

EFFECTS OF LIMESTONE APPLICATIONS AND TILLAGE ON
COWPEA (Vigna unguiculata L. WALP.) GROWTH IN ACID
SOILS OF THE INTERMEDIATE SAVANNAHS OF GUYANA

by

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A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Department of Renewable Resources,
McGill University, Montreal.

© May 1986

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ISBN 0-315-34455-5

Suggested short title:

LIME APPLICATION AND TILLAGE ON COWPEA GROWTH
IN GUYANA'S INTERMEDIATE SAVANNAHS

E.K. Dookie

ABSTRACT

PhD

E.K. DOOKIE

Renewable
Resources

Effects of Limestone Applications and Tillage on Cowpea (Vigna unguiculata L. Walp.) Growth in Acid Soils of the Intermediate Savannahs of Guyana.

Two field experiments were conducted on acid soils in Guyana's Intermediate Savannahs to determine the influence of chemical and physical changes in the soil profile on soil properties and cowpea growth.

Low rates of limestone (Crushed Shells- 98% CaCO_3) neutralised KCl-exchangeable Al, reduced KCl-exchangeable acidity, increased soil pH and exchangeable Ca and resulted in increased root growth, improved utilization of Ca and higher cowpea yields.

CaCO_3 and/or its solubility products were readily leached into the soil profile but limestone had to be applied sometime prior to planting for effectiveness.

Deep tillage decreased soil mechanical impedance and bulk density, and increased root mass and cowpea yields. The effects were however, temporary and confined to one season.

Effects of limestone placement depths, limestone rate-placement depth and limestone rate-tillage depth interactions were mostly non-significant for the soil and plant variables evaluated.

Cowpea yields differed among soil types and were higher in the long rainy season than in the short rainy season.

RESUME

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Ressources
Renouvelables

Effets du chaulage et du labourage sur la croissance de Vigna unguiculata (L. Walp.) sur les sols acides des Savanes Intermediaires de la Guyane.

Deux experiences furent entreprises sur les sols acides des Savanes Intermediaries de la Guyane afin de determiner l'influence des changements chimiques et physiques du profil du sol sur les proprietes du sol et la croissance de Vigna unguicalata (L. Walp.).

De bas taux de pierre calcaire (coquillages broyes-98% CaCO_3) ont neutralise l'Al KCl-echangeable, reduit l'acidite KCl-echangeable, et accru le pH du sol et le Ca echangeable. Ces taux ont resulte en une croissance accrue des racines, une meilleure utilisation du Ca, et des rendements plus eleves de Vigna unguiculata (L. Walp.).

Le CaCO_3 et ses produits de solubilite furent draines promptement dans le profil du sol mais il fallut appliquer la pierre calcaire quelque temps avant le semis pour qu'elle soit efficace.

Un profond labourage a diminue l'impedance mecanique et la densite de masse du sol et a augmente la masse des racines et les rendements de Vigna unguiculata (L. Walp.). Par contre, les effets ont ete temporaires et limites a une seule saison.

Les effets de la profondeur de placement de la pierre calcaire, et des interactions entre le taux de pierre calcaire et la profondeur de placement ainsi qu'entre le taux de pierre calcaire et la profondeur de labourage furent le plus souvent non-significatifs pour les variables evaluees.

Les rendements de Vigna unguiculata (L. Walp.) ont varié pour les différents types de sols et furent plus élevés dans la longue saison des pluies que dans la courte saison des pluies.

ACKNOWLEDGEMENTS

Sincere appreciation is extended to Prof. A.F. MacKenzie for his guidance, support and understanding during the course of this study. His advice and comments during thesis preparation were invaluable.

Deep appreciation is also extended to Prof. M. Panous for his advice on statistical analyses. Profs. G. Mehuys, V. Raghavan, W. Hendershot, I. Alli and R. Karamanos, Mr. P. Kirby and fellow graduate students are also acknowledged for their useful comments and advice.

Special thanks are extended to the agricultural staff at Ebini and Kimbia, especially Mr. A. MacKenzie, for their full support during field research. The assistance provided by technicians at the analytical laboratories of the Guyana Sugar Corporation and the National Agric. Res. Inst. is deeply appreciated.

Many thanks are extended to Mr. J. Piggott for his contributions both professionally and as a friend. Dr. M.A. Granger, Col. J. Singh, Col. D. Roberts, Mr. M. Holder, Mr. C. Bullen, Dr. P. MacKenzie, Dr. H.B. Davis, Mr. A. Rasheed and Dr. G. Muller are also thanked for providing technical support and research facilities in Guyana.

Special thanks are expressed to Prof. M. Ahmad, Dr. F. Gumbs and Dr. S. Griffith, U.W.I., St. Augustine Campus, Trinidad for providing technical advice and research facilities. Prof. M. Ahmad is further thanked for his useful comments after visiting the research plots at Ebini.

I must also thank Mr. A. Ishoof and Mr. D. Christopherson of Fert. Corp. of America, Miami, Fl., for their assistance and continued support. I am extremely grateful to Ms. S. Khan for typing the manuscript, Mr. S. Berard for drawing the figures and Ms. H. Crevier for translation of the

abstract.

Financial support provided by the Royal Bank-McGill International Caribbean Program and the Faculty of Graduate Studies, McGill University is gratefully acknowledged.

Finally, I am extremely grateful to my parents and family for their love, understanding and moral support during this endeavour.

FOREWORD

This thesis is presented in four chapters and describes two experiments, noted as Chapters II and III. It contains a general introduction and review of literature in Chapter I and discussion of experiments 1 and 2 in Chapters II and III, respectively. Chapter IV contains general conclusions and contributions to knowledge.

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CHAPTER I

GENERAL INTRODUCTION

LITERATURE REVIEW

1. GENERAL INTRODUCTION

Guyana's agricultural sector is confined primarily to a narrow, lowlying coastal belt with sugar (Saccharum officinarum L.) and rice (Oryza sativa L.) being the major crops. Attempts to develop a more diversified and productive agricultural economy have included production of non-traditional crops and utilization of underdeveloped land resources in hinterland regions. According to Sanchez and Buol (1975), tropical savannahs of South America may become important crop producing areas to satisfy increasing global food requirements. One such tropical area is the Intermediate Savannahs of Guyana (Fig. 1.1). The Intermediate Savannahs contain mainly highly weathered, permeable, acid soils extremely low in clay and organic matter. The cation exchange capacity (C.E.C.) in both surface and subsurface horizons is dominated by exchangeable acidity mainly from Al^{+3} and H^{+} ions. This condition is more pronounced in the subsoil (Downer, 1972; Chesney, 1979; Bullen et al., 1981). The savannahs receive significant annual precipitation (2150 mm) of high intensity. Annual mean temperature is approximately 26°C while the average annual relative humidity is about 80% (Fraser, 1980; Bullen et al., 1981).

However, intensive, large-scale cultivation of major food, feed and fiber crops such as cowpeas (Vigna unguiculata L. Walp.), peanuts (Arachis hypogaea L.), pigeon peas (Cajanus cajan L.), soybean (Glycine max L.), maize (Zea mays L.) and cotton (Gossypium hirsutum L.) since the early 1970's have been largely unsuccessful and economically marginal. Crop yields and productivity have not been sustained partly because of inadequate soil and crop management practices. Suspected problems with these crops include restricted rooting and inefficient utilization of

added nutrients. A poorly developed root system confined to acid surface and subsurface soil horizons cannot absorb plant nutrients and water efficiently, especially under the high leaching conditions that exist in the humid tropics. Many workers (Rios and Pearson, 1964; Howard and Adams, 1965; McCart and Kamprath, 1965; Adams and Lund, 1966; Kamprath, 1970, 1972; Reeve and Sumner, 1972; Gonzalez-Erico et al., 1979; Foy et al., 1980; Ritchey et al., 1980; Bullen et al., 1981), have concluded that soil acidity, specifically Al toxicity, is responsible for the undesirable soil conditions that result in restricted root development. Further, physical factors such as high mechanical impedance and/or unfavorable oxygen - carbon dioxide - water relationships may be involved (Foy et al., 1980; Henderson et al., 1981).

Root development and plant growth are therefore influenced by acid, infertile soil conditions, toxic Al levels, and soil physical limitations. Because of these characteristics, high levels of inputs such as limestone, fertilizers, energy and management, which may or may not be compatible with long-term economic agricultural production, will be required. Limited data are available on the interaction of the control of Al toxicity through limestone management practices and control of poor physical conditions through tillage, as they affect crop yields. Studies of liming and tillage effects on cowpea growth and soil chemical-physical properties were therefore proposed and subsequently carried out in 1982 and 1983 at Ebini, Berbice River, Guyana, South America. These studies noted as experiments 1 and 2 are presented in Chapters Two and Three, respectively.

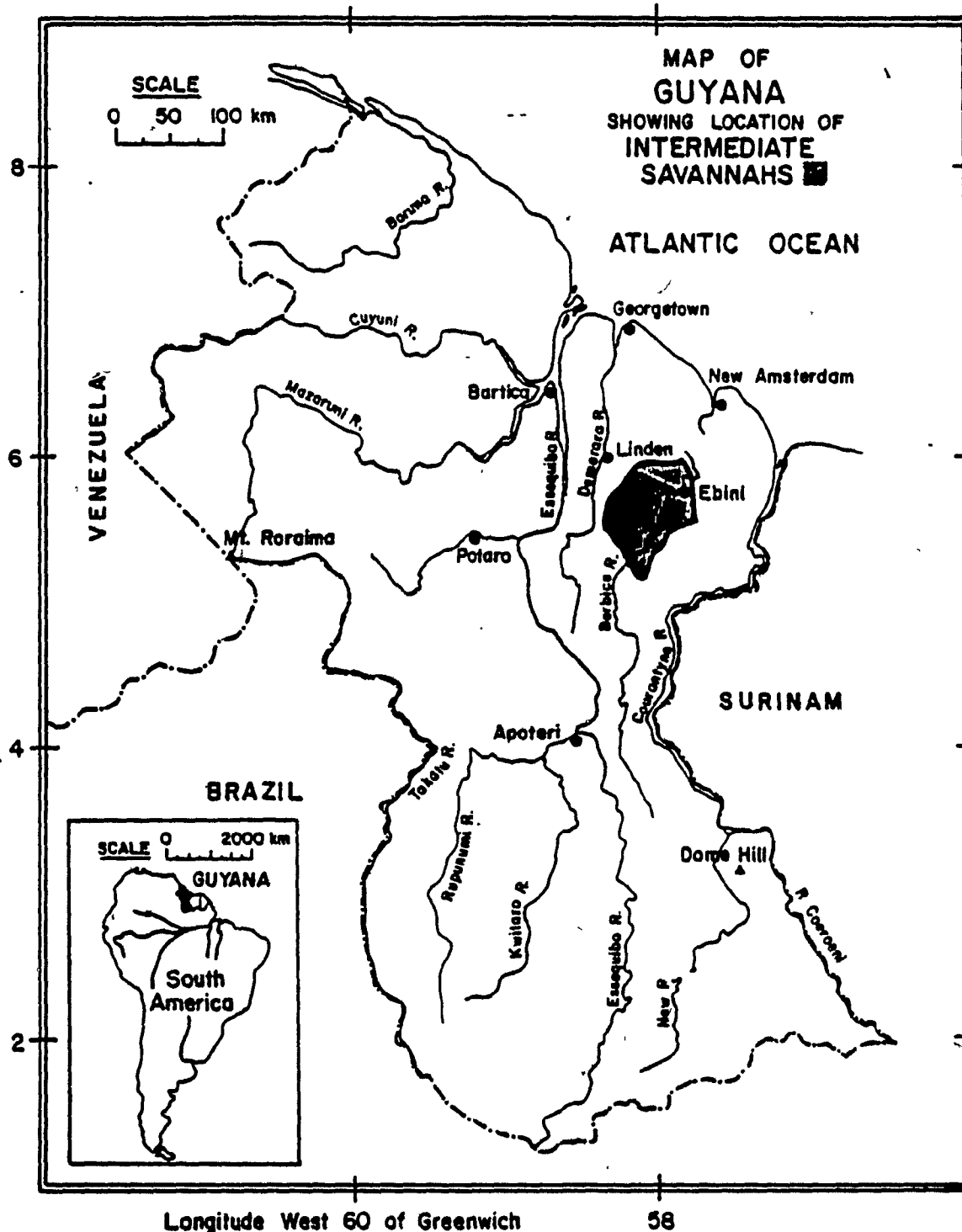


FIG. 1.1 Map of Guyana showing location of the Intermediate Savannas.

2. LITERATURE REVIEW

2.1 Acid soils of the Intermediate Savannas of Guyana

2.1.1 History of Development

The Intermediate Savannas of Guyana lie within the northern regions of the physiographic unit designated as the "white sand" plateau. This plateau is of somewhat uniform monotonous topography with gently undulating relief. It rises from an elevation of about 16 m in the north to 160 m in the south and its surface is dominated by irregularly distributed areas of white quartz sand (white sand) and brown loamy sand to sandy clay (brown sand). These sands are thought to have developed from Pliocene to Pleistocene continental-deltaic sediments corresponding to the Berbice formation (Bleackley and Khan, 1963; Downer, 1972; Norden *et al.*, 1972; Bullen *et al.*, 1982). According to Richards (1952) the soils of the Intermediate Savannas are mainly brown sands that change to bleached sands with changes in vegetation. A common occurrence also, is the presence of fairly large (1 to 2m wide at the base and up to 2m high) abandoned ant hills (Brinkman, 1964). Goodland, (1965) stated that termites impoverish the surrounding soils by concentrating soil nutrients into their termitaria, reducing the plant cover and decreasing the water retention capacity of the savannah ecosystem. However, they may aid the growth of woody plants by improving the drainage and allowing the growth of the roots of phreatophytes through a hard pan.

2.1.2 Classification

The major soils of agricultural importance in the Intermediate Savannas are grouped together as brown sands and include well drained

Ultisols, Oxisols and Entisols (Soil Survey Staff, 1975). These soils are coarse to medium-textured, ranging from pure white quartz sand to yellowish red sandy clay. Forty different kinds of soils have been identified but the most extensive include the Ebiní sandy loam No. 820 (Typic Paleudult), the Bukaruna loamy sand No. 816 (Grossarenic Paleudult), the Kairuni loamy sand No. 815 (Arenic Paleudult), Kasarama loamy sand No. 810 (Ultic Haplothox) and the Tabela sand No. 800 (Orthoxic Quartzispanment). Accordingly, the above mentioned soils have been the focus of research attention because of their agricultural potential and extensive distribution in the Intermediate Savannahs (Brinkman, 1964; Downer, 1972; Holder, 1972; Chesney, 1979; Dookie, 1981; Bullen et al., 1981).

2.1.3 Soil Characteristics and Fertility of Acid Soils

Soil behaviour depends to a large extent on texture and mineralogy. Most of the well drained, well watered, underutilized and potentially arable lands in tropical and subtropical regions are occupied by soils with low activity clays (Uehara, 1978). According to Bennema (1963), the inorganic portion of soils that developed under high temperature and rainfall regimes include small amounts of silt, 1:1 silicate clays, sesquioxides (usually less than 10 percent w/w of the clay fraction) and larger quantities of quartz or other minerals which are highly resistant to weathering. Bennema, (1982) concluded that Ultisols, Oxisols and Entisols of the humid tropics mostly have a kaolinitic clay mineralogy. For example, kaolinization has been found to be the dominant clay forming process under good soil drainage in tropical savannah regions of Nigeria (Ojanuga, 1979) as well as in the Cerrado and Llanos (savannah) regions of Brazil and Venezuela, respectively (Benites and Valverde, 1982). In a

study of brown sand soils of the Intermediate Savannahs, Downer, (1972) found that kaolinite was the predominant clay mineral and that its contribution to the cation exchange capacity was negligible.

Two fundamental factors limit fertility in acid soils, impoverished nutrient status and the presence of toxic substances (Reeve and Sumner, 1970a). On the highly weathered and leached soils of temperate-subtropical regions, soil acidity resulting in toxic concentrations of certain elements and unfavourable physical conditions exist to some degree according to Rios and Pearson, (1964). In the humid American tropics Sanchez and Cochrane, (1980) identified several major chemical and physical constraints in the region according to the Fertility Capability Soil Classification System described by Buol et al., (1975) and modified by Sanchez et al., (1982). In Oxisol-Ultisol regions located in areas under acid savannah and rain forest with udic or ustic moisture regimes (Benites and Valverde, 1982), the major chemical-physical limitations include soil acidity mainly from toxic levels of exchangeable Al, low cation exchange capacity, macro and micro nutrient deficiencies, P Fixation, Mn toxicity, low water holding capacity, susceptibility to erosion, compaction hazards, waterlogging for two months or more, presence of plinthite within 125 cm and mechanization difficulties (Camarago and Falesi, 1975; Spain, 1978; Sanchez and Cochrane, 1980; Sanchez and Salinas, 1981; Benites and Valverde, 1982; Sanchez et al., 1982; Smyth and Sanchez, 1982).

According to Isbell, (1978) the more acid, highly weathered tropical and subtropical soils are often characterized by high levels of Al saturation, low cation exchange capacities and generally low levels of plant nutrients. Awad et al., (1976) reported that acid soils of N.S.W. Australia suffer from Al toxicity and deficiencies of N, P, Ca and Mo.

The highly weathered soils of Hawaii contain active Al which induces extreme P deficiencies through fixation and/or precipitation (Monteith and Sherman, 1963; Fox et al., 1964; Khalid and Silva, 1979). Lopes and Cox, (1977) found that Al saturation greater than 40% was prevalent in most soils of the Central Plateau Savannahs of Brazil. Pleysier and Juo, (1981) further demonstrated the fertility limitations of Oxisols and Ultisols of high rainfall regions, by pointing out that rapid leaching losses of added nutrients may be expected on these highly permeable and low C.E.C. soils.

In the Intermediate Savannahs, brown sand soils are permeable, physically suited for plant growth but soil acidity and low fertility may restrict effective exploitation of land resources (Ignatieff and Lenos, 1963; Brinkman, 1964; Wagenaar, 1965; Downer, 1972; Holder, 1972; Chesney, 1972, 1973, 1979; Bullen et al., 1982). Follett-Smith, (1930) determined soil deficiencies of P_2O_5 and K_2O and low percentages of CaO and K_2O in native grasses. Rutherford and Stark, (1959) concluded that the basic fertilizer needs of brown sand soils are N, P and K but because of their origin and very leached nature, trace elements may also be important. Downer, (1972) in a study of four brown sand soils found that exchangeable bases were low in all soils, K and Mg were increasingly leached from the soils as pH increased, P levels were very low and less than 70% of added P was recoverable. Also, positive responses to added micronutrients were observed. Chesney, (1979) and Dookie, (1981) found that the soils responded differently to management and recovery of added fertilizers was very inefficient. Bullen et al., (1982) in a review of previous studies of brown sand soils stated that the soils were all very acid, with relatively large amounts of KCl-exchangeable acidity, low cation exchange capacities, base saturations, organic contents and water

holding capacities and almost devoid of natural fertility in both the topsoil and subsoil. Also, these soils are susceptible to erosion, because of slope, abrupt textural changes and/or poor structure and compaction due to pedogenic compacted layers, cultivation and soil texture and structure (Sanchez and Cochrane, 1980; Bullen et al., 1981).

2.1.4 Soil Utilization

Several authors have concluded that fragile ecosystems presently under forest and savannah vegetation in the humid American tropics, could sustain intensive agricultural production (Sanchez, 1976, 1981; Buol and Sanchez, 1978; Moormann and van Wambeke, 1978; Kamprath, 1980; Benites and Valverde, 1982).

However, efforts to develop viable farming systems in the Intermediate Savannahs of Guyana have been largely unsuccessful for several reasons. Shifting cultivation was the primary method of agricultural production until sedentary agriculture (Richards, 1952; Mayers, 1969; Bullen et al., 1982). Mayers (1969) suggested that as early as 1860 the Intermediate Savannahs were used as resting plane for cattle being driven from the interior Rupununi Savannahs to coastal markets. Observations by Follett-Smith, (1930) on the Takama ranch led to the conclusion that "it was a very unsuitable place to rest cattle because of emaciation." For immediate relief Follett-Smith suggested burning of the Savannah and feeding bone meal and recommended more research into the problem. This led to the establishment in 1941 of the Ebini Livestock station with the primary objective being the development of extensive beef production systems (Downer, 1972). This objective was modified in 1957 to include the solution of problems likely to occur in intensive systems of production. Exploratory studies on pasture grasses

and grass/legume associations were initiated and later field crop studies were commenced (Brinkman, 1964; Wagenaar, 1965; Mayers, 1969).

Further research efforts were intensified in 1969 with the cooperation of the Ministry of Agriculture and the University of Florida (Bullen et al., 1982). From these studies, it was determined that large scale commercial agricultural production was possible and four major agricultural projects were set up in the 1970's. In the Kibilibiri savannahs, a Corn and Soybean Project was set up in 1970 by Global Agri. Industries Guyana Ltd. The Guyana National Service established a Cotton and Legume Project in the Kimbia savannahs. In 1974 and in 1975 the Caricom Corn and Soybean Project began operations in the Eberoaabo Savannahs. At Ebini, the Ministry of Agriculture Livestock Station was consolidated into the Livestock Development Company Limited. Research activities were continued at Ebini by the Ministry of Agriculture and the Caribbean Agricultural and Development Institute and are now coordinated by the National Agricultural Institute of Guyana (Bullen et al., 1982; Personal Communication).

Because of many technical problems and severe financial losses the Corn and Soybean Projects were both terminated and operations at Kimbia were greatly scaled down. At the moment only the Livestock operations at Ebini remain fully operational. The National Agricultural Research Institute is now spearheading research activity at Ebini to find answers to some of the major technical problems that restrict effective exploitation of the savannah for economic crop and livestock production.

2.2 Soil Chemical Constraints and Plant Growth on Acid Soils

Bullen et al., (1981) reported that crops grown with apparently adequate fertilization in the Intermediate Savannahs of Guyana tend to

have very shallow, poorly developed root systems. This results in inefficient utilization of water and plant nutrients (Rios and Pearson, 1964; Adams and Lund, 1966; Gonzalez-Erico, et al., 1979; Foy et al., 1980; Ritchey et al., 1980). However, the specific causes of shallow rooting and subsequent negative effects on plant growth and development are not always easily identifiable. In some cases both chemical and physical factors may be involved (Rios and Pearson, 1964; Foy et al., 1980). A review will now be carried out of the chemical factors responsible for restricted plant growth in acid soils.

Because of limited fundamental research there is no consensus to the contribution of toxic soil factors and nutrient deficiencies on plant growth on acid soils of the humid tropics. Thus, studies done in both temperate and tropical regions will be reviewed. Tran and van Lierop (1981) in a review of previous studies indicated that poor crop yields often observed on acid soils are rarely a direct consequence of an excessive hydrogen ion concentration (Arnon and Johnson, 1942; Davis and Lucas, 1959; van Lierop et al., 1980), though they are frequently related to toxic concentrations of soluble Al. (Kamprath, 1970; Reeve and Sumner, 1970b), Mn (Berger and Gerlof, 1947) and to an insufficient availability of plant nutrients in soils assumed to be excessively acid (Adams and Pearson, 1967).

According to Crooke and Knight (1971), soil reaction may markedly influence nutrient availability and thus alter the mineral composition of the plant. Early workers suggested that low soil pH was responsible for poor root growth in acid soils of temperate regions (Lignon and Pierre, 1932; Pierre et al., 1932; Smith and Wallace, 1956; Howard and Adams, 1965). Acid soils of humid tropics in their natural state are generally acid with reactions of less than pH 5 (Pearson, 1975) and poor plant

growth is generally associated with low soil pH specifically high concentrations of H^+ (Islam et al., 1980; Kamprath, 1984). However, Islam et al., (1980) suggested that the effects of soil pH on plant growth are complex and that it is difficult to separate the direct effects of H^+ from the indirect effects associated with changes in the solubility and availability of various elements affecting plant growth.

Soil acidity is a major growth limiting factor in most temperate and tropical soils, with the detrimental effects being closely associated with exchangeable or soluble Al and more pronounced in the subsoil (Pohlman, 1946; Vlamis, 1953; Ragland and Coleman, 1959; Sartain and Kamprath, 1975; Juo, 1977; Bouldin, 1979; Nuwamanya, 1984). According, to Bache and Sharp, (1975), the Al ion is important both in the chemistry of acid soils (Coleman and Thomas, 1967) and its effect on plant growth (Jackson, 1967). Though, Al toxicity is a major factor in acid soil infertility, it has been shown that the tendency towards poor plant growth in acid soils may be genetically based, yet the mechanisms of genetic control remains unknown (Foy et al., 1980). Regardless of differential tolerance to Al among plant species and between cultivars of the same species (Foy and Brown, 1963, 1964; Foy et al., 1965, 1967, 1969), Al toxicity is still a significant factor in reducing plant growth in strongly acid soils in both temperate and tropical regions (Adams and Lund, - 1966; Zandstra, 1972; Awad et al., 1976; Kamprath, 1978; Gonzalez-Erico et al., 1979). Hesse, (1971) suggested that Al appears to affect root growth in particular and excess Al accumulating in roots reduces their capacity for translocating P and even in soils containing ample P, excess Al will cause a P deficiency. However, toxic amounts of Al will depend on soil pH, P content and tolerance of the plant to be grown. Zandstra, (1972) agreed that Al^{3+} is one of several cations which

may reduce root growth; presumably root growth restriction is a consequence of interference with Ca uptake in the meristematic portion of the root tip. Kamprath, (1978) stated that concentrations of Al in soil solutions of acid soils in tropical and subtropical regions are similar to those in solution cultures where growth of legumes is reduced. Reduced plant growth of legumes is due not only to Al toxicity but also to the inhibition effect of Al on uptake and translocation of Ca. Therefore, exchangeable acidity mainly from Al toxicity which may be prevalent below pH 5.5 and especially below pH 5.0 (Foy et al., 1978, 1980) could become a serious impediment to crop production on Ultisols and Oxisols of the humid tropics (Ritchey et al., 1980).

Though H and Al toxicities have been identified as major chemical constraints to plant growth on acid soils, some workers have implicated Mn as a toxic factor as well (Heylar, 1978; Barnard and Folsher, 1980; Ssali and Nuwamanya, 1982; Kamprath, 1984). However, according to Adams, (1979) although Al toxicity is common to all low pH soils, Mn toxicity may be the first limiting yield factor only on low pH, high Mn soils.

Downer (1972) found that the highly leached, low C.E.C., brown sand savannah soils are normally deficient in exchangeable Ca. Basic N-P-K fertilization does not supply Ca to these soils, further alleviating deficiency symptoms. This problem is aggravated on acid, low C.E.C. soils, especially Oxisols and Ultisols of the humid tropics where toxic H and Al severely inhibit Ca uptake (McCart and Kamprath, 1965; Adams, F. 1978; Barnard and Folsher, 1980; Ritchey et al., 1980; Ssali and Nuwamanya, 1982). Finally, Kamprath (1984) concluded that on acid soils of the humid tropics, toxicities of H, Al and Mn and deficiencies of Ca and/or Mg may be related to inhibition of normal plant growth.

2.3 Limestone Effects on Soil Chemical Properties and Crop Growth

According to Kamprath (1984) the response of crops to limestone applications is mainly a result of neutralization of H, Al and Mn toxicities and the supplying of Ca, Mg or both. With acid soils of the tropics, any one of these factors may be related to increased plant growth. It was further postulated that regardless of CaCO_3 , effects on soil chemical properties, crop response may differ widely among plant species and between cultivars of the same species in both temperate (Adams, F., 1984) and tropical regions (Pearson, 1975). As indicated earlier, highly weathered soils of the humid tropics are inherently low in fertility and often very acidic in reaction. These soils, the majority of which are classified as Oxisols and Ultisols (Soil Survey Staff, 1975) are often dominated by kaolinite and sesquioxide clay minerals. As a result they have a low cation exchange capacity (C.E.C.) which is dependent upon both soil pH and electrolyte concentration and which is often dominated by exchangeable Al (Bhumbla and McLean, 1965; Friesen et al., 1982). Corrective measures include use of soil amendments such as liming materials (Amedee and Peech, 1976), which are applied at different rates in different ways. The resulting effects on soil chemical properties such as soil pH, Al saturation and exchangeable cations and plant growth are variable and dependent on interactions of several soil, climatic and other factors.

Early work by Brown et al. (1956) indicated that it was possible to decrease soil acidity to depths far below where liming materials were actually placed. For a given soil and climate, rates and final depths of such penetrative effects depend on the amount of lime applied and on the lapse of time. However, there is no consensus on how to determine the most adequate limestone rate or the best method of placement for various

soils under differing climatic regimes (Shoemaker et al., 1961; Little, 1961; Peech, 1965; Ssali and Nuwamanya, 1981, 1982). This situation is further complicated because of crop and cultivar response differences (Foy and Brown, 1964; Cochrane et al., 1980). Whatsoever, are the variables involved, it is obvious that limestone (CaCO_3) applications have a profound effect on the soil chemical environment (Serpa and Gonzalez, 1979; Bertsch and Alley, 1981), root growth (Hourigan et al., 1961; Urrutia, 1972; Awad et al., 1976), nutrient uptake (Crooke and Knight, 1971) and crop yields (Sartain and Kamprath, 1975; Gonzalez-Erico, 1976; Friesen et al., 1982).

According to Kamprath, (1970) the major chemical problem in acid soils is exchangeable Al, which could be easily neutralized at around pH 5.5 for tropical Oxisols and Ultisols. Though, this may be factual, the indirect effects of limestone additions on other toxic factors and exchangeable bases cannot be overlooked (Reeve and Summer, 1970b; Jones, 1976; Ritchey et al., 1980). However, on Oxisols and Ultisols that are limed to a pH much higher than 5.5, though soil acidity is neutralized, problems could occur with luxury consumption and thus reduced crop yields (Farina, et al., 1980). Because of the complexities involved and limited research data, studies carried out in both temperate and tropical regions will be reviewed.

Most of the early limestone management studies on acid soils were carried out in temperate and subtropical regions. However, the research effort being now undertaken in the humid tropics, owes a great deal to these early studies. On acid soils in the southern U.S., limestone applications resulted in increased soil pH and exchangeable Ca levels in the soil profile (Hourigan et al., 1961; Adams W.E. et al., 1967) and reduction of soluble Al and increased Ca and Mg levels in acid subsoils

(Ragland and Coleman, 1959). Later, Kamprath, (1970) reported that lime additions on leached mineral soils of the Southern U.S. equivalent to or less than the amounts theoretically needed to neutralized the exchangeable Al, raised the soil pH and reacted primarily with exchangeable Al. Also, the effective C.E.C. was increased especially as the soil pH was raised above 5.2-5.4. The reduction in Al saturation on southeastern U.S. acid soils by use of limestone was further demonstrated by Sartain and Kamprath, (1975) and Bertsch and Alley (1981) who also reported increases in soil pH and extractable Ca and Mg with increasing rates of limestone.

Under tropical conditions, workers in different regions found that limestone applications resulted in significant effects on soil chemical properties. Awad et al., (1976) reported increases in soil pH and exchangeable Ca and neutralization of soluble Al on acid soils of Australia that were limed. Similar observations were made in Kenya (Nuwamanya, 1984), Nigeria (Jones 1976; Singh and Balasubramian, 1982; Ssali and Nuwamanya, 1982) and South Africa (Reeve and Summer, 1970b). On Oxisols and Ultisols of Puerto Rico added limestone resulted in reduction of Al saturation and Mn toxicity, increased soil pH and improvement of the base status of these acid soils (Abruna et al., 1964, 1974a,b; Adams et al., 1967). These changes were also observed on acid soils of Costa Rica (Serpa and Gonzalez, 1979) and Peru (Davelouis, 1980). The coarse textured, acid soils of Brazil, especially those found in the Cerrado (savannah) regions are quite similar to the acid soils of Guyana's Intermediate Savannahs. Studies have shown that soil acidity is a major problem which can be corrected by added limestone, thus reducing Al saturation of the exchange complex and increasing the effective cation exchange capacity of ameliorated soils (Gonzalez-Erico et al., 1979;

Muzilli and Godoy, 1979; Ritchey et al., 1980; Symth and Sanchez, 1980).

As observed earlier the effect of limestone applications on crop growth are quite variable, inconsistent and dependent on several inter-related factors. However, as chemical properties are changed in the soil profile the plant does respond to these chemical alterations. Studies on acid soils in the U.S. and Canada revealed significant plant responses to added limestone for several crops. Alfalfa root proliferation and plant yields were increased by added limestone on acid southern U.S. soils (Pohlman, 1946; Hourigan et al., 1961). Hourigan et al., (1961) concluded that Alfalfa response depended largely on adequate levels of limestone in both topsoil and subsoil. However, if sufficient limestone was applied to the topsoil, near maximum yield were obtained regardless of the limestone level in the subsoil. Subsoil liming had minor effects on yield except when the topsoil was shallow and more acid. The response obtained was due to increased soil pH and exchangeable Ca in the soil, resulting in greater uptake of Ca (Hourigan et al., 1961). Urrutia (1972) found that herbage and root yields of two forage legumes were increased linearly with limestone rates up to 1200 ppm on a Florida Spodosol. The plant effects observed were due mainly to neutralization of toxic levels of Al and Mn and increased availability and greater uptake of Ca. Soybean responded positively to limestone additions on acid, North Carolina (Sartain and Kamprath, 1975) and Virginia soils (Bertsch and Alley, 1981). Sartain and Kamprath (1975) determined that limestone caused a significant reduction in Al saturation, thus promoting the formation of a large number of small diameter lateral roots and increasing the dry weights of primary roots and tops without affecting total dry weights and root lengths. According to Bertsch and Alley, (1981) soybean grain yields increased regardless or whether conventional

or suspension limestone were used and occurred because of elimination of toxic soil factors and improved base status. Adams and Pearson (1970) found that peanuts responded significantly to added limestone on acid southeastern U.S. soils. This they concluded was a result of increased soil pH, reduction in soluble Al and significant improvement in the Ca nutrition of the plant. For legume crops, the effects of limestone applications on soil pH and exchangeable Ca levels are especially critical, since Rhizobia sp. react favourably to higher soil pH and Ca levels (McLean and Brown, 1984).

Limestone effects on acid soils are not only confined to leguminous crops. There has been significant yield responses to added limestone for maize grown on acid soils of Ontario (Bolton et al., 1976), the American Midwest (Lawton and Davis, 1956; Fox, 1979) and the Southern U.S. (Ragland and Coleman, 1959; Bertsch and Alley, 1981). The observed increases in root and grain yields were mainly due to reduced Al saturation of the exchange complex increased soil pH and higher levels of exchangeable Ca and Mg (Ragland and Coleman, 1959; Fox, 1979; Bertsch and Alley, 1981). Cotton was another crop that was significantly affected by added limestone on acid soils of the southeastern U.S. (McCart and Kamprath, 1965; Adams and Pearson, 1970). According to McCart and Kamprath, 1965), there was a large increase in dry matter yields of cotton on these acid, low C.E.C. soils because limestone applications resulted in increased soil pH and reduced exchangeable Al.

In tropical regions application of CaCO_3 on acid soils produced similar effects on crops as experienced with temperate acid soils (Russell, J., 1978; Kamprath, 1984). However, crop response on soils of the humid tropics is unique because of the different environmental conditions (Lathwell, 1979; Kamprath, 1984). A positive yield response

to added limestone was observed for field beans on acid soils of Puerto Rico (Abruna et al., 1974a) and Kenya (Nuwamanya, 1984), while Friesen et al., (1982) reported similar effects for cowpea in Nigeria. Urrutia (1972) also noted a limestone related yield increase of two legumes grown on an Oxisol of Guatemala. However, though herbage and root yields were increased by 600 ppm CaCO_3 , limestone rates of 1200 and 1800 ppm markedly depressed yields because of negative chemical effects due to overliming. In general, yield increases observed with beans and cowpea were due to removal of Al and Mn toxicity, increased soil pH and higher levels of exchangeable bases, especially Ca (Urrutia, 1972; Abruna et al., 1974a; Friesen et al., 1982). Friesen et al., (1982) also concluded that relatively low rates of limestone are adequate to sustain yields in a continuous maize-cowpea rotation system on acidic, coarse-textured Ultisols of Nigeria, while Abruna et al., (1974a) suggested that limestone thoroughly worked into the upper 15cm of soil was adequate to maintain high yields of beans on Ultisols and Oxisols of Puerto Rico.

As expected, non-leguminous crops also responded significantly to added limestone as was the case under temperate conditions. Yields of tropical grasses grown on Oxisols and Ultisols of Puerto Rico (Abruna et al., 1964) and an Oxisol of Brazil (Couto et al., 1985) were increased by added limestone. Added limestone also resulted in higher yields of sudangrass in an Oxisol of South Africa (Reeve and Sumner, 1970a) and kikuyu grass in Australia (Awad et al., 1976). In most of these studies, the increased yields were due to increased soil pH and exchangeable bases and reduced exchangeable Al and Mn, resulting in better root growth and uptake of nutrients especially Ca (Abruna et al., 1964; Reeve and Sumner 1970a; Couto et al., 1985). There was also increased plant growth and grain yields of maize due to limestone applications on acid soils of

Puerto Rico (Abruna et al., 1974b), Nigeria (Enwezor, 1977; Friesen et al., 1982) and Brazil (Gonzalez-Erico, 1976). Other crops such as sugarcane in Puerto Rico (Abruna and Vincente-Chandler, 1967), cassava in Columbia (Spain et al., 1975) and sorghum in Costa Rica (Serpa and Gonzalez, 1979) responded markedly to applied limestone as well. Abruna et al., (1964) noted that surface applications of limestone on the Oxisols and Ultisols of Puerto Rico were as effective as mixing limestone with the surface soil and one application was as effective as two applications at two-year intervals. With these crops, once toxic factors were eliminated, root growth and Ca uptake increased, thus significantly affecting overall plant growth (Abruna et al., 1964; Spain, 1975; Gonzalez-Erico et al., 1979; Friesen et al., 1982).

From these studies it is fair to observe that acid soils will become more productive once they are ameliorated by applied limestone. Though results are variable and inconsistent a pattern of soil chemical changes does exist. These changes include increased soil pH, reduction in Al and Mn toxicity and increased levels of exchangeable Ca in the soil solution as limestone applications increase. By far the most important soil chemical condition that is directly affected by limestone additions on acid soils is the Al content. However, although Al^{3+} saturation (an indicator of soil solution Al) and soil pH are closely correlated, there are other soil properties such as soil solution electrolyte concentration, labile P and soil organic matter content that also affect the Al acidity in the soil solution (Hunter, 1965; Evans and Kamprath, 1971; Brenes and Pearson, 1973; Thomas, 1975; Awad et al., 1976). Regardless of complexities in the acid soil system, differences in soil properties and climate and differential Al tolerances among plant species and between cultivars of same species, adequate liming enhances crop

productivity and plant yields.

2.4 Soil Physical Constraints and Plant Growth on Acid Soils

The main soil physical constraints to plant growth in the Oxisol-Ultisol regions of the humid tropics are low available water-holding capacity of many Oxisols and the susceptibility to erosion and compaction of many Ultisols with sandy topsoil textures (Sanchez and Salinas, 1981). In the Intermediate Savannas of Guyana, intensive cultivation has led to increased crust formation, enhanced sheet erosion and compacted subsoils (Bullen et al., 1982). These unfavourable physical conditions may be partly responsible for shallow rooting of several cultivated crops in the Intermediate Savannas. Observations indicate that tap roots grow downwards for only 10 cm, before running laterally and almost parallel to the soil surface (Bullen et al., 1981, 1982). Restricted growth and development of plant roots limits the plant's ability to effectively exploit nutrients and water (Ferrant and Sprague, 1940, Pearson, 1966, Taylor and Bruce, 1968; Lowry et al., 1970, Caassen and Barber, 1976; Maizlish et al., 1980; Maurya and Lal, 1980; Adeoye, 1982, Stitt et al., 1982). Overall plant growth will therefore be severely affected by the unfavourable physical characteristics of the root environment (Raghavan et al., 1979).

The soil's suitability as an environment for root growth and function depends on the availability of water, nutrients and oxygen, on temperature and on the degree of mechanical impedance to root extension (Eavis and Payne, 1968). Accordingly, the soil physical properties considered most important in plant growth are water supply, aeration, temperature and penetrability for root and seedling shoots (DeRoos, 1968; Eavis, 1970). Lowry et al., (1970) found that mechanical impedance by

compacted layers, for example can turn a normally deep-rooted plant into a very shallow-rooted one. Thus, the field situation very often corresponds to a horizontally layered environment in which most plant roots are growing in the chemical, and physical environment of the plow layer while roots below this layer may have to overcome the restraint imposed by unfavourable subsoil conditions (Pearson, 1974). It was further stated that the final root pattern of a given plant and its growth rate was genetically determined when the environment was favourable but was actually controlled by the physical or chemical environment in most field situations (Pearson, 1974). According to Gooderham and Fisher, (1975), the rate of seedling root growth is closely related to penetrometer resistance, and this soil property is dependent on bulk-density and moisture content. However, they concluded that there was little, if any direct effect of moisture on root elongation, although there was clearly an indirect effect through modification of the level of mechanical impedance. Jones and Wild (1975), reported that a major growth limiting factor in West African Savannas other than erosion and low nutrient supply was inadequate rooting depth due to compaction of the subsurface horizon. This results in severe drought stress during limited rainfall years. Foy et al., (1980) concluded that physical factors that limit root development include mechanical impedance and/or unfavourable $CO_2:O_2:H_2O$ relationships.

In the Intermediate Savannas of Guyana, poor root proliferation in acid subsoils is a serious problem (Bullen et al., 1982). According to Page and Willard, (1946), satisfactory crop production is obtained only when the soil possesses favourable chemical and physical properties. However, the physical condition of the soil is often considered to be an inherent property, though research shows that cultivation has a profound

effect upon mechanical impedance, bulk density and moisture content (Page and Willard, 1946). Floyd, (1979) working with a sandy loam, confirmed by physical measurements and detailed observations that surface crusting and subsoil compaction restricted root and shoot growth. Because of limited data, field studies are needed to develop a better appreciation of the relationship between soil physical conditions, plant growth and crop yields in coarse textured soils of Guyana's Intermediate Savannahs.

2.5 Tillage Effects on Soil Physical Properties and Crop Growth

Virgil (70-90 B.C.) as quoted in Tisdale and Nelson, (1975) discovered a method for determining soil bulk density and stated that "loose soils provide bounteous vines but dense soils provide reluctant clods and stiff ridges." According to Russell, E. W., (1971, 1973) soils which tend to settle in the course of a year into a relatively dense mass containing few transmission pores or fissures, can be loosened by plowing and harrowing to produce a fine 'tilth' of fine aggregates, between which there are ample transmission pores to allow easy root growth, seedling emergence and air movement. However, while tillage can create a favourable environment for crop production it can damage soil pore continuity, promote dispersion of clay promote creation of dense, non-friable clods and aggregates, (Greenland, 1980), encourage formation of tillage pans, (McCracken and Weed, 1963; Campbell et al., 1974; Greenland and Lal, 1977) and increase susceptibility to sheet erosion (Greenland and Lal, 1977; Sanchez and Salinas, 1981).

Several workers in both temperate (Adams E. et al., 1960; Lowry et al., 1970; Skidmore et al., 1975; Floyd, 1979; Kamprath et al., 1979; McKyes et al., 1979; Raghavan et al., 1979; Stitt et al., 1982) and tropical regions (Wilkinson, 1975; Lal, 1976, 1977, 1981; Greenland and

Lal, 1977; Roose, 1977; Aina, 1978; Maurya and Lal, 1980; Sanchez, 1981; Adeoye, 1982) have concluded that intensive cultivation has resulted in increased surface crusting, subsoil compaction, susceptibility to erosion, deterioration of physical properties such as bulk density, mechanical impedance, aggregate stability and porosity and depressed crop yields. In the Intermediate Savannas of Guyana, large scale mechanized cultivation has resulted in surface crusting, subsurface compaction and increased sheet erosion. With decreased infiltration and porosity and higher subsoil impedance, crop growth has declined significantly in this fragile ecosystem (Bullen et al., 1982).

As indicated earlier in this review, probably both chemical and physical soil factors are responsible for reduced root growth and crop yields on acid soils. However, in many instances it is difficult to determine exactly the phenomena involved and the degree of involvement. For example, early work by Ferrant and Sprague, (1940) showed that chemical and physical soil properties such as soil acidity, nutrient supply, soil texture and pore space, apparently had little influence on root penetration of red clover in a New Jersey loamy soil. However, some inhibitory factor or factors in the A2 horizon was corrected by tillage, and this permitted the red clover roots to pass through this horizon and develop extensively in the B horizon. Ferrant and Sprague (1940) further suggested that additional investigation was needed to find the underlying causes for this response to tillage. Later, De Roo (1968) concluded that quantitative relations between tillage, soil physical properties and crop growth are generally lacking and tillage is still a tradition based upon instinct, art and practical observation. Sanchez and Salinas, (1981) confirmed these observations in the humid tropics, where for example excessively deep and frequent tillage operations are common on the

Oxisols and Ultisols of the savannah regions.

Though, the direct relationships are difficult to establish and quantify, studies have shown that there is definite link between soil physical properties such as bulk density, mechanical impedance and porosity and excessive compaction and denseness of the soil that is produced by natural processes or mechanization (James and Wilkins, 1972; Dumas et al., 1973; Juo and Lal, 1977). The subsequent detrimental effects on root growth and plant yields are also documented (Page and Willard, 1946; De Roo, 1968; Lowry et al., 1970; Skidmore et al., 1975; Mckyes et al., 1979; Adeoye, 1982). However, the effects of tillage are variable and there is no consensus on what are the best forms of tillage nor the ideal physical properties such as bulk density, porosity and mechanical impedance that should be created. Regardless of these limitations, various types of tillage are used to create what is thought to be favourable soil physical conditions for root growth and development (Larson, 1964; Burnett and Hauser, 1967; Rasmussen et al., 1972; Burov et al., 1973; Kamprath, 1979; Mckyes et al., 1979; Nicou and Chopart, 1979; Greenland, 1981). Eavis and Payne, (1968) concluded that root growth and root function are affected by a large number of factors, of which soil water appears to be of particular importance since it acts both directly on growth and function (Taylor and Klepper, 1978), and indirectly by affecting other relevant factors such as aeration, soil impedance and soil temperature. However, the results are often of local interest only since they depend on climatic, crop and soil interactions.

Adams E. et al., (1960) stated that relationships between soil physical properties and crop yield must take into account deeper soil horizons than simply the plow layer. However, Larson, (1964) concluded that while primary tillage practices such as conventional plowing,

rototilling, subsoiling and deep plowing loosen the soil and increase its porosity, secondary tillage and other mechanized operations for crop maintenance and harvesting encourages soil repacking. Also, Sanchez and Salinas, (1981) found that deep tillage in the Oxisols and Ultisols of savannah regions result in a very pulverised seedbed that is subject to compaction and considerable sheet erosion, especially during high intensity rainstorms. Regardless of these negative effects, tillage is still widely used to reduce subsoil compaction and improve root growth.

McKyes et al., (1979) concluded from a Quebec study that the use of subsoiling is likely to be more suitable for the loosening of deep hardpans and the promotion of deep root growth in dense subsoils. Cassel et al., (1978) found that chisel-plowing and subsoiling were better than conventional tillage in reducing mechanical impedance and increasing crop growth on a Virginian Ultisol. The differences in mechanical impedance persisted throughout the growing season. Kamprath, (1979) studied tillage effects on two Coastal Plain Ultisols in the U.S. and determined that subsoiling or chisel-plowing of soils with compacted pans would increase soybean yields especially in years in which below average precipitation occurred. Yield increases were attributed to increased root proliferation below the pan and greater utilization of water. Henderson et al., (1981) evaluated the effects of three primary tillage treatments on some soil properties and on potato and wheat yields on a fine, clayey Lebanese soil and found no differences in crop yields among the compared tillage treatments. Deep plowing though, decreased bulk density, increased pore space and increased water intake rates but had little effect on other soil properties as compared to shallow and conventional tillage. Effects however, were temporary.

Maurya and Lal (1980) working in Nigeria found that occasionally,

plants grown without tillage were stunted and showed signs of nutritional deficiency because greater bulk density, lower porosity and inadequate nutrient distribution in the soil profile reduced root growth and development. Agboola, (1981) in another Nigerian study confirmed these findings even though tillage effects on soil bulk density, infiltration and moisture content were non-significant. Other studies have shown that with time, tillage operations result in reduced infiltration (Wilkinson, 1975), lower hydraulic conductivities (Kowal, 1968), higher mechanical impedance and lower moisture contents (Lal, 1976) and reduced aggregation and aggregate stability (Aina, 1978) on these well drained, coarse-textured Nigerian soils. Duque et al., (1980) concluded that deep plowing and disking should be avoided on coarse-textured savannah soils because of the subsoil compaction that is created with time. However, according to Couto, (1974) subsoiling increased maize yields by 25% in a Uruguayan soil, the beneficial effects being noted even in the year following subsoiling. In general, subsoiling effects were independent of fertiliser applications. Adeoye, (1982) in a later study in Nigeria found that yield of crops tended to increase with tillage depth, although yield differences between plots ploughed 15 and 30 cm deep were inconsistent and insignificant. The increases in porosity and decreases in bulk density, due to deep tillage were only temporary, and differences in water storage and movement were only noticeable during the early part of the season.

Finally, Adeoye (1982) reviewed previous work and concluded that the effects of deep tillage on soil physical properties are variable, while its success in increasing crop yields is at best mixed.

2.6 Summary

In the preceding sections, studies in both temperate and tropical regions have been reviewed. It can be concluded from the review that both chemical and/or physical factors may be responsible for the phenomenon of shallow rooting in many acid soils. However, limited data are available on the interaction of limestone practices and tillage as they affect root growth, crop yields and soil chemical-physical properties, especially in savannah ecosystems of the humid tropics. Therefore, the primary focus of this research was to study the effects of applied limestone and tillage depths on plant growth and soil properties in problem soils of the Intermediate Savannahs of Guyana. The following hypotheses were therefore proposed and study objectives outlined.

HYPOTHESES

Experiment 1

- 1.1 Root growth is restricted because of high soil acidity mainly from soluble Al. Thus, placement of CaCO_3 will result in increased soil pH, reduced toxic levels of soluble Al, increased availability of nutrients and enhanced crop growth.
- 1.2 Soils of the Intermediate Savannahs are deficient in Ca and addition of this ion to the exchange complex will result in increased crop growth.

Experiment 2

2. Root growth is restricted due to high impedance. Therefore, physical modification of the soil profile by tillage will result in more favourable soil physical properties and better crop growth.

OBJECTIVES

The specific objectives were as follows;

Experiment 1

1. To study the effects of limestone rates and placements on:
 - 1.1 Cowpea plant yields, rooting depths and plant heights.
 - 1.2 Soil chemical properties - soil pH, KCl-exchangeable acidity and Al, exchangeable K, Ca and Mg and extractable P.
 - 1.3 Plant content of P, K, Ca and Mg.

Experiment 2

2. To study the effects of added limestone and tillage depths on:
 - 2.1 Cowpea plant yields, rooting depths and plant heights.
 - 2.2 Soil chemical properties - soil pH, KCl-exchangeable acidity, K, Ca and Mg and extractable P.
 - 2.3 Plant content of P, K, Ca and Mg.
 - 2.4 Soil physical properties - bulk density, mechanical impedance and water content.

CHAPTER II

EFFECTS OF LIMESTONE RATES AND PLACEMENT DEPTHS
ON COWPEA (Vigna unguiculata L. Walp.) GROWTH AND
SOIL CHEMICAL PROPERTIES ON FOUR ACID SOILS

1. INTRODUCTION

Attempts to develop the agricultural potential of the Intermediate Savannas of Guyana have been inconclusive because of several limitations (Follett-Smith, 1930; Holder, 1972; Brinkman, 1964; Wagenaar, 1965; Downer, 1972; Holder, 1972; T.A.M.S., 1976; Chesney, 1979; Dookie, 1981; Bullen et al., 1982). A major limitation has been soil acidity mainly because of toxic levels of exchangeable Al. This results in restricted root development, inefficient utilization of added nutrients and water and poor plant growth. Negative effects on yields and productivity of major field crops have been demonstrated by several workers (Pohlman, 1946; Ragland and Coleman, 1959; McCart and Kamprath, 1965; Adams et al., 1967; Adams and Pearson, 1970; Abruna et al., 1974a,b; Sartain and Kamprath, 1975; Spain, 1975; Kamprath, 1978; Serpa and Gonzalez, 1979; Ritchey et al., 1980; Friesen et al., 1982) mainly in temperate and subtropical regions.

However, according to Uehara (1978), imported solutions developed from temperate experience have been largely unsuccessful and significant areas of potentially arable lands in the humid tropics have remained agriculturally non-productive. Variations in mineralogy caused by differences in climate and weathering require that two sets of management principles be used, one for clays with a high proportion of permanent charges (temperate regions) and another for clays with a high proportion of pH dependent charges (tropical and subtropical regions). The situation in the humid tropics, therefore, require development of specific soil management practices because of indigenous soil chemical-physical factors, climatic interactions with the soil ecosystem and existing economic realities. Low input technology that corrects

possible soil chemical imbalances and enhances development of the plant root environment must be sought.

Soil acidity has been defined as a limiting growth factor in tropical regions because of high soil solution Al and subsequent negative effects on plant uptake of essential nutrients, especially calcium (Kamprath, 1978). Studies of limestone applications to correct acidity problems have not resulted in a consensus with respect to rates and placements (Brown et al., 1956; Hourigan et al., 1961; Reeve and Sumner, 1970b, 1972; Fox, 1979; Gonzalez-Erico et al., 1979; Khalid and Silva, 1979; Cochrane et al., 1980; Ritchey et al., 1980; Tran and van Lierop, 1981; Ssali and Nuwamanya, 1982). It has been shown that liming of some acid soils in the Intermediate Savannas of Guyana is essential for normal plant growth and development of many field crops (Bullen et al., 1982). Yet overliming is a serious concern on acid soils and in addition limestone effects vary with the crop (Kamprath, 1984). Thus, best rates and placement of limestone may be a function of crops and soil properties.

The purpose of the proposed experiment therefore, was to study the effects of rates and placement depths of limestone on soil chemical properties, especially as a function of soil depth. Yield, plant height, root growth and nutrient content responses of cowpea (Vigna unguiculata L. Walp.) to these changes in soil properties will be evaluated.

2. MATERIALS AND METHODS

2.1 SITE CHARACTERISTICS

2.1.1 Location

A field study (experiment 1) was established in July, 1982 at the Ebini crop Research Station, located ($5^{\circ} 40' N$ latitude and $57^{\circ} 47' W$ longitude) in the north-eastern region of Guyana (Fig. 1.1). It lies within the area of the Berbice Savannas, which because of their position relative to the coastland and to the Rupununi Savannas, are known colloquially as the "Intermediate Savannas" (Richards, 1952; Downer, 1972).

2.1.2 Climate

The Intermediate Savannas are characterised by a "humid, tropical wet and dry equatorial climate", with two distinct wet and dry seasons. Average annual rainfall at Ebini is approximately 2250 mm, with the majority occurring between mid-April to early-August (long rainy season) and the remainder mainly from December to January (short rainy season), while annual evaporation is about 1270 mm, during normal years (Figure 2.1). Mean annual temperatures range between $31.4^{\circ}C$ (Maximum) and $22.6^{\circ}C$ (Minimum), with an average of $26.6^{\circ}C$ (Figure 2.2). The mean relative humidity varies from 90% (8 am) to 70% (2 pm) for most of the year. Day-length does not change much from the approximate 12 hours pattern while daily sunshine hours range from 6 in the long wet season to 8 during drier months (Wagenaar, 1965; T.A.M.S., 1976; Fraser, 1980).

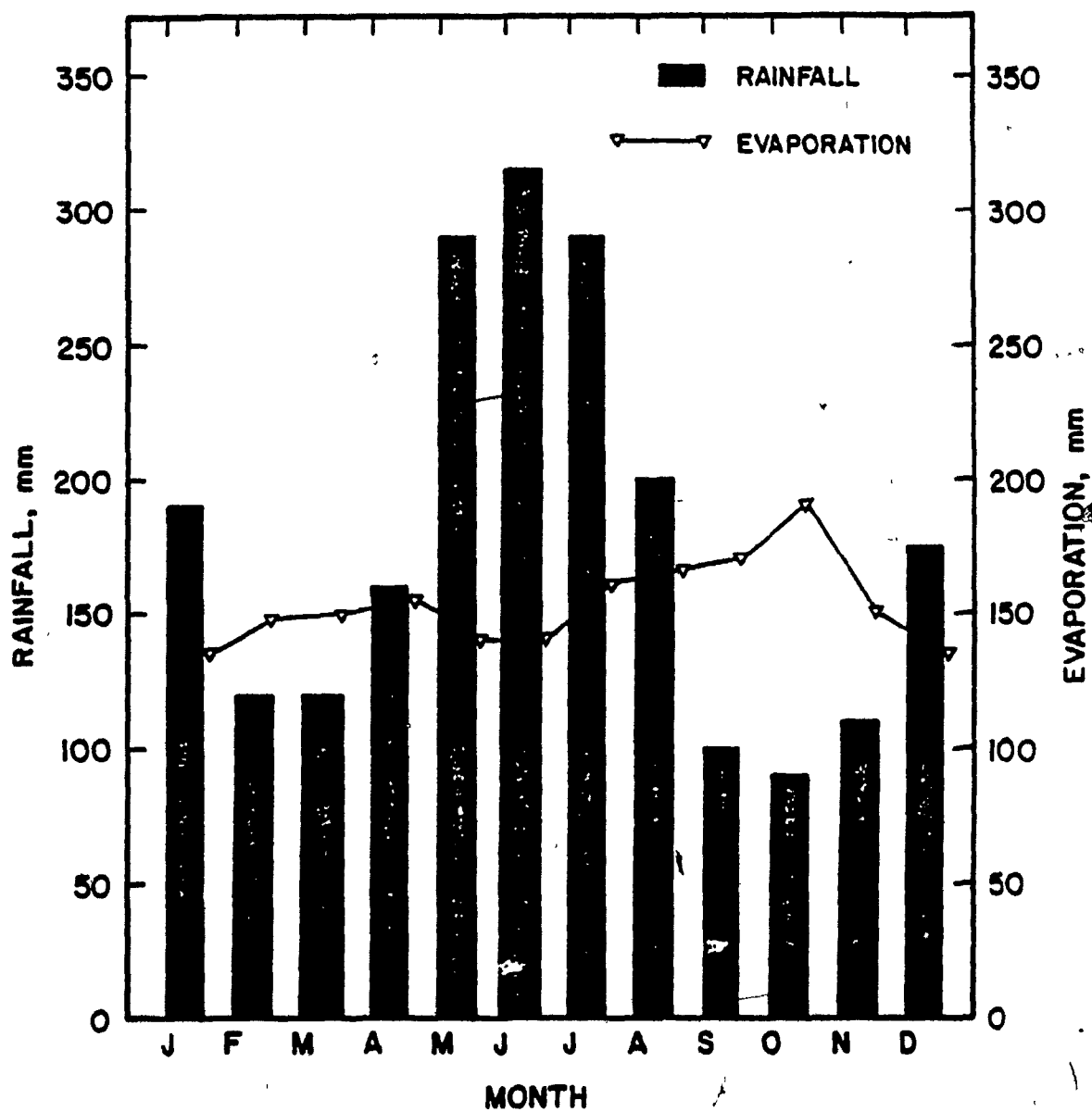


FIG. 2.1

Average monthly rainfall and evaporation (mm) at the Ebini Crop Research Station for 1982 and 1983.

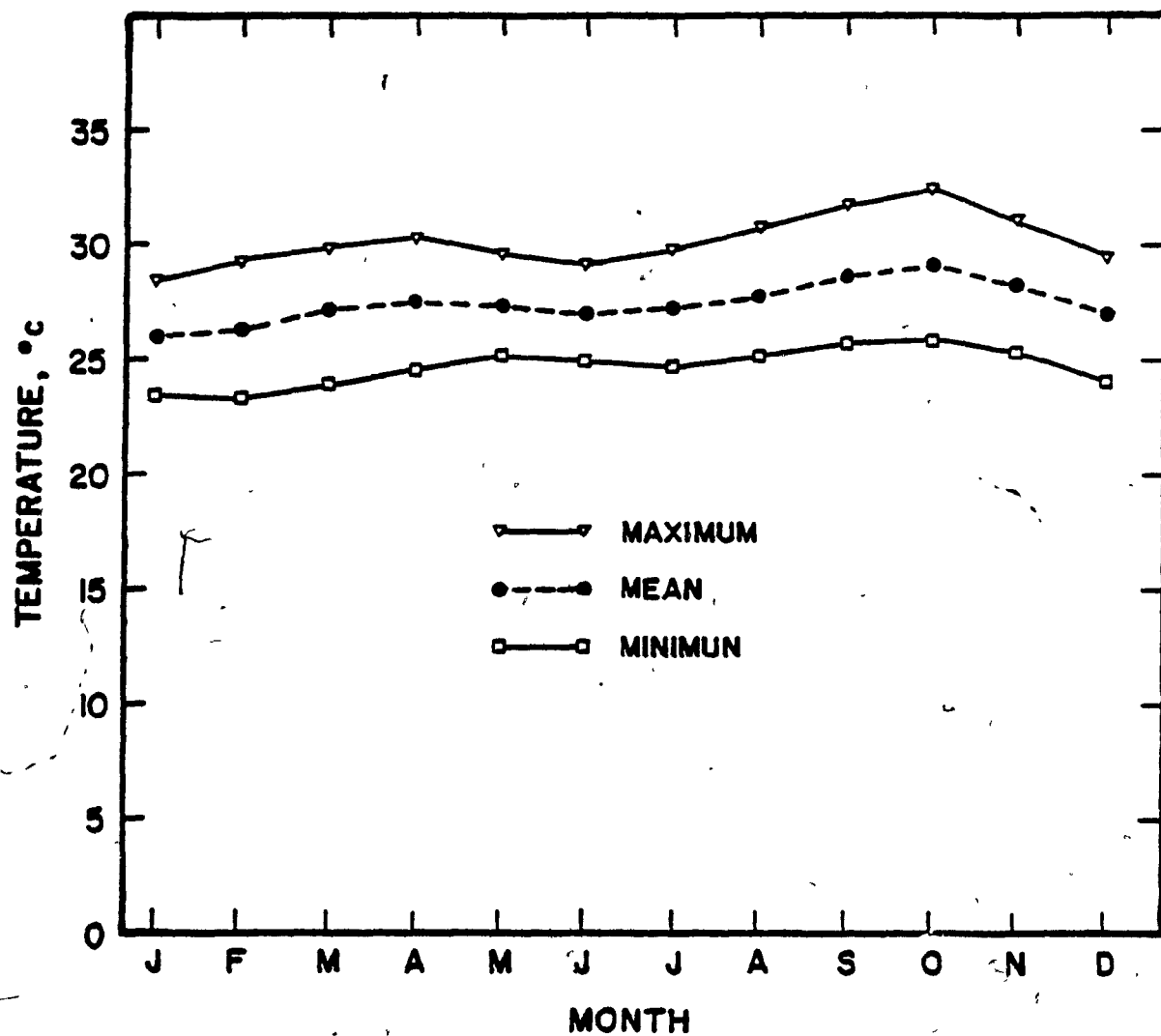


FIG. 2.2 Average monthly maximum, mean and minimum temperatures (°C) at the Ebini Crop Research Station for 1982 and 1983.

2.1.3 Vegetation.

Native savannah areas are dominated by grasses with "islands" of shrub and trees. The dominant grass species is Trachypogon plumosus L. with other grasses such as Axonopus aureus L., Axonopus stragalus L. and Andropogon virgatus being of minor importance. The most common trees are Curatella americana L. and Byrsonima crassifolia L. (Richards, 1952; Brinkman, 1964). The experimental areas were out of cultivation for several years and overgrown with the grasses Eleusine indica L. and Cenchrus echinatus L. and the legume Calypogonia sp.

2.1.4 Physiography and Geology

The Ebini area lies within the northern regions of the physiographic unit designated as the "white sand" plateau with somewhat uniform topography and gently undulating relief. This plateau rises from an elevation of about 16 m. in the north to about 160 m. in the south. Its surface is dominated by irregularly distributed areas of quartz sand (white sand and brown loamy sand to sandy clay), thought to have developed from deposition of river sediments. The Intermediate Savannas consists mainly of soils from the brown sand series, but these change to bleached sands with changes in vegetation (Richard, 1952; Bleackley and Khan, 1959, 1963; Downer, 1972). The brown sand series are part of the Berbice formation, with the Ebini area consisting of a group of Tertiary to Pleistocene and Holocene continental-deltaic sediments (Downer, 1972).

2.1.5 Soils

The soils include well drained Ultisols, Oxisols and Entisols that are coarse to medium-textured, ranging from pure white quartz sand to yellowish-red sandy clay. This study was carried out on the following soil types representative of four major agricultural soils of the region.

1. Tabela sand No. 800 (Typic Quartzispermament),
2. Kasarama loamy soil No. 810 (Ultic Haplorthox),
3. Kairuni loamy sand No. 815 (Arenic Paleudult) and
4. Bukaruna loamy sand No. 816 (Grossarenic Paleudult).

Experimental areas, selected for uniformity were each approximately 0.80 hectare in size (Fig. 2.3). The Tabela sand is the most extensive and referred to locally as "white sands" while the Kasarama, Kairuni and Bukaruna loamy sands are known as "brown sands". All the soils are very acid and extremely low in natural fertility both in surface and subsurface soil horizons. (Table 2.1) These soils have a low water-holding capacity, organic matter content, cation exchange capacity and base status, with the C.E.C. being dominated by exchangeable acidity, mainly from soluble aluminum. (Brinkman, 1964; Downer, 1972; Bullen et al., 1981). Detailed soil descriptions are given in Appendix A.

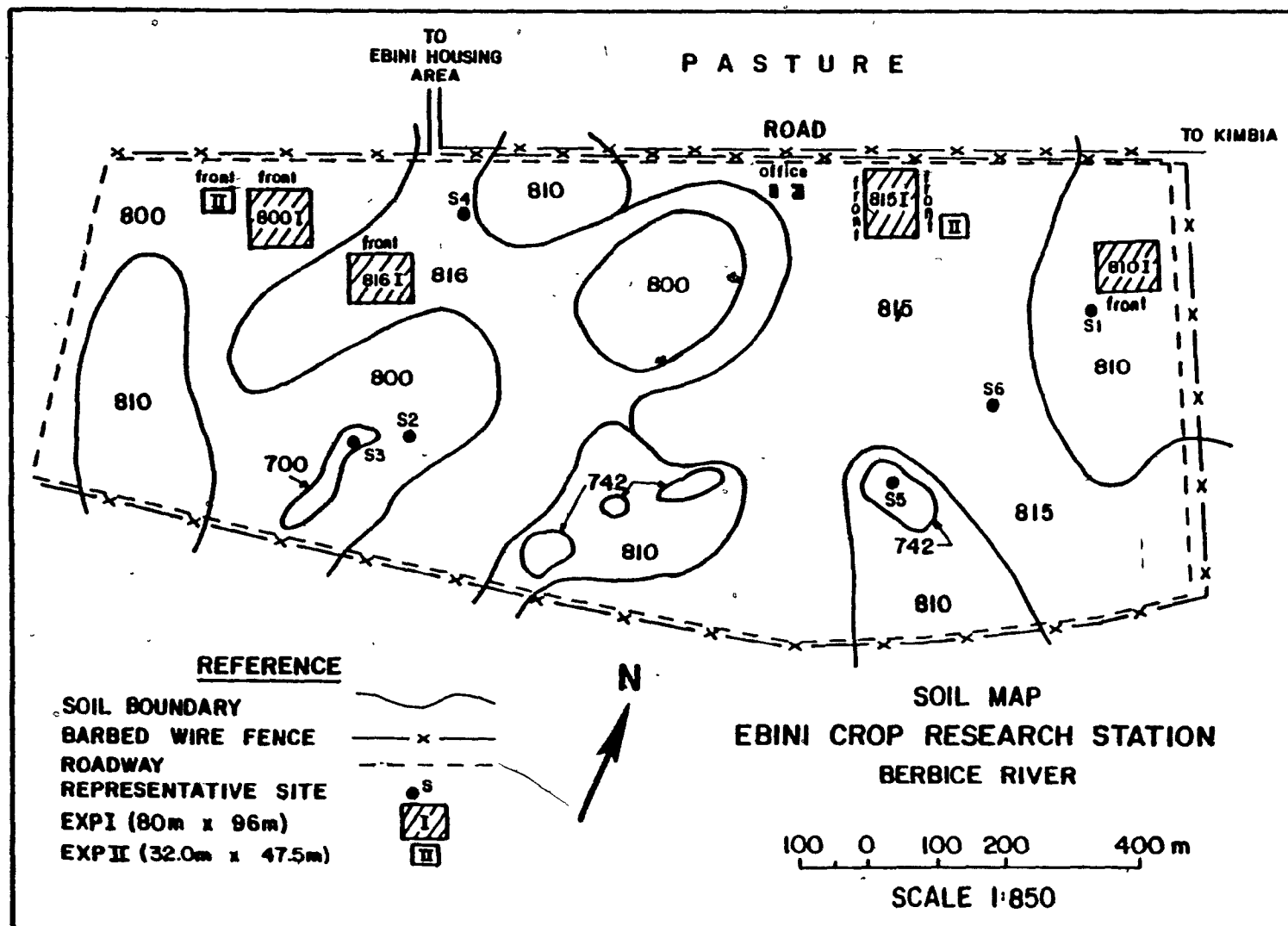


FIG. 2.3 Soil map of the Ebini Crop Research Station showing location of experimental areas.

Depth cm	Particle Size			pH	OC —%	Kj-N —	Ex. Al	Ex. Acid	Extractable Bases					Effec. C.E.C.	Base Sat. %	Ext. P ppm
	S	Si	C						Ca	Mg	K	Na	Total			
	—%—															
<u>Tabela sand No. 800</u>																
0-15	93	3	4	4.4	0.6	0.04	0.20	0.50	0.35	0.14	0.05	0.37	0.91	1.41	64	15
15-30	89	4	7	4.6	0.2	0.04	0.21	0.61	0.34	0.14	0.08	0.39	0.95	1.56	61	7
30-45	85	7	8	4.5	0.3	0.02	0.17	0.55	0.17	0.12	0.04	0.34	0.67	1.22	55	5
<u>Kasarama loamy sand No. 810</u>																
0-15	88	5	7	4.4	1.2	0.12	0.22	0.60	1.10	0.14	0.11	0.25	1.60	2.20	73	15
15-30	86	5	9	4.5	0.7	0.09	0.15	0.74	0.69	0.07	0.09	0.31	1.16	1.90	61	5
30-45	81	10	9	4.5	0.6	0.08	0.15	0.57	0.55	0.04	0.03	0.15	0.77	1.34	57	10
<u>Kairuni loamy sand No. 815</u>																
0-15	80	5	15	4.2	0.5	0.04	0.18	0.49	0.51	0.08	0.07	0.21	0.87	1.36	64	14
15-30	86	2	12	4.4	1.4	0.03	0.25	0.97	0.43	0.11	0.11	0.27	0.92	1.89	49	4
30-45	83	8	10	4.4	0.2	0.02	0.24	0.61	0.32	0.04	0.04	0.14	0.54	1.15	47	5
<u>Bukaruna loamy sand No. 816</u>																
0-15	85	5	10	4.4	0.9	0.08	0.10	0.66	0.65	0.21	0.09	0.21	1.16	1.82	64	8
15-30	80	9	11	4.7	0.6	0.06	0.16	0.47	0.55	0.06	0.18	0.13	0.92	1.39	67	5
30-45	82	10	8	4.5	0.5	0.03	0.13	0.47	0.30	0.04	0.07	0.08	0.49	0.96	51	3

Table 2.1 Some Chemical-Physical Properties of the Experimental Soils.

2.2 EXPERIMENTAL DESIGN

2.2.1 Design and Treatments

At each site, there were 12 treatments (4 x 3 factorial) with 3 replications in Randomized Complete Block Design. Limestone (Crushed Shells - 98% CaCO_3) was applied at 4 rates (A) in 3 different depths (B). The rates and placement depths of limestone were coded as follows:

1. A_1 - 0 Mg ha^{-1}	} Limestone
A_2 - 1.5 Mg ha^{-1}	
A_3 - 3.0 Mg ha^{-1}	
A_4 - 4.5 Mg ha^{-1}	

2. B_1 - All of the applied limestone surface broadcast before disc plowing.

B_2 - One half of the applied limestone surface broadcast before disc plowing and the remainder, surface broadcast after disc plowing, before harrowing.

B_3 - All of the applied limestone surface broadcast after disc plowing, before harrowing.

The disc-plowing and harrowing operations were carried out to depths of 30 and 15 cm, respectively. Each experimental unit (treatment) was 200 m^2 (25 m in length and 8 m in width) in size, and there was a 2.5 m pathway between each block of treatments. Limestone was uniformly broadcasted by hand on the surface of each 200 m^2 plot and treatments were applied between July 15, 1982 and July 21, 1982.

2.2.2 Statistical Analysis

2.2.2.1 Plant Variables

All results were analysed statistically according to procedures outlined in Steel and Torrie (1980). ANOVA (Analysis of Variance) and F ratios were calculated. Orthogonal polynomials and contrasts were used to compare treatment means for rates and placement depths of limestone and their interactions only when ANOVA F ratios were significant. All analyses were done using S.A.S. programs (SAS Institute Inc., 1982).

2.2.2.2 Soil Variables

Soil data were analyzed to determine F statistics, means and standard errors according to procedures outlined in Steel and Torrie (1980) using S.A.S. programs (SAS Institute Inc., 1982).

2.2.2.3 Regression Analyses

Analyses were carried out to determine the relationship of tissue and soil Ca levels to plant yields. The GLM (General Linear Models) procedure was used to determine F statistics according to procedures described in Steel and Torrie (1980). The analyses were carried out using S.A.S. programs (SAS Institute Inc., 1982).

2.3 PLOT ESTABLISHMENT AND MAINTENANCE

2.3.1 Land Clearing

The field plots at each site were cleared of existing vegetation by using a tractor-mounted, chain brushcutter along with manual weeding.

2.3.2 Land Preparation

Before planting, each site was first plowed with a conventional 5 furrow, disc-plow and then tilled with a trailing, double gang disc-harrow. For the second harrowing a rear mounted plank was attached to ensure preparation of a fine, firm, level seed bed.

2.3.3 Planting

Eight rows of the cowpea (Vigna unguiculata L. Walp.) cultivar, California Blackeye No. 5 were planted with a 4-Row Unit planter at a spacing of 75 cm inter-row and 10 cm intra-row. Each row was 25 m long and a stand of approximately 120,000 plants per hectare was achieved (based on a germination of approximately 90%). Before planting a seed treatment of Arasan 70-S (A.I. Thiram, Dupont Biochemicals Div., Wil., Del., U.S.A.) and Nitramo (A.I. Molybdenum, Kalo Lab Inc., Kansas City, MI, U.S.A.) were applied at the rate of 50 g per 10 kg seed and 100 g per 12 kg seed, respectively. Also, Cowpea Inoculant (Rhizobia sp., Microbiology Unit, Min. of Agriculture, Guyana) was applied at the rate of 0.5 kg Inoculant per 10 kg seed. The seeding dates for all 4 sites were as follows:-

1. January 21st, 1983 (First season) and
2. July 22nd, 1983 (Second season).

2.3.4 Fertilization

2.3.4.1 First Season

At planting a complete fertiliser (9% N-23% P_2O_5 -12% K_2O - 2% MgO + micronutrients¹, Fert. Corp. of America, Mi., Fl., U.S.A.) was banded 10 cm to side of the seed at a rate of 235 kg ha⁻¹. A second application of 9-23-12-2 was sidedressed at the rate of 200 kg ha⁻¹, 25 days after planting.

2.3.4.2. Second Season

A mixed fertiliser was applied at the rate of 250 kg ha⁻¹ at planting. The fertiliser was obtained by mixing 350 kg 16-9-12-2 (16% N - 9% P_2O_5 - 12% K_2O - 2% MgO + micronutrients¹, F.C.A., Mi. Fl., U.S.A.) + 225 kg Triple superphosphate (46% P_2O_5) + 50 kg Muriate of Potash (60% K_2O). At 25 days a second application of mixed fertiliser was sidedressed at the rate of 215 kg ha⁻¹. This fertiliser was obtained by mixing 300 kg 16-9-12-2 + 200 kg Tsp + 50 kg M of P.

2.3.5 Crop Management

2.3.5.1 First Season

For pre-emergent weed control Treflan (Trifluralin, Elanco Prod., Co., Indianapolis, Ind., U.S.A.) was pre-plant incorporated at the rate of 1.75 L ha⁻¹. The insecticide Ambush (Permethrin, FMC Corp., Phil., PA., U.S.A.) was sprayed twice during the season at the rate of 0.75 L ha⁻¹ for control of Lepidopterous sp. and other insect pests. Before the second insecticidal application the fungicide Kocide 101 (Cupric Hydroxide, Kocide Chem. Corp., Houston, Tx., U.S.A.) was tank mixed with

Ambush at the rate of 1.75 kg ha⁻¹ for control of fungal leaf and stem diseases.

2.3.5.2 Second Season

Gesagard (Prometryn, Ciba-Geigy Corp., Greenboro, N.C., U.S.A.) was applied immediately after seeding at a rate of 2.25 L ha⁻¹ for pre-emergent weed control. Nuvacron (Monocrotophos, Ciba-Geigy Ltd., Switzerland) and Dithane-M45 (Manzeb, Rohm and Haas Co., Phil., PA, U.S.A.) were tank mixed and applied together at the rate of 0.75 L ha⁻¹ and 2.25 kg ha⁻¹, respectively, for control of mites, aphids, leaf hoppers and plant bugs (*Lygus* sp.) and fungal diseases. A second fungicide, Benlate (Benomyl, Dupont Biochemicals Div., Wil., Del., U.S.A.) was applied later at a rate of 2.25 kg ha⁻¹ for control of pod and stem rot.

2.4 HARVESTING AND PLANT MEASUREMENTS

At maturity, 20 plants (tops and roots) were randomly selected from the middle 10 m section of the 4 inner rows and carefully harvested by excavation of roots from the soil. Plant samples were taken to the laboratory for yield determinations and plant measurements. Ten intact plants were randomly selected for determination of root lengths and plant heights. Soil particles were removed from the roots by light brushing and whole plants with pods were bagged and placed in a batch dryer for 36 hours. After this initial drying, pods were removed, oven-dried at 70°C to a constant weight and weighed. Plants excluding pods were also oven-dried at 70°C to a constant weight. The dried plants were then cut at the root-stem interface and root and above-ground plant (tissue)

weights were subsequently determined. Estimates of total plant, pod, root and tissue dry matter (D.M.) yields in kilograms per hectare (kg ha^{-1}) were then calculated.

2.5 SOIL SAMPLING

Composite soil samples obtained from 3 subsamples were taken for chemical analyses from each treatment at the end of both seasons. Each experimental unit was sampled at the following depths using an auger:

- (1) 0-15 cm,
- (2) 15-30 cm and
- (3) 30-45 cm.

Also, soil samples were taken at similar depths prior to cultivation for determination of soil chemical-physical properties (Table 2.1).

2.6 LABORATORY ANALYSIS

2.6.1. Soil Properties

Soil samples were air-dried, ground to pass a 2 mm sieve and stored at ambient temperatures until analysed. Soil pH was measured potentiometrically in a 1:2.5 (W/V) soil-water ratio (Jackson, M. 1958). Soil samples were extracted with 1 M KCl for KCl-exchangeable acidity, exchangeable Ca, Mg and Na (Coleman et al., 1959; Thomas, 1982; Hunter, 1974). KCl-exchangeable acidity (exchangeable acidity) was determined by titration with 0.10 M KOH (Jackson, 1954; Hunter, 1974). Exchangeable Ca and Mg were determined by titration with EDTA (Heald, 1965; Lanyon and Heald, 1982) and Na by flame emission (Hunter, 1974). KCl-exchangeable acidity was extracted using 1 M KCl (Barnhisel and Bertsch, 1982). The

leachate was titrated with 0.20 M KOH, 4% NaF added and then back-titrated with 0.20 M HCl to determine KCl-exchangeable Al (Yuan, 1959; McLean, 1965). Although the titrimetric determination of aluminum is not specific for this element, it is commonly employed in soil test laboratories as an estimate of exchangeable Al (Kamprath, 1970). Potassium was extracted by 1 M Ammonium Acetate and concentration determined by flame emission (Schollenberger and Simon, 1945; Knudsen et al., 1982). The effective cation exchange capacity (C.E.C.) was then calculated as sum of exchangeable bases plus exchangeable acidity (Seubert et al., 1977). Available P was extracted with 0.03 M NH_4F + 0.025 M HCl and determined colorimetrically using the method of Bray and Kurtz, (1945). For determination of total nitrogen and organic carbon, soil samples were ground and sieved to less than 0.2 mm. Total N was determined by the semi-micro Kjeldahl method (Bremner, 1965) and organic C by the Walkley-Black procedure (Allison, 1965). Particle size analyses were carried out by the pipette method (Kilmer and Alexander, 1949).

2.6.2 Plant Content of P, K, Ca and Mg

Plant samples were oven dried at 70°C for 4 hours, ground in a Cristy and Norris cast iron mill and screened to less than 0.2 mm before analysis. Tissue samples were digested with H_2SO_4 and P was determined spectrophotometrically by the vanadomolybdate method and K by flame emission (Jackson, 1958). Tissue samples were wet ashed with a ternary acid mixture of HNO_3 - H_2SO_4 - HClO_4 (10:1:1) and Ca and Mg were determined by E.D.T.A. titration (Gee et al., 1954; Jackson, 1958).

¹⁵S Mn, Zn, Cu, B and Mo.

3. RESULTS

3.1 Cowpea Yields

3.1.1 Total Plant Yields

Total plant yields were significantly increased by added limestone on all four soils in both seasons (Fig. 2.4.1, Table 2.2.1). In the first season the yield response to added limestone was cubic for the Tabela sand No. 800, linear for the Kairuni loamy sand No. 815 and quadratic for both the Kasarama loamy sand No. 810 and the Bukaruna loamy sand No. 816 (Fig. 2.4.1). Second season results were similar, except that there was a linear yield response to added limestone on the Tabela sand No. 800. The effects of limestone placement depths and limestone rate-placement depth interactions were non-significant on all soils in both seasons (Tables 2.2.2, 2.2.3). Total plant yields in the long rainy season (season 2) were higher than yields in the short rainy season (season 1) on all soils (Tables 2.2.4, 2.2.5, 2.2.6, 2.2.7).

3.1.2 Pod Yields

Pod yields were significantly increased by added limestone on all four soils in both seasons. (Fig. 2.4.2, Table 2.3.1). The pod yield response to rate of added limestone was cubic for the Tabela sand No. 800, quadratic for the Kasarama loamy sand No. 810 and Bukaruna loamy sand No. 816 and linear for the Kairuni loamy sand No. 815 in the first season (Fig. 2.4.2). In the second season, yield responses to added limestone were linear for all soils except the Bukaruna loamy sand No. 816, on which the pod yield response remained quadratic (Fig. 2.4.2). The effects of limestone placement depths and limestone rate-placement

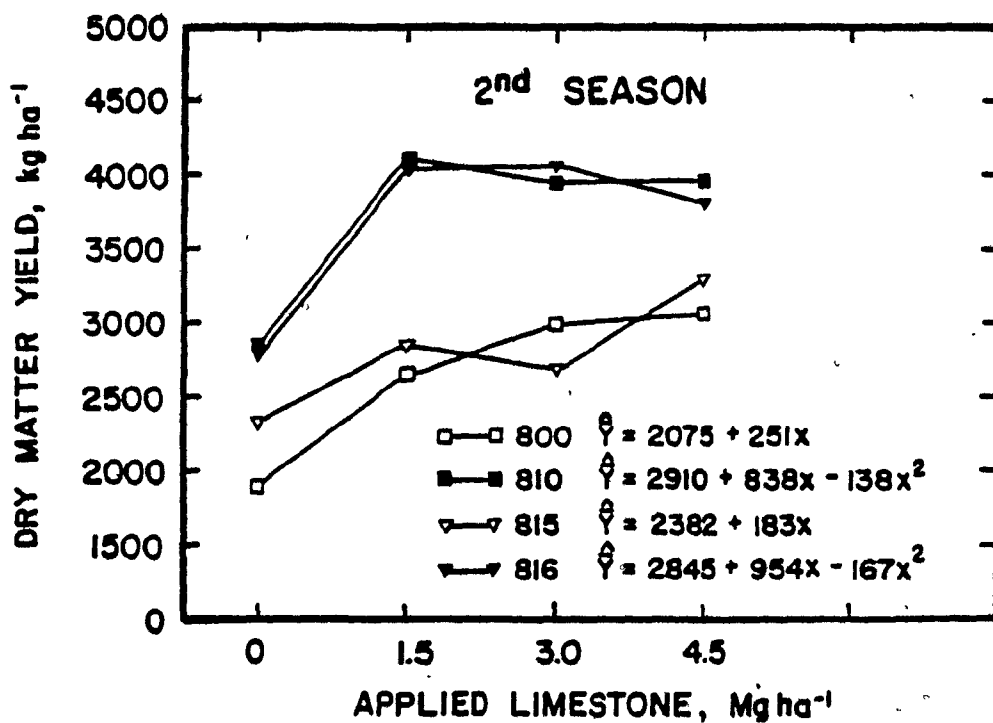
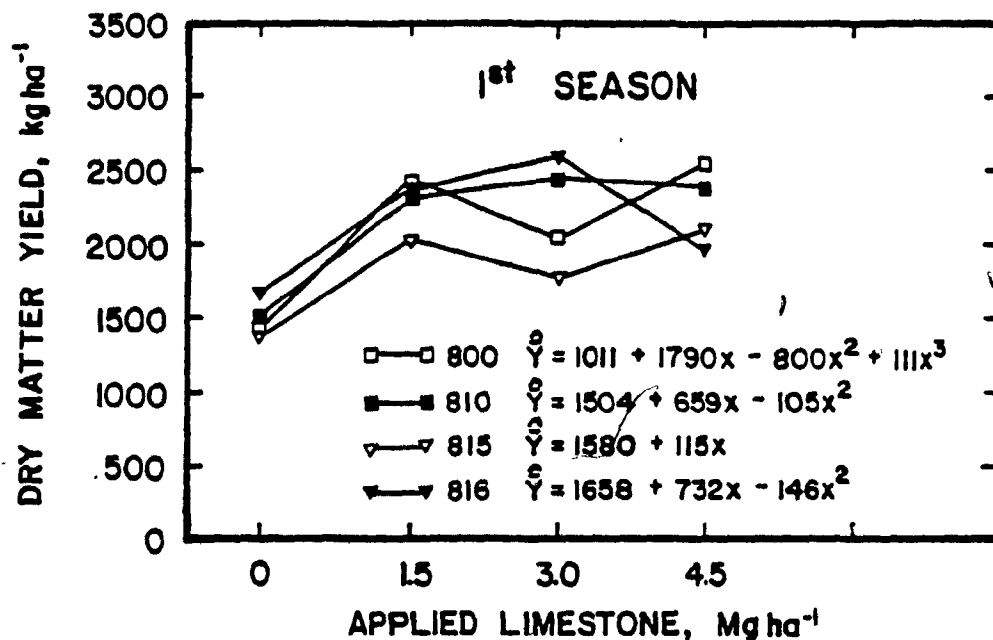


FIG. 2.4.1 Response of Cowpea total plant yields to limestone rates on four soils for two seasons.

Table 2.2.1 Orthogonal polynomial contrasts of limestone rates on observed mean total dry matter yields of Cowpea grown on four soils for two seasons.

Season	Source	df	SOIL TYPE			
			800	810	815	816
	Limestone Rate		MEAN SQUARES ($\times 10^{-4}$)			
1.	A ¹	3	214.26**	188.66**	81.95*	150.67**
	A linear	1	369.51**	349.47**	134.95*	57.60
	A quadratic	1	45.24	201.21*	19.27	387.49**
	A cubic	1	228.03*	15.29	91.62	6.91
	Exp. Error	22	36.71	27.45	22.70	13.75
Coefficient of Variation (%)			28.6	24.3	25.9	17.2
2.	A	3	245.30**	311.27*	148.51**	322.14**
	A linear	1	636.30**	472.97*	337.97**	415.62**
	A quadratic	1	98.37	347.94*	2.61	508.80**
	A cubic	1	1.18	112.90	104.95	41.99
	Exp. Error	22	23.57	75.98	29.29	39.10
Coefficient of Variation(%)			18.4	23.5	19.4	17.0

¹Rates of limestone.

*, ** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.2.2 Analysis of variance of Cowpea total dry matter yields (kg ha⁻¹) determined on four soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	4534582.75	12.35**
	A ¹	3	2142663.29	5.83**
	B ¹	2	819186.58	2.23
	A*B	6	52930.99	0.14
	Exp. Error	22	367108.20	
	Coefficient of Variation = 28.6%			
810	Blocks (R)	2	758546.19	2.76
	A	3	1886616.99	6.87**
	B	2	135185.86	0.49
	A*B	6	107279.82	0.39
	Exp. Error	22	274523.49	
	Coefficient of Variation = 24.3%			
815	Blocks (R)	2	101024.77	0.44
	A	3	819500.26	3.61*
	B	2	45092.11	0.20
	A*B	6	534834.15	2.36
	Exp. Error	22	227029.66	
	Coefficient of Variation = 28.9%			
816	Blocks (R)	2	526726.77	3.83*
	A	3	1506751.73	10.95**
	B	2	107532.11	0.78
	A*B	6	160601.59	1.17
	Exp. Error	22	137576.29	
	Coefficient of Variation = 17.2%			

¹A - limestone rates; B - limestone placement depths.
 *,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.2.3 Analysis of variance of Cowpea total dry matter yields (kg ha^{-1}) determined on four soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	145525.02	0.61
	A ¹	3	2453004.03	10.34**
	B ¹	2	229796.02	0.97
	A*B	6	166717.02	0.70
	Exp. Error	22	237132.87	
	Coefficient of Variation = 18.4%			
810	Blocks (R)	2	1234264.11	1.62
	A	3	3112765.81	4.10*
	B	2	1258626.77	1.66
	A*B	6	187419.37	0.25
	Exp. Error	22	759872.32	
	Coefficient of Variation = 23.5%			
815	Blocks (R)	2	1494745.44	5.10*
	A	3	1485187.88	5.07**
	B	2	360812.69	1.23
	A*B	6	356825.77	1.22
	Exp. Error	22	292948.75	
	Coefficient of Variation = 19.4%			
816	Blocks (R)	2	48774.11	0.12
	A	3	3221413.55	8.24**
	B	2	222787.86	0.57
	A*B	6	633474.75	1.62
	Exp. Error	22	391096.11	
	Coefficient of Variation = 17.0%			

¹A - limestone rates; B - limestone placement.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.2.4 - Effects of rates and placement depths of limestone on total plant yields of Cowpea grown on the Tabela sand No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	1690	1410	1280	1460
	1.5 - A ₂	2690	2610	1960	2420
	3.0 - A ₃	2160	2200	1740	2030
	4.5 - A ₄	2790	2520	2320	2550
	B mean	2330	2190	1830	
2.	0 - A ₁	2170	1520	2010	1900
	1.5 - A ₂	2600	2730	2610	2650
	3.0 - A ₃	3120	3100	2680	2970
	4.5 - A ₄	3290	2790	3050	3040
	B mean	2800	2540	2590	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.2.5 Effects of rates and placement depths of limestone on total plant yields of Cowpea grown on the Kasarama loamy sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	1600	1530	1290	1470
	1.5 - A ₂	2160	2430	2430	2430
	3.0 - A ₃	2350	2430	2550	2450
	4.5 - A ₄	2030	2500	2580	2370
	B mean	2340	2220	2210	
2.	0 - A ₁	2670	3380	2440	2830
	1.5 - A ₂	3560	4620	4090	4090
	3.0 - A ₃	3650	4120	4060	3940
	4.5 - A ₄	3810	4110	3960	3960
	B mean	3420	4060	3640	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.2.6 Effects of rates and placement depths of limestone on total plant yields of Cowpea grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ , dry matter					
1.	0 - A ₁	1280	1660	1367	1430
	1.5 - A ₂	2540	1470	2100	2040
	3.0 - A ₃	1620	2120	1620	1790
	4.5 - A ₄	1890	1870	2530	2100
	B mean	1830	1780	1900	
2.	0 - A ₁	2150	2290	2500	2330
	1.5 - A ₂	3090	2440	3040	2860
	3.0 - A ₃	3070	2110	2850	2670
	4.5 - A ₄	3300	3530	3080	3310
	B mean	2900	2590	2880	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.2.7 Effects of rates and placement depths of limestone on total plant yields of Cowpea grown on the Bukaruna loamy sand No. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ , dry matter					
1.	0 - A ₁	1640	1450	1940	1680
	1.5 - A ₂	2430	2570	2100	2370
	3.0 - A ₃	2690	2670	2440	2600
	4.5 - A ₄	2050	2170	1710	1980
	B mean	2200	2220	2050	
2.	0 - A ₁	2310	3290	2790	2800
	1.5 - A ₂	4010	3590	4540	4050
	3.0 - A ₃	4350	4000	3810	4060
	4.5 - A ₄	3390	4180	3840	3805
	B mean	3520	3770	3740	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

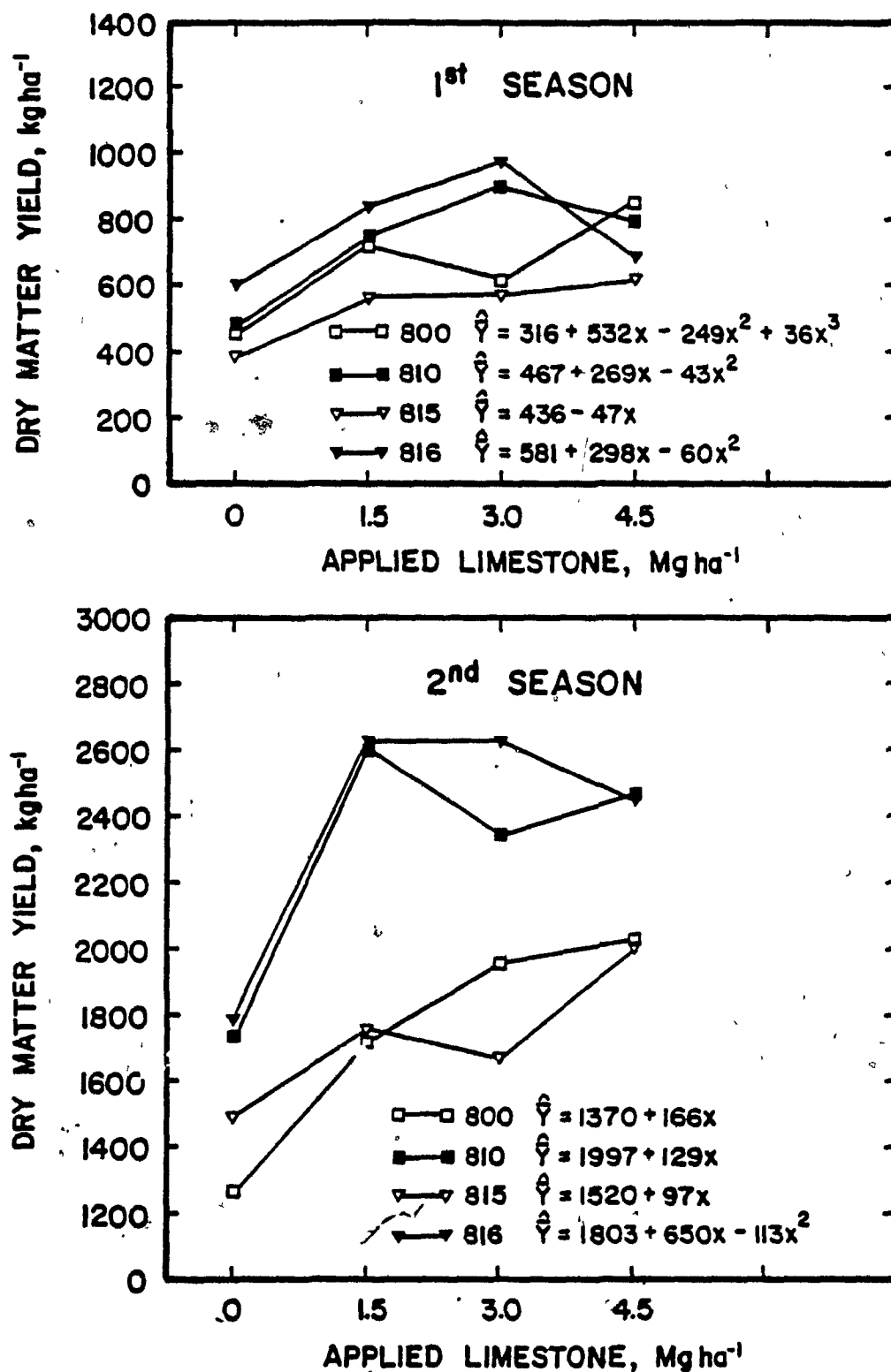


FIG. 2.4.2 Response of Cowpea pod yields to limestone rates on four soils for two seasons.

Table 2.3.1 Orthogonal polynomial contrasts of limestone rates on observed mean pod dry matter yields of Cowpea grown on four soils for two seasons.

			SOIL TYPE			
Season	Source	df	800	810	815	816
Limestone Rates			MEAN SQUARES ($\times 10^{-4}$)			
1.	A ¹	3	24.44*	30.08**	9.52*	26.33**
	A linear	1	48.70**	54.87**	22.16**	7.22
	A quadratic	1	0.14	34.51**	4.79	66.06**
	A cubic	1	24.50*	0.78	1.62	5.46
	Exp. Error	22	5.40	2.90	2.73	1.49
Coefficient of Variation (%)			35.1	23.3	30.6	20.3
2.	A	3	103.77**	131.27*	42.16*	150.41**
	A linear	1	278.40**	169.59*	95.16**	197.04**
	A quadratic	1	33.02	126.18	1.68	234.14**
	A cubic	1	0.19	98.03	29.73	20.07
	Exp. Error	22	11.91	36.40	9.33	13.56
Coefficient of Variation (%)			19.8	26.4	17.6	15.5

¹Rates of limestone

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.3.2 Analysis of variance of Cowpea pod dry matter yields (kg ha⁻¹) determined on four soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	829888.36	15.35**
	A ¹	3	244493.14	4.52*
	B ¹	2	4461.19	0.08
	A*B	6	39895.42	0.74
	Exp. Error	22	54061.39	
	Coefficient of Variation = 35.0%			
810	Blocks (R)	2	103568.69	5.62*
	A	3	300824.77	10.34**
	B	2	41456.44	1.43
	A*B	6	23141.07	0.80
	Exp. Error	22	29079.45	
	Coefficient of Variation = 23.3%			
815	Blocks (R)	2	23325.52	0.85
	A	3	95288.48	3.48*
	B	2	16736.77	0.61
	A*B	6	59900.37	2.18
	Exp. Error	22	27362.98	
	Coefficient of Variation = 30.6%			
816	Blocks (R)	2	145224.08	5.82**
	A	3	263331.80	10.56**
	B	2	28733.58	1.15
	A*B	6	7854.14	0.31
	Exp. Error	22	24935.41	
	Coefficient of Variation = 20.3%			

¹A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.3.3

Analysis of variance of Cowpea pod dry matter yields (kg ha⁻¹) determined on four soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	121630.11	1.02
	A ¹	3	1037772.22	8.72**
	B ¹	2	176992.52	1.49
	A*B	6	65370.86	0.55
	Exp. Error	22	119178.41	
	Coefficient of Variation = 20.0%			
810	Blocks (R)	2	74344.52	0.20
	A	3	1312728.59	3.61*
	B	2	364710.77	1.00
	A*B	6	236263.37	0.65
	Exp. Error	22	364092.28	
	Coefficient of Variation = 26.4%			
815	Blocks (R)	2	261801.00	2.80
	A	3	421654.74	4.52*
	B	2	167086.75	1.79
	A*B	6	138252.38	1.48
	Exp. Error	22	93347.82	
	Coefficient of Variation = 17.6%			
816	Blocks (R)	2	75273.58	0.56
	A	3	1504199.65	11.09**
	B	2	146048.25	1.08
	A*B	6	281102.33	2.07
	Exp. Error	22	135604.15	
	Coefficient of Variation = 15.5%			

¹A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.3.4 Effects of rates and placement depths of limestone on pod yields of Cowpea grown on the Tabela sand No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	480	460	440	460
	1.5 - A ₂	700	870	610	720
	3.0 - A ₃	570	660	590	610
	4.5 - A ₄	940	680	920	850
	B mean	670	670	640	
2.	0 - A ₁	1480	990	1350	1270
	1.5 - A ₂	1710	1750	1710	1720
	3.0 - A ₃	2080	1970	1800	1950
	4.5 - A ₄	2240	1860	1970	2020
	B mean	1880	1640	1710	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.3.5 Effects of rates and placement depths of limestone on pod yields of Cowpea grown on the Kasarama loamy sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	510	480	430	470
	1.5 - A ₂	790	650	820	750
	3.0 - A ₃	880	820	1010	900
	4.5 - A ₄	660	790	920	790
	B mean	710	690	800	
2.	0 - A ₁	1620	2170	1420	1740
	1.5 - A ₂	2290	2970	2540	2600
	3.0 - A ₃	2280	2380	2390	2350
	4.5 - A ₄	2270	2320	2800	2466
	B mean	2110	2460	2290	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.3.6 Effects of rates and placement depths of limestone on pod yields of Cowpea grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	330	430	410	390
	1.5 - A ₂	820	390	500	570
	3.0 - A ₃	570	650	540	580
	4.5 - A ₄	590	540	730	620
	B mean	580	500	540	
2.	0 - A ₁	1350	1490	1670	1500
	1.5 - A ₂	1840	1510	1950	1760
	3.0 - A ₃	1890	1370	1810	1670
	4.5 - A ₄	1940	2150	1970	2020
	B mean	1750	1610	1850	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.3.7 Effects of rates and placement depths of limestone on pod yields of Cowpea grown on the Bukaruna loamy sand No. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	580	620	600	600
	1.5 - A ₂	890	910	720	840
	3.0 - A ₃	1050	980	930	980
	4.5 - A ₄	680	730	630	680
	B mean	800	810	720	
2.	0 - A ₁	1420	2110	1780	1770
	1.5 - A ₂	2590	2330	2950	2620
	3.0 - A ₃	2820	2580	2490	2630
	4.5 - A ₄	2140	2700	2540	2460
	B mean	2240	2430	2440	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

depth interactions on pod yields were non-significant on all soils in both seasons (Tables 2.3.2, 2.3.3). Pod yields obtained in the second season were higher than first season yields (Tables 2.3.4, 2.3.5, 2.3.6, 2.3.7).

3.1.3 Root Yields

Root yields were significantly increased by limestone applications on all soils in both seasons except on the Kasarama loamy sand No. 810 in the second season (Fig. 2.4.3, Table 2.4.1). Yield responses in the first season were cubic for the Tabela sand No. 800 and Kairuni loamy sand No. 815 and quadratic for the other two soils while in the second season yield responses were quadratic for the Tabela sand No. 800 and Bukaruna loamy sand No. 816 and linear for the Kairuni loamy sand No. 815 (Fig. 2.4.3). In the first season, limestone placement depths had significant effects on root yields on the Tabela sand No. 800 and non-significant effects on the other three soils (Table 2.4.2). On the Tabela sand No. 800, deep placement of limestone (15-30 cm) gave significantly higher root yields in the first season than the 0-15 cm and 0-30 cm limestone placement depths (Tables 2.4.3, 2.4.6). Limestone rate-placement depth interactions were non-significant in the first season on all soils except on the Kairuni loamy sand No. 815 (Table 2.4.2). In this case there were significant cubic interaction effects with respect to limestone rate and the deep (15-30 cm) and shallow (0-15 cm) limestone placement depths (Tables 2.4.4, 2.4.8). In the second season limestone rate-placement depth interactions were non-significant on all soils (Table 2.4.5). Root yields were higher on the Kasarama loamy sand No. 810 and Bukaruna loamy sand No. 816 in the second season compared to the first season (Tables 2.4.7, 2.4.9). However, on the

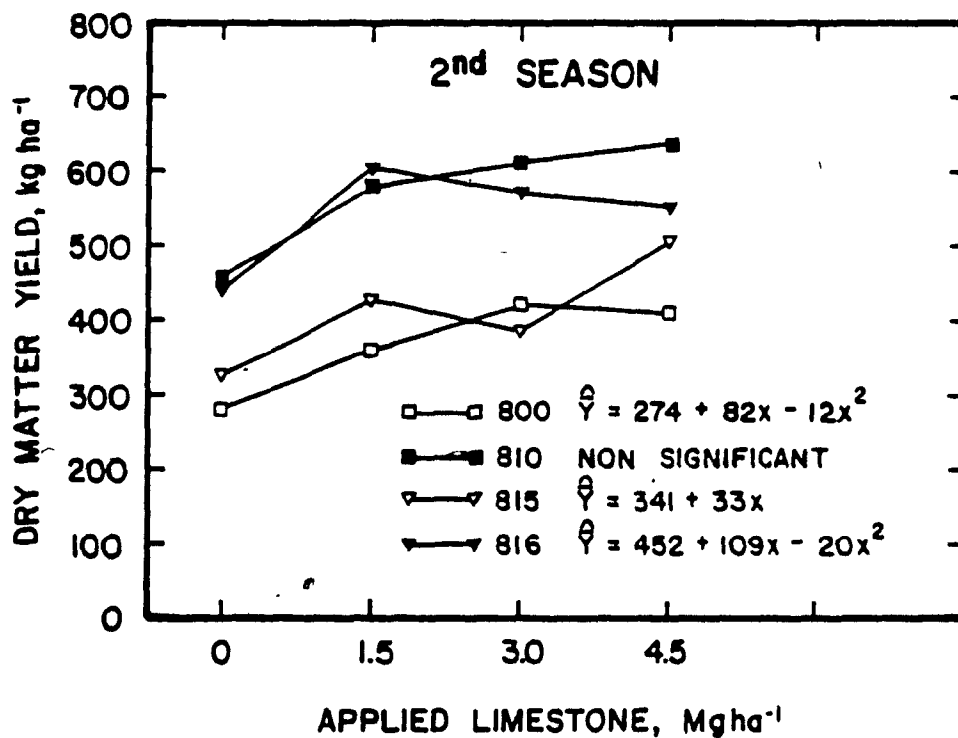
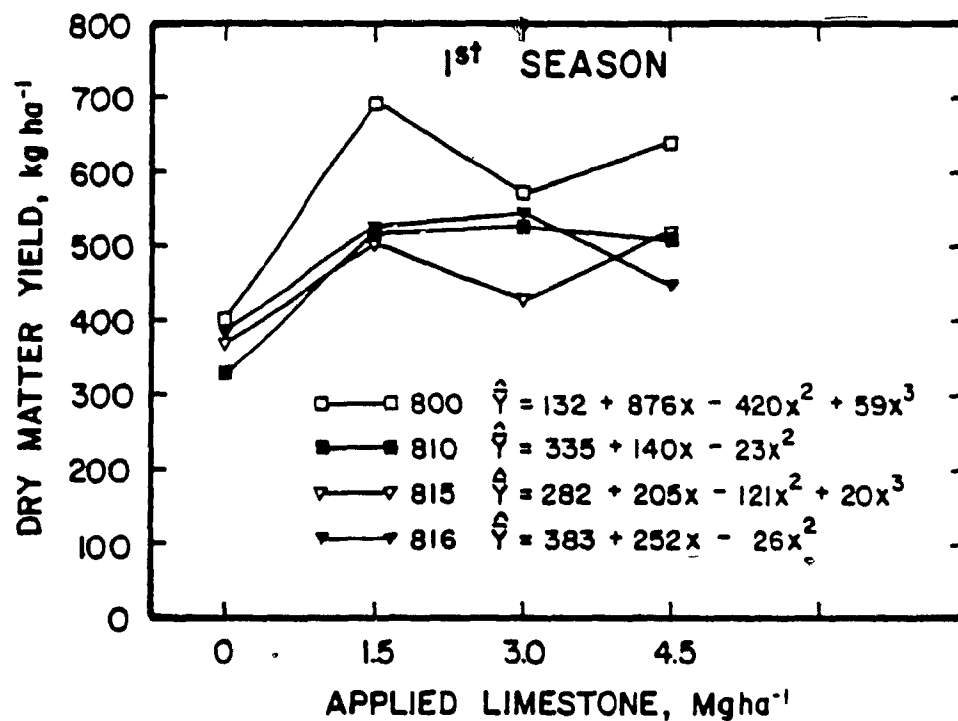


FIG. 2.4.3 Response of Cowpea root yields to limestone rates on four soils for two seasons.

Table 2.4.1 Orthogonal polynomial contrasts of limestone rates on observed mean root dry-matter yields of Cowpea grown on four soils for two seasons.

			SOIL TYPE			
Season	Source	df	800	810	815	816
Limestone Rate			MEAN SQUARES ($\times 10^{-4}$)			
1.	A ¹	3	14.59**	8.17**	4.69*	4.86**
	A linear	1	17.32*	14.04**	5.84	1.86
	A quadratic	1	10.58	9.42*	0.71	12.74**
	A cubic	1	15.88*	1.06	7.52*	0.01
	Exp. Error	22	2.88	1.62	1.43	0.94
Coefficient of Variation (%)			29.5	27.1	26.2	20.5
2.	A	3	3.87**	6.20	4.97*	4.25*
	A linear	1	9.05**	-	10.73**	3.58
	A quadratic	1	2.42*	-	0.15	7.38*
	A cubic	1	0.14	-	4.03	1.80
	Exp. Error	22	0.38	2.34	1.07	1.20
Coefficient of Variation (%)			16.9	26.6	25.0	20.5

¹Rates of limestone

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.4.2 Analysis of variance of C wpea root dry matter yields (kg ha⁻¹) determined on four soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	102181.00	3.54*
	A ¹	3	145988.00	5.06**
	B ¹	2	100342.00	3.48*
	A*B	6	1513.99	0.05
	Exp. Error	22	28845.50	
	Coefficient of Variation = 29.5%			
810	Blocks (R)	2	29499.70	1.81
	A	3	81790.00	5.02**
	B	2	17612.60	1.08
	A*B	6	6722.80	0.41
	Exp. Error	22	16290.70	
	Coefficient of Variation = 27.1%			
815	Blocks (R)	2	11323.40	0.79
	A	3	46948.20	3.27*
	B	2	5354.36	0.37
	A*B	6	36654.70	2.55*
	Exp. Error	22	14357.30	
	Coefficient of Variation = 26.2%			
816	Blocks (R)	2	22766.90	2.41
	A	3	48662.60	5.16**
	B	2	3663.40	0.39
	A*B	6	18025.50	1.91
	Exp. Error	22	9433.10	
	Coefficient of Variation = 20.5%			

¹A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.4.3 Orthogonal contrasts of limestone placement depths on root dry matter yields of Cowpea grown on The Tabela sand No. 800 in the first season.

Source	df	MEAN SQUARES ($\times 10^{-4}$)
B ¹	2	10.03*
B ₁ vs B ₂ , B ¹ ₁	1	14.17*
B ₂ vs B ₃	1	5.89
Exp. Error	22	2.88

Coefficient of Variation = 29.5%

¹B - limestone placement depths, B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.
*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.4.4 Simple effects of limestone rate-placement depth interactions on Cowpea root dry matter yields determined on the Kairuni loamy sand No. 815 in the first season.

Source	df	MEAN SQUARES ($\times 10^{-4}$)
A (B) ¹	9	4.00*
A linear in B ₁	1	0.01
A quadratic in B ₁	1	4.46
A cubic in B ₁	1	12.62**
A linear in B ₂	1	1.15
A quadratic in B ₂	1	0.00
A cubic in B ₂	1	1.80
A linear in B ₃	1	9.02*
A quadratic in B ₃	1	0.53
A cubic in B ₃	1	6.46*
Exp. Error	22	1.43

Coefficient of Variation = 26.2%

¹A - limestone rates.

¹B - limestone placement depths, B₁: 15-30cm; B₂: 0-30 cm; B₃: 0-15 cm.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.4.5 Analysis of variance of Cowpea root dry matter yields (kg ha⁻¹) determined on four soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	1401.19	0.36
	A ¹	3	38743.00	10.05**
	B ¹	2	2760.36	0.72
	A*B	6	4826.62	1.25
	Exp. Error	22	3853.10	
	Coefficient of Variation = 16.9%			
810	Blocks (R)	2	172404.00	7.35**
	A	3	62062.70	2.64
	B	2	9038.08	0.38
	A*B	6	21060.70	0.90
	Exp. Error	22	23466.49	
	Coefficient of Variation = 26.6%			
815	Blocks (R)	2	119303.00	11.12**
	A	3	49740.50	4.64*
	B	2	13530.10	1.26
	A*B	6	7466.70	0.70
	Exp. Error	22	10728.10	
	Coefficient of Variation = 25.0%			
816	Blocks (R)	2	2324.24	0.19
	A	3	42548.30	3.54*
	B	2	4832.58	0.40
	A*B	6	11960.40	0.99
	Exp. Error	22	12031.50	
	Coefficient of Variation = 20.5%			

¹A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.4.6 Effects of rates and placement depths of limestone on root yields of Cowpea grown on the Tabela sard No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ , dry matter					
1.	0 - A ₁	500	370	320	400
	1.5 - A ₂	790	700	580	690
	3.0 - A ₃	650	580	480	570
	4.5 - A ₄	710	670	550	640
	B mean	660	580	480	
2.	0 - A ₁	300	240	290	280
	1.5 - A ₂	370	380	330	360
	3.0 - A ₃	450	470	360	420
	4.5 - A ₄	410	380	430	410
	B mean	380	370	350	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.4.7. Effects of rates and placement depths of limestone on root yields of Cowpea grown on the Kasarama loamy sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	330	370	280	330
	1.5 - A ₂	450	600	500	520
	3.0 - A ₃	530	530	520	530
	4.5 - A ₄	420	550	560	510
	B mean	430	510	470	
2.	0 - A ₁	510	460	400	460
	1.5 - A ₂	480	650	600	580
	3.0 - A ₃	630	600	610	650
	4.5 - A ₄	550	580	600	570
	B mean	540	580	600	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.4.8 Effects of rates and placement depths of limestone on root yields of Cowpea grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	330	430	350	370
	1.5 - A ₂	630	390	520	510
	3.0 - A ₃	360	520	400	430
	4.5 - A ₄	430	470	650	520
	B mean	440	450	480	
2.	0 - A ₁	330	320	350	330
	1.5 - A ₂	480	370	430	430
	3.0 - A ₃	440	310	410	390
	4.5 - A ₄	550	540	440	510
	B mean	450	380	410	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.4.9 Effects of rates and placement depths of limestone on root yields of Cowpea grown on the Bukaruna loamy sand No. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	380	280	490	380
	1.5 - A ₂	570	530	470	520
	3.0 - A ₃	550	580	490	540
	4.5 - A ₄	460	500	380	440
	B mean	480	420	510	
2.	0 - A ₁	390	510	420	440
	1.5 - A ₂	570	560	670	600
	3.0 - A ₃	610	550	540	570
	4.5 - A ₄	510	620	510	550
	B mean	520	560	540	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Tabela sand No. 800 and Kairuni loamy sand No. 815 higher root yields were obtained in the first season (Tables 2.4.6, 2.4.8).

3.1.4 Tissue Yields

Tissue yields (above-ground portion of plant excluding pods) were significantly increased by added limestone on all soils in both seasons, except on the Kasarama loamy sand No. 810 in the second season (Fig. 2.4.4, Table 2.5.1). In the first season, tissue yield response was linear on the Kasarama loamy sand No. 810, quadratic on the Bukaruna loamy sand No. 816 and cubic on the remaining two soils (Fig. 2.4.4). Tissue yield response in the second season was quadratic on the Tabela sand No. 800 and Bukaruna loamy sand No. 816 and linear on the Kairuni loamy sand No. 815 (Fig. 2.4.4). Limestone placement depths had no significant effects on tissue yields on any soil in either season except on the Tabela sand No. 800 in the first season (Tables 2.5.2, 2.5.3). On this soil, deep placement (15-30 cm) of limestone produced the highest yields, though yields were not significantly different between the 15-30 cm and 0-30 cm limestone placement depths (Tables 2.5.4, 2.5.5). Limestone rate-placement depth interactions were non-significant in both seasons on all four soils (Tables 2.5.2, 2.5.3). Second season tissue yields on all four soils were lower than yields obtained in the first season (Tables 2.5.5, 2.5.6, 2.5.7, 2.5.8).

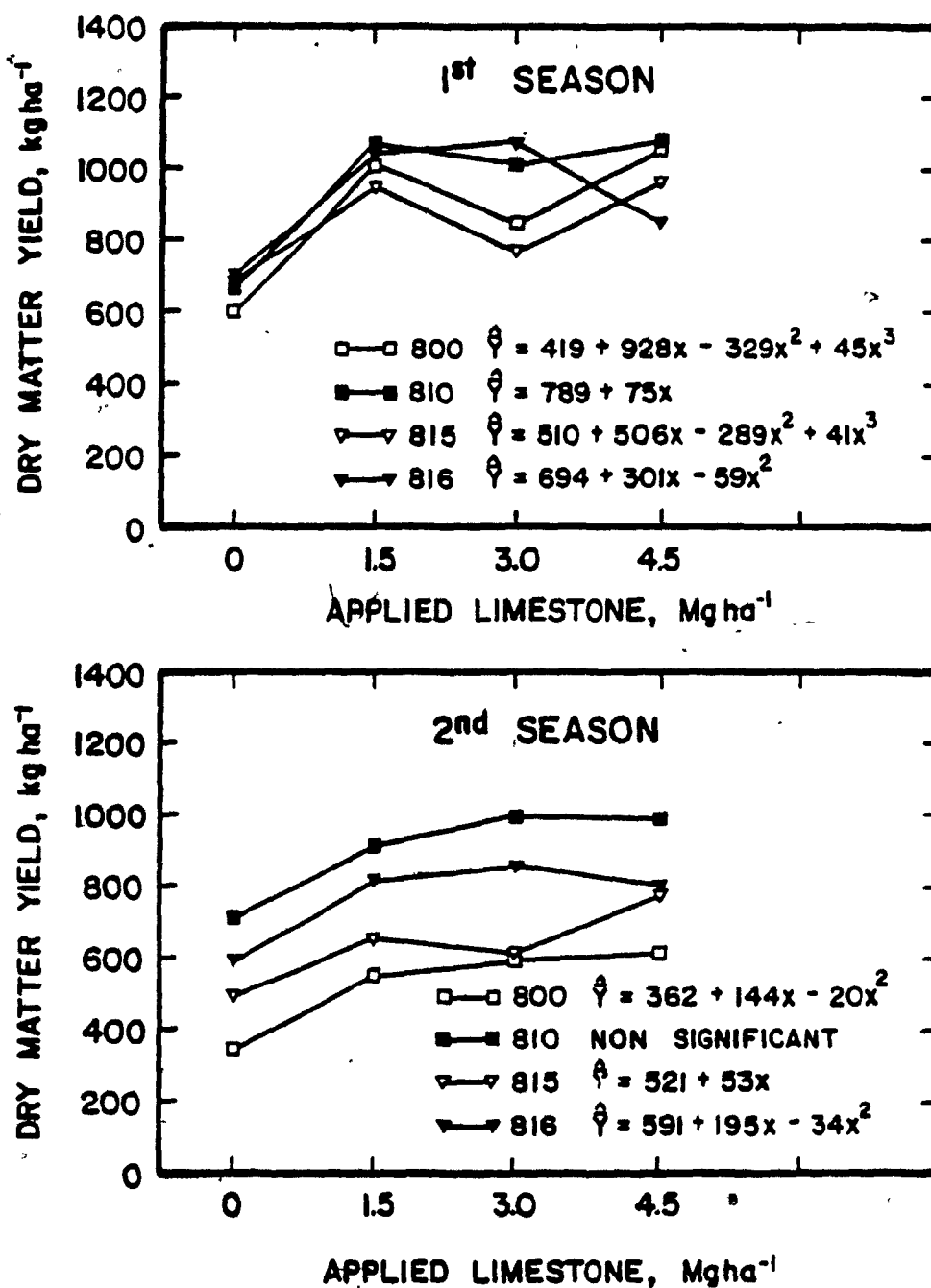


FIG. 2.4.4 Response of Cowpea tissue yields to limestone rates on four soils for two seasons.

Table 2.5.1 Orthogonal polynomial contrasts of limestone rates on observed mean tissue¹ dry matter yields of Cowpea grown on four soils for two seasons.

		SOIL TYPE				
Season	Source	df	800	810	815	816
		Limestone Rate	MEAN SQUARES ($\times 10^{-4}$)			
1.	A ²	3	37.63**	32.81*	18.44*	25.49**
	A linear	1	65.31**	56.84**	22.22	12.45
	A quadratic	1	9.57	27.40	1.41	63.89**
	A cubic	1	38.00	14.19	3.17**	0.14
	Exp. Error	22	6.88	7.43	5.47	3.69
	Coefficient of Variation (%)		29.8	28.5	27.7	21.2
2.	A	3	12.87**	15.02	12.14*	13.59*
	A linear	1	30.57**	-	28.60**	19.80
	A quadratic	1	6.95*	-	0.00	20.55
	A cubic	1	1.09	-	7.83	0.43
	Exp. Error	22	0.98	5.37	2.66	2.96
	Coefficient of Variation (%)		18.8	25.7	25.5	22.5

¹Above-ground portion of plant excluding pods.

²Rates of limestone

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.5.2 Analysis of variance of Cowpea tissue¹ dry matter yields (kg ha⁻¹) determined on four soils in the first season.

Soil type	Source	df	MS	F calculated
800	Blocks (R)	2	828964.00	12.04**
	A ²	3	376338.00	5.47*
	B ²	2	281421.00	4.09*
	A*B	6	17627.70	0.26
	Exp. Error	22	68853.60	
Coefficient of Variation = 29.8%				
810	Blocks (R)	2	145593.00	1.96
	A	3	328140.00	4.41*
	B	2	53295.10	0.72
	A*B	6	26603.40	0.35
	Exp. Error	22	74367.40	
Coefficient of Variation = 28.5%				
815	Blocks (R)	2	41195.00	0.75
	A	3	184492.00	3.37*
	B	2	11222.10	0.20
	A*B	6	104524.00	1.91
	Exp. Error	22	54753.70	
Coefficient of Variation = 27.7%				
816	Blocks (R)	2	56664.10	1.53
	A	3	254965.00	6.90**
	B	2	12248.40	0.33
	A*B	6	51986.10	1.40
	Exp. Error	22	36907.90	
Coefficient of Variation = 21.2%				

¹Above-ground portion of plant excluding pods.

²A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.5.3 Analysis of variance of Cowpea tissue¹ dry matter yields (kg ha⁻¹) determined on four soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	14865.90	1.51
	A ²	3	128736.00	13.06**
	B ²	2	559.40	0.06
	A*B	6	11136.20	1.13
	Exp. Error	22	9853.90	
	Coefficient of Variation = 18.8%			
810	Blocks (R)	2	340570.00	6.34**
	A	3	150237.00	2.80
	B	2	22833.80	0.42
	A*B	6	26244.40	0.49
	Exp. Error	22	53701.90	
	Coefficient of Variation = 25.7%			
815	Blocks (R)	2	137616.00	5.17*
	A	3	121458.00	4.56*
	B	2	33892.00	1.27
	A*B	6	22812.90	0.85
	Exp. Error	22	26624.60	
	Coefficient of Variation = 25.5%			
816	Blocks (R)	2	5421.70	0.18
	A	3	135939.00	4.59*
	B	2	1188.80	0.04
	A*B	6	28965.00	0.98
	Exp. Error	22	29636.10	
	Coefficient of Variation = 22.5%			

¹Above-ground portion of plant excluding pods.

²A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.5.4 Orthogonal contrasts of limestone placement depths on tissue¹ dry matter yields of Cowpea¹ grown on The Tabela sand No. 800 in the first season.

Source	df	MEAN SQUARES ($\times 10^{-4}$)
B ²	2	28.14*
B ₁ vs B ₂ , B ₃	1	24.31
B ₂ vs B ₃	1	31.97*
Exp. Error	22	6.88

Coefficient of Variation = 29.8%

¹Above-ground portion of plant excluding pods.

²B - limestone placement depths; B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

*,** Indicates that F values calculated from mean squares are significant at the 0.05, 0.01 levels of probability respectively.

Table 2.5.5 Effects of rates and placement depths of limestone on tissue¹ yields of Cowpea grown on the Tabela sand No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ² (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	700	570	527	600
	1.5 - A ₂	1200	1050	770	1010
	~~3.0 - A₃~~	930	960	670	850
	4.5 - A ₄	1150	1160	850	1050
	B mean	1000	940	710	
2.	0 - A ₁	390	290	380	350
	1.5 - A ₂	520	590	550	550
	3.0 - A ₃	580	660	530	590
	4.5 - A ₄	640	560	650	620
	B mean	540	530	520	

¹Above-ground portion of plant excluding pods.

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.5.6 Effects of rates and placement depths of limestone on tissue¹ yields of Cowpea grown on the Kasarama loamy sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	760	690	570	670
	1.5 - A ₂	920	1190	1110	1070
	3.0 - A ₃	950	1080	1020	1020
	4.5 - A ₄	940	1150	1100	1070
	B mean	890	1030	950	
2.	0 - A ₁	770	750	620	710
	1.5 - A ₂	790	1000	950	910
	3.0 - A ₃	1000	1010	890	990
	4.5 - A ₄	900	980	1070	990
	B mean	870	950	880	

¹Above-ground portion of plant excluding pods.

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.5.7 Effects of rates and placement depths of limestone on tissue¹ yields of Cowpea grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	620	800	610	680
	1.5 - A ₂	1090	700	1080	950
	3.0 - A ₃	690	950	680	770
	4.5 - A ₄	880	890	1140	970
	B mean	820	840	880	
2.	0 - A ₁	470	480	540	500
	1.5 - A ₂	770	560	660	660
	3.0 - A ₃	730	500	620	620
	4.5 - A ₄	820	840	680	780
	B mean	700	590	630	

¹Above-ground portion of plant excluding pods.

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.5.8 Effects of rates and placement depths of limestone on tissue¹ yields of Cowpea grown on the Bukaruna loamy sand No. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
kg ha ⁻¹ ; dry matter					
1.	0 - A ₁	680	550	868	700
	1.5 - A ₂	970	1130	910	1000
	3.0 - A ₃	1080	1120	1020	1070
	4.5 - A ₄	920	930	700	850
	B mean	910	930	870	
2.	0 - A ₁	510	660	590	590
	1.5 - A ₂	840	700	920	820
	3.0 - A ₃	930	870	770	860
	4.5 - A ₄	740	860	780	790
	B mean	780	770	770	

¹Above-ground portion of plant excluding pods.

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

3.2 Root Depths

Limestone rates had non-significant effects on root depths on all soils in both seasons, except on the Kairuni loamy sand No. 815 in the second season, where a cubic response was observed (Fig. 2.4.5, Tables 2.6.1). Limestone placement depths and limestone rate-placement depth interactions had no significant effects on root depths on any soil in both seasons, except that interaction effects were significant on the Kairuni loamy sand No. 815 in the first season (Tables 2.6.2, 2.6.3). On this soil there were significant cubic and quadratic interaction effects for the deep (15-30 cm) and shallow (0-15 cm) limestone placement depths, respectively (Tables 2.6.4, 2.6.7). Overall mean root depths were higher on all four soils in the second season as compared to the first season (Tables 2.6.5, 2.6.6, 2.6.7, 2.6.8).

3.3 Plant Heights

In the first season added limestone significantly increased plant height on the Bukaruna loamy sand No. 816 only, while in the second season significant increases were observed on all soils, except the Kasarama loamy sand No. 810 (Fig. 2.4.6, Table 2.7.1). In the first season, plant height response to limestone rates was quadratic on the Bukaruna loamy sand No. 816 and in the second season, plant height responses were linear on the Tabela sand No. 800 and Kairuni loamy sand No. 815 and quadratic on the Bukaruna loamy sand No. 816 (Fig. 2.4.6). Limestone placement depths and limestone rate-placement depth interactions had non-significant effects on plant heights on all soils in both seasons, except on the Kasarama loamy sand No. 810 in the second season (Tables 2.7.2, 2.7.3). In the second season, there were significant linear and quadratic interaction effects on the Kasarama

loamy sand No. 810 for the deep (15-30 cm) and shallow (0-15 cm) limestone placement depths, respectively (Tables 2.7.4, 2.7.6). Second season plant heights on the Tabela sand No. 800 were higher than plant heights obtained in the first season (Table 2.7.5). However, seasonal plant height differences on the Kasarama loamy sand No 810 were minimal, while lower plant heights were obtained in the second season compared to the first season on the Kairuni loamy sand No. 815 and Bukaruna loamy sand No. 816 (Tables 2.7.6, 2.7.7, 2.7.8).

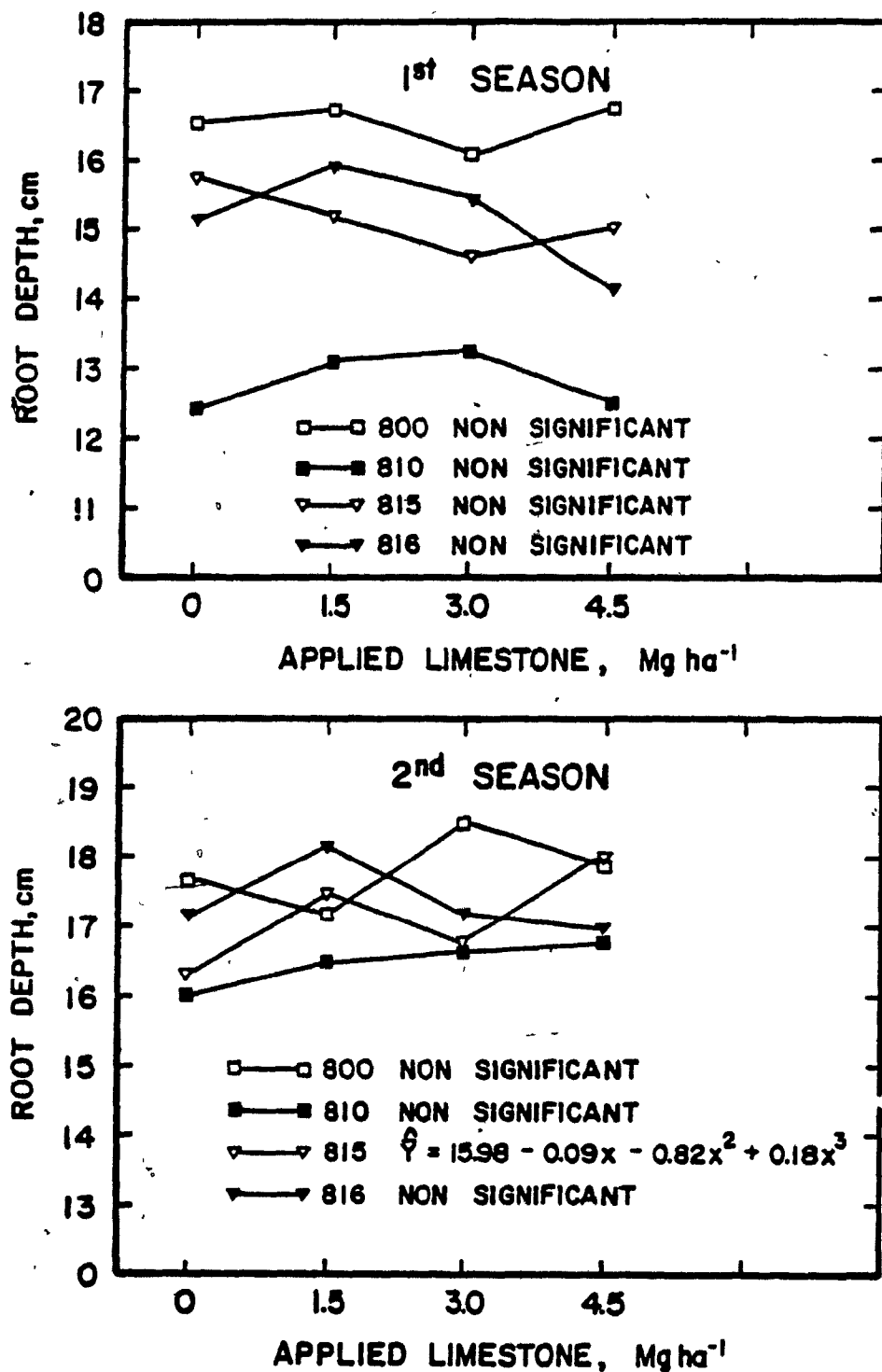


FIG. 2.4.5 Response of Cowpea root depths to limestone rates on four soils for two seasons.

Table 2.6.1 Orthogonal polynomial contrasts of limestone rate on observed mean root depths of Cowpea grown on four soils for two seasons.

			SOIL TYPE			
Season	Source	df	800	810	815	816/
Limestone Rate			MEAN SQUARES			
1.	A ¹	3	0.92	1.50	1.90	5.35
	A linear	1	-	-	-	-
	A quadratic	1	-	-	-	-
	A cubic	1	-	-	-	-
	Exp. Error	22	5.17	2.72	1.73	3.16
Coefficient of Variation (%)			13.9	12.9	8.7	11.8
2.	A	3	2.55	2.84	4.97*	2.42
	A linear	1	-	-	8.66*	-
	A quadratic	1	-	-	0.00	-
	A cubic	1	-	-	6.23*	-
	Exp. Error	22	2.00	1.17	1.23	2.06,
Coefficient of Variation (%)			7.9	6.5	6.4	8.2

¹Rates of limestone

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.6.2 Analysis of variance of Cowpea root depths (cm) determined on four soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	4.59	0.89
	A ¹	3	0.92	0.18
	B ¹	2	1.11	0.21
	A*B	6	2.83	0.55
	Exp. Error	22	5.17	
Coefficient of Variation = 13.9%				
810	Blocks (R)	2	10.51	3.85**
	A	3	1.50	0.55
	B	2	2.64	0.97
	A*B	6	1.59	0.58
	Exp. Error	22	2.72	
Coefficient of Variation = 12.9%				
815	Blocks (R)	2	8.24	4.75*
	A	3	1.90	1.09
	B	2	1.27	0.73
	A*B	6	9.07	5.23**
	Exp. Error	22	1.73	
Coefficient of Variation = 8.7%				
816	Blocks (R)	2	3.71	1.17
	A	3	5.35	1.69
	B	2	1.34	0.42
	A*B	6	3.62	1.15
	Exp. Error	22	3.16	
Coefficient of Variation = 11.8%				

¹A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.6.3 Analysis of variance of Cowpea root depths (cm) determined on four soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	4.26	2.13
	A ¹	3	2.55	1.28
	B ¹	2	0.23	0.11
	A*B	6	2.31	1.16
	Exp. Error	22	2.00	
	Coefficient of Variation = 7.9%			
810	Blocks (R)	2	27.74	23.79**
	A	3	2.84	2.44
	B	2	0.39	0.33
	A*B	6	1.49	1.28
	Exp. Error	22	1.17	
	Coefficient of Variation = 6.5%			
815	Blocks (R)	2	10.72	8.72**
	A	3	4.97	4.04*
	B	2	1.68	1.37
	A*B	6	1.74	1.42
	Exp. Error	22	1.23	
	Coefficient of Variation = 6.4%			
816	Blocks (R)	2	4.71	2.28
	A	3	2.44	1.18
	B	2	1.04	0.51
	A*B	6	3.52	1.71
	Exp. Error	22	2.06	
	Coefficient of Variation = 8.2%			

¹A - limestone rates, B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.6.4 Simple effects of limestone rate-placement depth interactions on Cowpea root depths determined on the Kairuni loamy sand No. 815 in the first season.

Source	df	MEAN SQUARES
A (B) ¹	9	6.68
A linear in B ₁	1	0.01
A quadratic in B ₁	1	9.72*
A cubic in B ₁	1	16.42**
A linear in B ₂	1	7.35
A quadratic in B ₂	1	1.08
A cubic in B ₂	1	3.75
A linear in B ₃	1	0.08
A quadratic in B ₃	1	20.80**
A cubic in B ₃	1	0.91
Exp. Error	22	1.73

Coefficient of Variation = 8.7%

¹A - limestone rate.

¹B - limestone placement depths; B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.6.5 Effects of rates and placement depths of limestone on root depths of Cowpea grown on the Tabela sand No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
cm					
1.	0 - A ₁	17.4	16.5	15.6	16.5
	1.5 - A ₂	15.8	16.9	17.4	16.7
	3.0 - A ₃	17.4	14.8	16.0	16.1
	4.5 - A ₄	16.1	16.1	16.2	16.1
	B mean	16.7	16.1	16.3	
2.	0 - A ₁	17.8	17.8	17.4	17.7
	1.5 - A ₂	17.1	17.1	17.3	17.2
	3.0 - A ₃	19.2	18.5	17.6	18.4
	4.5 - A ₄	17.1	17.1	19.4	17.8
	B mean	17.8	17.6	17.9	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.6.6 Effects of rates and placement depths of limestone on root depths of Cowpea grown on the Kasarama loamy sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
cm					
1.	0 - A ₁	11.5	12.8	13.0	12.4
	1.5 - A ₂	13.1	13.1	13.2	13.1
	3.0 - A ₃	13.7	12.4	13.5	13.2
	4.5 - A ₄	11.3	12.6	13.6	12.5
	B mean	12.4	12.7	13.3	
2.	0 - A ₁	16.5	16.0	15.6	16.0
	1.5 - A ₂	15.9	16.1	17.4	16.5
	3.0 - A ₃	17.2	15.9	17.2	16.8
	4.5 - A ₄	17.3	17.8	17.0	17.4
	B mean	16.7	16.5	16.8	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.6.7 Effects of rates and placement depths of limestone on root depths of Cowpea grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
		cm			
1.	0 - A ₁	13.4	17.1	16.7	15.7
	1.5 - A ₂	17.3	14.8	13.5	15.2
	3.0 - A ₃	14.1	15.6	14.2	14.6
	4.5 - A ₄	14.4	14.5	16.2	16.2
	B mean	14.8	15.5	15.1	
2.	0 - A ₁	17.3	15.6	16.1	16.4
	1.5 - A ₂	17.8	18.2	16.5	17.5
	3.0 - A ₃	17.0	16.1	17.4	16.8
	4.5 - A ₄	18.2	18.5	17.4	18.0
	B mean	17.6	17.1	16.8	

¹B₁: 15-30 cm.
 B₂: 0-30 cm.
 B₃: 0-15 cm.

Table 2.6.8 Effects of rates and placement depths of limestone on root depths of Cowpea grown on the Bukaruna loamy sand No. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A _i mean
		B ₁	B ₂ (AxB means)	B ₃	
cm					
1.	0 - A ₁	15.0	14.5	15.8	15.1
	1.5 - A ₂	17.8	15.2	14.8	15.9
	3.0 - A ₃	15.5	15.9	14.8	15.4
	4.5 - A ₄	13.5	15.1	13.7	14.1
	B mean	15.4	15.2	14.8	
2.	0 - A ₁	18.1	17.6	16.0	17.2
	1.5 - A ₂	17.7	18.5	18.3	18.2
	3.0 - A ₃	17.2	16.3	18.1	17.2
	4.5 - A ₄	16.3	18.6	16.3	17.0
	B mean	17.3	17.7	17.2	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

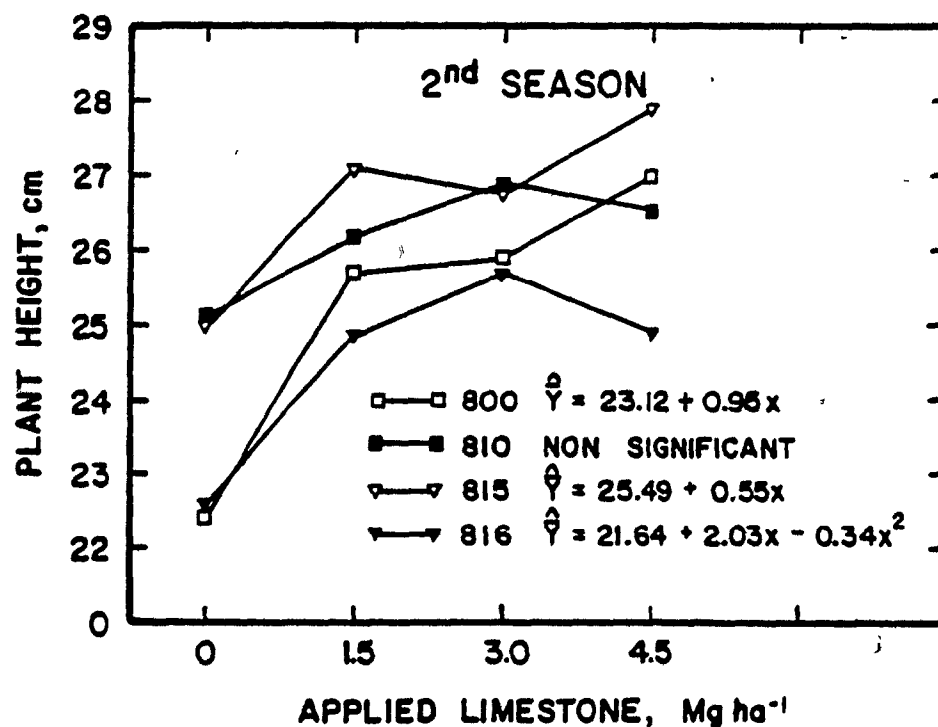
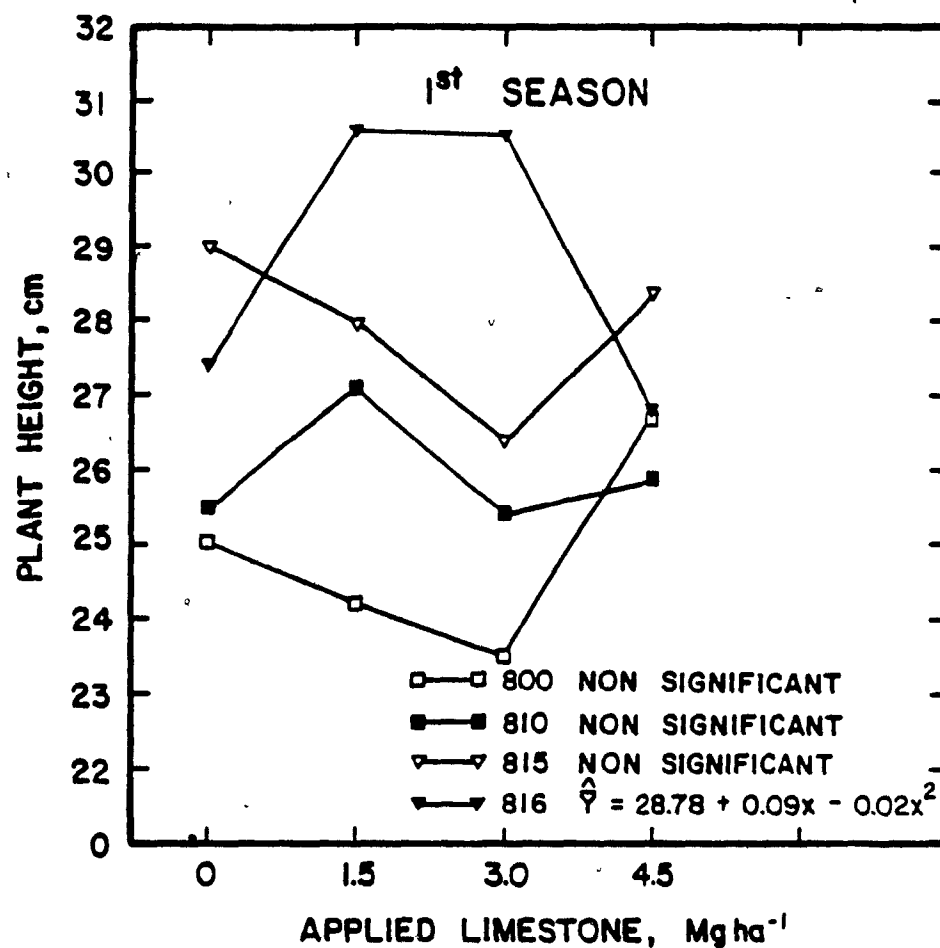


FIG. 2.4.6 Response of Cowpea plant heights to limestone rates on four soils for two seasons.

Table 2.7.1 Orthogonal polynomial contrasts of limestone rates on observed mean plant heights of Cowpea, grown on four soils for two seasons.

		SOIL TYPE				
Season	Source	df	800	810	815	816
Limestone Rates		MEAN SQUARES				
1.	A ¹	3	16.96	5.78	10.87	35.90*
	A linear	1	-	-	-	1.84
	A quadratic	1	-	-	-	105.04**
	A cubic	1	-	-	-	0.11
	Exp. Error	22	18.71	9.45	9.77	10.58
Coefficient of Variation (%)			17.4	11.8	11.2	11.3
2.	A	3	36.50**	5.26	13.12*	15.59*
	A linear	1	91.73**	-	30.26**	25.76*
	A quadratic	1	10.78	-	2.45	21.00*
	A cubic	1	7.00	-	6.65	0.00
	Exp. Error	22	4.37	1.75	3.77	3.97
Coefficient of Variation (%)			8.3	5.1	7.3	8.1

¹Rates of limestone.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.7.2 Analysis of variance of Cowpea plant heights (cm) determined on four soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	232.62	12.43**
	A ¹	3	16.96	0.91
	B ¹	2	5.70	0.30
	A*B	6	1.66	0.09
	Exp. Error	22	18.71	
	Coefficient of Variation = 17.4%			
810	Blocks (R)	2	40.00	4.32*
	A	3	5.78	0.61
	B	2	11.29	1.19
	A*B	6	3.05	0.32
	Exp. Error	22	9.45	
	Coefficient of Variation = 11.8%			
815	Blocks (R)	2	32.88	3.37
	A	3	10.87	1.11
	B	2	3.16	0.32
	A*B	6	21.19	2.17
	Exp. Error	22	9.77	
	Coefficient of Variation = 11.2%			
816	Blocks (R)	2	9.81	0.93
	A	3	35.90	3.39*
	B	2	11.63	1.10
	A*B	6	3.01	0.28
	Exp. Error	22	10.58	
	Coefficient of Variation = 11.3%			

¹A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.7.3 Analysis of variance of Cowpea plant heights (cm) determined on four soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	23.11	5.28*
	A ¹	3	36.50	8.34**
	B ¹	2	6.45	1.47
	A*B	6	4.57	1.04
	Exp. Error	22	4.37	
	Coefficient of Variation = 8.3%			
810	Blocks (R)	2	46.44	26.46**
	A	3	5.26	3.00
	B	2	9.88	5.63*
	A*B	6	6.42	3.66*
	Exp. Error	22	1.75	
	Coefficient of Variation = 5.1%			
815	Blocks (R)	2	4.35	1.16
	A	3	13.12	3.48*
	B	2	4.17	1.11
	A*B	6	3.60	0.96
	Exp. Error	22	3.77	
	Coefficient of Variation = 7.3%			
816	Blocks (R)	2	6.05	1.52
	A	3	15.59	3.92*
	B	2	0.19	0.05
	A*B	6	3.77	0.95
	Exp. Error	22	3.97	
	Coefficient of Variation = 8.1%			

¹A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.7.4 Simple effects of limestone rate-placement depth interactions on Cowpea plant heights determined on the Kasarama loamy sand No. 810 in the second season.

Source	df	MEAN SQUARES
A (B) ¹	9	6.03
A linear in B ₁	1	15.11**
A quadratic in B ₁	1	1.14
A cubic in B ₁	1	0.18
A linear in B ₂	1	7.14
A quadratic in B ₂	1	1.54
A cubic in B ₂	1	7.42
A linear in B ₃	1	0.66
A quadratic in B ₃	1	15.18**
A cubic in B ₃	1	5.95
Exp. Error	22	1.75

Coefficient of Variation = 5.1%

¹A - limestone rates.

¹B - limestone placement depths; B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.7.5 Effects of rates and placement depths of limestone on plant heights of Cowpea grown on the Tabela sand No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
cm					
1.	0 - A ₁	23.5	26.1	25.4	25.0
	1.5 - A ₂	23.9	24.6	24.0	24.2
	3.0 - A ₃	23.8	23.7	23.0	23.5
	4.5 - A ₄	25.9	28.1	26.0	26.7
	B mean	24.3	25.6	24.6	
2.	0 - A ₁	23.3	21.3	22.6	22.4
	1.5 - A ₂	24.1	26.3	26.7	25.7
	3.0 - A ₃	25.0	26.6	26.3	25.9
	4.5 - A ₄	26.9	25.4	28.9	27.1
	B mean	24.8	24.9	26.1	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.7.6 Effects of rates and placement depths of limestone on plant heights of Cowpea grown on the Kasarama loamy sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
cm					
1.	0 - A ₁	26.1	24.4	26.1	25.5
	1.5 - A ₂	26.5	25.6	29.3	27.1
	3.0 - A ₃	24.6	25.4	26.1	25.4
	4.5 - A ₄	24.5	26.2	26.9	25.9
	B mean	25.5	25.4	27.1	
2.	0 - A ₁	24.8	26.5	24.0	25.1
	1.5 - A ₂	26.2	25.1	27.3	26.2
	3.0 - A ₃	27.5	27.9	25.2	26.9
	4.5 - A ₄	27.7	27.9	24.0	26.5
	B mean	26.5	26.8	25.1	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.7.7

Effects of rates and placement depths of limestone on plant heights of Cowpea grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
			cm		
1.	0 - A ₁	25.5	32.6	28.9	29.0
	1.5 - A ₂	29.8	26.1	28.1	28.0
	3.0 - A ₃	26.7	28.4	24.2	26.4
	4.5 - A ₄	29.7	26.8	28.6	28.4
	B mean	27.9	28.5	27.4	
2.	0 - A ₁	25.5	24.0	25.6	25.0
	1.5 - A ₂	28.4	27.4	25.6	27.1
	3.0 - A ₃	27.8	26.1	26.6	26.8
	4.5 - A ₄	27.7	29.2	26.8	27.9
	B mean	27.3	26.7	26.2	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.7.8 Effects of rates and placement depths of limestone on plant heights of Cowpea grown on the Bukaruna loamy sand No. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
cm					
1.	0 - A ₁	26.6	28.5	27.2	27.4
	1.5 - A ₂	30.0	32.7	29.0	30.6
	3.0 - A ₃	30.5	30.4	30.7	30.5
	4.5 - A ₄	27.1	28.1	25.1	26.8
	B mean	28.5	29.9	28.0	
2.	0 - A ₁	23.1	22.8	22.0	22.6
	1.5 - A ₂	26.2	23.5	25.1	24.9
	3.0 - A ₃	25.8	25.4	25.8	25.7
	4.5 - A ₄	23.6	26.1	25.0	24.9
	B mean	24.7	24.4	24.5	

¹B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

3.4 Concentration of P, K, Ca and Mg in Plant Tissue

3.4.1 Phosphorus

Added limestone had no significant effects on P content of tissue (above-ground portion of plant excluding pods) on any soil in both seasons, except on the Tabela sand No. 800 in the second season (Tables 2.8.1, 2.8.2), where P concentration in tissue had a cubic response to increasing limestone rates (Tables 2.8.3, 2.8.5). Depth of limestone placement and limestone rate-placement depth interactions had no significant effect on P content of tissue in both seasons on all soils, except that interaction effects were significant on the Kairuni loamy soil No. 815 in the first season (Tables 2.8.1, 2.8.2). On this soil, there was significant quadratic and linear effects with added limestone and deep (15-30 cm) and shallow (0-15 cm) limestone placement depths, respectively (Tables 2.8.4, 2.8.7). Tissue P concentration was lower in the second season on all soils compared to contents determined in the first season (Tables 2.8.5, 2.8.6, 2.8.7, 2.8.8).

3.4.2 Potassium

The effects of limestone rates, limestone placement depths and limestone rate-placement depth interactions on K concentration in tissue were non-significant on all soils in both seasons, except on the Kairuni loamy sand No. 815 in the first season, where effects of limestone rates were significant (Tables 2.9.1, 2.9.2). Increasing limestone rates caused a significant linear decrease in K content in tissue on the Kairuni loamy sand No. 815 in the first season (Tables 2.9.3, 2.9.6). On all soils, mean K contents in tissue were lower in the second season compared to the first season (Tables 2.9.4, 2.9.5, 2.9.6, 2.9.7).

Table 2.8.1 Analysis of variance of percent phosphorus in Cowpea¹
grown on four soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.0091	11.98**
	A ²	3	0.0008	0.10
	B ²	2	0.0010	1.41
	A*B	6	0.0004	0.59
	Exp. Error	22	0.0008	
	Coefficient of Variation = 10.5%			
810	Blocks (R)	2	0.0010	0.86
	A	3	0.0005	0.41
	B	2	0.0002	0.19
	A*B	6	0.0005	0.41
	Exp. Error	22	0.0012	
	Coefficient of Variation = 13.3%			
815	Blocks (R)	2	0.0005	0.47
	A	3	0.0024	2.03
	B	2	0.0001	0.08
	A*B	6	0.0032	2.74*
	Exp. Error	22	0.0012	
	Coefficient of Variation = 11.3%			
816	Blocks (R)	2	0.0001	0.12
	A	3	0.0009	1.48
	B	2	0.0003	0.48
	A*B	6	0.0008	1.35
	Exp. Error	22	0.0006	
	Coefficient of Variation = 8.8%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.8.2 Analysis of variance of percent phosphorus in Cowpea¹ grown on four soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.0015	7.18**
	A ²	3	0.0006	3.09*
	B ²	2	0.0001	0.58
	A*B	6	0.0005	2.30
	Exp. Error	22	0.0002	
Coefficient of Variation = 12.4%				
810	Blocks (R)	2	0.0219	43.83**
	A	3	0.0001	0.19
	B	2	0.0004	0.86
	A*B	6	0.0003	0.67
	Exp. Error	22	0.0005	
Coefficient of Variation = 10.0%				
815	Blocks (R)	2	0.0117	13.19**
	A	3	0.0011	1.24
	B	2	0.0001	0.08
	A*B	6	0.0007	0.76
	Exp. Error	22	0.0009	
Coefficient of Variation = 18.8%				
816	Blocks (R)	2	0.0001	0.10
	A	3	0.0001	0.09
	B	2	0.0002	0.35
	A*B	6	0.0004	0.49
	Exp. Error	22	0.0008	
Coefficient of Variation = 23.5%				

¹ Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates, B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.8.3

Orthogonal polynomial contrasts of limestone rates on percent Phosphorus in Cowpea¹ grown on The Tabela sand No. 800 in the second season.

Source	df	MEAN SQUARES ($\times 10^2$)
A ¹	3	0.06*
A linear	1	0.00
A quadratic	1	0.02
A cubic	1	0.18**
Exp. Error	22	0.02

Coefficient of Variation = 12.4 %

¹Above-ground portion of plant excluding pods (sampled at harvest).

Table 2.8.4

Simple effects of limestone rate-placement depth interactions on percent Phosphorus in Cowpea¹ grown on the Kairuni loamy sand No. 815 in the first season.

Source	df	MEAN SQUARES ($\times 10^2$)
A (B) ¹	9	0.03*
A linear in B ₁	1	0.02
A quadratic in B ₁	1	0.08*
A cubic in B ₁	1	0.00
A linear in B ₂	1	0.00
A quadratic in B ₂	1	0.01
A cubic in B ₂	1	0.01
A linear in B ₃	1	0.06*
A quadratic in B ₃	1	0.02
A cubic in B ₃	1	0.04
Exp. Error	22	0.01

Coefficient of Variation = 11.2%

¹A - limestone rates.

¹B - limestone placement depths, B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.8.5 Effects of rates and placement depths of limestone on percent phosphorus in Cowpea¹ grown on the Tabela sand No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	0.27	0.26	0.26	0.27
	1.5 - A ₂	0.25	0.28	0.26	0.26
	3.0 - A ₃	0.27	0.27	0.25	0.26
	4.5 - A ₄	0.27	0.27	0.24	0.26
	B mean	0.27	0.27	0.25	
2.	0 - A ₁	0.11	0.13	0.11	0.11
	1.5 - A ₂	0.14	0.11	0.14	0.13
	3.0 - A ₃	0.12	0.11	0.11	0.11
	4.5 - A ₄	0.12	0.13	0.11	0.12
	B mean	0.12	0.12	0.12	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

²B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.8.6 Effects of rates and placement depths of limestone on percent phosphorus in Cowpea¹ grown on the Kasarama loamy sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	0.27	0.26	0.24	0.26
	1.5 - A ₂	0.27	0.26	0.27	0.27
	3.0 - A ₃	0.25	0.27	0.24	0.25
	4.5 - A ₄	0.28	0.25	0.28	0.27
	B mean	0.27	0.26	0.26	
2.	0 - A ₁	0.22	0.23	0.23	0.23
	1.5 - A ₂	0.20	0.23	0.22	0.22
	3.0 - A ₃	0.22	0.23	0.21	0.22
	4.5 - A ₄	0.22	0.23	0.22	0.22
	B mean	0.22	0.23	0.22	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.8.7 Effects of rates and placement depths of limestone on percent phosphorus in Cowpea¹ grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	0.35	0.30	0.31	0.32
	1.5 - A ₂	0.29	0.31	0.35	0.32
	3.0 - A ₃	0.27	0.33	0.28	0.29
	4.5 - A ₄	0.31	0.29	0.27	0.29
	B mean	0.30	0.31	0.30	
2.	0 - A ₁	0.15	0.14	0.14	0.14
	1.5 - A ₂	0.19	0.16	0.17	0.17
	3.0 - A ₃	0.14	0.17	0.16	0.16
	4.5 - A ₄	0.14	0.17	0.16	0.16
	B mean	0.16	0.16	0.16	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.8.8 Effects of rates and placement depths of limestone on percent phosphorus in Cowpea¹ grown on the Bukaruna loamy sand No. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	0.28	0.25	0.26	0.26
	1.5 - A ₂	0.29	0.26	0.28	0.27
	3.0 - A ₃	0.27	0.28	0.30	0.28
	4.5 - A ₄	0.28	0.30	0.28	0.28
	B mean	0.28	0.27	0.28	
2.	0 - A ₁	0.13	0.12	0.12	0.12
	1.5 - A ₂	0.11	0.11	0.15	0.12
	3.0 - A ₃	0.14	0.13	0.12	0.13
	4.5 - A ₄	0.11	0.12	0.13	0.12
	B mean	0.12	0.12	0.13	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.9.1 Analysis of variance of percent potassium in Cowpea¹ grown on four soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.22	1.51
	A ²	3	0.05	0.36
	B ²	2	0.18	1.25
	A*B	6	0.04	0.30
	Exp. Error	22	0.14	
	Coefficient of Variation = 12.0%			
810	Blocks (R)	2	1.82	25.59**
	A	3	0.11	1.60
	B	2	0.13	1.96
	A*B	6	0.05	0.68
	Exp. Error	22	0.07	
	Coefficient of Variation = 8.1%			
815	Blocks (R)	2	0.28	2.81
	A	3	0.50	4.94**
	B	2	0.30	3.01
	A*B	6	0.06	0.65
	Exp. Error	22	0.10	
	Coefficient of Variation = 6.9%			
816	Blocks (R)	2	1.14	7.96**
	A	3	0.22	1.57
	B	2	0.08	0.61
	A*B	6	0.20	1.43
	Exp. Error	22	0.14	
	Coefficient of Variation = 9.5%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.9.2 Analysis of variance of percent potassium in Cowpea¹ grown on four soils in the second season.

Soil Type	Source	df	MS	F calculated
80C	Blocks (R)	2	0.56	4.45*
	A ²	3	0.07	0.52
	B ²	2	0.01	0.03
	A*B	6	0.04	0.29
	Exp. Error	22	0.13	
	Coefficient of Variation = 13.6%			
810	Blocks (R)	2	0.59	8.31**
	A	3	0.14	2.02
	B	2	0.13	1.81
	A*B	6	0.07	1.01
	Exp. Error	22	0.07	
	Coefficient of Variation = 8.7%			
815	Blocks (R)	2	0.62	3.80*
	A	3	0.29	1.74
	B	2	0.47	2.88
	A*B	6	0.11	0.67
	Exp. Error	22	0.16	
	Coefficient of Variation = 13.7%			
816	Blocks (R)	2	0.22	1.17
	A	3	0.12	0.63
	B	2	0.09	0.50
	A*B	6	0.08	0.43
	Exp. Error	22	0.19	
	Coefficient of Variation = 13.4%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.9.3 Orthogonal polynomial contrasts of limestone rates on percent potassium in Cowpea¹ grown on Kairuni loamy sand No. 815 in the first season.

Source	df	MEAN SQUARES
A ²	3	0.50**
A linear	1	1.42**
A quadratic	1	0.00
A cubic	1	0.09
Exp. Error	22	0.10

Coefficient of Variation = 6.9%

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates.

*,** Indicates that F values calculated from mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.9.4. Effects of rates and placement depths of limestone on percent potassium in Cowpea¹ grown on the Tabela sand No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
		%			
1.	0 - A ₁	3.04	3.31	3.04	3.13
	1.5 - A ₂	3.33	3.12	3.01	3.15
	3.0 - A ₃	3.25	3.20	2.91	3.12
	4.5 - A ₄	3.24	3.44	3.17	3.28
	B mean	3.22	3.07	3.03	
2.	0 - A ₁	2.16	2.77	2.80	2.73
	1.5 - A ₂	2.67	2.51	2.67	2.61
	3.0 - A ₃	2.67	2.51	2.40	2.52
	4.5 - A ₄	2.56	2.59	2.61	2.59
	B mean	2.63	2.59	2.62	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.9.5

Effects of rates and placement depths of limestone on percent potassium in Cowpea¹ grown on the Kasarama loamy sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
		%			
1.	0 - A ₁	3.42	2.96	3.31	3.23
	1.5 - A ₂	3.47	3.33	3.59	3.46
	3.0 - A ₃	3.24	3.13	3.40	3.26
	4.5 - A ₄	3.23	3.27	3.20	3.23
	B mean	3.34	3.17	3.34	
2.	0 - A ₁	3.23	3.12	3.36	3.23
	1.5 - A ₂	2.77	3.25	3.01	3.01
	3.0 - A ₃	2.99	3.07	3.08	3.11
	4.5 - A ₄	2.93	2.80	3.09	2.94
	B mean	2.98	3.06	3.19	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.9.6 Effects of rates and placement depths of limestone on percent potassium in Cowpea¹ grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	4.80	4.93	4.86	4.87
	1.5 - A ₂	4.67	4.67	4.93	4.75
	3.0 - A ₃	4.20	4.53	4.60	4.44
	4.5 - A ₄	4.20	4.20	4.73	4.38
	B mean	4.47	4.58	4.78	
2.	0 - A ₁	3.28	2.93	3.47	3.23
	1.5 - A ₂	2.88	2.48	3.07	2.81
	3.0 - A ₃	2.88	2.69	3.20	2.92
	4.5 - A ₄	2.69	3.07	3.01	2.92
	B mean	2.93	2.79	3.19	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.9.7 Effects of rates and placement depths of limestone on percent potassium in Cowpea¹ grown on the Bukaruna loamy sand No. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depths ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	3.87	3.73	4.33	3.98
	1.5 - A ₂	4.07	3.80	3.73	3.87
	3.0 - A ₃	4.20	4.07	4.40	4.22
	4.5 - A ₄	4.13	4.00	3.60	3.91
	B mean	4.07	3.90	4.02	
2.	0 - A ₁	3.25	3.52	3.39	3.39
	1.5 - A ₂	3.33	3.23	3.09	3.22
	3.0 - A ₃	3.28	3.07	3.19	3.18
	4.5 - A ₄	3.41	3.04	2.91	3.12
	B mean	3.32	3.21	3.14	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

3.4.3 Calcium

Increasing limestone rates had a significant effect on Ca concentration in tissue in both seasons on all soils, except the Bukaruna loamy sand No. 816 (Fig. 2.5, Table 2.10.1). The Ca concentration responses to added limestone were linear on the Tabela sand No. 800, Kasarama loamy sand No. 810 and Kairuni loamy sand No. 815 in both seasons, except on the Kairuni loamy sand No. 815 in the first season, where the response was cubic (Fig. 2.5). The effects of limestone placement depths on Ca content in tissue were non-significant in both seasons on every soil, except on the Tabela sand No. 800 and Kairuni loamy sand No. 815 in the first season (Tables 2.10.2, 2.10.3). On the Tabela sand No. 800, limestone mixed in the 0-30 cm soil depth produced significantly higher Ca contents than limestone mixed in the 0-15 cm soil depth; however, there were no significant differences between deep limestone placement (15-30 cm) and the 0-15 cm and 0-30 cm limestone placement depths (Tables 2.10.4, 2.10.7). On the Kairuni loamy sand No. 815, deep limestone placement (15-30 cm) produced significantly higher Ca contents than the 0-30 cm and 0-15 cm limestone placements (Tables 2.10.5, 2.10.9). Limestone rate-placement depth interactions were non-significant on all soils in both seasons, except on the Bukaruna loamy sand No. 816 in the first season (Tables 2.10.2, 2.10.3). On the Bukaruna loamy sand No. 816, limestone rates and the 0-30 cm placement of limestone resulted in a significant quadratic response for Ca content in tissue (Tables 2.10.6, 2.10.10). On all soils, second season Ca contents in tissue were lower than values obtained in the first season (Tables 2.10.7, 2.10.8, 2.10.9, 2.10.10).

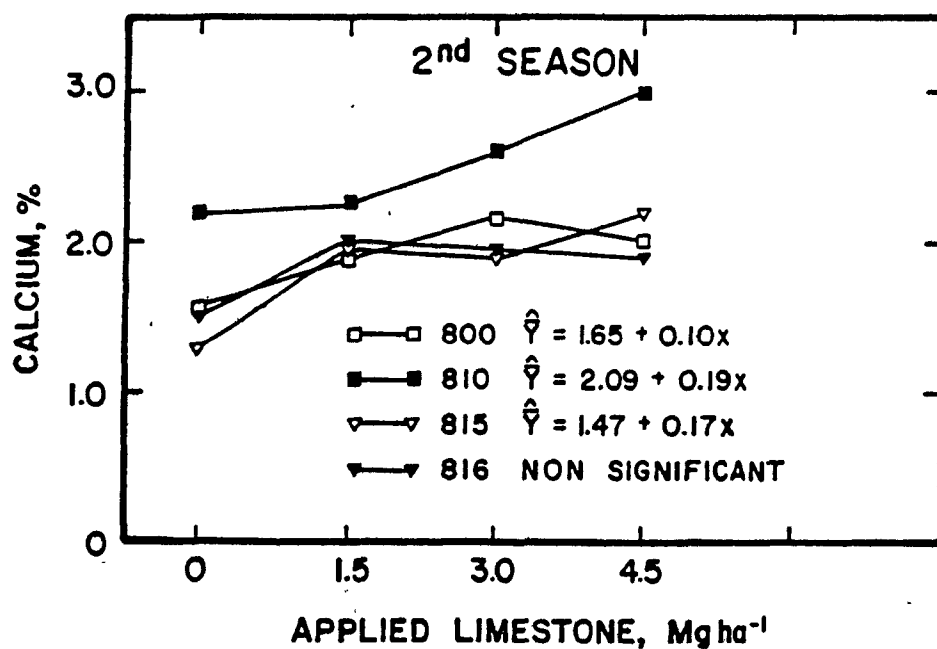
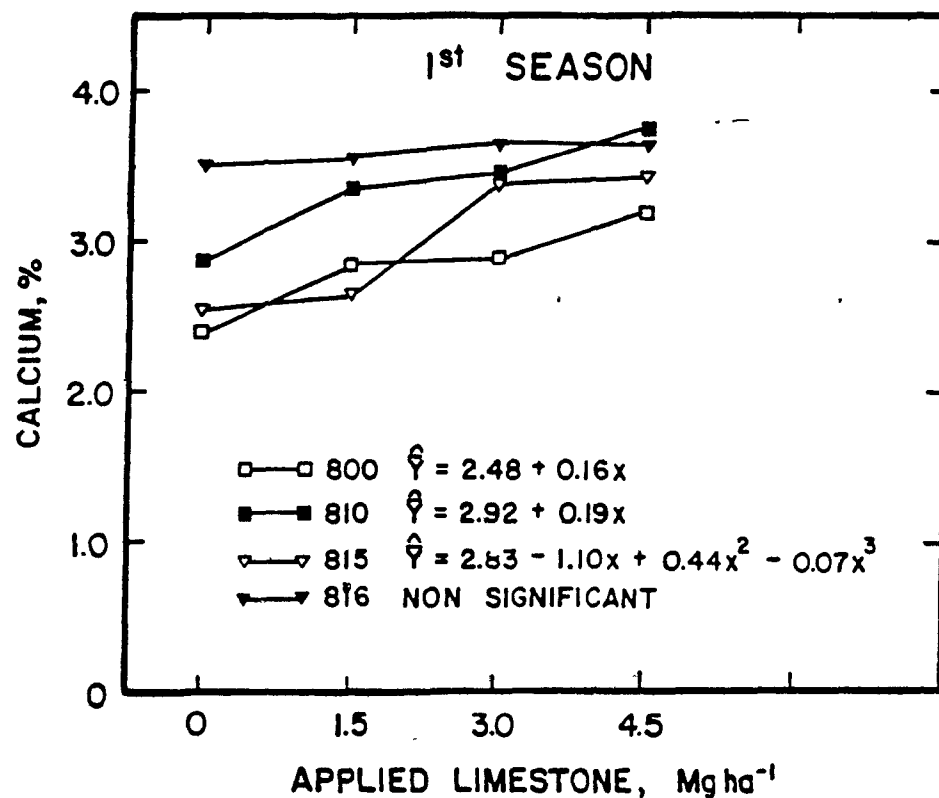


FIG. 2.5 Response of percent calcium in Cowpea tissue to limestone rates on four soils for two seasons.

Table 2.10.1 Orthogonal polynomial contrasts of limestone rates on percent calcium in Cowpea¹ grown on four soils for two seasons.

			SOIL TYPE			
Season	Source	df	800	810	815	816
Limestone Rates			MEAN SQUARES			
1.	A ²	3	0.97**	1.26**	2.04**	0.05
	A linear	1	2.73**	3.61**	5.31**	N.S.
	A quadratic	1	0.03	0.09	0.00	N.S.
	A cubic	1	0.15	0.11	0.82*	N.S.
	Exp. Error	22	0.15	0.24	0.15	0.22
Coefficient of Variation (%)			12.9	14.7	12.8	25.1
2.	A	3	0.56**	1.30**	1.23**	0.45
	A linear	1	1.11**	3.54**	2.86**	N.S.
	A quadratic	1	0.53	0.31	0.35	N.S.
	A cubic	1	0.03	0.04	0.48	N.S.
	Exp. Error	22	0.15	0.37	0.12	0.20
Coefficient of Variation (%)			20.4	24.1	19.1	24.5

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.10.2 Analysis of variance of percent calcium in Cowpea¹ grown on four soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	1.39	10.32**
	A ²	3	0.97	7.16*
	B ²	2	0.48	3.60*
	A*B	6	0.03	0.24
	Exp. Error	22	0.13	
	Coefficient of Variation = 12.9%			
810	Blocks (R)	2	0.42	1.74
	A	3	1.27	5.26**
	B	2	0.04	0.16
	A*B	6	0.12	0.52
	Exp. Error	22	0.24	
	Coefficient of Variation = 14.7%			
815	Blocks (R)	2	0.20	1.33
	A	3	2.04	13.63**
	B	2	0.52	3.50*
	A*B	6	0.17	1.14
	Exp. Error	22	0.15	
	Coefficient of Variation = 12.8%			
816	Blocks (R)	2	0.71	6.77**
	A	3	0.05	0.46
	B	2	0.13	1.23
	A*B	6	0.27	2.58*
	Exp. Error	22	0.10	
	Coefficient of Variation = 9.1%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.10.3 Analysis of variance of percent calcium in Cowpea¹ grown on four soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.90	6.07**
	A ²	3	0.55	3.74*
	B ²	2	0.20	1.39
	A*B	6	0.08	0.53
	Exp. Error	22	0.15	
	Coefficient of Variation = 20.4%			
810	Blocks (R)	2	0.61	1.66
	A	3	1.30	3.52*
	B	2	0.00	0.00
	A*B	6	0.20	0.55
	Exp. Error	22	0.37	
	Coefficient of Variation = 24.6%			
815	Blocks (R)	2	0.68	5.45**
	A	3	1.23	9.82**
	B	2	0.35	2.79
	A*B	6	0.19	1.54
	Exp. Error	22	0.12	
	Coefficient of Variation = 19.1%			
816	Blocks (R)	2	0.20	0.94
	A	3	0.37	1.69
	B	2	0.07	0.35
	A*B	6	0.14	0.67
	Exp. Error	22	0.22	
	Coefficient of Variation = 25.1%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates; B - limestone placement depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.10.4 Orthogonal contrasts of limestone placement depths on percent calcium in Cowpea¹ grown on the Tabela sand No. 800 in the first season.

Source	df	MEAN SQUARES
B ¹	2	0.48*
B ₁ vs B ₂ , B ₃	1	0.00
B ₂ vs B ₃	1	0.97*
Exp. Error	22	0.13
Coefficient of Variation = 12.9%		

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B - limestone placement depths; B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.10.5 Orthogonal contrasts of limestone placement depths on percent calcium in Cowpea¹ grown on the Kairuni loamy sand No. 815 in the first season.

Source	df	MEAN SQUARE
B ¹	2	0.52*
B ₁ vs B ₂ , B ₃	1	1.04*
B ₂ vs B ₃	1	0.01
Exp. Error	22	0.15
Coefficient of Variation = 12.8%		

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B - limestone placement depths; B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.10.6 Simple effects of limestone rate-placement depths interactions on percent calcium in Cowpea¹ grown on the Bukaruna loamy sand No. 816 in the first season.

Source	df	MEAN SQUARES
A (B) ²	9	0.20*
A linear in B ₁	1	0.04
A quadratic in B ₁	1	0.06
A cubic in B ₁	1	0.14
A-linear in B ₂	1	0.34
A quadratic in B ₂	1	0.87**
A cubic in B ₂	1	0.00
A linear in B ₃	1	0.03
A quadratic in B ₃	1	0.25
A cubic in B ₃	1	0.04
Exp. Error	22	0.10

Coefficient of Variation = 9.1%

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates;

²B - limestone placement depths; B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

*,** Indicates that F values calculated from mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.10.7 Effects of rates and placement depths of limestone on percent calcium in Cowpea¹ grown on the Tabela sand No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	2.49	2.58	2.20	2.42
	1.5 - A ₂	2.71	3.15	2.66	2.84
	3.0 - A ₃	3.03	3.09	2.63	2.92
	4.5 - A ₄	3.19	3.37	3.09	3.22
	B mean	2.85	3.05	2.64	
2.	0 - A ₁	1.66	1.80	1.18	1.54
	1.5 - A ₂	2.05	1.78	1.85	1.89
	3.0 - A ₃	2.15	2.13	2.11	2.13
	4.5 - A ₄	2.09	2.06	1.82	1.99
	B mean	1.99	1.94	1.74	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.10.8 Effects of rates and placement depths of limestone on percent calcium in Cowpea¹ grown on the Kasarama loamy sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	2.79	2.91	2.85	2.85
	1.5 - A ₂	3.13	3.20	3.66	3.33
	3.0 - A ₃	3.48	3.65	3.26	3.46
	4.5 - A ₄	3.75	3.86	3.64	3.75
	B mean	3.29	3.40	3.35	
2.	0 - A ₁	2.39	2.20	2.02	2.20
	1.5 - A ₂	2.29	2.38	2.05	2.24
	3.0 - A ₃	2.40	2.38	3.04	2.60
	4.5 - A ₄	2.97	3.07	3.01	3.01
	B mean	2.51	2.51	2.53	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.10.9 Effects of rates and placement depths of limestone on percent calcium in Cowpea¹ grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	2.75	2.58	2.34	2.56
	1.5 - A ₂	2.84	2.43	2.69	2.65
	3.0 - A ₃	3.96	3.27	2.98	3.40
	4.5 - A ₄	3.48	3.38	3.51	3.45
	B mean	3.26	2.92	2.88	
2.	0 - A ₁	1.53	1.41	1.03	1.32
	1.5 - A ₂	2.02	2.17	1.74	1.98
	3.0 - A ₃	1.63	2.02	2.10	1.92
	4.5 - A ₄	1.88	2.59	2.08	2.18
	B mean	1.76	2.05	1.74	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.10.10 Effects of rates and placement depths of limestone on percent calcium in Cowpea¹ grown on the Bukaruna loamy sand NO. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂	B ₃	
(AxB means)					
%					
1.	0 - A ₁	3.68	3.18	3.66	3.51
	1.5 - A ₂	3.39	3.86	3.44	3.56
	3.0 - A ₃	3.73	4.03	3.23	3.66
	4.5 - A ₄	3.73	3.63	3.59	3.65
	B mean	3.63	3.68	3.48	
2.	0 - A ₁	1.51	1.45	1.59	1.51
	1.5 - A ₂	1.74	2.00	2.32	2.02
	3.0 - A ₃	2.22	1.87	1.76	1.95
	4.5 - A ₄	1.93	1.80	1.95	1.89
	B mean	1.85	1.78	1.90	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

3.4.4 Magnesium

Limestone rates had no significant effect on Mg content of tissue on any soil in both seasons, except on the Kasarama loamy sand No. 815 in the first season and on the Tabela sand No. 800 in the second season (Tables 2.11.1, 2.11.2). In the first season, increasing limestone rates resulted in a significant linear decrease of Mg content in tissue on the Kasarama loamy sand No. 810 (Tables 2.11.3, 2.11.6), whereas, in the second season a similar response was observed on the Tabela sand No. 800 (Tables 2.11.4, 2.11.5). The effects of limestone placement depths and limestone rate-placement depth interactions on Mg concentration in tissue were non-significant on all soils in both seasons (Tables 2.11.1, 2.11.2). Mean Mg contents in tissue were lower on all soils in the second season compared to the first season (Tables 2.11.5, 2.11.6, 2.11.7, 2.11.8).

Table 2.11.1 Analysis of variance of percent magnesium in Cowpea¹ grown on four soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.1113	0.77
	A ²	3	0.0227	1.54
	B ²	2	0.0023	0.16
	A*B	6	0.0080	0.54
	Exp. Error	22	0.0148	
	Coefficient of Variation = 32.0%			
810	Blocks (R)	2	0.0486	5.66*
	A	3	0.0602	7.00**
	B	2	0.0153	1.79
	A*B	6	0.0120	1.41
	Exp. Error	22	0.0086	
	Coefficient of Variation = 17.3%			
815	Blocks (R)	2	0.0128	0.76
	A	3	0.0243	1.44
	B	2	0.0104	0.62
	A*B	6	0.0108	0.64
	Exp. Error	22	0.0168	
	Coefficient of Variation = 28.9%			
816	Blocks (R)	2	0.0099	0.88
	A	3	0.0060	0.53
	B	2	0.0140	1.25
	A*B	6	0.0119	1.06
	Exp. Error	22	0.0113	
	Coefficient of Variation = 23.6%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.11.2 Analysis of variance of percent magnesium in Cowpea¹ grown on four soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.0032	1.34
	A ²	3	0.0123	5.04**
	B ²	2	0.0009	0.40
	A*B	6	0.0022	0.89
	Exp. Error	22	0.0024	
	Coefficient of Variation = 28.7%			
810	Blocks (R)	2	0.0113	4.78*
	A	3	0.0010	0.41
	B	2	0.0062	2.62
	A*B	6	0.0029	1.23
	Exp. Error	22	0.0024	
	Coefficient of Variation = 30.9%			
815	Blocks (R)	2	0.0032	2.43
	A	3	0.0035	2.68
	B	2	0.0038	2.88
	A*B	6	0.0015	1.14
	Exp. Error	22	0.0013	
	Coefficient of Variation = 27.1%			
816	Blocks (R)	2	0.0015	0.27
	A	3	0.0082	1.45
	B	2	0.0105	1.86
	A*B	6	0.0047	0.83
	Exp. Error	22	0.0057	
	Coefficient of Variation = 37.1%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates; B - limestone placement depths.

*,** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 2.11.3 Orthogonal polynomial contrasts of limestone rates on percent magnesium in Cowpea¹ grown on the Kasarama loamy sand No. 810 in the first season.

Source	df	MEAN SQUARES ($\times 10^2$)
A ²	3	6.00**
A linear	1	12.93**
A quadratic	1	2.84
A cubic	1	2.28
Exp. Error	22	0.86

Coefficient of Variation = 17.3%

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.11.4 Orthogonal polynomial contrasts of limestone rates on percent magnesium in Cowpea¹ grown on Tabela sand No. 800 in the first season.

Source	df	MEAN SQUARES ($\times 10^2$)
A ²	3	1.23**
A linear	1	3.42**
A quadratic	1	0.25
A cubic	1	0.03
Exp. Error	22	0.24

Coefficient of Variation = 28.7%

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 2.11 Effects of rates and placement depths of limestone on percent magnesium in Cowpea¹ grown on the Tabela sand No. 800 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	0.39	0.45	0.49	0.44
	1.5 - A ₂	0.39	0.36	0.31	0.35
	3.0 - A ₃	0.28	0.40	0.30	0.33
	4.5 - A ₄	0.40	0.36	0.41	0.39
	B mean	0.36	0.39	0.38	
2.	0 - A ₁	0.22	0.20	0.26	0.22
	1.5 - A ₂	0.16	0.20	0.16	0.17
	3.0 - A ₃	0.14	0.13	0.19	0.15
	4.5 - A ₄	0.13	0.15	0.13	0.14
	B mean	0.16	0.17	0.18	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.11.6 Effects of rates and placement depths of limestone on percent magnesium in Cowpea¹ grown on the Kasarama sand No. 810 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	0.65	0.59	0.66	0.63
	1.5 - A ₂	0.59	0.63	0.49	0.57
	3.0 - A ₃	0.45	0.44	0.46	0.45
	4.5 - A ₄	0.57	0.54	0.38	0.49
	B mean	0.56	0.55	0.49	
2.	0 - A ₁	0.18	0.17	0.10	0.15
	1.5 - A ₂	0.18	0.17	0.17	0.17
	3.0 - A ₃	0.17	0.16	0.13	0.15
	4.5 - A ₄	0.20	0.10	0.16	0.15
	B mean	0.18	0.15	0.14	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.11.7 Effects of rates and placement depths of limestone on percent magnesium in Cowpea¹ grown on the Kairuni loamy sand No. 815 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ²			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	0.44	0.37	0.57	0.45
	1.5 - A ₂	0.54	0.45	0.56	0.52
	3.0 - A ₃	0.34	0.46	0.41	0.40
	4.5 - A ₄	0.45	0.41	0.41	0.42
	B mean	0.44	0.42	0.48	
2.	0 - A ₁	0.13	0.18	0.13	0.15
	1.5 - A ₂	0.13	0.10	0.11	0.11
	3.0 - A ₃	0.14	0.19	0.12	0.15
	4.5 - A ₄	0.10	0.13	0.12	0.12
	B mean	0.13	0.15	0.12	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

Table 2.11.8 Effects of rates and placement depths of limestone on percent magnesium in Cowpea¹ grown on the Bukaruna loamy sand No. 816 for two seasons.

Season	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
%					
1.	0 - A ₁	0.39	0.49	0.53	0.47
	1.5 - A ₂	0.45	0.40	0.39	0.41
	3.0 - A ₃	0.47	0.40	0.52	0.46
	4.5 - A ₄	0.52	0.36	0.46	0.45
	B mean	0.46	0.41	0.48	
2.	0 - A ₁	0.19	0.23	0.22	0.22
	1.5 - A ₂	0.24	0.29	0.17	0.23
	3.0 - A ₃	0.22	0.18	0.19	0.20
	4.5 - A ₄	0.19	0.21	0.09	0.16
	B mean	0.21	0.23	0.17	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 15-30 cm.

B₂: 0-30 cm.

B₃: 0-15 cm.

3.5 Soil Chemical Properties

3.4.1 Soil pH

At the end of the first season, soil pH in the 0-15 cm soil layer was significantly increased by added limestone on all soils (Fig. 2.6.1, Table 2.12.1). Effects of limestone placement depths and limestone rate-placement depth interactions were non-significant on all soils (Table 2.12.1). At this time also, added limestone had no significant effect on soil pH on any soil at both the 15-30 cm and 30-45 cm soil depths (Table 2.12.1). At the 15-30 cm soil depth, limestone placement depths had no significant effects on soil pH, except on the Tabela sand No. 800 (Table 2.12.1). However, at this soil depth, limestone rate-placement depth interactions were also significant on the Tabela sand No. 800 (Fig. 2.6.2, Table 2.12.1). There was no significant effects of limestone placement depths and limestone rate-placement depth interactions on soil pH on any soil at the 30-45 cm soil depth, except on the Tabela sand No. 800 where limestone placement depths had significant effects (Table 2.12.1). At this sampling depth, limestone placement at the 15-30 cm soil depth on the Tabela sand No. 800 resulted in significantly higher soil pH than limestone mixed in the 0-15 cm soil layer (Fig. 2.6.3, Table 2.12.1).

Soil pH at the end of the second harvest was significantly increased by added limestone on all soils at each soil depth (0-15 cm, 15-30 cm, 30-45 cm), except on the Kasarama loamy sand No. 810 and Bukaruna loamy sand No. 816 at the 0-15 cm and 30-45 cm soil depths, respectively (Figs. 2.6.4, 2.6.5, 2.6.6, Table 2.12.2). Limestone placement depths and limestone rate-placement depth interactions had no significant effects on soil pH on any soil at all three sampling depths (Table 2.12.2).

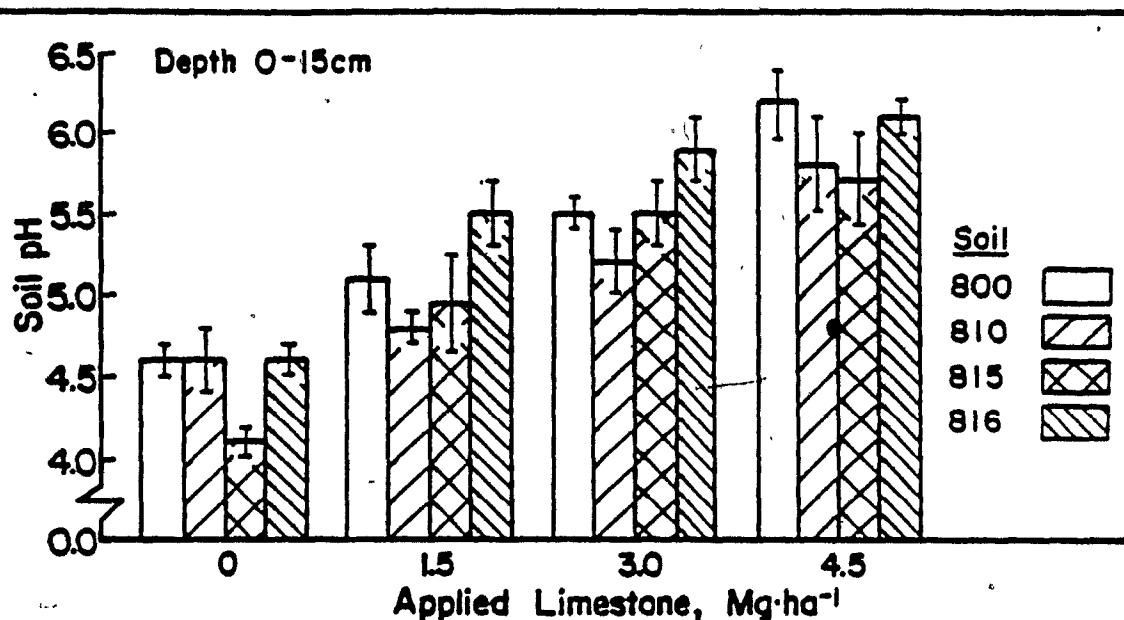


FIG. 2.6.1 Effects of limestone rates on soil pH on four soils at the end of the first season.

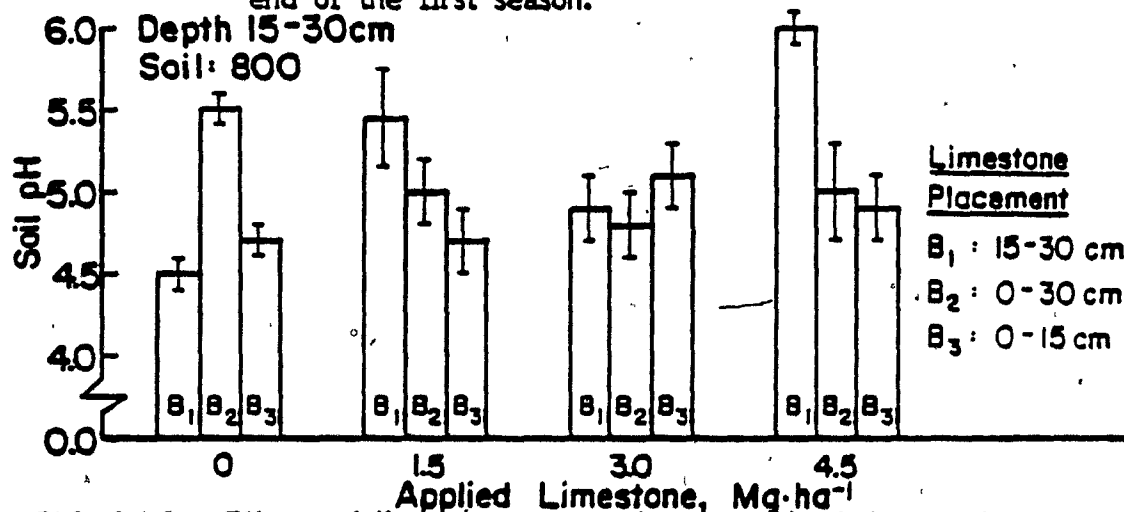


FIG. 2.6.2 Effects of limestone rate - placement depth interactions on soil pH on the Tabela sand No. 800 at the end of the first season.

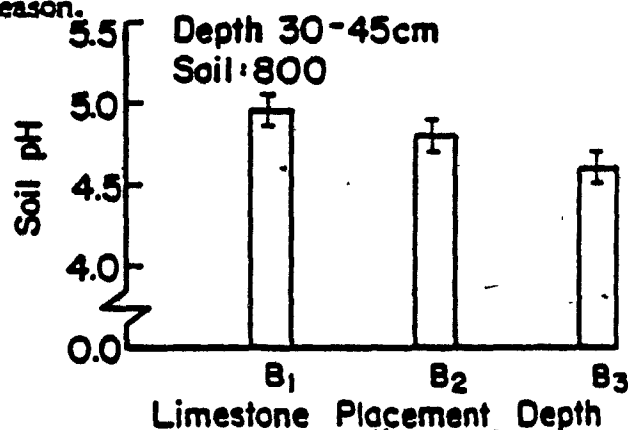


FIG. 2.6.3 Effects of limestone placement depths on soil pH on the Tabela sand No. 800 at the end of the first season.

Table 2.12.1 Analysis of variance of soil pH at three soil depths on four soils at the end of the first season.

Soil Depth (cm)	Source	df	SOIL TYPE			
			800	810 MEAN SQUARES	815	816
0-15	Blocks(R)	2	0.31	1.11	0.47	2.21**
	A ¹	3	3.99**	2.58**	4.64**	3.54**
	B ¹	2	0.21	0.08	0.26	0.00
	A*B	6	0.18	0.18	0.43	0.06
	Exp. Error	22	0.22	0.40	0.61	0.32
Coefficient of Variation (%)			8.8	12.3	15.5	10.3
15-30	Blocks(R)	2	0.13	0.94	0.07	0.44
	A	3	0.12	0.63	0.53	0.43
	B	2	0.68*	0.08	0.26	0.00
	A*B	6	0.91**	0.16	0.54	0.58
	Exp. Error	22	0.13	0.35	0.20	0.39
Coefficient of Variation (%)			7.2	12.1	9.6	12.0
30-45	Blocks(R)	2	0.23	0.07	0.05	0.04
	A	3	0.07	0.12	0.04	0.06
	B	2	0.40*	0.27	0.08	0.33
	A*B	6	0.10	0.04	0.07	0.14
	Exp. Error	22	0.09	0.16	0.13	0.13
Coefficient of Variation (%)			6.4	8.1	7.4	7.3

¹A: limestone rates; B: limestone placement depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

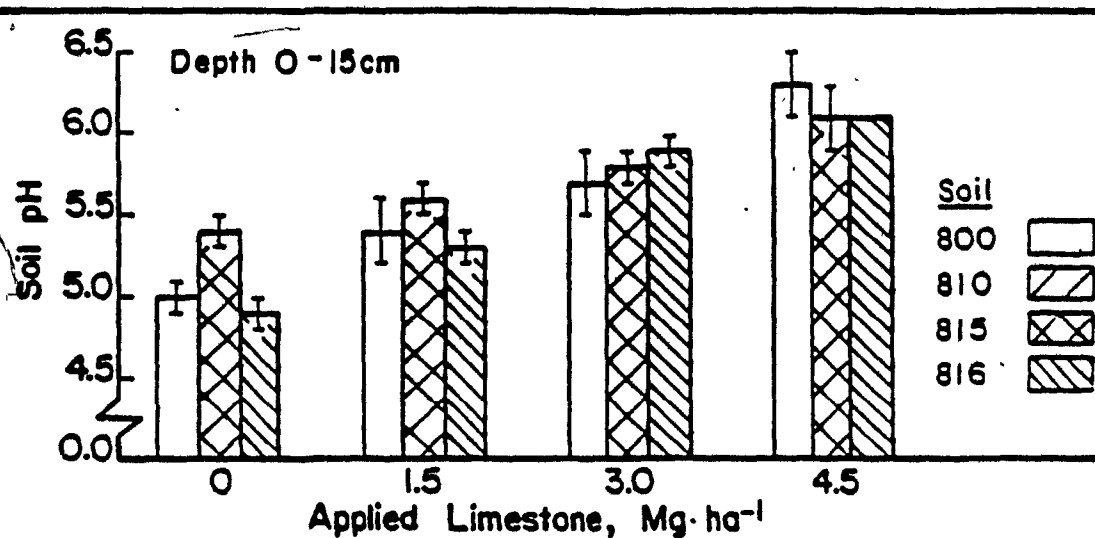


FIG. 2.6.4 Effects of limestone rates on soil pH on four soils at the end of the second season.

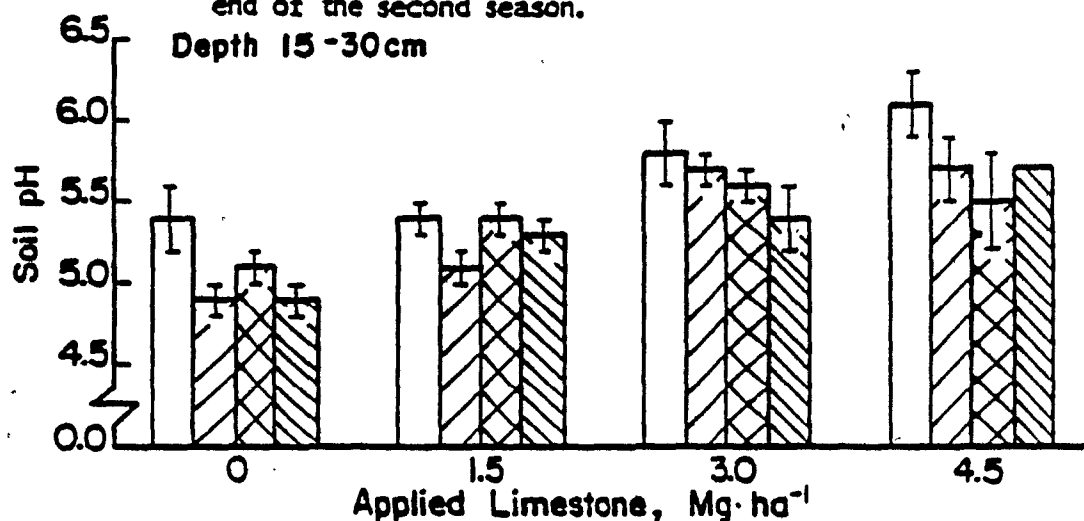


FIG. 2.6.5 Effects of limestone rates on soil pH on four soils at the end of the second season.

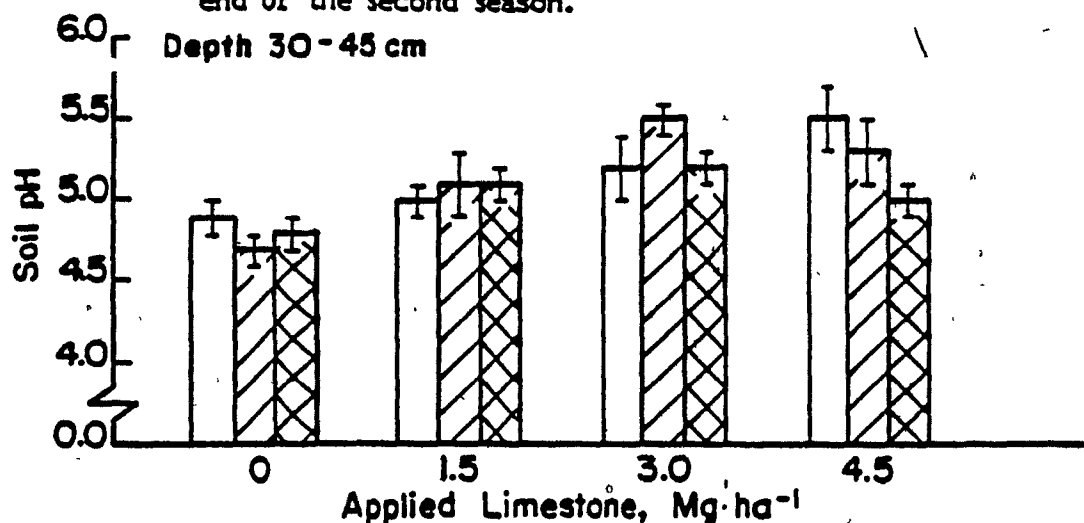


FIG. 2.6.6 Effects of limestone rates on soil pH on four soils at the end of the second season.

Table 2.12.2 Analysis of variance of soil pH at three soil depths on four soils at the end of the second season.

			SOIL TYPE			
Soil Depth (cm)	Source	df	800	810 MEAN SQUARES	815	816
0-15	Blocks(R)	2	0.03	0.33	0.05	0.01
	A ¹	3	2.56**	0.85	1.43**	2.47**
	B ¹	2	0.26	0.22	0.04	0.15
	A*B	6	0.17	0.16	0.23	0.09
	Exp. Error	22	0.32	0.30	0.15	0.10
	Coefficient of Variation (%)		10.1	9.8	6.8	5.6
15-30	Blocks(R)	2	0.16	0.10	0.18	0.06
	A	3	0.47**	1.82**	2.49**	0.91**
	B	2	0.07	0.11	0.05	0.17
	A*B	6	0.14	0.23	0.19	0.34
	Exp. Error	22	0.28	0.20	0.14	0.17
	Coefficient of Variation (%)		9.3	8.4	6.7	7.8
30-45	Blocks(R)	2	0.02	0.04	0.66*	0.08
	A	3	0.74*	1.48**	1.42**	0.41
	B	2	0.06	0.02	0.00	0.29
	A*B	6	0.07	0.33	0.34	0.15
	Exp. Error	22	0.22	0.21	0.15	0.19
	Coefficient of Variation (%)		9.1	9.0	7.3	8.9

¹A: limestone rates; B: limestone placement depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

3.5.2 Exchangeable acidity

Exchangeable acidity in the 0-15 cm soil depth was significantly reduced by added limestone at the end of the first season on every soil, except the Bukaruna loamy sand No. 816 (Fig. 2.7.1, Table 2.13.1). At this soil depth, limestone placement depths and limestone rate-placement depth interactions did not affect exchangeable acidity significantly on any soil (Table 2.13.1). Exchangeable acidity in the 15-30 cm soil layer was significantly affected by limestone rates, limestone placement depths and their interactions on the Tabela sand No. 800 and Kairuni loamy sand No. 815 (Figs. 2.7.2, 2.7.3, Table 2.13.1). No significant treatment effects were observed on the Kasarama loamy sand No. 810 and Bukaruna loamy sand No. 816 (Table 2.13.1). At the 30-45 cm soil layer limestone rates, limestone placement depths and limestone rate-placement depth interactions had no significant effect on exchangeable acidity on any soil, except that interaction effects were significant on the Tabela sand No. 800 (Fig. 2.7.4, Table 2.13.1).

Added limestone resulted in significant decreases in exchangeable acidity at the end of the second season on every soil at all three sampling depths except on the Kairuni loamy sand No. 815 at the 0-15 cm and 15-30 cm soil layers and on the Bukaruna loamy sand No. 810 at the 30-45 cm soil depth (Figs. 2.7.5, 2.7.6, 2.7.7, Table 2.13.2). Limestone placement depths had no significant effects on exchangeable acidity on any soil in all soil layers, except on the Bukaruna loamy sand No. 816 at the 15-30 cm sampling depths (Table 2.13.2). There was no significant limestone rate-placement depth interactions on any soil at all sampling depths, except on the Kairuni loamy sand No. 815 and the Bukaruna loamy sand No. 816 at the 0-15 cm and 15-30 cm soil depths, respectively (Figs. 2.7.8, 2.7.9, Table 2.13.2).

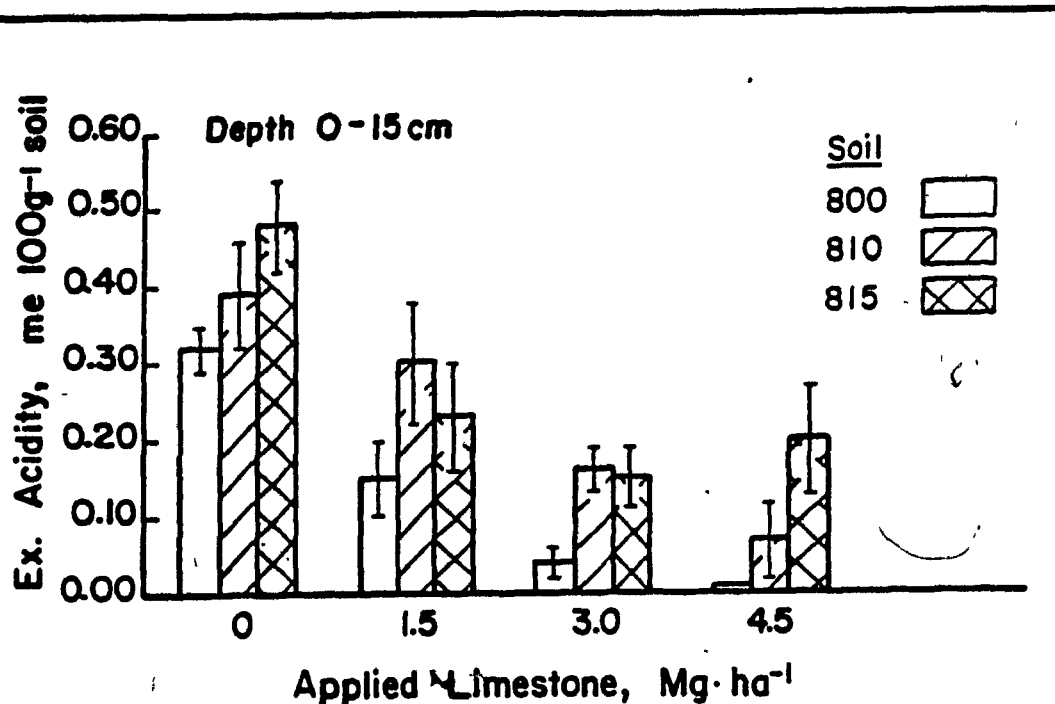


FIG. 2.7.1 Effects of limestone rates on exchangeable acidity on three soils at the end of the first season.

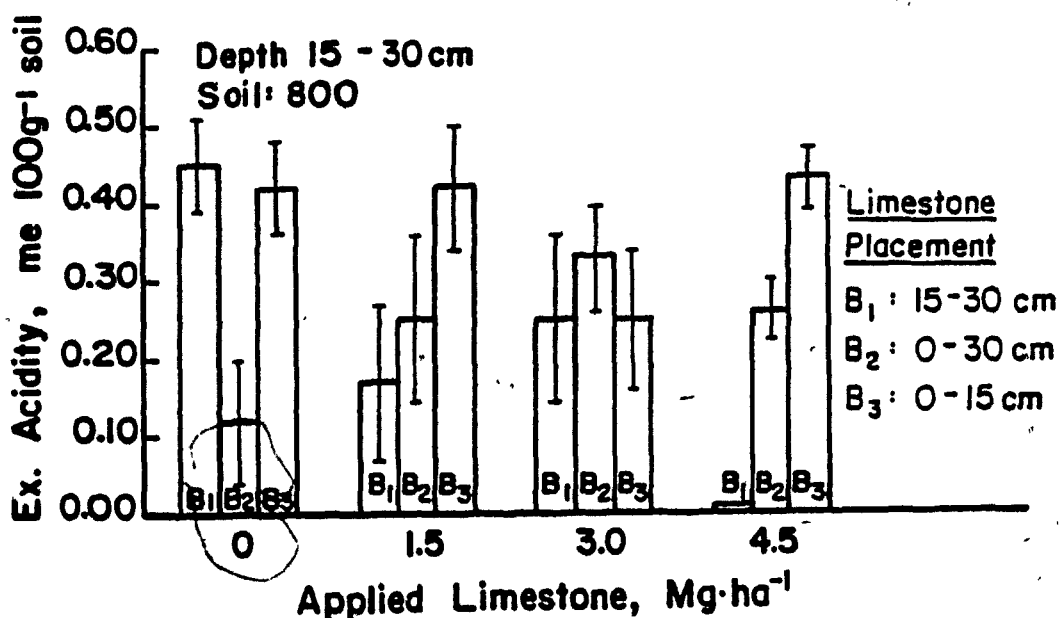


FIG. 2.7.2 Effects of limestone rate - placement depth interactions on exchangeable acidity on the Tablea sand No. 800 at the end of the first season.

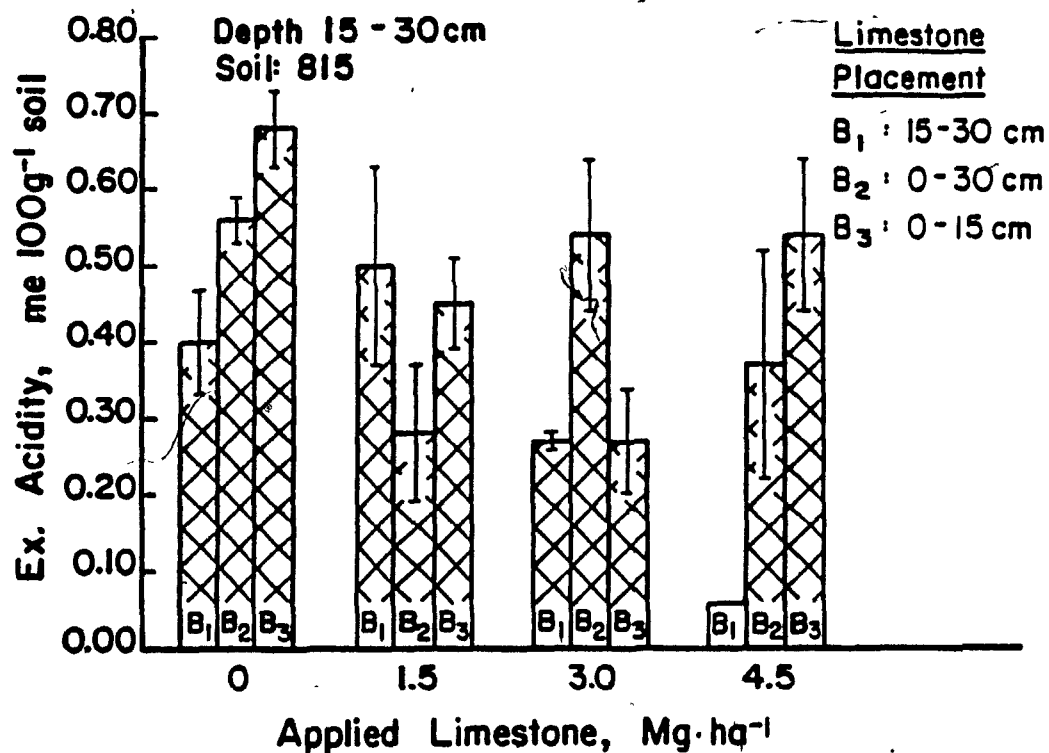


FIG. 2.7.3 Effects of limestone rate - placement depth interactions on exchangeable acidity on the Kairuni loamy sand No. 815 at the end of the first season.

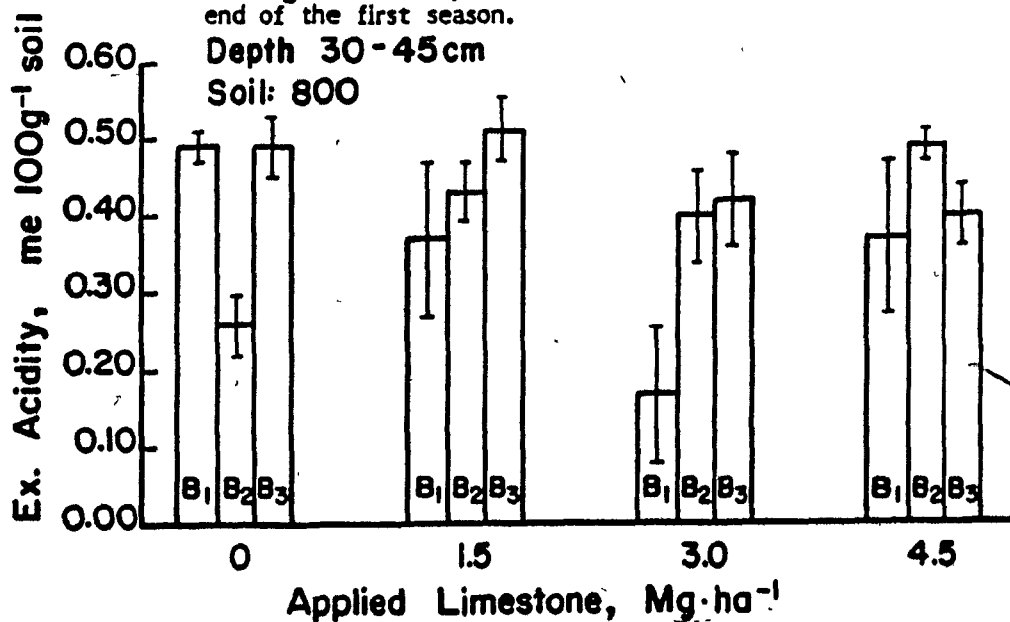


FIG. 2.7.4 Effects of limestone rate - placement depth interactions on exchangeable acidity on the Tablea sand No. 800 at the end of the first season.

Table 2.13.1 Analysis of variance of exchangeable acidity at three soil depths on four soils at the end of the first season.

Soil Depth (cm)	Source	df	SOIL TYPE			
			800	810 MEAN SQUARES	815	816
0-15	Blocks(R)	2	0.01	1.06	0.07	0.05
	A ¹	3	0.26**	0.33**	0.38**	0.07
	B ¹	2	0.04	0.05	0.05	0.02
	A*B	6	0.01	0.11	0.04	0.02
	Exp. Error	22	0.01	0.06	0.07	0.02
Coefficient of Variation (%)			71.9	83.5	75.2	115.5
15-30	Blocks(R)	2	0.00	0.20	0.03	0.16*
	A	3	0.03**	0.11	0.18*	0.00
	B	2	0.16*	0.06	0.22*	0.07
	A*B	6	0.11*	0.02	0.18*	0.03
	Exp. Error	22	0.03	0.10	0.05	0.04
Coefficient of Variation (%)			53.1	56.6	42.9	73.3
30-45	Blocks(R)	2	0.03	0.07	0.11	0.41**
	A	3	0.04	0.10	0.01	0.01
	B	2	0.06	0.21	0.01	0.04
	A*B	6	0.07*	0.03	0.07	0.02
	Exp. Error	22	0.02	0.07	0.08	0.04
Coefficient of Variation (%)			27.5	50.7	51.9	48.6

¹A: limestone rates; B: limestone placement depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

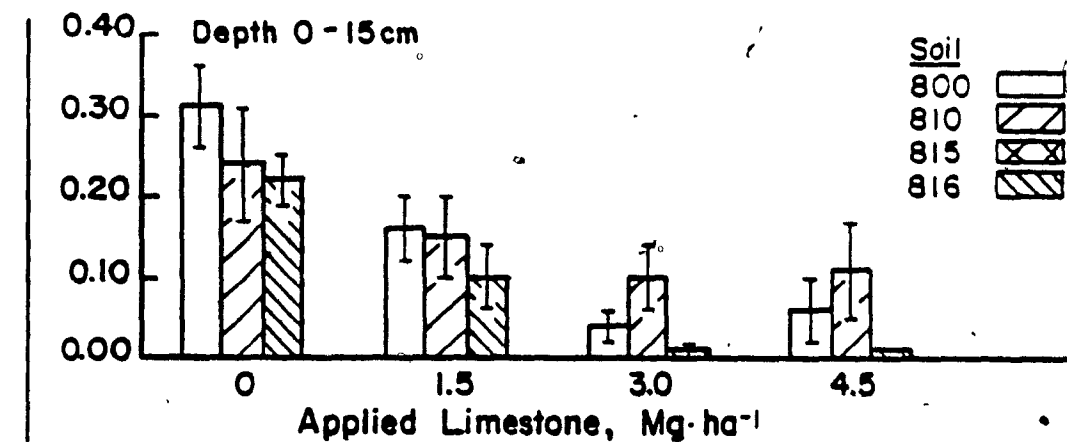


FIG. 2.7.5 Effects of limestone rates on exchangeable acidity on three soils at the end of the second season.

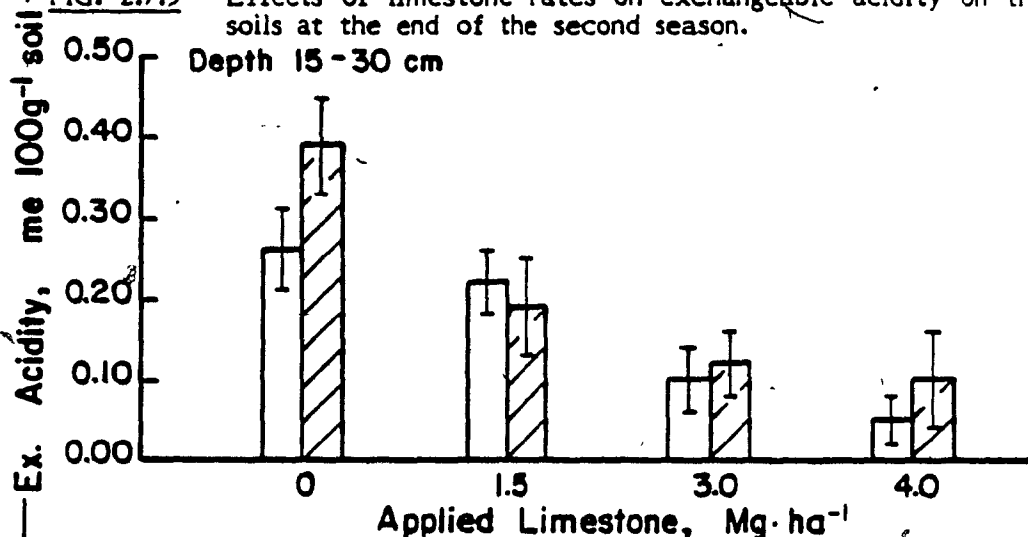


FIG. 2.7.6 Effects of limestone rates on exchangeable acidity on two soils at the end of the second season.

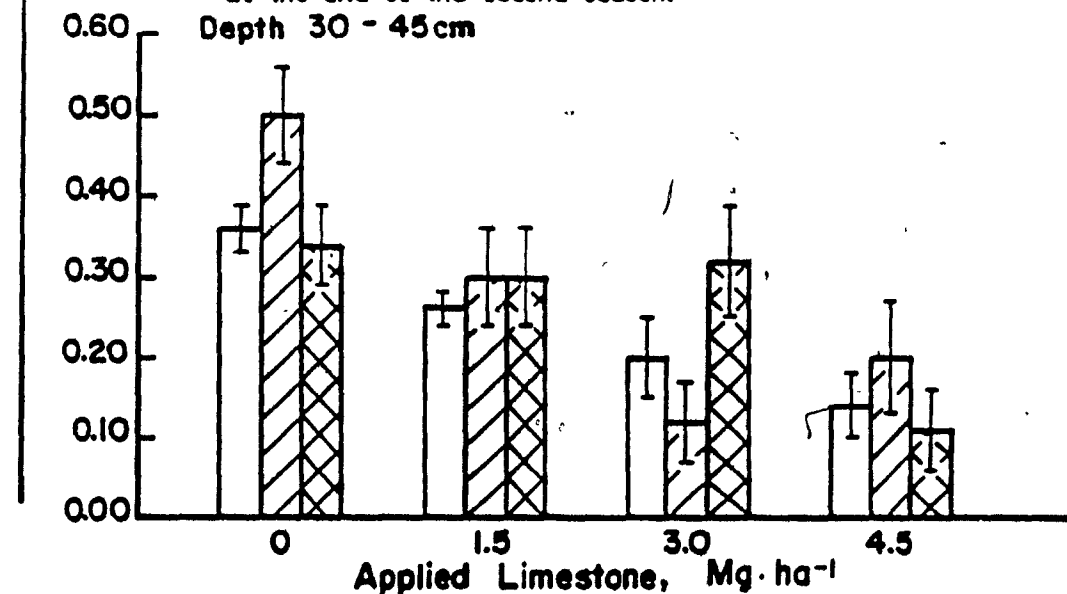


FIG. 2.7.7 Effects of limestone rates on exchangeable acidity on three soils at the end of the second season.

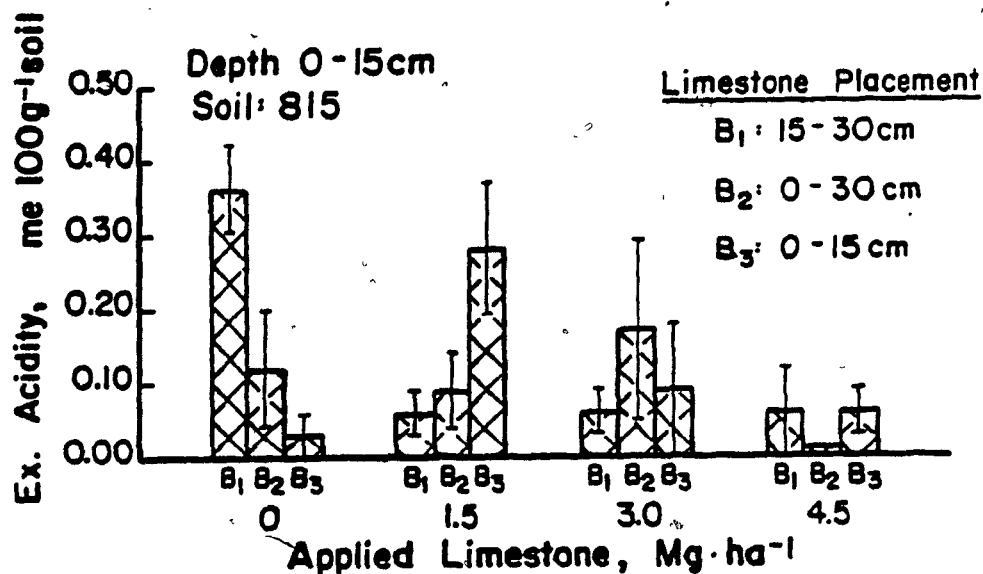


FIG. 2.7.8 Effects of limestone rate - placement depth interactions on exchangeable acidity on the Kairuni loamy sand No. 815 at the end of the second season.

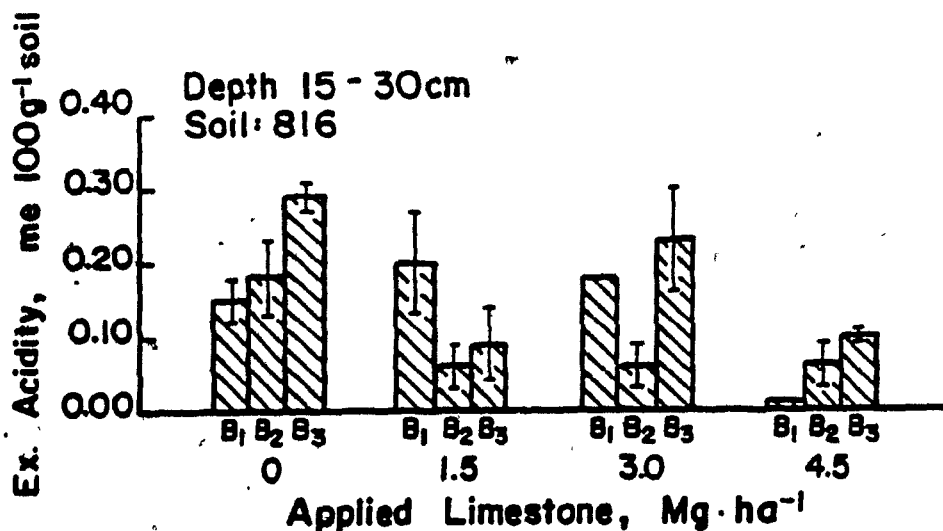


FIG. 2.7.9 Effects of limestone rate - placement depth interactions on exchangeable acidity on the Bukaruna loamy sand No. 816 at the end of second season.

Table 2.13.2 Analysis of variance of exchangeable acidity at three soil depths on four soils at the end of the second season.

Soil Depth (cm)	Source	df	SOIL TYPE			
			800	810 MEAN SQUARES	815	816
0-15	Blocks(R)	2	0.03	0.07	0.01	0.01
	A ¹	3	0.21**	0.20**	0.04	0.13**
	B ¹	2	0.04	0.04	0.01	0.01
	A*B	6	0.01	0.01	0.07*	0.01
	Exp. Error	22	0.02	0.03	0.02	0.01
Coefficient of Variation (%)			77.7	94.8	97.9	86.1
15-30	Blocks(R)	2	0.03	0.07	0.01	0.00
	A	3	0.19**	0.31**	0.21	0.05**
	B	2	0.00	0.07	0.02	0.04*
	A*B	6	0.02	0.08	0.04	0.02*
	Exp. Error	22	0.01	0.04	0.10	0.01
Coefficient of Variation (%)			54.4	69.8	13.5	60.6
30-45	Blocks(R)	2	0.00	0.04	0.02	0.00
	A	3	0.12**	0.59**	0.17*	0.05
	B	2	0.01	0.01	0.02	0.07
	A*B	6	0.01	0.09	0.09	0.01
	Exp. Error	22	0.02	0.05	0.05	0.02
Coefficient of Variation (%)			53.0	62.0	68.6	50.6

¹A: limestone rate; B: limestone placement depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

3.5.3 Exchangeable Aluminum

Analysis of variance was not performed on data sets of KCl-exchangeable Al. However, the effects of limestone rates, limestone placement depths and limestone rate-placement depth interactions were summarized in two-way table of means. Increasing levels of added limestone caused a reduction in KCl-exchangeable Al at the end of the first season on all soils at the three soil depths (Tables 2.14.1, 2.14.2, 2.14.3, 2.14.4) with the decreases being more pronounced at the end of the second season (Tables 2.14.5, 2.14.6, 2.14.7, 2.14.8).

3.5.4 Exchangeable Calcium

At the end of the first season exchangeable Ca in the 0-15 cm soil depth was significantly increased by added limestone on all soils (Fig. 2.8.1., Table 2.15.1). At this soil depth, effects of limestone placement depths and limestone rate-placement depth interactions were non-significant on every soil (Table 2.15.1). At the 15-30 cm soil depth, limestone rates had significant effects on exchangeable Ca on the Tabela sand No. 800 and Kasarama loamy sand No. 810 (Table 2.15.1). On the Kasarama loamy sand No. 810, increasing limestone rates resulted in significant increases in exchangeable Ca (Fig. 2.8.2, Table 2.15.1). However, on the Tabela sand No. 800 limestone placement depths and limestone rate-placement depth interactions had significant effects on exchangeable Ca as well (Fig. 2.8.3, Table 2.15.1). On the remaining soils, limestone placement and limestone rate-placement depth interactions did not have any significant effects on exchangeable Ca at the 15-30 cm soil depth (Table 2.15.1). Limestone rates did not affect exchangeable Ca significantly at the 30-45 cm soil depth on all soils (Table 2.15.1). Limestone placement and limestone rate-placement depth

Table 2.14.1 Effects of rates and placement depths of limestone on exchangeable Al on the Tabela sand No. 800 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
me 100g ⁻¹ soil					
0-15	0 - A ₁	0.07	0.03	0.20	0.10
	1.5 - A ₂	0.00	0.00	0.03	0.01
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.00	0.00
	B mean	0.02	0.01	0.06	
15-30	0 - A ₁	0.17	0.00	0.23	0.13
	1.5 - A ₂	0.00	0.10	0.00	0.03
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.00	0.00
	B mean	0.04	0.02	0.06	
30-45	0 - A ₁	0.13	0.10	0.23	0.15
	1.5 - A ₂	0.03	0.17	0.17	0.12
	3.0 - A ₃	0.00	0.17	0.17	0.11
	4.5 - A ₄	0.03	0.20	0.10	0.11
	B mean	0.05	0.16	0.17	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table 2.14.2 Effects of rates and placement depths of limestone on exchangeable Al on the Kasarama loamy sand No. 810 at the end of the first season.

Soil Depth Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
me 100g ⁻¹ soil					
0-15	0 - A ₁	0.07	0.23	0.12	0.14
	1.5 - A ₂	0.07	0.02	0.00	0.03
	3.0 - A ₃	0.00	0.02	0.00	0.01
	4.5 - A ₄	0.00	0.02	0.07	0.03
	B mean	0.03	0.07	0.05	
15-30	0 - A ₁	0.22	0.13	0.27	0.21
	1.5 - A ₂	0.06	0.10	0.23	0.13
	3.0 - A ₃	0.23	0.13	0.03	0.13
	4.5 - A ₄	0.18	0.00	0.10	0.09
	B mean	0.17	0.09	0.16	
30-45	0 - A ₁	0.22	0.03	0.32	0.19
	1.5 - A ₂	0.05	0.13	0.28	0.15
	3.0 - A ₃	0.23	0.13	0.03	0.13
	4.5 - A ₄	0.23	0.00	0.13	0.12
	B mean	0.18	0.07	0.19	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table 2.14.3 Effects of rates and placement depths of limestone on exchangeable Al on the Kairuni loamy sand No. 815 at the end of the first season.

Soil Depth Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
me 100g ⁻¹ soil					
0-15	0 - A ₁	0.28	0.22	0.30	0.27
	1.5 - A ₂	0.00	0.06	0.00	0.02
	3.0 - A ₃	0.10	0.00	0.00	0.03
	4.5 - A ₄	0.00	0.00	0.05	0.02
	B mean	0.09	0.07	0.09	
15-30	0 - A ₁	0.22	0.33	0.37	0.31
	1.5 - A ₂	0.17	0.10	0.13	0.13
	3.0 - A ₃	0.10	0.15	0.00	0.08
	4.5 - A ₄	0.00	0.05	0.20	0.08
	B mean	0.12	0.16	0.17	
30-45	0 - A ₁	0.33	0.32	0.20	0.28
	1.5 - A ₂	0.10	0.10	0.00	0.07
	3.0 - A ₃	0.23	0.20	0.20	0.21
	4.5 - A ₄	0.08	0.10	0.13	0.10
	B mean	0.18	0.18	0.13	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table 2.14.4 Effects of rates and placement depths of limestone on exchangeable Al on the Bukaruna loamy sand NO. 816 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
me 100g ⁻¹ soil					
0-15	0 - A ₁	0.10	0.13	0.06	0.10
	1.5 - A ₂	0.00	0.00	0.00	0.00
	3.0 - A ₃	0.03	0.00	0.00	0.01
	4.5 - A ₄	0.00	0.02	0.00	0.01
	B mean	0.04	0.05	0.02	
15-30	0 - A ₁	0.13	0.10	0.15	0.13
	1.5 - A ₂	0.05	0.03	0.03	0.04
	3.0 - A ₃	0.03	0.03	0.10	0.05
	4.5 - A ₄	0.00	0.00	0.03	0.01
	B mean	0.05	0.04	0.08	
30-45	0 - A ₁	0.17	0.15	0.15	0.16
	1.5 - A ₂	0.13	0.06	0.06	0.08
	3.0 - A ₃	0.10	0.10	0.17	0.12
	4.5 - A ₄	0.00	0.06	0.13	0.06
	B mean	0.10	0.09	0.13	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table 2.14.5 Effects of rates and placement depths of limestone on exchangeable Al on the Tabela sand No. 800 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
me 100g ⁻¹ soil					
0-15	0 - A ₁	0.20	0.10	0.10	0.13
	1.5 - A ₂	0.00	0.00	0.00	0.00
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.00	0.00
	B mean	0.05	0.02	0.02	
15-30	0 - A ₁	0.10	0.03	0.17	0.10
	1.5 - A ₂	0.00	0.06	0.00	0.02
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.00	0.00
	B mean	0.03	0.03	0.04	
30-45	0 - A ₁	0.17	0.10	0.13	0.13
	1.5 - A ₂	0.03	0.00	0.00	0.01
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.03	0.01
	B mean	0.05	0.02	0.04	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table 2.14.6 Effects of rates and placement depths of limestone on exchangeable Al on the Kasarama loamy sand No. 810 at the end of the second season.

Soil Depth Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
mé 100g ⁻¹ soil					
0-15	0 - A ₁	0.10	0.13	0.12	0.12
	1.5 - A ₂	0.03	0.00	0.00	0.01
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.13	0.04
	B mean	0.04	0.04	0.06	
15-30	0 - A ₁	0.23	0.17	0.03	0.14
	1.5 - A ₂	0.06	0.00	0.03	0.03
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.03	0.01
	B mean	0.07	0.04	0.02	
30-45	0 - A ₁	0.20	0.43	0.20	0.28
	1.5 - A ₂	0.13	0.13	0.13	0.13
	3.0 - A ₃	0.00	0.00	0.03	0.01
	4.5 - A ₄	0.00	0.00	0.13	0.04
	B mean	0.08	0.14	0.12	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table 2.14.7 Effects of rates and placement depths of limestone on exchangeable Al on the Kairuni loamy sand No. 815 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
me 100g ⁻¹ soil					
0-15	0 - A ₁	0.10	0.10	0.03	0.08
	1.5 - A ₂	0.00	0.00	0.00	0.00
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.00	0.00
	B mean	0.02	0.02	0.01	
15-30	0 - A ₁	0.23	0.07	0.50	0.27
	1.5 - A ₂	0.00	0.00	0.03	0.01
	3.0 - A ₃	0.00	0.03	0.00	0.01
	4.5 - A ₄	0.00	0.00	0.00	0.00
	B mean	0.06	0.02	0.13	
30-45	0 - A ₁	0.27	0.20	0.27	0.25
	1.5 - A ₂	0.13	0.03	0.17	0.11
	3.0 - A ₃	0.13	0.17	0.00	0.10
	4.5 - A ₄	0.00	0.03	0.00	0.11
	B mean	0.13	0.11	0.11	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table 2.14.8 Effects of rates and placement depths of limestone on exchangeable Al on the Bukaruna loamy sand No. 816 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Limestone Placement Depth ¹			A mean
		B ₁	B ₂ (AxB means)	B ₃	
me 100g ⁻¹ soil					
0-15	0 - A ₁	0.06	0.13	0.17	0.12
	1.5 - A ₂	0.00	0.00	0.00	0.00
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.00	0.00
	B mean	0.01	0.03	0.04	
15-30	0 - A ₁	0.13	0.07	0.20	0.13
	1.5 - A ₂	0.00	0.00	0.00	0.00
	3.0 - A ₃	0.00	0.00	0.00	0.00
	4.5 - A ₄	0.00	0.00	0.00	0.00
	B mean	0.04	0.02	0.05	
30-45	0 - A ₁	0.17	0.17	0.20	0.18
	1.5 - A ₂	0.00	0.00	0.00	0.00
	3.0 - A ₃	0.03	0.00	0.00	0.01
	4.5 - A ₄	0.00	0.00	0.00	0.00
	B mean	0.05	0.04	0.05	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

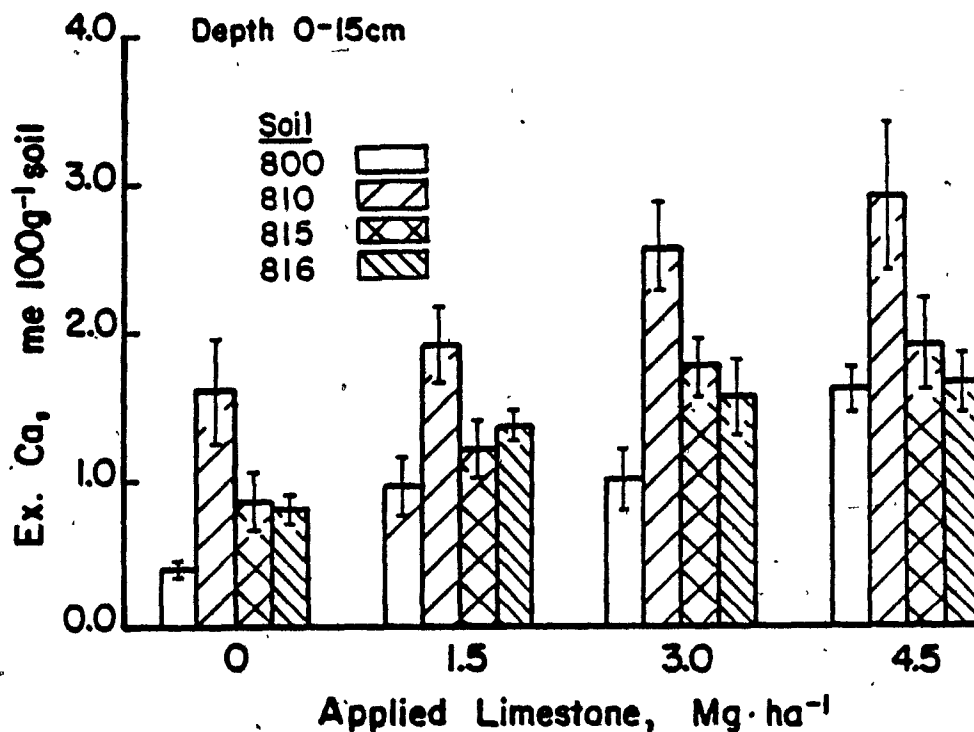


FIG. 2.8.1 Effects of limestone rates on exchangeable Ca on four soils at the end of the first season.

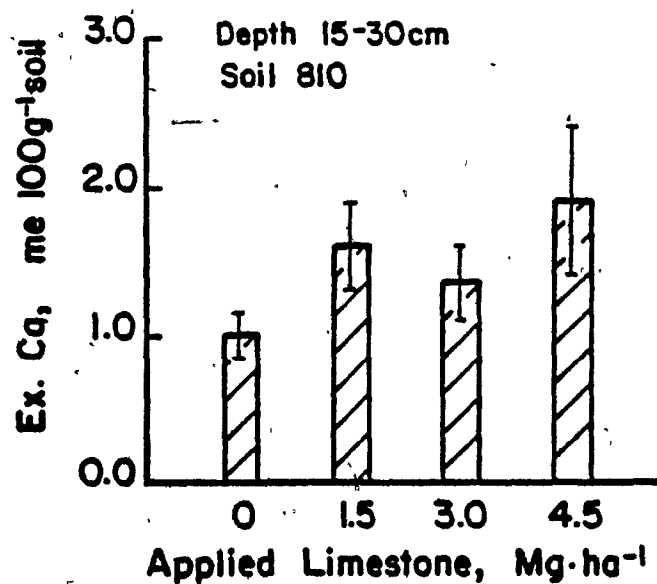


FIG. 2.8.2 Effects of limestone rates on exchangeable Ca on the Kasarama loamy sand No. 810. at the end of the first season.

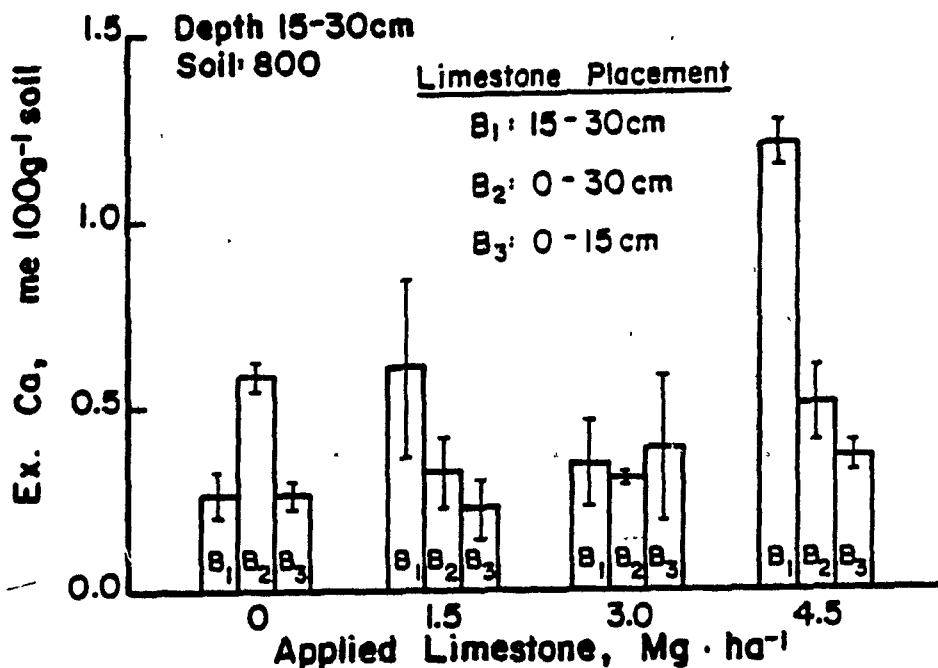


FIG. 2.8.3 Effects of limestone rate - placement depth interactions on exchangeable Ca on the Tabela sand No. 800 at the end of the first season.

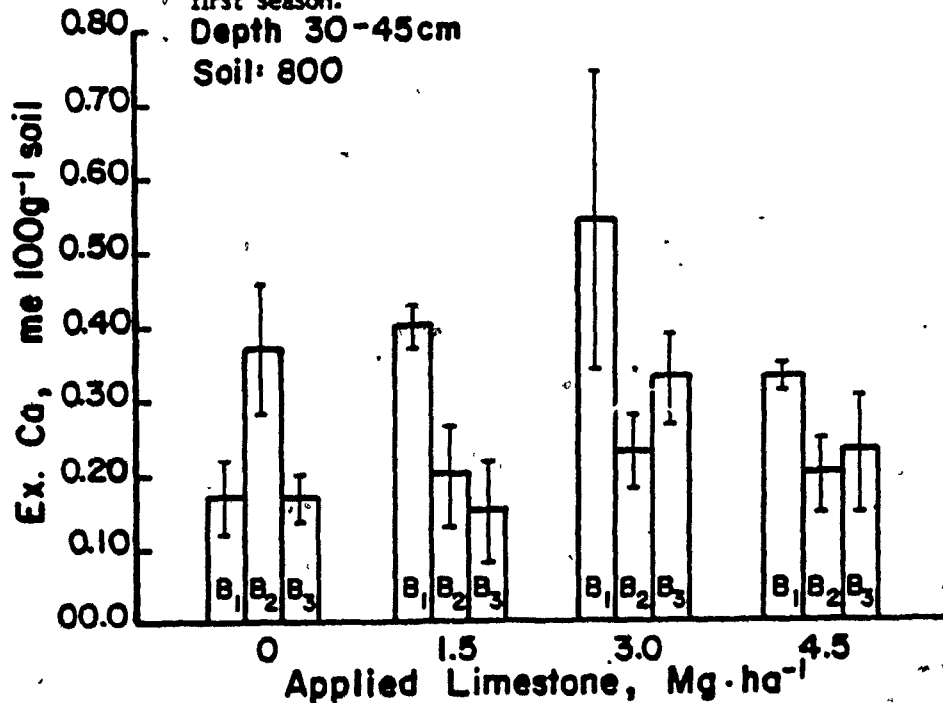


FIG. 2.8.4 Effects of limestone rate - placement depth interactions on exchangeable Ca on the Tabela sand No. 800 at the end of the first season.

Table 2.15.1 Analysis of variance of exchangeable Ca at three soil depths on four soils at the end of the first season.

Soil Depth (cm)	Source	df	SOIL TYPE			
			800	810 MEAN SQUARES	815	816
0-15	Blocks(R)	2	0.30	8.36**	0.37	0.17
	A ¹	3	2.22**	3.11*	2.14**	1.30*
	B ¹	2	0.62	0.23	0.18	0.23
	A*B	6	0.20	0.50	0.63	0.24
	Exp. Error	22	0.21	0.73	0.40	0.30
Coefficient of Variation (%)			45.8	38.3	44.3	41.1
15-30	Blocks(R)	2	0.09	7.50**	0.02	0.29
	A	3	0.23**	1.33*	0.39	0.07
	B	2	0.27**	0.43	0.35	0.43*
	A*B	6	0.19**	0.62	0.24	0.10
	Exp. Error	22	0.03	0.40	0.11	0.20
Coefficient of Variation (%)			41.0	43.5	42.0	52.8
30-45	Blocks(R)	2	0.06*	2.85**	0.35	0.25
	A	3	0.03	0.34	0.13	0.00
	B	2	0.07*	0.28	0.36	0.06
	A*B	6	0.04*	0.05	0.03	0.08
	Exp. Error	22	0.01	0.20	0.18	0.04
Coefficient of Variation (%)			44.3	39.7	61.3	40.7

¹A: limestone rates; B: limestone placement depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

interactions had no significant effects on exchangeable Ca at the 30-45 cm soil depth, except on the Tabela sand No. 800 (Figure 2.8.4, Table 2.15.1).

Added limestone resulted in significant increases in exchangeable Ca levels in the 0-15 cm soil depth at the end of the second season on all soils, except the Kairuni loamy sand No. 815 (Fig. 2.8.5, Table 2.15.2). At this soil depth, limestone placement and limestone rate-placement depth interaction effects were non-significant on all soils (Table 2.15.2). At the 15-30 cm soil depth, added limestone resulted in significant increases in exchangeable Ca levels on the Tabela sand No. 800 and the Kairuni loamy sand No. 815 (Fig. 2.8.6, Table 2.15.2). There was also a significant limestone rate effect on the Bukaruna loamy sand No. 816 (Table 2.15.2). The effects of limestone placement depths and limestone rate-placement depth interactions were non-significant on every soil at the 15-30 soil depth, except for significant interaction effects on the Bukaruna loamy sand No. 816 (Fig. 2.8.7, Table 2.15.2). At the 30-45 cm soil depth, limestone rates had a significant effect in increasing exchangeable Ca levels only on the Kasarama loamy sand No. 810 (Fig. 2.8.8, Table 2.15.2). The effects of limestone placement depths and limestone rate-placement depth interactions were non-significant on all soils at this soil depth (Table 2.15.2).

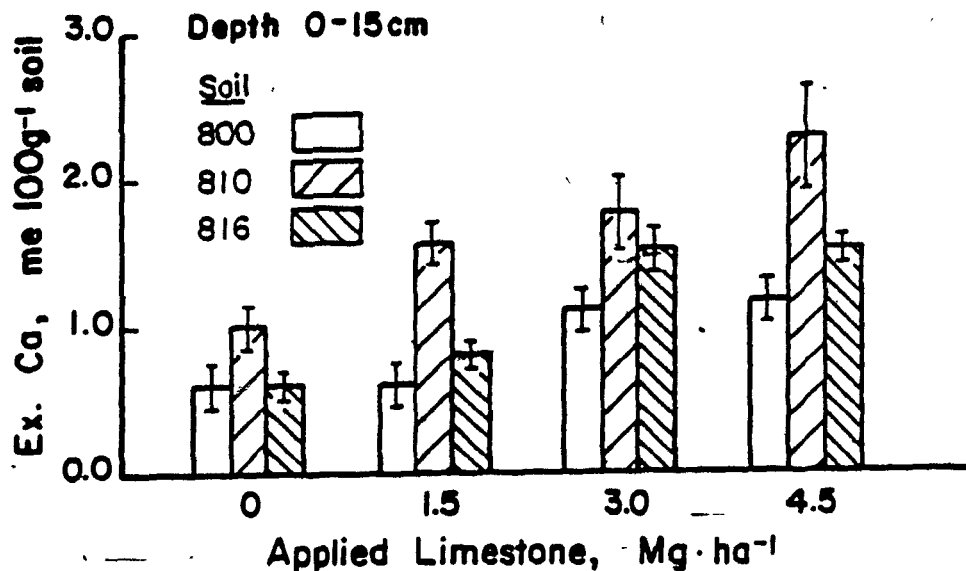


FIG. 2.3.5 Effects of limestone rates on exchangeable Ca on three soils at the end of the second season.

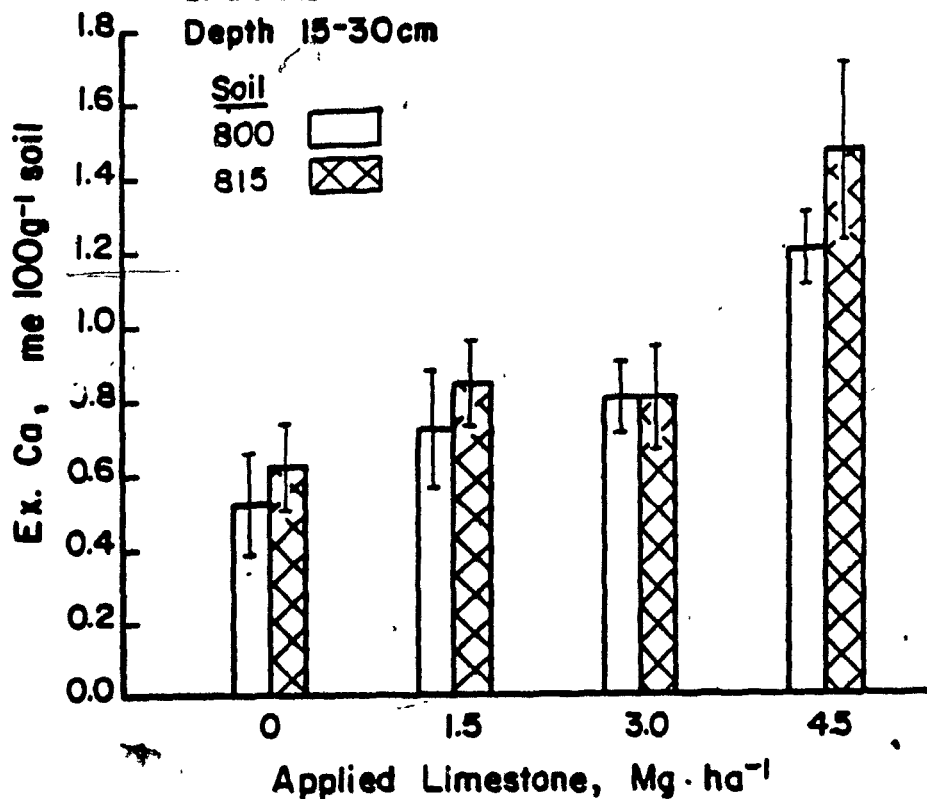


FIG. 2.3.6 Effects of limestone rates on exchangeable Ca on two soils at the end of the second season.

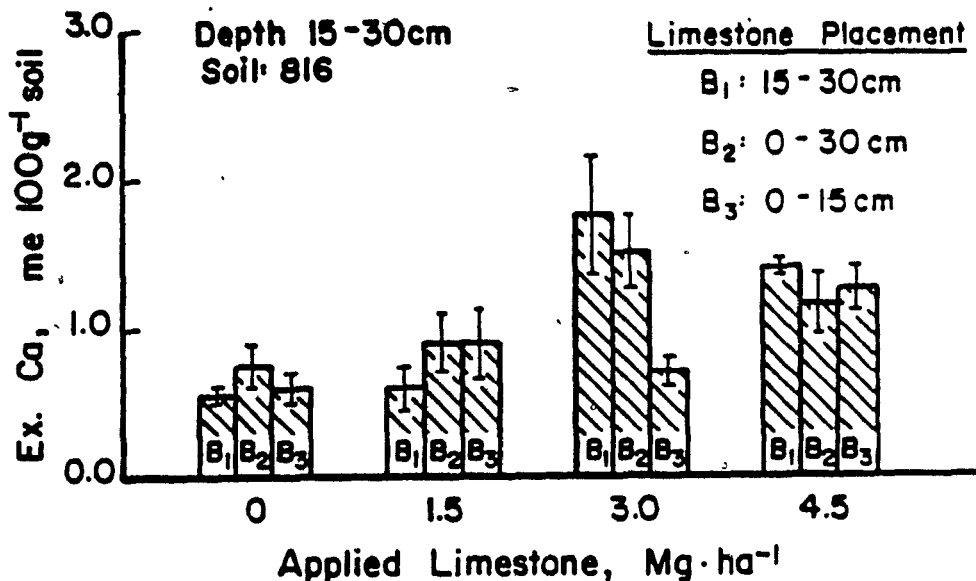


FIG. 2.8.7 Effects of limestone rate - placement depth interactions on exchangeable Ca on the Bukaruna loamy sand No. 816 at the end of the second season.

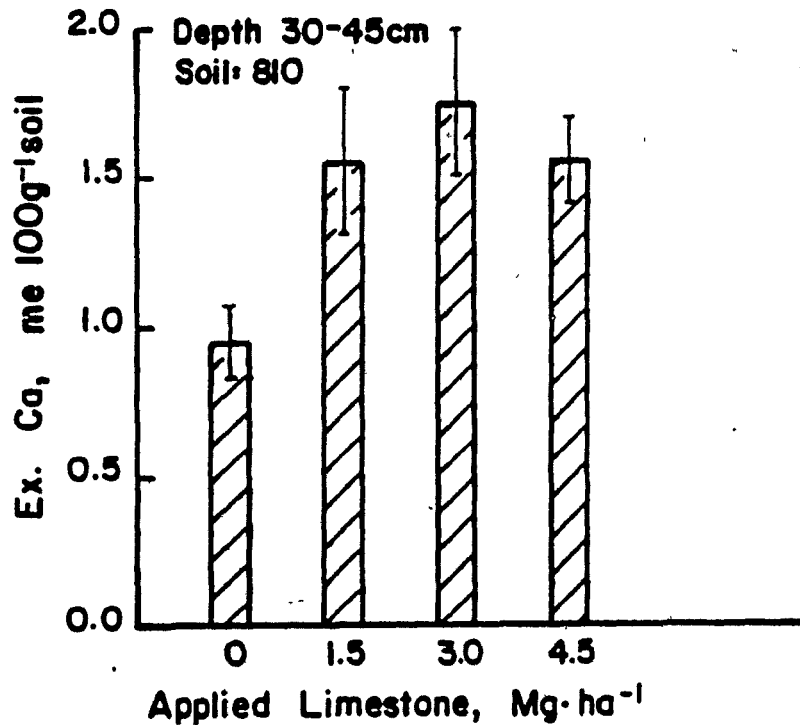


FIG. 2.8.8 Effects of limestone rate - placement depth interactions on exchangeable Ca on the Kasarama loamy sand No. 810 at the end of the second season.

Table 2.15.2 Analysis of variance of exchangeable Ca at three soil depths on four soils at the end of the second season.

Soil Depth (cm)	Source	df	SOIL TYPE			
			800	810 MEAN SQUARES	815	816
0-15	Blocks(R)	2	0.14	0.45	0.36	0.18
	A ¹	3	0.73*	2.43*	0.27	2.11**
	B ¹	2	0.01	0.45	0.01	0.11
	A*B	6	0.26	0.37	0.09	0.09
	Exp. Error	22	0.22	0.51	0.22	0.11
Coefficient of Variation (%)			54.4	43.6	55.7	30.6
15-30	Blocks(R)	2	0.58*	0.98	0.24	0.17
	A	3	0.73**	1.72	1.18*	1.02**
	B	2	0.06	0.23	0.44	0.15
	A*B	6	0.11	0.45	0.24	0.30*
	Exp. Error	22	0.14	0.64	0.25	0.11
Coefficient of Variation (%)			45.6	45.3	53.8	32.5
30-45	Blocks(R)	2	0.25	0.99	0.21	0.01
	A	3	0.15	1.13*	0.31	0.45
	B	2	0.07	0.42	0.05	0.13
	A*B	6	0.05	0.12	0.15	0.10
	Exp. Error	22	0.11	0.35	0.12	0.15
Coefficient of Variation (%)			51.4	40.7	47.2	50.3

¹A: limestone rates; B: limestone placement depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

3.5.5 Extractable Phosphorus, Exchangeable Potassium and Magnesium

Analysis of variance was carried out on data obtained at the two post-harvest soil sampling periods for extractable P, and exchangeable K and Mg. On all soils the main effects and interactions were in general non-significant at every soil depth at both sampling periods. Probability tables and soil mean values for limestone rates are presented in appendices C and D, respectively.

3.6 Relationship of Calcium Content in Tissue to Plant Yields

Total plant, pod and root yields of cowpea were significantly affected by Ca content in tissue on the Tabela sand No. 800 and Bukaruna loamy sand No. 816 (Table 2.16). Tissue yields on the Bukaruna loamy sand No. 816 were also significantly affected by Ca concentration in tissue (Table 2.16).

3.7 Relationship of Soil Exchangeable Ca to Plant Yields

Soil exchangeable Ca at the 0-15 and 15-30 cm soil depth did not significantly affect plant yields on any soil. An exception was found in that total plant and pod yields on the Kairuni loamy sand No. 815 were significantly affected by soil exchangeable Ca at the 15-30 cm soil depth (Tables 2.17.1, 2.17.2).

Table 2.16 Regressions of percent Ca in Cowpea¹ and total plant, pod, root and tissue yields (kg ha⁻¹; dry matter) determined on four soils in the second season.

Plant Variable	SOIL TYPE			
	800	810	815	816
	----- F calculated-----			
Total Plant Yield	23.49*	0.58	10.43	112.53**
R ²	0.92	0.23	0.84	0.98
Pod Yield	18.59*	0.44	8.64	106.94**
R ²	0.90	0.18	0.81	0.98
Root Yield	56.85*	0.47	10.02	453.47**
R ²	0.97	0.19	0.83	0.99
Tissue Yield	15.03	2.29	17.63	27.80*
R ²	0.88	0.53	0.90	0.93

¹Above-ground portion of plant excluding pods (sampled at harvest).

*,** Indicates significance at the 0.05, 0.01 levels of probability, respectively.

Table 2.17.1 Regressions of exchangeable Ca¹ (me 100 g⁻¹soil) at the 0-15 cm soil depth and total plant, pod, root and tissue yields (kg ha⁻¹; dry matter) determined on four soils in the second season.

Plant Variable	SOIL TYPE			
	800	810	815	816
	----- F calculated -----			
Total Plant Yield	3.80	3.19	1.23	1.33
R ²	0.65	0.61	0.38	0.40
Pod Yield	4.79	2.60	1.02	1.38
R ²	0.70	0.56	0.34	0.41
Root Yield	5.15	1.51	1.30	0.64
R ²	0.72	0.43	0.39	0.24
Tissue Yield	2.43	9.95	1.50	1.99
R ²	0.55	0.83	0.43	0.50

¹Measured at the end of the second season.

*,** Indicates significance at the 0.05, 0.01 levels of probability, respectively.

Table 2.17.2 Regressions of exchangeable Ca¹ (me 100 g⁻¹ soil) at the 15-30 cm soil depth and total plant, pod, root and tissue yields (kg ha⁻¹; dry matter) determined on four soils in the second season.

Plant Variable	SOIL TYPE			
	800	810	815	816
	----- F calculated -----			
Total Plant Yield	4.01	1.86	19.50*	1.57
R ²	0.67	0.48	0.91	0.44
Pod Yield	4.93	1.16	27.52*	1.63
R ²	0.71	0.37	0.93	0.45
Root Yield	2.86	2.59	17.99	0.76
R ²	0.59	0.56	0.90	0.47
Tissue Yield	3.79	10.44	13.18	2.38
R ²	0.65	0.84	0.86	0.54

¹Measured at the end of the second season.

*,** Indicates significance at the 0.05, 0.01 levels of probability, respectively.

4. DISCUSSION

Cowpea yield responses indicated that increasing rates of limestone and not depth of limestone placement were responsible for increasing crop growth. The increase in crop yields with added limestone (CaCO_3) was consistent with other work, in which liming of Oxisols and Ultisols in the humid tropics has resulted in higher yields of several crops, including cowpea (Abruna *et al.*, 1964, 1974a,b; Spain *et al.*, 1975; Gonzalez-Erico *et al.*, 1979; Edwards *et al.*, 1981; Friesen *et al.*, 1982). However, though crop responses to liming may be similar, yield increases may be a function of several factors including climatic effects, limestone rates, method of placement, reduction of toxic compounds such as Al, increases in exchangeable Ca, plant uptake of Ca and plant morphological responses to these factors.

Though added limestone increased plant yields on all soils in both seasons, crop yields were higher in the long rainy season (season 2) compared to yields obtained in the short rainy season (season 1), except for tissue (vegetative) yields. Higher total plant, pod and root yields were probably obtained in the long rainy season because of more ideal growing conditions (Figs. 2.1, 2.2) and/or greater effectiveness of added limestone with time on soil chemical properties. In the long rainy season, more moisture was available to the plant during early growth, and secondly, higher temperatures and reduced moisture availability later in the season stimulated flowering. Therefore, pod formation and development were enhanced. However, in the first season, less moisture was available to the plant initially and temperatures and evapo-transpiration were lower, especially during maturity. This

resulted in vining, increased vegetative (tissue) growth, reduced flowering and low pod yields. This growth pattern may also be part of the reason why added limestone had no significant effects on plant heights in the first season, but significantly increased plant heights in the second season. Thus, response of cowpea to limestone applications may be a function of stage of development, which in turn affects yield. Further discussions will focus on crop response observed in the second season.

Crop yields results indicated that optimum rates of added limestone were between 1.5 and 4.5 Mg ha⁻¹ depending on the soil type. On the Kasarama loamy sand No. 810 and Bukaruna loamy sand No. 816, a rate of 1.5 Mg ha⁻¹ of limestone was adequate, since plant yields were depressed at higher levels of applied limestone. It seems that on these two soils, the primary reasons for increased crop yields were precipitation of exchangeable Al, reduction in exchangeable acidity and increased soil pH. However, on the Bukaruna loamy sand No. 816, increased availability of Ca could have also contributed to the observed yield increases, since a significant positive relationship was observed between Ca content in tissue and plant yields. This was consistent with initial low Ca levels in the soil which were lower than those on the Kasarama loamy sand No. 810 (Table 2.1). On the Kasarama loamy sand no. 810, higher levels of limestone beyond 1.5 Mg ha⁻¹ resulted in luxury consumption of Ca since yields decreased.

On the Tabela sand No. 800 and Kairuni loamy sand No. 815, plant yield increases were observed at levels of applied limestone higher than the 1.5 Mg ha⁻¹ rate. The effects observed on the Tabela sand No. 800 and Kairuni loamy sand No. 815 may not be due to elimination of soil acidity factors, since 1.5 Mg ha⁻¹ of limestone was adequate to remove

exchangeable Al, reduce extractable acidity and increase soil pH. It seems that increased crop yields at higher limestone rates on the Tabela sand No. 800 and Kairuni loamy sand No. 815 were related to lower initial amounts of exchangeable Ca in both soils and an increase in exchangeable Ca as a result of increasing rates of added limestone. The observed plant response was consistent with low cation-exchange capacities (C.E.C.) and low initial levels of exchangeable Ca, especially at 0-15 cm soil depth. Exchangeable Ca was related to plant growth, since plant yields on both soils were positively affected by Ca concentration in tissue and soil exchangeable Ca for the most part. The yield increases occurred even though P, K and Mg contents in tissue were not significantly affected by added CaCO_3 . This was consistent with a Ca deficiency for cowpea growth on the Tabela sand No. 800 and Kairuni loamy sand No. 815.

Regardless of the differing yield responses among soils, optimum yields were obtained on all soils when exchangeable Ca in the soil ranged at, or above $0.80-1.00 \text{ me } 100\text{g}^{-1} \text{ soil}$ and Ca content in tissue reached $2.0-2.2\%$. Andrew and Norris (1961) concluded from an Australian study that on acid soils a Ca level of $1.0 \text{ me } 100\text{g}^{-1} \text{ soil}$ appears to be a minimum value for good growth of many plants. In a greenhouse study with an Ultisol of Nigeria, Edwards et al., (1981) found that several Al-tolerant and Al-sensitive cowpea cultivars produced approximately 85% of maximum growth with application of 0.5 Mg ha^{-1} of CaCO_3 and average Ca content of plant tops at harvest (six weeks) was 2.24% . However, it should be stated that concentration of Ca in plants will vary according to cultivars, stage of development and plant part sampled. Crop response differences on the Tabela sand No. 800 and Kairuni loamy sand No. 815 may be also due to competitive effects of purple nutsedge (Cyperus rotundus

L.) on the Kairuni loamy sand No. 815 and moisture limitations on the Tabela sand No. 800 with the lowest clay content. Therefore, since economic factors may preclude use of higher limestone rates on the Tabela sand No. 800 and Kairuni loamy sand No. 815 and if Ca could be applied by other means, 1.5 Mg ha^{-1} of limestone should be adequate for high cowpea yields on all soils.

Added limestone had little effect on P and Mg-tissue concentrations but caused slight decreases in K contents. These nutrients were supplied by fertilizers applied as a basal application and soil chemical data indicated no significant effects of added limestone on these nutrient levels. Edwards *et al.*, (1981) found a similar trend on a Nigerian Ultisol, except that Mg contents decreased markedly with increasing limestone rates.

Limestone placement depths did not influence crop yields in the second season probably because rainfall leached CaCO_3 and/or its dissolution products into the soil profile. Also small amounts of CaCO_3 were adequate to reduce soil acidity, precipitate exchangeable Al and increase the availability of Ca. Initially, soil chemical changes were confined to the upper soil layers, but by the end of the second season added limestone significantly affected soil chemical properties lower in the soil profile to a depth of 30-45 cm, even when limestone was applied to a depth of 30 cm. This response clearly indicated that there was significant downward movement of limestone solution products with time. Limestone placement effects observed in this experiment were not consistent with findings of Gonzalez-Erico *et al.*, (1979) who found that shallow limestone incorporation (0-15 cm) did not result in significant changes in soil chemical properties at the 15-30 cm soil depth over three successive crops on a Brazilian savannah Oxisol (49% clay). Further,

incorporation of limestone to a depth of 30 cm resulted in higher maize grain yields than when limestone was incorporated in the upper 0-15 cm soil zone. However, Ritchey et al., (1980) in a column experiment simulating field conditions (Brazilian savannah Oxisol - 49% clay) found that leaching the soil with 1200 mm of water caused movement of Ca added as CaCO_3 (0-15 cm) to a depth of 25 cm. In this study, the clay contents of the experimental soils were less than 20%. On these coarse-textured soils and with an annual precipitation of about 2000 mm, one could expect the observed phenomena of leaching of CaCO_3 and/or its reaction products into subsoil layers.

Cowpea yield responses seem to be due to increased root mass as opposed to deeper root penetration into the subsoil. Root depths were not influenced by limestone treatments probably because the dense subsoil limited root penetration. Apparently, added limestone in the upper soil layers resulted in reduction of exchangeable Al and exchangeable acidity and increased levels of exchangeable Ca, thus enhancing root development within this soil zone.

Finally, even though limestone rates should be a function of added crop value and limestone costs, 1.5 Mg ha^{-1} of limestone (CaCO_3) applied as a shallow incorporation would be adequate to effectively reduce Al toxicity and soil acidity for efficient cowpea production on these acid soils. Since limestone is imported, perhaps Ca could be more cheaply supplied by gypsum (CaSO_4) or fertilizers containing Ca.

5. CONCLUSIONS

Added limestone (CaCO_3) increased cowpea yields, regardless of limestone placement depths. Optimum crop yields were obtained with 1.5 Mg ha^{-1} of limestone on the Kasarana loamy sand No. 810 and Bukaruna loamy sand No. 816, 3.0 Mg ha^{-1} of limestone on the Tabela sand No. 800 and 4.5 Mg ha^{-1} of limestone on the Kairuni loamy sand No. 815.

Response of cowpea to liming was primarily the result of neutralization of KCl-exchangeable Al, reduction of KCl-exchangeable acidity and increased soil pH. However, yield increases on the Bukaruna loamy sand No. 816 and especially the Tabela sand No. 800 and Kairuni loamy sand No. 815 may be also due to increased availability and utilization of exchangeable Ca. On these soils, Ca should not be deficient at, or above 0.80-me of exchangeable Ca 100 g^{-1} soil.

Leaching of limestone and/or its dissolution products to lower soil depths with time and the low limestone requirements for cowpea grown on these soils, most likely resulted in the non-significant effects observed for limestone placement depths.

Higher plant yields were obtained on the Kasarana loamy sand No. 810 and Bukaruna loamy sand No. 816 as compared to yields produced on the Tabela sand No. 800 and Kairuni loamy sand No. 815. These lower yields on the latter soils were probably due to the lower C.E.C. (cation-exchange-capacity) and exchangeable Ca levels, competitive effects of purple nutsedge (Cyperus rotundus L.) on the Kairuni loamy sand No. 815 and moisture limitations (lowest clay content) on the Tabela sand No. 800.

Greater availability of moisture early in the growing season and warmer temperatures during maturity (long rainy season) resulted in

— higher cowpea yields, except for tissue yields in the second season compared to yields obtained in the first season (short rainy season).

CHAPTER III

EFFECTS OF LIMESTONE RATES AND TILLAGE

DEPTHS ON COWPEA (Vigna unguiculata L. Walp.) GROWTH AND SOIL

CHEMICAL-PHYSICAL PROPERTIES ON TWO ACID SOILS

1. INTRODUCTION

In the Intermediate Savannas of Guyana, soils are generally low in clay and low in organic matter thus, having a reduced capacity for retention of water and nutrients (Bullen et al., 1982). Chemical and physical barriers to normal root development will therefore aggravate existing problems by reducing even further the plant's capacity for absorption of water and nutrients. Al in acid soils may be responsible for limiting the normal development of plant roots (Estrada and Cummings, 1968). However, according to Foy et al., (1980) the specific causes of shallow rooting are not always easily identifiable. In some instances, both chemical and physical factors are probably involved.

Mechanical impedance of subsoil restrictive layers is related to soil physical, chemical and mineralogical properties (Stitt et al., 1982). These layers, whether pedogenic or tillage - induced significantly affect plant growth and crop yields (Ferrant and Sprague, 1940; Estrada and Cummings, 1968; McKyes et al., 1979; Raghavan et al., 1979; Foy et al., 1980; Stitt et al., 1982). According to Russell (1971) soils which tend to settle into a relatively dense mass containing few transmission pores or fissures, can be loosened by ploughing and harrowing to produce a 'tilth' of fine aggregates, between which there are ample transmission pores to allow easy root growth, seedling emergence and air movement. Ferrant and Sprague (1940), reported that tillage alone of an acid A horizon was sufficient to greatly increase the penetration of red clover roots into the B horizon. McKyes et al., (1979) concluded that subsoiling is likely to be more suitable for the loosening of deep hardpans and the promotion of deep root growth in dense subsoils. Other workers have concluded that routine tillage operations

either by conventional plowing, subsoiling or chiselling may be necessary to create favourable subsoil physical conditions for good root proliferation (Kamprath et al., 1979; Foy et al., 1980; Maurya and Lal, 1980; Agboola, 1981; Adeoye, 1982).

Thus, reasons given for reduced penetration and development of plant roots in acid Savannah subsoils include subsoil acidity and soil physical limitations as major constraints. Resolution of these problems may require studies of the interaction of limestone applications and tillage and their effects on soil chemical-physical properties and plant growth. The purpose of this experiemnt, therefore, was to evaluate the effects of added limestone and tillage depths on soil chemical-physical properties and Cowpea (Vigna unguiculata L. Walp.) growth in the Intermediate Savannahs of Guyana.

2. MATERIALS AND METHODS

2.1 SITE CHARACTERISTICS

A field study (experiment 2) was established in January, 1983 at the Ebini Crop Research Station at sites each 0.20 hectare in size (Figs. 1.1, 2.3). They were representative of the following two soils:

- 1: Tabela sand No. 800 (Typic Quartzisamment) and
- 2: Kairuni loamy sand No. 815 (Arenic Paleudult).

A detailed description of the study environment is provided in Chapter II, including chemical-physical properties of experimental soils (Table 2.1). Soil types are fully described in Appendix A.

2.2 EXPERIMENTAL DESIGN

2.2.1 Design and Treatments

At each site, there were 4 treatments (2 x 2 factorial) with 3 replications in a Randomized Complete Block Design. Limestone was applied at 2 rates (A) after 2 tillage treatments (B). The rates of limestone and tillage treatments depths were coded as follows:

1. $A_1 - 0 \text{ Mg ha}^{-1}$
 $A_2 - 3.0 \text{ Mg ha}^{-1}$ } Limestone

2. $B_1 - \text{shallow cultivation to 15 cm and}$
 $B_2 - \text{deep cultivation to 30 cm.}$

Each experimental unit was 100 m² in size (12.5 m in length and 8 m in width) and there was a 5 m pathway between each block of treatments. The two tillage treatments were carried out prior to planting of the first crop and before limestone applications. For shallow tillage, a mounted tandem disc-harrow was utilised while a conventional 5-furrow disc plow was used to perform deep cultivation. After primary tillage,

limestone was surface broadcast as required and the complete site disc-harrowed twice to 15 cm, before planting. In the second season primary and secondary tillage treatments were uniform for every plot and carried out to a depth of 15 cm.

2.2.2. Statistical Analysis

All results were analysed statistically according to procedures outlined in Steel and Torrie (1980), using S.A.S. programs (SAS Institute Inc., 1982). ANOVA (Analysis of variance) and F ratios were calculated for both plant and soil variables. Means and standard errors were determined for soil physical properties. Regression analyses were also carried out to determine the relationship of dry bulk density and mechanical impedance to plant yields.

2.3 PLOT ESTABLISHMENT AND MAINTENANCE

The same field procedures and practices previously described for Experiment 1 (Chapter II) were utilised for this study, except that rows were 12.5 m long. Limestone-tillage treatments were as described in section 2.2.1.

2.4 HARVESTING AND PLANT MEASUREMENTS

Harvesting and plant measurements were carried out using methods outlined for Experiment 1. (Chapter II).

2.5 SOIL SAMPLING

2.5.1 Chemical Properties

Soil sampling for fertility analyses was done as described for

Experiment 1. (Chapter II).

2.5.2 Physical Properties

Core samples for determination of dry bulk density (Mg m^{-3}) and water content (%) were taken at the following times:

1. pre-tillage,
2. post-tillage,
3. post-harvest, first season
4. post-harvest, second season.

Horizontal core sampling in pits was carried out at depths between:

1. 0-15 cm,
2. 15-30 cm
3. 30-45 cm.

Cores were obtained by horizontal sampling using a cylinder that had a total volume of 100 cm^3 (diameter: 4.6 cm; height: 6 cm). Soil cores were trimmed flush with cylinder after removal and immediately bagged. Wet weights were determined and then soil cores were taken to the laboratory for water content and bulk density determinations.

2.6. SOIL MEASUREMENTS

Field measurements of penetration resistance (kPa) were determined at the following times and average depths:

1. pre-tillage, post-tillage, post-harvest (first season) and post-harvest (second season).
2. 0-15, 15-30 and 30-45 cm, respectively.

These readings were taken simultaneously during core sampling for bulk density and water content determinations. Penetrometer resistance measurements were determined by using a manually-operated Proving Ring

Cone Penetrometer (Soiltest Inc., Evanston, Ill., U.S.A.) that was calibrated in the laboratory prior to use. The penetrometer had a 30 degree angle cone, a diameter of 20.5 mm and the rate of penetration was 30 mm per sec (ASAE, 1978). Field readings were then converted from dial gauge deflections to mechanical impedance (kPa) by using the calibration curve: load vs dial gauge deflection (Davidson, 1965).

2.7 LABORATORY ANALYSIS

2.7.1 Soil

2.7.1.1 Chemical Properties

For chemical determinations, samples were analysed by procedures previously described in Chapter II.

2.7.1.2 Physical Properties

Subsamples of cores were oven dried to constant weight at 105°C and dry bulk density values then calculated (Blake, 1965). Gravimetric water contents were determined by the method described by Gardner, (1965).

2.7.2 Plant Content of P, K, Ca and Mg

Tissue samples were analysed by procedures as described for Experiment 1 (Chapter II).

3. RESULTS

3.1 Cowpea Yields

3.1.1 Total Plant Yields

Added limestone had no significant effect on total plant yields on any soil in either season (Tables 3.1.1, 3.1.2, 3.1.3). Depth of tillage had a significant effect on total plant yields on both soils in the first season (Table 3.1.2). Significantly higher total plant yields were obtained with deep tillage (0-30 cm) as compared to shallow tillage (0-15 cm) in the first season (Table 3.1.1). However, in the second season tillage effects on total plant yields were non-significant on both soils (Tables 3.1.1, 3.1.3). Limestone rate-tillage depth interactions were non-significant on all soils in both seasons (Tables 3.1.2, 3.1.3). On both soils, total plant yields were higher in the second season compared to yields obtained in the first season (Table 3.1.1).

3.1.2 Pod Yields

Pod yields were not significantly affected by added limestone on any soil in both seasons, except on the Tabela sand No. 800 in the second season (Tables 3.2.1, 3.2.2, 3.2.3). In the second season liming resulted in significantly higher pod yields on the Tabela sand No. 800 compared to the treatment receiving no limestone (Table 3.2.1). Depth of tillage and limestone rate-tillage depth interactions had no significant effect on pod yields on either soil in both seasons (Tables 3.2.2, 3.2.3). On both soils, pod yields obtained in the second season were higher than first season yields (Table 3.2.1).

Table 3.1.1 Effects of limestone rates and tillage depths on total plant yields of Cowpea grown on two soils for two seasons.

Soil Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹		A mean
			B ₁	B ₂	
(AxB means)					
kg ha ⁻¹ ; dry matter					
Tabela sand No. 800	1.	0-A ₁	1130	1510	1320 a
		3.0-A ₂	1010	1530	1270 a
		B mean	1070 a	1520 b	
	2.	0-A ₁	2610	2410	2510 a
		3.0-A ₂	2940	3280	3110 a
		B mean	2780 a	2840 a	
Kairuni loamy sand No. 815	1.	0-A ₁	1580	2350	1960 a
		3.0-A ₂	1620	2180	1900 a
		B mean	1600 a	2260 b	
	2.	0-A ₁	3760	3250	3500 a
		3.0-A ₂	3980	4850	4410 a
		B mean	3870 a	4050 a	

¹B₁: 0-15 cm, B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P<0.05; F test).

Table 3.1.2. Analysis of variance of Cowpea total dry matter yields (kg ha⁻¹) determined on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	28804.00	0.47
	A ¹	1	8427.00	0.14
	B ¹	1	612008.33	10.00*
	A*B	1	14981.34	0.24
	Exp Error	6	61170.89	
	Coefficient of Variation = 19.1%			
815	Blocks (R)	2	22973.58	0.37
	A	1	12610.09	0.20
	B	1	1308780.75	21.36**
	A*B	1	32760.75	0.53
	Exp. Error	6	61263.03	
	Coefficient of Variation = 12.8%			

Table 3.1.3. Analysis of variance of Cowpea total dry matter yields (kg ha⁻¹) determined on two soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	212611.00	0.93
	A ¹	1	1093844.08	4.80
	B ¹	1	13534.08	0.06
	A*B	1	220594.09	0.97
	Exp. Error	6	228008.67	
	Coefficient of Variation = 17.0%			
815	Blocks (R)	2	515265.10	0.79
	A	1	2487941.40	3.83
	B	1	97560.40	0.15
	A*B	1	1403567.90	2.16
	Exp. Error	6	650234.97	
	Coefficient of Variation = 20.4%			

¹A - limestone rates, B - tillage depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 3.2.1 Effects of limestone rates and tillage depths on pod yields of cowpea grown on two soils for two seasons.

Soil, Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ²		A mean
			B ₁	B ₂	
(AxB means)					
kg ha ⁻¹ ; dry matter					
Tabela sand No. 800	1.	0-A ₁	400	470	430 a
		3.0-A ₂	320	410	360 a
		B mean	360 a	440 a	
	2.	0-A ₁	1570	1350	1460 a
		3.0-A ₂	1870	2100	1980 b
		B mean	1720 a	1720 a	
Kairuni loamy sand No. 815	1.	0-A ₁	480	710	600 a
		3.0-A ₂	610	680	650 a
		B mean	550 a	700 a	
	2.	0-A ₁	1930	1810	1820 a
		3.0-A ₂	1870	2000	1940 a
		B mean	1900 a	1910 a	

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05; F test).

Table 3.2.2 Analysis of variance of Cowpea pod dry matter yields (kg ha⁻¹) determined on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	28.58	0.00
	A ¹	1	13804.09	1.08
	B ¹	1	20584.09	1.61
	A*B	1	330.74	0.03
	Exp. Error	6	12781.56	
	Coefficient of Variation = 28.4%			
815	Blocks (R)	2	887.58	0.00
	A ¹	1	7500.00	0.00
	B ¹	1	66901.34	4.01
	A*B	1	20833.33	0.40
	Exp. Error	6	16672.14	
	Coefficient of Variation = 20.8%			

Table 3.2.3 Analysis of variance of Cowpea pod dry matter yields (kg ha⁻¹) determined on two soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	77042.58	0.82
	A	1	831606.75	8.94*
	B	1	80.09	0.00
	A*B	1	159390.75	1.71
	Exp. Error	6	93005.69	
	Coefficient of Variation = 17.7%			
815	Blocks (R)	2	126265.75	1.01
	A	1	13134.08	0.10
	B	1	140.08	0.00
	A*B	1	47754.09	0.38
	Exp. Error	6	124701.42	
	Coefficient of Variation = 18.5%			

¹A - limestone rates, B - tillage depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

3.1.3 Root Yields

Added limestone had no significant effect on root yields on any soil in either season (Tables 3.3.1, 3.3.2, 3.3.3). In the first season depth of tillage had a significant effect on root yields on both soils (Table 3.3.2), with deep tillage giving significantly higher root yields than the shallow tillage (Table 3.3.1). Limestone rate-tillage depth interactions had non-significant effects on root yields in both seasons on the two soils (Tables 3.3.2, 3.3.3). On both soils root yields were higher in the second season compared to yields obtained in the first season (Table 3.3.1).

3.1.4 Tissue Yields

Limestone application did not significantly affect tissue yields on any soil in both seasons, except on the Kairuni loamy soil No. 815 in the second season (Tables 3.4.1, 3.4.2, 3.4.3). On this soil, tissue yields were significantly higher with added limestone compared to the treatment receiving no limestone (Table 3.4.1). Depth of tillage had a significant effect on tissue yields in the first season on both soils (Table 3.4.2), while in the second season tillage effects were non-significant (Table 3.4.3). In the first season, deep tillage resulted in significantly higher tissue yields on both soils as compared to shallow tillage (Table 3.4.1). Limestone rate-tillage depth interactions were non-significant in both seasons on the two soils (Tables 3.4.2, 3.4.3). On both soils, tissue yields were higher in the second season compared to yields observed in the first season (Table 3.4.1).

Table 3.3.1 Effects of limestone rates and tillage depths on root yields of Cowpea grown on two soils for two seasons.

Soil Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹		A mean
			B ₁	B ₂	
(AxB means)					
kg ha ⁻¹ , dry matter					
Tabela sand No. 800	1.	0-A ₁	330	470	400 a
		3.0-A ₂	330	540	440 a
		B mean	330 a	500 b	
	2.	0-A ₁	480	470	470 a
		3.0-A ₂	480	530	510 a
		B mean	480 a	500 a	
Kairuni loamy sand No. 815	1.	0-A ₁	400	540	470 a
		3.0-A ₂	330	490	410 a
		B mean	370 a	520 b	
	2.	0-A ₁	760	600	680 a
		3.0-A ₂	800	1160	980 a
		B mean	780 a	880 a	

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05; F test).

Table 3.3.2 Analysis of variance of Cowpea root dry matter yields (kg ha⁻¹) grown on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	10002.33	1.32
	A ¹	1	4070.09	0.54
	B ¹	1	88924.09	11.76*
	A*B	1	3640.07	0.48
	Exp. Error	6	7564.35	
	Coefficient of Variation = 20.6%			
815	Blocks (R)	2	4874.33	1.41
	A ¹	1	8910.75	2.58
	B ¹	1	67050.75	19.40**
	A*B	1	494.09	0.14
	Exp. Error	6	3455.78	
	Coefficient of Variation = 13.3%			

Table 3.3.3 Analysis of variance of Cowpea root dry matter yields (kg ha⁻¹) grown on two soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	5601.08	0.74
	A	1	3536.33	0.46
	B	1	1008.34	0.13
	A*B	1	2352.00	0.31
	Exp. Error	6	7590.63	
	Coefficient of Variation = 17.7%			
815	Blocks (R)	2	71820.08	1.07
	A	1	275427.00	4.11
	B	1	28616.33	0.43
	A*B	1	202280.34	3.01
	Exp. Error	6	67003.97	
	Coefficient of Variation = 31.2%			

¹A - limestone rates; B - tillage depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 3.4.1 Effects of limestone rates and tillage depths on tissue¹ yields of Cowpea grown on two soils for two seasons.

Soil Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ²		A mean
			B ₁	B ₂	
(AxB means)					
kg ha ⁻¹ ; dry matter					
Tabela sand No. 800	1.	0-A ₁	400	570	490 a
		3.0-A ₂	360	580	470 a
		B mean	380 a	580, b	
	2.	0-A ₁	560	590	580 a
		3.0-A ₂	590	640	610 a
		B mean	570 a	610 a	
Kairuni loamy sand No. 815	1.	0-A ₁	700	1100	900 a
		3.0-A ₂	680	1040	840 a
		B mean	690 a	1050 b	
	2.	0-A ₁	980	840	910 a
		3.0-A ₂	1310	1680	1490 b
		B mean	1140 a	1260 a	

¹Above-ground portion of plant excluding pods.

²B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P<0.05; F test).

Table 3.4.2 Analysis of variance of Cowpea tissue¹ dry matter yields (kg ha⁻¹) grown on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	16393.58	0.95
	A ²	1	1386.75	0.80
	B ²	1	111979.59	6.52*
	A*B	1	5415.25	0.31
	Exp. Error	6	17186.70	
	Coefficient of Variation = 27.3%			
815	Blocks (R)	2	6636.33	0.77
	A ¹	1	10980.75	1.27
	B ²	1	391324.08	45.59**
	A*B	1	3502.09	0.41
	Exp. Error	6	8583.55	
	Coefficient of Variation = 10.6%			

Table 3.4.3 Analysis of variance of Cowpea tissue¹ dry matter yields (kg ha⁻¹) grown on two soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	22777.08	1.79
	A	1	4294.08	0.34
	B	1	4602.40	0.36
	A*B	1	184.09	0.01
	Exp. Error	6	12688.42	
	Coefficient of Variation = 18.9%			
815	Blocks (R)	2	139764.58	1.74
	A	1	1017918.75	12.68*
	B	1	41418.75	0.51
	A*B	1	196864.09	2.45
	Exp. Error	6	80277.50	
	Coefficient of Variation = 23.5%			

¹Above-ground portion of plant excluding pods.

²A - limestone rates, B - tillage depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

3.2 Root Depths

Added limestone, tillage depth and limestone rate-tillage depth interactions had no significant effects on root depths on either soil in any season (Tables 3.5.1, 3.5.2, 3.5.3). Root depths on both soils in the second season were higher than rooting depths determined in the first season (Table 3.5.1).

3.3 Plant Heights

Added limestone had no significant effect on plant heights on both soils in the first season (Tables 3.6.1, 3.6.2). In the second season, effects of added limestone were significant on the Kairuni loamy sand No. 815 (Table 3.6.3). Liming resulted in higher plant heights than the treatment receiving no limestone (Table 3.6.1). Tillage depth had no significant effect on plant height on any soil in both seasons, except on the Kairuni loamy sand No. 815 in the first season (Table 3.6.2). On this soil, deep tillage produced significantly higher plant height than shallow tillage (Table 3.6.1). Limestone rate-tillage depth interactions were non-significant on both soils in each season (Tables 3.6.2, 3.6.3).

Table 3.5.1 Effects of limestone rates and tillage depths on root depths of Cowpea grown on two soils for two seasons.

Soil Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹		A mean
			B ₁	B ₂	
			(AxB means)		
			cm		
Tabela sand No. 800	1.	0-A ₁	12.9	14.3	13.6 a
		3.0-A ₂	12.8	14.0	13.4 a
		B mean	12.8 a	14.2 a	
	2.	0-A ₁	19.6	17.1	18.3 a
		3.0-A ₂	19.7	18.3	19.0 a
		B mean	19.6 a	19.7 a	
Kairuni loamy sand No. 815	1.	0-A ₁	12.7	13.0	12.1 a
		3.0-A ₂	11.5	12.8	12.2 a
		B mean	12.1 a	12.9 a	
	2.	0-A ₁	17.3	16.6	17.0 a
		3.0-A ₂	17.9	18.4	18.1 a
		B mean	17.6 a	17.5 a	

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05; F test).

Table 3.5.2. Analysis of variance of Cowpea root depths (cm) determined on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	5.74	4.38
	A ¹	1	0.14	0.11
	B ¹	1	5.20	3.97
	A*B	1	0.01	0.01
	Exp. Error	6	1.31	
	Coefficient of Variation = 8.5%			
815	Blocks (R)	2	1.44	0.84
	A	1	1.40	0.81
	B	1	2.00	1.17
	A*B	1	0.70	0.41
	Exp. Error	6	1.71	
	Coefficient of Variation = 10.5%			

Table 3.5.3 Analysis of variance of Cowpea root depths (cm) determined on two soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	10.08	3.72
	A	1	1.55	0.57
	B	1	11.41	4.21
	A*B	1	8.10	2.99
	Exp. Error	6	2.71	
	Coefficient of Variation = 8.8%			
815	Blocks (R)	2	0.08	0.01
	A	1	4.20	0.70
	B	1	0.04	0.01
	A*B	1	1.14	0.19
	Exp. Error	6	6.02	
	Coefficient of Variation = 14.0%			

¹A - limestone rates; B - tillage depths. *, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 3.6.1 Effects of limestone rates and tillage depths on plant heights of Cowpea grown on two soils for two seasons.

Soil Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹		A mean
			B ₁	B ₂	
(AxB means)					
cm					
Tabela sand No. 800	1.	0-A ₁	15.7	17.2	16.4 a
		3.0-A ₂	13.7	19.0	16.4 a
		B mean	14.7 a	18.1 a	
	2.	0-A ₁	22.4	21.0	21.7 a
		3.0-A ₂	24.0	23.3	23.6 a
		B mean	23.2 a	22.1 a	
Kairuni loamy sand No. 815	1.	0-A ₁	22.4	26.9	24.6 a
		3.0-A ₂	23.6	26.1	24.8 a
		B mean	23.0 a	26.5 b	
	2.	0-A ₁	24.3	23.1	23.7 a
		3.0-A ₂	29.1	27.2	28.2 b
		B mean	26.7 a	25.2 a	

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05; F test).

Table 3.6.2. Analysis of variance of Cowpea plant heights (cm) determined on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	2.48	0.38
	A ¹	1	0.02	0.00
	B ¹	1	35.37	5.48
	A*B	1	10.44	1.62
	Exp. Error	6	6.45	
	Coefficient of Variation = 15.5%			
815	Blocks (R)	2	5.27	0.95
	A	1	0.10	0.02
	B	1	36.40	6.63*
	A*B	1	2.90	0.52
	Exp. Error	6	5.49	
	Coefficient of Variation = 9.5%			

Table 3.6.3. Analysis of variance of Cowpea plant heights (cm) determined on two soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	2.78	0.58
	A	1	12.21	2.57
	B	1	1.12	0.23
	A*B	1	2.04	0.43
	Exp. Error	6	4.76	
	Coefficient of Variation = 9.6%			
815	Blocks (R)	2	2.74	0.29
	A	1	59.85	6.25*
	B	1	7.36	0.76
	A*B	1	0.34	0.03
	Exp. Error	6	9.56	
	Coefficient of Variation = 11.9%			

¹A - limestone rates, B - tillage depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

3.4 Concentration of P, K, Ca and Mg in Plant Tissue

3.4.1 Phosphorus

Added limestone, tillage depth and limestone rate-tillage depth interactions had no significant effects on P content in tissue on both soils in the two seasons (Tables 3.7.1, 3.7.2, 3.7.3).

3.4.2 Potassium

Liming had no effect on K content in tissue on any soil in either season, except on the Tabela sand No. 800 in the second season (Tables 3.8.1, 3.8.2, 3.8.3), where a lower K content was observed with liming compared to the control (Table 3.8.1). Tillage depth and limestone rate-tillage depth interactions had non-significant effects on K content in tissue on both soils in each season (Tables 3.8.2, 3.8.3).

3.4.3 Calcium

Added limestone did not result in any effect on Ca content in tissue in the first season on both soils, but did result in significant effects in the second season (Tables 3.9.1, 3.9.2, 3.9.3). In the second season, treatments receiving no limestone resulted in lower Ca contents in tissue than limed treatments on both soils (Table 3.9.1). Tillage depth and limestone rate-tillage depth interactions had no effect on Ca content in tissue on either soil in both seasons (Tables 3.9.2, 3.9.3).

3.4.4 Magnesium

Added limestone, tillage depth and limestone rate-tillage depth interactions had no effects on Mg content in tissue on both soils in either season (Tables 3.10.1, 3.10.2, 3.10.3).

Table 3.7.1

Effects of limestone rates and tillage depths on percent phosphorus in cowpea¹ grown on two soils for two seasons.

Soil Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ²		A mean
			B ₁ (AxB means)	B ₂	
%					
Tabela sand No. 800	1.	0-A ₁	0.25	0.26	0.25 a
		3.0-A ₂	0.25	0.23	0.24 a
		B mean	0.25 a	0.24 a	
	2.	0-A ₁	0.13	0.13	0.13 a
		3.0-A ₂	0.13	0.14	0.13 a
		B mean	0.13 a	0.13 a	
Kairuni loamy sand No. 815	1.	0-A ₁	0.27	0.26	0.26 a
		3.0-A ₂	0.27	0.28	0.27 a
		B mean	0.27 a	0.27 a	
	2.	0-A ₁	0.22	0.14	0.18 a
		3.0-A ₂	0.20	0.19	0.19 a
		B mean	0.21 a	0.16 a	

¹Above-ground portion of plant excluding pods (sampled at harvest).

²B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P<0.05; F test).

Table 3.7.2 Analysis of variance of percent phosphorus in Cowpea¹ grown on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.0006	1.29
	A ²	1	0.0003	0.32
	B ²	1	0.0001	0.06
	A*B	1	0.0008	0.91
	Exp. Error	6	0.0009	
	Coefficient of Variation = 12.4%			
815	Blocks (R)	2	0.0050	5.28*
	A	1	0.0002	0.22
	B	1	0.0000	0.04
	A*B	1	0.0003	0.31
	Exp. Error	6	0.0009	
	Coefficient of Variation = 11.4%			

Table 3.7.3. Analysis of variance of percent phosphorus in Cowpea¹ grown on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.000008	0.08
	A	1	0.000003	0.01
	B	1	0.000033	0.16
	A*B	1	0.000085	0.42
	Exp. Error	6	0.000205	
	Coefficient of Variation = 10.8%			
815	Blocks (R)	2	0.0044	9.49*
	A	1	0.0001	0.20
	B	1	0.0012	2.55
	A*B	1	0.0001	0.14
	Exp. Error	6	0.0005	
	Coefficient of Variation = 10.9%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates, B - tillage depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 3.8.1

Effects of limestone rates and tillage depths on percent potassium in Cowpea¹ grown on two soils for two seasons.

Soil Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ²		A mean
			~~B₁~~	B ₂	
			(AxB means)		
Tabela sand No. 800	1.	0-A ₁	3.25	3.20	3.22 a
		3.0-A ₂	2.93	3.07	3.00 a
		B mean	3.09 a	3.13 a	
	2.	0-A ₁	2.99	3.04	3.01 a
		3.0-A ₂	2.56	2.11	2.33 b
		B mean	2.77 a	2.57 a	
Kairuni loamy sand No. 815	1.	0-A ₁	4.47	5.40	4.93 a
		3.0-A ₂	4.60	4.07	4.33 a
		B mean	4.53 a	4.73 a	
	2.	0-A ₁	2.75	2.93	2.84 a
		3.0-A ₂	2.83	2.91	2.87 a
		B mean	2.79 a	2.92 a	

¹Above-ground portion of plant excluding pods.²B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05, F test).

Table 3.8.2 Analysis of variance of percent potassium in Cowpea¹ grown on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.10	3.47
	A ²	1	0.15	2.74
	B ²	1	0.01	0.09
	A*B	6	0.03	0.46
	Exp. Error	6	0.06	
	Coefficient of Variation 7.6%			
815	Blocks (R)	2	0.71	1.07
	A	1	1.08	1.51
	B	1	0.12	0.17
	A*B	1	1.61	2.26
	Exp. Error	6	0.71	
	Coefficient of Variation 18.2%			

Table 3.8.3 Analysis of variance of percent potassium in Cowpea¹ grown on two soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.12	1.53
	A	3	1.38	8.49*
	B	2	0.12	0.73
	A*B	6	0.19	1.18
	Exp. Error	6	0.16	
	Coefficient of Variation = 15.1%			
815	Blocks (R)	2	0.330	1.78
	A	1	0.002	0.01
	B	1	0.053	0.28
	A*B	1	0.008	0.04
	Exp. Error	6	0.190	
	Coefficient of Variation = 15.3%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates, B - tillage depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 3.9.1 **Effects of limestone rates and tillage depths on percent calcium in Cowpea¹ grown on two soils for two seasons.**

Soil Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ²		A mean
			B ₁	B ₂	
			(AxB means)		
			%		
Tabela sand No. 800	1.	O-A ₁	2.31	2.08	2.19 a
		3.0-A ₂	2.12	2.82	2.47 a
		B mean	2.21 a	2.45 a	
	2.	O-A ₁	1.86	1.49	1.67 a
		3.0-A ₂	2.27	2.62	2.44 b
		B mean	2.06 a	2.05 a	
Kairuni loamy sand No. 815	1.	O-A ₁	2.42	2.52	2.47
		3.0-A ₂	2.94	2.48	2.71
		B mean	2.68 a	2.50 a	
	2.	O-A ₁	1.72	1.71	1.71 a
		3.0-A ₂	2.55	2.64	2.59 b
		B mean	2.13 a	2.17 a	

¹Above-ground portion of plant excluding pods. $^2B_1: 0-15 \text{ cm. } B_2: 0-30 \text{ cm.}$

Means followed by the same letter are not significantly different ($P \leq 0.05$; F test).

Table 3.9.2 Analysis of variance of percent calcium in Cowpea¹ grown on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.0323	0.31
	A ²	1	0.2214	1.06
	B ²	1	0.1610	0.77
	A*B	1	0.6394	3.05
	Exp. Error	6	0.2098	
	Coefficient of Variation = 19.6%			
815	Blocks (R)	2	0.2689	0.91
	A	1	0.1728	0.59
	B	1	0.0972	0.33
	A*B	1	0.2352	0.80
	Exp. Error	6	0.2942	
	Coefficient of Variation = 20.9%			

Table 3.9.3 Analysis of variance of percent calcium in Cowpea¹ grown on two soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.1547	2.78
	A	1	1.7556	15.75**
	B	1	0.0004	0.00
	A*B	1	0.3924	3.52
	Exp. Error	6	0.1114	
	Coefficient of Variation = 16.2%			
815	Blocks (R)	2	0.1255	1.01
	A	1	2.3408	18.90**
	B	1	0.0040	0.03
	A*B	1	0.0085	0.07
	Exp. Error	6	0.1238	
	Coefficient of Variation = 16.3%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates, B - tillage depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

Table 3.10.1 Effects on limestone rates and tillage depths on percent magnesium in Cowpea¹ grown on two soils for two seasons.

Soil Type	Season	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ²		A mean
			B ₁ (AxB means)	B ₂	
%					
Tabela sand No. 800	1.	0-A ₁	0.30	0.45	0.37 a
		3.0-A ₂	0.26	0.33	0.29 a
		B mean	0.28 a	0.39 a	
	2.	0-A ₁	0.23	0.24	0.23 a
		3.0-A ₂	0.22	0.22	0.22 a
		B mean	0.22 a	0.23 a	
Kairuni loamy sand No. 815	1.	0-A ₁	0.48	0.60	0.54 a
		3.0-A ₂	0.44	0.44	0.44 a
		B mean	0.46 a	0.52 a	
	2.	0-A ₁	0.20	0.24	0.22 a
		3.0-A ₂	0.15	0.18	0.16 a
		B mean	0.17 a	0.21 a	

¹Above-ground portion of plant excluding pods.

²B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05; F test).

Table 3.10.2 Analysis of variance of percent magnesium in Cowpea¹ grown on two soils in the first season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.0003	0.08
	A ²	1	0.0171	2.14
	B ²	1	0.0371	4.63
	A*B	1	0.0052	0.66
	Exp. Error	6	0.0080	
	Coefficient of Variation = 26.7%			
815	Blocks (R)	2	0.0118	0.43
	A	1	0.0325	1.19
	B	1	0.0123	0.45
	A*B	1	0.0107	0.39
	Exp. Error	6	0.0274	
	Coefficient of Variation = 33.7%			

Table 3.10.3 Analysis of variance of percent magnesium in Cowpea¹ grown on two soils in the second season.

Soil Type	Source	df	MS	F calculated
800	Blocks (R)	2	0.0020	1.38
	A	1	0.0007	0.26
	B	1	0.0003	0.10
	A*B	1	0.0002	0.08
	Exp. Error	6	0.0030	
	Coefficient of Variation = 24.2%			
815	Blocks (R)	2	0.0007	0.11
	A	1	0.0086	1.36
	B	1	0.0032	0.51
	A*B	1	0.0000	0.00
	Exp. Error	6	0.0063	
	Coefficient of Variation = 41.6%			

¹Above-ground portion of plant excluding pods (sampled at harvest).

²A - limestone rates; B - tillage depths.

*, ** Indicates significance at the 0.05, 0.01 probability levels, respectively.

3.5 Soil Chemical Properties

3.5.1 Soil pH

Soil pH at the end of the first season was not significantly affected by limestone rate, tillage depth and limestone rate-tillage depth interactions on any soil at each soil depth (Tables 3.11.1, 3.11.2). In the second season, tillage depth and limestone rate-tillage depth interactions resulted in non-significant effects on soil pH at each soil depth, whereas limestone rate had a significant effect on soil pH on both soils at the three soil depths (Table 3.11.3). An exception was found on the Tabela sand No. 800 at the 30-45 cm soil depth where a non-significant effect was observed. In all cases where significance was observed, added limestone resulted in higher soil pH values than the no limestone treatment (Table 3.11.3).

3.5.2 Exchangeable Acidity

Liming had no significant effect on exchangeable acidity at the end of the first season at all soil depths on both soils, except at the 0-15 cm soil depth on the Kairuni loamy sand No. 815 (Tables 3.12.1, 3.12.2). Exchangeable acidity was significantly reduced by limestone on this soil at the 0-15 cm soil depth (Table 3.12.1). At the end of the second season, exchangeable acidity was significantly decreased by added limestone on the Tabela sand No. 800 at the 0-15 cm and 15-30 cm soil depths, and at the 30-45 cm soil depth on the Kairuni loamy sand No. 815 (Tables 3.12.3, 3.12.4). The effects of tillage depth and limestone rate-tillage depth interactions were non-significant for both soils at each soil depth (Table 3.12.4).

Table 3.11.1 Effects on limestone rates and tillage depths on soil pH on two soils at the end of the first season.

Soil Type	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹		A mean
			B ₁ (AxB means)	B ₂	
Tabela sand No. 800	0-15	0 - A ₁	4.65	5.01	4.83 a
		3.0 - A ₂	5.46	5.10	5.28 a
		B mean	5.05 a	5.05 a	
	15-30	0 - A ₁	4.40	4.31	4.36 a
		3.0 - A ₂	4.28	4.48	4.38 a
		B mean	4.34 a	4.39 a	
	30-45	0 - A ₁	4.18	4.23	4.21 a
		3.0 - A ₂	4.21	4.27	4.24 a
		B mean	4.19 a	4.25 a	
Kairuni loamy sand No. 815	0-15	0 - A ₁	4.31	4.70	4.50 a
		3.0 - A ₂	5.48	5.26	5.37 a
		B mean	4.89 a	4.98 a	
	15-30	0 - A ₁	3.98	4.04	4.01 a
		3.0 - A ₂	4.13	4.17	4.15 a
		B mean	4.05 a	4.10 a	
	30-45	0 - A ₁	4.11	4.07	4.09 a
		3.0 - A ₂	4.30	4.17	4.23 a
		B mean	4.20 a	4.12 a	

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P<0.05; F test).

Table 3.11.2 Analysis of variance of soil pH at three soil depths on two soils at the end of the first season.

Soil Depth (cm)	Source	df	SOIL TYPE	
			800	815
			MEAN SQUARES	
0-15	Blocks(R)	2	0.02	0.85
	A ¹	1	0.60	2.26
	B ¹	1	0.00	0.02
	A*B	1	0.39	0.28
	Exp. Error	6	0.12	0.61
Coefficient of Variation (%)			6.8	15.9
15-30	Blocks(R)	2	0.02	0.01
	A	1	0.00	0.06
	B	1	0.01	0.01
	A*B	1	0.06	0.00
	Exp. Error	6	0.01	0.02
Coefficient of Variation (%)			2.7	3.5
30-45	Blocks(R)	2	0.00	0.13
	A	1	0.00	0.06
	B	1	0.01	0.02
	A*B	1	0.00	0.01
	Exp. Error	6	0.01	0.01
Coefficient of Variation (%)			1.9	2.0

¹A: limestone rates, B: tillage depths.

*_a** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 3.11.3 Effects on limestone rates and tillage depths on soil pH on two soils at the end of the second season.

Soil Type	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ²		A mean
			B ₁	B ₂	
(AxB means)					
Tabela sand No. 800	0-15	0 - A ₁	4.99	4.83	4.91 a
		3.0 - A ₂	5.91	6.00	5.96 b
		B mean	5.45 a	5.41 a	
	15-30	0 - A ₁	5.01	4.91	4.96 a
		3.0 - A ₂	5.48	5.27	5.37 b
		B mean	5.24 a	5.09 a	
	30-45	0 - A ₁	4.88	4.89	4.88 a
		3.0 - A ₂	5.12	4.74	4.93 a
		B mean	5.00 a	4.81 a	
Kairuni loamy sand No. 815	0-15	0 - A ₁	4.99	4.89	4.94 a
		3.0 - A ₂	5.71	5.84	5.77 b
		B mean	5.35 a	5.36 a	
	15-30	0 - A ₁	4.87	4.77	4.82 a
		3.0 - A ₂	5.18	5.47	5.33 b
		B mean	5.03 a	5.12 a	
	30-45	0 - A ₁	4.51	4.55	4.53 a
		3.0 - A ₂	4.97	4.85	4.91 a
		B mean	4.74 a	4.70 a	

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05, F test).

Table 3.11.4. Analysis of Variance of soil pH at three soil depths on two soils at the end of the second season.

SOIL TYPE				
Soil Depth (cm)	Source	df	800 MEAN SQUARES	815
0-15	Blocks(R)	2	0.03	0.45
	A ¹	1	3.31**	2.07**
	B ¹	1	0.01	0.00
	A*B	1	0.05	0.04
	Exp. Error	6	0.21	0.12
	Coefficient of Variation (%)		8.4	6.5
15-30	Blocks(R)	2	0.04	0.05
	A	1	0.52*	0.76*
	B	1	0.07	0.03
	A*B	1	0.01	0.11
	Exp. Error	6	0.08	0.07
	Coefficient of Variation (%)		5.5	5.1
30-45	Blocks(R)	2	0.04	0.04*
	A	1	0.01	0.44**
	B	1	0.10	0.01
	A*B	1	0.11	0.02
	Exp. Error	6	0.09	0.01
	Coefficient of Variation (%)		6.3	1.5

¹A: limestone rates; B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 3.12.1

Effects of limestone rates and tillage depths on exchangeable acidity on two soils at the end of the first season.

Soil Type	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹ B ₁ B ₂ (AxB means)	A mean	
me 100 g ⁻¹ soil					
Tabela sand No. 800	0-15	0 - A ₁	0.33	0.27	0.30 a
		3.0 - A ₂	0.13	0.27	0.20 a
		B mean	0.23 a	0.27 a	
	15-30	0 - A ₁	0.37	0.43	0.40 a
		3.0 - A ₂	0.40	0.43	0.42 a
		B mean	0.38 a	0.43 a	
	30-45	0 - A ₁	0.53	0.57	0.55 a
		3.0 - A ₂	0.50	0.50	0.50 a
		B mean	0.52 a	0.53 a	
Kairuni loamy sand No. 815	0-15	0 - A ₁	0.58	0.73	0.65 a
		3.0 - A ₂	0.07	0.30	0.18 b
		B mean	0.32 a	0.52 a	
	15-30	0 - A ₁	0.83	0.70	0.77 a
		3.0 - A ₂	0.83	0.73	0.78 a
		B mean	0.83 a	0.72 a	
	30-45	0 - A ₁	0.87	0.80	0.83 a
		3.0 - A ₂	0.47	0.83	0.65 a
		B mean	0.67 a	0.82 a	

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05; F test).

Table 3.12.2 Analysis of variance of exchangeable acidity at three soils depths on two soils at the end of the first season.

			SOIL TYPE	
Soil Depth (cm)	Source	df	800	815
			MEAN SQUARES	
0-15	Blocks(R)	2	0.01	0.04
	A ¹	1	0.03	0.67*
	B ¹	1	0.00	0.11
	A*B	1	0.03	0.00
	Exp. Error	6	0.01	0.08
	Coefficient of Variation (%)		43.7	69.0
15-30	Blocks(R)	2	0.02	0.06
	A	1	0.00	0.00
	B	1	0.01	0.04
	A*B	1	0.00	0.00
	Exp. Error	6	0.01	0.01
	Coefficient of Variation (%)		18.2	15.3
30-45	Blocks(R)	2	0.00	0.04
	A	1	0.01	0.10
	B	1	0.00	0.07
	A*B	1	0.00	0.14
	Exp. Error	6	0.02	0.05
	Coefficient of Variation (%)		32.4	31.0

¹A: limestone rates; B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 3.12.3 Effects on limestone rates and tillage depths on exchangeable acidity on two soils at the end of the second season.

Soil Type	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹		A mean	
			B ₁	B ₂		
(AxB means)						
me 100 g ⁻¹ soil						
Tabela sand No. 800	0-15	0 - A ₁	0.33	0.40	0.37 a	
		3.0 - A ₂	0.10	0.00	0.05 b	
		B mean	0.22 a	0.20 a		
	15-30	0 - A ₁	0.22	0.33	0.27 a	
		3.0 - A ₂	0.13	0.07	0.10 b	
		B mean	0.17 a	0.20 a		
	30-45	0 - A ₁	0.43	0.43	0.43 a	
		3.0 - A ₂	0.23	0.43	0.33 a	
		B mean	0.33 a	0.43 a		
	Kairuni loamy sand No. 815	0-15	0 - A ₁	1.12	0.76	0.96 a
			3.0 - A ₂	1.03	0.57	0.80 a
			B mean	1.10 a	0.67 a	
15-30		0 - A ₁	1.43	1.10	1.26 a	
		3.0 - A ₂	1.13	0.73	0.93 a	
		B mean	1.28 a	0.92 a		
30-45		0 - A ₁	1.77	1.60	1.68 a	
		3.0 - A ₂	0.83	0.93	0.88 b	
		B mean	1.30 a	1.27 a		

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05; F test).

Table 3.12.4. Analysis of variance of exchangeable acidity at three soil depths on two soils at the end of the second season.

SOIL TYPE				
Soil Depth (cm)	Source	df	800 MEAN SQUARES	815
0-15	Blocks(R)	2	0.001	0.57
	A ¹	1	0.301**	0.08
	B ¹	1	0.001	0.56
	A*B	1	0.021	0.00
	Exp. Error	6	0.017	0.29
	Coefficient of Variation (%)		63.5	61.3
15-30	Blocks(R)	2	0.004	1.01*
	A	1	0.092*	0.33
	B	1	0.002	0.40
	A*B	1	0.025	0.00
	Exp. Error	6	0.012	0.17
	Coefficient of Variation (%)		58.8	37.9
30-45	Blocks(R)	2	0.02	1.57**
	A	1	0.03	0.92**
	B	1	0.03	0.00
	A*B	1	0.03	0.05
	Exp. Error	6	0.03	0.08
	Coefficient of Variation (%)		45.8	22.7

¹A: limestone rates; B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

3.5.3 Exchangeable Calcium

There were no significant effects of added limestone on exchangeable Ca at the end of the first season at all soil depths for both soils (Tables 3.13.1, 3.13.2). Exchangeable Ca levels were not significantly affected by tillage depth and limestone rate-tillage depth interactions on either soil at all soil depths (Table 3.13.2). Added limestone significantly affected exchangeable Ca levels on both soils at the end of the second season at all soil depths, except on the Tabela sand No. 800 at the 15-30 cm and 30-45 cm soil depths (Table 3.13.4). In all cases exchangeable Ca levels were significantly increased by liming compared to no limestone additions (Table 3.13.3). At the end of the second season tillage depth and limestone rate-tillage depth interactions had no significant effects on exchangeable Ca levels at each soil depth on both soils (Table 3.13.4).

3.5.4 Extractable Phosphorus, Exchangeable Potassium and Magnesium

In general P, K and Mg levels in the soil were not affected significantly by treatment variables at neither sampling period. Probability tables and limestone rate means for these soil chemical variables are presented in appendices E and F, respectively.

Table 3.13.1 Effects on limestone rates and tillage depths on exchangeable Ca on two soils at the end of the first season.

Soil Type	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹		A mean
			B ₁	B ₂	
(AxB means)					
me 100 g ⁻¹ soil					
Tabela sand No. 800	0-15	0 - A ₁	0.41	0.54	0.47 a
		3.0 - A ₂	0.85	0.85	0.85 a
		B mean	0.63	0.69	
	15-30	0 - A ₁	0.39	0.43	0.40 a
		3.0 - A ₂	0.40	0.43	0.42 a
		B mean	0.38	0.43	
	30-45	0 - A ₁	0.25	0.17	0.21 a
		3.0 - A ₂	0.19	0.19	0.19 a
		B mean	0.22	0.18	
Kairuni loamy sand No. 815	0-15	0 - A ₁	0.17	0.11	0.14 a
		3.0 - A ₂	0.25	0.22	0.23 a
		B mean	0.21	0.17	
	15-30	0 - A ₁	0.06	0.12	0.09 a
		3.0 - A ₂	0.08	0.18	0.13 a
		B mean	0.07	0.15	
	30-45	0 - A ₁	0.05	0.07	0.06 a
		3.0 - A ₂	0.06	0.27	0.17 a
		B mean	0.06	0.17	

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P≤0.05; F test).

Table 3.13.2. Analysis of variance of exchangeable Ca at three soil depths on two soils at the end of the first season.

SOIL TYPE				
Soil Depth (cm)	Source	df	800	815
			MEAN SQUARES	
0-15	Blocks(R)	2	0.18	0.25
	A ¹	1	0.42	0.02
	B ¹	1	0.01	0.00
	A*B	1	0.01	0.00
	Exp. Error	6	0.12	0.01
	Coefficient of Variation (%)		52.5	55.9
15-30	Blocks(R)	2	0.05	0.06**
	A	1	0.00	0.00
	B	1	0.03	0.02
	A*B	1	0.00	0.00
	Exp. Error	6	0.02	0.00
	Coefficient of Variation (%)		44.0	47.6
30-45	Blocks(R)	2	0.01	0.11
	A	1	0.00	0.03
	B	1	0.00	0.04
	A*B	1	0.00	0.03
	Exp. Error	6	0.01	0.03
	Coefficient of Variation (%)		37.5	159.9

¹A: limestone rates; B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 3.13.3 Effects of limestone rates and tillage depths on exchangeable Ca on two soils at the end of the second season.

Soil Type	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹		A mean	
			B ₁ (AxB means)	B ₂		
me 100 g ⁻¹ soil						
Tabela sand No. 800	0-15	0 - A ₁	0.32	0.28	0.30 a	
		3.0 - A ₂	0.74	1.44	1.09 b	
		B mean	0.53 a	0.86 a		
	15-30	0 - A ₁	0.43	0.32	0.37 a	
		3.0 - A ₂	0.56	0.92	0.74 a	
		B mean	0.49 a	0.62 a		
	30-45	0 - A ₁	0.42	0.42	0.42 a	
		3.0 - A ₂	0.39	0.28	0.34 a	
		B mean	0.41 a	0.35 a		
	Kairuni loamy sand No. 815	0-15	0 - A ₁	0.17	0.28	0.23 a
			3.0 - A ₂	1.27	1.06	1.17 b
			B mean	0.72 a	0.67 a	
15-30		0 - A ₁	0.18	0.24	0.21 a	
		3.0 - A ₂	0.92	0.71	0.82 b	
		B mean	0.55 a	0.47 a		
30-45		0 - A ₁	0.25	0.11	0.18 a	
		3.0 - A ₂	0.39	0.35	0.37 b	
		B mean	0.32 a	0.23 a		

¹B₁: 0-15 cm; B₂: 0-30 cm.

Means followed by the same letter are not significantly different (P<0.05, F test).

Table 3.13.4 Analysis of variance of exchangeable Ca at three soil depths on two soils at the end of the second season.

Soil/Depth (cm)	Source	df	SOIL TYPE	
			800	815
			MEAN SQUARES	
0-15	Blocks(R)	2	0.03	0.16
	A ¹	1	1.89*	2.63*
	B ¹	1	0.33	0.01
	A*B	1	0.41	0.07
	Exp. Error	6	0.16	0.06
	Coefficient of Variation (%)		57.5	35.6
15-30	Blocks(R)	2	0.16	0.01
	A	1	0.41	1.11**
	B	1	0.04	0.02
	A*B	1	0.16	0.06
	Exp. Error	6	0.18	0.02
	Coefficient of Variation (%)		77.2	27.5
30-45	Blocks(R)	2	0.06	0.00
	A	1	0.02	0.11*
	B	1	0.01	0.02
	A*B	1	0.01	0.01
	Exp. Error	6	0.04	0.02
	Coefficient of Variation (%)		50.3	49.4

¹A: limestone rates; B: tillage depths.

* ** Indicates the F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

3.6 Soil Physical Properties

3.6.1 Bulk Density

Post-harvest bulk densities at all soil depths were not significantly affected by limestone rate, tillage depth or their interactions on any soil in both seasons (Tables 3.14.1, 3.14.2). However, bulk densities (measured after tillage treatments) at the 0-15 cm soil depth were significantly lowered by deep plowing on the Kairuni loamy sand No. 815 (Fig. 3.1.2, Table 3.14.3). At the 15-30 cm soil depth though, deep tillage resulted in higher bulk densities than shallow cultivation on both soils, with the effects being significant on the Kairuni loamy sand No.815, while at the 30-45 cm soil depth, tillage effects were non-significant on the two soils (Fig. 3.1.1, 3.1.2, Table 3.14.3). Also, bulk densities tended to increase with time on the Kairuni loamy sand No. 815, especially at the 0-15 cm soil depth (Fig. 3.1.2) and at all soil depths on the Tabela sand No. 810 (Fig. 3.1.1), regardless of tillage depths.

Table 3.14.1 Analysis of variance of dry bulk density (Mg m^{-3}) at three soil depths on two soils at the end of the first season.

SOIL TYPE				
Soil Depth (cm)	Source	df	800 MEAN SQUARES	815
0-15	Blocks(R)	2	0.0050	0.0072
	A ¹	1	0.0008	0.0040
	B ¹	1	0.0005	0.0001
	A*B	1	0.0027	0.0005
	Exp. Error	6	0.0078	0.0216
	Coefficient of Variation (%)		5.8	10.4
15-30	Blocks(R)	2	0.0012	0.0052
	A	1	0.0016	0.0003
	B	1	0.0065	0.0048
	A*B	1	0.0003	0.0033
	Exp. Error	6	0.0022	0.0042
	Coefficient of Variation (%)		3.1	4.4
30-45	Blocks(R)	2	0.0019	0.0045
	A	1	0.0001	0.0033
	B	1	0.0016	0.0027
	A*B	1	0.0000	0.0000
	Exp. Error	6	0.0015	0.0040
	Coefficient of Variation (%)		2.7	4.3

¹A: limestone rates; B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 3.14.2 Analysis of variance of dry bulk density (Mg m^{-3}) at three soil depths on two soils at the end of the second season.

SOIL TYPE				
Soil Depth (cm)	Source	df	800	815
			MEAN SQUARES	
0-15	Blocks(R)	2	0.0022	0.0112
	A ¹	1	0.0008	0.0014
	B ¹	1	0.0005	0.0007
	A*B	1	0.0027	0.0127
	Exp. Error	6	0.0078	0.0134
	Coefficient of Variation (%)		5.8	7.1
15-30	Blocks(R)	2	0.0093	0.0068
	A	1	0.0001	0.0574
	B	1	0.0003	0.0010
	A*B	1	0.0005	0.0014
	Exp. Error	6	0.0039	0.0108
	Coefficient of Variation (%)		3.7	6.8
30-45	Blocks(R)	2	0.0086	0.0361
	A	1	0.0120	0.0033
	B	1	0.0012	0.0027
	A*B	1	0.0120	0.0208
	Exp. Error	6	0.0095	0.0028
	Coefficient of Variation (%)		6.0	3.6

¹A: limestone rates; B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

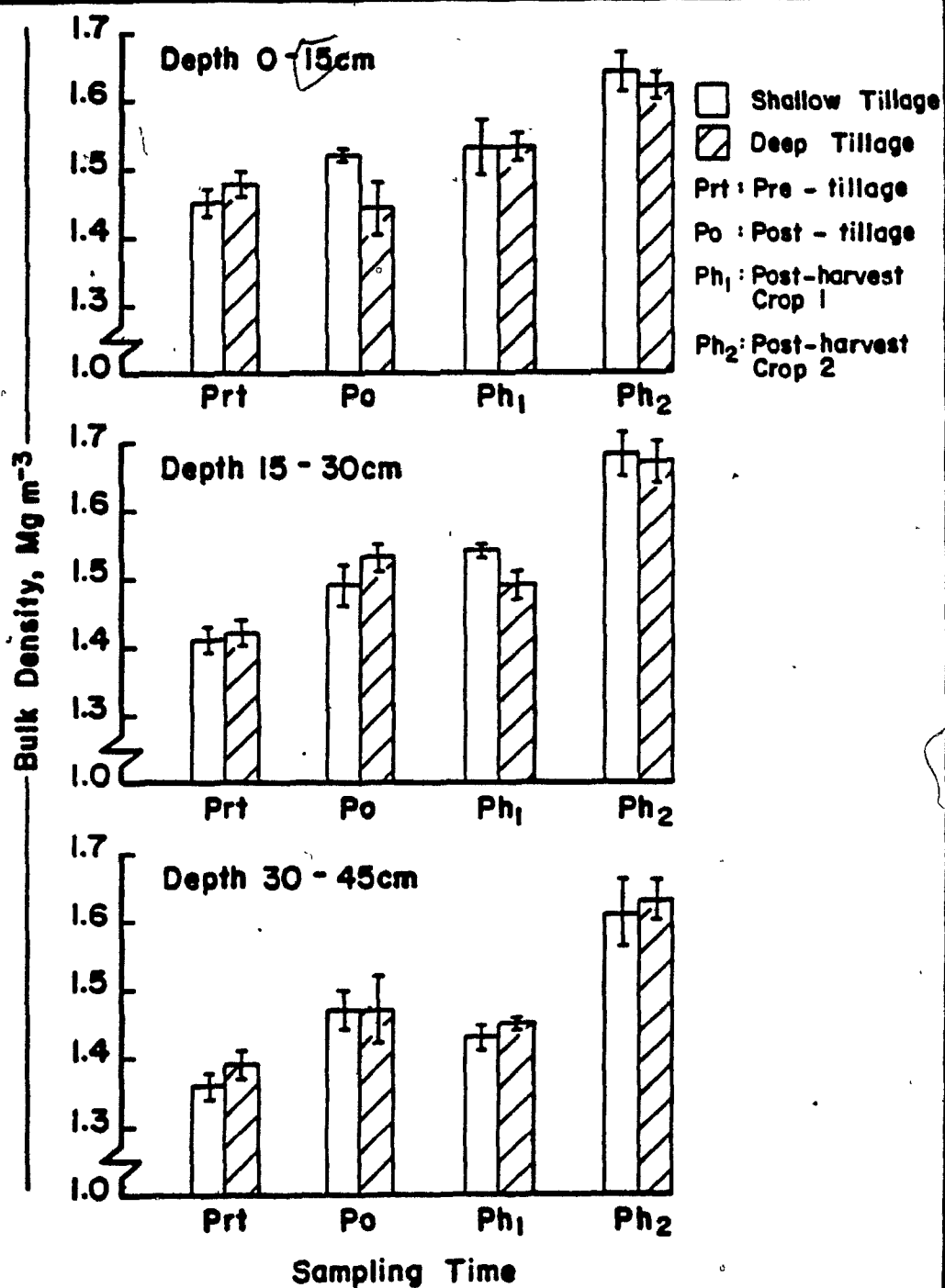


FIG. 3.1.1 Tillage effects on dry bulk density means at three soil depths on the Tabela sand No. 800.

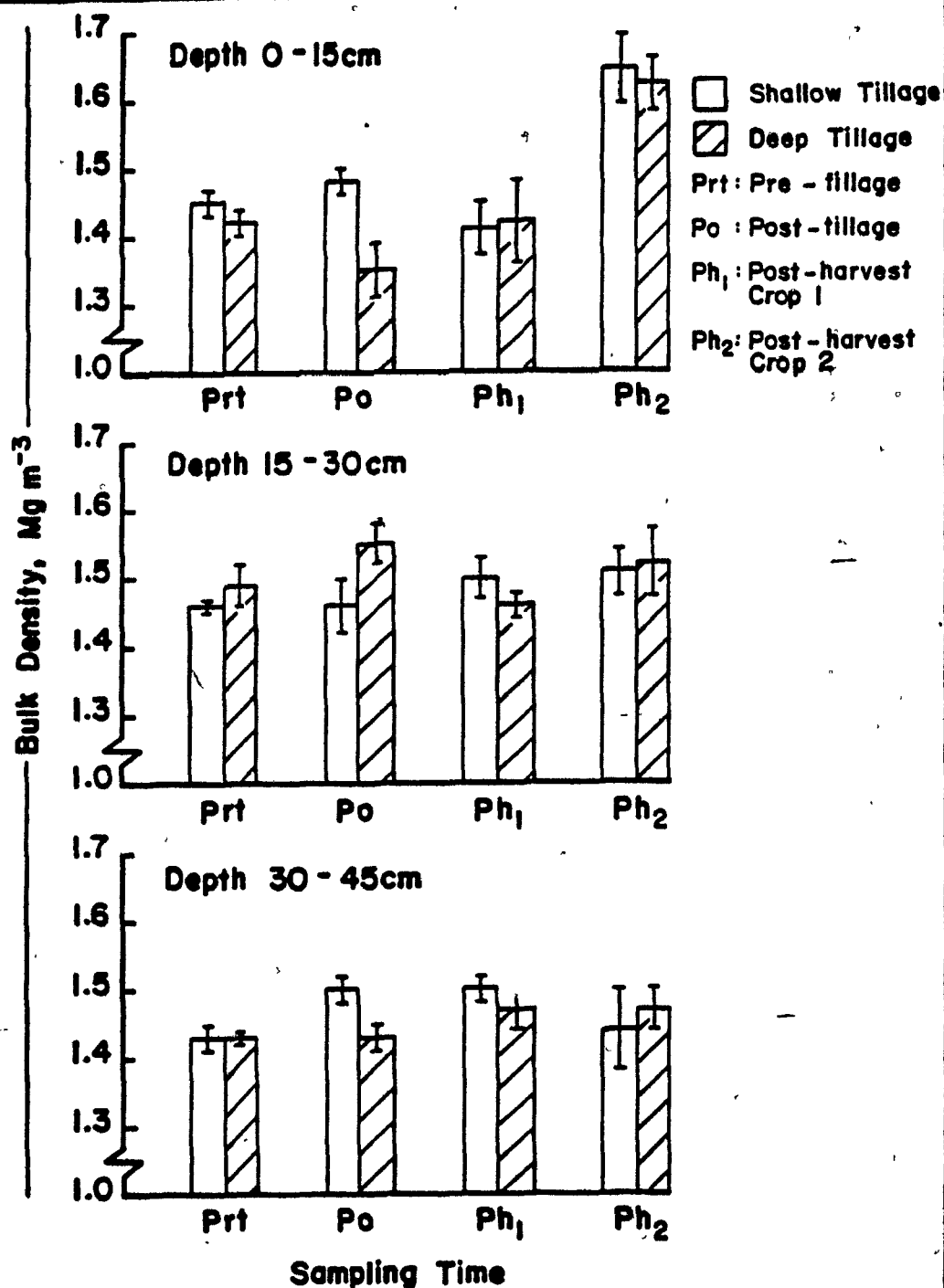


FIG. 3.1.2 Tillage effects on dry bulk density means at three soil depths on the Kairuni loamy sand No. 815.

Table 3.14.3 Analysis of variance of dry bulk density (Mg m^{-3}) at three soil depths on two soils at the end of tillage.

SOIL TYPE				
Soil Depth	Source (cm)	df	800 + MEAN SQUARES	815
0-15	Blocks(R)	2	0.0090	0.0056
	B ¹	1	0.0208	0.0560*
	Exp. Error	6	0.0036	0.0052
	Coefficient of Variation (%)		4.0	5.1
15-30	Blocks(R)	2	0.0052	0.0052
	B	1	0.0065	0.0271*
	Exp. Error	6	0.0036	0.0032
	Coefficient of Variation (%)		3.9	3.7
30-45	Blocks(R)	2	0.0025	0.0041
	B	1	0.0001	0.0161
	Exp. Error	6	0.0072	0.0036
	Coefficient of Variation (%)		5.8	4.1

¹B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

3.6.2 Mechanical Impedance and Water Content

Mechanical impedance and water content were not significantly affected by treatment main effects and their interactions in any soil depth at the two post-harvest sampling periods. An exception was found in that interaction effects (0-15 cm soil depth) for both variables were significant on the Tabela sand No. 800 at the second season post-harvest sampling period (Tables 3.15.1, 3.15.2, 3.16.1, 3.16.2). On this soil, mechanical impedance and moisture content were higher with deep tillage when no limestone was applied, while with added limestone shallow tillage resulted in increased moisture content and mechanical impedance (Table 3.17).

Both tillage treatments significantly reduced mechanical impedance (measured after cultivation) on the two soils at the 0-15 cm soil depth. However, at the 15-30 cm soil depth deep plowing caused a significant decrease in mechanical impedance as compared to shallow cultivation, while differences at the 30-45 cm soil depth were non-significant (Figs. 3.2.1, 3.2.2, 3.2.3, Table 3.15.3). Moisture contents were unaffected by tillage treatments on both soils at all three soil depths (Figs. 3.2.1, 3.2.2, 3.2.3, Table 3.15.3). In general, while water content decreased with time, mechanical impedance tended to increase, regardless of tillage depths, soil type and soil depths (Figs. 3.2.1, 3.2.2, 3.2.3).

Table 3.15.1 Analysis of variance of mechanical impedance (kPa) at three soil depths on two soils at the end of the first season.

SOIL TYPE				
Soil Depth	Source (cm)	df	800 MEAN SQUARES	815
0-15	Blocks(R)	2	440280.15	563283.15
	A ¹	1	157185.63	873342.61
	B ¹	1	1552609.08	2605592.41
	A*B	1	542130.03	1623984.19
	Exp. Error	6	619920.87	124385.59
	Coefficient of Variation (%)		50.2	56.6
15-30	Blocks(R)	2	1279940.13	1773952.11
	A	1	205303.68	3547904.22
	B	1	157185.63	4273684.81
	A*B	1	157185.63	3183009.01
	Exp. Error	6	2216638.17	64959.37
	Coefficient of Variation (%)		28.6	21.6
30-45	Blocks(R)	2	342440.12	1999304.97
	A	1	3207.87	1552609.08
	B	1	461933.28	1696963.23
	A*B	1	320787.00	461933.28
	Exp. Error	6	1396760.06	628475.19
	Coefficient of Variation (%)		20.5	12.3

¹A: limestone rates; B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 3.15.2. Analysis of variance of mechanical impedance (kPa) at three soil depths on two soils at the end of the second season.

SOIL TYPE				
Soil Depth	Source (cm)	df	800 MEAN SQUARES	815
0-15	Blocks(R)	2	3729950.84**	656811.38
	A ¹	1	12831.48	1482837.91
	B ¹	1	51325.92	97038.07
	A*B	1	1552609.08*	64959.37
	Exp. Error	6	15951.53	1284484.61
Coefficient of Variation (%)			18.8	28.3
15-30	Blocks(R)	2	3609655.71	1853346.89
	A	1	821214.72	7217.71
	B	1	927074.43	353667.67
	A*B	1	205303.68	424240.81
	Exp. Error	6	1261494.88	1950652.28
Coefficient of Variation (%)			25.9	23.5
30-45	Blocks(R)	2	8278710.50	1023834.48
	A	1	7217.71	64959.37
	B	1	1348107.37	2252726.71
	A*B	1	6352384.57	135532.51
	Exp. Error	6	2904458.96	3687179.24
Coefficient of Variation (%)			23.1	25.9

¹A: limestone rates; B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 3.15.3 Analysis of variance of mechanical impedance (kPa) at two soil depths on two soils at the end of tillage.

Soil Depth	Source (cm)	* df	SOIL TYPE	
			800 MEAN SQUARES	815
15-30	Blocks(R)	2	548545.54	1003261.34
	B ¹	1	48138099.19**	21833565.19**
	Exp. Error	6	1166595.36	1537906.34
	Coefficient of Variation (%)		37.0	25.9
30-45	Blocks(R)	2	1588697.61	1907880.18*
	B	1	1348107.37	801.97
	Exp. Error	6	843402.49	194878.10
	Coefficient of Variation (%)		22.1	6.5

¹B: B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 3.16.1 Analysis of variance of water content (%) at three soil depths on two soils at the end of the first season.

Soil Depth (cm)	Source	df	SOIL TYPE	
			800	815
			MEAN SQUARES	
0-15	Blocks(R)	2	0.49	0.18
	A ¹	1	1.92	2.17
	B ¹	1	5.07	0.24
	A*B	1	1.92	6.02
	Exp. Error	6	1.95	3.19
	Coefficient of Variation (%)		18.9	33.4
15-30	Blocks(R)	2	5.20	8.42
	A	1	22.96	1.69
	B	1	8.67	14.74
	A*B	1	25.81	1.40
	Exp. Error	6	8.88	2.07
	Coefficient of Variation (%)		38.4	22.3
30-45	Blocks(R)	2	12.60	0.62
	A	1	3.20	4.32
	B	1	0.85	0.40
	A*B	1	3.85	6.16
	Exp. Error	6	4.74	2.08
	Coefficient of Variation (%)		29.5	18.7

¹A: limestone rates; B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

Table 3.16.2 Analysis of variance of water content (%) at three soil depths on two soils at the end of the second season.

Soil Depth (cm)	Source	df	SOIL TYPE	
			800	815
			MEAN SQUARES	
0-15	Blocks(R)	2	15.15**	58.46
	A ¹	1	1.02	0.27
	B ¹	1	2.71	6.45
	A*B	1	3.97*	8.33
	Exp. Error	6	0.47	3.19
	Coefficient of Variation (%)		7.8	34.2
15-30	Blocks(R)	2	5.20	7.56
	A	1	22.96	9.19
	B	1	8.67	2.90
	A*B	1	25.81	0.00
	Exp. Error	6	8.88	5.28
	Coefficient of Variation (%)		38.4	22.7
30-45	Blocks(R)	2	8.55	20.96
	A	1	3.10	0.56
	B	1	3.97	1.47
	A*B	1	0.02	0.00
	Exp. Error	6	2.07	12.34
	Coefficient of Variation (%)		37.5	159.9

¹A: limestone rates; B: tillage depths. *

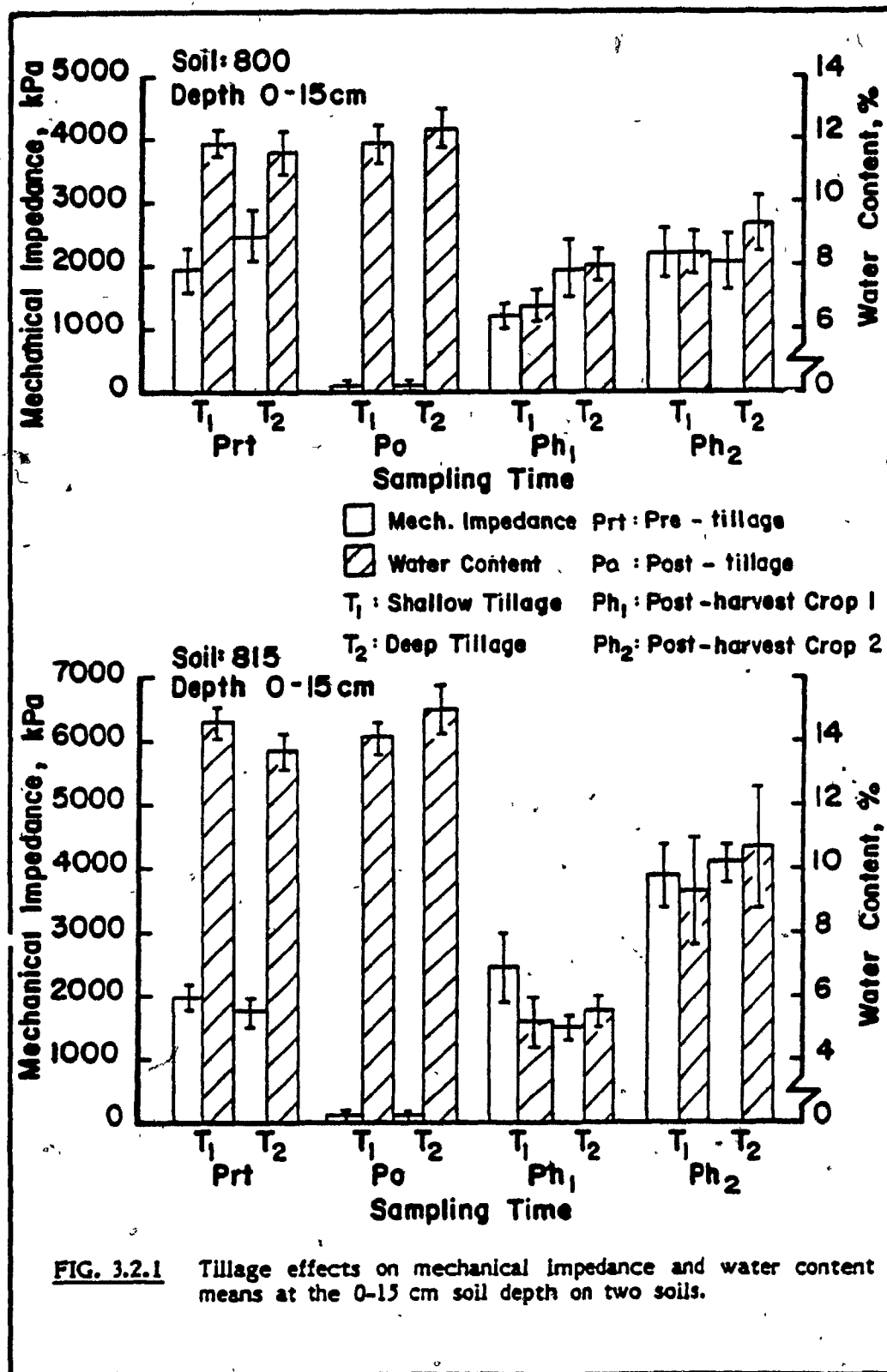
*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.

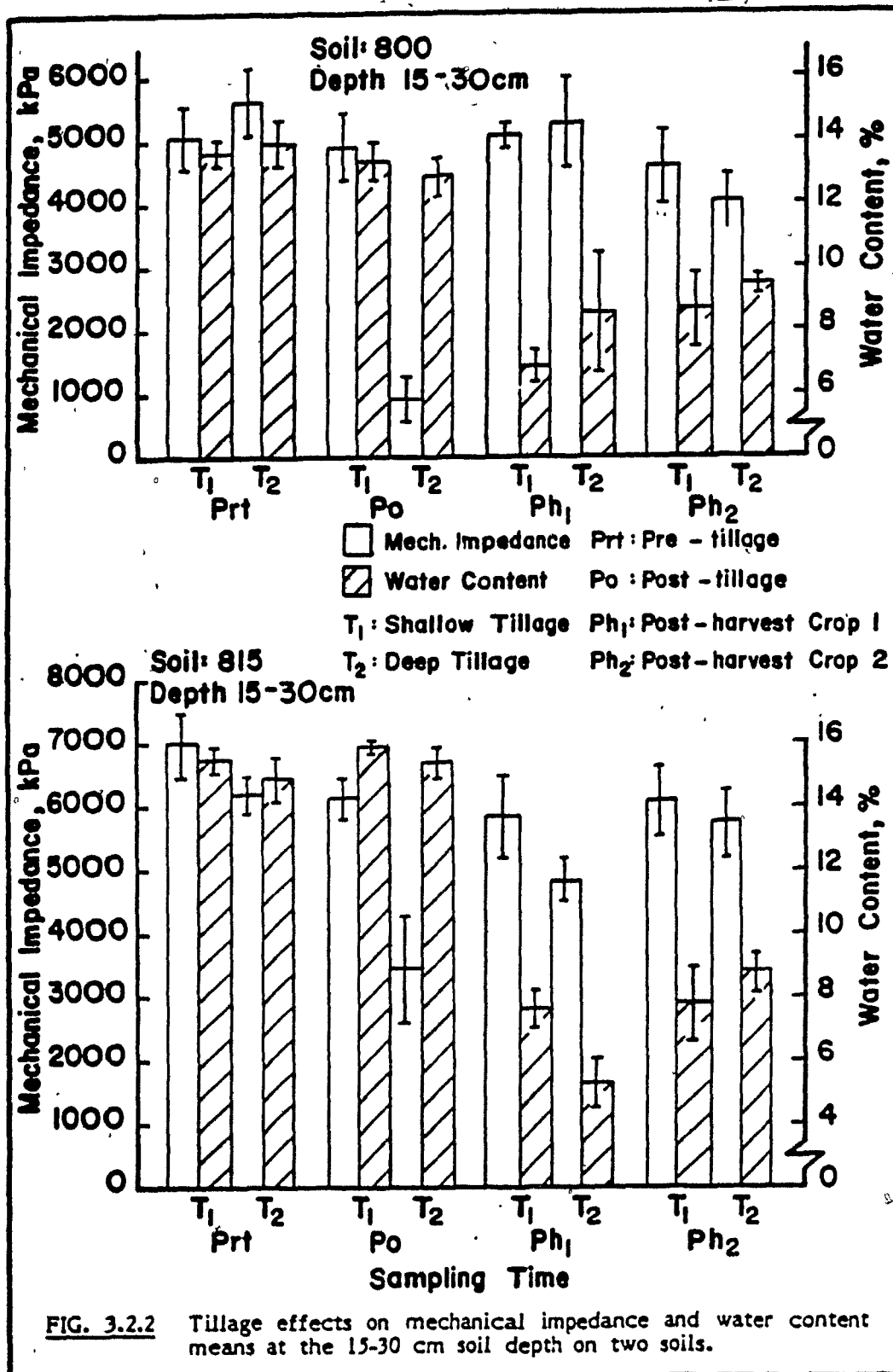
Table 3.16.3 Analysis of variance of moisture content (%) at three soil depths on two soils at the end of tillage.

			SOIL TYPE	
Soil Depth (cm)	Source	df	800	815
			MEAN SQUARES	
0-15	Blocks(R)	2	2.49	3.16
	B ¹	1	0.61	2.71
	Exp. Error	6	2.26	1.99
Coefficient of Variation (%)			12.5	9.7
15-30	Blocks(R)	2	4.32	1.27
	B	1	0.70	0.65
	Exp. Error	6	1.83	0.84
Coefficient of Variation (%)			10.3	5.8
30-45	Blocks(R)	2	1.05	0.70
	B	1	0.27	0.10
	Exp. Error	6	0.81	0.40
Coefficient of Variation (%)			6.0	4.1

¹B: tillage depths.

*,** Indicates that F values calculated from the mean squares are significant at the 0.05, 0.01 levels of probability, respectively.





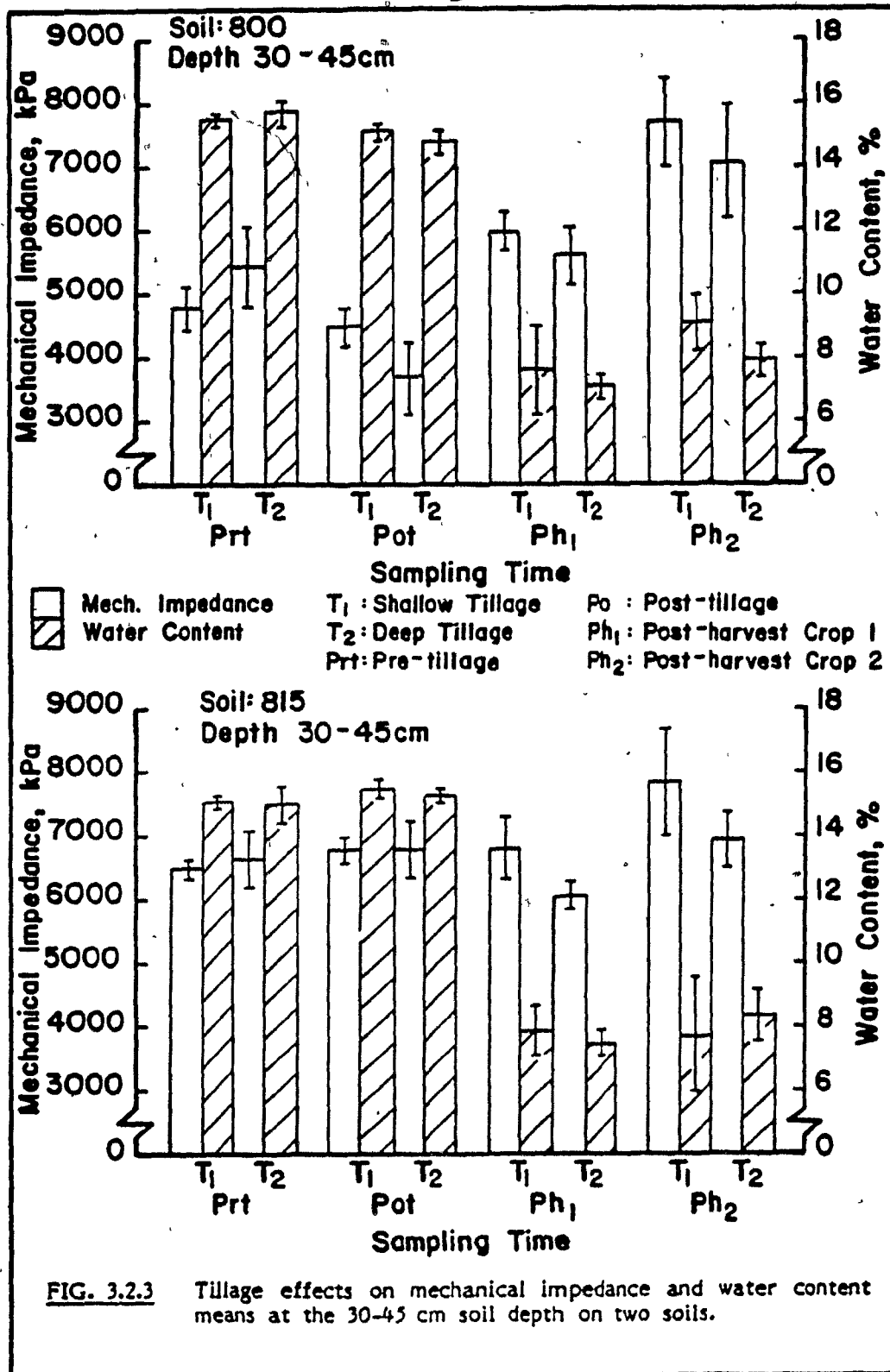


Table 3.17

Effects of limestone rates and tillage depths on mechanical impedance and water content on the Tabela sand No. 800 at the end of the second season.

Soil Variable	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Tillage Depth ¹		A mean
			B ₁	B ₂	
			(AxB means)		
			----- kPa -----		
Mechanical Impedance	0-15	0-A ₁	1770	2350	2060
		3.0-A ₂	2550	1770	2160
		B mean	2160	2160	
			----- % -----		
Moisture Content	0-15	0-A ₁	7.5	9.6	8.5
		3.0-A ₂	9.2	5.7	7.4
		B mean	8.3	7.6	

¹B₁: 0-15 cm; B₂: 0-30 cm.

3.7 Relationship of Bulk Density and Mechanical Impedance to Crop Yields

3.7.1 Bulk Density

Bulk Density at the 0-15 cm soil depth (measured after tillage treatments) did not significantly affect plant yields on any soil (Table 3.18).

3.7.2 Mechanical Impedance

Mechanical Impedance at the 15-30 cm soil depth (measured after tillage treatments) had no significant effects on plant yields on either soil (Table 3.19).

Table 3.18

Regressions of dry bulk density¹ (Mg m^{-3}) at the 0-15 cm soil depth and total plant, pod, root and tissue yields (kg ha^{-1} , dry matter) determined on two soils in the first season.

Plant Variable	SOIL TYPE	
	800	815
	F calculated	
Total Plant Yield	3.26	5.54
	R ² 0.62	0.73
Pod Yield	8.62	0.95
	R ² 0.81	0.32
Root Yield	1.07	12.25
	R ² 0.35	0.86
Tissue Yield	3.40	9.96
	R ² 0.63	0.83

¹Soil Depth: 0-15 cm (sampled after tillage treatments).

*,** Indicates significance at the 0.05, 0.01 levels of probability, respectively.

Table 3.19

Regressions of mechanical impedance (kPa) and total plant, pod, root and tissue yields (kg ha⁻¹, dry matter) determined on two soils in the first season.

Plant Variable	SOIL TYPE	
	800	815
	F calculated	
Total Plant Yield	6.73	8.40
	R ² 0.77	0.81
Pod Yield	0.98	5.03
	R ² 0.33	0.71
Root Yield	10.91	3.63
	R ² 0.84	0.64
Tissue Yield	8.29	5.30
	R ² 0.80	0.73

¹Soil Depth: 0-15 cm (sampled after tillage treatments).

*,** Indicates significance at the 0.05, 0.01 levels of probability, respectively.

4. DISCUSSION

Response of cowpea to applied limestone and depth of tillage differed between seasons and effects of factors were independent.

In the first season, the highest yields were obtained with deep cultivation probably because reduced bulk-density at the 0-15 cm soil depth and lower mechanical impedance at the 15-30 cm soil depth increased root proliferation and consequently produced higher plant yields. However, it seems that the significant decrease in subsoil mechanical impedance may be responsible for the increased plant growth observed on the deep tilled treatments, since on both soils penetration resistance at the 15-30 cm soil depth was significantly reduced by deep plowing.

Though the effects observed in this study may not be conclusive, similar results have been obtained by other workers (Lowry *et al.*, 1970; Adeoye, 1982). Lowry (1970) found that cotton yields on a Norfolk sandy loam were reduced as soil bulk density and penetration resistance increased and high yields were associated with increased rooting volume and improved water utilization. Adeoye (1982) concluded that on a Nigerian Alfisol (sandy loam), maize yields were increased by deep plowing compared to shallow plowing probably because of decreased bulk density and subsequently increased root proliferation. Although these soils and conditions are not identical to those of this experiment, the results are consistent, indicating that bulk density and penetration resistance are indications of soil properties that are extremely important for cowpea growth. The effects of deep plowing on crop performance were temporary which was consistent with the return of penetration resistance and bulk density to higher values that would restrict root growth and development.

Further, the temporary effect of deep plowing was supported by the fact that there were no significant differences in soil physical properties between deep and shallow tillage at both post-harvest sampling periods. It seems that cultivation of these coarse-textured, low organic-matter soils encourages soil repacking and formation of dense subsoils. This most likely is due to the impact of high intensity rainfall and machine traffic. These findings have been confirmed by Adeoye (1982) who stated that by the end of the growing season (14 weeks after planting), the favourable physical effects of deep plowing had disappeared. Also, Duque et al., (1980) concluded that deep-plowing resulted in transient changes in physical properties on coarse-textured, savannah soils of Brazil. Thus, effects of tillage on soil physical properties must be assumed to be short term.

The lack of limestone effects observed in the first season probably occurred because limestone was applied at the beginning of the short rainy season, only a few days prior to crop planting. Thus, there was insufficient time and moisture for effective dissolution and subsequent soil reaction of added CaCO_3 . In experiment 1 (Chapter II) liming was carried out during the long rainy season, six months before crop planting. Therefore, adequate moisture and sufficient time were available for CaCO_3 to react. This conflicts with observations made by Alley (1981), who stated that if the soil amendment had enough fines and there was good limestone-soil mixing, soil reaction should be immediate. One possible reason for the slow reaction of CaCO_3 in this experiment was a low amount of fines in the liming material (Aragonite) and hence poor soil-limestone surface contact. The non-significant effects of added limestone on soil chemical properties and plant content of Ca at the end of the first season supports this argument. Plant and soil responses to

added limestone in the second season were similar to effects observed in experiment 1 (Chapter II).

Seasonal variations in crop growth and plant yields in this study were similar to observations made in experiment 1 and are most likely due to the same reasons. The higher crop yields obtained on the Kairuni loamy sand No. 815 compared to the Tabela sand No. 800 could be related to soil texture as the Tabela sand No. 800 had a lower clay content, and moisture could have been a limiting factor. Observations made by Ritchey et al., (1980) on an Oxisol in the Brazilian savannahs support this hypothesis since yields of many field crops were reduced, particularly during dry periods when plants exhausted available water in the limed surface layers.

Limestone effects on soil chemical properties and cowpea growth were not immediate indicating that CaCO_3 should be applied sometime before planting for best results. Though deep plowing resulted in a temporary improvement in soil physical properties and higher yields in the first season, bulk density and mechanical impedance increased to undesirable values regardless of tillage depth. Therefore, because of high energy costs associated with deep plowing and greater possibility of deterioration in soil physical properties with cultivation, studies on effects of minimum tillage, green manuring and crop rotations should be carried out to determine whether viable alternatives to present tillage and cultivation practices exist.

5. CONCLUSIONS

Cowpea yields were increased by deep tillage in the first season and added limestone in the second season.

The effects observed in the first season were most likely due to reduction of mechanical impedance in the subsoil and bulk-density in the topsoil. However, the effects of reduced bulk-density and penetration resistance on crop performance were temporary as positive effects on yield were confined to the first season. The crop response observed in the second season was consistent with reversion of mechanical impedance and bulk density to levels higher than pre-tillage values. This resulted in formation of more dense soils, especially on the Tabela sand No. 800. Mechanical impedance was a more sensitive measurement of the impact of soil compaction on root growth than bulk density on these soils.

Cowpea growth in the second season was increased by CaCO_3 , because of reduction in exchangeable acidity, increased soil pH and greater availability of exchangeable Ca. These effects on soil chemical properties and cowpea yields were not noted in the first season because of the short time span between limestone applications and crop planting and/or poor soil-limestone contact. Reaction of CaCO_3 with the soil was a slow process under these circumstances.

Higher cowpea yields were produced in the long rainy season than the short rainy season and seasonal plant growth patterns were similar to those in experiment 1 (Chapter II) and due to the same reasons. Plant yields determined on the Kairuni loamy sand No. 815 were greater than yields obtained on the Tabela sand No. 800. This was most likely due to moisture limitations on the Tabela sand No. 800 (lowest clay content) since the soils have similar chemical properties.

CHAPTER IV

GENERAL CONCLUSIONS

CONTRIBUTIONS TO KNOWLEDGE

1. GENERAL CONCLUSIONS

This study identified two major constraints to crop production in soils of Guyana's Intermediate Savannas. These were - problems associated with high KCl-exchangeable Al and acidity and low levels of soil exchangeable Ca, and physical limitations of high mechanical impedance and high bulk density. However, limestone reduced soil acidity and increased exchangeable Ca and the effects seemed to have a permanent nature, since limestone effects on soil chemical properties increased with time. Deep tillage reduced mechanical impedance in the subsoil, decreased bulk density in the topsoil and promoted increased root growth and consequently higher cowpea yields. However, deep tillage effects were temporary and soils reverted to their previous physical properties shortly after deep plowing was carried out.

Surprisingly, there was no limestone rate-placement depth and limestone rate-tillage depth interactions. This could be for several reasons. With regard to limestone rate- placement depth, though limestone was shown to react slowly it was applied well in advance of crop seeding, a low rate was adequate to correct chemical problems and there was good downward movement of CaCO_3 and/or its solubility products into the soil profile with time. Thus, the effects of limestone placement depths were minimal. Limestone rate-tillage depth non-interaction appeared to be due to the fact that limestone reacted very slowly in the soil gradually moving to lower soil depths, whereas the effect of deep tillage was of a transient nature. Therefore, it could be that the two management practices never had the opportunity to work in conjunction but operated sequentially on the experimental sites. If an interaction is considered possible, then it is clear that liming would have to precede deep tillage

by a significant time period.

Added to this was the impact of the different growing seasons on crop responses. Cowpea yields and plant growth patterns differed between the short and long rainy season, with the exception of vegetative yields. The more ideal growing conditions of the long rainy season and the cumulative effect of added limestone in the long rainy season (which was the second growth period tested) resulted in much improved seasonal yields and greater effectiveness of added limestone. This implies that liming and tillage management practices would be best suited to the long rainy season with higher potential yields.

Crop response to added limestone and deep tillage differed among soil types. Given the low clay and organic matter contents of these soils, it would seem probable that moisture availability would be limited. Therefore, one would consider that as clay content increases there should be increased response to the management factors. In fact, the factor most responsible for soil response differences to liming seemed to be the exchangeable Ca level as far as the limestone was concerned. With the small buffering capacity of these soils, it is not surprising that only 1.5 Mg ha^{-1} of limestone was required to neutralise acidity and precipitate exchangeable Al. However, more calcium seemed to be required to increase yields on two of the soils with low exchangeable Ca. It is hypothesized that other sources of Ca could operate as effectively as limestone if the only problem was to supply exchangeable Ca to the soil.

Further, the improvement in measured soil chemical and physical properties with the treatments resulted in increased root growth. This should be very important in such an environment to enhance efficient use of soil moisture and effective exploitation of nutrients in these low

fertility soils.

The implications for management seem to be obvious. It is clear that 1.5 Mg ha⁻¹ of limestone applied exclusively as a shallow incorporation should be adequate to improve soil chemical properties and promote increased plant and root growth, regardless of soil type. However, limestone reacts slowly with the soil and must be added early enough to be effective and penetrate the soil profile. Thus, limestone must be applied well in advance of deep plowing.

However, two problems for soil management remain to be resolved. Since, the exchangeable Ca content seems to indicate the degree to which response will be expected, application of fertilizers containing Ca could preclude use of higher rates of limestone to alleviate an apparent Ca deficiency. Also, deep tillage obviously is a practice that will have to be carried out frequently and routinely for it to be effective in sustaining high crop yields in this area. Implications of such routine deep tillage on soil deterioration would have to be considered as would the impact of added limestone on long term soil chemical changes and nutrient availability in the soil. Solutions to these problems remain to be determined.

2. CONTRIBUTIONS TO KNOWLEDGE

The major contributions to knowledge are as follows:

1. Low rates of limestone (CaCO_3) applied exclusively as a shallow incorporation were adequate to neutralise KCl-exchangeable Al, reduce KCl-exchangeable acidity, increase soil pH, eliminate a possible Ca deficiency and increase cowpea yields on acid soils in Guyana's Intermediate Savannas. This conflicts with present limestone management practices that include deep placement and frequent applications of high levels of limestone.
2. On these soils, Ca may become limiting below approximately 0.80 me of exchangeable Ca 100 g^{-1} soil, while plant Ca critical levels in cowpea tissue at harvest in the long rainy season were between 2.0-2.2%.
3. Limestone required sometime to become reactive as its effects on soil chemical properties and crop growth were not immediate. However, CaCO_3 and/or its dissolution products were leached to lower soil depths with time on these well drained, acid soils low in clay and organic matter.
4. Deep tillage reduced mechanical impedance in the subsoil and bulk-density in the topsoil, thus promoting increased root growth and cowpea yields. However, tillage effects on soil physical properties were transient as soils became more dense by the end of the first season.
5. Mechanical impedance is a more useful measurement for predicting the impact of soil compaction on crop response than bulk-density on these soils.
6. Soil chemical and physical factors studied acted independently in

their effects on soil properties and cowpea growth. The lack of interaction was because although low levels of limestone are required, CaCO_3 and/or its solubility products leached slowly into the soil profile, whereas the effects of deep plowing were immediate but temporary.

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APPENDICES

APPENDIX A

SOIL DESCRIPTIONS

PEDON NO. 1: Tabela sand No. 800.

(Coated, isohyperthermic - Orthoxic quartzispanment)

Location: Ebini Crop Research Station; Line 38-388m Southeast of fence.

Physiographic position: Intermediate Savannas, Elevation 30m.

Topography: Nearly level.

Vegetation: Bur grass (Cenchrus echinatus L.).

Parent Material: Brown Sands of the Berbice Formation.

A11 0-28cm Dark brown (10Yr 4/3) sand; weak fine granular structure; fine roots common; medium acid; gradual smooth boundary. A thin layer of coarse sand is present on the surface.

A12 28-46cm Dark brown (7.5YR 4/4) sand; weak medium and fine granular structure; very friable; non sticky and non plastic; few fine pores; extremely acid; gradual smooth boundary.

B1 46-61cm Reddish yellow (7.5YR 6/8) sand; weak medium and fine granular structure; very friable; penetration of some material from above horizon; common quartz grains 3-5 mm in size; few fine pores; extremely acid; gradual smooth boundary.

B2 61-84cm Reddish yellow (5YR 6/8) loamy sand; weak medium granular structure; very friable; penetration of some A1 material; common quartz grains 2-3 mm in size; common fine pores; extremely acid; diffuse boundary.

- c1 84-145cm Yellowish red (5YR 5/8) loamy sand; weak medium subangular blocky structure; very friable; few fine roots; common fine pores; few scattered pockets of organic material; common quartz grains; extremely acid; diffuse boundary.
- c2 145-203cm Yellowish red (5YR 5/8) loamy sand; weak medium subangular blocky structure; very friable common fine pores; common quartz grains 2-3 mm in size; occasional medium dead roots; extremely acid.

Range in Characteristics

Sand or loamy sand to 2m.

PEDON NO. 2: Kasarama loamy sand NO. 810.

(Loamy, siliceous, isohyperthermic - Ultic Haploorthox)

Location: Ebini Crop Research Station; Line 5-213m Southeast of fence.

Physiographic position: Intermediate Savannas, Elevation 30m.

Topography: Gently sloping.

Vegetation: Bur grass (Cenchrus echinatus L.).

Parent Material: Brown Sands of the Berbice Formation.

- A1 0-13cm Dark greyish brown (10YR 4/2) loamy sand; weak medium and fine granular structure; friable; many fine roots; extremely acid; clear smooth boundary.
- A3 13-25cm Yellowish brown (10YR 5/4) and Dark greyish brown (10YR 4/2) loamy sand; moderate medium subangular blocky structure; friable; common fine roots; common fine pores; a thin band (2.5cm) of charcoal in the middle of the horizon; extremely acid; gradual smooth boundary.
- B1 25-48cm Yellowish brown (10YR 5/6) sandy loam; moderate medium subangular blocky structure; friable; slightly sticky and non plastic; some penetration of A1 material; common fine pores; common fine roots; very strongly acid; gradual smooth boundary.
- B21 48-71cm Yellowish brown (10YR 5/8) sandy loam; moderate medium subangular blocky structure; friable slightly sticky and non plastic; few fine roots; few fine pores; few scattered pockets of organic material; very strongly acid; gradual smooth boundary.
- B22 71-89cm Reddish yellow (7.5YR 6/6) heavy sand loam; moderate medium subangular blocky structure; slightly sticky and slightly plastic; occasional fine roots; very strongly acid; diffuse boundary.

B23 89-112cm Reddish yellow (5YR 6/8) sandy clay loam; moderate medium subangular blocky structure; very friable; slightly sticky and slightly plastic; occasional fine roots; few fine pores; few quartz grains 3-4 mm in size; few scattered pockets of organic material; very strongly acid; diffuse boundary.

C1 112-135cm Reddish yellow (5YR 6/8) sandy clay loam; moderate medium subangular blocky structure; very friable; slightly sticky and slightly plastic; few scattered pockets of organic material; few quartz grains 3-5 mm in size; extremely acid; diffuse boundary.

C2 135-203cm Yellowish red (5YR 5/8) sandy clay loam; moderate medium subangular blocky structure; very friable; slightly sticky and slightly plastic; few fine pores; very strongly acid.

Range in Characteristics Loamy sand less than 50cm over sandy loam or sandy clay loam to 2m.

PEDON NO. 3: Kairuni loamy sand No. 815.

(Loamy, siliceous, isohyperthermic - Arenic Paleudult)

Location: Ebini Crop Research Station; Line 10-342m Southeast of fence.

Physiographic position: Intermediate Savannas, Elevation 30m.

Topography: Nearly level.

Vegetation: Bur grass (Cenchrus echinatus L.), Calypogonia sp.

Parent Material: Brown Sands of the Berbice Formation.

- A1 0-18cm Dark greyish brown (10YR 4/2) loamy sand; moderate medium granular structure; very friable; non sticky; non plastic; many fine roots; extremely acid; clear smooth boundary.
- A3 18-30cm Dark brown (10YR 4/3) loamy sand; weak fine granular structure; very friable; non sticky; non plastic; many fine roots; extremely acid; clear smooth boundary.
- B1 30-57cm Yellowish brown (10YR 5/4) loamy sand; weak, medium subangular blocky structure; very friable; non sticky; non plastic; many fine roots; extremely acid; gradual smooth boundary.
- B21 57-70cm Strong brown (7.5YR 5/6) sandy loam; weak medium subangular blocky structure; friable; slightly sticky, slightly plastic; common fine roots; few fine pores; extremely acid; gradual smooth boundary.
- B22 70-97cm Strong brown, (7.5YR 5/8) heavy sandy loam; moderate medium subangular blocky structure; slightly sticky, slightly plastic; few fine roots; few fine pores; very strongly acid; gradual smooth boundary.
- C1 97-127cm Yellowish red (5YR 5/6) sandy clay loam; moderate medium subangular blocky structure; slightly sticky, slightly plastic; few fine roots; extremely acid; diffuse boundary.

C2 127-193cm Yellowish red (5YR 5/8) sandy clay loam; moderate medium subangular blocky structure; slightly sticky; slightly plastic; few fine pores; extremely acid.

Range in Characteristics Sand over loamy sand 50 to 100cm over sandy loam or sandy clay loam to 2m.

PEDON NO. 4: Bukaruna loamy sand No. 816.

(Loamy, siliceous, isohyperthermic - Grossarenic Paleudult)

Location: Ebini Crop Research Station; Line 35-91m Southeast of fence.

Physiographic position: Intermediate Savannas, Elevation 30m.

Topography: Gently sloping, about 2% slope.

Vegetation: Bur grass (Cenchrus echinatus L.) Calypogonia sp.

Parent Material: Brown Sands of the Berhice Formation.

All 0-23cm Dark greyish brown (10YR 4/2) loamy sand; weak medium granular structure; very friable; non sticky, non plastic; common medium and fine roots; very strongly acid; clear smooth boundary.

A12 23-53cm Dark brown (10YR 4/3) loamy sand; weak medium subangular blocky structure; very friable; non sticky, non plastic; few quartz grains 3-5 mm in size; common fine roots; very strongly acid; clear smooth boundary.

B1 53-67cm Strong brown (7.5YR 5/6) loamy sand; weak medium subangular blocky structure; very friable; non sticky; non plastic; penetration of some darker material from above; few fine pores; few smooth boundary.

B21 67-91cm Reddish yellow (7.5YR 7/8) loamy sand; medium and coarse subangular blocky structure; friable; non sticky, non plastic; few scattered pocket of darker material; few fine roots; few fine pores; few quartz grains 3-5 mm in size; extremely acid; gradual smooth boundary.

B22 91-124cm Reddish yellow (5YR 6/8) loamy sand; medium and coarse subangular blocky structure; non sticky, non plastic; dark grey material along old root channels; few fine pores; few fine roots; few quartz grains 3-5 mm in size; extremely acid; diffuse boundary.

C1 124-176cm Yellowish red (5YR 5/8) sandy loam; medium and coarse subangular blocky structure; friable; slightly sticky, slightly plastic; few fine pores; extremely acid; diffuse boundary.

C2 172-203cm Yellowish red (5YR 5/8) heavy sandy loam; medium and coarse subangular blocky structure; friable; slightly sticky, slightly plastic; dark yellowish brown band (2.5cm thick) in middle of horizon; few quartz grains about 1-3 mm in size.

Range in Characteristics Sand on loamy sand greater than 100cm to 2m.

APPENDIX B

Effects of Limestone Applications on Soil Chemical Properties

Table A2.1.1 Effects of limestone applications on soil pH on the Tabela sand No. 800 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
0-15	0 - A ₁	4.5 ± 0.1	4.8 ± 0.2	4.4 ± 0.1	4.6 ± 0.1
	1.5 - A ₂	5.1 ± 0.3	5.3 ± 0.3	5.0 ± 0.5	5.1 ± 0.2
	3.0 - A ₃	5.3 ± 0.2	5.5 ± 0.3	5.7 ± 0.3	5.5 ± 0.1
	4.5 - A ₄	6.4 ± 0.3	6.3 ± 0.2	5.8 ± 0.3	6.2 ± 0.2
	B mean	5.3 ± 0.2	5.5 ± 0.2	5.2 ± 0.2	
15-30	0 - A ₁	4.5 ± 0.1	5.5 ± 0.1	4.7 ± 0.1	5.0 ± 0.2
	1.5 - A ₂	5.4 ± 0.3	5.0 ± 0.2	4.7 ± 0.2	5.0 ± 0.2
	3.0 - A ₃	4.9 ± 0.2	4.8 ± 0.2	5.1 ± 0.2	4.9 ± 0.1
	4.5 - A ₄	6.0 ± 0.1	5.0 ± 0.3	4.9 ± 0.2	5.2 ± 0.2
	B mean	5.2 ± 0.2	5.2 ± 0.1	4.8 ± 0.1	
30-45	0 - A ₁	4.6 ± 0.1	4.9 ± 0.2	4.7 ± 0.1	4.7 ± 0.1
	1.5 - A ₂	4.9 ± 0.2	4.8 ± 0.1	4.4 ± 0.1	5.0 ± 0.1
	3.0 - A ₃	5.3 ± 0.3	4.8 ± 0.2	4.6 ± 0.1	4.9 ± 0.2
	4.5 - A ₄	5.0 ± 0.3	4.9 ± 0.2	4.6 ± 0.1	4.8 ± 0.1
	B mean	4.9 ± 0.1	4.8 ± 0.1	4.6 ± 0.1	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table A2.1.2 Effects of limestone applications on soil pH on the Kasarama loamy sand No. 810 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
0-15	0 - A ₁	4.5 ± 0.1	4.6 ± 0.5	4.7 ± 0.4	4.6 ± 0.2
	1.5 - A ₂	4.5 ± 0.3	4.9 ± 0.2	5.0 ± 0.1	4.8 ± 0.1
	3.0 - A ₃	5.1 ± 0.3	5.4 ± 0.4	5.0 ± 0.1	5.2 ± 0.2
	4.5 - A ₄	6.1 ± 0.5	5.8 ± 0.4	5.6 ± 0.7	5.8 ± 0.3
	B mean	5.0 ± 0.2	5.2 ± 0.2	5.1 ± 0.2	
15-30	0 - A ₁	4.6 ± 0.1	4.8 ± 0.3	4.6 ± 0.1	4.7 ± 0.1
	1.5 - A ₂	4.7 ± 0.1	5.1 ± 0.5	4.7 ± 0.2	4.8 ± 0.2
	3.0 - A ₃	4.6 ± 0.3	5.0 ± 0.1	4.9 ± 0.2	4.8 ± 0.1
	4.5 - A ₄	5.5 ± 0.8	5.2 ± 0.6	5.1 ± 0.2	5.3 ± 0.3
	B mean	4.9 ± 0.2	5.0 ± 0.2	4.8 ± 0.1	
30-45	0 - A ₁	4.7 ± 0.1	5.0 ± 0.3	4.9 ± 0.1	4.9 ± 0.1
	1.5 - A ₂	4.8 ± 0.2	5.2 ± 0.3	4.7 ± 0.1	4.9 ± 0.1
	3.0 - A ₃	4.8 ± 0.3	4.9 ± 0.1	4.9 ± 0.3	4.9 ± 0.1
	4.5 - A ₄	5.0 ± 0.4	5.4 ± 0.2	5.0 ± 0.2	5.1 ± 0.1
	B mean	4.8 ± 0.1	5.1 ± 0.1	4.9 ± 0.1	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table A2.1.3 Effects of limestone applications on soil pH on the Kairuni loamy sand No. 815 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
0-15	0 - A ₁	4.2 ± 0.2	4.0 ± 0.1	4.1 ± 0.1	4.1 ± 0.1
	1.5 - A ₂	4.8 ± 0.5	4.7 ± 0.4	5.0 ± 0.9	4.9 ± 0.3
	3.0 - A ₃	5.4 ± 0.5	5.4 ± 0.5	5.9 ± 0.1	5.5 ± 0.2
	4.5 - A ₄	6.4 ± 0.2	5.5 ± 0.5	5.1 ± 0.5	5.7 ± 0.3
	B mean	5.2 ± 0.3	4.9 ± 0.2	5.0 ± 0.3	
15-30	0 - A ₁	4.8 ± 0.3	4.0 ± 0.2	4.4 ± 0.2	4.3 ± 0.2
	1.5 - A ₂	4.6 ± 0.4	5.2 ± 0.4	4.5 ± 0.1	4.8 ± 0.2
	3.0 - A ₃	5.1 ± 0.2	4.6 ± 0.3	4.9 ± 0.2	4.9 ± 0.1
	4.5 - A ₄	5.4 ± 0.2	4.6 ± 0.2	4.3 ± 0.2	4.8 ± 0.2
	B mean	4.9 ± 0.2	4.6 ± 0.2	4.6 ± 0.1	
30-45	0 - A ₁	4.7 ± 0.2	4.5 ± 0.1	4.6 ± 0.2	4.6 ± 0.1
	1.5 - A ₂	4.6 ± 0.1	4.8 ± 0.2	4.9 ± 0.1	4.8 ± 0.1
	3.0 - A ₃	5.0 ± 0.3	4.0 ± 0.2	4.7 ± 0.2	4.7 ± 0.1
	4.5 - A ₄	5.0 ± 0.3	4.7 ± 0.3	4.6 ± 0.1	4.8 ± 0.1
	B mean	4.8 ± 0.1	4.6 ± 0.1	4.7 ± 0.1	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table A2.1.4 Effects of limestone applications on soil pH on the Bukaruna loamy sand No. 816 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
0-15	0 - A ₁	4.6 ₋ ± 0.1	4.6 ₋ ± 0.3	4.7 ₋ ± 0.3	4.6 ₋ ± 0.1
	1.5 - A ₂	5.4 _± ± 0.4	5.4 _± ± 0.4	5.6 _± ± 0.7	5.5 _± ± 0.2
	3.0 - A ₃	5.9 _± ± 0.3	5.8 _± ± 0.6	5.9 _± ± 0.6	5.9 _± ± 0.2
	4.5 - A ₄	6.1 _± ± 0.3	6.2 _± ± 0.5	5.9 _± ± 0.4	6.1 _± ± 0.1
	B mean	5.5 _± ± 0.2	5.5 _± ± 0.3	5.5 _± ± 0.2	
15-30	0 - A ₁	5.2 _± ± 0.3	4.8 _± ± 0.2	4.8 _± ± 0.2	4.9 _± ± 0.1
	1.5 - A ₂	4.8 _± ± 0.2	5.6 _± ± 0.1	5.0 _± ± 0.2	5.1 _± ± 0.1
	3.0 - A ₃	5.1 _± ± 0.3	5.6 _± ± 0.3	4.9 _± ± 0.3	5.2 _± ± 0.2
	4.5 - A ₄	5.2 _± ± 0.6	5.8 _± ± 0.7	5.4 _± ± 0.4	5.7 _± ± 0.2
	B mean	5.1 _± ± 0.2	5.4 _± ± 0.2	5.0 _± ± 0.1	
30-45	0 - A ₁	4.7 _± ± 0.1	5.0 _± ± 0.3	4.8 _± ± 0.1	4.8 _± ± 0.1
	1.5 - A ₂	4.6 _± ± 0.1	5.5 _± ± 0.2	4.7 _± ± 0.1	4.9 _± ± 0.2
	3.0 - A ₃	4.8 _± ± 0.2	4.9 _± ± 0.1	4.7 _± ± 0.1	4.8 _± ± 0.1
	4.5 - A ₄	4.9 _± ± 0.3	5.0 _± ± 0.2	5.1 _± ± 0.3	5.2 _± ± 0.2
	B mean	4.8 _± ± 0.1	5.1 _± ± 0.1	4.8 _± ± 0.1	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table A2.1.5 Effects of limestone applications on soil pH on the Tabela sand No. 800 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
0-15	0 - A ₁	4.9 ± 0.1	5.1 ± 0.1	5.1 ± 0.4	5.0 ± 0.1
	1.5 - A ₂	5.5 ± 0.5	5.2 ± 0.3	5.3 ± 0.2	5.4 ± 0.2
	3.0 - A ₃	5.2 ± 0.3	5.8 ± 0.1	6.1 ± 0.3	5.7 ± 0.2
	4.5 - A ₄	6.1 ± 0.5	6.4 ± 0.3	6.3 ± 0.4	6.3 ± 0.2
	B mean	5.4 ± 0.2	5.6 ± 0.2	5.7 ± 0.2	
15-30	0 - A ₁	5.6 ± 0.4	5.4 ± 0.2	5.2 ± 0.2	5.4 ± 0.2
	1.5 - A ₂	5.7 ± 0.2	5.2 ± 0.2	5.3 ± 0.2	5.4 ± 0.1
	3.0 - A ₃	5.4 ± 0.4	6.2 ± 0.3	5.8 ± 0.1	5.8 ± 0.2
	4.5 - A ₄	5.9 ± 0.4	6.2 ± 0.3	6.0 ± 0.4	6.1 ± 0.2
	B mean	5.7 ± 0.2	5.8 ± 0.2	5.6 ± 0.1	
30-45	0 - A ₁	4.7 ± 0.1	4.9 ± 0.1	4.9 ± 0.1	4.9 ± 0.1
	1.5 - A ₂	5.2 ± 0.2	4.9 ± 0.1	5.0 ± 0.2	5.0 ± 0.1
	3.0 - A ₃	5.4 ± 0.5	5.1 ± 0.1	5.2 ± 0.2	5.2 ± 0.2
	4.5 - A ₄	5.7 ± 0.4	5.6 ± 0.3	5.2 ± 0.4	5.5 ± 0.2
	B mean	5.3 ± 0.2	5.2 ± 0.1	5.1 ± 0.1	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table A2.1.6 Effects of limestone applications on soil pH on the Kasarama loamy sand No. 810 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
0-15	0 - A ₁	5.1 ± 0.1	5.6 ± 0.3	5.5 ± 0.6	5.4 ± 0.2
	1.5 - A ₂	5.3 ± 0.2	5.7 ± 0.1	5.3 ± 0.1	5.4 ± 0.1
	3.0 - A ₃	5.7 ± 0.3	5.9 ± 0.1	5.7 ± 0.3	5.8 ± 0.1
	4.5 - A ₄	5.6 ± 0.7	5.8 ± 0.1	5.7 ± 0.6	5.7 ± 0.3
	B mean	5.4 ± 0.2	5.8 ± 0.1	5.6 ± 0.2	
15-30	0 - A ₁	4.7 ± 0.1	4.8 ± 0.2	5.2 ± 0.2	4.9 ± 0.1
	1.5 - A ₂	4.8 ± 0.2	5.5 ± 0.1	5.0 ± 0.2	5.1 ± 0.1
	3.0 - A ₃	5.6 ± 0.3	5.6 ± 0.2	5.8 ± 0.3	5.7 ± 0.1
	4.5 - A ₄	5.9 ± 0.5	5.6 ± 0.1	5.6 ± 0.5	5.7 ± 0.2
	B mean	5.3 ± 0.2	5.4 ± 0.1	5.4 ± 0.2	
30-45	0 - A ₁	4.7 ± 0.1	4.7 ± 0.2	4.7 ± 0.3	4.7 ± 0.1
	1.5 - A ₂	4.9 ± 0.2	5.6 ± 0.1	4.7 ± 0.2	5.1 ± 0.2
	3.0 - A ₃	5.3 ± 0.1	5.6 ± 0.1	5.6 ± 0.4	5.5 ± 0.1
	4.5 - A ₄	5.6 ± 0.5	5.1 ± 0.2	5.2 ± 0.4	5.3 ± 0.2
	B mean	5.1 ± 0.2	5.3 ± 0.1	5.1 ± 0.2	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table A2.1.7 Effects of limestone applications on soil pH on the Kairuni loamy sand No. 815 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
0-15	0 - A ₁	5.1 ± 0.2	5.7 ± 0.3	5.4 ± 0.2	5.4 ± 0.1
	1.5 - A ₂	5.8 ± 0.3	5.8 ± 0.1	5.0 ± 0.9	5.6 ± 0.1
	3.0 - A ₃	5.6 ± 0.1	5.8 ± 0.1	6.0 ± 0.1	5.8 ± 0.1
	4.5 - A ₄	6.4 ± 0.3	6.0 ± 0.4	6.6 ± 0.1	6.1 ± 0.2
	B mean	5.7 ± 0.2	5.8 ± 0.1	5.9 ± 0.2	
15-30	0 - A ₁	5.0 ± 0.1	5.4 ± 0.2	4.9 ± 0.2	5.1 ± 0.1
	1.5 - A ₂	5.4 ± 0.2	5.7 ± 0.2	5.1 ± 0.1	5.4 ± 0.1
	3.0 - A ₃	5.5 ± 0.2	5.5 ± 0.3	5.8 ± 0.1	5.6 ± 0.1
	4.5 - A ₄	6.4 ± 0.3	6.1 ± 0.3	6.5 ± 0.1	5.5 ± 0.3
	B mean	5.6 ± 0.2	5.7 ± 0.1	5.6 ± 0.2	
30-45	0 - A ₁	4.8 ± 0.1	4.9 ± 0.1	4.8 ± 0.3	4.8 ± 0.1
	1.5 - A ₂	4.8 ± 0.1	5.5 ± 0.3	4.9 ± 0.2	5.1 ± 0.1
	3.0 - A ₃	5.2 ± 0.3	5.0 ± 0.1	5.6 ± 0.2	5.2 ± 0.1
	4.5 - A ₄	6.1 ± 0.3	5.6 ± 0.4	5.7 ± 0.3	5.0 ± 0.1
	B mean	5.2 ± 0.2	5.2 ± 0.1	5.3 ± 0.1	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table A2.1.8 Effects of limestone applications on soil pH on the Bukaruna loamy sand No. 816 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
0-15	0 - A ₁	5.0 ± 0.1	4.8 ± 0.2	4.8 ± 0.1	4.9 ± 0.1
	1.5 - A ₂	5.1 ± 0.1	5.5 ± 0.1	5.4 ± 0.1	5.3 ± 0.1
	3.0 - A ₃	5.9 ± 0.2	6.1 ± 0.2	5.6 ± 0.1	5.9 ± 0.1
	4.5 - A ₄	6.0 ± 0.3	6.1 ± 0.2	6.2 ± 0.3	6.1 ± 0.2
	B mean	5.5 ± 0.2	5.7 ± 0.1	5.5 ± 0.2	
15-30	0 - A ₁	5.0 ± 0.1	5.0 ± 0.1	4.6 ± 0.1	4.9 ± 0.1
	1.5 - A ₂	5.0 ± 0.2	5.4 ± 0.2	5.5 ± 0.2	5.3 ± 0.1
	3.0 - A ₃	5.8 ± 0.4	5.5 ± 0.2	4.9 ± 0.2	5.4 ± 0.2
	4.5 - A ₄	5.4 ± 0.3	5.8 ± 0.4	5.8 ± 0.1	5.7 ± 0.2
	B mean	5.3 ± 0.1	5.4 ± 0.1	5.2 ± 0.1	
30-45	0 - A ₁	4.6 ± 0.1	4.7 ± 0.2	4.5 ± 0.1	4.6 ± 0.1
	1.5 - A ₂	4.6 ± 0.1	5.2 ± 0.2	5.0 ± 0.3	5.0 ± 0.1
	3.0 - A ₃	5.1 ± 0.4	5.1 ± 0.2	4.6 ± 0.1	4.9 ± 0.2
	4.5 - A ₄	4.9 ± 0.2	5.3 ± 0.4	5.3 ± 0.3	5.2 ± 0.1
	B mean	4.8 ± 0.1	5.1 ± 0.1	4.9 ± 0.1	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm.

Table A2.2.1 Effects of limestone applications on exchangeable acidity on the Tabela No. 800 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.33 ± 0.07	0.24 ± 0.03	0.38 ± 0.02	0.32 ± 0.03
	1.5 - A ₂	0.15 ± 0.08	0.09 ± 0.09	0.22 ± 0.11	0.15 ± 0.05
	3.0 - A ₃	0.03 ± 0.03	0.00 ± 0.00	0.09 ± 0.05	0.04 ± 0.02
	4.5 - A ₄	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	B mean	0.13 ± 0.05	0.08 ± 0.03	0.17 ± 0.05	
15-30	0 - A ₁	0.45 ± 0.06	0.12 ± 0.08	0.42 ± 0.06	0.33 ± 0.06
	1.5 - A ₂	0.17 ± 0.10	0.25 ± 0.11	0.42 ± 0.08	0.28 ± 0.06
	3.0 - A ₃	0.25 ± 0.11	0.33 ± 0.07	0.25 ± 0.09	0.28 ± 0.05
	4.5 - A ₄	0.00 ± 0.00	0.26 ± 0.04	0.43 ± 0.04	0.23 ± 0.06
	B mean	0.22 ± 0.06	0.24 ± 0.04	0.38 ± 0.04	
30-45	0 - A ₁	0.49 ± 0.02	0.26 ± 0.04	0.49 ± 0.04	0.41 ± 0.04
	1.5 - A ₂	0.37 ± 0.10	0.43 ± 0.04	0.51 ± 0.04	0.44 ± 0.04
	3.0 - A ₃	0.17 ± 0.09	0.40 ± 0.06	0.42 ± 0.06	0.33 ± 0.05
	4.5 - A ₄	0.37 ± 0.10	0.49 ± 0.02	0.40 ± 0.04	0.43 ± 0.04
	B mean	0.22 ± 0.06	0.24 ± 0.04	0.38 ± 0.04	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.2.2 Effects of limestone applications on exchangeable acidity on the Kasarama loamy sand No. 810 at the end of the first season.

me 100 g ⁻¹ soil					
Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
0-15	0 - A ₁	0.43 ± 0.03	0.41 ± 0.18	0.34 ± 0.17	0.39 ± 0.07
	1.5 - A ₂	0.55 ± 0.15	0.18 ± 0.08	0.17 ± 0.05	0.30 ± 0.08
	3.0 - A ₃	0.14 ± 0.06	0.15 ± 0.05	0.21 ± 0.07	0.16 ± 0.03
	4.5 - A ₄	0.00 ± 0.00	0.05 ± 0.03	0.17 ± 0.15	0.07 ± 0.05
	B mean	0.28 ± 0.08	0.20 ± 0.06	0.22 ± 0.06	
15-30	0 - A ₁	0.45 ± 0.07	0.45 ± 0.15	0.55 ± 0.05	0.48 ± 0.05
	1.5 - A ₂	0.47 ± 0.05	0.32 ± 0.14	0.49 ± 0.16	0.42 ± 0.07
	3.0 - A ₃	0.41 ± 0.19	0.49 ± 0.04	0.45 ± 0.11	0.45 ± 0.06
	4.5 - A ₄	0.23 ± 0.21	0.26 ± 0.13	0.41 ± 0.08	0.30 ± 0.08
	B mean	0.39 ± 0.07	0.38 ± 0.06	0.47 ± 0.05	
30-45	0 - A ₁	0.49 ± 0.05	0.32 ± 0.07	0.53 ± 0.07	0.44 ± 0.05
	1.5 - A ₂	0.49 ± 0.10	0.26 ± 0.11	0.53 ± 0.08	0.29 ± 0.07
	3.0 - A ₃	0.40 ± 0.12	0.46 ± 0.03	0.40 ± 0.17	0.44 ± 0.06
	4.5 - A ₄	0.37 ± 0.14	0.15 ± 0.09	0.36 ± 0.08	0.29 ± 0.06
	B mean	0.45 ± 0.05	0.30 ± 0.05	0.45 ± 0.05	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.2.3 Effects of limestone applications on exchangeable acidity on the Kairuni loamy sand No. 815 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.52 ± 0.08	0.37 ± 0.17	0.53 ± 0.03	0.48 ± 0.06
	1.5 - A ₂	0.13 ± 0.08	0.26 ± 0.14	0.32 ± 0.14	0.23 ± 0.07
	3.0 - A ₃	0.16 ± 0.09	0.14 ± 0.06	0.16 ± 0.09	0.15 ± 0.04
	4.5 - A ₄	0.05 ± 0.03	0.28 ± 0.14	0.27 ± 0.14	0.20 ± 0.07
	B mean	0.22 ± 0.06	0.26 ± 0.06	0.32 ± 0.06	
15-30	0 - A ₁	0.40 ± 0.07	0.56 ± 0.03	0.68 ± 0.05	0.55 ± 0.05
	1.5 - A ₂	0.50 ± 0.13	0.28 ± 0.09	0.45 ± 0.06	0.41 ± 0.06
	3.0 - A ₃	0.27 ± 0.01	0.54 ± 0.10	0.27 ± 0.07	0.36 ± 0.06
	4.5 - A ₄	0.06 ± 0.06	0.37 ± 0.15	0.54 ± 0.10	0.32 ± 0.09
	B mean	0.31 ± 0.06	0.44 ± 0.06	0.48 ± 0.05	
30-45	0 - A ₁	0.41 ± 0.07	0.50 ± 0.05	0.36 ± 0.09	0.42 ± 0.04
	1.5 - A ₂	0.55 ± 0.05	0.35 ± 0.11	0.32 ± 0.04	0.41 ± 0.05
	3.0 - A ₃	0.46 ± 0.21	0.45 ± 0.08	0.45 ± 0.08	0.46 ± 0.07
	4.5 - A ₄	0.25 ± 0.19	0.43 ± 0.19	0.51 ± 0.04	0.40 ± 0.09
	B mean	0.42 ± 0.07	0.43 ± 0.05	0.41 ± 0.04	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.2.4 Effects of limestone applications on exchangeable acidity on the Bukaruna loamy sand No. 816 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.21 ± 0.06	0.21 ± 0.06	0.24 ± 0.03	0.22 ± 0.02
	1.5 - A ₂	0.11 ± 0.06	0.03 ± 0.03	0.03 ± 0.03	0.06 ± 0.03
	3.0 - A ₃	0.21 ± 0.19	0.03 ± 0.03	0.03 ± 0.03	0.09 ± 0.06
	4.5 - A ₄	0.02 ± 0.02	0.07 ± 0.07	0.07 ± 0.07	0.06 ± 0.03
	B mean	0.14 ± 0.05	0.09 ± 0.03	0.09 ± 0.03	
15-30	0 - A ₁	0.19 ± 0.08	0.23 ± 0.05	0.29 ± 0.02	0.24 ± 0.03
	1.5 - A ₂	0.29 ± 0.12	0.09 ± 0.05	0.24 ± 0.03	0.20 ± 0.05
	3.0 - A ₃	0.18 ± 0.18	0.11 ± 0.06	0.37 ± 0.02	0.22 ± 0.07
	4.5 - A ₄	0.24 ± 0.14	0.14 ± 0.14	0.17 ± 0.12	0.18 ± 0.07
	B mean	0.22 ± 0.06	0.14 ± 0.04	0.27 ± 0.04	
30-45	0 - A ₁	0.35 ± 0.05	0.34 ± 0.06	0.35 ± 0.01	0.35 ± 0.02
	1.5 - A ₂	0.37 ± 0.02	0.14 ± 0.14	0.38 ± 0.11	0.29 ± 0.06
	3.0 - A ₃	0.31 ± 0.14	0.34 ± 0.08	0.39 ± 0.07	0.35 ± 0.05
	4.5 - A ₄	0.31 ± 0.17	0.25 ± 0.09	0.30 ± 0.19	0.29 ± 0.08
	B mean	0.33 ± 0.05	0.27 ± 0.05	0.35 ± 0.05	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.2.5 Effects of limestone applications on exchangeable acidity on the Tabela No. 800 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.38 ± 0.02	0.31 ± 0.02	0.24 ± 0.14	0.31 ± 0.05
	1.5 - A ₂	0.17 ± 0.10	0.15 ± 0.06	0.14 ± 0.10	0.16 ± 0.04
	3.0 - A ₃	0.06 ± 0.06	0.06 ± 0.03	0.00 ± 0.00	0.04 ± 0.02
	4.5 - A ₄	0.18 ± 0.08	0.00 ± 0.00	0.00 ± 0.00	0.06 ± 0.04
	B mean	0.20 ± 0.05	0.13 ± 0.04	0.10 ± 0.05	
15-30	0 - A ₁	0.22 ± 0.12	0.23 ± 0.07	0.33 ± 0.04	0.26 ± 0.05
	1.5 - A ₂	0.12 ± 0.03	0.29 ± 0.05	0.26 ± 0.08	0.22 ± 0.04
	3.0 - A ₃	0.20 ± 0.10	0.03 ± 0.03	0.06 ± 0.03	0.10 ± 0.04
	4.5 - A ₄	0.12 ± 0.08	0.03 ± 0.03	0.00 ± 0.00	0.05 ± 0.03
	B mean	0.17 ± 0.04	0.15 ± 0.04	0.16 ± 0.05	
30-45	0 - A ₁	0.43 ± 0.02	0.28 ± 0.07	0.36 ± 0.02	0.36 ± 0.03
	1.5 - A ₂	0.26 ± 0.07	0.26 ± 0.00	0.26 ± 0.00	0.26 ± 0.02
	3.0 - A ₃	0.19 ± 0.14	0.21 ± 0.03	0.20 ± 0.07	0.20 ± 0.05
	4.5 - A ₄	0.12 ± 0.08	0.09 ± 0.05	0.20 ± 0.10	0.14 ± 0.04
	B mean	0.25 ± 0.05	0.21 ± 0.05	0.26 ± 0.03	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.2.6 Effects of limestone applications on exchangeable acidity on the Kasarama loamy sand No. 810 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.35 ± 0.09	0.12 ± 0.06	0.26 ± 0.16	0.24 ± 0.07
	1.5 - A ₂	0.28 ± 0.09	0.06 ± 0.03	0.21 ± 0.03	0.15 ± 0.05
	3.0 - A ₃	0.12 ± 0.08	0.03 ± 0.03	0.14 ± 0.10	0.10 ± 0.04
	4.5 - A ₄	0.09 ± 0.05	0.03 ± 0.03	0.20 ± 0.20	0.11 ± 0.06
	B mean	0.21 ± 0.05	0.06 ± 0.02	0.20 ± 0.06	
15-30	0 - A ₁	0.51 ± 0.02	0.43 ± 0.04	0.24 ± 0.15	0.39 ± 0.06
	1.5 - A ₂	0.41 ± 0.12	0.06 ± 0.03	0.31 ± 0.07	0.19 ± 0.06
	3.0 - A ₃	0.09 ± 0.05	0.12 ± 0.08	0.14 ± 0.10	0.12 ± 0.04
	4.5 - A ₄	0.09 ± 0.09	0.03 ± 0.03	0.18 ± 0.18	0.30 ± 0.08
	B mean	0.28 ± 0.07	0.16 ± 0.05	0.22 ± 0.06	
30-45	0 - A ₁	0.51 ± 0.02	0.58 ± 0.10	0.42 ± 0.16	0.50 ± 0.06
	1.5 - A ₂	0.37 ± 0.12	0.10 ± 0.00	0.42 ± 0.09	0.30 ± 0.06
	3.0 - A ₃	0.15 ± 0.06	0.03 ± 0.03	0.17 ± 0.12	0.12 ± 0.05
	4.5 - A ₄	0.17 ± 0.10	0.23 ± 0.09	0.20 ± 0.20	0.20 ± 0.07
	B mean	0.30 ± 0.06	0.23 ± 0.07	0.30 ± 0.07	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.2.7 Effects of limestone applications on exchangeable acidity on the Kairuni loamy sand No. 815 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.36 ± 0.06	0.12 ± 0.08	0.03 ± 0.03	0.17 ± 0.06
	1.5 - A ₂	0.06 ± 0.03	0.09 ± 0.05	0.28 ± 0.09	0.15 ± 0.05
	3.0 - A ₃	0.06 ± 0.03	0.17 ± 0.12	0.09 ± 0.09	0.11 ± 0.05
	4.5 - A ₄	0.06 ± 0.06	0.00 ± 0.00	0.06 ± 0.03	0.04 ± 0.02
	B mean	0.14 ± 0.04	0.09 ± 0.04	0.12 ± 0.04	
15-30	0 - A ₁	0.22 ± 0.14	0.22 ± 0.11	0.28 ± 0.11	0.24 ± 0.06
	1.5 - A ₂	0.24 ± 0.14	0.09 ± 0.05	0.22 ± 0.12	0.19 ± 0.06
	3.0 - A ₃	0.15 ± 0.08	0.35 ± 0.18	0.31 ± 0.26	0.27 ± 0.10
	4.5 - A ₄	0.00 ± 0.00	0.03 ± 0.03	0.00 ± 0.00	0.01 ± 0.01
	B mean	0.15 ± 0.05	0.18 ± 0.06	0.20 ± 0.08	
30-45	0 - A ₁	0.39 ± 0.12	0.23 ± 0.07	0.40 ± 0.07	0.34 ± 0.05
	1.5 - A ₂	0.40 ± 0.07	0.14 ± 0.10	0.35 ± 0.10	0.30 ± 0.06
	3.0 - A ₃	0.29 ± 0.15	0.48 ± 0.09	0.17 ± 0.10	0.32 ± 0.07
	4.5 - A ₄	0.09 ± 0.05	0.09 ± 0.09	0.14 ± 0.14	0.11 ± 0.05
	B mean	0.29 ± 0.06	0.24 ± 0.06	0.26 ± 0.06	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.2.8 Effects of limestone applications on exchangeable acidity on the Bukaruna loamy sand No. 816 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.18 ± 0.05	0.20 ± 0.07	0.29 ± 0.05	0.22 ± 0.03
	1.5 - A ₂	0.17 ± 0.10	0.03 ± 0.03	0.09 ± 0.05	0.10 ± 0.04
	3.0 - A ₃	0.21 ± 0.19	0.00 ± 0.00	0.03 ± 0.03	0.01 ± 0.01
	4.5 - A ₄	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	B mean	0.09 ± 0.04	0.06 ± 0.03	0.10 ± 0.04	
15-30	0 - A ₁	0.15 ± 0.03	0.18 ± 0.05	0.29 ± 0.02	0.21 ± 0.03
	1.5 - A ₂	0.20 ± 0.07	0.06 ± 0.03	0.09 ± 0.05	0.12 ± 0.03
	3.0 - A ₃	0.18 ± 0.18	0.06 ± 0.03	0.23 ± 0.07	0.11 ± 0.04
	4.5 - A ₄	0.00 ± 0.00	0.06 ± 0.03	0.10 ± 0.01	0.05 ± 0.02
	B mean	0.10 ± 0.03	0.09 ± 0.02	0.18 ± 0.03	
30-45	0 - A ₁	0.26 ± 0.04	0.21 ± 0.03	0.34 ± 0.00	0.27 ± 0.02
	1.5 - A ₂	0.29 ± 0.05	0.06 ± 0.03	0.17 ± 0.09	0.17 ± 0.04
	3.0 - A ₃	0.17 ± 0.12	0.09 ± 0.05	0.26 ± 0.04	0.17 ± 0.05
	4.5 - A ₄	0.15 ± 0.03	0.09 ± 0.09	0.12 ± 0.06	0.12 ± 0.03
	B mean	0.22 ± 0.04	0.11 ± 0.03	0.22 ± 0.03	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.3.1 Effects of limestone applications on exchangeable Ca on the Tabela sand No. 800 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.42 ± 0.21	0.50 ± 0.05	0.29 ± 0.06	0.40 ± 0.07
	1.5 - A ₂	0.85 ± 0.07	1.15 ± 0.51	0.87 ± 0.47	0.96 ± 0.21
	3.0 - A ₃	0.70 ± 0.03	1.58 ± 0.25	0.79 ± 0.40	1.02 ± 0.20
	4.5 - A ₄	1.91 ± 0.24	1.74 ± 0.19	1.21 ± 0.12	1.62 ± 0.14
	B mean	0.97 ± 0.18	1.24 ± 0.19	0.79 ± 0.17	
15-30	0 - A ₁	0.27 ± 0.06	0.59 ± 0.04	0.27 ± 0.04	0.38 ± 0.06
	1.5 - A ₂	0.61 ± 0.24	0.33 ± 0.10	0.23 ± 0.08	0.39 ± 0.10
	3.0 - A ₃	0.35 ± 0.13	0.30 ± 0.01	0.38 ± 0.20	0.34 ± 0.07
	4.5 - A ₄	1.21 ± 0.06	0.50 ± 0.11	0.37 ± 0.05	0.69 ± 0.14
	B mean	0.61 ± 0.13	0.43 ± 0.05	0.31 ± 0.05	
30-45	0 - A ₁	0.17 ± 0.05	0.37 ± 0.09	0.17 ± 0.03	0.24 ± 0.05
	1.5 - A ₂	0.40 ± 0.03	0.20 ± 0.07	0.15 ± 0.07	0.25 ± 0.05
	3.0 - A ₃	0.54 ± 0.20	0.23 ± 0.05	0.33 ± 0.06	0.37 ± 0.08
	4.5 - A ₄	0.33 ± 0.02	0.20 ± 0.05	0.23 ± 0.08	0.25 ± 0.03
	B mean	0.36 ± 0.06	0.25 ± 0.04	0.22 ± 0.03	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.3.2 Effects of limestone applications on exchangeable Ca on the Kasarama loamy sand No. 810 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	1.18 ± 0.31	1.87 ± 0.85	1.78 ± 0.78	1.61 ± 0.36
	1.5 - A ₂	1.50 ± 0.13	2.14 ± 0.39	2.06 ± 0.59	1.90 ± 0.23
	3.0 - A ₃	2.58 ± 0.38	2.73 ± 0.73	2.31 ± 0.58	2.54 ± 0.30
	4.5 - A ₄	3.09 ± 0.99	2.31 ± 0.39	3.30 ± 1.18	2.90 ± 0.48
	B mean	2.09 ± 0.33	2.26 ± 0.28	2.36 ± 0.39	
15-30	0 - A ₁	1.03 ± 0.30	0.97 ± 0.19	0.97 ± 0.33	0.99 ± 0.14
	1.5 - A ₂	1.33 ± 0.30	1.63 ± 0.53	1.77 ± 0.76	1.58 ± 0.29
	3.0 - A ₃	1.44 ± 0.58	1.28 ± 0.46	1.26 ± 0.40	1.33 ± 0.24
	4.5 - A ₄	2.86 ± 1.27	1.50 ± 0.43	1.33 ± 0.53	1.90 ± 0.48
	B mean	1.66 ± 0.38	1.35 ± 0.20	1.33 ± 0.24	
30-45	0 - A ₁	0.82 ± 0.25	1.02 ± 0.11	0.88 ± 0.24	0.91 ± 0.11
	1.5 - A ₂	0.97 ± 0.23	1.45 ± 0.49	0.91 ± 0.36	1.11 ± 0.21
	3.0 - A ₃	0.90 ± 0.37	1.13 ± 0.39	1.20 ± 0.50	1.08 ± 0.22
	4.5 - A ₄	1.30 ± 0.57	1.55 ± 0.24	1.28 ± 0.45	1.38 ± 0.22
	B mean	1.00 ± 0.17	1.29 ± 0.16	1.07 ± 0.18	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.3.3 Effects of limestone applications on exchangeable Ca on the Kairuni loamy sand No. 815 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.54 ± 0.07	1.16 ± 0.54	0.79 ± 0.22	0.83 ± 0.19
	1.5 - A ₂	1.33 ± 0.38	1.06 ± 0.32	1.27 ± 0.42	1.22 ± 0.19
	3.0 - A ₃	1.66 ± 0.49	1.65 ± 0.17	1.97 ± 0.35	1.76 ± 0.19
	4.5 - A ₄	2.73 ± 0.19	1.48 ± 0.47	1.43 ± 0.40	1.88 ± 0.28
	B mean	1.56 ± 0.28	1.33 ± 0.19	1.37 ± 0.22	
15-30	0 - A ₁	0.70 ± 0.22	0.45 ± 0.12	0.51 ± 0.10	0.56 ± 0.09
	1.5 - A ₂	0.61 ± 0.22	0.87 ± 0.19	0.60 ± 0.16	0.69 ± 0.11
	3.0 - A ₃	1.03 ± 0.23	0.52 ± 0.18	0.94 ± 0.27	0.83 ± 0.14
	4.5 - A ₄	1.56 ± 0.14	0.99 ± 0.18	0.58 ± 0.06	1.04 ± 0.16
	B mean	0.98 ± 0.14	0.71 ± 0.10	0.66 ± 0.09	
30-45	0 - A ₁	0.69 ± 0.20	0.51 ± 0.18	0.41 ± 0.07	0.54 ± 0.09
	1.5 - A ₂	1.01 ± 0.62	0.64 ± 0.06	0.86 ± 0.05	0.84 ± 0.19
	3.0 - A ₃	0.98 ± 0.40	0.55 ± 0.10	0.57 ± 0.13	0.70 ± 0.14
	4.5 - A ₄	0.90 ± 0.20	0.71 ± 0.27	0.55 ± 0.14	0.72 ± 0.12
	B mean	0.90 ± 0.17	0.60 ± 0.08	0.60 ± 0.07	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.3.4 Effects of limestone applications on exchangeable Ca on the Bukaruna loamy sand No. 816 at the end of the first season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.58 ± 0.10	0.98 ± 0.18	0.85 ± 0.07	0.80 ± 0.09
	1.5 - A ₂	1.29 ± 0.14	1.21 ± 0.33	1.55 ± 0.13	1.35 ± 0.12
	3.0 - A ₃	1.07 ± 0.34	1.68 ± 0.48	1.92 ± 0.37	1.56 ± 0.24
	4.5 - A ₄	1.89 ± 0.48	1.46 ± 0.40	1.61 ± 0.34	1.65 ± 0.21
	B mean	1.21 ± 0.19	1.33 ± 0.17	1.48 ± 0.16	
15-30	0 - A ₁	1.02 ± 0.53	0.76 ± 0.24	0.62 ± 0.20	0.80 ± 0.19
	1.5 - A ₂	0.78 ± 0.12	1.08 ± 0.05	0.74 ± 0.28	0.87 ± 0.10
	3.0 - A ₃	0.69 ± 0.11	1.18 ± 0.14	0.39 ± 0.16	0.75 ± 0.13
	4.5 - A ₄	0.99 ± 0.41	1.07 ± 0.36	0.82 ± 0.05	0.96 ± 0.16
	B mean	0.87 ± 0.15	1.02 ± 0.11	0.64 ± 0.09	
30-45	0 - A ₁	0.32 ± 0.01	0.58 ± 0.28	0.62 ± 0.24	0.51 ± 0.12
	1.5 - A ₂	0.43 ± 0.14	0.76 ± 0.02	0.28 ± 0.04	0.49 ± 0.08
	3.0 - A ₃	0.51 ± 0.03	0.46 ± 0.12	0.41 ± 0.17	0.46 ± 0.06
	4.5 - A ₄	0.45 ± 0.12	0.44 ± 0.05	0.62 ± 0.09	0.50 ± 0.05
	B mean	0.43 ± 0.04	0.56 ± 0.08	0.48 ± 0.08	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.3.5 Effects of limestone applications on exchangeable Ca on the Tabela sand No. 800 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.41 ± 0.11	0.86 ± 0.46	0.61 ± 0.25	0.62 ± 0.17
	1.5 - A ₂	0.79 ± 0.35	0.46 ± 0.18	0.62 ± 0.22	0.62 ± 0.14
	3.0 - A ₃	1.42 ± 0.15	0.89 ± 0.05	0.93 ± 0.34	1.08 ± 0.14
	4.5 - A ₄	0.79 ± 0.24	1.19 ± 0.35	1.45 ± 0.24	1.14 ± 0.17
	B mean	0.85 ± 0.15	0.85 ± 0.15	0.90 ± 0.15	
15-30	0 - A ₁	0.44 ± 0.20	0.72 ± 0.42	0.43 ± 0.13	0.53 ± 0.15
	1.5 - A ₂	0.97 ± 0.45	0.67 ± 0.32	0.52 ± 0.12	0.72 ± 0.17
	3.0 - A ₃	0.90 ± 0.27	0.60 ± 0.03	0.93 ± 0.06	0.81 ± 0.10
	4.5 - A ₄	1.19 ± 0.17	1.36 ± 0.08	1.07 ± 0.20	1.21 ± 0.09
	B mean	0.87 ± 0.15	0.84 ± 0.15	0.74 ± 0.10	
30-45	0 - A ₁	0.50 ± 0.09	0.69 ± 0.26	0.69 ± 0.20	0.63 ± 0.10
	1.5 - A ₂	0.61 ± 0.17	0.51 ± 0.25	0.75 ± 0.18	0.62 ± 0.11
	3.0 - A ₃	0.59 ± 0.22	0.49 ± 0.06	0.53 ± 0.17	0.54 ± 0.08
	4.5 - A ₄	0.98 ± 0.33	0.60 ± 0.22	0.93 ± 0.15	0.84 ± 0.14
	B mean	0.67 ± 0.11	0.57 ± 0.09	0.72 ± 0.09	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.3.6 Effects of limestone applications on exchangeable Ca on the Kasarama loamy sand No. 810 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.84 ± 0.12	1.27 ± 0.16	0.88 ± 0.36	1.00 ± 0.14
	1.5 - A ₂	1.55 ± 0.44	1.65 ± 0.09	1.48 ± 0.16	1.56 ± 0.14
	3.0 - A ₃	1.09 ± 0.34	2.14 ± 0.34	2.07 ± 0.47	1.77 ± 0.26
	4.5 - A ₄	2.50 ± 0.65	2.39 ± 0.53	1.86 ± 0.70	2.25 ± 0.33
	B mean	1.50 ± 0.26	1.86 ± 0.19	1.57 ± 0.24	
15-30	0 - A ₁	0.81 ± 0.07	1.37 ± 0.56	1.62 ± 0.07	1.27 ± 0.20
	1.5 - A ₂	1.37 ± 0.21	1.69 ± 0.21	1.58 ± 0.69	1.55 ± 0.22
	3.0 - A ₃	1.69 ± 0.21	2.21 ± 0.34	2.32 ± 0.53	2.07 ± 0.21
	4.5 - A ₄	2.60 ± 0.83	2.29 ± 0.55	1.69 ± 0.62	2.19 ± 0.36
	B mean	1.62 ± 0.27	1.89 ± 0.22	1.80 ± 0.25	
30-45	0 - A ₁	0.63 ± 0.06	1.16 ± 0.12	1.02 ± 0.30	0.94 ± 0.12
	1.5 - A ₂	1.27 ± 0.49	1.86 ± 0.14	1.55 ± 0.68	1.56 ± 0.86
	3.0 - A ₃	1.55 ± 0.18	1.76 ± 0.36	1.93 ± 0.64	1.75 ± 0.23
	4.5 - A ₄	1.62 ± 0.34	1.79 ± 0.30	1.30 ± 0.07	1.57 ± 0.15
	B mean	1.27 ± 0.18	1.64 ± 0.14	1.45 ± 0.23	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.3.7 Effects of limestone applications on exchangeable Ca on the Kairuni loamy sand No. 815 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.69 ± 0.14	0.48 ± 0.12	0.59 ± 0.23	0.59 ± 0.09
	1.5 - A ₂	1.00 ± 0.21	0.77 ± 0.35	1.27 ± 0.42	1.22 ± 0.19
	3.0 - A ₃	0.87 ± 0.25	1.01 ± 0.33	0.95 ± 0.26	0.94 ± 0.14
	4.5 - A ₄	0.76 ± 0.14	1.24 ± 0.34	0.92 ± 0.14	0.97 ± 0.13
	B mean	0.83 ± 0.09	0.88 ± 0.15	0.81 ± 0.14	
15-30	0 - A ₁	0.72 ± 0.17	0.63 ± 0.32	0.55 ± 0.25	0.63 ± 0.13
	1.5 - A ₂	0.89 ± 0.17	0.72 ± 0.31	0.93 ± 0.25	0.85 ± 0.13
	3.0 - A ₃	0.97 ± 0.20	0.53 ± 0.32	0.86 ± 0.21	0.79 ± 0.14
	4.5 - A ₄	1.22 ± 0.10	1.05 ± 0.16	2.10 ± 0.63	1.46 ± 0.25
	B mean	0.95 ± 0.09	0.73 ± 0.14	1.11 ± 0.24	
30-45	0 - A ₁	0.67 ± 0.32	0.52 ± 0.26	0.60 ± 0.14	0.60 ± 0.13
	1.5 - A ₂	0.52 ± 0.07	0.82 ± 0.17	0.53 ± 0.14	0.62 ± 0.08
	3.0 - A ₃	0.62 ± 0.16	0.45 ± 0.17	1.04 ± 0.20	0.71 ± 0.12
	4.5 - A ₄	1.24 ± 0.24	0.83 ± 0.20	0.94 ± 0.28	1.00 ± 0.14
	B mean	0.76 ± 0.13	0.66 ± 0.10	0.78 ± 0.11	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

Table A2.3.8 Effects of limestone applications on exchangeable Ca on the Bukaruna loamy sand No. 816 at the end of the second season.

Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	Depth of Limestone Placement ¹			A mean
		B ₁	B ₂	B ₃	
me 100 g ⁻¹ soil					
0-15	0 - A ₁	0.57 ± 0.09	0.69 ± 0.15	0.48 ± 0.16	0.58 ± 0.08
	1.5 - A ₂	0.58 ± 0.20	0.95 ± 0.07	0.85 ± 0.28	0.79 ± 0.11
	3.0 - A ₃	1.47 ± 0.18	1.79 ± 0.26	1.28 ± 0.23	1.51 ± 0.14
	4.5 - A ₄	1.66 ± 0.31	1.41 ± 0.08	1.47 ± 0.21	1.51 ± 0.12
	B mean	1.07 ± 0.18	1.21 ± 0.14	1.02 ± 0.15	
15-30	0 - A ₁	0.53 ± 0.05	0.77 ± 0.14	0.62 ± 0.11	0.64 ± 0.06
	1.5 - A ₂	0.61 ± 0.16	0.91 ± 0.22	0.92 ± 0.24	0.81 ± 0.12
	3.0 - A ₃	1.77 ± 0.38	1.49 ± 0.27	0.71 ± 0.09	1.32 ± 0.21
	4.5 - A ₄	1.38 ± 0.05	1.15 ± 0.21	1.27 ± 0.13	1.27 ± 0.08
	B mean	1.07 ± 0.18	1.08 ± 0.12	0.88 ± 0.10	
30-45	0 - A ₁	0.42 ± 0.07	0.53 ± 0.17	0.39 ± 0.09	0.44 ± 0.06
	1.5 - A ₂	0.81 ± 0.32	1.02 ± 0.11	0.62 ± 0.25	0.82 ± 0.13
	3.0 - A ₃	1.19 ± 0.43	0.97 ± 0.18	0.65 ± 0.18	0.94 ± 0.17
	4.5 - A ₄	0.70 ± 0.19	0.97 ± 0.17	0.99 ± 0.16	0.89 ± 0.10
	B mean	0.78 ± 0.15	0.87 ± 0.09	0.66 ± 0.10	

¹B₁: 15-30 cm; B₂: 0-30 cm; B₃: 0-15 cm

APPENDIX C

Soil Chemical Properties - Probability Tables

Table A2.4 Probabilities associated with F values for sources and soil extractable P on four soils at the end of two seasons.

SOIL DEPTH (cm)	SOURCE ¹	SOIL TYPE							
		800		810		815		816	
		PH1 ²	PH2 ²	PH1	PH2	PH1	PH2	PH1	PH2
0-15	R	N.S.	N.S.	N.S.	**	*	N.S.	N.S.	N.S.
	A	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	**
15-30	R	N.S.	N.S.	N.S.	*	N.S.	N.S.	**	N.S.
	A	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
30-45	R	**	N.S.	N.S.	N.S.	N.S.	N.S.	**	N.S.
	A	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

¹R - blocks; A - limestone rates; B - limestone placement depths.

²PH1: Post-harvest Crop 1; PH2: Post-harvest Crop 2.

*,** Indicates that F values are significant at the 0.05, 0.01 levels of probability, respectively.

Table A2.5

Probabilities associated with F values for sources and soil exchangeable K on four soils at the end of two seasons.

SOIL DEPTH (cm)	SOURCE ¹	SOIL TYPE							
		800		810		815		816	
		PH1 ²	PH2 ²	PH1	PH2	PH1	PH2	PH1	PH2
0-15	R	**	N.S.	N.S.	N.S.	*	N.S.	**	**
	A	*	N.S.	N.S.	N.S.	N.S.	*	N.S.	N.S.
	B	N.S.	N.S.	N.S.	*	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
15-30	R	**	*	N.S.	N.S.	**	**	**	N.S.
	A	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
30-45	R	N.S.	N.S.	N.S.	N.S.	*	*	**	**
	A	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*
	B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

¹R - blocks; A - limestone rates; B - limestone placement depths.

²PH1: Post-harvest Crop 1; PH2: Post-harvest Crop 2.

*, ** Indicates that F values are significant at the 0.05, 0.01 levels of probability, respectively.

Table A2.6

Probabilities associated with F values for sources and soil exchangeable Mg on four soils at the end of two seasons.

SOIL DEPTH (cm)	SOURCE ¹	SOIL TYPE							
		800		810		815		816	
		PH1 ²	PH2 ²	PH1	PH2	PH1	PH2	PH1	PH2
0-15	R	N.S.	**	*	N.S.	N.S.	N.S.	**	N.S.
	A	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
15-30	R	**	**	**	N.S.	N.S.	N.S.	**	**
	A	N.S.	N.S.	N.S.	N.S.	*	N.S.	N.S.	N.S.
	B	*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
30-45	R	**	**	**	N.S.	N.S.	N.S.	N.S.	**
	A	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

¹R - blocks; A - limestone rates; B - limestone placement depths.

²PH1: Post-harvest Crop 1; PH2: Post-harvest Crop 2.

*,** Indicates that F values are significant at the 0.05, 0.01 levels of probability, respectively.

APPENDIX D

Soil Chemical Properties - Mean Values for Limestone Rates

Table A2.7 P means for limestone rates.

Season	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	SOIL TYPE				
			800	810	815	816	
-----P (ppm)-----							
1.	0-15	0 - A ₁	13	69	35	14	
		1.5 - A ₂	17	54	29	18	
		3.0 - A ₃	14	49	33	23	
		4.5 - A ₄	21	54	29	11	
	15-30	0 - A ₁	6	24	12	9	
		1.5 - A ₂	6	26	11	10	
		3.0 - A ₃	6	24	6	7	
		4.5 - A ₄	9	42	12	9	
	30-45	0 - A ₁	9	14	7	7	
		1.5 - A ₂	11	17	9	6	
		3.0 - A ₃	6	16	9	6	
		4.5 - A ₄	8	26	10	6	
	2.	0-15	0 - A ₁	30	70	50	23
			1.5 - A ₂	30	70	43	18
			3.0 - A ₃	39	57	42	25
			4.5 - A ₄	39	57	42	25
15-30		0 - A ₁	27	53	33	23	
		1.5 - A ₂	29	58	36	17	
		3.0 - A ₃	44	43	30	17	
		4.5 - A ₄	29	62	30	14	
30-45		0 - A ₁	18	82	20	11	
		1.5 - A ₂	19	79	21	16	
		3.0 - A ₃	17	77	23	13	
		4.5 - A ₄	17	82	24	15	

Table A2.8 K means for limestone rates.

Season	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	800	SOIL TYPE		
				810	815	816
----- K (me 100 g ⁻¹ soil)-----						
1.	0-15	0 - A ₁	0.09	0.19	0.11	0.17
		1.5 - A ₂	0.03	0.18	0.13	0.14
		3.0 - A ₃	0.03	0.16	0.15	0.10
		4.5 - A ₄	0.03	0.17	0.09	0.13
	15-30	0 - A ₁	0.05	0.19	0.09	0.13
		1.5 - A ₂	0.03	0.12	0.08	0.19
		3.0 - A ₃	0.04	0.18	0.11	0.17
		4.5 - A ₄	0.07	0.14	0.11	0.17
	30-45	0 - A ₁	0.05	0.18	0.07	0.16
		1.5 - A ₂	0.13	0.15	0.08	0.12
		3.0 - A ₃	0.03	0.19	0.07	0.12
		4.5 - A ₄	0.04	0.14	0.10	0.17
2.	0-15	0 - A ₁	0.03	0.25	0.19	0.07
		1.5 - A ₂	0.01	0.22	0.25	0.07
		3.0 - A ₃	0.02	0.24	0.19	0.13
		4.5 - A ₄	0.02	0.22	0.10	0.09
	15-30	0 - A ₁	0.03	0.14	0.17	0.07
		1.5 - A ₂	0.02	0.12	0.11	0.11
		3.0 - A ₃	0.03	0.19	0.12	0.10
		4.5 - A ₄	0.03	0.12	0.14	0.15
	30-45	0 - A ₁	0.02	0.15	0.11	0.12
		1.5 - A ₂	0.01	0.16	0.12	0.10
		3.0 - A ₃	0.01	0.13	0.15	0.08
		4.5 - A ₄	0.02	0.11	0.11	0.07

Table A2.9 Mg means for limestone rates.

Season	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	SOIL TYPE			
			800	810	815	816
----- Mg (me 100 g ⁻¹ soil) -----						
1.	0-15	0 - A ₁	0.08	0.19	0.12	0.09
		1.5 - A ₂	0.11	0.19	0.10	0.13
		3.0 - A ₃	0.09	0.17	0.11	0.10
		4.5 - A ₄	0.10	0.18	0.13	0.11
	15-30	0 - A ₁	0.07	0.16	0.09	0.08
		1.5 - A ₂	0.07	0.15	0.09	0.10
		3.0 - A ₃	0.06	0.16	0.09	0.10
		4.5 - A ₄	0.10	0.14	0.12	0.09
	30-45	0 - A ₁	0.05	0.15	0.08	0.07
		1.5 - A ₂	0.05	0.15	0.09	0.06
		3.0 - A ₃	0.06	0.13	0.09	0.06
		4.5 - A ₄	0.06	0.13	0.11	0.07
2.	0-15	0 - A ₁	0.05	0.23	0.16	0.14
		1.5 - A ₂	0.04	0.19	0.14	0.14
		3.0 - A ₃	0.05	0.17	0.10	0.19
		4.5 - A ₄	0.08	0.18	0.11	0.16
	15-30	0 - A ₁	0.05	0.22	0.09	0.15
		1.5 - A ₂	0.06	0.17	0.14	0.14
		3.0 - A ₃	0.06	0.08	0.09	0.13
		4.5 - A ₄	0.07	0.18	0.14	0.14
	30-45	0 - A ₁	0.05	0.21	0.16	0.12
		1.5 - A ₂	0.06	0.17	0.11	0.12
		3.0 - A ₃	0.05	0.15	0.11	0.12
		4.5 - A ₄	0.06	0.21	0.15	0.12

APPENDIX E

Soil Chemical Properties - Probability Tables

Table A3.1 Probabilities associated with F values for sources and soil extractable P on two soils at the end of two seasons.

Soil Depth (cm)	SOURCE ¹	SOIL TYPE			
		800	PH1 ²	PH2 ²	815
		PH1 ²		PH1	PH2
0-15	R	*	N.S.	N.S.	N.S.
	A	N.S.	N.S.	N.S.	N.S.
	B	N.S.	*	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.
15-30	R	N.S.	N.S.	*	N.S.
	A	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.
30-45	R	N.S.	N.S.	N.S.	N.S.
	A	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	*	N.S.	N.S.

¹R - blocks; A - limestone rates; B - tillage depths.

²PH1: Post-harvest Crop 1; PH2: Post-harvest Crop 2.

*,** Indicates that F values are significant at the 0.05, 0.01 levels of probability, respectively.

Table A3.2 Probabilities associated with F values for sources and soil exchangeable K on two soils at the end of two seasons.

Soil Depth (cm)	SOURCE ¹	SOIL TYPE			
		800	815		
		PH1 ²	PH2 ²	PH1	PH2
0-15	R	N.S.	N.S.	N.S.	N.S.
	A	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.
15-30	R	N.S.	N.S.	N.S.	N.S.
	A	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.
30-45	R	N.S.	N.S.	*	N.S.
	A	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	*	N.S.

¹R - blocks; A - limestone rate; B - tillage depths.

²PH1: Post-harvest Crop 1; PH2: Post-harvest Crop 2.

*,** Indicates that F values are significant at the 0.05, 0.01 levels of probability, respectively.

Table A3.3

Probabilities associated with F values for sources and soil exchangeable Mg on two soils at the end of two seasons.

Soil Depth (cm)	SOURCE ¹	SOIL TYPE			
		800		815	
		PH1 ²	PH2 ²	PH1	PH2
0-15	R	N.S.	N.S.	N.S.	N.S.
	A	N.S.	*	N.S.	*
	B	N.S.	N.S.	N.S.	*
	A*R	N.S.	N.S.	N.S.	N.S.
15-30	R	N.S.	N.S.	N.S.	N.S.
	A	N.S.	N.S.	N.S.	N.S.
	B	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	N.S.	N.S.	N.S.
30-45	R	**	**	N.S.	N.S.
	A	N.S.	N.S.	N.S.	*
	B	N.S.	N.S.	N.S.	N.S.
	A*B	N.S.	*	N.S.	N.S.

¹R - blocks; A - limestone rates; B - tillage depths.

²PH1: Post-harvest Crop 1; PH2: Post-harvest Crop 2.

*, ** Indicates that F values are significant at the 0.05, 0.01 levels of probability, respectively.

APPENDIX F

Soil Chemical Properties - Mean Values for Limestone Rates

Table A3.4 P Means for limestone rates.

Season	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	SOIL TYPE	
			800	815
----- P (ppm) -----				
1.	0-15	0 - A ₁	19	24
		3.0 - A ₂	16	21
	15-30	0 - A ₁	10	17
		3.0 - A ₂	12	14
	30-45	0 - A ₁	4	5
		3.0 - A ₂	4	13
2.	0-15	0 - A ₁	10	29
		3.0 - A ₂	13	29
	15-30	0 - A ₁	14	23
		3.0 - A ₂	13	35
	30-45	0 - A ₁	10	7
		3.0 - A ₂	11	18

Table A3.5 K means for limestone rates.

Season	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	SOIL TYPE	
			800	815
-- K (me 100 g ⁻¹ soil) --				
1.	0-15	0 - A ₁	0.02	0.13
		3.0 - A ₂	0.02	0.07
	15-30	0 - A ₁	0.02	0.09
		3.0 - A ₂	0.02	0.08
	30-45	0 - A ₁	0.02	0.06
		3.0 - A ₂	0.01	0.05
2.	0-15	0 - A ₁	0.03	0.07
		3.0 - A ₂	0.04	0.09
	15-30	0 - A ₁	0.04	0.08
		3.0 - A ₂	0.04	0.09
	30-45	0 - A ₁	0.05	0.12
		3.0 - A ₂	0.03	0.09

Table A3.6 Mg means for limestone rates.

Season	Soil Depth (cm)	Applied Limestone (Mg ha ⁻¹)	SOIL TYPE	
			800	815
-- Mg (me 100 g ⁻¹ soil) --				
1.	0-15	0 - A ₁	0.58	0.12
		3.0 - A ₂	0.69	0.16
	15-30	0 - A ₁	0.31	0.07
		3.0 - A ₂	0.26	0.09
	30-45	0 - A ₁	0.25	0.06
		3.0 - A ₂	0.19	0.07
2.	0-15	0 - A ₁	0.14	0.05
		3.0 - A ₂	0.27	0.19
	15-30	0 - A ₁	0.21	0.10
		3.0 - A ₂	0.18	0.07
	30-45	0 - A ₁	0.25	0.01
		3.0 - A ₂	0.19	0.09

APPENDIX G

Tillage Depth Effects on Soil Physical Properties

Table A3.7 Effects of two tillage¹ depths on dry bulk density means (Mg m^{-3}) at four sampling intervals on two soils.

Soil Type	Soil Depth (cm)	Tillage Depth ¹ (cm)	Pre-tillage	Post-tillage	Post-harvest1	Post-harvest2
----- (Mg m^{-3}) -----						
Tabela sand No. 800	0-15	B ₁	1.45±0.02	1.52±0.01	1.53±0.04	1.64±0.03
		B ₂	1.44±0.02	1.44±0.04	1.53±0.02	1.62±0.02
Kairuni loamy sand No. 815		B ₁	1.45±0.02	1.48±0.02	1.41±0.04	1.64±0.05
		B ₂	1.42±0.02	1.35±0.04	1.42±0.06	1.62±0.04
Tabela sand No. 800	15-30	B ₁	1.41±0.02	1.49±0.03	1.54±0.01	1.68±0.03
		B ₂	1.42±0.02	1.53±0.02	1.49±0.02	1.67±0.03
Kairuni loamy sand No. 815		B ₁	1.46±0.01	1.46±0.04	1.50±0.03	1.51±0.04
		B ₂	1.49±0.03	1.55±0.03	1.46±0.02	1.52±0.05
Tabela sand No. 800	30-45	B ₁	1.36±0.02	1.47±0.03	1.43±0.02	1.61±0.05
		B ₂	1.38±0.02	1.47±0.05	1.45±0.01	1.63±0.03
Kairuni loamy sand No. 815		B ₁	1.43±0.02	1.50±0.02	1.50±0.02	1.44±0.06
		B ₂	1.43±0.01	1.43±0.02	1.47±0.03	1.47±0.03

¹B₁: 0-15 cm; B₂: 0-30 cm.

Table A3.8

Effects of two tillage depths on mechanical impedance means (kPa) at four sampling intervals on two soils.

Soil Type	Soil Depth (cm)	Tillage Depth ¹ (cm)	Pre-tillage	Post-tillage	Post-harvest1	Post-harvest2
----- kPa -----						
Tabela sand No. 800	0-15	B ₁	1946±298	100	1210±175	2191±416
		B ₂	2452±379	100	1929±382	2060±402
Kairuni loamy sand No. 815		B ₁	1978±208	100	2436±569	3908±514
		B ₂	1782±245	100	1504±213	4087±297
Tabela sand No. 800	15-30	B ₁	5085±484	4921±566	5085±190	4611±598
		B ₂	5641±556	916±334	5314±710	4055±722
Kairuni loamy sand No. 815		B ₁	7112±506	6131±287	5870±663	6115±543
		B ₂	6197	3433	4840	5771
Tabela sand No. 800	30-45	B ₁	4774±352	4496±302	5968±321	7717±722
		B ₂	5428±581	3826±566	5575±458	7047±907
Kairuni loamy sand No. 815		B ₁	6524±167	6802±226	6802±532	7832±788
		B ₂	6638±448	6785±449	6049±207	6965±441

¹B₁: 0-15 cm; B₂: 0-30 cm.

Table A3.9

Effects of two tillage depths on water content means (%)
at four sampling intervals on two soils.

Soil Type	Soil Depth (cm)	Tillage Depth ¹ (cm)	Pre-tillage	Post-tillage	Post-harvest1	Post-harvest2
----- % -----						
Tabela sand No. 800	0-15	B ₁	11.9±0.4	11.8±0.6	6.7±0.5	8.4±0.7
		B ₂	11.6±0.6	12.3±0.6	8.0±0.5	9.3±0.9
Kairuni loamy sand No. 815		B ₁	14.6±0.5	14.1±0.5	5.2±0.8	9.3±1.7
		B ₂	13.7±0.6	15.0±0.8	5.5±0.5	10.7±1.9
Tabela sand No. 800	15-30	B ₁	13.7±0.4	13.4±0.6	6.9±0.5	8.7±1.2
		B ₂	14.0±0.7	12.9±0.6	8.6±1.9	9.5±0.9
Kairuni loamy sand No. 815		B ₁	15.5±0.4	15.9±0.2	7.6±0.6	7.7±1.8
		B ₂	14.9±0.7	15.4±0.5	5.3±0.8	8.8±0.6
Tabela sand No. 800	30-45	B ₁	15.5±0.2	15.1±0.3	7.6±1.4	9.1±0.9
		B ₂	15.7±0.4	14.8±0.4	7.1±0.4	7.9±0.5
Kairuni loamy sand No. 815		B ₁	15.1±0.2	15.5±0.3	7.9±0.8	7.7±1.8
		B ₂	15.0±0.6	15.3±0.2	7.5±0.4	8.4±0.8

¹B₁: 0-15 cm; B₂: 0-30 cm.