
Error	8	0.00970	0.0012	
Root-Total	11	2036.92		
Treat	3	1948.25	649.412	58.5939^{xx}
Error	8	88.667	11.0833	

x Significant at 5% level

xx Significant at 1% level

Appendix V contd.

Magnesium

Source	df	SS	MSS	F
Top-Total	11	0.00207		
Treat	3	0.00022	0.00007	0.323^{NS}
Error	8	0.00185	0.00023	
Root-Total	11	195302.25		
Treat	3	174496.25	58165.42	22.365^{xx}
Error	8	20806	2600.75	

Iron

Source	df	SS	MSS	F
Top-Total	11	535576.6		
Treat	3	520510	173503.33	92.1257^{xx}
Error	8	15066.6	1883.33	
Root-Total	11	550589.1		
Treat	3	218889.2	72963	1.759^{NS}
Error	8	331700	41462.5	

xx Significant at 1% level

Appendix V contd.

Aluminium

Source	df	SS	MSS	F
Top-Total	11	144825		
Treat	3	96158	32052.67	5.2689^{x}
Error	8	48667	6083.375	
Root-Total	11	843000		
Treat	3	838000	279333	446.93^{xx}
Error	8	5000	625	

Zinc

Source	df	SS	MSS	F
Top-Total	11	1027		
Treat	3	633.67	211.222	4.296^{x}
Error	8	39.33	49.167	
Root-Total	11	506.25		
Treat	3	240.92	80.3056	2.42
Error	8	265.33	33.167	

x Significant at 5% level
xx Significant at 1% level

Appendix V contd.

Copper

Source	df	SS	MSS	F
Top-Total	11	20.67		
Treat	3	12.67	4.222	4.22^{x}
Error	8	8	1	
Root-Total	11	60.9167		
Treat	3	7.5833	2.5277	0.3792^{NS}
Error	8	53.333	6.6667	

x Significant at 5% level

Appendix VI

Correlation between soil properties and nutrient uptake at different stages of growth of cowpea

a) Percentage Aluminium saturation

	N	P	K	Ca	Mg	Fe	Al content in tops	Al content in roots
S_1	-0.507	-0.434	-0.544	-0.909^{xx}	-0.460	-0.207	+0.389	+0.673^{x}
S_2	-0.415	-0.400	-0.269	-0.919^{xx}	-0.356	-0.089	+0.229	+0.665^{x}
S_3	-0.361	-0.521^{x}	-0.261	-0.657^{xx}	-0.256	-0.371	+0.437	+0.739^{xx}

b) Exchangeable Aluminium content

	N	P	K	Ca	Mg	Fe	Al content in tops	Al content in roots
S_1	-0.527	-0.455	-0.550	-0.909^{xx}	-0.478	-0.226	+0.383	+0.679^{x}
S_2	-0.425	-0.409	-0.282	-0.912^{xx}	-0.369	-0.104	+0.222	+0.661^{x}
S_3	-0.372	-0.533^{x}	-0.275	-0.653^{xx}	-0.404	-0.574	+0.440	+0.744^{xx}

x Significant at 5% level

xx Significant at 1% level

Appendix VII

Correlation between soil properties and plant characters at different stages of growth of cowpea

a) Percentage aluminium saturation

	Nodule count	Root length	Dry weight	Grain weight	Husk weight
S_1	-0.618^{x}	-0.750^{xx}	-0.287	-	-
S_2	-0.697^{x}	-0.450	-0.389	-	-
S_3	-0.411	-0.260	-0.192	-0.508^{x}	-0.491^{x}

b) Exchangeable Aluminium content

	Nodule count	Root length	Dry weight	Grain weight	Husk weight	Total dry matter
S_1	-0.623^{x}	-0.759^{xx}	-0.310			
S_2	-0.608^{x}	-0.463	-0.348			
S_3	-0.420	-0.174	-0.199	-0.520^{x}	-0.501^{x}	-0.589^{x}

x Significant at 5% level

xx Significant at 1% level

Appendix VIII(a)

Correlation between aluminium content and nutrient composition of tops

	N	P	K	Ca	Mg	Fe	Al	Zn	Cu
S_1	-0.196	-0.910^{xx}	-0.493	-0.328	-0.441	+0.494	-	+0.200	-0.129
S_2	-0.345	-0.070	-0.432	-0.072	-0.466	+0.489	-	+0.359	-0.015
S_3	-0.294	-0.344	-0.042	-0.413	-0.072	+0.481	-	+0.584^{x}	+0.007

Appendix VIII(b)

Correlation between aluminium content of tops and plant characters

	Nodule count	Root length	Dry weight	Grain yield	Husk yield
S_1	-0.325	-0.727^{xx}	-0.451		
S_2	-0.409	-0.113	-0.269		
S_3	-0.316	-0.480	-0.343	-0.597^{x}	-0.450

xx Significant at 1% level

x Significant at 5% level

Appendix VIII(c)

Correlation between aluminium content of tops and nutrient content of root

	N	P	K	Ca	Mg	Fe	Al	Zn	Cu
S_1	-0.509	-0.444	-0.069	-0.474	-0.452	-0.409	+0.638^{x}	+0.293	-0.261
S_2	-0.516	-0.700^{x}	+0.558	-0.237	-0.124	-0.464	+0.536	-0.311	-0.202
S_3	-0.016	-0.045	+0.052	-0.769^{xx}	-0.552^{x}	-0.481	+0.736^{xx}	-0.354	+0.188

Appendix VIII(d)

Correlation between aluminium content of tops and nutrient uptake

	N	P	K	Ca	Mg	Fe	Al
S_1	-0.576^{x}	-0.552	-0.610^{x}	-0.566	-0.533	-0.201	+0.540
S_2	-0.369	-0.363	-0.171	-0.134	-0.197	-0.372	+0.130
S_3	-0.476	-0.546^{x}	-0.394	-0.488	-0.262	-0.361	+0.396

x Significant at 5% level

xx Significant at 1% level

Appendix IX(a)

Correlation between the aluminium content of roots and nutrient composition of tops

	N	P	K	Ca	Mg	Fe	Al	Zn	Cu
S_1	$^{-}0.479$	$^{-}0.170$	$^{-}0.383$	$^{-}0.509$	$^{-}0.350$	$^{+}0.741^{xx}$	$^{+}0.638^{x}$	$^{+}0.278$	$^{+}0.095$
S_2	$^{-}0.634^{x}$	$^{-}0.463$	$^{+}0.488$	$^{-}0.645^{x}$	0.019	$^{+}0.378$	$^{+}0.536$	$^{+}0.093$	$^{+}0.518$
S_3	$^{-}0.248$	$^{-}0.545^{x}$	$^{+}0.119$	$^{-}0.748^{xx}$	$^{-}0.114$	$^{+}0.427$	$^{+}0.736^{xx}$	$^{+}0.594^{x}$	$^{-}0.063$

Appendix IX(b)

Correlation between the aluminium content of root and plant characters

	Nodule count	Root length	Dry weight	Plant height	Grain weight	Husk weight
S_1	$^{-}0.597^{x}$	$^{-}0.710^{xx}$	$^{-}0.284$	$^{-}0.070$	-	-
S_2	$^{-}0.822^{xx}$	$^{-}0.569$	$^{-}0.624^{x}$	$^{-}0.392$	-	-
S_3	$^{-}0.514^{x}$	$^{-}0.529^{x}$	$^{-}0.171$	$^{-}0.101$	$^{-}0.568^{x}$	$^{-}0.607^{x}$

xx Significant at 1% level

x Significant at 5% level

Appendix IX(c)

Correlation between the aluminium content and nutrient content of roots

	N	P	K	Ca	Mg	Fe	Zn	Cu
S_1	-0.460	-0.491	-0.065	-0.502	-0.554	-0.586^{x}	-0.409	-0.038
S_2	-0.323	-0.412	-0.059	-0.643^{x}	-0.670^{x}	-0.178	-0.170	-0.036
S_3	-0.165	-0.271	+0.086	-0.681^{xx}	-0.737^{xx}	-0.317	-0.336	-0.002

Appendix IX(d)

Correlation between the aluminium content of roots and nutrient uptake

	N	P	K	Ca	Mg	Fe	Al
S_1	-0.529	-0.422	-0.456	-0.636^{x}	-0.402	+0.090	+0.418
S_2	-0.625^{x}	-0.717^{xx}	-0.405	-0.747^{xx}	-0.644^{xx}	-0.446	+0.398
S_3	-0.411	-0.596^{x}	-0.223	-0.499^{x}	-0.249	-0.278	+0.636^{xx}

x Significant at 5% level

xx Significant at 1% level

Appendix X(a)

Correlations between soil properties and nutrient uptake by maize

	N	P	K	Ca	Mg	Fe	Al content of top	Al content of root
Percentage aluminium saturation	$^{-}0.744^{xx}$	$^{-}0.855^{xx}$	$^{-}0.833^{xx}$	$^{-}0.904^{xx}$	$^{-}0.797^{xx}$	$^{-}0.767^{xx}$	$^{+}0.408$	$^{+}0.799^{xx}$
Exchangeable aluminium content	$^{-}0.768^{xx}$	0.853^{xx}	0.823^{xx}	$^{-}0.898^{xx}$	$^{-}0.791^{xx}$	$^{-}0.763^{xx}$	-	$+0.804^{xx}$
Percentage base saturation	$^{+}0.805^{xx}$	$^{+}0.850^{xx}$	$^{+}0.953^{xx}$	$^{+}0.930^{xx}$	$^{+}0.884^{xx}$	$^{-}0.696^{xx}$	-	$^{-}0.706^{x}$

Appendix X(b)

Correlations between soil properties and plant characters of maize

	Root Length	Root weight	Top weight	Total dry weight
Percentage aluminium saturation	$^{-}0.676^{x}$	$^{-}0.690^{x}$	$^{-}0.767^{xx}$	$^{-}0.816^{xx}$
Exchangeable aluminium content	$^{-}0.681^{x}$	$^{-}0.773^{xx}$	$^{-}0.680^{x}$	$^{-}0.811^{xx}$
Percentage base saturation	$^{+}0.656^{x}$	$^{+}0.682^{x}$	$^{+}0.778^{xx}$	$^{+}0.847^{xx}$

xx Significant at 1% level

x Significant at 5% level

Appendix XI Correlation between the aluminium content of fodder maize tops and

(a) nutrient content of tops

N	P	K	Ca	Mg	Fe	Zn	Cu
-0.371	-0.642^{x}	+0.144	-0.598^{x}	-0.278	+0.746^{xx}	-0.374	-0.212

(b) plant characters

Root length	Top weight	Root weight	Total weight
-0.544	-0.167	-0.464	-0.310

(c) nutrient content of roots

N	P	K	Ca	Mg	Fe	Al	Zn	Cu
-0.405	-0.203	+0.309	-0.447	-0.168	-0.632^{x}	+0.700^{xx}	+0.120	-0.321

x Significant at 5% level

xx Significant at 1% level

Appendix XII Correlation between the aluminium content of maize roots and

(a) nutrient content of tops

N	P	K	Ca	Mg	Fe	Al	Zn	Cu
-0.020	-0.803^{xx}	-0.100	-0.882^{xx}	-0.292	+0.818^{xx}	+0.700^{x}	+0.310	+0.312

(b) Plant parameters

Root length	Root weight	Top length	Top weight	Total dry matter
-0.764^{xx}	-0.733^{xx}	-0.037	-0.749^{xx}	-0.845^{xx}

(c) nutrient content of roots

N	P	K	Ca	Mg	Fe	Zn	Cu
-0.173	-0.055	-0.620^{x}	-0.849^{xx}	-0.610^{x}	-0.624^{x}	-0.039	-0.394

(d) nutrient uptake

N	P	K	Ca	Mg	Fe
-0.826^{xx}	-0.882^{xx}	-0.771^{xx}	-0.838^{xx}	-0.684^{x}	-0.601^{x}

xx Significant at 1% level

x Significant at 5% level

EXCHANGEABLE ALUMINIUM AS AN INDEX OF LIMING FOR THE ACIDIC UPLAND SOILS OF KERALA

By

MEENA, K.

ABSTRACT OF THE
THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT
FOR THE DEGREE OF
MASTER OF SCIENCE IN AGRICULTURE
(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, TRIVANDRUM

1987

ABSTRACT

Aluminium toxicity is the major factor limiting crop production in the acidic soils and the usual practice of alleviating aluminium toxicity is liming. The present investigation was carried out to find out the distribution of water soluble and exchangeable aluminium in the acidic upland soils of Kerala and to test the suitability of exchangeable aluminium as an index for liming them. It was further programmed to find out the growth, yield and nutrient uptake pattern of two acid sensitive crops namely cowpea and fodder maize in soils under different levels of exchangeable aluminium brought out by the use of different levels of lime.

Chemical analysis of eighty soil samples representing the five major upland soil types of Kerala viz. laterite, alluvial, red loam, sandy and forest soil have indicated the highest amount of exchangeable aluminium and percentage aluminium saturation in the laterite soils.

The soil with a high level of exchangeable aluminium and percentage aluminium saturation was selected for conducting a pot culture experiment to test the suitability of using exchangeable aluminium as an index of liming. The exchangeable aluminium content of this soil was maintained at different levels by applying different levels of lime and the performance of these crops in this soil was compared by making biometric observations and by chemically analysing plant and soil samples.

From the results of the study it was seen that higher levels of exchangeable aluminium adversely affected the growth, yield and nutrient uptake in cowpea and fodder maize.

Maintenance of exchangeable aluminium at 1.26 me/100 g with a corresponding percentage aluminium saturation value of around 30, by the use of 500 kg lime/ha appeared to be the optimum for maximising the yield of cowpea. But in fodder maize this level of lime was found to be insufficient and complete elimination of aluminium toxicity appeared to be essential for maximising production.

Since the critical levels of exchangeable aluminium appears to be different for different crops, it is desirable that lime levels to reduce exchangeable aluminium to such a critical level alone be applied. The results of the present study thus point to the advantage in adopting the exchangeable aluminium level of soil as a better index of liming for various crops grown in the upland acidic soils of Kerala.