STATUS, AVAILABILITY AND TRANSFORMATION OF MAGNESIUM IN ACID SOILS OF KERALA

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Status, availability and transformation of magnesium in acid soils of Kerala"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any University or Society.

Vellanikkara,
24th September, 1992.

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Certified that this thesis entitled **'Status, availability and transformation of magnesium in acid soils of Kerala'** is a record of research work done independently by **Miss D. Prema** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Miss D. Prema,** a candidate for the degree of Doctor of Philosophy in Agriculture with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled '**Status, availability and transformation of magnesium in acid soils of Kerala**' may be submitted by Miss D. Prema in partial fulfilment of the requirement for the degree.

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Dedicated to the
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CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF APPENDICES

Introduction

INTRODUCTION

Magnesium is needed by all green plants as it is a constituent of chlorophyll, the vital green colouring matter of plants. Being the only metal constituent of chlorophyll, it is essential for photosynthesis. It plays an important role in plant metabolism, as an activator of many enzymes. It also takes part in protein synthesis and acts as a carrier in transport of P in plants. Magnesium regulates the uptake of other nutrients and base economy of plants. This plant nutrient is supposed to increase resistance to harmful environmental influences such as drought and disease, because of its positive influence on the swelling and strength of the cell walls and on the permeability of the cell membrane. Deficient level of Mg in herbage dry matter causes grass tetany, a metabolic disorder in ruminant animals.

With modern high analysis fertilizers and present intensive cropping systems, deficiencies of secondary and micronutrients are reported to be common and the importance of Mg as a secondary nutrient is accepted universally. Magnesium deficiency has been reported in many crops. Magnesium is highly mobile and major deficiency symptoms are interveinal chlorosis mainly on older leaves exhibiting a streaked patchy appearance. In acute deficiency, the affected tissue may dry up and die. Leaves usually become small, brittle in final stages and curve upwards at margin.

Deficiency of magnesium is encountered in light, sandy soils, acid soils, coarse textured soils of humid tropics and in areas of continued cropping with the use of heavy doses of NPK fertilizers. Magnesium being highly susceptible to leaching, replenishment by weathering of soil minerals cannot keep pace with the loss by leaching. Under intensive cropping, crop removal is also a major form of loss from soil. The lack of Mg in soil causes absolute deficiency, which is aggrevated by soil acidity. Heavy fertilization with K and Ca may cause an induced deficiency of Mg, where high exchangeable K and/or Ca and high base saturation play an important role. Preventive measures need to be taken to reduce high losses of Mg through run off and leaching and balanced use of fertilizers has to be encouraged. Need based application of Mg fertilizers may also be suggested.

Magnesium is of considerable significance in acid soils (Prasad *et al.*, 1983). The content of MgO in acid soils of India is low varying from 0.1 to 1 per cent. This necessitates the use of ameliorating agents to bring about a favourable soil environment. A major portion of Kerala comprises of acid soils except a small patch of neutral to alkaline soils of Chittoor.

The availability of Mg has become very critical in the acid soils of Kerala. Though Mg deficiency has been often reported in many crops in the State, application of Mg is recommended as a regular practice only for a few crops, mainly due to limited information available on the status, availability and transformation of magnesium with special reference to crop requirements. The exchangeable Mg in soil is considered available to plants but the attempts to correlate it with Mg removed by crops have not been successful (Kanwar, 1976). It may indicate the potential supply over a long term, but does not indicate the amount which will become available to the crop over a short term. Banana is an important economic crop of Kerala, which is cultivated with heavy application of K fertilizer. This situation may aggrevate Mg deficiency and application of Mg fertilizers may become necessary. The principal Mg fertilizer is magnesium sulphate ($MgSO_4.7H_2O$) which contains 16 per cent MgO. It is costlier than nitrogenous fertilizers on unit nutrient basis. Magnesite quarried from northern districts of Tamil Nadu contains 28 to 30 per cent MgO and is the cheapest source of Mg. Though it contains no water soluble Mg, it is soluble under acid conditions. Another common source is dolomite. The study of pattern of release of Mg from these sources in two important soil types of Kerala, namely laterite and Kuttanad alluvium will be useful for a better fertilizer management which includes magnesium fertilizers.

Hence, the present investigation was taken up with the following objectives:

(1) To assess the Mg status of soils of Kerala

(2) To evolve a suitable extractant for the estimation of available Mg in Kerala soils

(3) To study the pattern of release of Mg in relation to the transformation of applied Mg in the form of $MgSO_4 \cdot 7H_2O$, magnesite and dolomite in two important soil types of Kerala viz., laterite and Kuttanad alluvium (karappadam); and

(4) To know the requirement of Mg for banana in relation to different sources of Mg and the pattern of uptake of nutrients by the crop.

Review of Literature

REVIEW OF LITERATURE

1. Magnesium content in soils

Magnesium is the eighth most common element in the lithosphere. As quoted by Jacob (1958), the solid earth crust contains an average concentration of 2.68 per cent of Mg. Average Mg concentration of most soils generally lies in the range of 0.05 per cent for sandy soils to 0.5 per cent for clayey soils.

Mathan (1964) recorded 0.01 to 0.76 per cent of magnesia (MgO) in the Nilgiris soils. The mean values of total Mg were observed to be 0.22, 0.09, 0.11 and 0.03 per cent for black, red, alluvial and laterite soils of South India, respectively (Loganathan, 1973). Ramanathan (1974) recorded 0.01 to 0.02 per cent total Mg in the soils of Ootacamund and Coonoor in the Nilgiris district. Mathan (1979) reported a wide variation in total Mg content in the soils of Nilgiris District.

The exchangeable Mg in the Nilgiris was studied by Mathan *et al.* (1973) and about 25 per cent of the area investigated was found to be deficient. The exchangeable base content of different soils of Kerala was generally found to be in the decreasing order of Ca, Mg, K and Na. The maximum amount of exchangeable Mg was observed in black soils (Venugopal and Koshy, 1976).

1.1 Factors influencing magnesium content

The occurrence and level of Mg in soil depend to a large extent on soil type, rainfall, elevation, particle size distribution and organic matter content.

1.1.1 Soil type

Schroeder and Zahiroleslam (1963) found that Mg content decreased from 0.5 per cent in marsh soils to 0.05 per cent in podzols. Tomar and Verma (1970) found that the available Mg content of Madhya Pradesh soils varied considerably, the highest being in black soils and lowest in red soils. Oxisols contained very little Mg, whereas soils formed from recent alluvial materials contained relatively higher amounts (Mokwunye and Melsted, 1972). Kirkby and Mengel (1976) observed that podzols and lateritic soils were low in Mg.

Schweder (1983) observed that alluvial soils had low Mg reserves. Residual soils rich in dolomite and clay minerals showed a high Mg content whereas residual soils rich in quartz and feldspar contained small amounts of Mg.

1.1.2 Rainfall

Gray (1910) estimated an average of 3 kg ha^{-1} of Mg in the rainfall at Lincoln Canterbury. Hendriksen (1970), Low and

Armitage (1970) and Bolton and Slope (1971) have reported the addition of 6, 2 and 3 kg ha^{-1} of Mg respectively by rain.

Excessive rainfall caused Mg deficiency in light textured soils (McMartrey, 1947 and Prince *et al*., 1947).

1.1.3 Elevation

Messing (1974) reported acute Mg deficiency in soils of higher elevation. Magnesium exhibited exponential relationship with elevation (Mathan, 1964).

1.1.4 Particle size distribution

Magnesium content decreased regularly from the clay to the coarse sand fractions (Jaffries and White, 1938; Albrecht *et al*., 1943 and Prince *et al*., 1947). Magnesium deficiency developed earlier in coarse textured soils than in heavy textured (Foy and Barber, 1958; Bolton, 1973). Silt and clay fractions contained more than 95 per cent of the total Mg (Metson and Gibson, 1977). Chu and Johnson (1985) observed no correlation between the clay content and total Mg.

1.1.5 Organic matter

An increase in Mg content was observed due to high organic matter in soil (Carolus, 1933). But Prince *et al.* (1947) observed Mg deficiency in soils rich in organic matter. Metson (1974) stated that this contrast might be due to variations in the intensity of rainfall and leaching. According to Lombin (1979), Mg availability is a product of interactions between secondary soil factors such as cation balance, soil reaction and CEC (largely governed by organic matter levels) acting on the exchangeable form.

2. Magnesium availability indices

Available Mg is often regarded as exchangeable Mg for practical purposes, but many other extractable forms have been suggested.

Bower *et al.* (1952) used sodium acetate for soils containing $MgCO_3$. Schachtschabel (1954) introduced the use of 0.0125 *M* $CaCl_2$ solution. Loch (1964) also considered it as less arbitrary than other extractants.

Welte *et al.* (1960) found no definite relationship between Mg extracted in the dilute $CaCl_2$ solution and plant uptake of Mg or yield. They concluded that mobility of Mg in soil was better estimated from exchangeable Mg or that extracted by 0.05 *M* HCl. Graham *et al.* (1956) and Gerzabek and Schaffer (1987) also preferred 0.05 *M* HCl.

Giessler and Kurnoth (1960) modified the bioassay method using *Aspergillus niger* as availability index of Mg. Gartel (1962) extracted available Mg with Egner-Riehm's calcium lactate reagent.

Schroeder and Zahiroleslam (1963) combined Schachtschabel's solution and 0.05 *M* HCl solution. They carried out pot experiments using rye grass as test plant. Their results indicated that the major part of the Mg released by 2 *M* HCl minus exchangeable Mg was non-available and that a close correlation existed between Mg uptake and $CaCl_2$ soluble Mg, exchangeable Mg or HCl soluble Mg. They concluded that 0.0125 *M* $CaCl_2$ solution was the best general measure of Mg availability.

Reith (1963) compared ammonium acetate and 2.5 per cent acetic acid as extractants of available Mg and found that both removed about the same amount of Mg from a soil.

Boratyniski *et al.* (1964) observed that only the determination of both pH and sorption capacity allows valid conclusion to be drawn on the probable Mg status of soils.

Magnesium extracted by 0.05 *M* HCl + 0.025 *N* H_2SO_4 was significantly correlated with amount extracted by 0.2 *N* NH_4Cl + 0.2 *N* NH_4OAc + 0.015 *N* NH_4F + 0.012 *N* HCl (new Mehlich) in forest soils (Lea *et al.*, 1980).

According to Stahlberg (1980) 0.1 *M* ammonium sulphate may be used for extraction of exchangeable soil Mg.

A correlation was found between Mg concentration in plants and ½pMg - pK, an expression for the relative availability of Mg and K by the Baker method (Rahmatullah and Baker, 1981).

Extractions of K and Mg by the Mehlich III and ammonium bicarbonate-DTPA multielement extraction solutions were found highly correlated to the Bray/Kurtz and 1 *N* NH_4OAc extractants (Hanlon and Johnson, 1984).

Qui *et al.* (1984) found that 1 *M* NH_4OAc was suitable for determination of exchangeable Mg. Exchangeable Mg and percentage Mg saturation were found to be the most accurate parameters for Mg availability by Estrada and Guerrero (1985).

Raij *et al.* (1986) used ion exchange resin for extraction of Mg. Barium chloride triethanolamine and citric acid phosphate buffer were used by Gerzabek (1988a). Gerzabek (1988b) found that Mg extracted with 0.01 *M* HCl as well as K/Mg gave the best correlation with Mg uptake in plants. The method developed by Trueby and Aldinger (1989) using 0.05 *M* NH_4Cl was found to be feasible for extraction of exchangeable Mg.

3. Transformation of Mg in soil

Magnesium is the fifth element in the group of six macro-nutrients. The distribution and availability of Mg in soils are influenced by the segregation and concentration during the geochemical evolution of the globe, characteristics of the valence electronic shells and free energy oxidation and the radii of ions capable of readily entering into particular crystalline structures of soil minerals (Cooper *et al* ., 1947).

3.1 Forms of Mg in soil

Magnesium in soil occurs , in watersoluble, exchangeable, lattice and primary mineral forms (Prince *et al.*, 1947 and Salmon, 1963).

3.1.1 Magnesium bearing minerals

The main reservoir of soil Mg is silicate containing minerals (Salmon, 1963; Rice and Kamprath, 1968 and Mokwunye and Melsted, 1972). Magnesium is present in relatively easily weatherable ferromagnesian minerals (Beeson, 1959), in $MgCO_3$, dolomite and $MgSO_4$ (Metson, 1974). It is also present in clay minerals (Aderikhin and Belyayev, 1974 and Kirkby and Mengel, 1976).

3.1.2 Exchangeable Mg

Exchangeable Mg is usually in the order of about 5 per cent of the total Mg and 4 to 20 per cent of the cation exchange capacity. This fraction along with the water soluble Mg is of greater importance in the supply of Mg to plants.

Barshad (1960) found that Mg ions account for a large percentage of the total exchangeable ions in HCl acidified clays and considered this to explain the high percentage of exchangeable Mg present in solonetz soils and in near neutral soils derived from serpentine rocks. Alston (1972) observed a higher content of exchangeable Mg in the soils derived from basaltic parent material. Loganathan (1973) reported exchangeable Mg contents of 6.8 to 24.0, 2.8 to 19.1, 4.2 to 10.6 and 1.3 to 2.5 cmol(+) kg^{-1} for black, red, alluvial and laterite soils respectively.

3.1.3 Soil solution Mg

Soil solution Mg is in equilibrium with exchangeable Mg and this portion comprises 1 to 2 per cent of the total Mg in soil. Lindsay (1979) has reviewed pH versus solubility characteristics of various soil Mg minerals. At pH less than 7, all of the minerals are sufficiently soluble to maintain a soluble Mg concentration in excess of 1 mmol. Because of their solubility, minerals such as magnesium sulphate, brucite and magnesite are leached out of weathered soils.

Magnesium cycle in the soil includes addition, removal and conversion of Mg in soil (Biswas *et al.*, 1985). Conversion of Mg in soil involves reactions such as fixation, release and solubilisation which are related to Mg availability in soil. Isomorphous substitution of Mg^{++} for Al^{+++} in the octahedral layer results in the fixation of Mg in 2:1 type of clay minerals. Release of Mg is the greatest from the clay fraction followed by the silt and the least from the sand. Solubilisation of Mg compounds in the soil is the process leading to the release of Mg as Mg^{2+} ions.

Magnesium was found to be highly susceptible to leaching (Kanwar, 1976; Gajbhiye and Goswami, 1980 and Goswami and

Sahrawat, 1982). The release of Mg from soils and minerals was found to be inversely related to particle size (Stahlberg, 1960). Nartea and Castro (1977) found that low Mg soils released Mg more easily than high Mg soils. Reduction in Mg uptake due to liming soils to neutrality is due to Mg fixation, reducing the amount of exchangeable Mg (Sumner *et al.*, 1978). The transformation of Mg in soil under submerged condition was highly dynamic; release and fixation existed side by side, the equilibrium being decided by the dominance of the nature of the reaction involved (Varughese, 1992).

3.2 Effect of soil characters on magnesium transformation in soil

Among the various soil factors influencing the Mg transformations in soil, pH, particle size distribution, organic matter content, Mg saturation per cent, cation exchange capacity and the presence of other cations play a major role.

3.2.1 pH

Carolus (1933) reported that increased acidity of the soil did not interfere markedly with the exchangeable Mg. Pope and Munger (1953), Ferrari and Sluijsmans (1955), Fischer (1956), Adams and Henderson (1962), Metson (1974) and Simpson (1983) observed that the amount of exchangeable Mg was influenced by soil pH. Low pH of soil tended to promote Mg deficiency.

Salmon (1963) stated that the well known release of Al from acid clays into the soil solution implied that lattice Mg would also be released, that would explain the increased Mg saturation of soils with increased leaching and acidification. Wiklander and Anderson (1963) found that H^+ ions strongly enhanced the mobility of Mg.

Edmeades *et al.* (1985) and Myers *et al.* (1988) reported that liming reduced exchangeable Mg due to Mg fixation at higher pH values.

3.2.2 Particle size distribution

Foy and Barber (1958), Mazayeva (1965) and Bolton (1973) observed that exchangeable Mg content was more in clay fractions of the soil. The Mg concentration of the soil fractions increased as the particle size decreased except that the concentration of the fine clay fraction tended to be less than the medium clay fraction (Christenson and Doll, 1973). Hendriksen (1971) reported that the content of exchangeable Mg in soil was in the decreasing order of heath, sandy soils, other sandy soils and clay soils. Chu and Johnson (1985) reported that sand and silt but not clay were the important sources of exchangeable Mg.

3.2.3 Magnesium saturation

The exchangeable Mg in soil increased as the exchange complex got more saturated with Mg^{++} ions. Exchangeable Mg expressed as a percentage of the total exchangeable bases was observed to be a better guide of plant available Mg. The exchangeable Mg comes into soil solution as and when the equilibrium between Mg in exchange complex and soil solution get disrupted and thus triggers the transformation of forms of Mg in soil (Alston, 1972).

3.2.4 Organic matter

Due to high organic matter content of certain acid soils, less exchangeable Mg was lost by leaching (Carolus, 1933). The exchangeable Mg was found to be influenced by the organic matter content of soil (Bolton, 1972 and During and Weeda, 1973).

3.2.5 Cation exchange capacity

A positive relationship was observed between exchangeable Mg and CEC of acid soils (Boynton, 1947). Exchangeable Ca and Mg constitute about 5 to 10 per cent of the CEC (Martin and Page, 1969). Kirkby and Mengel (1976) reported that 4 to 20 per cent of the CEC was constituted by exchangeable Mg.

3.2.6 Other cations

Fischer (1956) and Salmon (1963) have observed that soils rich in potassium showed deficiency of Mg, though exchangeable Mg content was found adequate. The interaction between Mg and K was more marked than that between Mg and Ca.

3.3 Availability of Mg in acid sulphate soils

Acid sulphate soils are base unsaturated and are deficient in Ca and Mg (Howeler, 1973; Rorison, 1973; Attanandana *et al.*, 1982; Ottow *et al* ., 1983; Moore and Patrick, 1989 and Pal *et al.*, 1991). Though the concentration of Ca and Mg in water soluble fraction have been shown to increase following flooding (Ponnamperuma, 1972 and Islam and Islam, 1973), most Mg minerals were too soluble to persist in acid soils and exchange reactions maintained the level of Mg in soil solution at low pH (Lindsay, 1979).

Work done by Varghese (1963), Varghese and Money (1965), Padmaja and Verghese (1966) and Varughese (1992) indicated that addition of Mg improved crop growth, increased grain yield of rice and soil pH. Acid sulphate soils responded significantly to liming (Panicker, 1980) and liming with CaO and $MgCO_3$ was found to be more effective than liming with CaO alone (Padmaja and Verghese, 1972a).

4. Magnesium in crop nutrition

Magnesium is needed by all green plants as it is a constitutent of chlorophyll and it has a vital role as a plant nutrient. The amount of Mg required annually by many of the arable crops is in the range of 10 to 25 kg ha^{-1}. Deficiencies occur particularly in highly leached humus acid soils or on sandy soils which have been given heavy dressings of lime.

The essentiality of Mg for photosynthesis is well known. Magnesium increases the content of chlorophyll (Panak and Wojnowska, 1977; Ananthanarayana and Rao, 1980 and Kiss, 1981). Magnesium deficiency reduced biosynthesis of pigments to one-third of its original level (Yordanov *et al* ., 1978).

Magnesium is an activator of many enzyme systems involved in carbohydrate metabolism (Kondrat'ev and Kondrat'eva, 1978). It promotes uptake and translocation of phosphorus and also helps in better P utilisation of crops (Varghese and Money, 1965). Ananthanarayana and Rao (1982) and Subramanian *et al.* (1975) found that Mg increased N uptake by crops.

Generally Mg is taken up by the plant in smaller quantities than Ca or K. A great diversity of figures is reported in the literature for Mg removed by different crops (Teichman, 1957; Jacob, 1958 and Kirkby and Mengel, 1976). Generally the uptake by root crops is about double that of cereals.

4.1 Response of crops to Mg application

Kerschberger *et al.* (1986) observed that the yield response to Mg decreased in the order cereals > forage plants > potatoes.

Positive beneficial effect of Mg on rice was noted by many workers (Varghese and Money, 1965; Nayar and Koshy, 1969; Padmaja and Verghese, 1972b; Chandramony and George,1975;

Thomas and Koshy, 1977; Panicker, 1980; Sanchez, 1984; Moore and Patrick, 1989; Yamauchi and Winslow, 1989 and Varughese, 1992). Application of Mg showed positive response in oats (Jokinen, 1977a and Mahler *et al.*, 1986), in maize (Krstic *et al.*, 1981; Stout and Bennet, 1983 and Frölich, 1987), in wheat (Kumar *et al.*, 1981; Singh and Balasubramanian, 1985; Fecenko *et al.*, 1986 and Mahler *et al.*, 1986) and in barley (Fecenko *et al.*, 1986; Mahler *et al.*, 1986 and Grant and Racz, 1987).

Potato responded well to Mg application in acid soils (Carolus, 1933; Mathan *et al.*, 1973; Krishnamoorthy *et al.*, 1979 and Sharma *et al.*, 1981). Beneficial effects of Mg have been reported in cowpea (Nad and Goswami, 1983), in groundnut (Tajuddin, 1970; Subramanian *et al.*, 1975; Ananthanarayana and Rao, 1979 and Sudhir *et al.*, 1987), and in soybean (Kabeerathumma *et al.*, 1977).

In coconut, favourable response to application of Mg was observed by Varkey *et al.* (1979), Kamalakshiamma and Pillai (1980) and Cecil (1991). Magnesium increased yield of rubber (Onuwaje, 1983) and of tea (Godziashvili and Peterburgsky, 1985).

A good response of applied Mg was exhibited by vegetable crops such as capsicum (Kiss, 1979), tomatoes (Kiss, 1979; Asiegbu and Uzo, 1983; Elamin and Wilcox, 1985 and Sonneveld, 1987), cabbage (Shukla and Banerjee, 1980; Hara and Sonoda, 1981 and Harrison and Bergman, 1981), cauliflower (Shukla and Banerjee,

1980) and melons (Elamin and Wilcox, 1986 and Simon *et al*., 1986).

Application of Mg was found to cause favourable responses in pear (Ystaas and Steenberg, 1978), apple (Kuleza and Szafranek, 1978), pineapple (Anon, 1979 and Chinea *et al*., 1986), papaya (Awada and Suehisa, 1985), citrus (Razeto and Salas, 1986) and in grapes (Cline, 1987 and Colapietra, 1987).

But there were also reports of lack of decisive favourable response of applied Mg in crops. George and Sreedharan (1966) found that application of Ca - Mg carbonate either alone or in combination with Na - Mg silicate did not have any significant effect on the yield of grain and straw in rice. Yield of grain and tiller production in paddy were not influenced by the application of Mg silicate and $MgCO_3$ in Kuttanad soils of Kerala (Kurup and Ramankutty, 1969). Similar observations on the effect of Mg on rice in laterite soil were also reported by Varughese (1992) and Muralidharan (1992).

Pedersen and Vang-Petersen (1984) found that fruit yield and fruit size in apple were not affected by Mg applications.

4.1.1 Response of banana to Mg application

Nambiar (1963) found that Mg alone or in combination with Ca has a remarkable effect in delaying bunchy top disease in banana. Pillai (1965) observed that CaO/MgO ratio seemed to

20

have a role in delaying the incidence of bunchy top disease of banana. The appearance of the disease, banana plant 'blue' (chlorosis and appearance of purple brown spots on petioles) was found to be due to sub-optimal levels of Mg in leaves (Moreira and Hiroce, 1978).

Nambiar (1972) observed that K/Ca, K/Mg and K/Ca+Mg ratios in banana midribs were positively and significantly correlated with the yield of banana. Increasing K and Mg supply of banana increased dry matter production and uptake of most elements with the exception of Mg, whose uptake was unaffected by K supply (Turner and Barkus, 1983). The symptoms of Mg deficiency due to K/Mg imbalance were noted in banana plantations. The K/Mg ratio was 6.36. Neighbouring banana plantations with K:Mg ratio 3.84 did not show symptoms. The plants recovered after application of dolomitic limestone at 3 t ha^{-1} or spraying with 5 per cent $MgSO_4$ solution. Application of Mg compounds is recommended for banana plantations on soils poor in Mg (Lightemberg and Malburg, 1984).

4.2 Soil factors influencing Mg uptake

The soil factors influencing Mg uptake may be broadly classified into (1) those causing absolute Mg deficiency and (2) induced Mg deficiency.

4.2.1 Absolute Mg deficiency

The limiting values of Mg increased as the soil texture became heavier (Schachtschabel, 1954, 1957; Brugger, 1961 and Holmes, 1962). Magnesium deficiency is also associated with sandy soils (Hester *et al.*, 1947; Semb and Tragethon, 1958; Welte and Werner, 1963 and Reith, 1963). Instead of using exchangeable Mg as a measure of Mg deficiency in soils, many scientists preferred the use of exchangeable Mg as percentage of CEC or of total exchangeable bases (Prince *et al.*, 1947; Bear and Toth, 1948; Yamasaki *et al.*, 1956 and Lombin and Fayemi, 1975).

4.2.2 Induced deficiency

This situation usually arises as a result of competition from some antagonistic cations. The following nutrient ratios are generally considered to characterise the induced Mg deficiency.

4.2.2.1 Potassium/magnesium

Increased K supply in soil reduced Mg supply and uptake by crops (Walsh and O'Donoboe, 1945; Boynton, 1947; Camp, 1947; Prince *et al.*, 1947; Bear and Toth, 1948; Johannesson, 1951; McNaught and Gdanitz, 1952; Jacob, 1958; Salmon, 1964; Birch *et al.*, 1966; Nayar and Koshy, 1969; Hossner and Doll, 1970; McIntosh *et al.*, 1973a; Holcomb and White, 1974; Sekhon *et al.*, 1975; Johansson and Halilin, 1977; Jokinen, 1977b; Spear *et al.*, 1978; Heenan and Campbell, 1981; Dejou and DeMontard, 1982; Turner and Barkus, 1983 and Osiname and Kang, 1986) and vice versa (Bandyopadhyay and Goswami, 1988; Seggewiss and Jungk, 1988; Muralidharan, 1992 and Varughese, 1992).

A synergestic effect of K and Mg was observed by Fageria (1983) and Narwal *et al*. (1985).

Jayaraman (1988) observed that added Mg did not show any marked variation in the availability of K.

Magnesium/potassium ratio is a better estimate of Mg availability than exchangeable Mg (Walsh and O'Donoboe, 1945; McColloch *et al.*, 1957 and Hane and Woodruff, 1976).

4.2.2.2 Calcium/magnesium

Loew in 1892 first proposed Ca/Mg ratio hypothesis (Moser, 1933). The ratio was found to be an important factor in crop nutrition (Gile, 1913; Mehlich, 1946; Johnson *et al.*, 1957; Halstead *et al.*, 1958; Berry and Ulrich, 1970 and Krishnappa *et al.*, 1974). But, Russell (1973) observed that Ca-Mg ratio had very little influence on soil productivity.

Antagonistic effects of Ca and Mg were observed by McNaught, (1964); Christensen *et al.* (1973); Fageria (1983); Edmeads *et al.* (1985); Gama (1987); Mohebbi and Mahler (1988); Myers *et al.* (1988); Phillips *et al.* (1988) and Varughese (1992).

4.2.2.3 Hydrogen/magnesium

The specific effects of soil acidity or H/Mg ratio on uptake of Mg have been little studied.

Welte and Werner (1963) suggested that H/Mg antogonism was more intense than K/Mg antagonism. The influence of pH on Mg uptake was observed to be more than the effect of level of soil Ca (Christenson *et al.*, 1973).

A positive correlation between Mg uptake and pH was observed by Kabeerathumma (1969) and Prohaszka (1980).

4.2.2.4 Aluminium/magnesium

Excess aluminium in soil caused Mg deficiency by reducing the uptake of Mg (Grimme, 1983; Hecht-Buchholz *et al.*, 1987).

4.3 Magnesium sources

Commercially important sources of Mg are magnesite, brucite, dolomite, magnesium sulphate and magnesium chloride (Wicken and Duncan, 1983).

Magnesite either alone or in the presence of Ca was being used as a source of Mg for different crops in different soils by many workers and favourable responses had been observed (Wolf, 1963; Padmaja and Verghese, 1966; Vasil'eva, 1966; Tajuddin, 1970; During, 1972; Padmaja and Verghese, 1972a; Padmaja and Verghese, 1972b and Hogg and Toxopeus, 1973).

Wolf (1963), also observed a depression in yield, when calcined magnesite was applied to the soil just before planting of beans. Yields were not depressed when the material was applied 10 days before seeding or was mixed with the fertilizer. Kurup and Ramankutty (1969) could not find any influence of application of $MgCO_3$ on rice yield.

Application of 2 per cent $MgSO_4$ was found to increase the grain yield of rice by 17 per cent (Mahapatra and Gupta, 1978).

4.3.1 Comparison between Mg sources

4.3.1.1 Magnesite and water soluble Mg sources

Magnesium carbonate was more effective than soluble Mg salts on strongly acid soil, but the soluble salts were more effective on neutral and slightly acid soil (Shieh *et al*., 1965).

During (1972) considered magnesite approximately equivalent to the soluble sulphate minerals as a source of Mg whereas McIntosh *et al.* (1973b) found calcined magnesite approximately equivalent to epsom salts or magnesium ammonium phosphate. Effect of $CaCO_3$ and $MgCO_3$ on the yield of soybean and gram had been found to be superior to other salts of Ca and Mg in acid soils of Ranchi, Bihar (Prasad *et al.*, 1983).

Magnesium treatments tended to increase the yield of rice over control in the Vellayani lake area in Kerala. The effect was more marked in the case of MgO and $MgSO_4$ than $MgCO_3$ (Nayar and Koshy, 1966). Magnesium in $MgSO_4$ is more rapidly effective than Mg in the carbonate form (Zehler, 1982).

4.3.1.2 Dolomite and magnesium sulphate

Munk (1961) reported that powdered dolomite was superior to $MgSO_4$ under acid conditions upto pH 5.5, but the solubility and efficiency of dolomite decreased as the soil was limed to higher pH values, and Mg-Ca antagonism began to operate with both products at pH 6.5.

Kuhn (1962) compared the efficiency of (1) $MgSO_4$ (2) half burned dolomite and (3) crude dolomite under neutral and acid conditions. Magnesium sulphate and half burned dolomite increased the Mg uptake and content of crops independent of soil reaction, while the Mg supply from crude dolomite decreased with increasing soil reaction. The Mg supply to cereals was slower from half burned dolomite and very much slower from crude dolomite than from $MgSO_4$. In strongly acid soil, the Mg uptake by potato was greater from half burned dolomite than from $MgSO_4$, in weakly acid soil both $MgSO_4$ and half burned dolomite supplied similar amounts of Mg to fodder beet, while at nearly neutral reaction $MgSO_4$ was distinctly superior and crude dolomite rather inefficient.

Dolomitic limestone was as efficient as $MgSO_4$ as a source of Mg for tobacco (De Mello and Arzolla, 1970). On the acid soil, the dolomitic limestone was a more effective source of Mg than $MgSO_4$ but on the nearly neutral soil, the two sources were equally effective (Jokinen, 1982).

4.3.1.3 Magnesite, dolomite and magnesium sulphate

Vasil'eva (1965) reported that magnesite and dolomite were more effective on acid soils while $MgSO_4$ and schoenite (K_2SO_4 $MgSO_4.6H_2O$) were more effective for crops of greater acid tolerance (flax, winter rye, potatoes, oats).

Magnesite was 78.66 and 63.25 per cent as efficient as $MgSO_4$ with regard to the release of water soluble Mg in a karappadam and a laterite soil of Kerala respectively. In karappadam soil, magnesite (99.9 per cent) and dolomite (95.3 per cent) were almost as efficient as $MgSO_4$ in their ability to release NH_4OAc extractable Mg. In laterite soil, their relative efficiency was 76.9 and 82.2 per cent (Varughese, 1992). The soils were under submerged condition.

Materials and Methods

MATERIALS AND METHODS

The study consisted of the following parts: (1) magnesium status of the soils of Kerala, (2) evaluation of laboratory indices of magnesium availability, (3) transformation of applied magnesium at field capacity; and (4) pattern of magnesium uptake by banana from different sources at different levels.

1. Magnesium status of soils of Kerala

1.1 Collection of soil samples

One hundred and fifty surface soil samples (0-15 cm) were collected from all over the State of Kerala, covering different districts for assuring wide variation in the content of available magnesium and physico-chemical characteristics of the soil.

Samples were collected to a depth of 15 cm from the surface of the soil with the help of a spade, making a 'V' shaped cut, with one side perpendicular to the surface. About 1 kg of well mixed soil (composited) was collected out of 4 to 6 pits from a plot representing a soil type.

1.2 Laboratory studies

1.2.1 Preparation of the sample

The samples were dried in shade, powdered gently using a mortar and pestle and sieved through a 2 mm sieve. The prepared samples were kept in labelled containers for further studies.

The soil samples were grouped into three based on the type of soil, to facilitate statistical analysis and interpretation. Details of the location of the soils selected for the study are given in Appendix 1.

1.2.2 Analytical procedures

The soils were analysed for organic carbon, pH, EC, CEC, total Mg, available Mg, exchangeable Mg, exchangeable Ca, exchangeable K and exchangeable Na.

The organic carbon content of soil was determined by Walkley and Black method as described by Piper (1942). The pH of the soil in water was determined using a soil : water ratio of 1 : 2.5 by a pH meter (Jackson, 1958). Electrical conductivity of the supernatant liquid of the soil-water suspension used for the determination of pH was read with the help of a conductivity bridge (Jackson, 1958).

The CEC was determined by saturating the exchange sites with K. Five g of soil was weighed out into a 15 ml centrifuge tube. Potassium saturation was obtained by five washings with 1 *N* KCl solution, 10 ml at a time. Removal of excess salt was done by washing once with distilled water and twice with 95 per cent ethanol, 10 ml each and once with 10 ml acetone. To the sample, 10 ml of 1 *N* NH_4Cl solution was added and the suspension was centrifuged. This was done five times and each time the supernatant liquid was quantitatively transferred to 100 ml volumetric flask. The volume was diluted to the mark with 0.5 *N* NH_4Cl and K was estimated in the solution using a flame photometer (Jackson, 1969).

To determine the total Mg, 1 g of air dry 0.5 mm soil was weighed into a digestion tube, 20 ml of concentrated nitric acid was added, and cautiously heated to oxidise organic matter. After cooling, 10 ml of 60 per cent perchloric acid was added and digested the mixture until the content in the tube was white and clear. The digested content was filtered and made upto 100 ml (Hesse, 1971). The sesqui-oxide in this solution was precipitated and removed as described by Jackson (1958) and the Mg content was determined by the versenate titration method (Hesse, 1971).

The available Mg was extracted using 0.0125 *M* $CaCl_2$ solution as described by Hesse (1971) and the Mg content in solution was determined by versenate titration method.

The exchangeable cations were brought into solution by saturation with neutral 1 *N* ammonium acetate solution and further leaching as described by Jackson (1958). The exchangeable Ca and Mg were determined by versenate titration method (Hesse, 1971). The exchangeable K and Na were determined with the help of a flame photometer.

1.3 Statistical analysis

Coefficients of simple linear correlation and regression between various characteristics were worked out, as described by Snedecor and Cochran (1967).

2. Evaluation of laboratory indices of magnesium availability

In order to select the best extractant for the estimation of available Mg in soil, Mg extracted by various chemical agents were correlated with uptake of Mg by a test crop grown under modified Neubauer seedling technique. Twenty selected soils were used for this purpose and the details of these soils are given in Appendix 2. The soils were selected assuring maximum variation in characteristics relating to the behaviour of Mg in soil.

2.1 Estimation of Mg uptake from soils using rice as the test crop

The total uptake of Mg from the soils was determined by growing rice crop in soils taken in small plastic containers following the Neubauer seedling technique (Kanwar, 1976) with some modifications. This experiment was so planned that maximum removal of magnesium from soils was effected in a short period of time by growing a large number of plants in a small quantity of soil.

One hundred g of soil was taken in small plastic containers of 12 cm diameter and 5 cm depth and mixed with 50 g of acid washed sand. A control pot was maintained in which no soil was taken. The short duration high yielding variety of rice, viz., Annapoorna was used as the test crop. Germinated seeds were used as the seed material and 100 seedlings were grown in the pots for a period of 35 days. The plants along with roots were harvested and the adhering soil particles were completely removed. The harvested plant material was dried in an electric oven at 80°C till a constant weight was obtained.

2.1.1 Magnesium uptake by plants

The whole plant material was powdered, dried and 1 g was transferred into a digestion tube. The content was digested in triple acid mixture consisting of nitric, sulphuric and perchloric acids in the ratio of 10:1:4 till the content turned colourless. The digest was diluted with water, the volume made up, kept aside for one day and filtered when the whole silica settled down. Magnesium in the digest was determined by versenate titration method.

The percentage of Mg in the plant material was calculated and Mg uptake by plants was then computed from total dry weights.

2.2 Screening of chemical extractant as index of available magnesium in soil

To evolve the best extractant for available Mg, various extractants were tried.

2.2.1 Initial screening of chemical extractants

To fix up extractants for preliminary screening, an initial study was taken up, using one soil, ten extractants and two equilibration periods. The extractants were:

1. 2.5 per cent acetic acid + 0.04 *M* ammonium acetate (Reith's reagent)
2. 0.05 *M* HCl
3. 0.06 *N* H_2SO_4 + 0.06 *N* HCl + 0.05 *N* $H_2C_2O_4$ (Mathew's triacid)
4. 1 *N* ammonium acetate
5. 0.0125 *M* $CaCl_2$ (Schachtschabel's solution)
6. 0.1 *M* acetic acid + 0.04 *M* calcium lactate
7. 0.005 *M* DTPA
8. 0.01 *M* DTPA
9. 0.005 *M* DTPA + 0.005 *M* $CaCl_2$
10. 0.0025 *M* DTPA

Five g of soil was taken in a 250 ml conical flask and 50 ml of extractant solution was added. The content was shaken for different periods (30 and 60 min) in a mechanical shaker. Immediately after shaking, the content was filtered through Whatman No.1 filter paper. Magnesium in the filtrate was determined by versenate titration method (Hesse, 1971).

On the basis of rate of release of Mg into the soil solution, some extractants were eliminated and eight extractants were tried for the next phase of the study, viz., preliminary screening of the extractants.

2.2.2 Preliminary screening of extractants

In the preliminary screening, eight extractants were tried within the workable limits. Thus preliminary screening consisted of eight extractants at six periods of equilibration viz., 10, 20, 30, 40, 50 and 60 min with one soil and a single soil solution ratio of 1:10. In each case the extraction was repeated thrice and the mean value was adopted. Selected extractants for preliminary screening are listed below:

1. 2.5 per cent acetic acid + 0.04 *M* ammonium acetate (Reith's reagent)
2. 0.05 *M* HCl
3. 0.06 *N* H_2SO_4+ 0.06 *N* HCl + 0.05 *N* $H_2C_2O_4$ (Mathew's triacid)
4. 1 *N* ammonium acetate
5. 0.0125 *M* $CaCl_2$ (Schachtschabel's solution)
6. 0.01 *M* acetic acid + 0.04 *M* calcium lactate
7. 0.005 *M* DTPA
8. 0.005 *M* DTPA + 0.005 *M* $CaCl_2$

Graphs were plotted taking period of equilibration on the X axis and Mg values on the Y axis for each extractant solution. From the nature of the curves obtained, these extractants with suitable equilibration periods were selected for studying their performance in the 20 soils for the final selection.

The selected extractants and their equilibration periods are given below:

Sl.No.	Name of extractant	Equilibration period
1	2.5 per cent acetic acid + 0.04 *M* ammonium acetate	60 min
2	0.05 *M* HCl	30 min
3	0.06 *N* H_2SO_4 + 0.06 *N* HCl + 0.06 *N* $H_2C_2O_4$	30 min
4	1 *N* ammonium acetate	40 min
5	0.0125 *M* $CaCl_2$	30 min
6	0.1 *M* acetic acid + 0.04 *M* calcium lactate	60 min
7	0.005 *M* DTPA	60 min
8	0.005 *M* DTPA + 0.005 *M* $CaCl_2$	60 min

2.2.3 Final selection of extractant

The performance of the selected eight extractants from the preliminary screening was studied using the 20 soils with the selected equilibration period for each extractant. Magnesium in solution was estimated by using versenate titration method (Hesse, 1971).

2.3 Statistical analysis

Coefficients of simple linear correlation and regression between the amount of magnesium extracted by various chemical agents and plant uptake were worked out, as described by Snedecor and Cochran (1967).

3. Transformation of applied magnesium in soil

This is an incubation study with two acid soils of Kerala, three sources of Mg (magnesium sulphate, magnesite and dolomite) and three levels of Mg (1250, 2500 and 3750 kg MgO ha^{-1}) to study the transformation of added Mg from the different sources at field capacity.

3.1 Collection of soil samples

A karappadam soil of Kuttanad alluvium (Moncompu, Alappuzha district) and a laterite soil (Vellanikkara, Thrissur district) which represented two important soils of Kerala were collected (0-15 cm depth). The soils were dried in shade, powdered, sieved and used for incubation study.

3.2 Laboratory studies

A laboratory incubation study was carried out with two soils (the karappadam and laterite), three sources of Mg namely magnesium sulphate ($MgSO_4.7H_2O$) with 15.95 per cent MgO, magnesite ($MgCO_3$) with 27.00 per cent MgO and dolomite ($CaMg[CO_3]_2$) with 15.36 per cent MgO in a completely randomised design with two replications. The treatments were as follows.

Serial No.	Treatment notation	Form and level of MgO, kg ha^{-1}
1	T_1	No Mg (control)
2	T_2	Magnesium sulphate 1250
3	T_3	Magnesium sulphate 2500
4	T_4	Magnesium sulphate 3750
5	T_5	Magnesite 1250
6	T_6	Magnesite 2500
7	T_7	Magnesite 3750
8	T_8	Dolomite 1250
9	T_9	Dolomite 2500
10	T_{10}	Dolomite 3750

The treatments were the same for both karappadam and laterite soils.

3.2.1 Experimental procedure

The soils were weighed (800 g) and transferred into plastic containers of 1 kg capacity. The basic properties of the soils are given in Table 12. The magnesium sources as per the treatments described above were added and thoroughly mixed with the soil. The soils were maintained at field capacity and incubated at room temperature (28-31°C) for 180 days. Soil samples were drawn regularly at 15 day intervals for the determination of available Mg and at 60 day intervals for determination of other important chemical properties.

The rhizomes were further selected and those having 2.00 to 2.50 kg weight were selected for experimental planting. The suckers were smeared with cowdung solution and ash and dried in partial shade for a week and stored in shade upto 15 days before planting.

The field was cleared, ploughed, levelled and pits of 50 cm^3 were dug at a spacing of 2 m on either way during the last week of October, 1990. Suckers were planted on 30th October, 1990. A basal application of 10 kg green leaves was given at the time of planting. Thirty g of Furadan granules was also applied into the pits before planting as a prophylactic measure. Farmyard manure at the rate of 10 kg per pit was applied one month after planting. Uniform cultural operations and crop management were adopted during the cropping period, as per the package of practice recommendations of the Kerala Agricultural University (KAU, 1989). Nitrogen, phosphorus and potassium at the rate of 190, 115, 300 g N, P_2O_5 and K_2O respectively per plant per year were applied in two equal splits, at two and four months after planting. The sources of N, P and K were urea (46% N), superphosphate (18% P_2O_5) and muriate of potash (60% K_2O). The crop was irrigated from December to May twice a week.

4.4 Experimental design and lay out

The experiment was laid out in randomised blocks with

3.2.2 Analytical procedure

The particle size analysis of the soils was carried out by the international pipette method (Piper, 1942). The pH, EC, organic carbon and CEC were determined as described in 1.2.2.

Total elemental analysis of P, K, Ca and Mg was done using diacid ($HClO_4$: HNO_3 in 1:2 ratio) extract. Total P from this extract was determined by vanadomolybdophosphoric yellow colour method in nitric acid system (Jackson, 1958). Total K was read in an EEL flame photometer. Total Ca and Mg were determined by versenate titration method (Hesse, 1971). Total N was estimated by Kjeldahl digestion distillation procedure described by Jackson (1958).

Available N in the soil was determined by alkaline permanganate method (Subbiah and Asija, 1956). Available P of the soil was extracted using Bray and Kurtz No.1 extractant and determined by chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system (Jackson, 1958). Available K was determined flame photometrically in the neutral normal ammonium acetate extract of the soil (Jackson, 1958).

Exchangeable cations and available Mg were determined as described in 1.2.2. The slowly available Mg was calculated by the difference between total Mg and available Mg extracted by 0.0125 *M* $CaCl_2$.

3.2.3 Statistical analysis

Statistical analysis of the data was carried out as per the analysis of variance technique for CRD (Panse and Sukhatme, 1985).

4. Pattern of Mg uptake by banana from different sources at different levels

This investigation was carried out to compare the pattern of Mg uptake from different sources, namely, magnesium sulphate, magnesite and dolomite at different levels namely, 0, 500, 1000 and 1500 g MgO per plant per year.

4.1 Experiment site

The experiment was conducted at the Banana Research Station, Kannara during the period of 1990-91. The location enjoys a typical tropical climate. The meteorological parameters of the experiment site are given in Appendix 3.

4.2 Soil

The soil of the experimental area was well drained, acidic and lateritic sandy loam. The basic characteristics of the soil are presented in Table 30.

4.3 Planting and management practices

Suckers of uniform size and age (3 month old) were selected and psuedostems were cut back retaining 15-25 cm from the corm.

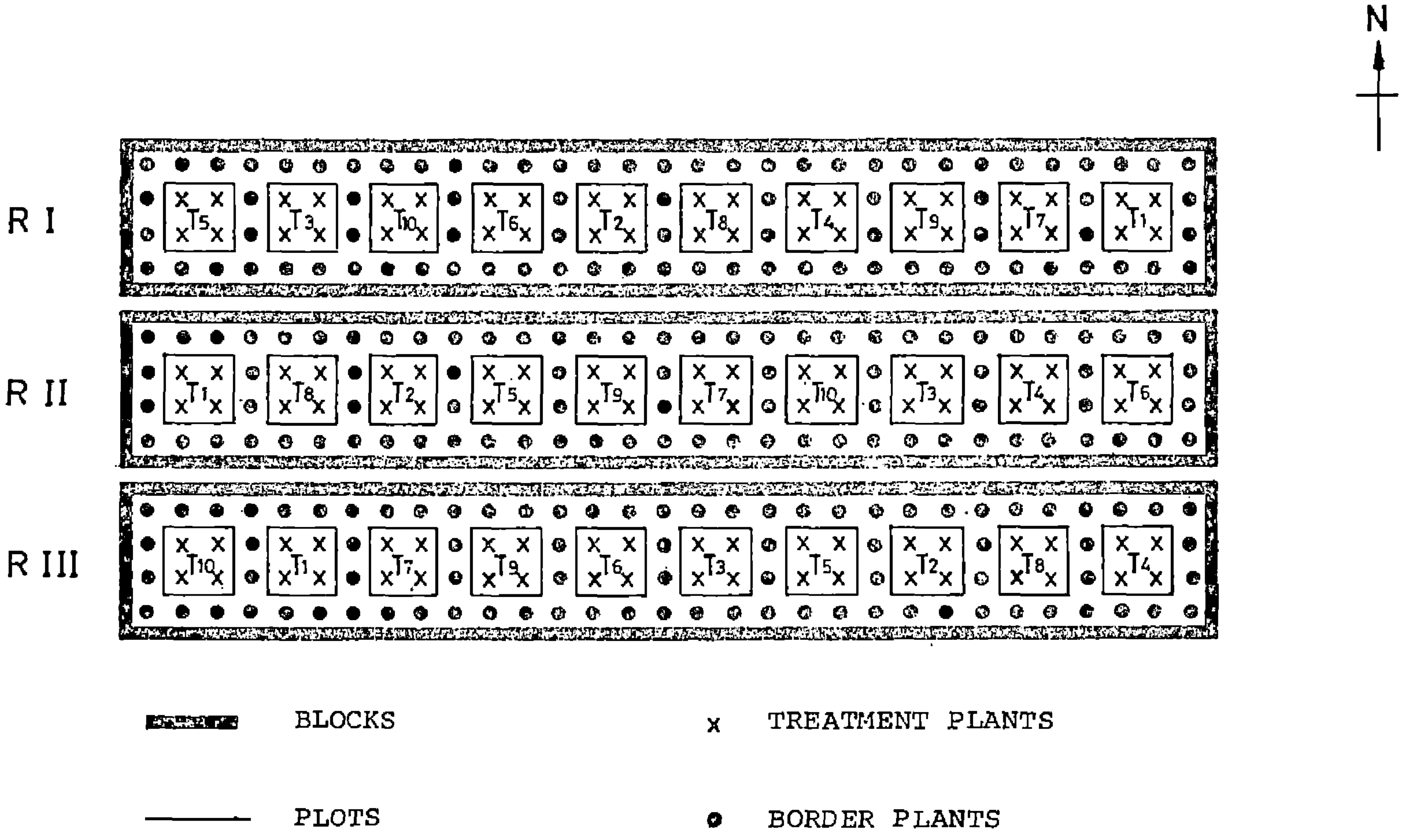

FIG 1 LAYOUT OF THE FIELD EXPERIMENT

10 treatments and three replications. In each plot there were four rows and each row contained four plants. Out of total sixteen plants in a plot, the central four plants comprised the observation plants and all remaining plants were kept as border plants.

4.5 Treatments

The treatments were as follows:

Sl.No.	Treatment notation	Source and level of MgO, g $plant^{-1}$ $year^{-1}$
1	T_1	Control
2	T_2	Magnesium sulphate 500
3	T_3	Magnesium sulphate 1000
4	T_4	Magnesium sulphate 1500
5	T_5	Magnesite 500
6	T_6	Magnesite 1000
7	T_7	Magnesite 1500
8	T_8	Dolomite 500
9	T_9	Dolomite 1000
10	T_{10}	Dolomite 1500

All treatments except those applied as magnesium sulphate were applied as basal. The magnesium sulphate was applied in two equal splits, 15 days prior to the application of N, P and K.

4.6 Biometric observations

Observations on various morphological characters were recorded at four different growth stages of the plant, viz., early vegetative stage, late vegetative stage, shooting and harvest, adopting the method suggested by Yang and Pao (1962).

4.6.1 Plant characters

4.6.1.1 Height of the psuedostem

The height of the psuedostem was measured from the base of the psuedostem to the axil of the youngest leaf and recorded in cm.

4.6.1.2 Girth of the psuedostem

Girth of the psuedostem was measured at 20 cm from the ground level and expressed in cm.

4.6.1.3 Total number of leaves per plant

The total number of leaves produced by the plant was counted by tagging the leaves at each observation.

4.6.1.4 Duration of the crop

The number of days taken from planting to shooting and shooting to harvest was recorded. From these, the total duration from planting to harvest was computed.

4.6.1.5 Sucker production

The number of suckers per plant was recorded as and when they were produced. Suckers were not allowed to grow until shooting. After the emergence of the inflorescence one sucker per plant was retained.

4.6.1.6 Bunch characters

The bunches were harvested from experimental plants when they were fully mature as indicated by the disappearance of angles, that is 'round full' (Simmonds, 1959). The following observations were made on the bunches harvested from the treatment plants.

4.6.1.6.1 Weight of the bunch

Weight of the bunch including the portion of the peduncle (exposed outside the plant) was recorded in kg.

4.6.1.6.2 Length of the bunch

Length of the bunch was measured from the point of attachment of first hand to that of last hand and expressed in cm.

4.6.1.6.3 Number of hands and fingers per bunch

The total number of hands per bunch and the total number of fingers in each bunch were recorded.

4.6.1.6.4 Mean weight of finger

The middle fruit in the top row of the second hand (from the base of the bunch) was selected as the representative finger for finding out the mean weight, girth and length of finger (Gottreich *et al* ., 1964).

4.6.1.6.5 Girth and length of finger

Girth of finger was measured at the mid portion and the length from the point of attachment to the tip using a fine thread and scale.

4.7 Chemical analysis

4.7.1 Studies on the nutrient status of plants

In order to assess the nutrient status of the plants under different treatments, the leaf analysis technique as adopted by Hewitt (1955) was followed. Leaf samples were collected at early vegetative phase (2 months after planting), late vegetative phase (5 months after planting), at shooting (7 months after planting) and at harvest (10 months after planting).

The central portion including both lamina and midrib from the middle portion of the third leaf were taken for chemical analysis. The samples were anlysed for N, P, K, Ca and Mg. At the time of harvest, Ca and Mg content of different plant parts were determined to find out the total uptake and partitioning.

Nitrogen content of the plant sample was estimated by microkjeldahl digestion-distillation method (AOAC, 1960).

One g of the ground leaf sample was digested in 15 ml of a mixture of nitric, sulphuric and perchloric acids in the proportion of 10:1:4 and the volume was made upto 100 ml with distilled water and filtered. Phosphorus content of this extract was determined as per the vanadomolybdophosphoric yellow colour method (Jackson, 1958). Potassium content was determined using a flame photometer (Jackson, 1958). Calcium and magnesium contents were determined using versenate titration method (Hesse, 1971).

Digestion of other plant parts was done as in the case of leaf samples and Ca and Mg contents were determined using versenate titration method.

The chlorophyll content of the index leaf was determined by acetone extraction and estimation by reading the intensity of the green colour at 645, 663 and 652 nm, for chlorophyll 'a', chlorophyll 'b' and total chlorophyll respectively, making use of a spectrophotometer (Harbone, 1973).

4.7.2 Studies on the nutrient status of soil

4.7.2.1 Collection of soil sample

Soil samples were collected at early vegetative stage, late vegetative stage, shooting and at the time of harvest. Samples were collected to a depth of 15 cm from the surface of the soil with the help of a spade, making a 'V' shaped cut, with one side perpendicular to the surface. Samples collected from four plants of a plot were well mixed and composited.

4.7.2.2 Preparation of the sample

The samples were dried in shade, powdered gently using a mortar and pestle and sieved through a 2 mm sieve. The prepared samples were kept in labelled containers for further studies.

4.7.2.3 Analytical procedures

The soils were analysed for organic carbon, total N, available Mg, exchangeable Ca, Mg, K and Na, pH, EC and CEC as described in 1.2.2.

Available phosphorus was extracted by Bray No.1 extractant (0.025 *N* HCl + 0.03 *N* NH_4F, soil solution ratio 1:10, period of extraction 5 min) and the P content was determined colorimetrically by the ascorbic acid reduced molybdophosphoric blue colour method (Watanabe and Olsen, 1965). Available K was extracted with 1 *N* neutral ammonium acetate (soil solution ratio 1:5, period of extraction 5 min) and the K content was determined using a flame photometer (Jackson, 1958).

4.8 Statistical analysis

The data were analysed using analysis of variance method for RBD (Panse and Sukhatme, 1985). Coefficients of simple linear correlation and regression between various factors were worked out as described by Snedecor and Cochran (1967).

Results and Discussion

RESULTS AND DISCUSSION

PART 1. MAGNESIUM STATUS OF THE SOILS OF KERALA

One hundred and fifty surface samples (0-15 cm) were collected from all over the State of Kerala, covering different districts for assuring wide variation in the content of available Mg and physico-chemical characteristics of the soil.

The soil samples were grouped into three based on the type of soil to facilitate statistical analysis and interpretation. Group 1 included red, laterite and brown hydromorphic soils. Group 2 consisted of coastal alluvium, reverine alluvium, Onattukara alluvium and acid saline reverine alluvium of Kuttanad. The black soils formed Group 3. Details of the location of soils selected for the study are given in Appendix 1.

1. General characteristics of soils in relation to behaviour of Mg in soil

Properties relating to the behaviour of Mg in soils selected for determination of Mg status are furnished in Table 1 and the mean values of different groups are presented in Table 2. Soil sample numbers 1 to 101 formed Group 1 (red, laterite and brown hydromorphic soils), 102 to 145 formed Group 2 (alluvium) and 146 to 150 formed Group 3 (black soils).

Table 1. Properties relating to the behaviour of Mg in soil

Soil sample No.	Organic carbon, %	pH	EC, dS m^{-1}	CEC, cmol(+) kg^{-1}	Total Mg, ppm	Available Mg, ppm	Exchangeable Mg, cmol(+) kg^{-1}	Exchangeable Ca, cmol(+) kg^{-1}	Exchangeable K, cmol(+) kg^{-1}	Exchangeable Na, cmol(+) kg^{-1}
1	2	3	4	5	6	7	8	9	10	11
1	0.990	4.68	0.168	11.54	500	261.60	0.816	1.630	0.297	0.026
2	0.660	5.38	0.143	10.26	1500	497.00	0.816	1.225	0.164	0.026
3	1.920	4.95	0.157	14.36	1000	444.70	0.816	1.225	0.164	0.070
4	2.070	4.80	0.192	9.23	1000	470.90	0.734	2.040	0.123	0.061
5	1.890	5.29	0.072	13.85	1000	418.60	1.632	0.410	0.195	0.035
6	2.250	5.85	0.062	15.38	1500	143.90	1.836	0.305	0.246	0.026
7	0.510	7.11	0.188	11.28	1000	104.60	0.408	3.265	0.092	0.017
8	0.810	5.11	0.276	7.69	1000	26.16	0.122	1.225	0.256	0.061
9	1.560	5.31	0.141	8.20	1000	497.00	1.873	1.630	0.380	0.035
10	0.930	5.46	0.072	16.41	1500	575.50	0.694	2.040	0.113	0.026
11	1.230	4.80	0.143	21.02	1000	523.20	0.816	2.450	0.287	0.035
12	0.570	6.33	0.151	7.69	500	183.10	0.408	2.855	0.339	0.009
13	0.840	5.34	0.533	7.69	1000	52.32	0.204	0.815	0.185	0.017

Contd.

Table 1 Continued

1	2	3	4	5	6	7	8	9	10	11
14	2.520	6.00	0.390	18.46	1000	523.20	1.795	8.160	0.431	0.061
15	0.870	5.54	0.088	24.10	500	313.90	0.734	1.630	0.154	0.017
16	0.480	5.79	0.136	16.41	1000	444.70	0.816	2.040	0.144	0.035
17	1.470	5.78	0.135	10.77	1250	758.60	2.122	2.450	0.215	0.017
18	0.870	5.26	0.055	7.69	500	26.16	0.204	2.450	0.150	0.026
19	0.300	5.47	0.112	10.26	500	340.10	0.979	0.410	0.144	0.009
20	1.650	4.90	0.305	7.18	500	183.10	0.408	1.630	0.123	0.078
21	0.780	5.67	0.199	17.44	500	130.80	0.286	2.450	0.236	0.022
22	0.630	5.23	0.051	11.79	500	104.60	0.408	1.225	0.144	0.009
23	1.350	7.03	0.140	13.33	1500	52.32	0.408	7.345	0.236	0.026
24	0.120	5.73	1.000	9.23	250	26.16	0.082	0.410	0.021	0.017
25	0.690	5.71	0.092	16.92	500	52.32	0.408	0.815	0.113	0.013
26	1.230	6.02	0.061	17.95	1600	274.70	1.632	2.040	0.226	0.022
27	1.050	6.54	0.175	16.41	400	78.48	0.408	7.750	0.169	0.035
28	1.020	5.06	0.770	3.08	500	78.48	0.408	1.225	0.072	0.026
29	1.260	5.52	0.087	5.64	500	78.48	0.408	1.630	0.174	0.009
30	0.630	5.76	0.142	10.26	500	287.80	0.816	2.040	0.164	0.026

Contd.

Table 1 Continued

1	2	3	4	5	6	7	8	9	10	11
31	0.900	6.12	0.108	9.74	1700	470.90	1.224	2.040	0.431	0.017
32	0.960	5.87	0.064	12.82	1100	444.70	0.816	2.450	0.308	0.017
33	0.930	4.90	0.660	5.13	1000	732.50	1.224	0.815	0.154	0.313
34	0.750	5.51	0.156	22.05	1400	366.20	1.632	1.630	0.159	0.052
35	1.080	5.52	0.158	3.08	500	104.60	0.204	1.630	0.174	0.078
36	1.770	5.25	0.039	17.44	1000	26.16	0.245	0.815	0.062	0.017
37	0.870	5.73	0.080	7.18	100	78.48	0.125	2.450	0.185	0.009
38	0.930	5.44	0.114	5.90	500	287.80	1.347	2.450	0.185	0.035
39	0.960	5.63	0.089	9.23	1000	601.70	1.224	2.855	0.174	0.026
40	2.160	5.30	0.800	7.69	1500	497.00	0.408	2.450	0.297	0.026
41	0.420	4.51	0.108	6.67	750	26.16	0.734	0.410	0.164	0.022
42	0.390	5.45	0.118	5.13	500	235.40	1.224	2.450	0.256	0.026
43	0.810	6.57	0.136	6.41	750	26.16	0.816	4.080	0.297	0.052
44	2.040	5.32	0.108	5.13	500	287.80	0.408	2.450	0.385	0.026
45	2.070	5.60	0.185	5.13	1000	157.00	0.816	3.670	0.174	0.035
46	0.600	6.16	0.101	6.67	1000	313.90	2.040	1.630	0.359	0.017
47	0.630	5.56	0.100	7.18	2000	235.40	0.816	4.080	0.267	0.017

Contd.

Table 1 Continued

1	2	3	4	5	6	7	8	9	10	11
48	0.900	5.05	0.084	6.15	500	130.80	0.816	1.225	0.062	0.035
49	0.270	8.16	0.186	6.15	500	52.32	0.204	2.450	0.421	0.017
50	0.450	4.25	0.226	2.05	100	52.32	0.082	0.205	0.154	0.052
51	0.540	5.09	0.087	14.87	500	78.48	0.408	1.630	0.072	0.026
52	0.210	5.98	0.055	3.59	1750	157.00	0.204	2.040	0.164	0.017
53	0.630	5.63	0.085	4.62	500	366.20	0.816	2.040	0.123	0.026
54	0.330	6.50	0.120	24.10	1000	235.40	2.448	4.490	0.103	0.052
55	0.720	5.21	0.048	2.56	500	287.80	0.612	1.430	0.113	0.035
56	0.360	5.31	0.048	16.41	1000	549.40	3.264	0.815	0.041	0.017
57	0.390	5.06	0.436	1.54	500	26.16	0.204	0.410	0.051	0.009
58	0.600	4.68	0.523	5.64	500	209.30	0.816	3.265	0.318	0.022
59	0.930	5.38	0.069	3.59	400	287.80	0.816	2.040	0.236	0.013
60	0.720	6.00	0.089	6.15	500	287.80	0.816	3.265	0.195	0.017
61	0.870	5.93	0.123	8.20	800	209.30	1.224	3.670	0.421	0.026
62	0.480	5.04	0.100	4.10	500	287.80	1.224	0.815	0.072	0.035
63	0.390	6.00	0.143	4.10	500	209.30	0.816	2.450	0.226	0.009
64	1.110	4.41	0.327	4.10	1500	313.90	1.632	1.632	0.103	0.130

Contd.

Table 1 Continued

1	2	3	4	5	6	7	8	9	10	11
65	1.200	6.30	0.246	12.31	1500	313.90	0.816	5.305	0.200	0.035
66	0.030	5.47	0.074	6.67	550	209.30	0.408	0.815	0.051	0.017
67	0.060	5.36	0.193	6.67	1500	26.16	0.204	1.225	0.154	0.026
68	0.270	5.21	0.078	24.10	1550	130.80	0.612	0.815	0.092	0.009
69	2.280	5.29	0.190	7.18	1500	130.80	0.816	4.490	0.503	0.017
70	1.710	4.94	0.082	2.56	950	157.00	0.408	1.225	0.092	0.009
71	1.650	4.82	0.128	9.23	650	104.60	0.408	2.040	0.277	0.013
72	1.800	5.21	0.635	5.38	250	130.80	0.816	1.630	0.082	0.035
73	2.370	4.92	0.082	5.13	1450	183.10	0.408	0.815	0.113	0.022
74	1.710	4.97	0.051	9.23	750	261.60	0.204	1.225	0.051	0.017
75	1.110	5.59	0.135	7.18	500	157.00	0.204	1.835	0.359	0.009
76	1.830	6.93	0.242	8.72	750	340.10	1.632	8.570	0.390	0.026
77	1.290	5.45	0.184	12.82	500	52.32	0.408	7.750	0.195	0.017
78	1.590	5.25	0.056	12.31	1500	26.16	0.122	2.450	0.195	0.017
79	0.840	4.82	0.063	11.79	500	26.16	0.408	0.410	0.051	0.017
80	1.860	5.58	0.055	3.59	500	52.32	0.286	3.265	0.174	0.017
81	1.320	5.96	0.078	4.10	600	104.60	0.734	2.855	0.205	0.017

Contd.

Table 1 Continued

1	2	3	4	5	6	7	8	9	10	11
82	1.350	5.12	0.069	7.69	1000	78.48	0.653	1.225	0.164	0.009
83	0.600	5.28	0.075	5.13	500	130.80	0.612	0.410	0.256	0.017
84	1.290	5.97	0.159	6.15	500	340.10	0.775	4.895	0.169	0.026
85	0.960	5.23	0.068	4.10	2000	261.60	0.734	1.630	0.103	0.022
86	1.260	5.59	0.131	16.41	1500	235.40	0.612	2.855	0.205	0.017
87	0.570	5.28	0.244	8.72	500	261.60	0.408	1.630	0.236	0.026
88	1.590	5.56	0.076	5.38	900	104.60	0.408	2.855	0.164	0.017
89	1.590	5.78	0.173	2.31	4000	130.80	0.408	2.040	0.195	0.044
90	0.750	5.85	0.342	8.72	1500	52.32	0.408	14.850	0.400	0.044
91	0.750	5.55	0.201	13.85	1350	313.90	0.612	5.100	0.236	0.017
92	0.480	5.34	0.125	4.62	750	523.20	0.816	0.410	0.154	0.022
93	0.450	5.30	0.383	12.31	500	130.80	0.408	0.410	0.195	0.026
94	0.330	5.63	0.194	2.56	400	183.10	0.816	0.815	0.205	0.035
95	1.320	5.00	0.277	4.62	600	52.32	0.204	1.430	0.246	0.096
96	0.720	5.00	0.141	6.67	500	340.10	1.224	0.815	0.256	0.044
97	0.300	4.95	0.148	4.36	750	444.70	1.632	1.630	0.267	0.017
98	0.660	4.99	0.144	8.72	500	287.80	1.224	0.815	0.318	0.017

Contd.

Table 1 Continued

1	2	3	4	5	6	7	8	9	10	11
99	0.900	5.68	0.079	21.02	500	209.30	1.224	1.630	0.400	0.017
100	0.960	4.99	0.170	9.23	500	274.70	1.632	0.815	0.123	0.026
101	1.170	5.02	0.214	9.23	250	78.48	0.408	0.815	0.349	0.017
102	0.300	6.74	0.192	12.82	1500	78.48	0.408	0.815	0.144	0.009
103	0.510	4.64	0.352	17.44	1000	117.70	0.816	0.410	0.051	0.009
104	0.390	4.19	0.320	5.64	500	470.90	0.204	0.410	0.030	0.017
105	0.330	6.69	0.715	15.38	500	287.80	0.122	0.205	0.082	0.052
106	0.840	5.90	0.131	9.74	1000	706.30	0.898	2.855	0.174	0.017
107	2.070	2.93	20.600	12.31	2500	1203.00	8.160	3.265	0.410	0.122
108	0.300	6.52	0.280	9.74	1000	706.30	1.224	2.040	0.205	0.026
109	0.540	5.24	0.107	15.38	500	26.16	0.082	1.225	0.123	0.017
110	0.540	5.53	0.084	23.59	250	52.32	0.408	1.225	0.092	0.017
111	0.030	5.53	0.059	4.62	500	157.00	0.816	0.410	0.082	0.009
112	0.210	7.36	0.178	3.08	1500	183.10	0.408	4.895	0.185	0.026
113	1.950	6.02	0.202	16.41	500	52.32	0.408	1.225	0.133	0.017
114	2.220	4.89	0.300	5.64	250	52.32	0.082	2.040	0.092	0.022
115	0.390	7.59	0.726	4.10	1750	183.10	0.408	12.240	0.503	0.287

Contd.

Table 1 Continued

1	2	3	4	5	6	7	8	9	10	11
116	0.150	6.53	0.059	2.82	200	78.48	0.408	1.225	0.123	0.017
117	0.300	5.13	0.069	1.54	250	26.16	0.082	0.410	0.103	0.009
118	0.090	6.01	0.105	6.15	250	13.08	0.082	0.410	0.205	0.009
119	0.300	6.01	0.065	3.59	500	157.00	0.816	2.040	0.082	0.017
120	4.230	5.22	0.081	4.87	2150	13.08	0.082	1.225	0.051	0.009
121	0.090	6.29	0.167	3.08	250	52.32	0.408	3.265	0.164	0.026
122	0.810	5.69	0.058	5.64	100	13.08	0.082	0.410	0.051	0.013
123	0.030	6.06	0.043	12.82	130	26.16	0.082	0.410	0.021	0.009
124	0.150	6.24	0.065	5.13	400	235.40	0.204	0.815	0.051	0.009
125	1.830	4.49	2.459	20.00	1950	575.40	3.264	6.120	0.169	0.296
126	0.390	5.29	0.070	6.67	250	26.16	0.204	0.410	0.062	0.009
127	2.160	5.04	0.141	5.64	500	13.08	0.082	0.410	0.041	0.009
128	0.030	5.98	0.075	12.82	500	26.16	0.204	1.225	0.010	0.026
129	0.120	7.73	0.270	8.72	500	26.16	0.204	0.610	0.041	0.022
130	0.060	5.64	0.077	7.18	250	26.16	0.204	0.410	0.031	0.009
131	0.030	5.94	0.073	11.28	250	130.80	0.204	0.815	0.062	0.009
132	0.510	5.39	0.096	8.20	500	418.60	1.224	0.410	0.113	0.017

Contd.

Table 1 Continued

1	2	3	4	5	6	7	8	9	10	11
133	0.870	5.15	0.192	2.56	600	183.10	0.204	1.225	0.072	0.026
134	0.600	5.02	0.118	7.18	250	26.16	0.204	0.410	0.051	0.017
135	1.500	4.76	0.192	3.07	500	157.00	1.632	0.815	0.318	0.104
136	0.180	5.27	0.432	4.10	500	261.60	0.408	1.225	0.164	0.087
137	0.840	4.60	0.174	15.90	500	287.80	0.408	0.815	0.154	0.026
138	0.510	5.24	0.134	4.62	130	26.16	0.082	0.410	0.041	0.017
139	0.750	6.35	4.820	3.59	1000	418.60	3.264	6.120	0.164	0.017
140	0.870	7.00	0.136	3.08	250	78.48	0.204	1.630	0.092	0.017
141	0.030	7.12	0.078	7.18	130	26.16	0.082	0.410	0.021	0.017
142	0.750	6.93	0.061	4.62	500	209.30	1.224	1.630	0.103	0.026
143	1.470	6.45	0.136	3.08	2000	130.80	0.449	4.080	0.123	0.052
144	0.450	5.73	0.052	4.10	500	157.00	0.979	2.040	0.092	0.009
145	0.300	5.09	0.047	4.62	400	26.16	0.082	0.410	0.031	0.009
146	0.480	8.56	0.262	25.64	10880	915.60	5.304	19.180	0.328	0.252
147	0.870	8.29	0.286	14.87	5990	758.60	9.393	1.142	0.297	0.139
148	0.270	8.17	0.051	15.38	1500	340.10	2.856	0.228	0.103	0.157
149	1.350	7.95	0.422	20.51	6740	784.80	4.080	1.175	0.267	0.122
150	0.480	7.83	0.396	6.15	2150	392.40	2.856	8.160	0.226	0.157

Table 2. Mean values of the properties relating to behaviour of Mg in different soil groups

Soil characteristics	Soil group			Overall mean
	Red, laterite and brown hydromorphic	Alluvium	Black	
Organic carbon, %	1.012	0.705	0.690	0.911
pH	5.49	5.75	8.16	5.66
EC, dS m^{-1}	0.179	0.791	0.283	0.362
CEC, cmol(+) kg^{-1}	9.335	7.949	16.510	9.168
Exchangeable Ca, cmol(+) kg^{-1}	2.305	1.707	5.977	2.252
Exchangeable K, cmol(+) kg^{-1}	0.203	0.116	0.244	0.179
Exchangeable Na, cmol(+) kg^{-1}	0.031	0.036	0.165	0.037
Total Mg, ppm	869.8	669.1	5452	963.7
Available Mg, ppm	231.9	184.6	638.3	231.6
Exchangeable Mg, cmol(+) kg^{-1}	0.785	0.716	4.896	0.902

1.1 Organic carbon

The soil samples varied widely in their organic carbon content (from 0.03 to 4.23 per cent). The overall mean value was 0.911 per cent. In general, the Group 1 soils contained more organic carbon than the other two groups. The mean value was minimum for black soils (0.69 per cent).

In Group 1, the lowest amount recorded was 0.03 per cent (soil No.66) and the highest amount was 2.52 per cent (soil No.14). The soils in Group 1 are generally medium in organic carbon content (1.012 per cent). In Group 2 also, wide variation in organic carbon was observed. The lowest amount was 0.03 per cent (soil No.111) and the highest was 4.23 per cent (soil No.120). Here, the majority of the samples were low in organic carbon probably because they represented the coastal sandy soils. The mean value was 0.705 per cent. The organic carbon in black soils varied from 0.27 per cent (soil No.148) to 1.35 per cent (soil No.149), the mean being 0.69 per cent. The soils were medium in organic carbon content.

Pooled analysis of the soil showed that organic carbon had significant positive correlation with exchangeable K ($r = 0.2365^{**}$). This may be due to the increase in exchange sites with increase in organic colloids.

In Group 1 soils organic carbon content was found positively correlated with total Mg ($r = 0.2242^{*}$), exchangeable Ca (r = 0.2524*) and with exchangeable K (r = 0.2150*). These relationships are the consequence of the release of nutrients on organic matter decomposition and also due to the adsorption of cations on the negatively charged sites of organic colloids.

In Group 2 also, organic carbon was found positively correlated with total Mg (r = 0.5176**). The reason may be the same as explained before. The pH was found negatively correlated with organic carbon (r = -0.3952**). This may be due to the release of organic acids on decomposition of organic matter.

1.2 pH

Wide variation was observed in the pH of the soil samples collected for the study. Most of the soils were acidic. The overall mean pH recorded was 5.66. Considering the three types of soils, Group 1 soils were more acidic (pH 5.49) than alluvial soils (pH 5.75). The black soils were alkaline (pH 8.16).

When the three groups of soils were considered together, positive correlation was observed between pH and exchangeable Ca (r = 0.5560**), pH and exchangeable Na (r = 0.2179**) and pH and total Mg (r = 0.4010**). The increase in pH increases base saturation thus increasing exchangeable bases. The correlation between pH and total Mg may be attributed to the increase in CEC with increase in pH. Negative correlation was observed between pH and EC (r = -0.2455**). This may be because of the increased solubility of iron and aluminium compounds in strongly acid conditions. The release of iron and aluminium ions from the soil colloids will itself contribute to soil acidity in turn.

When the soil groups were considered separately, exchangeable Ca and exchangeable K were found positively correlated with pH in Group 1 soils ($r = 0.5052^{**}$ and $r = 0.3007^{**}$ respectively). This increase in these exchangeable cations with increase in pH can be attributed to the rise in CEC due to pH dependent charges.

In alluvial soils, negative correlation was again observed between pH and EC ($r = -0.4366^{**}$). The reason has been explained before. In this group, pH was also negatively correlated with available Mg ($r = -0.3425^{*}$). The solubility of Mg compounds increases as the soil reaction becomes more and more acidic and hence the negative correlation between pH and available Mg. There was a negative correlation between pH and organic carbon ($r = -0.3952^{**}$), the reason for which has been explained earlier.

1.3 Specific conductance

The mean value of specific conductance of all soils selected for the study was 0.362 dS m^{-1}, the range being 0.051 to 20.6 dS m^{-1}. The average specific conductance of three different groups of soils showed that all the soil groups were nonsaline.

The specific conductance of the soils in Group 1 ranged from 0.039 to 1.0 dS m^{-1}. All the soil samples in this group were nonsaline. The alluvial soils showed a variation in specific conductance from 0.043 to 20.6 dS m^{-1}. Soil No.107 registered the highest value and it was found to be acid saline (Kaipad). All other soils were nonsaline. In black soils, the variation in specific conductance was from 0.051 to 0.422 dS m^{-1}. All the soils of this group were nonsaline, the mean being 0.283 dS m^{-1}

Specific conductance was negatively correlated with pH (r = -0.2455**), the reason being discussed before. Positive correlation existed between EC and exchangeable Mg (r = 0.3585**), EC and available Mg (r = 0.4087**), EC and exchangeable K (r = 0.1766*) and EC and exchangeable Na (r = 0.1944*). The exchangeable cations are in equilibrium with the cations in soil solution and therefore a change in the concentration of the cations in soil solution will invariably increase the exchangeable cations. Thus the exchangeable cations inturn increase the specific conductance of soil solution. This may be the reason for the positive correlation between EC and exchangeable cations.

In Group 1 soils, exchangeable Na was found to correlate positively with EC (r = 0.3025**). In alluvial soils also positive correlation was observed between EC and exchangeable Mg (r = 0.9262**), EC and available Mg (r = 0.7107**) and EC and exchangeable K (r = 0.4964**). This substantiates the indirect influence of exchangeable cations in increasing the specific conductance as discussed previously. The specific conductance was found to correlate positively with total Mg ($r = 0.5228^{**}$) also. As exchangeable Mg and available Mg contribute to the total Mg content, this correlation may be the indirect influence of exchangeable and available Mg in increasing specific conductance.

1.4 Cation exchange capacity

The CEC of soils selected for the study ranged from 1.54 to 25.64 cmol(+) kg^{-1}.

The overall mean value was 9.168 cmol(+) kg^{-1}. The alluvial soils showed lowest average CEC (7.949 cmol(+) kg^{-1}) and the black soils, the highest (16.51 cmol(+) kg^{-1}).

Majority of the soils in Group 1 exhibited a CEC of less than 10 cmol(+) kg^{-1}, the average being 9.335 cmol(+) kg^{-1}. This may be because of the dominance of kaolinitic type of clay minerals in these soils. In the alluvial group, majority of the soils showed a lower CEC compared to Group 1. This may be attributed to the lower organic matter status of these soils. The black soils exhibited comparitively higher CEC than the other two groups. The CEC of these soils ranged from 6.15 to 25.64 cmol(+) kg^{-1}, having a mean of 16.51 cmol(+) kg^{-1}. The increased CEC of this group may be due to the presence of 2:1 type of clay minerals in these soils.

Pooled analysis of the three soil types revealed that CEC was found positively correlated with exchangeable Mg ($r = 0.2563^{**}$), available Mg ($r = 0.2834^{**}$), exchangeable Ca ($r = 0.273^{**}$) and with total Mg ($r = 0.3287^{**}$). The fact that an increase in exchange sites consequent to a rise in CEC increases the exchangeable cations, supports the positive correlation of CEC and exchangeable cations. Since exchangeable Mg is a Mg reserve and a replenishing factor of available Mg, a rise in CEC indirectly raises the level of available Mg in soil. Both exchangeable Mg and available Mg contribute to the total Mg content of soil and this may be attributed to the positive relationship of total Mg and CEC.

Statistical analysis of the data on CEC in separate soil groups failed to show any significant correlation between CEC and other soil characteristics. This may probably be due to the lack of sufficient variation in CEC among the soils within each group.

1.5 Exchangeable Ca

The soils varied in their exchangeable Ca content from 0.205 to 19.18 cmol(+) kg^{-1}. On an average, the exchangeable Ca content was 2.252 cmol(+) kg^{-1}. The highest amount was seen in black soils (5.977 cmol(+) kg^{-1}). The laterites contained an amount less than that of black soils (2.305 cmol(+) kg^{-1}). The alluvial soils showed the lowest amount of exchangeable Ca (1.707 cmol(+) kg^{-1}).

Significant positive relationships were observed when exchangeable Ca was correlated with pH (r = 0.556**), CEC (r = 0.273**), exchangeable Mg (r = 0.4048**), total Mg (r = 0.7465**), exchangeable K (r = 0.3845**) and with exchangeable Na (r = 0.4803**) in the pooled analysis of the three groups of soils. An increase in exchangeable Ca leads to a rise in pH which in consequence, increases CEC and in turn exchangeable cations retained by the soil. The decreased solubility of Mg compounds due to increase in pH and increased content of exchangeable Mg will together contribute to increase in total Mg. The positive correlation between exchangeable Ca and exchangeable Mg is in line with the observations made by Jayaraman (1988).

In Group 1 soils, exchangeable Ca was found to correlate positively with organic carbon (r = 0.2524*), pH (r = 0.5052**) and with exchangeable K (r = 0.4097**). These correlations further indicate the influence of exchangeable Ca in raising pH and the influence of pH and organic carbon in increasing exchange sites. In alluvial soils pH was again positively correlated with exchangeable Mg (r = 0.3230*), total Mg (r = 0.5937**) exchangeable K (r = 0.6989**) and with exchangeable Na (r = 0.7429**). There was also a positive correlation between exchangeable Ca and available Mg (r = 0.3051*). This may be attributed to the positive relationship between exchangeable Mg and available Mg.

1.6 Exchangeable K

The overall mean value of exchangeable K of soils was 0.179 cmol(+) kg^{-1}, the range being 0.010 to 0.503 cmol(+) kg^{-1}. As in the case of exchangeable Ca, the exchangeable K contents of the three different groups of soils were in the decreasing order of black soils, laterite group soils and alluvial soils.

Pooled analysis of soils showed that exchangeable K was found to be in positive correlation with organic carbon (r = 0.2365**), exchangeable Mg (r = 0.2219**), exchangeable Ca (r = 0.3845**), total Mg (r = 0.2593**), EC (r = 0.1766*) and with exchangeable Na (r = 0.2718**). These relationships have already been discussed.

Some of the above correlations are repeatedly observed in Group 1 and Group 2 soils. In Group 1, exchangeable K was positively correlated with organic carbon (r = 0.2150*), pH (r= 0.3007**) and with exchangeable Ca (r = 0.4097**). In Group 2, exchangeable K showed significant positive relation with EC (r= 0.4964**), total Mg (r = 0.5463**), exchangeable Mg (r = 0.549**), available Mg (r = 0.5134**), exchangeable Ca (r = 0.6989**) and with exchangeable Na (r = 0.6743**). The increase in pH and consequent rise in exchange sites explains the correlation between exchangeable K and exchangeable cations. The positive correlation of exchangeable K and exchangeable Mg is in line with a similar observation by Jayaraman (1988). The positive relationship among available Mg, exchangeable Mg and total Mg may be attributed to their interrelationship.

1.7 Exchangeable Na

The exchangeable Na content of different soils ranged from 0.009 to 0.313 cmol(+) kg^{-1}. The overall mean value was 0.037 cmol(+) kg^{-1}. The average amount of exchangeable Na was observed to be maximum in black soils (0.165 cmol(+) kg^{-1}). This group was followed by alluvial soils (0.036 cmol(+) kg^{-1}) and the laterite group soils showed the least content (0.031 cmol(+) kg^{-1}).

When the three soil types were pooled together, the statistical analysis of the data showed that exchangeable Na was positively correlated with exchangeable Mg ($r = 0.3221^{**}$), exchangeable Ca ($r = 0.4803^{**}$), exchangeable K ($r = 0.2718^{**}$), pH ($r = 0.2179^{**}$) and with total Mg ($r = 0.4638^{**}$). Here also, the influence of pH on exchangeable bases is further emphasized. The correlation between exchangeable Na and total Mg may be attributed to the positive correlation between total Mg and exchangeable Mg.

Most of the above relationships are also observed when the soils are considered group-wise. In Group 1 soils, exchangeable

Na was found to correlate positively with EC (r = 0.3025**) and available Mg (r = 0.2812**). The relationship between exchangeable Na and EC has been discussed before. The high values of exchangeable Na are always associated with a relatively high pH of the soil and under this condition the solubility of Mg compounds is considerably decreased. Consequently, such soils usually retain a moderately high pool of available Mg. In alluvial soils (Group 2), exchangeable Na was found to have positive relationship with total Mg (r = 0.5419**), exchangeable Mg (r = 0.4124**), available Mg (r = 0.3715*), exchangeable Ca (r = 0.7429**) and exchangeable K (r = 0.6743**). The reasons for these relations have already been discussed.

2. Magnesium status of soils

2.1 Total Mg

A wide variation of 100 ppm to 10,880 ppm in the content of total Mg was recorded in the soils selected for the study. The overall mean was 963.7 ppm. The total Mg content was maximum in black soils (5452 ppm) and minimum in alluvial soils (669.1 ppm).

In Group 1 soils, total Mg content showed a variation of 100 to 4000 ppm, the average being 869.8 ppm. Out of the 101 soils in this group, 41 per cent showed a total Mg content of 1000 ppm and above. Only 5 per cent showed a content of

250 ppm and below. The rest were in the range of 250 to 1000 ppm. The total Mg content of alluvial soils ranged from 100 to 2500 ppm. Among the 44 alluvial soils 25 per cent showed a content of 1000 ppm total Mg and above. About 36 per cent were at or below 250 ppm in their total Mg content and the rest contained total Mg in the range of 250 to 1000 ppm. The soils of Group 3 showed a higher amount of total Mg compared to the other two groups. The lowest value was 1500 ppm (soil No.148) and the highest value was 10,880 ppm (soil No.146).

In general, the soils of Kerala can be considered to be deficient in total Mg reserves. The normal range of total Mg in soil as stated by Tisdale *et al.* (1985) is 0.1 to 4.0 per cent. The mean content of total Mg of soils selected for this study is only 963.7 ppm which is less than even the lower limit of the range suggested (1000 ppm). Of the 150 soils selected for the study, 92 soils (61 per cent) were therefore deficient with regard to the total Mg content in soil.

This could be attributed to the following reasons. (1) Magnesium in soil originates from the decomposition of rocks containing primary minerals such as biotite, dolomite, hornblende, olivine, serpentine etc. The Mg released by the disintegration of these rocks is lost by leaching under humid tropical conditions. (2) Magnesium salts like epsomite ($MgSO_4.7H_2O$), magnesium sulphate hexa-hydrate ($MgSO_4.6H_2O$), bloedite ($Na_2Mg(SO_4)_3.4H_2O$) are never stable under acid leaching situations and therefore are seldom met with in the acid soils of Kerala. (3) The soils of Kerala predominantly are kaolinitic in nature and therefore are deficient in Mg containing clay minerals like chlorite, illite, montmorillonite and vermiculite. Only the black soil which is present in a small tract of Palghat District of the State is relatively rich in total Mg with the mean value of 5452 ppm. The highest value recorded in this group of soil was 10,880 ppm. Thus it can be concluded that the soils of Kerala except the black soils are in general deficient in total Mg considering a threshold value of 0.1 per cent (1000 ppm).

In pooled analysis, total Mg was found to have positive relationship with pH ($r = 0.401^{**}$), exchangeable Mg ($r = 0.4414^{**}$), available Mg ($r = 0.5024^{**}$), exchangeable Ca ($r = 0.7465^{**}$), CEC ($r = 0.3287^{**}$), exchangeable K ($r = 0.2593^{**}$) and exchangeable Na ($r = 0.4638^{**}$). Relationship of total Mg with exchangeable cations may be attributed to its correlation with CEC. Influence of pH on production of pH dependent charges may also be taken into consideration. The exchangeable and available fractions of Mg are parts of total Mg and this fact explains the correlation between these fractions and total Mg.

In Group 1, total Mg was positively correlated with organic carbon ($r = 0.2242^{*}$). In Group 2, significant positive relationship was observed between total Mg and organic carbon ($r = 0.5176^{**}$), total Mg and EC (r = 0.5228**), total Mg and exchangeable Mg (r = 0.5752**), total Mg and available Mg (r = 0.5404**), total Mg and exchangeable Ca (r = 0.5937**) and between total Mg and exchangeable K (r = 0.5463**). A positive correlation between total Mg and available Mg was observed in black soils (r = 0.9619**). These correlations have already been discussed.

2.2 Available Mg

The available Mg content of the soils selected for the study varied from 13.08 to 1203 ppm. The average content of available Mg in these soils was 231.6 ppm. The black soils contained the highest amount of available Mg (638.3 ppm) and the alluvial soils showed the least (184.6 ppm). The laterite group was in between (231.9 ppm).

In coarse textured soils of the humid region, Mg deficiency often manifests when the soil contains less than 25 to 50 ppm of exchangeable Mg (Tisdale *et al.*, 1985). The relationship between available Mg and exchangeable Mg in the present study showed that in general the content of available Mg is almost double the quantity of exchangeable Mg and therefore, a value of 50 ppm of available Mg can be considered as the critical value for the humid tropical soils of Kerala. Accordingly it may be suggested that soils containing less than 50 ppm available Mg are considered deficient and those containing 50 to 100 ppm as marginal and more than 100 ppm as sufficient. A soil with more than 500 ppm available Mg can be taken as high or rich in available Mg. Adopting these criteria, 10 per cent of the soils in Group 1 and 34 per cent of the soils in Group 2 were deficient in available Mg. They together constituted 17 per cent of the total soils. In Group 1 soils, 14 per cent and in Group 2 soils, 16 per cent were marginal containing only 50 to 100 ppm of available Mg. All the black soils were sufficient in available Mg registering values higher than 100 ppm. More number of soils which are deficient in Mg was under Group 2 which mainly consisted of sandy loam soils of coastal alluvium with very little organic matter.

It was seen that the soils selected for the study especially Group 1 and Group 2 were in general deficient in Mg reserves. But examination of the status of available Mg in soil shows that Mg deficiency in terms of available Mg values is not that much extensive. This is because, though these soils are poor in total Mg reserves, whatever Mg is present in soil becomes easily available due to its high solubility under acidic soil conditions.

The black soils showed a range of available Mg from 340.1 ppm to 915. 6 ppm. The black soils are relatively rich in available Mg obviously because they contain higher amounts of total Mg. The dominant clay minerals in this type of soil are of 2:1 type which are rich in Mg, while the soils of Group 1 and Group 2, contain kaolinite as the most important clay mineral.

More over, the neutral to alkaline reaction of black soils facilitates the formation and retention of Mg containing minerals.

The pooled analysis of the soils revealed that available Mg positively correlated with exchangeable Mg (r = 0.5473**), EC (r = 0.4087**), CEC (r = 0.5024**) and total Mg (r = 0.2834**). Exchangeable Mg is in equilibrium with the soil solution Mg and it is the Mg reserve and replenishing factor for available Mg. Thus an increase in exchangeable Mg, increases available Mg also. These two fractions contributed to total Mg, causing a positive relationship between available Mg and total Mg.

In Group 1 soils, positive relationships were observed between available Mg and exchangeable Mg (r = 0.3109**) and also between available Mg and exchangeable Mg (r = 0.2812**). In alluvial soils, available Mg was found to be positively correlated with total Mg (r = 0.5404**), exchangeable Mg (r = 0.8009**), exchangeable Ca (r = 0.3051*), exchangeable K (r = 0.5134**), exchangeable Na (r = 0.3715*) and EC (r = 0.7107**). In black soils, available Mg was found to increase with increase in total Mg (r = 0.9619**).

2.3 Exchangeable Mg

The selected soil samples showed a wide variation in exchangeable Mg from 0.082 to 9.383 cmol(+) kg^{-1}. The average content was 0.902 cmol(+) kg^{-1}. The alluvial soils showed the lowest average exchangeable Mg content (0.716 cmol(+) kg^{-1}). The black soils showed the maximum content (4.896 cmol(+) kg^{-1}). The laterite group was in between. The coarse textured soils of the humid regions are usually deficient in Mg and as expected, soils of Group 1 and 2 in the present study manifested very low values for exchangeable Mg. For such soils, Tisdale *et al.* (1985) considered a Mg level of less than 25 ppm as deficient. Assuming this threshold value of 25 ppm (which corresponds 0.208 cmol(+) kg^{-1}), 25 per cent of the total soils selected for the study were deficient in exchangeable Mg and another 25 per cent was marginal being within the range of 25 to 50 ppm (0.208 to 0.417 cmol(+) kg^{-1}). The remaining 50 per cent can be considered as sufficient in exchangeable Mg, as they exhibited values higher than 50 ppm. Among the soil groups, black soils were rather rich in exchangeable Mg, all the soils giving Mg values higher than 50 ppm. The most deficient soils were those under Group 2 mainly because they were coastal alluvium of sandy loam texture with very low content of organic matter.

Exchangeable Mg formed the major portion of the available Mg pool of the soil. In general, exchangeable Mg constituted almost half of the available Mg content. The exchangeable Mg represented approximately 11 per cent of the total Mg, when all the soils are considered together.

The soils of Group 1 exhibited value of exchangeable Mg ranging from 0.082 to 3.264 cmol(+) kg^{-1}. Among the 101 samples, about 15 per cent were below 0.208 cmol(+) kg^{-1} (25 ppm) in their exchangeable Mg content, probably because of the low CEC of this group of soils. About 27 per cent showed a value of exchangeable Mg between 0.208 and 0.417 cmol(+) kg^{-1} 25 to 50 ppm) whereas the rest (58 per cent) were found to be above 0.407 cmol(+) kg^{-1} (50 ppm).

The exchangeable Mg content of alluvial soils ranged from 0.082 to 8.16 cmol(+) kg^{-1}. Fifty per cent of the samples of this group were having exchangeable Mg in the range of less than 0.208 cmol(+) kg^{-1} (deficient). About 23 per cent were marginal in exchangeable Mg while around 27 per cent exhibited an exchangeable Mg content of sufficient range (above 0.407 cmol(+) kg^{-1}).

The exchangeable Mg in black soils ranged from 2.856 to 9.383 cmol(+) kg^{-1} with a mean of 4.896 cmol(+) kg^{-1}. This may be because of the higher CEC exhibited by this type of soils.

The exchangeable Mg was found positively correlated with EC (r = 0.3585**), CEC (r = 0.2563**), total Mg (r = 0.4414**), available Mg (r = 0.5473**), exchangeable Ca (r = 0.4048**), exchangeable K (r = 0.2219**) and exchangeable Na (r = 0.3221**) in the pooled analysis. The correlations between exchangeable Mg and other exchangeable cations like exchangeable

Ca and K were also observed by Jayaraman (1988). The fact that the magnitude of exchangeable Mg in soil depends upon the CEC of the soil, will explain the positive correlation between exchangeable Mg and other exchangeable cations. Since an equilibrium exists between the exchangeable cations in soil, the factors that will increase the concentration of exchangeable Mg will also tend to increase the concentration of other exchangeable cations.

In Group 1, significant positive correlation was observed between exchangeable Mg and available Mg ($r = 0.3109^{**}$). In alluvial soils (Group 2), positive relationships of exchangeable Mg with exchangeable Ca ($r = 0.3230^{*}$), exchangeable K ($r = 0.5490^{**}$) and exchangeable Na ($r = 0.4124^{**}$) were observed. This is in line with the observation of Jayaraman (1988). Exchangeable Mg in Group 2 soils was also found to have significant positive correlation with total Mg ($r = 0.5752^{**}$), available Mg ($r = 0.8009^{**}$) and EC ($r = 0.9262^{**}$).

The study thus tends to conclude that in general, the acid soils of Kerala are deficient in total Mg reserves. About 24 per cent of the total Mg was considered as available Mg. In terms of the magnitude of available Mg in soil, the acid soils of the state were deficient to marginal whereas all the black soils were rated as sufficient. This trend was also seen in the distribution of exchangeable Mg in soil. Thus Mg can be considered

Table 3. Correlation coefficients (r) between various soil characteristics in the pooled analysis of soils under Part 1

	Organic carbon (1)	pH (2)	EC (3)	CEC (4)	Exchangeable Ca (5)	Exchangeable K (6)	Exchangeable Na (7)	Total Mg (8)	Available Mg (9)	Exchangeable Mg (10)
(1)	-	-0.2644**	0.1510	0.0548	0.1111	0.2365**	0.1099	0.1464	0.1274	0.1539
(2)		-	-0.2455**	0.1327	0.5560**	0.1438	0.2179**	0.4010**	0.0402	0.1174
(3)			-	0.0390	0.0533	0.1766*	0.1944*	0.1222	0.4087**	0.3585**
(4)				-	0.2730**	0.0712	0.1284	0.3287**	0.2834**	0.2563**
(5)					-	0.3845**	0.4803**	0.7465**	0.3856**	0.4048**
(6)						-	0.2718**	0.2593**	0.3093**	0.2219**
(7)							-	0.4638**	0.4271**	0.3221**
(8)								-	0.5024**	0.4414**
(9)									-	0.5473**
(10)										-

* Significant at 5% level
** Significant at 1% level

Table 4. Coefficients of correlation (r) between soil characteristics in Group 1 soils

	Organic carbon (1)	pH (2)	EC (3)	CEC (4)	Exchangeable Ca (5)	Exchangeable K (6)	Exchangeable Na (7)	Total Mg (8)	Available Mg (9)	Exchangeable Mg (10)
(1)	-	-0.1100	0.0231	0.0441	0.2524*	0.2150*	0.1624	0.2242*	0.1133	0.1487
(2)		-	-0.0984	0.1611	0.5052**	0.3007**	0.0206	0.1212	0.0583	0.02996
(3)			-	-0.1629	0.0310	-0.0236	0.3025**	-0.0817	-0.0157	-0.1069
(4)				-	0.1671	-0.0006	0.0856	0.1262	0.1775	0.1687
(5)					-	0.4097**	0.1579	0.1833	0.0424	0.0593
(6)						-	0.0492	0.0757	0.1109	0.0434
(7)							-	0.0518	0.2812**	0.0737
(8)								-	0.1902	0.0675
(9)									-	0.3109**
(10)										-

* Significant at 5% level
** Significant at 1% level

Table 5. Coefficients of correlation (r) between soil characteristics in Group 2 soils

	Organic carbon (1)	pH (2)	EC (3)	CEC (4)	Exchangeable Ca (5)	Exchangeable K (6)	Exchangeable Na (7)	Total Mg (8)	Available Mg (9)	Exchangeable Mg (10)
(1)	-	-0.3952**	0.2735	0.0490	0.1157	0.1435	0.1893	0.5176**	0.1552	0.2832
(2)		-	-0.4366**	0.2128	0.2631	-0.0154	-0.0669	-0.1088	-0.3425*	-0.4244**
(3)			-	0.1391	0.2302	0.4964**	0.2952	0.5228**	0.7107**	0.9262**
(4)				-	-0.0897	-0.0323	0.1560	0.1202	0.1843	0.1683
(5)					-	0.6989**	0.7429**	0.5937**	0.3051*	0.3230*
(6)						-	0.6743**	0.5463**	0.5134**	0.5490**
(7)							-	0.5419**	0.3715*	0.4124**
(8)								-	0.5404**	0.5752**
(9)									-	0.8009**
(10)										-

* Significant at 5% level
** Significant at 1% level

as a very critical element in the successful management of the acid soils of Kerala.

PART 2. EVALUATION OF LABORATORY INDICES OF MAGNESIUM AVAILABILITY

Any soil test that measures the available quantity of a nutrient will provide enough information to support at least an approximation of the quantity of the nutrient to be supplied to soil for correcting the deficiency. However, all soil tests so far used could not predict the corrective treatment for a wide range of soils and environmental conditions. This is true in the case of Mg also. Very often the amount of Mg extracted by the widely accepted and presently followed method viz., neutral 1 *N* ammonium acetate varies in its correlation with the plant responses when different soils and varying climatic conditions are considered.

On the choice of the extracting solution best suited for the determination of available Mg, many restrictions must be necessarily imposed. The extracting solution must remove a portion of the element under consideration that can be related to plant uptake in the field and the results of the test must correlate with known crop responses to fertilizers.

A satisfactory extracting solution should effect complete or proportional removal of the portion of plant nutrients that will be really available to the crop under field conditions. The extractant should yield a clear filtrate with minimum interference due to organic matter. The extractant solution should not contain ions that will interfere with the proper execution of the individual tests. The concentration of the reagents must be within limits of acceptable sensitivity of the respective tests (Peech and English, 1944).

Unfortunately, only very few of the chemicals used in soil analysis possess a sufficient degree of specificity to permit their direct use in the presence of diverse ions. In addition to the chemical interference, there are so many biological and environmental factors involved in the interpretation and practical use of the soil tests.

Because of the above reasons, the results of chemical tests involving different extractants have provided only a part of information necessary for an intelligent fertilizer recommendation, with Mg fertilizers. Hesse (1971) gives a review of extractants used by various scientists, for the evaluation of laboratory index of Mg availability. The search for a universally applicable extractant for available Mg is typical of all attempts to determine available nutrients and demonstrates the absolute necessity to correlate extracted amounts of nutrient with the results of field trials on a specific soil using a specific crop. It is futile to try and apply the results to different soils or crops. The present study was planned in order to evolve a suitable extractant of available Mg for Kerala soils. Some selected chemical agents were tried with twenty selected soils of Kerala, varying in properties relating to Mg availability.

The investigation was carried out through different stages. The first stage was an initial study, in order to fix up extractants for preliminary screening. Initial study was taken up using one soil, ten extractants and two equilibration periods. The second stage was a preliminary screening of extractants, trying eight extractants within the workable limits. Thus the preliminary screening consisted of eight extractants at 6 periods of equilibration viz., 10, 20, 30, 40, 50 and 60 min with one soil and a single soil solution ratio of 1:10. The optimum equilibration period for each extractant was finalised at this stage. The selected extractants from this preliminary screening with suitable equilibration periods were then used for the final screening using twenty soils. The plant uptake study was conducted using Neubauer seedling technique with some modifications with rice as test crop and the amount of Mg extracted by various extractants, at different equilibration periods from the twenty soils were correlated with plant uptake of Mg.

The availability of nutrients to plants in soils is decided upon by a number of factors which are influenced by soil characteristics. Therefore, estimation of general characteristics of the soil related to Mg availability was made prior to the evaluation of extractants.

From the 150 soil samples collected to assess the Mg status of soils of Kerala, 20 soils were selected for this study based on their properties in relation to Mg availability, viz., organic carbon, pH, EC, CEC, total Mg, available Mg, exchangeable Mg, exchangeable Ca, exchangeable K and exchangeable Na. Considerable variation in these characteristics were observed in these soils.

The properties of these soils are presented in Table 6. The location of the soils collected is given in Appendix 2.

The organic carbon content of soils varied from 0.03 per cent to 2.25 per cent which showed that the organic carbon content of the soils under study was extremely varying. The pH of the soils selected for the study showed that they were mainly acidic with a few alkaline soils. The EC of the soils was in the range of 0.043 to 2.459 dS m^{-1} indicating that all soils were nonsaline. The CEC of the soils was varying, the range being 1.54 to 25.64 cmol(+) kg^{-1}.

Wide variation was seen in total Mg content of soils ranging from 130 to 10,880 ppm. Similarly the samples varied in their available Mg content from 26.16 to 915.6 ppm. The exchangeable Mg was found to vary from 0.082 to 9.383 cmol(+) kg^{-1}. Variations from 0.163 to 19.18 cmol(+) kg^{-1} in exchangeable

Table 6. Properties relating to the behaviour of Mg of soils selected for evaluation of laboratory indices of Mg availability

							cmol (+) .kg^{-1}				
Sl. No.	Soil sample No.	Organic C, %	pH	EC dS m^{-1}	Total Mg, ppm	Available Mg, ppm	Exchange-able Mg	Exchange-able Ca	Exchange-able K	Exchange-able Na	CEC
1	2	3	4	5	6	7	8	9	10	11	12
1	103	0.51	4.64	0.352	1000	117.70	0.816	0.410	0.051	0.009	17.44
2	6	2.25	5.85	0.062	1500	143.90	1.836	0.305	0.246	0.026	15.38
3	80	1.86	5.58	0.055	500	52.32	0.286	3.265	0.174	0.017	3.59
4	143	1.47	6.45	0.136	2000	130.80	0.449	4.080	0.123	0.052	3.08
5	113	1.95	6.02	0.202	500	52.32	0.408	1.225	0.133	0.017	16.41
6	123	0.03	6.06	0.043	130	26.16	0.082	0.410	0.021	0.009	12.82
7	24	0.12	5.73	1.000	250	26.16	0.082	0.410	0.021	0.017	9.23
8	25	0.69	5.71	0.092	500	52.32	0.408	0.815	0.113	0.013	16.92
9	26	1.23	6.02	0.061	1600	274.70	1.632	2.040	0.226	0.022	17.95
10	146	0.48	8.56	0.262	10880	915.60	5.304	19.180	0.328	0.252	25.64
11	147	0.87	8.29	0.286	5990	758.60	9.383	1.142	0.297	0.139	14.87

Contd.

Table 6 Continued

1	2	3	4	5	6	7	8	9	10	11	12
12	125	1.83	4.49	2.459	1950	575.40	3.264	6.120	0.169	0.296	20.00
13	31	0.90	6.12	0.108	1700	470.90	1.224	2.040	0.431	0.017	9.74
14	47	0.63	5.56	0.100	2000	235.40	0.816	4.080	0.267	0.017	7.18
15	54	0.33	6.50	0.120	1000	235.40	2.448	4.490	0.103	0.052	24.10
16	57	0.39	5.06	0.436	500	26.16	0.204	0.410	0.051	0.009	1.54
17	59	0.93	5.38	0.069	400	287.80	0.816	2.040	0.236	0.013	3.59
18	60	0.72	6.00	0.089	500	287.80	0.816	3.265	0.195	0.017	6.15
19	61	0.87	5.93	0.123	800	209.30	1.224	3.670	0.421	0.026	8.20
20	64	1.11	4.41	0.327	1500	313.90	1.632	0.163	0.103	0.130	4.10
Mean		0.96	5.92	0.319	1760	259.60	1.657	2.978	0.185	0.058	11.90

Ca were recorded by the soils. The soils differed in exchangeable K (0.021 to 0.431 cmol(+) kg^{-1}) and exchangeable Na (0.009 to 0.296 cmol(+) kg^{-1}).

The results of the initial study, preliminary screening and final screening are discussed below.

1. Initial study

The initial study was planned to identify chemical extractants capable of solubilising certain quantity of Mg from the soil which can be considered sufficient for a normal laboratory estimation without being subjected to considerable error. It is also important that such a quantity of Mg should be extracted within a reasonable period of 30 min or one hour so that if found suitable, the method could be adopted in advisory soil testing procedures. With these two intentions, the extracting ability of the following 10 chemcal extractants was observed by extracting Mg from a soil (soil No.61) at equilibration periods of 30 and 60 min, with a constant soil solution ratio of 1:10.

1. 2.5 per cent acetic acid + 0.04 *M* ammonium acetate
   (Reith's reagent)
2. 0.05 *M* HCl
3. 0.06 *N* H_2SO_4 + 0.06 *N* HCl + 0.05 *N* $H_2C_2O_4$ (Mathew's triacid)
4. 1 *N* ammonium acetate
5. 0.0125 *M* $CaCl_2$ (Schachtschabel's solution)

6. 0.1 *M* acetic acid + 0.04 *M* calcium lactate
7. 0.005 *M* DTPA
8. 0.01 *M* DTPA
9. 0.005 *M* DTPA + 0.005 *M* $CaCl_2$
10. 0.0025 *M* DTPA

With the increase in equilibration period to 60 min, the amount of Mg extracted by 0.005 *M* DTPA, Reith's reagent, Mathew's triacid, 1 *N* NH_4OAc, 0.01 *M* DTPA, 0.005 *M* DTPA + 0.005 *M* $CaCl_2$ and 0.0025 *M* DTPA increased. The amount of Mg extracted by 0.0125 *M* $CaCl_2$ decreased when the period of equilibration was increased to 60 min. Magnesium extracted by 0.05 *M* HCl remained stable at 30 and 60 min equilibration (Table 7). DTPA of 0.01 *M* could not extract any appreciable quantity of Mg at 30 min equilibration. The quantity of Mg extracted by 0.0025 *M* DTPA was rather low at 30 min. Hence these two extractants were eliminated and the rest were carried over for preliminary screening.

2. Preliminary screening

The preliminary study was aimed at testing the performance of the extractant with reference to the pattern of release of Mg during equilibration. In the initial study, it was observed that invariably the rate of dissolution of Mg in the extracting solution is relatively high during the initial period of equilibration. Afterwards the rate of release continues at a very slow rate. Such a release pattern can be represented by an initial quadratic

Table 7. Magnesium extracted by the various extractants at different periods of equilibration in the initial study

Sl. No.	Name of extractant	Mg, ppm	
		30 min	60 min
1	0.005 *M* DTPA	78.5	130.8
2	Reith's reagent	139.5	191.8
3	Mathew's triacid	148.2	157.1
4	1 *N* NH_4OAc	78.5	104.6
5	0.0125 *M* $CaCl_2$	104.6	52.3
6	0.05 *M* HCl	130.8	130.8
7	0.1 *M* acetic acid + 0.04 *M* Ca lactate	122.1	157.1
8	0.01 *M* DTPA	-	104.6
9	0.005 *M* DTPA + 0.005 *M* $CaCl_2$	87.2	157.1
10	0.0025 *M* DTPA	52.3	104.6

function and a later linear function. It is rather difficult to attain complete extraction within a reasonable period of time. Therefore, it is sufficient to allow for the completion of the initial fast release represented by the quadratic function, since the constant release rate thereafter will not modify the estimated value of available Mg appreciably. Theoretically, the ideal period of equilibration is the one within which the quadratic release is completed and after which the linear pattern will prevail. But such an ideal condition cannot be expected due to the resorption of Mg ions from the soil solution back to the colloidal surfaces. The stability of the Mg released into the soil solution should therefore be a prime consideration in the selection of the optimum equilibration period to be employed in the estimation of available Mg. With these objectives different periods of equilibration were tried in the preliminary study, namely 10, 20, 30, 40, 50 and 60 min. Graphs were then plotted to examine the pattern of release and to decide the optimum period of equilibration required in each case. Table 8 shows the Mg extracted by certain selected extractants at different periods of equilibration. Figures 2 to 9 depict the pattern of release of Mg from the soil by each extractant at different periods of equilibration.

Relative stability, in the extraction of Mg was attained with an equilibration period of 30 min in the case of Mathew.'s triacid, 0.05 *M* HCl and 0.0125 *M* $CaCl_2$. A period of 40 min

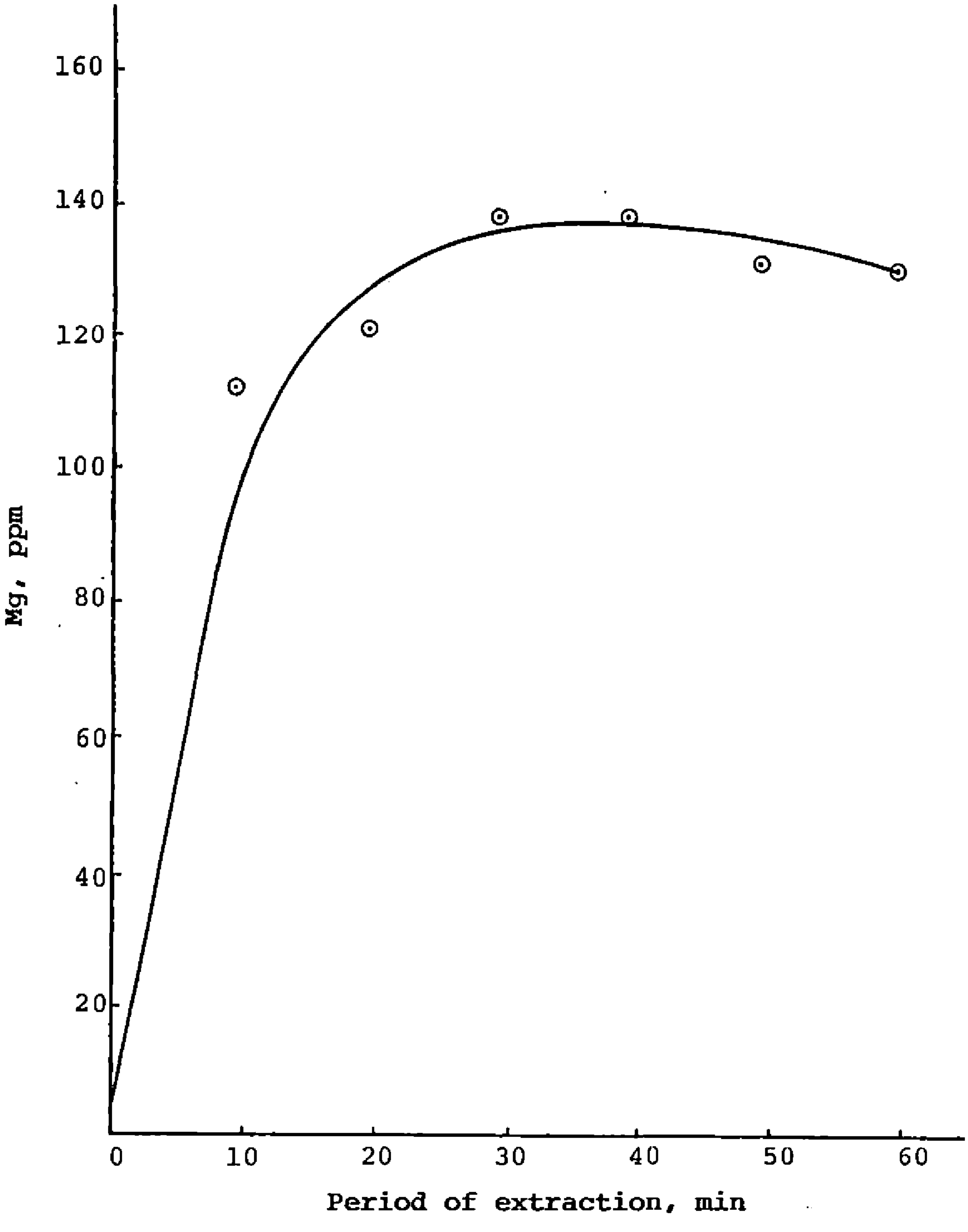

FIG 2. RELEASE OF Mg DURING EXTRACTION WITH 0.05 M HCl

Table 8. Magnesium extracted by various extractants at different intervals, ppm (mean of three replications)

Sl. No.	Name of extractant	Period of equilibration, min					
		10	20	30	40	50	60
1	1 *N* NH_4OAc	95.9	104.6	148.2	165.7	104.6	104.6
2	0.05 *M* HCl	113.4	122.1	139.5	139.5	131.8	131.8
3	0.1 *M* acetic acid + 0.04 *M* Ca lactate	61.0	122.1	104.6	87.2	131.8	174.3
4	0.0125 *M* $CaCl_2$	104.6	87.2	95.9	113.4	131.8	87.2
5	Mathew's triacid	226.7	139.5	183.1	183.1	183.1	200.6
6	Reith's reagent	45.6	87.2	139.5	157.1	173.2	191.8
7	0.005 *M* DTPA + 0.005 *M* $CaCl_2$	37.2	52.3	87.2	115.2	139.5	157.2
8	0.005 *M* DTPA	28.6	56.8	78.5	98.5	105.2	130.8
	Mean	89.1	96.5	122.1	138.5	137.6	147.3

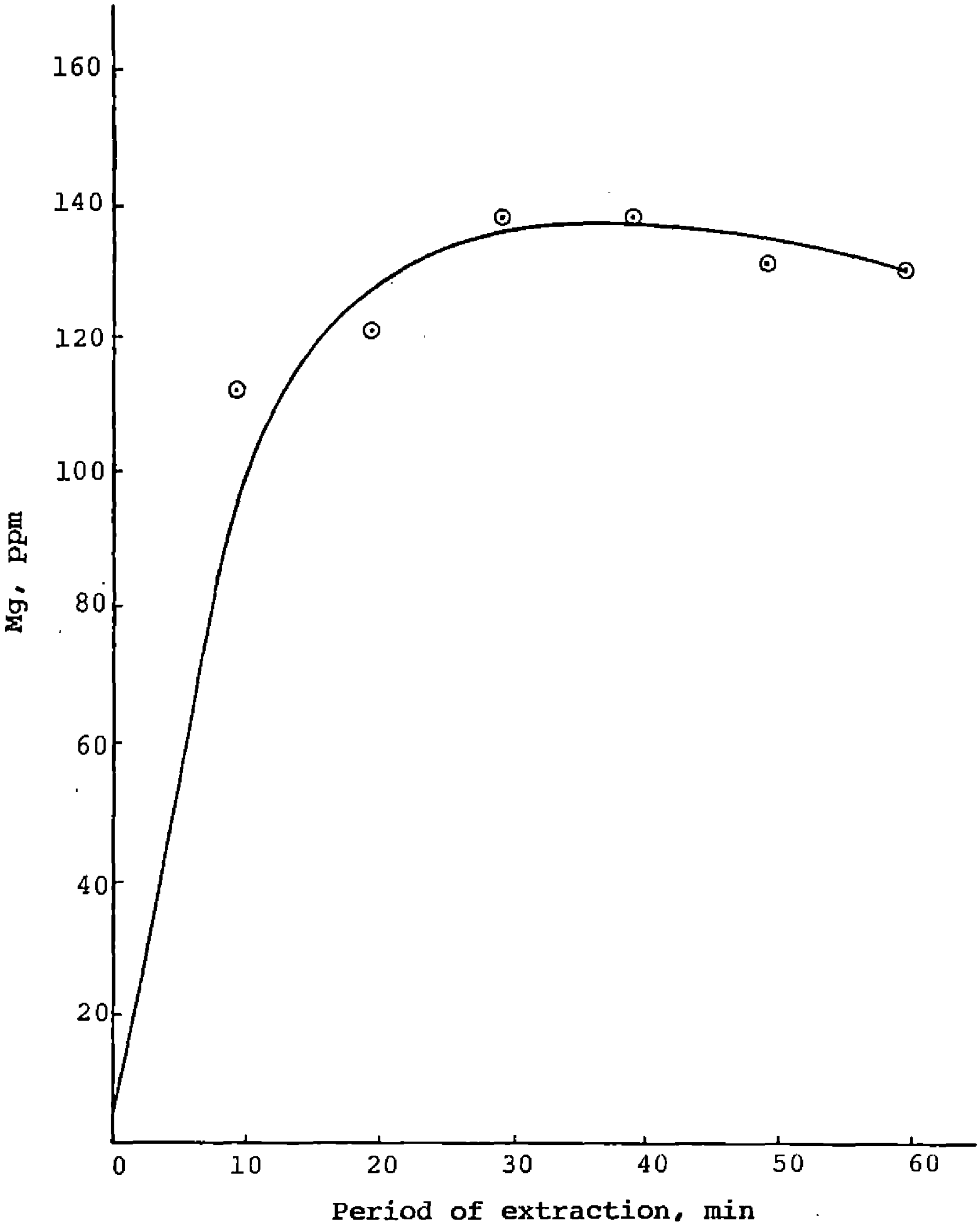

FIG 2. RELEASE OF Mg DURING EXTRACTION WITH 0.05 M HCl

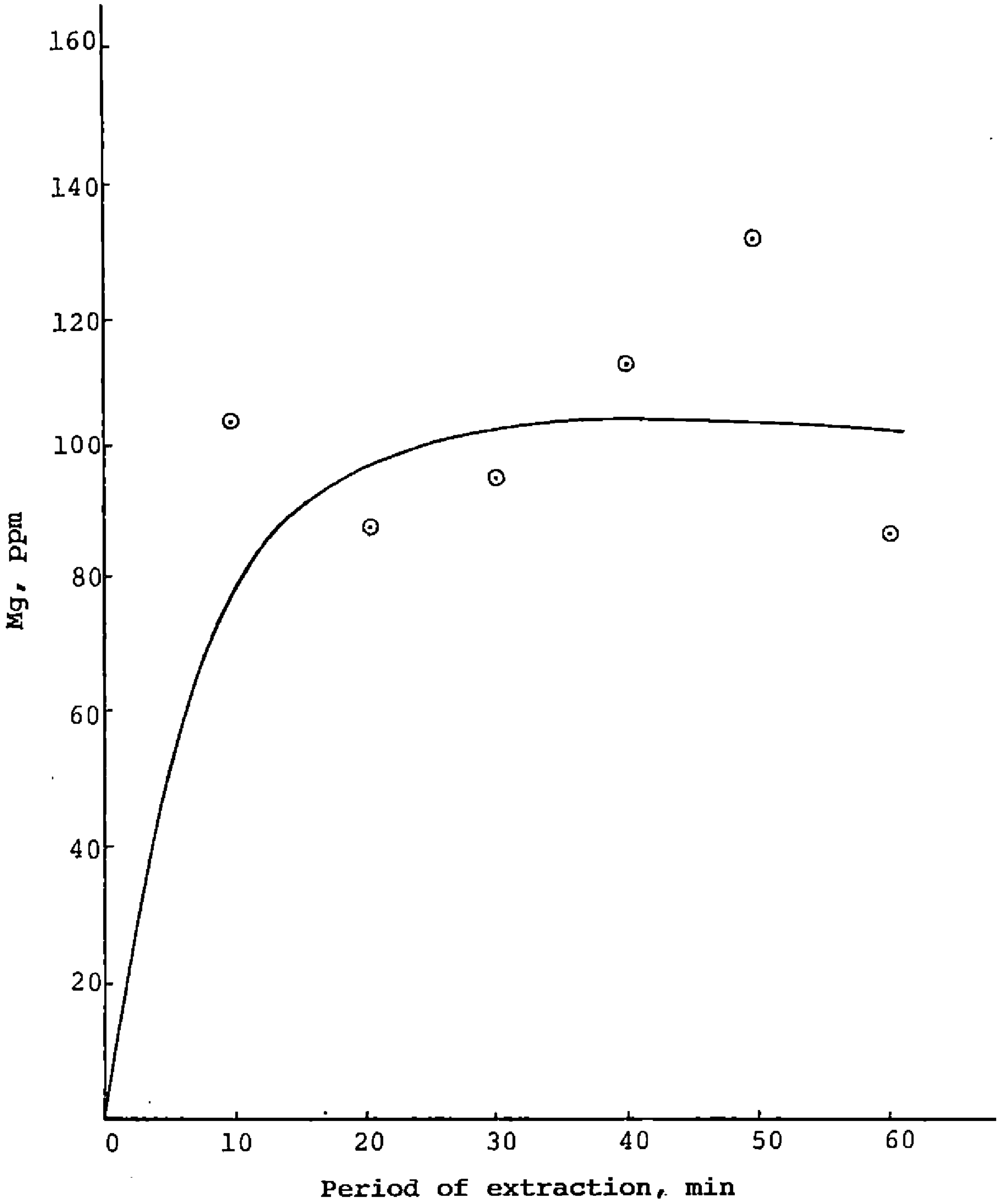

FIG 3. RELEASE OF Mg DURING EXTRACTION WITH 0.0125 M $CaCl_2$

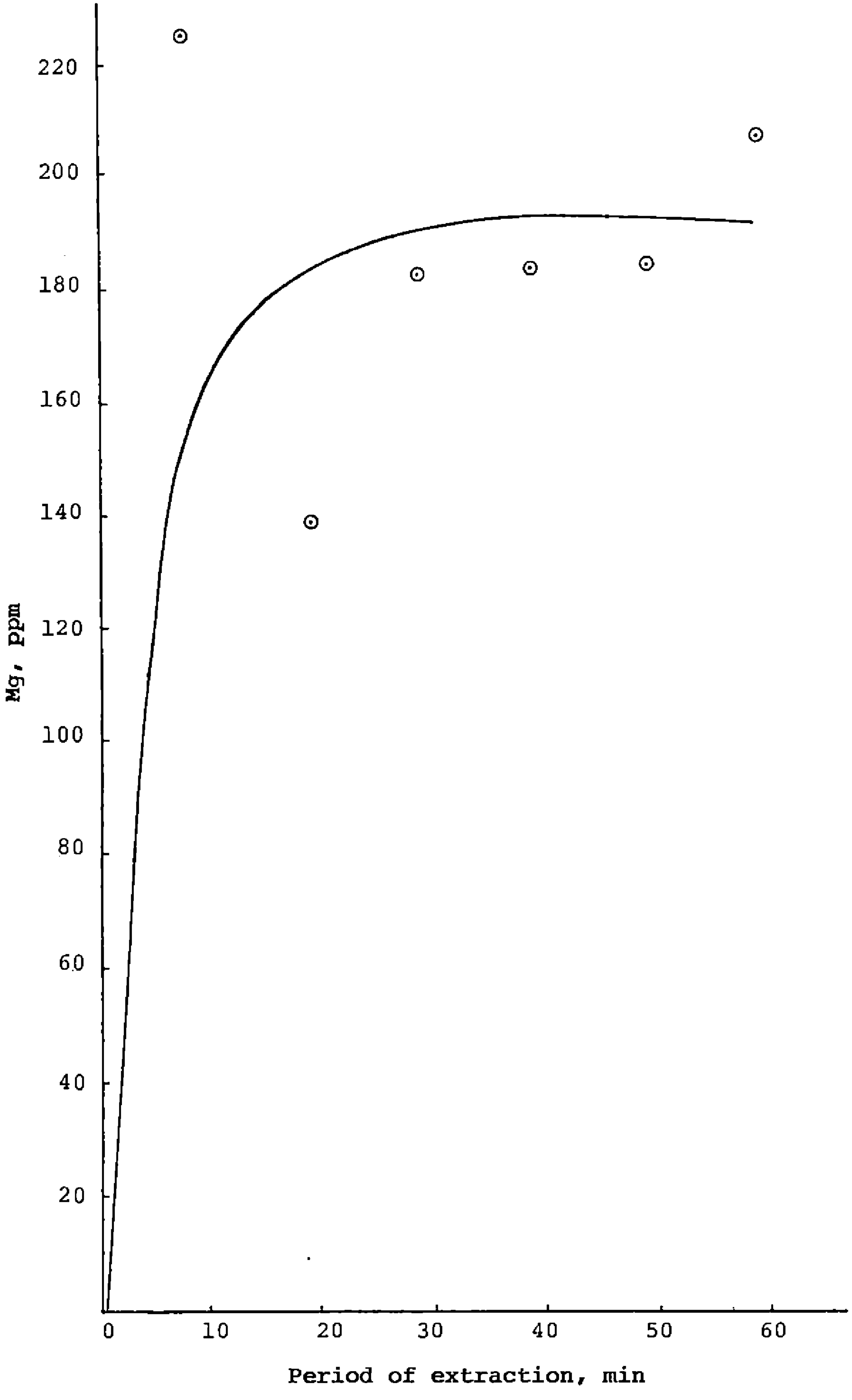

FIG. 4. RELEASE OF Mg DURING EXTRACTION WITH MATHEW'S TRIACID

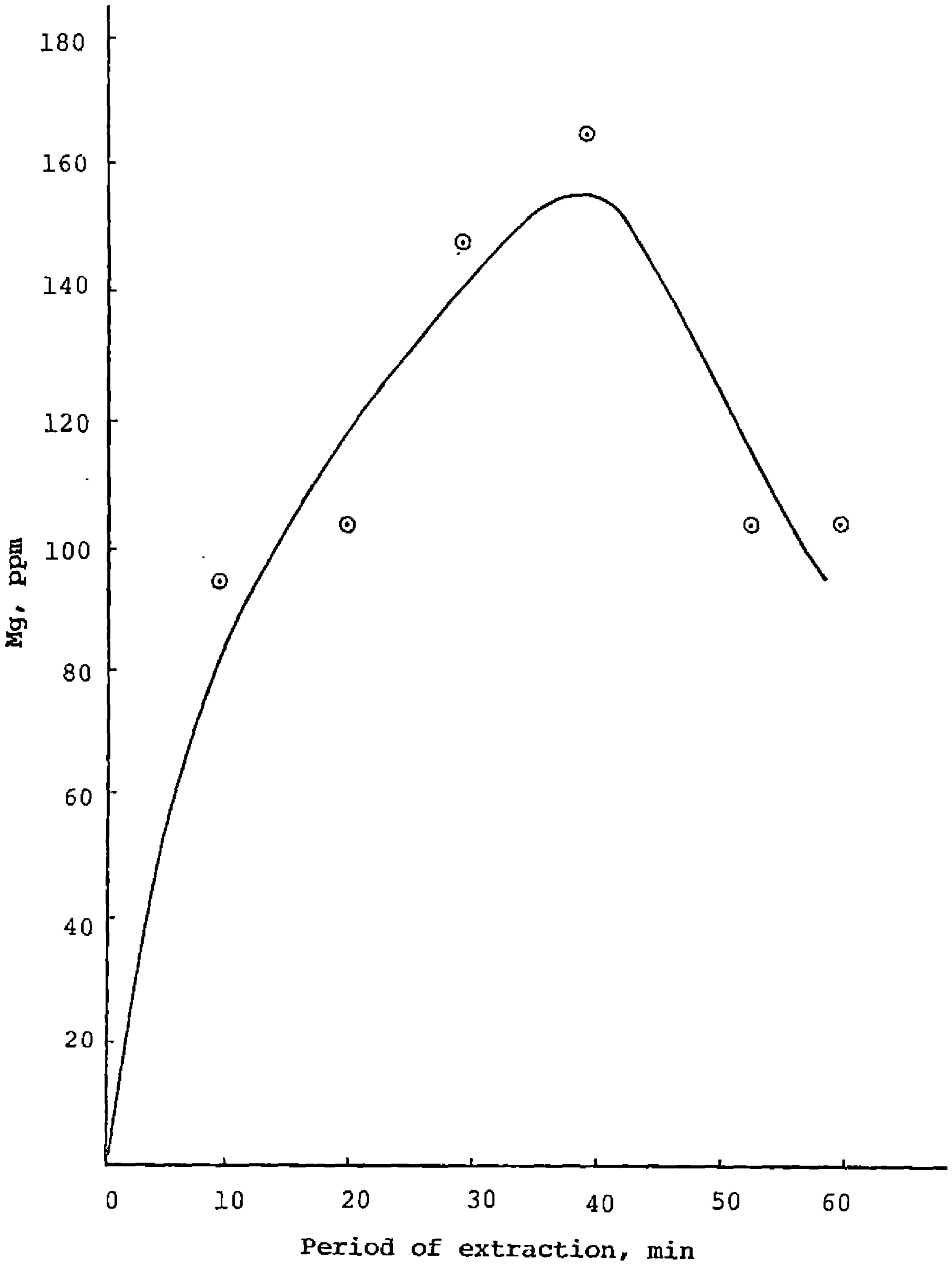

FIG 5. RELEASE OF Mg DURING EXTRACTION WITH 1N AMMONIUM ACETATE

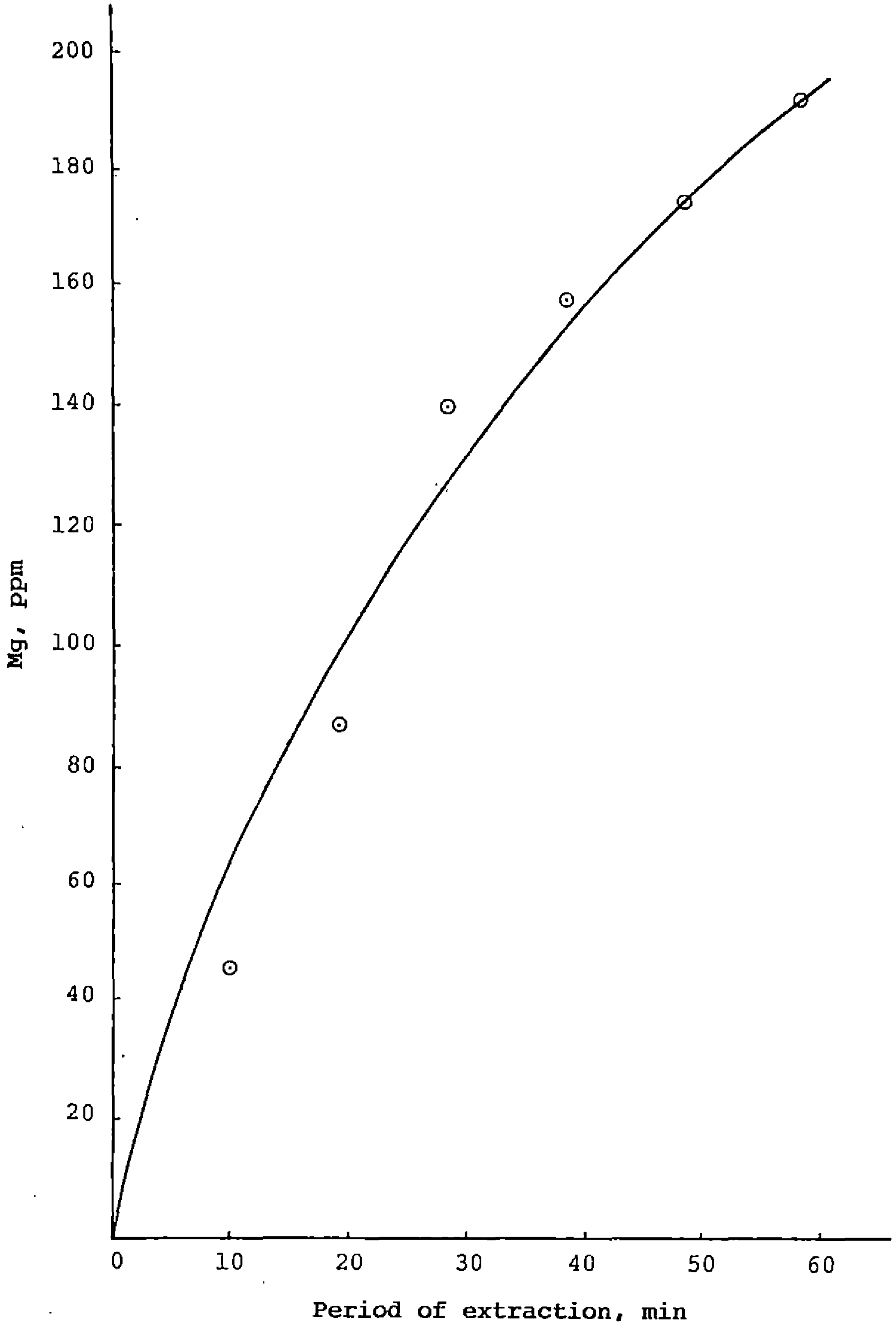

FIG 6. RELEASE OF Mg DURING EXTRACTION WITH REITH'S REAGENT

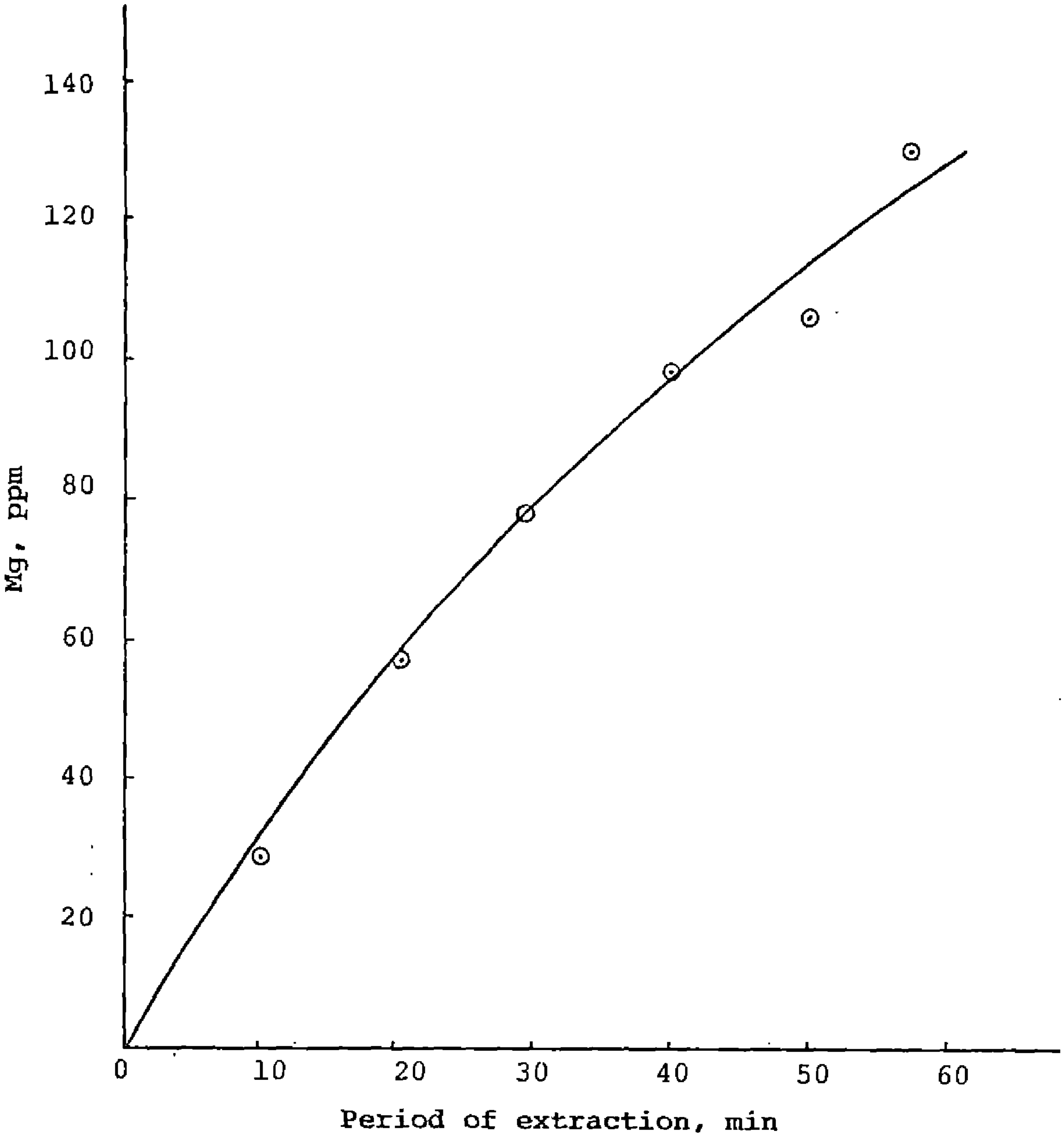

FIG 7. RELEASE OF Mg DURING EXTRACTION WITH 0.005 M DTPA

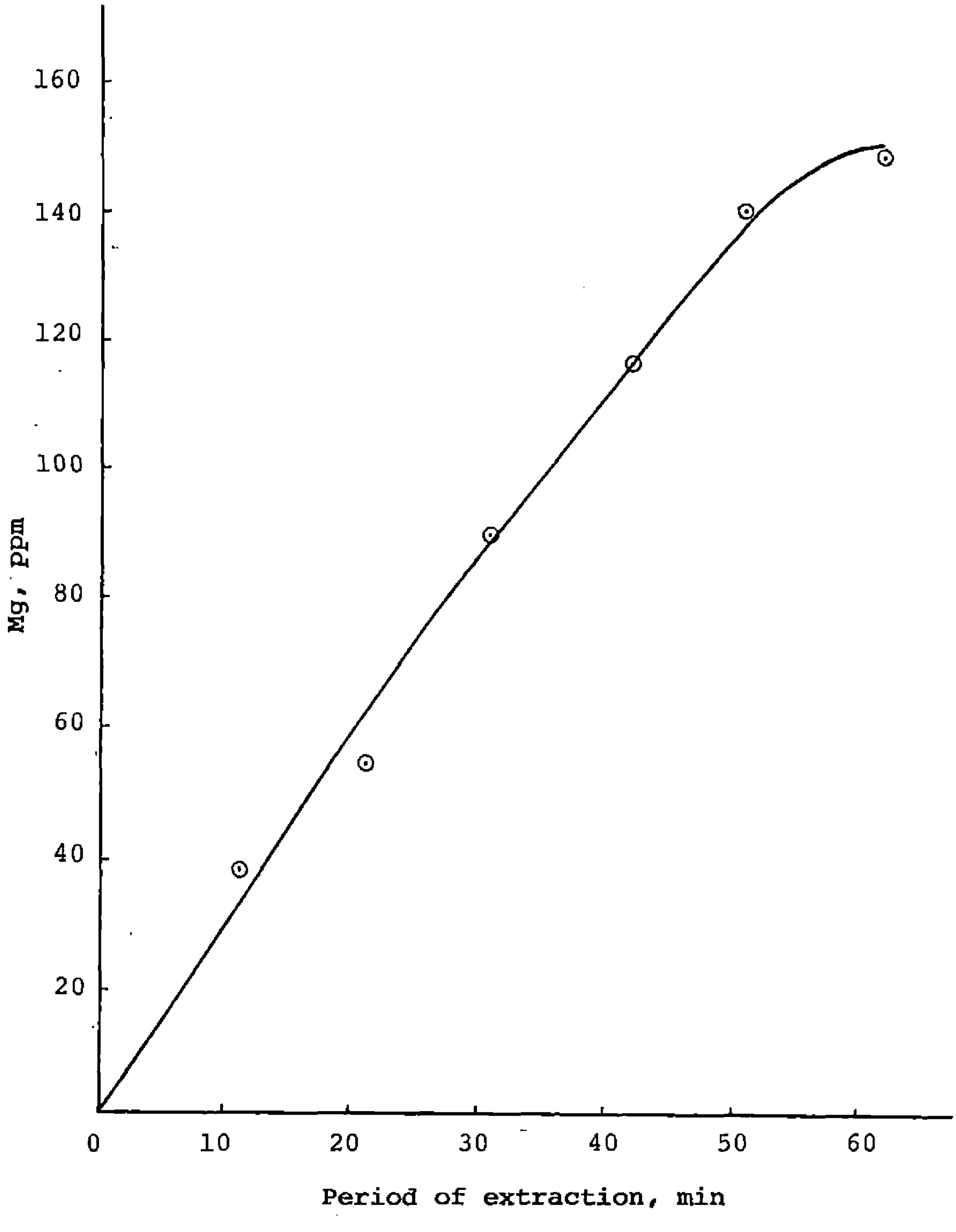

FIG 8. RELEASE OF Mg DURING EXTRACTION WITH 0.005 M DTPA + 0.005 M $CaCl_2$

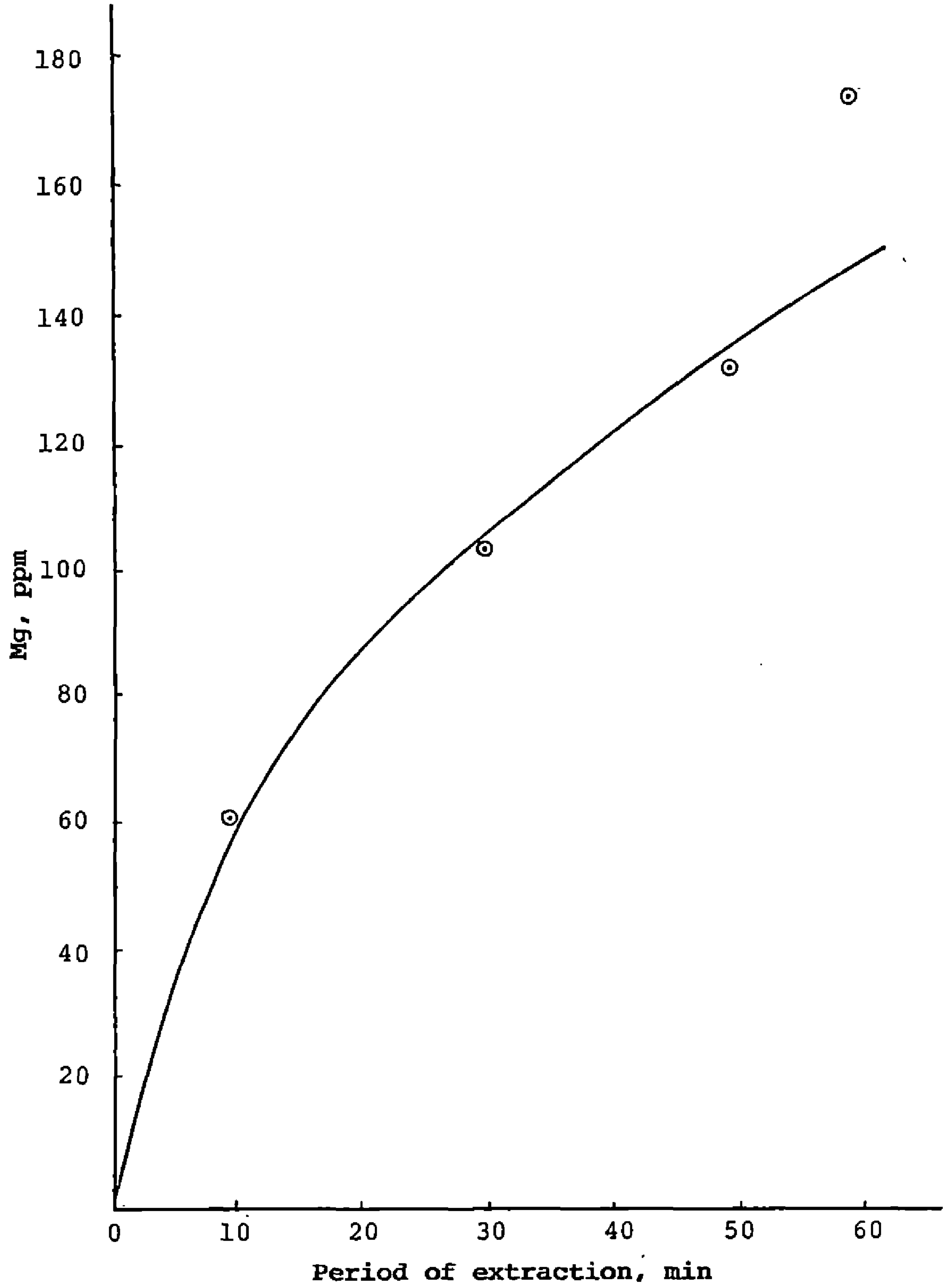

FIG 9 . RELEASE OF Mg DURING EXTRACTION WITH 0.1 M ACETIC ACID + 0.04 M CALCIUM LACTATE appeared to be the optimum for 1 *N* ammonium acetate. Reith's reagent, 0.005 *M* DTPA + 0.005 *M* $CaCl_2$, 0.005 *M* DTPA and 0.1 *M* acetic acid + 0.04 *M* Ca lactate required longer periods of equilibration, and therefore the longest period tried namely 60 min was taken as optimum for these extractants.

3. Final screening of the extractants

The name of extractant and the period of equilibration employed in the final selection were,

1. Mathew's triacid	30 min
2. Reith's reagent	60 min
3. 1 *N* NH_4OAc	40 min
4. 0.05 *M* HCl	30 min
5. 0.005 *M* DTPA + 0.005 *M* $CaCl_2$	60 min
6. 0.005 *M* DTPA	60 min
7. 0.1 *M* acetic acid + 0.04 *M* Ca lactate	60 min
8. 0.0125 *M* $CaCl_2$	30 min

They were tried at a constant soil solution ratio of 1:10. Twenty selected soils, the general characteristics of which already have been discussed were extracted by these extractants. The soils were selected in such a way that they will provide maximum diversity in characters relating to behaviour of Mg in soil as manifested in the different soils of the State. The amounts of

Mg extracted by these extractants have to be finally evaluated based on their relationship with uptake of Mg by plants. For this purpose, Mg uptake by a test crop (rice) was worked out by modified Neubauer technique.

3.1 Magnesium uptake by rice

The modified Neubauer technique was so planned that maximum removal of Mg from soils was effected in a short period of time by growing a large number of plants in a small quantity of soil. The data on uptake of Mg by rice are given in Table 9. The values range from 0.45 to 10.3 mg pot^{-1}. Though wide variation was observed in the available Mg content of the different soils selected as determined by chemical extraction methods, the Mg uptake by rice as well as the Mg per cent in rice failed to correlate significantly with the Mg extracted by the chemical agents. This may be probably due to the fact that the growth of the plant and hence the dry matter accumulation was not decisively influenced by the available Mg content of the soil. Probably the amount of available Mg in these soils was sufficient to allow the growth of the test crop without itself manifesting as a limiting factor. The total duration of the crop under the modified Neubauer technique employed was only 35 days and the amount of Mg removed by the crop was rather negligible as compared to the total amount of Mg present in these soils, or even available Mg estimated by chemical extractants was considered.

Table 9. Uptake of Mg by rice

Sl. No.	Soil sample number	Mg uptake, mg pot^{-1}
1	103	5.24
2	6	4.23
3	80	2.34
4	143	4.27
5	113	4.18
6	123	5.41
7	24	3.88
8	25	5.76
9	26	5.60
10	146	6.02
11	147	4.34
12	125	6.24
13	31	3.38
14	47	0.45
15	54	3.27
16	57	5.79
17	59	10.30
18	60	3.09
19	61	3.62
20	64	3.01
Mean		4.52

On an average, the amount of total Mg contained by the soils was 176 mg of Mg per 100 g of soil. The quantity of available Mg extracted by 0.0125 *M* $CaCl_2$ was 25.96 mg per 100 g of soil whereas the total amount of Mg removed by the crop, on an average was only 4.52 mg. This explains the failure of Mg uptake to establish significant positive correlations with total Mg or with available Mg extracted by different chemical agents. Though the selection of a chemical agent as an index of available nutrient status should be based on the strength of relationship between the quantity of nutrient extracted by the reagent with that of the plant uptake, selection based on this criterion was not possible since plant uptake of Mg by the test crop under the modified Neubauer technique failed to establish significant correlation with Mg extracted by chemical agents.

3.2 Interrelationship between different extractants

The mean values of Mg extracted by various extractants from different soils are furnished in Table 10. The extractant containing 0.005 *M* DTPA + 0.005 *M* $CaCl_2$ extracted the maximum average amount of Mg (374.1 ppm). The minimum amount of Mg was registered by 0.005 *M* DTPA (160.9 ppm). The DTPA of 0.005 *M* strength + 0.005 *M* $CaCl_2$ reacts with soil by means of exchange. Calcium chloride is a good chemical agent for exchange of Mg^{++} ions by Ca^{++} ions. DTPA is a good chelating agent. DTPA, when

Table 10. Magnesium extracted by various extractants

Sl. No.	Soil sample No.	Mg, ppm							
		Mathew's triacid	Reith's reagent	1 *N* NH_4OAc	0.05 *M* HCl	0.005 *M* DTPA + 0.005 *M* $CaCl_2$	0.005 *M* DTPA	0.1 *M* acetic acid + 0.04 *M* Ca lactate	0.0125 *M* $CaCl_2$
1	2	3	4	5	6	7	8	9	10
1	103	78.5	78.5	Traces	104.6	157.0	52.3	104.6	117.7
2	6	52.3	235.4	130.8	418.6	418.6	235.4	366.2	143.9
3	80	130.8	130.8	26.2	52.3	235.4	104.6	183.1	52.3
4	143	313.9	104.6	157.0	287.8	366.2	130.8	78.5	130.8
5	113	235.4	52.3	26.2	130.8	183.1	52.3	130.8	52.3
6	123	157.0	26.2	Traces	52.3	183.1	104.6	52.3	26.2
7	24	104.6	52.3	Traces	104.6	130.8	104.6	157.0	26.2
8	25	104.6	130.8	52.3	235.4	575.5	104.6	261.6	52.3
9	26	209.3	130.8	104.6	235.4	313.9	183.1	261.6	274.7
10	146	1648.0	1596.0	994.1	167.4	863.3	497.0	1491.0	915.6

Contd.

Table 10 Continued

1	2	3	4	5	6	7	8	9	10
11	147	1413.0	1282.0	1256.0	120.3	680.2	313.9	1256.0	758.6
12	125	601.7	392.4	601.7	601.7	601.7	287.8	444.7	575.5
13	31	157.0	78.5	26.2	261.6	313.9	183.1	130.8	470.9
14	47	183.1	235.4	130.8	235.4	392.4	183.1	183.1	235.4
15	54	78.5	287.8	183.1	392.4	366.2	157.0	157.0	235.4
16	57	26.2	78.5	Traces	130.8	261.6	26.2	104.6	26.2
17	59	78.5	209.3	26.2	209.3	313.9	130.8	52.3	287.8
18	60	78.5	130.8	104.6	104.6	340.1	130.8	130.8	287.8
19	61	235.4	157.0	26.2	235.4	418.6	183.1	209.3	209.3
20	64	130.8	52.3	26.2	183.1	366.2	52.3	183.1	313.9
Mean		300.9	272.1	242.0	213.2	374.1	160.9	296.9	259.6

added with $CaCl_2$, prevents resorption of the Mg^{++} ions coming into soil solution. The properties of these two chemicals together might have contributed the maximum average amount of Mg extracted by this extractant. The range of extraction of Mg by this chemical agent varied from 130.8 to 863.3 ppm. While using DTPA alone at the strength of 0.005 *M*, the smallest amount of Mg extracted was 26.2 ppm and the highest value was 497 ppm. The mean value of Mg extracted by 0.005 *M* DTPA from 20 different soils was found to be the minimum of the average extraction of Mg (160.9 ppm) by the various extractants. This may be because of the removal of Mg into soil solution by chelation alone.

The amount of Mg extracted by Mathew's triacid (0.06 *N* H_2SO_4 + 0.06 *N* HCl + 0.05 *N* $H_2C_2O_4$) ranged from 52.3 ppm to 1648 ppm with a mean of 300.9 ppm. It is a good extractant of Mg either because of its ability to solubilise Mg containing minerals or due to the high replacing power of H^+ ions. Reith's reagent (2.5 per cent acetic acid + 0.04 *M* ammonium acetate) extracted Mg in the lowest order in soil No.123 (26.2 ppm) and the highest in soil No.146 (1596 ppm). The mean content of available Mg from different soils was 272.1 ppm. Here the extraction of Mg is by way of exchange between Mg^{++} and NH_4^+ ions and also by chelation. The acetate ion is a good chelating agent. The pH of the soil solution will not vary considerably as the extractant itself is a buffer. In the case of neutral normal ammonium acetate, the lowest amount extracted was found to be traces in four soils. Three of these soils were earlier classified as deficient in available Mg and one belonged to the group classified as sufficient in available Mg. This shows the relative inefficiency of neutral normal ammonium acetate in extracting Mg from soil. The maximum amount of Mg extracted was 1256 ppm, from a soil which was alkaline. The mean amount was 242 ppm. The extraction of Mg into soil solution is by way of exchange. Hydrochloric acid of 0.05 *M* concentration extracted an amount of Mg as low as 52.3 ppm and as high as 601.7 ppm with a mean value of 213.2 ppm. The mechanism of extraction by HCl is either by solubilisation thus releasing Mg from the Mg containing minerals in soil or by the exchange between H^+ ion and Mg^{++} ion. In the case of 0.1 *M* acetic acid + 0.04 *M* calcium lactate, the extraction of Mg is mainly by way of exchange. The average amount extracted was 296.9 ppm, the range varying from 52.3 to 1491 ppm. Calcium chloride of 0.0125 *M*. concentration also reacted by way of exchange in soil. The available Mg estimated using this extractant varied from 26.2 to 915.6 ppm, the mean being 259.6 ppm.

The coefficients of correlation among Mg extracted by various extractants are furnished in Table 11 (Fig 10 to 14). It was seen that all of the extractants tried, were highly and significantly correlated among one another. This is because of

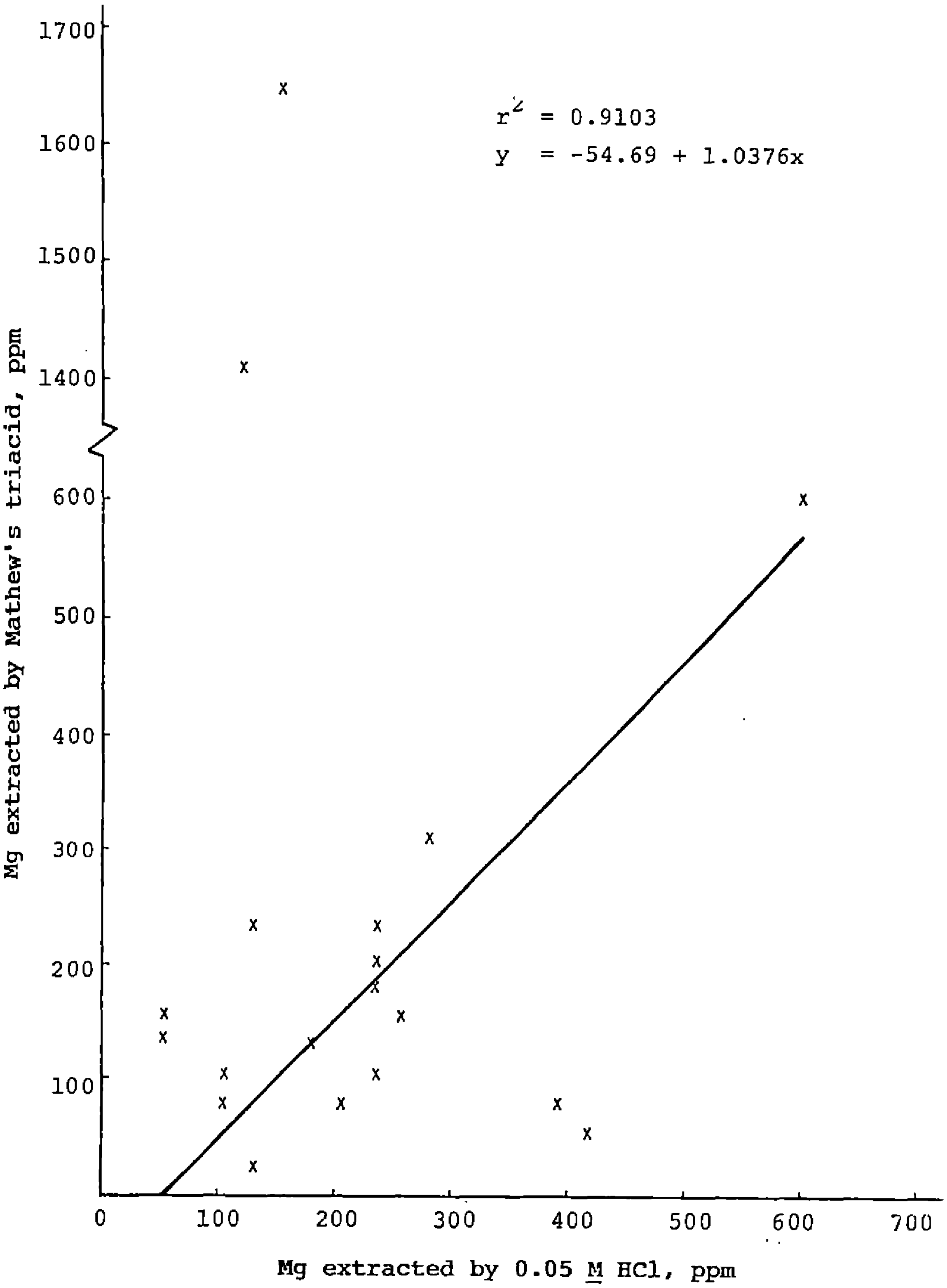

FIG 10. RELATIONSHIP BETWEEN Mg EXTRACTED BY 0.05 M HCl AND MATHEW'S TRIACID

Table 11. Correlation matrix showing inter-relationship of Mg extracted by various extractants, Mg uptake by rice and per cent Mg in rice

Mg availability indices	1	2	3	4	5	6	7	8	9	10
1. Mathew's triacid	-	0.9629**	0.9506**	0.9541**	0.8000**	0.8424**	0.9621**	0.8572**	0.1342	0.081
2. Reith's reagent		-	0.9394**	0.9792**	0.8298**	0.8710**	0.9785**	0.8556**	0.1475	0.105
3. 1 *N* NH_4OAc			-	0.9282**	0.8091**	0.8202**	0.9355**	0.8548**	0.1189	0.098
4. 0.05 *M* HCl				-	0.8743**	0.9096**	0.9692**	0.8806**	0.1689	0.089
5. 0.005 *M* DTPA + 0.005 *M* $CaCl_2$					-	0.8445**	0.8381**	0.8075**	0.1407	0.049
6. 0.005 *M* DTPA						-	0.8637**	0.8620**	0.1054	0.003
7. 0.1 *M* acetic acid + 0.04 *M* Ca lactate							-	0.8361**	0.1073	0.025
8. 0.0125 *M* $CaCl_2$								-	0.1393	0.150
9. Mg uptake by rice									-	0.907**
10. Mg % in rice										-

** Significant at 1% level

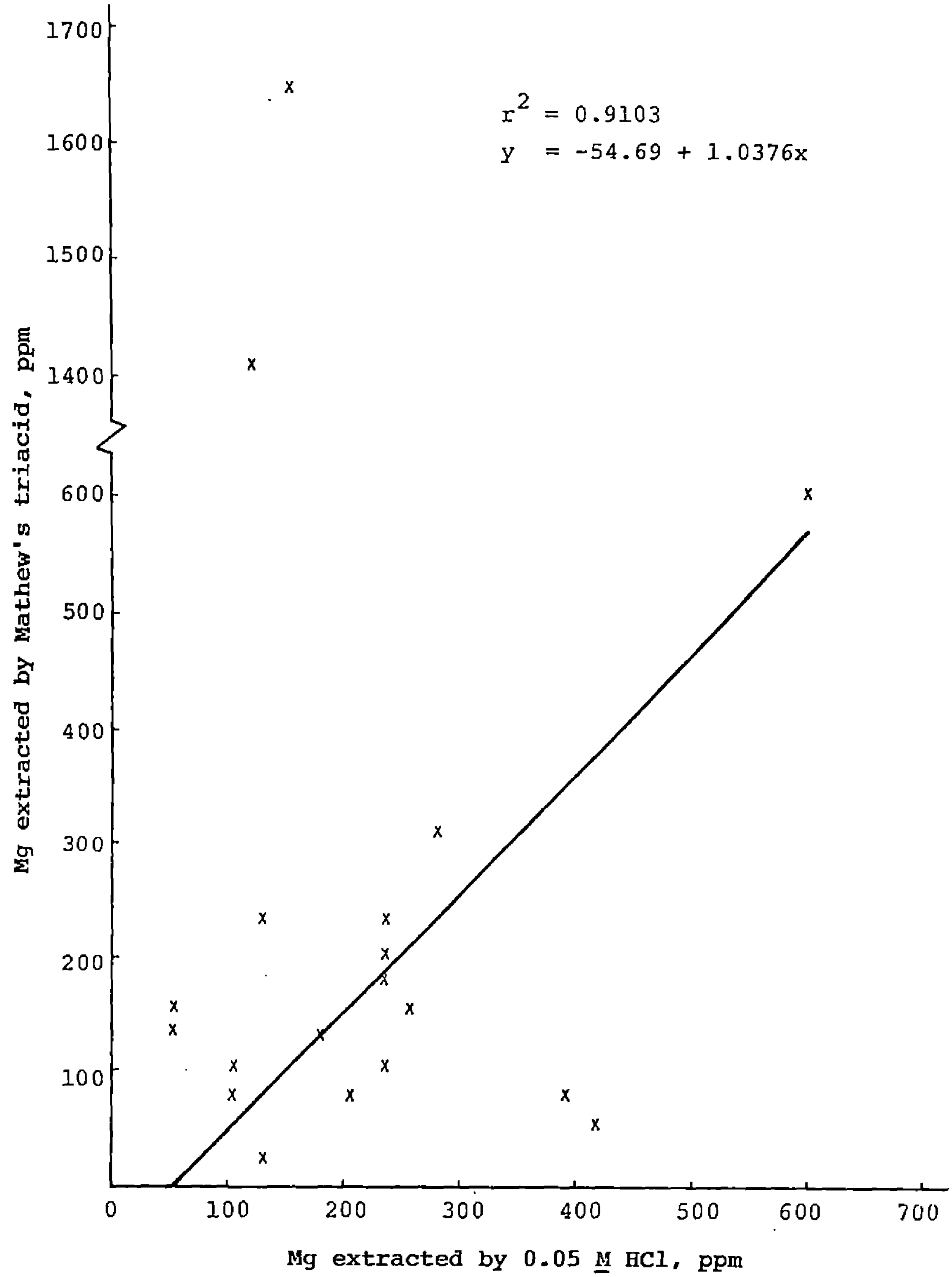

FIG 10. RELATIONSHIP BETWEEN Mg EXTRACTED BY 0.05 M HCl AND MATHEW'S TRIACID

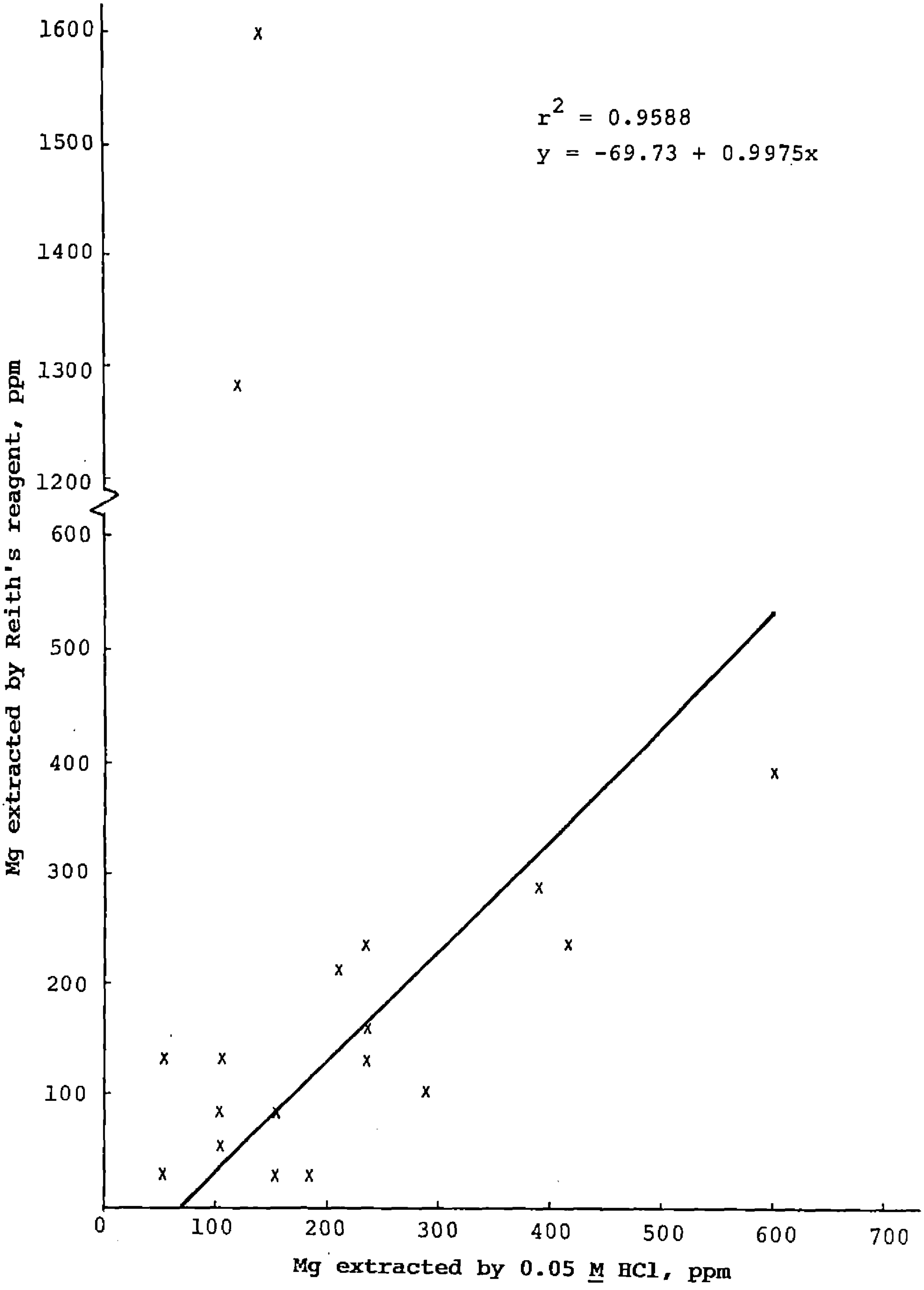

FIG 11. RELATIONSHIP BETWEEN Mg EXTRACTED BY 0.05 M HCl AND REITH'S REAGENT

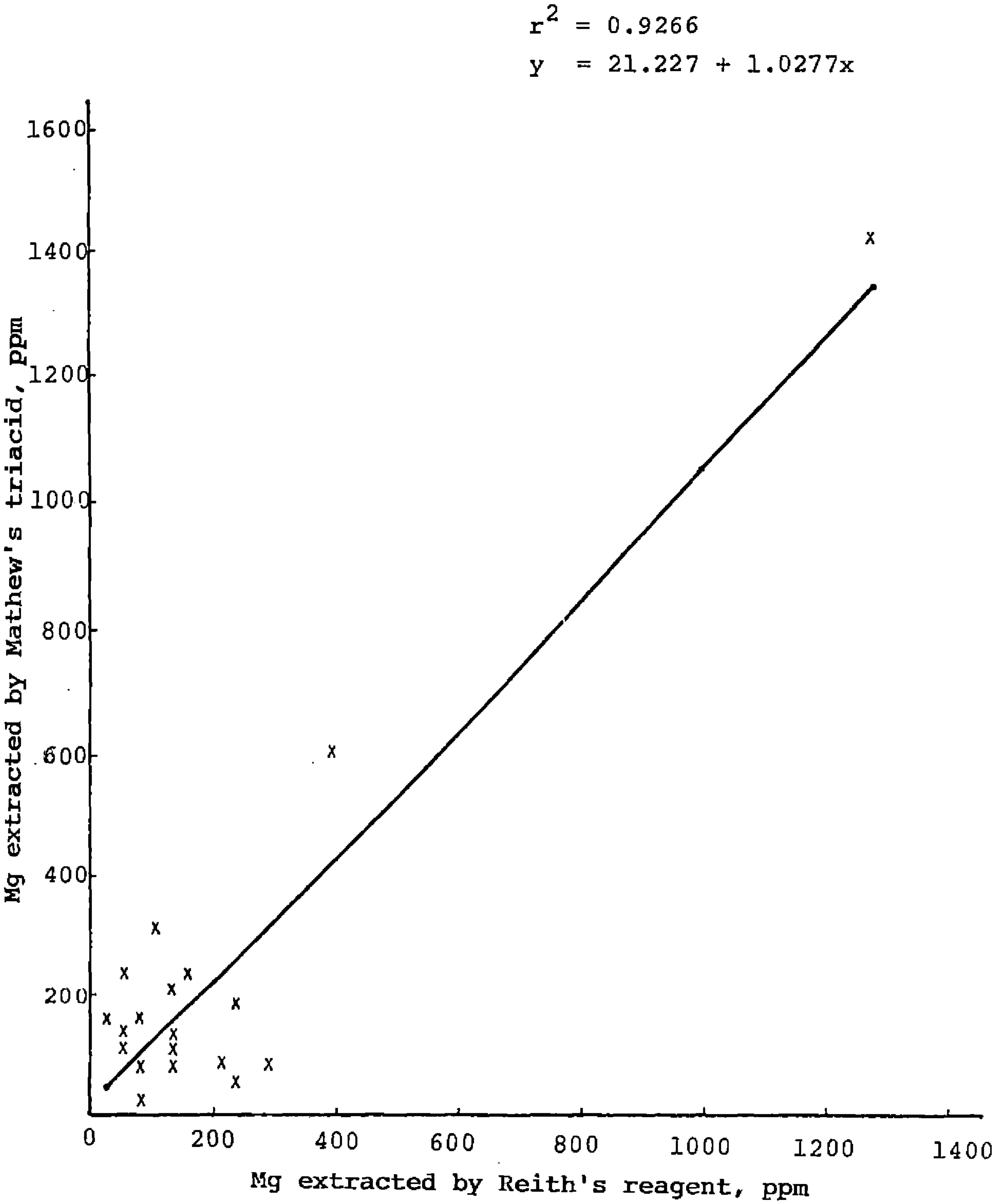

FIG .12. RELATIONSHIP BETWEEN Mg EXTRACTED BY REITH'S REAGENT AND MATHEW'S TRIACID

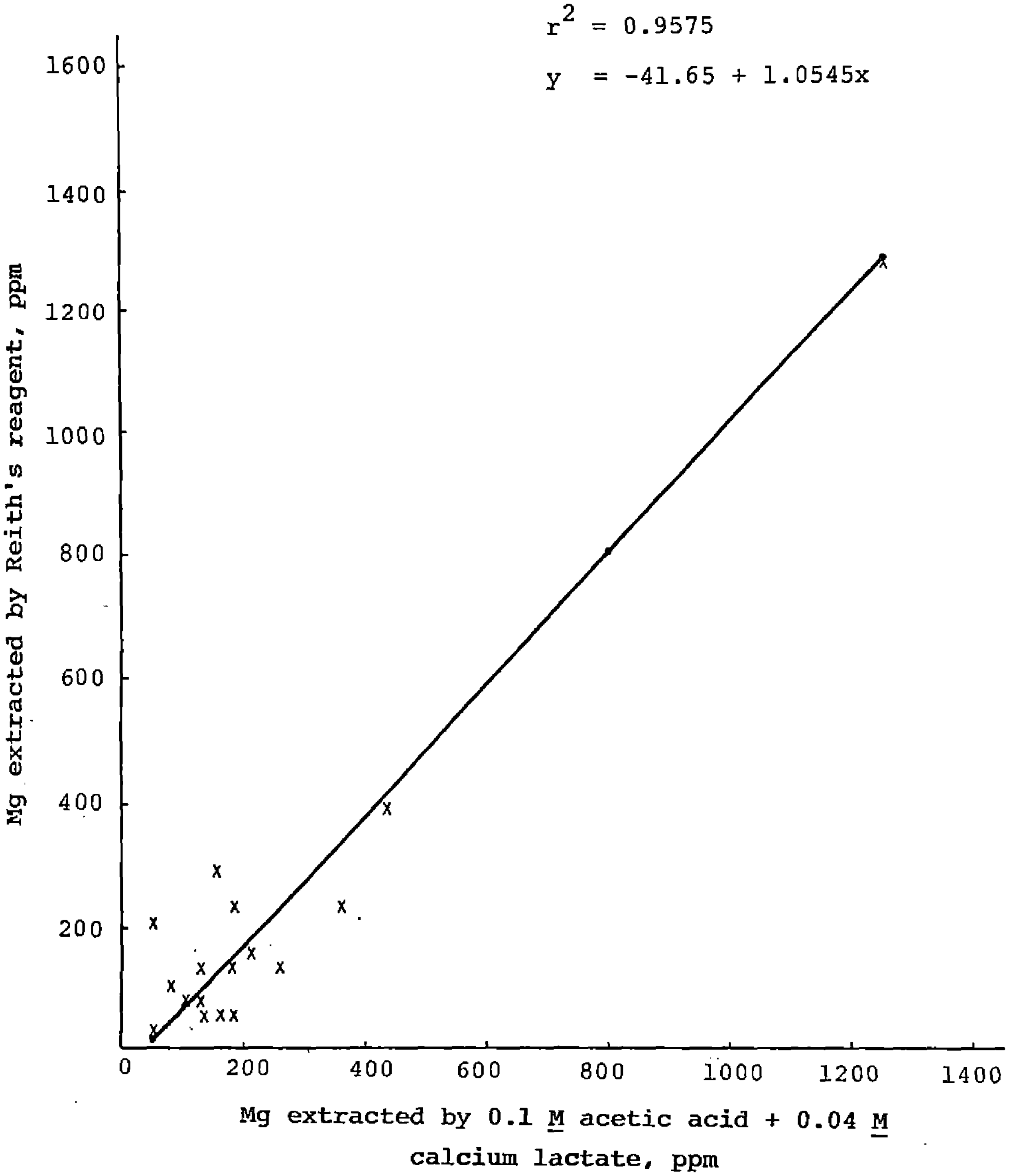

FIG 13. RELATIONSHIP BETWEEN Mg EXTRACTED BY 0.1 M ACETIC ACID + 0.04 M CALCIUM LACTATE AND REITH'S REAGENT

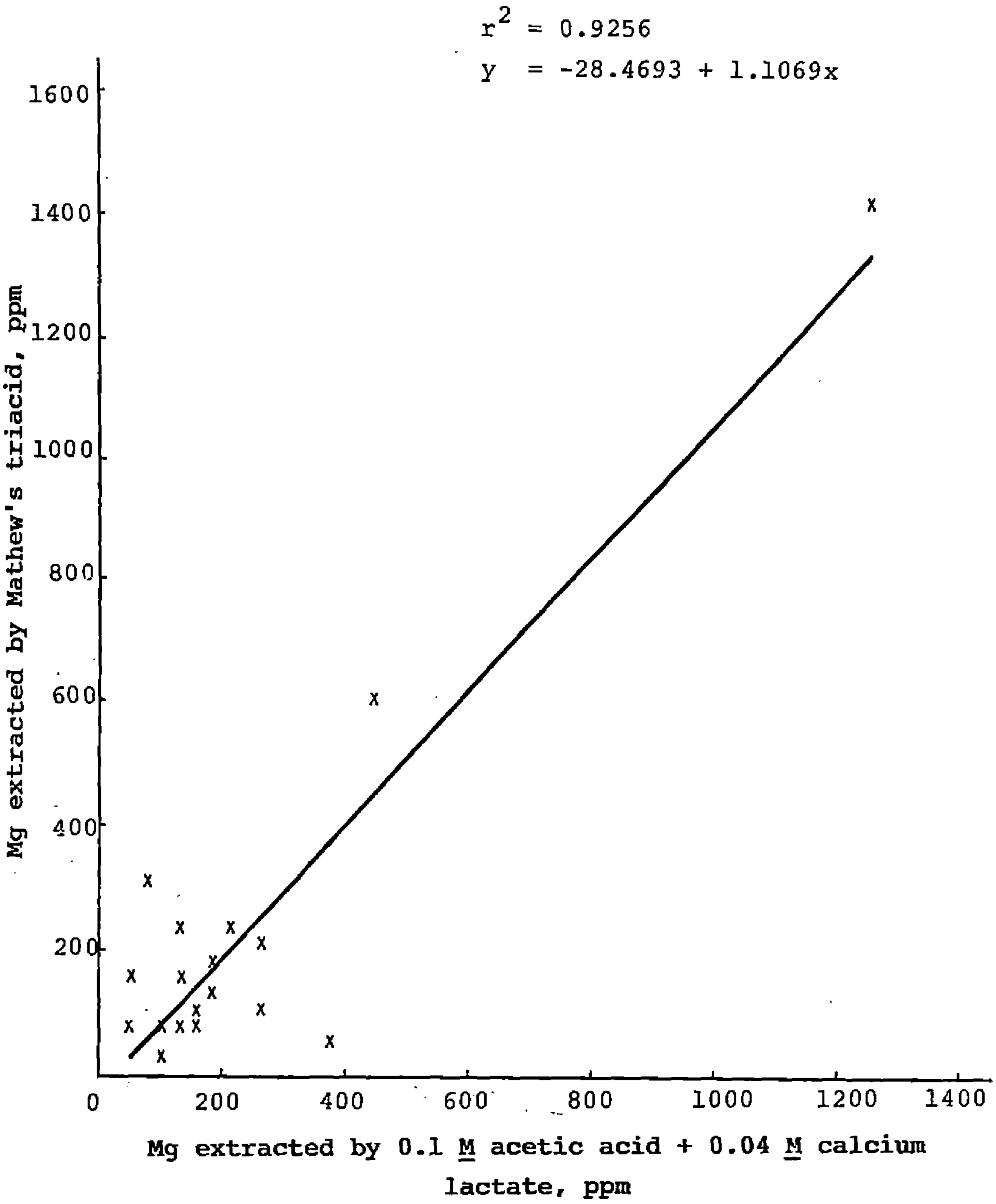

FIG 14. RELATIONSHIP BETWEEN Mg EXTRACTED BY 0.1 M ACETIC ACID + 0.04 M CALCIUM LACTATE AND MATHEW'S TRIACID

the fact that all the chemical agents tried could extract a part of the total Mg present in the soil. But while correlating the amount of Mg extracted by various extractants with plant uptake, no significant correlation was observed. Magnesium extracted by none of the extractants, correlated significantly with per cent of Mg in plant.

3.3 Final selection of the extractant

The final screening of the extractant was intended to examine the degree of relationship between the quantity of Mg extracted from twenty different soils by these extractants with that of the plant uptake of Mg in the modified Neubauer pot culture technique. But as already pointed out no significant correlation was observed between uptake and Mg extracted by any of the extractants tried. Moreover, the Mg per cent of the plants also did not exhibit correlation with the Mg extracted by the chemical agents. The possible reasons for the failure of establishing correlation between Mg uptake and Mg extracted by the chemical agents have already been discussed. Under these circumstances, it was not possible to effect the final selection of the extractant based on its relationship with plant uptake. The study was therefore constrained to select the extractant based on the pattern of release of Mg during equilibration and the stability of the estimated value, with respect to varying periods of equilibration. As already mentioned under preliminary screening, the performance of 0.05 *M* HCl was promising with respect to the pattern of release, degree of variability due to varying periods of equilibration and the magnitude of Mg extracted at the optimum period of equilibration. The curve depicting the pattern of Mg release by this chemical agent showed that the initial release following the quadratic function is completed within 30 min and thereafter, variation due to the increasing period of equilibration was minimum. The degree of variation between the quantity of Mg extracted within a range of 30 to 60 min was the least as compared to the pattern of release by the other extracting solutions. The study therefore tended to conclude that among the chemical extractants tried, 0.05 *M* HCl appeared to be the most suited for the soils under study. Though one may expect that being an acid extractant it may extract a large quantity of Mg from neutral to alkaline soils, the study reveals that ability of this extractant to extract Mg from alkaline soil is not very strong as compared to many other acid extractants like Mathew's triacid, Reith's reagent etc.

PART 3. TRANSFORMATION OF APPLIED MAGNESIUM IN SOIL

In this experiment two acid rice soils of Kerala namely karappadam and laterite were incubated at field capacity for a period of 180 days, with and without the addition of magnesium sulphate, magnesite and dolomite at the rate of 1250, 2500 and 3750 kg MgO ha^{-1}. Soil samples were drawn regularly at 15 day intervals for the determination of available Mg and at 60 day intervals for determination of other important chemical properties.

1. General characteristics of the soil selected for the study

Two important soil types of the State, namely the alluvium of Kuttanad (karappadam) collected from Moncompu, Alappuzha district and the laterite from the Instructional Farm, Vellanikkara, Thrissur district were made use of. Data on the general characteristics of the soils are presented in Table 12.

The karappadam soil was sandy loam in texture, nonsaline (EC = 1.31 dS m^{-1}) and acidic (pH = 5.0). According to the fertility ratings followed in the soil testing laboratories in Kerala, this soil was high in organic carbon, medium in available P and high in available K. The relatively higher content of organic matter and poor P status are usually considered as the general features of Kuttanad alluvium. As regards the Mg fractions, it contained 507.1 ppm of available Mg and 1.92 cmol(+) kg^{-1} of exchangeable Mg. The content of water soluble Mg was negligible. The exchangeable Mg content was 21.34 per cent of the total Mg whereas the available Mg contributed 46.95 per cent.

The laterite soil was sandy clay loam in texture and less acidic (pH = 5.4) than the karappadam soil and contained less

Table 12. General characteristics of the soils selected for the incubation study

Characteristics	Karappadam	Laterite
Coarse sand, %	9.00	46.25
Fine sand, %	51.00	15.55
Silt, %	21.60	16.80
Clay, %	16.20	20.80
pH	5.00	5.40
Specific conductance, dS m^{-1}	1.31	0.61
Organic carbon, %	1.85	1.16
Cation exchange capacity, cmol(+) kg^{-1}	20.68	16.03
Total N, ppm	2660	0.17
Total P, ppm	830	2920
Total K, ppm	880	1380
Total Ca, ppm	11690	8350
Total Mg, ppm	1080	870
Available N, ppm	163.0	182.7
Available P, ppm	7.50	34.00
Available K, ppm	125.00	187.50
Available Ca, ppm	1864	1637
Available Mg, ppm	507.1	312.5
Water soluble Mg, ppm	Traces	Traces
Exchangeable Mg, cmol(+) kg^{-1}	1.92	1.17

soluble salts (EC = 0.612 dS m^{-1}). The content of organic matter also was relatively low (1.16 per cent) as compared to karappadam soil. The ratings for both available P and K were high probably since this soil has been put under continuous cultivation. The exchangeable Mg, available Mg and total Mg were lower than those of karappadam soil likely due to the decreased content of organic matter in this soil. Exchangeable Mg contributed only 16.13 per cent and available Mg contributed 35.92 per cent of the total. The content of water soluble Mg was practically nil.

2. Available Mg

The values of available Mg as influenced by the treatments at different periods of incubation are presented in Table 13.

The incubation study was programmed with the intention of delineating the pattern of changes in the different forms of Mg in soil during the course of incubation at field capacity with and without the the addition of Mg fertilizers at three different levels. Therefore, the most important soil characteristic, available Mg which is expected to be decisively influenced by the transformation of Mg in soil was monitored at close intervals of 15 days for a period of six months.

Application of Mg fertilizers resulted in an increase in the available Mg content of both the soils in all the periods of incubation (Fig 15). This is understandably due to the increased

Table 13. Available Mg as influenced by treatments, ppm
(mean of two replications)

Soil	Treatment	Periods, fortnight					
		1	2	3	4	5	6
Karappadam	T_1	457.6	294.3	261.6	163.5	196.2	261.6
	T_2	490.6	490.6	490.6	621.4	817.4	817.4
	T_3	588.4	588.4	686.6	883.0	1177.0	1373.0
	T_4	654.0	948.2	1340.6	1930.0	1733.0	2289.0
	T_5	817.4	523.2	490.6	588.4	752.2	1112.0
	T_6	392.4	784.8	686.6	980.8	817.4	1177.0
	T_7	784.8	784.8	752.2	980.8	1373.2	1079.0
	T_8	588.4	392.4	228.9	490.6	588.4	850.0
	T_9	359.7	261.6	228.9	392.4	359.7	752.0
	T_{10}	261.6	261.6	228.9	261.6	163.5	719.2
	Mean	539.5	533.0	540.0	729.2	797.8	1043.0
Laterite	T_1	261.6	327.0	261.6	294.3	228.9	621.4
	T_2	641.1	490.6	621.4	686.6	654.0	621.4
	T_3	693.0	948.2	948.2	784.8	883.0	1439.0
	T_4	980.8	1079.0	1373.0	1014.0	1668.0	1635.0
	T_5	693.0	555.8	621.4	1046.0	850.0	457.6
	T_6	471.0	490.2	555.8	654.0	1242.0	457.6
	T_7	627.7	621.4	686.6	686.6	1177.0	523.2
	T_8	209.3	327.0	196.2	425.1	459.4	98.1
	T_9	471.0	65.4	130.8	261.6	588.4	98.1
	T_{10}	340.1	98.1	130.8	490.6	137.4	Traces
	Mean	538.9	500.3	552.6	634.4	788.8	661.3

Contd.

Table 13 Continued

Soil	Treatment	Periods, fortnight					
		7	8	9	10	11	12
Karappadam	T_1	458.0	294.3	523.2	228.9	359.7	359.7
	T_2	883.0	719.6	752.2	327.0	719.6	555.8
	T_3	1308.0	1668.0	1242.0	980.8	752.2	752.2
	T_4	1831.0	2681.0	1668.0	850.4	915.6	817.4
	T_5	1112.0	621.4	752.2	523.2	719.6	654.0
	T_6	980.8	915.6	1014.0	817.4	784.8	980.8
	T_7	1014.0	948.2	1046.0	686.6	850.4	980.8
	T_8	523.2	588.8	784.8	490.6	621.4	555.8
	T_9	458.0	196.2	523.2	294.3	425.1	545.1
	T_{10}	392.4	196.2	196.2	458.0	523.2	359.7
	Mean	896.0	883.0	850.2	565.7	667.2	656.1
Laterite	T_1	458.0	130.8	588.8	392.4	228.9	228.9
	T_2	591.1	327.0	719.6	523.2	392.4	261.6
	T_3	981.3	654.0	1014.0	719.6	850.5	392.4
	T_4	1242.0	817.4	1602.0	948.2	850.5	752.2
	T_5	490.6	327.0	621.4	458.0	523.2	588.8
	T_6	555.8	588.8	588.8	555.8	621.4	555.8
	T_7	523.2	490.6	817.4	654.0	686.6	523.2
	T_8	130.8	458.0	261.6	196.2	392.4	98.1
	T_9	32.7	65.4	228.9	163.5	196.2	65.4
	T_{10}	Traces	65.4	228.9	130.8	130.8	65.4
	Mean	556.2	392.4	667.1	474.2	487.3	353.2

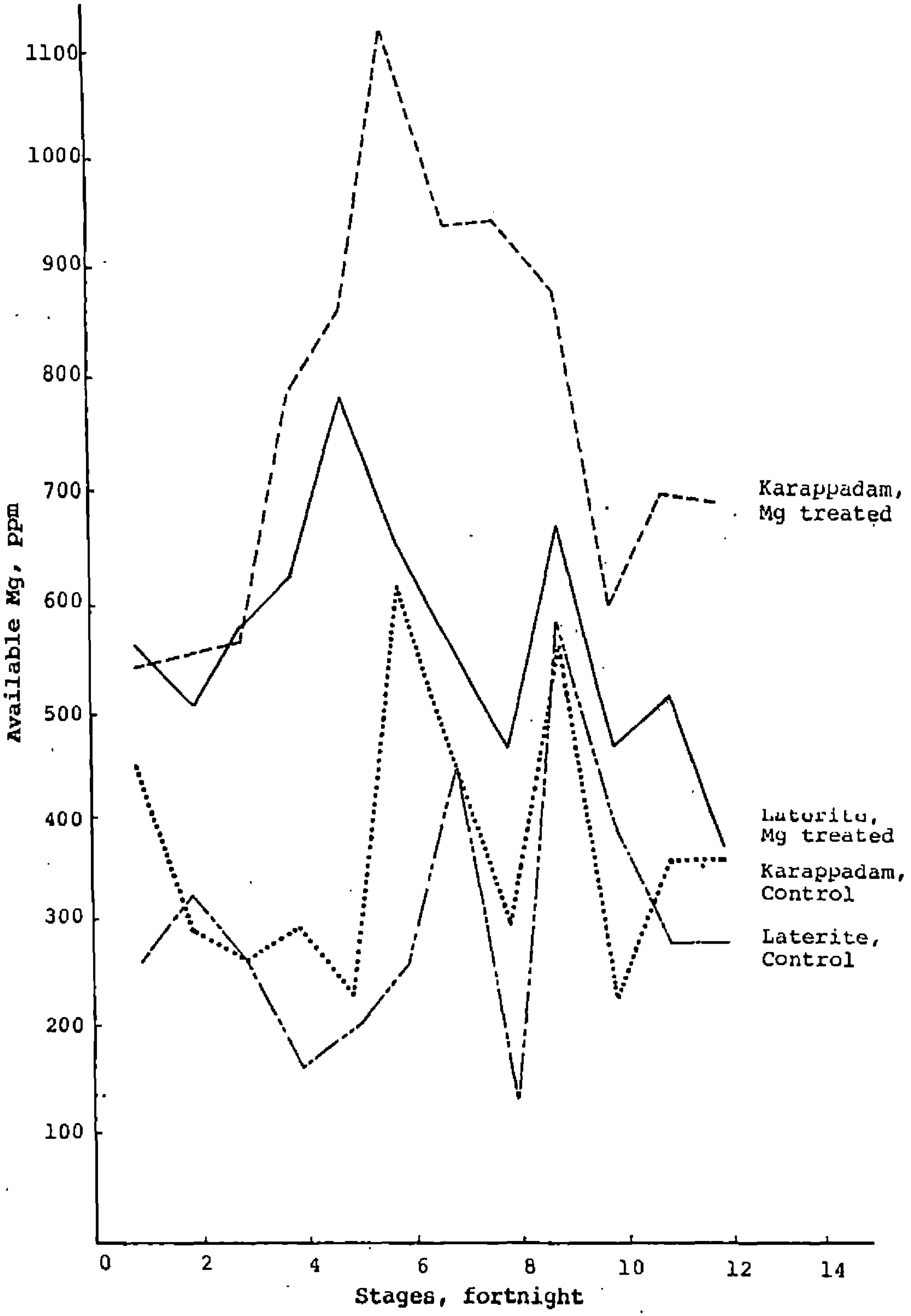

FIG 15. EFFECT OF SOIL ON AVAILABLE MAGNESIUM

availability of Mg in the soil from the applied sources. The overall trend of changes in available Mg revealed that the change was in a fluctuating pattern. In karappadam the treatments showed an increase in the available Mg content upto the sixth stage (3 months), obviously due to the release of Mg from applied sources. Then it remained more or less stable, probably due to the attainment of an equilibrium between the added Mg sources and the Mg in soil. But in control, there was a gradual decrease upto the fourth stage. This could be attributed to a reduction in the solubility of soil Mg components due to the transformation of different forms of soil Mg. In laterite soil, the variation in available Mg with advancing period of incubation was not so conspicuous. The treatments showed a general trend of increase in available Mg upto the fifth stage and thereafter the levels were inconsistent.

The overall trend in the change in available Mg due to the effect of source is given in Fig 16. In control, there was a gradual decrease in the available Mg content upto the fifth stage. As explained earlier this may be due to the reduction in solubility of soil Mg components due to the transformation of different forms of soil Mg. Thereafter, the change in available Mg was in a fluctuating manner. While comparing the sources, treatments in magnesium sulphate registered highest values of available Mg in all the stages except in the last. The increase in available Mg

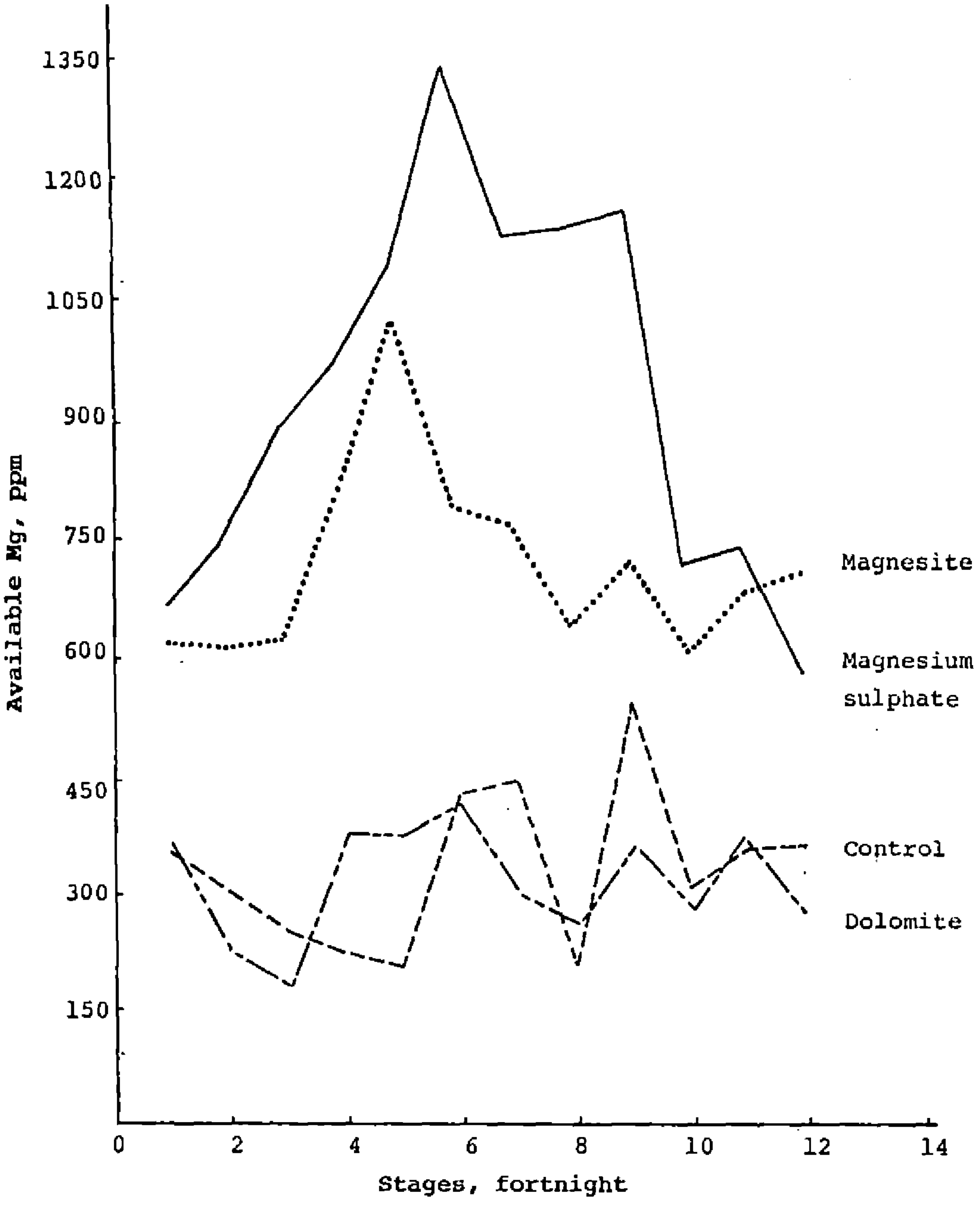

FIG 16 . EFFECT OF Mg SOURCES ON AVAILABLE Mg IN SOIL content of samples treated with magnesium sulphate is obviously due to the higher solubility of magnesium sulphate compared to magnesite and dolomite. The reported solubility of magnesium sulphate with a dissociation log K° of 8.15 reflects a very high solubility for this mineral. It is much too soluble to be retained in well drained soils. The solubility of carbonates of Mg decreases in the order magnesite (log K^{o} = 10.69) $>$ dolomite (log K^{o} = 18.46) (Lindsay, 1979). The available Mg content of samples treated with magnesium sulphate increased upto the 8th stage (4 months) manifesting the increased release of Mg from the added magnesium sulphate. The level of available Mg was almost stable upto the 9th stage, probably due to the attainment of equilibrium between the Mg released from the source and that in the soil. Thereafter, the levels of available Mg showed a tendency of decline. This may be indicative of the conversion to available Mg to insoluble forms by the process of fixation which may involve the interlocking of Mg in crystal lattice of clay minerals as well as the formation of Mg containing minerals of low solubility. The treatments with magnesite also followed a similar trend of increase in available Mg upto the sixth stage showing the release of Mg from added magnesite. The release was at a slower rate than from that of magnesium sulphate, indicated by the lower content of available Mg in the samples treated with magnesite. This can be attributed to the lower solubility of magnesite compared to magnesium sulphate. After the sixth stage, the available Mg content, decreased or it was more or less stable. This may be due to the equilibrium formed between the released Mg and the Mg in soil. The equilibrium was attained earlier in treatments with magnesite compared to treatments with magnesium sulphate, further proving the lower solubility of magnesite. The treatments with dolomite registered very low amounts of available Mg compared to those of magnesium sulphate and magnesite. This confirms the least solubility of dolomite among the three sources. The initial decline in available Mg in the samples treated with dolomite, can be attributed to a reduction in solubility of dolomite itself due to transformation of different forms of soil Mg. The increase in available Mg in these treatments with advancing period of incubation, was not very marked, indicating almost stabilised release of Mg till the last stage of incubation.

Considering the effect of sources on available Mg in the two soils separately, there was a difference in the behaviour of the two soils in this aspect. The available Mg content was in the decreasing order in treatments with magnesium sulphate > magnesite > dolomite, but the magnitude of release of Mg was more in karappadam soil than in the laterite. This may be due to the higher inherent Mg content of karappadam soil. It is also possible that the more acidic nature of karappadam soil, increases its solubilising power. This is further evidenced by the increased solubility of dolomite in karappadam soil, indicated by a higher

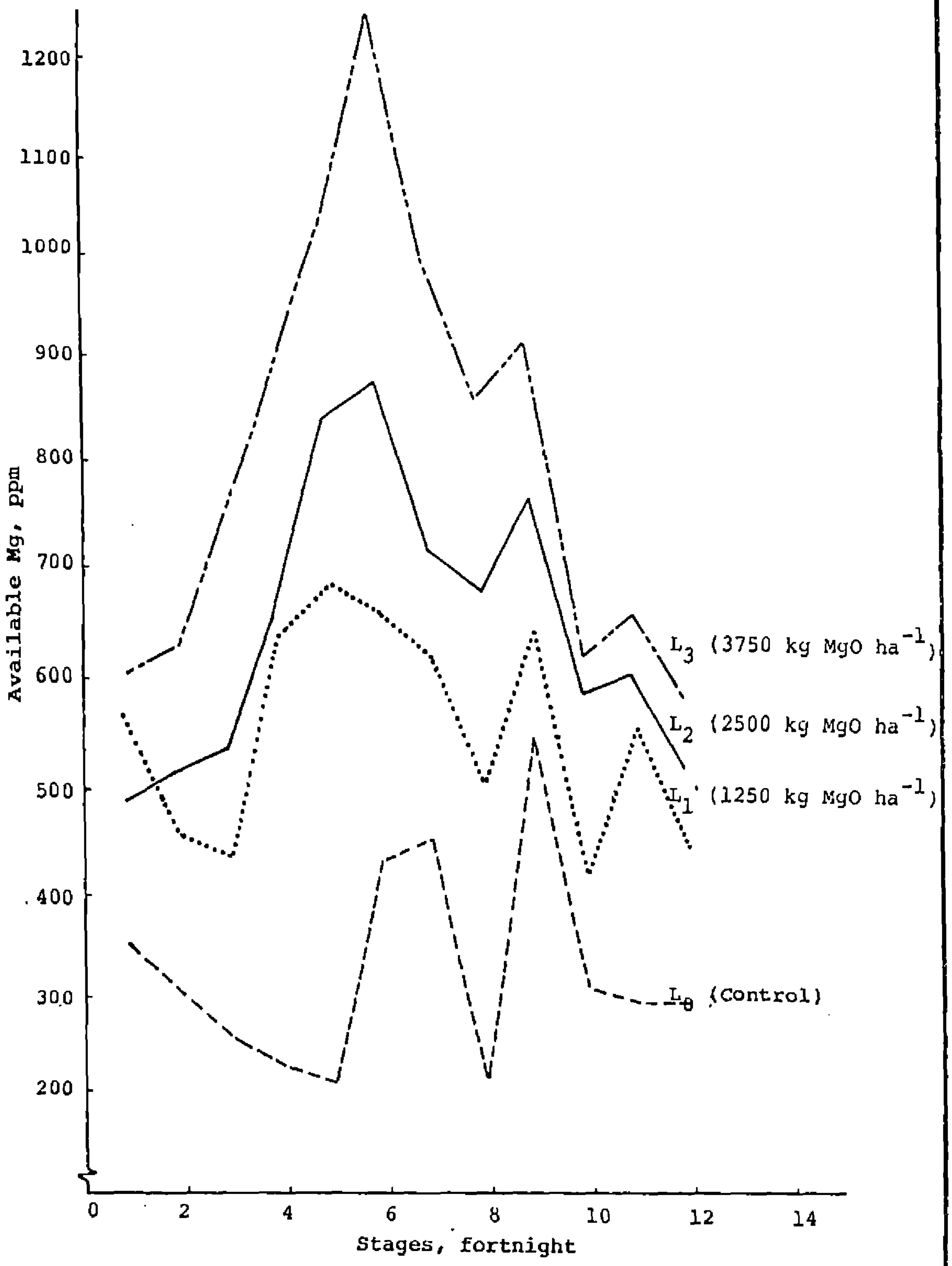

FIG 17. EFFECT OF LEVELS OF Mg ON AVAILABLE Mg IN SOIL

content of available Mg in samples treated with dolomite in karappadam, compared to laterite.

Regarding the effect of levels of available Mg in both soils together (Fig 17), the available Mg content was found to increase with increasing levels of application of MgO, understandably due to the increase in magnitude of release of Mg from the applied Mg fertilizers, at higher levels. The quantity of available Mg registered by the control was lower than that for any of the applied level of MgO, in all the stages of incubation. This shows that the transformation of Mg in both soils is dominated by the dynamics of applied Mg rather than the native Mg. The difference in the availability of Mg with increased level of application of Mg fertilizers, was narrow in the initial stages. The increased availability at higher levels, was more conspicuous with advancing period of incubation upto three months (between fifth and sixth stages). Thereafter the difference in availability again became narrow. This trend is in line with the general increase and subsequent decrease in available Mg with advancing stages of incubation. In the early stages, the solubility of any source is less and then there is an increased release of Mg due to solubilisation with advancing period, followed by the attainment of equilibrium between the released Mg and the soil Mg, ultimately leading to fixation of a part of available Mg by its conversion into insoluble or less soluble forms. The two soils (karappadam

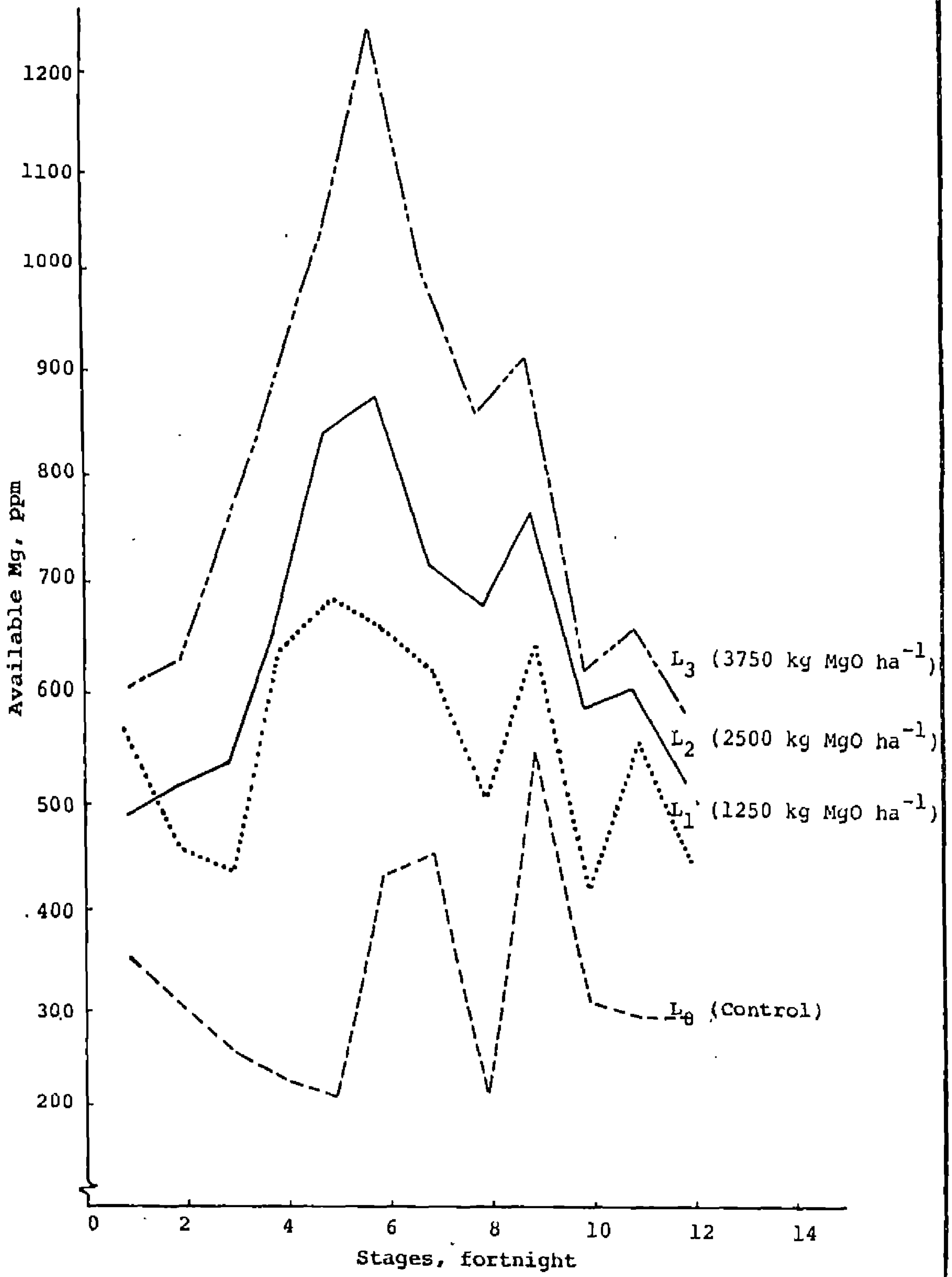

FIG 17. EFFECT OF LEVELS OF Mg ON AVAILABLE Mg IN SOIL

and laterite) did not show considerable variation in the pattern of release of Mg with increasing levels of application of Mg fertilizers.

The analysis of variance of the data at bimonthly intervals showed that the treatments had significant influence on the available Mg content. The mean values of available Mg as influenced by soil type, Mg source and Mg level at two, four and six months of incubation are presented in Tables 17 to 22. The available Mg content of the two soils differed significantly at these stages. The higher content of available Mg in karappadam may be due to the higher initial Mg content of this soil.

The three sources of Mg differed significantly in the release of available Mg at two, four and six months of incubation. The highest amount of available Mg was registered in soils treated with magnesium sulphate except at sixth month of incubation. This may be due to the lower solubility of carbonate forms of Mg viz., magnesite and dolomite. The content of available Mg was the highest in samples treated with magnesite after six months of incubation. Magnesite being relatively less soluble than magnesium sulphate gives slow but prolonged release of available Mg, making it less susceptible to conversion into unavailable forms. Dolomite was found to be the least soluble at all stages of incubation.

The pattern of release of available Mg differed significantly in the two soils. This may be due to the difference in the native Mg content and other characteristics of these soils influencing the behaviour of Mg in soil.

The levels within source were found to differ significantly. There was significant increase in available Mg with increasing levels of MgO in the form of different Mg fertilizers.

There was significant difference in available Mg content between Mg treated samples and the control.

While comparing the efficiency of different Mg fertilizers to supply available Mg after six months of incubation, magnesite was found superior in both soils (49.8 per cent efficiency in karappadam and 36.1 per cent efficiency in laterite soil). The efficiency of magnesium sulphate was 40.5 per cent in karappadam and 30.4 per cent in laterite. The corresponding values for dolomite were 27.8 in karappadam and 4.96 per cent in laterite at field capacity.

At different stages of incubation, available Mg in soil was positively correlated with exchangeable Mg (Tables 24 to 29). Since exchangeable Mg is a part of available Mg, this positive correlation is well understood. Positive correlation was also seen between available Mg and specific conductance (Tables 24 and 26). As the available Mg content increases, the soluble salt content and in turn the specific conductance increases. Antagonism between Mg and Ca was observed by the negative correlation between available Mg and exchangeable Ca at different stages (Tables 24, 25, 27, 28 and 29). A negative correlation was observed between available Mg and pH (Tables 26, 27 and 29). At lower pH, the solubility of Mg compounds is higher.

3. Exchangeable Mg

The mean values of exchangeable Mg as influenced by treatments at different periods after incubation are presented in Table 14.

The karappadam soil the overall mean values of exchangeable Mg at zero, two, four and six months after incubation were 1.92, 6.467, 6.997 and 2.387 cmol(+) kg^{-1} respectively. In laterite, the corresponding values were 1.17, 2.428, 3.113 and 1.945 cmol(+) kg^{-1}. In karappadam, upto two months, there was considerable increase in exchangeable Mg content. Then the increase was not so conspicuous upto four months and then there was a considerable decrease. The initial increase may be due to the release of Mg from the added sources. This is further confirmed by the significant difference in the change of exchangeable Mg in the control from that of the rest of the treatments with advancing period of incubation. The considerable decrease in exchangeable Mg after six months of incubation may be due to

Table 14. Effect of treatments on exchangeable Mg and exchangeable Ca, cmol(+) kg^{-1}
(mean of two replications)

Soil	Treatment	Exchangeable Mg			Exchangeable Ca		
		Periods, months			Periods, months		
		2	4	6	2	4	6
Karappadam	T_1	1.224	2.040	1.020	5.305	4.690	5.100
	T_2	4.692	6.528	1.530	6.120	5.100	6.120
	T_3	8.976	8.160	2.550	5.100	5.710	5.100
	T_4	17.340	18.560	2.550	4.690	6.325	4.590
	T_5	5.916	6.120	3.060	4.895	5.510	5.100
	T_6	8.568	8.568	4.080	4.490	4.690	5.100
	T_7	9.996	9.792	4.080	4.285	4.490	5.100
	T_8	3.876	4.488	2.040	10.610	10.200	8.670
	T_9	2.856	3.672	2.550	16.320	14.690	11.220
	T_{10}	1.224	2.040	0.408	21.220	18.770	16.830
	Mean	6.467	6.997	2.387	8.304	8.012	7.293
Laterite	T_1	0.612	0.408	0.612	3.470	3.670	2.450
	T_2	1.836	3.060	1.632	3.670	3.470	3.060
	T_3	4.488	6.120	1.632	3.265	3.265	2.245
	T_4	6.732	6.732	4.284	3.265	2.160	2.650
	T_5	3.060	2.856	1.088	3.875	3.470	2.650
	T_6	2.856	4.408	4.080	4.285	3.875	2.650
	T_7	3.672	5.508	4.080	4.895	3.060	2.450
	T_8	0.408	1.224	1.020	8.570	8.570	5.305
	T_9	0.408	0.408	0.612	13.870	12.240	7.955
	T_{10}	0.204	0.408	0.408	17.550	16.320	10.410
	Mean	2.428	3.113	1.945	6.672	6.010	4.183

conversion of Mg into nonexchangeable forms in the crystal lattices. In laterite also there was an increase in exchangeable Mg upto fourth month but the rate of release was rather slow compared to karappadam. This difference may be viewed in the context of more acidic nature of karappadam soil.

The exchangeable Mg content was the highest in treatments with magnesium sulphate followed by contents of exchangeable Mg in treatments with magnesite and the least in treatments with dolomite after four months of incubation. This is in line with the relative solubility of these sources of Mg. But after six months of incubation, treatments with magnesite retained more Mg in the exchangeable form, probably because, magnesite released Mg in a slower rate making it less susceptible for fixation. The magnitude of exchangeable Mg in the control was the lowest at different periods of incubation. In karappadam soil, the amount of exchangeable Mg was higher in the control and also in the treatments with different sources of Mg compared to those in laterite soil. This is due to the higher availability of Mg in karappadam soil.

Considering the effect of levels on exchangeable Mg, the content increased with increasing levels of application in all the stages of incubation. With the advancing period of incubation, the exchangeable Mg content was found to increase upto the fourth month and then decreased irrespective of the levels of application. This may be assigned to the increased availability of Mg till the fourth month and later on, the decrease in availability due to fixation. While comparing the two soils for the effect of levels on exchangeable Mg karappadam soil registered higher quantities of exchangeable Mg.

The mean values of exchangeable Mg as influenced by soil type, Mg source and Mg level are furnished in Tables 17 to 22. The analysis of variance of the data showed that the two soils differed significantly in their content of exchangeable Mg at four months after incubation. This may be due to the difference in the native content of exchangeable Mg. The sources of Mg differed significantly in their contribution to exchangeable Mg. The highest amount was contributed by magnesium sulphate, followed by magnesite and the least by dolomite after four months of incubation. This may be correlated with the higher solubility of magnesium sulphate. After six months, the highest amount of exchangeable Mg was supplied in samples treated with magnesite and the least from dolomite. The slowly released Mg ions from magnesite might have occupied a major portion of the exchange sites whereas dolomite was relatively inefficient in the release. Levels of MgO within sources were found to influence the exchangeable Mg content significantly. The exchangeable Mg increased with increasing levels of MgO supplied. The soils did not show any significant difference in the contribution to exchangeable Mg after six months of incubation. After a period of six months, the difference in the native exchangeable Mg content of these soils might have become insignificant as the transformation is dominated by the dynamics of added Mg.

While comparing the efficiency of the three sources to supply exchangeable Mg, magnesite was found superior (25.7 per cent in karappadam and 24.02 per cent in laterite soil). Magnesium sulphate was second (15.2 per cent in karappadam and 19.6 per cent in laterite). The least efficient was dolomite (11.4 per cent in karappadam and 5.3 per cent in laterite). The behaviour of the sources to supply exchangeable Mg did not differ significantly between the soils.

The exchangeable Mg in the control pot (0.816 cmol(+) kg^{-1}) was found to differ significantly from the rest of the treatments.

At different stages of incubation positive correlation was seen between exchangeable Mg and available Mg (Table 24 to 29).

Exchangeable Mg was negatively correlated with exchangeable Ca showing antagonism between the two (Tables 24, 25, 27, 28 and 29). Exchangeable Mg was negatively correlated with exchangeable K and with exchangeable Na (Tables 25 and 27). This shows the possible displacement of Mg from the exchange sites by K and Na.

4. Exchangeable Ca

The mean values of exchangeable Ca at two, four and six months after incubation are presented in Table 14. There was a decrease in the exchangeable Ca content at the sixth month of incubation in karappadam soil. In laterite soil also, decrease in exchangeable Ca content was observed at the sixth month of incubation. The reduction may be due to fixation of the native Ca present in these soils. It may also be possible that the occupation of exchange sites by Mg and increase in the available Mg content with advancing period of incubation might have caused the displacement of Ca. This is further evidenced by the negative correlation between exchangeable Mg and exchangeable Ca. The exchangeable Ca in all the stages was higher in karappadam soil than in laterite soil, probably due to the higher native Ca of karappadam soil.

With the advancing period of incubation, a reduction in exchangeable Ca was observed only at the sixth month of incubation in all the treatments with different sources. A similar trend was observed in the case of the control also. This may be due to the fixation of native Ca. Regarding the influence of soils on exchangeable Ca content at different periods, the content of exchangeable Ca was found to be more in karappadam than that in laterite. This may be accounted for the higher Ca content of karappadam soil.

There was an increase in the exchangeable Ca with the increasing levels of application of MgO in the case of dolomite since it also supplied Ca, in addition to Mg. This was applicable in both karappadam and laterite soils.

The data on the exchangeable Ca content at two months after incubation as influenced by soil type, Mg source and Mg level, are presented in Tables 17 to 22. The two soils differed significantly in exchangeable Ca. The effect of sources of Mg on exchangeable Ca was also significantly different. In samples treated with dolomite, exchangeable Ca was significantly higher. In dolomite treated samples, there was significant increase in exchangeable Ca with increasing level of MgO supplied as dolomite. The effect of the sources of Mg on exchangeable Ca was significantly different in the two soils.

Exchangeable Ca was found to correlate positively with pH (Tables 24 to 29). This is obviously because of the increase in base saturation by the occupation of Ca^{++} ions in the exchange sites. Antagonism between Ca and Mg was observed through the negative correlation between exchangeable Ca and available Mg and also between exchangeable Ca and exchangeable Mg (Tables 24, 25, 27, 28 and 29). Exchangeable Ca correlated negatively with exchangeable K (Tables 26, 27 and 29) showing the displacement of K from exchange sites by Ca^{++} ions.

5. Exchangeable K

Table 15 presents values of exchangeable K at two, four and six months after incubation in karappadam and laterite soils. The exchangeable K was found to decrease as the period of incubation increased to six months in both soils. This may be accounted for by the displacement of exchangeable K by exchangeable Mg, further confirmed by the negative correlation between exchangeable K and exchangeable Mg.

When both the soils are considered together, though not much variation was observed in exchangeable K content of samples treated with various sources of Mg, the exchangeable K content was found to decrease after six months of incubation, probably due to displacement of K^+ ions from exchange sites by Mg^{++} ions. But the two soils behaved differently, with regard to the content of exchangeable K probably due to the difference in available K content of these two soils. With the advancing period of incubation, the exchangeable K content in samples treated with various levels of MgO decreased in both the soils, possibly due to displacement of K^+ ions by Mg^{++} ions.

The mean values of exchangeable K at two, four and six months after incubation as influenced by Mg source, soil type and Mg level are presented in Tables 17 to 22. The effect of the two soils on exchangeable K was significantly different. The

Table 15. Effect of treatments on exchangeable K and Na, cmol(+) kg^{-1} (mean of two replications)

Soil	Treatment	Exchangeable K			Exchangeable Na		
		Periods, months			Periods, months		
		2	4	6	2	4	6
Karappadam	T_1	0.498	0.436	0.400	1.435	0.222	0.591
	T_2	0.426	0.405	0.354	1.087	0.265	0.522
	T_3	0.426	0.421	0.318	1.261	0.235	0.504
	T_4	0.456	0.426	0.297	1.145	0.326	0.417
	T_5	0.415	0.354	0.354	1.174	0.252	0.557
	T_6	0.354	0.374	0.318	0.913	0.235	0.565
	T_7	0.385	0.359	0.333	1.044	0.252	0.557
	T_8	0.359	0.344	0.313	1.000	0.270	0.563
	T_9	0.395	0.369	0.358	1.217	0.217	0.687
	T_{10}	0.354	0.333	0.313	0.957	0.252	0.644
	Mean	0.407	0.382	0.336	1.123	0.253	0.561
Laterite	T_1	0.459	0.439	0.446	0.222	0.313	0.374
	T_2	0.451	0.441	0.400	0.209	0.322	0.304
	T_3	0.446	0.472	0.405	0.217	0.322	0.365
	T_4	0.457	0.462	0.410	0.191	0.322	0.304
	T_5	0.467	0.477	0.364	0.183	0.296	0.326
	T_6	0.426	0.487	0.436	0.165	0.287	0.304
	T_7	0.426	0.472	0.380	0.139	0.257	0.313
	T_8	0.472	0.474	0.385	0.226	0.317	0.296
	T_9	0.421	0.436	0.385	0.243	0.330	0.309
	T_{10}	0.410	0.431	0.387	0.296	0.383	0.365
	Mean	0.444	0.459	0.400	0.209	0.315	0.326

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higher content in laterite may be due to the higher native available K and the less acidic nature of the laterite soil. There was significant difference in exchangeable K between the control and soils treated with Mg.

Positive correlation was observed between exchangeable K and electrical conductivity (Tables 24 and 26). This may be due to the increased specific conductance due to K^+ ions released from exchange sites into soil solution. Exchangeable K was negatively correlated with exchangeable Mg (Table 27) exhibiting the displacement of K^+ ions from the exchange sites by Mg^{++} ions. For the same reason, exchangeable K was found negatively correlated with exchangeable Ca (Tables 26 and 27).

6. Exchangeable Na

Table 15 indicates values of exchangeable Na at two, four and six months after incubation for karappadam and laterite soils. The values of exchangeable Na at two, four and six months of karappadam soil were 1.123, 0.253 and 0.561 cmol(+) kg^{-1} respectively. The exchangeable Na in karappadam was found to decrease after four months of incubation. This may be due to the displacement of Na^+ ions by Mg^{++} ions as exchangeable Mg at this stage was high in all the treatments. In the later stage (six months after incubation), there was an increase in exchangeable Na probably due to the occupation of more number of Na^+ ions in the exchange sites as there was a reduction in exchangeable Mg content at this stage. In laterites, no considerable variation was observed in the exchangeable Na content at different stages of incubation. The general trend of variation in exchangeable Na when the two soils were considered together was more similar to that in karappadam, as the influence of this soil was more pronounced due to the higher initial level of exchangeable Na of this soil. The pattern of change in the amount of exchangeable Na at different periods of incubation by the effect of sources was similar for all the three sources. But the soils differed in this pattern because of the difference in the native exchangeable Na of these soils. Increasing levels of MgO did not cause variation in the content of exchangeable Na.

The data on the mean values of exchangeable Na at two, four and six months after incubation as influenced by Mg sources, soil types and Mg levels are presented in Tables 17 to 22. The analysis of variance of the data after two, four and six months of incubation showed that soils differed significantly in their content of exchangeable Na. The higher content of exchangeable Na in karappadam was due to its higher initial level of exchangeable Na. After four months of incubation, there was also significant difference in the exchangeable Na content of samples treated with different sources. The variation may be according to the displacement of Na^+ ions by Mg^{++} ions in the case of samples treated with magnesium sulphate and dolomite. But in the case of samples treated with dolomite, an increase in exchangeable Ca might have caused an increase in pH, causing an accumulation of Na^+ ions in exchange complex. This is further revealed by the positive correlations between exchangeable Na and pH and between exchangeable Na and exchangeable Ca. The values of exchangeable Na for samples treated with magnesium sulphate, magnesite and dolomite are 0.30, 0.26 and 0.29 cmol(+) kg^{-1} respectively.

Exchangeable Na was found positively correlated with pH (Table 28). The increase in pH reflects the accumulation of Na^+ ions in the exchange sites by the increase in pH dependent charges. The influence of Ca^{++} ions in increasing the pH reveals the positive relationship of exchangeable Na and exchangeable Ca (Tables 25, 27 and 28). The Na^+ ions in the exchange sites come to soil solution to keep the ionic equilibrium between soil solution and exchange sites, thus increasing the specific conductance. Probably this fact may account for the positive correlation between exchangeable Na and EC (Tables 26 and 27).

6. pH

The mean values of pH at different stages of incubation are given in Table 16. The overall mean values of pH were 5.0, 5.7, 5.69 and 5.64 for karappadam after two, four and six months of incubation. The corresponding values for laterite soil were

Table 16. Effect of treatments on pH and EC (mean of two replications)

Soil	Treatment	pH			EC, dS m^{-1}		
		Periods, months			Periods, months		
		2	4	6	2	4	6
Karappadam	T_1	4.44	4.27	4.50	2.440	1.280	0.782
	T_2	4.40	4.20	4.24	2.844	2.655	0.981
	T_3	4.43	4.27	4.36	3.480	3.663	0.946
	T_4	4.46	4.47	4.50	5.000	4.985	0.485
	T_5	5.34	5.44	5.34	2.085	1.800	0.705
	T_6	6.18	6.26	5.91	1.745	1.800	0.742
	T_7	6.36	6.60	5.92	2.215	1.699	0.928
	T_8	6.49	6.62	6.53	2.249	2.150	0.788
	T_9	7.33	7.26	7.33	2.040	2.173	0.910
	T_{10}	7.61	7.55	7.76	2.340	1.923	0.896
	Mean	5.70	5.69	5.64	2.644	2.413	0.816
Laterite	T_1	5.09	6.41	5.42	0.641	0.709	1.045
	T_2	4.99	5.10	5.36	1.684	1.393	1.310
	T_3	5.03	5.01	5.38	2.525	2.520	1.920
	T_4	4.97	5.05	5.39	3.230	2.775	2.450
	T_5	6.21	6.20	6.24	0.882	1.007	1.025
	T_6	6.64	6.99	6.94	0.799	0.864	1.032
	T_7	7.14	7.15	7.06	0.739	0.800	0.854
	T_8	7.15	7.26	7.13	0.980	0.700	0.951
	T_9	7.64	7.71	7.62	0.993	0.904	1.130
	T_{10}	7.81	7.84	7.78	0.972	5.455	1.350
	Mean	6.27	6.47	6.43	1.345	1.713	1.307

5.4, 6.27, 6.47 and 6.43. The pH of the karappadam soil was lower in all stages compared to laterite as the inherent pH of karappadam soil was lower. There was an increase in pH of karappadam soil from 5 to 5.7 after two months of incubation and thereafter there was no considerable variation in pH with advancing period of incubation. A similar trend was followed by laterite soil. When the soils were pooled, the pH of Mg treatments was higher than that of the control in all the stages. This may be due to the increase in pH of the soil by application of Mg fertilizers. Magnesium, a basic cation, increases the pH.

On comparing the different sources of Mg, it was found that pH was maximum in soils supplied with dolomite in both soils. Dolomite being a source of both Mg and Ca increases pH considerably. Efficiency of different sources in correcting soil reaction was in the order dolomite > magnesite > magnesium sulphate.

Increasing the level of Mg increased the pH of the soil indicating the role of Mg sources in correcting the soil reaction in acid soils.

The mean values of pH after two, four and six months of incubation as influenced by Mg sources, soil types and Mg levels are presented in Tables 17 to 22. The analysis of variance of the data at bimonthly intervals showed that the effect of soil, sources of Mg and levels of Mg on soil reaction was significant.

The pH of the control pot was significantly different from the rest of the treatments.

As expected, the pH of the soils was found positively correlated with basic exchangeable cations like exchangeable Ca and exchangeable Na (Tables 24 to 29). The soil reaction was negatively correlated with available Mg (Tables 26, 27 and 29), indicating the higher solubility of Mg compounds at lower pH. The pH was also found negatively correlated with specific conductance (Tables 24 and 25). Probably, this may be the outcome of the higher solubility of Mg compounds at lower pH. The increased release of Fe and Al ions into soil solution from the Fe and Al compounds in soil, as they become soluble at lower pH may also be accounted for explaining this relationship.

7. Specific conductance

The data on specific conductance at different periods of incubation are presented in Table 16. The overall mean values of specific conductance in karappadam soil at zero, two, four and six months of incubation were 1.31, 2.644, 2.413 and 0.816 dS m^{-1} respectively. The corresponding values in laterite soil were 0.61, 1.345, 1.713 and 1.307 dS m^{-1}. In karappadam, the addition of Mg fertilizers has increased the specific conductance upto two months by way of increased release of Mg into soil solution. Thereafter, there was no appreciable variation in the specific conductance upto four months and then there was a considerable decrease in specific conductance after six months of incubation. In the initial periods of incubation the release of Mg was faster and thereafter it was slower due to the attainment of equilibrium between added Mg and Mg in soil. The decrease after six months of incubation may be due to the conversion of soluble form of Mg into insoluble forms. In laterite soil, there was an increase in the specific conductance upto two months of incubation due to the increased release of available Mg. Thereafter the change in specific conductance was inconsistent. This may be correlated with the inconsistent change in available Mg after the fifth stage ($2\frac{1}{2}$ months) of incubation in laterite soil.

On comparing the different sources, the increase in specific conductance was more in samples treated with magnesium sulphate than the other two sources upto the fourth month of incubation. This is because of its higher solubility. After six months of incubation, there was considerable variation in the specific conductance in samples treated with the three sources. This may be because of the conversion of soluble Mg into insoluble Mg compounds at this stage.

Increased levels of MgO applied increased specific conductance, probably due to the increased supply of Mg^{++} ions.

Table 17. Soil characteristics as influenced by Mg sources at two months after incubation (mean values)

Soil characteristics	Soil type	Control	Magnesium sulphate	Magnesite	Dolomite
Available Mg, ppm	Karappadam	163.50	1144.50	850.20	381.50
	Laterite	294.39	828.39	795.69	392.40
Exchangeable Mg, cmol(+) kg^{-1}	Karappadam	1.22	10.34	8.16	2.65
	Laterite	0.61	4.35	3.20	0.41
Exchangeable Ca, cmol(+) kg^{-1}	Karappadam	5.30	5.30	4.56	16.05
	Laterite	3.47	3.40	4.35	13.33
Exchangeable K, cmol(+) kg^{-1}	Karappadam	0.50	0.44	0.38	0.37
	Laterite	0.46	0.45	0.44	0.43
Exchangeable Na, cmol(+) kg^{-1}	Karappadam	1.43	1.14	1.04	1.06
	Laterite	0.22	0.21	0.16	0.26
pH	Karappadam	4.44	4.43	5.96	7.14
	Laterite	5.09	5.00	6.66	7.53
Specific conductance, dS m^{-1}	Karappadam	2.44	3.77	2.02	2.21
	Laterite	0.64	2.48	0.81	0.98

Table 18. Soil characteristics as influenced by levels of Mg application at two months after incubation (mean values)

Soil characteristics	Levels of MgO, kg ha^{-1}	Soil type		Sources of Mg		
		Karappadam	Laterite	Magnesium sulphate	Magnesite	Dolomite
Available Mg, ppm	1250	566.80	719.40	654.00	817.50	457.80
	2500	752.10	566.80	833.85	817.50	327.00
	3750	1057.30	730.30	1471.50	833.85	376.05
Exchangeable mg, cmol(+) kg^{-1}	1250	4.83	1.77	3.26	4.49	2.14
	2500	6.80	2.58	6.73	5.71	1.63
	3750	9.52	3.60	12.04	6.83	0.82
Exchangeable Ca, cmol(+) kg ha^{-1}	1250	7.21	5.37	4.90	4.39	9.59
	2500	8.64	7.14	4.18	4.39	15.10
	3750	10.06	8.57	3.98	4.59	19.38
Exchangeable K, cmol(+) kg^{-1}	1250	0.40	0.46	0.44	0.44	0.42
	2500	0.39	0.43	0.44	0.40	0.41
	3750	0.40	0.43	0.46	0.41	0.38
Exchangeable Na, cmol(+) kg^{-1}	1250	1.09	0.21	0.65	0.68	0.61
	2500	1.13	0.21	0.74	0.54	0.73
	3750	1.03	0.21	0.64	0.59	0.63
pH	1250	5.41	6.11	4.69	5.77	6.82
	2500	5.98	6.44	4.73	6.41	7.48
	3750	6.14	6.64	4.71	6.75	7.71
Specific conductance, dS m^{-1}	1250	2.39	1.18	2.26	1.48	1.61
	2500	2.42	1.14	3.00	1.27	1.52
	3750	3.19	1.65	4.11	1.48	1.66

Table 19. Soil characteristics as influenced by Mg sources at four months after incubation (mean values)

Soil characteristics	Soil type	Control	Magnesium sulphate	Magnesite	Dolomite
Available Mg, ppm	Karappadam	294.30	1689.50	828.40	327.00
	Laterite	130.80	599.50	468.70	196.20
Exchangeable Mg, cmol(+) kg^{-1}	Karappadam	2.04	11.15	8.16	3.40
	Laterite	0.41	5.30	4.28	0.75
Exchangeable Ca, cmol(+) kg^{-1}	Karappadam	4.69	5.71	4.90	14.55
	Laterite	3.67	2.96	3.47	12.38
Exchangeable K, cmol(+) kg^{-1}	Karappadam	0.44	0.42	0.36	0.35
	Laterite	0.44	0.46	0.48	0.45
Exchangeable Na, cmol(+) kg^{-1}	Karappadam	0.22	0.28	0.24	0.25
	Laterite	0.31	0.32	0.28	0.34
pH	Karappadam	4.27	4.31	6.10	7.14
	Laterite	6.40	5.05	6.78	7.60
Specific conductance, dS m^{-1}	Karappadam	1.28	3.77	1.77	2.08
	Laterite	0.71	2.23	0.89	2.35

Table 20. Soil characteristics as influenced by levels of Mg application at four months after incubation (mean values)

Soil characteristics	Levels of MgO, kg ha^{-1}	Soil type		Sources of Mg		
		Karappadam	Laterite	Magnesium sulphate	Magnesite	Dolomite
Available Mg, ppm	1250	643.10	370.60	523.20	474.15	523.20
	2500	926.50	436.00	1160.85	752.10	130.80
	3750	1275.30	457.80	1749.45	719.40	130.80
Exchangeable Mg, cmol(+) kg^{-1}	1250	5.71	2.38	4.79	4.49	2.86
	2500	6.87	3.74	7.24	6.53	2.14
	3750	10.13	4.22	12.65	7.65	1.22
Exchangeable Ca, cmol(+) kg^{-1}	1250	6.94	5.17	4.28	4.49	9.38
	2500	8.36	6.46	4.49	3.43	13.46
	3750	9.86	7.18	4.24	3.77	17.54
Exchangeable K, cmo(+) kg^{-1}	1250	0.37	0.46	0.42	0.42	0.41
	2500	0.39	0.47	0.45	0.43	0.40
	3750	0.37	0.45	0.44	0.42	0.38
Exchangeable Na, cmol(+) kg^{-1}	1250	0.26	0.31	0.29	0.27	0.29
	2500	0.23	0.31	0.28	0.26	0.27
	3750	0.27	0.32	0.32	0.25	0.32
pH	1250	5.42	6.18	4.65	5.82	4.76
	2500	5.93	6.57	4.64	6.62	6.87
	3750	6.21	6.68	4.76	7.49	7.70
Specific conductance, dS m^{-1}	1250	7.61	1.03	2.02	1.40	1.42
	2500	2.55	1.43	3.09	1.33	1.54
	3750	2.87	3.01	3.88	1.25	3.69

Table 21. Soil characteristics as influenced by Mg sources at six months after incubation (mean values)

Soil characteristics	Soil type	Control	Magnesium sulphate	Magnesite	Dolomite
Available Mg, ppm	Karappadam	359.70	708.50	872.00	490.50
	Laterite	228.70	468.70	555.90	76.30
Exchangeable Mg, cmol(+) kg^{-1}	Karappadam	1.02	2.21	3.74	1.67
	Laterite	0.61	2.52	3.13	0.68
Slowly available Mg, ppm	Karappadam	720.30	1041.20	877.80	1262.80
	Laterite	1060.60	1070.90	983.70	1463.40
Exchangeable Ca, cmol(+) kg^{-1}	Karappadam	5.10	5.27	5.10	12.24
	Laterite	2.45	2.67	2.59	7.89
Exchangeable K, cmol(+) kg^{-1}	Karappadam	0.40	0.32	0.34	0.33
	Laterite	0.45	0.41	0.39	0.38
Exchangeable Na, cmol(+) kg^{-1}	Karappadam	0.59	0.48	0.56	0.63
	Laterite	0.37	0.33	0.32	0.32
pH	Karappadam	4.50	4.37	5.72	7.20
	Laterite	5.42	5.37	6.74	7.51
Specific conductance, dS m^{-1}	Karappadam	0.78	0.80	0.79	0.87
	Laterite	1.05	1.89	0.97	1.14
Organic carbon, %	Karappadam	1.86	1.79	1.76	1.78
	Laterite	0.96	1.00	0.93	0.96

Table 22. Soil characteristics as influenced by levels of Mg application at six months after incubation (mean values)

Soil characteristics	Levels of MgO, kg ha^{-1}	Soil type		Sources of Mg		
		Karappadam	Laterite	Magnesium sulphate	Magnesite	Dolomite
Available Mg, ppm	1250	588.60	316.10	408.80	621.30	327.00
	2500	763.00	337.90	572.30	768.50	310.70
	3750	719.40	446.90	784.80	752.10	212.60
Exchangeable Mg, cmol(+) kg^{-1}	1250	2.21	1.43	1.58	2.35	1.53
	2500	3.06	2.11	2.09	4.08	1.58
	3750	2.35	2.79	3.42	3.88	0.41
Slowly available Mg, ppm	1250	826.30	886.60	901.10	688.40	982.90
	2500	990.30	1201.80	1072.40	876.40	1339.50
	3750	1365.20	1427.60	1194.70	1227.50	1767.00
Exchangeable Ca, cmol(+) kg^{-1}	1250	4.97	3.67	4.59	3.88	3.62
	2500	7.14	4.29	3.67	3.88	3.78
	3750	8.84	5.17	3.62	9.59	13.62
Exchangeable K, cmol(+) kg^{-1}	1250	0.34	0.38	0.38	0.36	0.35
	2500	0.23	0.41	0.36	0.38	0.37
	3750	0.32	0.39	0.35	0.36	0.34
Exchangeable Na, cmol(+) kg^{-1}	1250	0.55	0.31	0.41	0.44	0.43
	2500	0.59	0.33	0.44	0.44	0.50
	3750	0.54	0.33	0.36	0.44	0.50

Contd.

Table 22 Continued

Soil characteristics	Levels of MgO, kg ha^{-1}	Soil type		Sources of Mg		
		Karappadam	Laterite	Magnesium sulphate	Magnesite	Dolomite
pH	1250	5.37	6.24	4.80	5.79	6.83
	2500	5.86	6.64	4.87	6.42	7.47
	3750	6.06	6.74	4.95	6.49	7.77
Specific conductance, dS m^{-1}	1250	0.83	1.10	1.15	0.87	0.87
	2500	0.87	1.37	1.43	0.89	1.02
	3750	0.77	1.55	1.47	0.89	1.12
Organic carbon, %	1250	1.79	0.96	1.37	1.36	1.39
	2500	1.78	1.01	1.40	1.37	1.38
	3750	1.76	0.93	1.40	1.30	1.34

The effect of treatments on specific conductance as influenced by soil types, Mg sources and Mg levels is presented in Tables 17 to 22. The analysis of variance of the data showed that the influence of soils, sources of Mg and levels of MgO was significant.

Specific conductance was positively correlated with available Mg and various exchangeable cations including exchangeable Mg (Tables 24 to 27). This confirms the effect of soluble cations in soil solution and exchange sites on increasing specific conductance. The specific conductance was seen negatively correlated with pH.

8. Slowly available Mg

Data on slowly available Mg are presented in Table 23. After six months of incubation, this fraction of Mg in Mg treated pots was considerably higher than that of control pots in both karappadam and laterite. The value of slowly available Mg in the control was 720.3 ppm and that in Mg treatments was 1060.6 ppm in karappadam soil. The corresponding values for laterite soil were 641.1 and 1172.7 ppm respectively. This may be due to the effect of added Mg fertilizers. The soils treated with Mg retained a considerable part of their Mg in the slowly available form. The effect of soil types, sources of Mg and levels of Mg on slowly available Mg is presented in Tables 21 and 22. There

Table 23. Slowly available Mg and organic carbon as influenced by treatments at six months after incubation (mean of two replications)

Treatment	Slowly available Mg, ppm		Organic carbon, %	
	Karappadam	Laterite	Karappadam	Laterite
T_1	720.3	641.1	1.860	0.960
T_2	859.0	943.2	1.770	0.975
T_3	997.5	1147.3	1.800	1.005
T_4	1267.1	1122.3	1.785	1.005
T_5	760.8	616.0	1.800	0.915
T_6	768.9	983.9	1.740	0.990
T_7	1103.7	1351.3	1.725	0.870
T_8	859.0	1106.7	1.785	0.990
T_9	1204.6	1474.3	1.785	0.975
T_{10}	1724.8	1809.1	1.770	0.915
Mean	1026.6	1119.5	1.782	0.960

was difference in the content of slowly available Mg in soils treated with different sources of Mg. The amount of Mg in the slowly available form was the lowest in treatments with magnesite. This may be attributed to the higher amount of available Mg extracted from samples treated with magnesite. The highest content was in dolomite, which can be viewed in the context of the relatively insoluble nature of dolomite. With increasing levels of MgO, the Mg in slowly available form also increased.

9. Organic carbon

Table 23 indicates the values of organic carbon after six months of incubation. The analysis of variance of the data showed that the treatments did not differ significantly within the soil. But the two soils showed significant difference in their content of organic carbon. The karappadam soil showed a value of 1.782 per cent whereas in laterite it was only 0.960 per cent. The higher content of organic cabon in karappadam is due to the higher content of organic carbon originally present in that soil. The data on organic carbon as influenced by Mg sources, soil types and Mg levels after six months of incubation are given in Tables 21 and 22.

Organic carbon was found to correlate positively with exchangeable K ($r = 0.6395^{**}$). This may be due to the increased number of exchange sites formed by the influence of organic colloids.

Table 24. Correlation coefficients between various characteristics under incubation study (for karappadam soil at 2 months after incubation)

Sl. No.	X	Y	Correlation coefficient (r)
1	Available Mg	Exchangeable Mg	0.9834**
2	,,	Exchangeable Ca	-0.4923*
3	,,	Electrical conductivity	0.7104**
.4	Exchangeable Mg	Exchangeable Ca	-0.5624**
5	,,	Electrical conductivity	0.6934**
6	Exchangeable Ca	pH	0.7644**
7	Exchangeable K	EC	0.4753*
8	pH	EC	-0.5737**

* Significant at 5% level
** Significant at 1% level

Table 25. Correlation coefficients between various characteristics under incubation study (for laterite soil at 2 months after incubation)

Sl. No.	X	Y	Correlation coefficient (r)
1	Available Mg	Exchangeable Mg	0.6934**
2	,,	Exchangeable Ca	-0.4770*
3	,,	Exchangeable Na	-0.5565*
4	Exchangeable Mg	Exchangeable Ca	-0.5979**
5	,,	Exchangeable Na	-0.4948*
6	,,	EC	0.7211**
7	Exchangeable Ca	Exchangeable Na	0.7138**
8	,,	pH	0.7878**
9	pH	EC	-0.6049**

* Significant at 5% level
** Significant at 1% level

Table 26. Correlation coefficients between various characteristics under incubation study (for karappadam soil, at 4 months after incubation)

Sl. No.	X	Y	Correlation coefficient (r)
1	Available Mg	Exchangeable Mg	0.9304**
2	,,	pH	-0.5120*
3	,,	EC	0.8716**
4	Exchangeable Mg	EC	0.7821**
5	Exchangeable Ca	Exchangeable K	-0.4735*
6	,,	pH	0.7121**
7	Exchangeable K	EC	0.4576*
8	Exchangeable Na	EC	0.6981**

* Significant at 5% level
** Significant at 1% level

Table 27. Correlation coefficients between various characteristics under incubation study (for laterite soil, at 4 months after incubation)

Sl. No.	X	Y	Correlation coefficient (r)
1	Available Mg	Exchangeable Mg	0.8556**
2	,,	Exchangeable Ca	-0.6449**
3	,,	pH	-0.5406*
4	Exchangeable Mg	Exchangeable Ca	-0.6866**
5	,,	Exchangeable K	-0.5037*
6	Exchangeable Ca	Exchangeable K	-0.4435*
7	,,	Exchangeable Na	0.5677**
8	,,	pH	0.7068**
9	Exchangeable Na	EC	0.4567*

* Significant at 5% level
** Significant at 1% level

Table 28. Correlation coefficients between various characteristics under incubation study (for karappadam soil at 6 months after incubation)

Sl. No.	X	Y	Correlation coefficient
1	Available Mg	Exchangeable Mg	0.8618**
2	,,	Exchangeable Ca	-0.5594*
3	Exchangeable Mg	Exchangeable Ca	-0.5137*
4	Exchangeable Ca	Exchangeable Na	0.5961*
5	,,	pH	0.8133**
6	Exchangeable Na	pH	0.6410**
7	Organic carbon	Exchangeable K	0.6395**

* Significant at 5% level
** Significant at 1% level

Table 29. Correlation coefficients between various characteristics under incubation study (for laterite soil at 6 months after incubation)

Sl. No.	X	Y	Correlation coefficient
1	Available Mg	Exchangeable Mg	0.8395**
2	,,	Exchangeable Ca	-0.7003**
3	,,	pH	-0.4420*
4	Exchangeable Mg	Exchangeable Ca	-0.5470*
5	Exchangeable Ca	pH	0.7396**

* Significant at 5% level
** Significant at 1% level

PART 4. PATTERN OF Mg UPTAKE BY BANANA FROM DIFFERENT SOURCES AT DIFFERENT LEVELS

A field experiment was conducted to study the response of applied Mg on the uptake, growth and yield of banana (variety Nendran) under irrigated condition. Three sources of Mg were applied at three levels viz., 500, 1000 and 1500 g of MgO per plant per year. The sources of Mg applied were $MgSO_4.7H_2O$, magnesite and dolomite. Soil and plant samples were drawn at early vegetative stage, late vegetative stage, at the time of shooting and at the time of harvest of banana.

A. Biometric observations

1. Vegetative characters

Data on the influence of Mg treatments on the vegetative characters namely, mean height of plants, girth of plants, total number of leaves, total number of suckers, days to flower, days to mature and total duration are presented in Tables 31, 34, 37 and 40.

The growth characters of the plant were recorded for early vegetative stage, late vegetative stage, at shooting and at harvest separately.

The mean height of plants increased from 57.37 cm at early vegetative stage to 330.6 cm at the time of harvest. The

Table 30. General characteristics of the soil selected for the field experiment

Soil type	Laterite
Texture	Sandy loam
Coarse sand, %	16.30
Fine sand, %	33.93
Silt, %	5.30
Clay, %	44.50
pH	5.59
Specific conductance, dS m^{-1}	0.073
Organic carbon, %	1.14
Cation exchange capacity, cmol(+) kg^{-1}	11.8
Total N, %	0.155
Available P, kg ha^{-1}	176.6
Available K, kg ha^{-1}	466.7
Available Mg, kg ha^{-1}	179
Exchangeable Mg, cmol(+) kg^{-1}	0.999
Exchangeable Ca, cmol(+) kg^{-1}	4.661
Exchangeable K, cmol(+) kg^{-1}	0.556
Exchangeable Na, cmol(+) kg^{-1}	0.122

analysis of variance of the data at four stages showed that the treatments did not significantly influence the height of plants. The mean girth of plants increased from 21.07 cm at early vegetative stage to 67.73 cm at the time of shooting. Then the girth decreased to 62.23 cm at harvest, probably due to the onset of senescence and the removal of nutrients to the developing bunches. The girth did not differ significantly under the influence of the treatments. The mean number of leaves at early vegetative stage was 9.46 which increased to 33.62 at the time of shooting. The number of leaves was not significantly influenced by the treatments at any stage of the growth. The total number of suckers produced by the mother plants was independent of the treatments imposed. The treatments also failed to influence the days to flower, days to mature and the total duration of the crop.

These results in general reveal that the requirement of Mg to effect vegetative growth through tissue development is met by the native Mg originally contained in the soil and Mg additions through fertilizers could not influence the vegetative growth of the plant. Though Mg forms the structual constituent of chlorophyll and ribosomes, its function in the plant is mainly physiological by serving as the metallic cofactor of a large number of enzymes especially phosphorylases. The fact that the absolute amount of metallic cofactors required to catalyse a biochemical reaction is very limited and also that the Mg is a very mobile element, tends

Table 31. Biometric observations and content of chlorophyll in banana leaves at early vegetative stage (mean of three replications)

Treatment	Mean height of plants, cm	Mean girth of plants, cm	Total number of leaves (Mean)	Chlorophyll, mg g^{-1} tissue		
				Total	Chlorophyll 'a'	Chlorophyll 'b'
T_1	58.33	22.50	9.330	1.358	0.590	0.768
T_2	63.00	20.50	9.580	1.126	0.516	0.606
T_3	57.58	20.50	9.330	1.406	0.620	0.787
T_4	66.08	22.92	9.420	1.181	0.540	0.641
T_5	61.75	22.33	10.080	1.268	0.374	0.717
T_6	57.25	20.92	9.080	1.345	0.592	0.753
T_7	56.92	22.08	9.920	1.204	0.542	0.685
T_8	57.75	20.83	9.830	1.312	0.587	0.819
T_9	54.67	21.33	9.580	1.256	0.521	0.735
T_{10}	40.33	16.75	8.420	1.224	0.549	0.674
Mean	57.37	21.07	9.457	1.268	0.543	0.719

The treatment effects are not significant

to infer that the total requirement of Mg for the crop could be satisfied by the pool of available Mg present in the soil. The soil of the experimental site contained 179 kg ha^{-1} of available Mg which corresponded to 80 ppm approximately. In the foregoing chapter on the Mg status of Kerala soils it was observed that a soil containing 100 ppm of available Mg can be rated as sufficient and values ranging from 50 to 100 ppm are treated as marginal. Probably, 80 ppm of available Mg contained in the experimental soil would have been sufficient to meet the Mg requirement of the crop for attaining the optimum vegetative growth.

Height of plants correlated positively with girth of plants at early vegetative stage (r = 0.9445**), at late vegetative stage (r = 0.9338**), at the time of shooting (r = 0.4430*) and at the time of harvest (r = 0.6379**). Positive correlation was observed between height of plants and total number of leaves at early vegetative stage (r = 0.6878**), and at late vegetative stage (r = 0.7947**). At the time of harvest, height of plants correlated positively with yield (r = 0.6112**) and with number of fingers per bunch (r = 0.4115*). Girth of plants also positively correlated with total number of leaves at early vegetative stage (r = 0.6701**) and at late vegetative stage (r = 0.7978**). At the time of harvest, girth was found to be positively correlated with weight of bunch (r = 0.6939**), number of fingers per bunch (r = 0.5324**) and weight of finger (r = 0.3862*). These correlations emphasise the

Table 32. Nutrient content in banana leaf at early vegetative stage, per cent (mean of three replications)

Treatment	N	P	K	Ca	Mg
T_1	3.285	0.322	5.870	0.740	0.788
T_2	3.524	0.311	5.600	0.430	1.203
T_3	3.584	0.333	5.530	0.501	1.260
T_4	3.405	0.289	5.930	0.382	1.131
T_5	3.704	0.344	5.600	0.668	1.117
T_6	3.524	0.333	5.530	1.002	1.017
T_7	3.524	0.333	5.870	0.740	1.045
T_8	3.345	0.367	5.670	0.740	1.060
T_9	3.226	0.367	6.000	0.597	1.088
T_{10}	3.166	0.367	5.670	0.764	1.174
Mean	3.429	0.337	5.727	0.656	1.088

For Ca content in leaf, CD (0.05) for the comparison of treatments is 0.3214. Other treatment effects are not significant.

interrelationship among the vegetative characteristics and also its influence on yield and yield attributes.

In the late vegetative stage, height of plants was found to correlate positively with total chlorophyll content of leaf ($r = 0.4235^{*}$), chlorophyll 'a' ($r = 0.4646^{**}$) and with chlorophyll 'b' ($r = 0.4621^{*}$). This might have resulted from the increased photosynthesis in consequence of the increase in the total number of leaves and the level of total chlorophyll, chlorophyll 'a' and chlorophyll 'b' in the leaf.

At early and late vegetative stages of growth, the various vegetative characteristics were found to correlate negatively with the level of various nutrients in the index leaf (Tables 46 and 47). This may be indicative of the increased utilisation of these nutrients for the vegetative growth and also the transport of the nutrients from the leaf to other vegetative parts. At these stages the vegetative characteristics were also found negatively correlated with various nutrient levels in soil (Tables 46 and 47). Probably, the increased absorption of nutrients from soil in accordance with their increased utilisation in the plant would have resulted in a decrease in the level of nutrients in the soil.

At the time of shooting and harvest, positive correlations were observed among the various vegetative characteristics and the level of nutrients in the index leaf (Tables 48 and 49). This

Table 33. Nutrient content in soil at early vegetative stage (mean of three replications)

Treatment	Organic carbon, %	Total N, %	Available nutrients, kg ha^{-1}			Exchangeable cations, cmol(+). kg^{-1}				pH	EC, dS m^{-1}	CEC, cmol(+) kg^{-1}
			P	K	Mg	Mg	Ca	K	Na			
T_1	0.47	0.167	255.7	802.7	418	0.670	6.88	0.962	0.216	4.97	0.575	7.86
T_2	0.41	0.161	221.1	933.3	2267	4.220	6.88	1.239	0.235	5.07	0.793	11.62
T_3	0.48	0.167	194.9	672.0	3043	5.330	6.21	0.940	0.209	5.03	1.010	10.09
T_4	0.50	0.167	250.5	728.0	5072	7.100	5.10	0.897	0.217	4.73	1.180	10.09
T_5	0.39	0.167	246.8	746.7	1074	0.890	6.88	0.940	0.223	5.11	0.589	8.55
T_6	0.37	0.167	249.0	785.3	2247	1.330	7.77	1.026	0.209	5.28	0.534	8.89
T_7	0.50	0.167	235.2	1008.0	1253	2.000	7.10	1.154	0.209	5.19	0.593	7.86
T_8	0.55	0.167	226.2	746.7	4535	2.000	8.66	0.897	0.228	5.65	0.542	9.06
T_9	0.46	0.120	231.5	840.0	1313	2.000	10.21	1.154	0.215	5.33	0.579	9.23
T_{10}	0.48	0.201	191.5	728.0	1671	0.890	13.99	0.983	0.244	6.04	0.612	8.72
Mean	0.46	0.165	230.2	799.1	2289	2.643	7.96	1.019	0.221	5.24	0.701	9.20

For available Mg, exchangeable Mg and pH CD (0.05) for the comparison of treatments are 2573.2, 1.41 and 0.6324 respectively. Other treatment effects are not significant.

Table 34. Biometric observations and content of chlorophyll in banana leaves at late vegetative stage (mean of three replications)

Treatment	Mean height of plants, cm	Mean girth of plants, cm	Total number of leaves (mean)	Chlorophyll, mg g^{-1} tissue		
				Total	Chlorophyll 'a'	Chlorophyll 'b'
T_1	187.6	50.58	22.67	0.781	0.300	0.481
T_2	201.7	54.17	23.42	0.822	0.324	0.498
T_3	198.1	52.75	22.42	0.868	0.334	0.534
T_4	194.0	51.28	22.86	0.872	0.315	0.499
T_5	205.1	53.94	23.61	0.810	0.312	0.499
T_6	186.5	51.67	22.25	0.789	0.313	0.476
T_7	189.3	50.42	23.50	0.792	0.312	0.480
T_8	186.6	49.67	23.25	0.724	0.291	0.433
T_9	193.7	52.17	22.89	0.732	0.293	0.440
T_{10}	170.8	47.58	21.00	0.771	0.301	0.470
Mean	191.3	51.42	22.79	0.796	0.310	0.481

The treatment effects are not significant

Table 35. Nutrient content in banana leaf at late vegetative stage, per cent (mean of three replications)

Treatment	N	P	K	Ca	Mg
T_1	2.807	0.333	5.458	1.456	0.258
T_2	3.046	0.347	5.417	1.170	0.701
T_3	3.166	0.378	5.208	1.241	0.687
T_4	3.046	0.337	4.500	1.528	0.645
T_5	2.926	0.344	5.292	1.074	0.687
T_6	2.986	0.335	5.292	1.217	0.601
T_7	3.046	0.340	4.792	1.217	0.602
T_8	3.046	0.355	6.042	1.289	0.544
T_9	3.225	0.365	5.000	1.170	0.544
T_{10}	3.046	0.327	5.542	1.313	0.559
Mean	3.034	0.346	5.254	1.268	0.583

For Mg content in leaf, CD (0.05) for comparison of treatments is 0.2197. Other treatment effects are not significant.

Table 36. Nutrient content in soil at late vegetative stage (mean of three replications)

Treatment	Organic carbon, %	Total N, %	Available nutrients, kg ha^{-1}			Exchangeable cations, cmol(+) kg^{-1}				pH	EC, dS m^{-1}	CEC, cmol(+) kg^{-1}
			P	K	Mg	Mg	Ca	K	Na			
T_1	0.390	0.179	395.7	1475.0	238.7	0.890	8.880	1.496	0.228	4.970	1.109	13.50
T_2	0.340	0.173	243.4	970.7	895.0	1.110	5.990	0.940	0.194	4.850	0.541	14.53
T_3	0.420	0.185	262.1	989.3	1372.0	2.660	1.220	0.983	0.212	4.720	0.638	14.70
T_4	0.340	0.161	262.1	858.7	2148.0	3.770	6.000	0.940	0.201	4.720	0.962	14.69
T_5	0.410	0.167	390.1	784.0	775.7	3.110	7.990	0.940	0.236	4.990	0.909	16.06
T_6	0.360	0.167	321.1	1026.7	1134.0	0.670	8.440	1.154	0.207	4.826	0.618	14.70
T_7	0.370	0.167	292.0	952.0	2208.0	5.110	7.550	1.239	0.216	5.013	0.940	14.70
T_8	0.400	0.161	350.9	1083.0	1611.0	0.670	9.320	1.282	0.216	4.990	0.673	13.67
T_9	0.300	0.137	206.1	1008.0	2029.0	1.550	5.990	1.282	0.206	4.963	0.650	12.64
T_{10}	0.330	0.155	209.8	1502.0	2626.0	2.220	12.880	1.282	0.238	5.746	1.143	16.58
Mean	0.366	0.165	293.3	1064.9	1504.0	2.176	7.426	1.154	0.215	4.979	0.818	14.58

For available Mg and pH, CD (0.05) values for comparison of treatments are 1397.6 and 0.505 respectively. Other treatment effects are not significant.

Table 37. Biometric observations and content of chlorophyll in banana leaves at the time of shooting (mean of three replications)

Treatment	Mean height of plants, cm	Mean girth of plants, cm	Total number of leaves (mean)	Chlorophyll, mg g^{-1} tissue		
				Total	Chlorophyll 'a'	Chlorophyll 'b'
T_1	293.6	67.33	34.05	1.449	0.711	0.739
T_2	335.8	77.19	33.58	1.644	0.951	0.694
T_3	328.7	67.58	33.72	1.099	0.666	0.434
T_4	318.4	65.19	33.69	1.365	0.809	0.556
T_5	332.2	67.72	33.72	0.956	0.655	0.635
T_6	320.8	64.75	32.25	1.079	0.669	0.411
T_7	319.8	65.08	34.08	1.393	0.672	0.724
T_8	330.8	66.58	34.41	1.410	0.844	0.565
T_9	331.7	67.55	33.11	1.456	0.862	0.565
T_{10}	328.8	68.31	33.58	1.200	0.744	0.525
Mean	324.1	67.73	33.62	1.305	0.758	0.585

The treatment effects are not significant

Table 38. Nutrient content of banana leaf at the time of shooting, per cent (mean of three replications)

Treatment	N	P	K	Ca	Mg
T_1	3.822	0.232	2.250	2.442	0.240
T_2	3.763	0.256	2.667	1.643	0.799
T_3	3.584	0.228	2.833	1.820	0.560
T_4	3.464	0.263	2.833	1.820	0.639
T_5	3.643	0.253	2.583	1.776	0.586
T_6	3.345	0.214	2.708	1.687	0.320
T_7	3.823	0.272	2.500	1.732	0.559
T_8	3.524	0.258	2.708	1.731	0.480
T_9	3.404	0.236	2.833	1.687	0.613
T_{10}	3.345	0.273	3.058	1.687	0.426
Mean	3.572	0.249	2.697	1.803	0.522

For Mg content in leaf, CD (0.05) for the comparison of treatments is 0.3820. Other treatment effects are not significant.

Table 39. Nutrient content in soil at the time of shooting (mean of three replications).

Treatment	Organic carbon, %	Total N, %	Available nutrients, kg ha^{-1}			Exchangeable cations, cmol(+) kg^{-1}				pH	EC, dS m^{-1}	CEC, cmol(+) kg^{-1}
			P	K	Mg	Mg	Ca	K	Na			
T_1	0.370	0.155	281.5	354.7	1313.0	0.670	6.660	0.812	0.226	5.136	0.341	16.07
T_2	0.390	0.120	315.1	392.0	2506.0	1.550	6.880	0.726	0.210	5.196	0.359	17.09
T_3	0.410	0.114	285.6	392.0	4508.0	1.550	8.440	0.641	0.228	5.310	0.364	14.70
T_4	0.370	0.120	288.9	336.0	1790.0	2.660	7.330	0.598	0.223	5.200	0.451	14.36
T_5	0.360	0.125	296.4	298.7	298.4	1.110	7.770	0.556	0.220	5.343	0.320	14.87
T_6	0.330	0.114	219.9	392.0	1313.0	1.110	6.440	0.726	0.212	5.303	0.247	16.07
T_7	0.440	0.131	390.1	466.7	716.0	1.330	8.210	0.812	0.225	5.283	0.373	16.92
T_8	0.520	0.114	256.8	336.0	1193.0	1.110	7.990	0.641	0.230	5.450	0.259	14.70
T_9	0.360	0.125	334.1	392.0	3521.0	1.110	8.210	0.834	0.222	5.603	0.255	13.84
T_{10}	0.390	0.137	296.0	448.0	656.4	1.330	7.770	0.812	0.222	5.356	0.268	12.99
Mean	0.394	0.126	296.4	380.8	1781.5	1.353	7.570	0.716	0.222	5.318	0.324	15.16

For exchangeable Mg and EC, the CD (0.05) for comparison of treatments are 0.888 and 0.108 respectively. For available Mg, CD (0.01) for comparison of treatment means is 2440.5. Other treatment effects are not significant.

Table 40. Biometric observations at the time of harvest (mean of three replications)

Treatment	Mean height of plants, cm	Mean girth of plants, cm	Total number of leaves (mean)	Total number of suckers (mean)	Days to flower	Days to mature	Total duration, days, (mean)
T_1	324.4	63.11	34.05	7.640	231.5	87.64	319.1
T_2	342.5	63.25	33.58	9.083	225.3	86.00	311.3
T_3	335.0	63.47	33.72	8.916	228.4	84.08	312.5
T_4	319.6	59.25	33.69	8.333	227.9	85.33	313.2
T_5	341.1	64.33	33.72	9.223	224.2	88.11	312.3
T_6	321.3	60.58	32.25	7.583	221.0	80.42	301.4
T_7	303.8	61.17	34.08	9.000	213.4	84.58	298.0
T_8	336.9	60.08	34.41	7.416	232.3	87.36	319.7
T_9	343.2	63.11	33.11	9.140	228.9	81.50	310.4
T_{10}	338.5	63.94	33.58	8.250	240.0	82.25	322.5
Mean	330.6	62.23	33.62	8.458	227.3	84.73	312.0

The treatment effects are not significant

may be due to the decreased translocation of nutrients to the vegetative parts at the time of flowering and maturity. This may also be viewed in the context of the positive correlations among vegetative characteristics and various nutrient levels in soil (Tables 48 and 49), which might have resulted from the decreased absorption of nutrients as the plants reached senescence.

No significant correlation was observed between the level of Mg in the index leaf and the vegetative characteristics.

A negative correlation was seen between days to flower and chlorophyll 'a' (r = -0.5792**), between days to flower and chlorophyll 'b' (r = -0.4805**) and also between days to flower and total chlorophyll (r = -0.5216**). These correlations may be indicative of the influence of chlorophyll in inducing early flowering nature of the plant which might be the consequence of increased photosynthesis.

2. Yield characteristics

The effect of treatments on various yield characteristics such as weight of bunch, length of bunch, number of hands per bunch, weight of finger, length and girth of finger is furnished in Table 41. The treatment effects were not significantly different. As already explained, the level of available Mg in the soil of the experiment site (179 kg ha^{-1}) may be sufficient to meet the

Table 41. Yield characteristics of banana at the time of harvest (mean of three replications)

Treatment	Mean weight of bunch, kg	Mean length of bunch, cm	Number of hands per bunch (mean)	Number of fingers per bunch (mean)	Mean weight of finger, g	Mean length of finger, cm	Mean girth of finger, cm
T_1	9.466	36.25	5.056	51.05	176.3	21.71	12.87
T_2	8.960	34.33	4.916	50.83	160.5	21.89	13.52
T_3	10.240	35.66	5.166	50.75	196.3	22.08	13.36
T_4	8.720	35.27	5.083	48.77	178.5	22.54	12.80
T_5	10.600	39.11	5.443	54.22	197.6	22.28	13.10
T_6	8.143	32.47	5.000	45.66	166.5	20.29	12.78
T_7	8.926	33.83	5.083	50.83	8 182.3	22.09	13.01
T_8	10.200	37.02	5.375	50.44	186.1	22.80	13.17
T_9	9.006	34.86	4.750	48.10	178.9	22.21	13.03
T_{10}	9.543	35.39	5.166	51.39	178.1	23.30	12.87
Mean	9.380	35.42	5.104	50.20	180.2	22.12	13.05

The treatment effects are not significant

Mg requirement of the crop. Probably, this may be the cause of the lack of yield response of the crop by the application of Mg.

Similar results of lack of significant increase in crop yield was reported earlier by George and Sreedharan (1966) and Kurup and Ramankutty (1969) in rice. Varughese (1992) and Muralidharan (1992) also did not obtain a positive response to applied Mg in rice grown in laterite soil of Kerala.

Weight of bunch correlated positively with girth (0.6939**), number of fingers per bunch (r = 0.7822**) and with weight of finger (r = 0.7008**). Weight of finger correlated positively with girth (r = 0.3862*) and with number of fingers per bunch (r = 0.4496*). These correlations are well understood because of the positive interrelationship of the yield characteristics. Calcium uptake by leaf was seen positively correlated with yield (0.3966*) indicating the influence of Ca in physiological processes of carbohydrate, protein and fat metabolism. It acts as a regulator of many enzymes. Positive correlations were also found between weight of finger and exchangeable Ca (r = 0.4288*) and between weight of finger and available K (r = 0.3910*). The exchangeable Ca in soil improves intake of Ca and other nutrients, especially N and trace elements by correcting soil pH. This might have led to the increased weight of fingers, inturn increasing yield. The essentiality of K in large quantities for the formation and transfer of starch and sugars is well known. This explains the positive correlation between available K and weight of finger. The per cent of N in leaf correlated negatively with the weight of finger (r = -0.3683*), possibly because of the translocation of N from the leaf to bunch.

B. Plant analysis

1. Leaf

1.1 Chlorophyll

The data on the total chlorophyll, chlorophyll 'a' and chlorophyll 'b' in the index leaf as influenced by the treatments at different growth stages are presented in Tables 31, 34, 37 and 42. The mean values at early vegetative stage were 1.268, 0.543 and 0.719 mg of total chlorophyll, chlorophyll 'a' and chlorophyll 'b' per g tissue respectively. The contents were reduced to 0.796, 0.310 and 0.481 mg g^{-1} tissue respectively at the late vegetative stage. This may be due to the increased use of chlorophyll at this rapid growth stage. At the time of shooting, the contents again increased to 1.305, 0.758 and 0.585 mg g^{-1} tissue of total chlorophyll, chlorophyll 'a' and chlorophyll 'b' respectively, probably because of the arrest of vegetative growth. The values were almost the same at the time of harvest (1.286, 0.710 and 0.586 mg g^{-1} tissue respectively). The treatments could not significantly affect the content of chlorophyll at any stage of growth.

Table 42. Nutrient and chlorophyll content of banana leaf at the time of harvest (mean of three replications)

Treatment	N%	P%	K%	Ca%	Mg%	Chlorophyll, mg g^{-1} tissue		
						Total	Chlorophyll 'a'	Chlorophyll 'b'
T_1	3.344	0.333	3.000	1.414	0.058	1.438	0.781	0.698
T_2	3.405	0.272	2.316	1.193	0.150	1.137	0.633	0.504
T_3	2.986	0.332	3.133	1.886	0.216	1.017	0.594	0.424
T_4	3.286	0.323	4.033	1.692	0.092	0.956	0.598	0.435
T_5	3.106	0.360	2.900	1.872	0.150	1.270	0.694	0.577
T_6	3.703	0.368	2.633	1.178	0.075	1.363	0.737	0.627
T_7	3.165	0.310	3.033	1.483	0.233	1.544	0.827	0.718
T_8	2.867	0.299	2.666	1.317	0.083	1.079	0.669	0.411
T_9	2.986	0.320	2.700	1.803	0.083	1.742	0.900	0.822
T_{10}	3.046	0.344	3.233	1.844	0.067	1.311	0.666	0.646
Mean	3.189	0.326	2.965	1.568	0.121	1.286	0.710	0.586

For K content in leaf, CD (0.01) for comparison of treatments is 0.7842. Other treatment effects are not significant.

Positive correlation was observed between total chlorophyll and chlorophyll 'a' and between total chlorophyll and chlorophyll 'b' at all stages of growth (Tables 46 to 49). Chlorophyll 'a' was found positively correlated with chlorophyll 'b' except at early vegetative stage (Tables 47, 48 and 49). These correlations are self explanatory as chlorophyll 'a' and 'b' form parts of total chlorophyll.

In the late vegetative stage, height of plants was seen positively correlated with total chlorophyll (r = 0.4235*), chlorophyll 'a' (r = 0.4646*) and with chlorophyll 'b' (r = 0.4621*). These correlations have been discussed before. This may be correlated with decrease in the mean values of the contents of chlorophyll pigments, at late vegetative stage. But, the increased contents of chlorophyll pigments at the time of shooting may be influenced by the positive correlations between total chlorophyll and total N in soil (r = 0.4390*) and between total chlorophyll and per cent Mg of leaf (r = 0.3616*). Nitrogen is an essential constituent of chlorophyll. Increase in total N in soil may cause an increased absorption of this nutrient. Magnesium also is an essential constituent of chlorophyll. In addition, Mg helps in the biosynthesis of pigments. Thus an increase in Mg content of leaf increases the total chlorophyll content. This is in line with the observation of Panak and Wojnowska (1977), Ananthanarayana and Rao (1980) and Kiss (1981).

The negative relationships of the days to flower with total chlorophyll ($r = -0.5216^{**}$), chlorophyll 'a' ($r = -0.5792^{**}$) and with chlorophyll 'b' ($r = -0.4805^{**}$) have already been discussed. The P content of leaf was found negatively correlated with chlorophyll 'b' ($r = -0.3841^{*}$) and with chlorophyll 'a' ($r = -0.3662^{*}$) at late vegetative stage. This may be the consequence of the characteristic of P in stimulation of flowering. The uptake of Ca by the finger at the time of harvest was found negatively correlated with total chlorophyll ($r = -0.4000^{*}$) and chlorophyll 'a' ($r = -0.3985^{*}$). This may be correlated with the role of Ca in carbohydrate metabolism. An increase in Ca uptake by finger may have stimulated an increased utilisation of chlorophyll in leaves.

1.2 Nitrogen

Results on the effect of various treatments of applied Mg on N per cent in leaf at different growth stages are presented in Tables 32, 35, 38 and 42. The N content of leaf at various stages did not vary considerably. The influence of the treatments within each stage was also not significant.

The uptake of N at harvest varied from 97.71 to 145.53 g plant^{-1}. The average uptake was 119.27 g plant^{-1} (Table 43).

In the late vegetative stage, N content of leaf was positively correlated with P content of leaf ($r = 0.6081^{**}$) and

Table 43. Uptake of nutrients by banana leaves at the time of harvest (mean of three replications), g plant^{-1}

Treatment	N	P	K	Ca	Mg
T_1	128.41	12.79	115.20	55.68	2.243
T_2	145.53	11.61	98.99	51.45	6.452
T_3	119.44	13.28	125.32	75.55	8.745
T_4	114.77	11.28	140.87	57.47	3.426
T_5	119.71	13.88	111.77	72.30	5.864
T_6	105.42	10.47	74.96	32.30	2.044
T_7	123.97	12.15	118.80	58.29	8.924
T_8	97.71	10.18	90.86	44.86	2.849
T_9	117.47	12.60	106.22	68.36	3.635
T_{10}	120.29	13.56	127.67	73.14	2.390
Mean	119.27	12.18	111.07	58.94	4.657

exchangeable K (r = 0.3638*) indicating synergism between N and P and increased uptake of N in the presence of K. A positive NP and NK interaction in plants is a usual phenomenon since the increased growth due to application of N invariably necessitated enhanced absorption and utilization of P and K.

Negative correlation was observed between content of N in leaf and height (r = -0.4106*) and with weight of finger (r= -0.3683*) which have been discussed earlier. The increased rate of growth as shown by the height of plants would have caused a reduction of the nitrogen content of the leaf. The transportation of nitrogen to the developing fingers would also cause a decrease in N in leaf.

1.3 Phosphorus

Data on the influence of different treatments on per cent of phosphorus in leaf are presented in Tables 32, 35, 38 and 42. The mean P per cent at various stages are 0.337, 0.346, 0.249 and 0.326 respectively at early vegetative stage, late vegetative stage, at the time of shooting and at the time of harvest. There was a decrease in the level of P in leaf at the time of shooting, probably due to the use of P by the inflorescence. The P per cent in leaf within each stage was independent of the treatment effects. The average P uptake at harvest was 12.18 g plant^{-1}. It ranged from 10.18 to 13.88 g plant^{-1} between treatments (Table 43).

The P content of leaf was found positively correlated with exchangeable Ca at early vegetative stage (r = 0.5202**), in the late vegetative stage (r = 0.4064*), at the time of shooting (r = 0.3545*) and also at the time of harvest (r = 0.3965*). This may be due to the correction of soil pH caused by an increase in exchangeable Ca, leading to increased P uptake at near neutral pH. This is further proved by the positive correlation between pH and P content of leaf (r = 0.4688**) at early vegetative stage. This influence of pH can also explain the correlation between P content of leaf and exchangeable Na (r = 0.5332**), at the time of harvest.

Negative correlation was observed between P content of leaf and height of plants (r = -0.6468**) and between P content of leaf and girth of plants (r = -0.6737**) at early vegetative stage. In the late vegetative stage, N content of leaf was found positively correlated with P content of leaf (r = 0.6081**). At the time of shooting and harvest P per cent in leaf was found positively correlated with vegetative characters (Tables 48 and 49).

1.4 Potassium

Influence of the treatments on K content of leaf is given in Tables 32, 35, 38 and 42, at different stages of growth. The K content of leaf did not vary considerably in early and late vegetative stages whereas the content decreased considerably at the time of shooting and harvest (5.727, 5.254, 2.697 and 2.965 per cent respectively). This may be due to the translocation of nutrients from leaf to fingers with the onset of flowering.

The treatments did not differ significantly in their influence on the content of K at early and late vegetative stages and at the time of shooting. But at the time of harvest the K content of leaf varied significantly. The maximum content of K was seen in treatment with highest level of MgO in the form of magnesium sulphate and the minimum in treatment with lowest level of MgO in the form of magnesium sulphate. There was no significant variation in the content of K in plants treated with different sources. At the time of harvest, the uptake values of K registered by different treatments ranged from 74.96 to 140.87 g plant^{-1}, the mean being 111.07 g plant^{-1} (Table 43).

The leaf content of K was found positively correlated with available P in soil (r = 0.4029*) at early vegetative stage. This may be indicative of the role of P in increasing K uptake.

In the late vegetative stage, the K content of leaf was negatively correlated with Mg content of leaf (r = -0.3957*). This antagonism between K and Mg in plant has been observed by several workers. Potassium content of leaf was found positively correlated with organic carbon (r = 0.3682*). With the increase in organic carbon, the CEC may be increased so that the increase in K content may be expected.

At the time of shooting a negative correlation between K content of leaf and Ca content of leaf (r = -0.4868**) was observed showing antagonism between K and Ca. The K content of leaf was negatively correlated with total number of leaves (r= -0.4125*) at this stage. This may be due to the dilution effect.

1.5 Calcium

Calcium content of leaf as influenced by various treatments at the different stages of growth is presented in Tables 32, 35, 38 and 42. The overall mean of content of Ca varied at different stages (0.540, 1.268, 1.803 and 1.568 per cent respectively at early vegetative stage, late vegetative stage, at the time of shooting and at the time of harvest respectively). The Ca uptake at harvest ranged from 32.3 to 73.14 g plant^{-1}, the mean being 58.94 g plant^{-1} (Table 43).

In the early vegetative stage the treatments differed significantly in the Ca content of leaf. Among the sources, the effect of magnesium sulphate differed from other treatments. Antagonism between Ca and Mg was confirmed by the negative correlation between Ca content of leaf and Mg content of leaf (r= -0.4909**) and also between Ca content of leaf and exchangeable

Mg (r = -0.5687**) at early vegetative stage. Negative correlation between Ca and Mg content of leaf was also observed in the late vegetative stage and shooting (Tables 47 and 48). Antagonism between K and Ca was indicated by the negative correlation between K and Ca content in leaf at the time of shooting and harvest (Tables 48 and 49). The Ca content of leaf was positively correlated with CEC (r = 0.3642*). This may be due to the increase in exchangeable Ca in soil caused by an increase in CEC which is inturn reflected in the increased Ca content of leaf.

Data on the effect of uptake of Ca by leaves at the time of harvest are given in Table 43. The analysis of variance of the data showed that the treatments differed significantly in their influence on the uptake of Ca by leaves. The treatments did not differ significantly between the sources. Within the sources, significant difference between levels was observed only in the case of magnesite. The uptake of Ca was found to be maximum in the lowest level of MgO (500 g MgO plant^{-1}) in the form of magnesite. At higher levels of magnesite, Ca uptake reduced.

Uptake of Ca by leaves correlated positively with height of the plants (r = 0.4374*), girth of the plants (r = 0.4244*), weight of bunches (r = 0.3966*) and number of fingers per bunch (r = 0.4097*). This explains the importance of Ca in banana nutrition. The positive correlation between Ca content of leaf and uptake of Ca by leaves is obvious (r = 0.8386**).

1.6 Magnesium

Effect of various treatments on Mg content of leaf at different growth stages is given in Tables 32, 35, 38 and 42. The content of Mg in leaves was found to decrease from 1.088 to 0.121 per cent at the time of harvest. The values at the time of late vegetative stage and shooting are 0.583 and 0.522 respectively. The decrease in content with advancing growth of the plant may be due to the utilisation of Mg for vegetative as well as reproductive growth of the plant. At the time of harvest the plants in different plots registered an average uptake of 2.04 to 8.92 g Mg plant^{-1}, the overall mean being 4.657 g plant^{-1}.

The analysis of variance of the data showed that the Mg content of leaf was decisively influenced by the treatments at the late vegetative stage and at the time of shooting. At late vegetative stage the maximum content of Mg (0.701 per cent) was in T_2 (500 g MgO plant^{-1} in the form of magnesium sulphate) and the minimum (0.258 per cent) was in T_1 (control). The significant difference between treatments was only between the control (no magnesium) and the rest of the treatments. The treatments except T_1 (control) were on par.

At the time of shooting also, the treatments differed significantly in their effect on Mg content of leaf. Here also the maximum content (0.791 per cent) was observed in T_2 (500 g MgO plant^{-1} in the form of magnesium sulphate) and the minimum (0.24

per cent) in T_1 (control). The increase in content of Mg between treatments was not in a regular manner with increasing level of MgO. No significant difference was observed among the sources but the content of Mg in control was significantly lower than that of the rest of the treatments.

The different sources showed no significant variation in the release of Mg for plant availability. This may lead to the conclusion that any source of Mg is as good as the other so that the cheapest one can be used. The level of MgO can also be kept to the lowest, as the increased levels could not make any significant difference in the content of Mg within the source.

A negative correlation between Mg and Ca contents of leaf was observed in all stages of growth (Tables 46 to 49) exhibiting Ca-Mg antagonism in plant. This is in line with the observation of Varughese (1992) and several other workers.

In the late vegetative stage, antagonism between Mg and K in leaf was exhibited by the negative correlation of leaf Mg content with K content of leaf ($r = -0.3957^*$). A positive correlation of Mg content in leaf and CEC was observed ($r = 0.3665^*$) indicating an increased uptake of Mg by the plant when the exchangeable Mg in soil was increased with increase in CEC.

At the time of shooting, the Mg content of leaf was positively correlated with total chlorophyll content ($r = 0.3616^*$).

Table 44. Nutrient content in soil at the time of harvest (mean of three replications)

Treatment	Organic carbon, %	Total N, %	Available nutrients, kg ha^{-1}			Exchangeable cations, cmol(+) kg^{-1}				pH	EC, dS m^{-1}	CEC, cmol(+) kg^{-1}
			P	K	Mg	Mg	Ca	K	Na			
T_1	0.550	0.102	151.4	255.1	3521	0.890	5.110	0.321	0.116	5.26	0.075	15.55
T_2	0.220	0.108	182.9	298.7	4118	1.330	5.550	0.342	0.107	5.42	0.092	15.73
T_3	0.240	0.125	169.9	320.4	4356	1.550	5.790	0.363	0.115	5.39	0.141	14.69
T_4	0.470	0.137	172.5	292.4	4296	1.560	5.530	0.449	0.106	5.29	0.119	17.43
T_5	0.330	0.125	240.4	283.1	3998	0.670	6.000	0.342	0.107	5.44	0.065	16.58
T_6	0.220	0.114	208.3	286.2	1909	0.890	5.110	0.385	0.129	5.50	0.097	15.38
T_7	0.520	0.383	216.2	289.3	5192	2.000	4.880	0.342	0.107	5.50	0.051	17.61
T_8	0.950	0.581	216.5	323.5	3282	2.220	4.660	0.385	0.109	5.50	0.069	16.58
T_9	0.340	0.114	177.7	323.6	4655	1.550	5.110	0.427	0.103	5.58	0.071	16.06
T_{10}	0.490	0.102	127.8	273.8	2387	2.220	5.550	0.321	0.113	5.61	0.082	17.09
Mean	0.433	0.189	186.4	294.6	3771	1.488	5.329	0.368	0.111	5.45	0.086	16.27

The treatment effects are not significant

This is in line with the observations of Panak and Wojnowska (1977), Ananthanarayana and Rao (1980) and Kiss (1981).

At the time of harvest the Mg content in leaf positively correlated with the uptake of Mg by leaf (r = 0.9766**). This relationship is self explanatory. It was also found positively correlated with Mg uptake by finger (r = 0.4059*) and with total Mg uptake (r = 0.8597**). A part of the Mg content in leaf may be translocated to finger and its content might have thus increased. The content of Mg in leaf may contribute a major part of total Mg uptake by the plant.

Results on the effect of various treatments on the uptake of Mg by leaves at the time of harvest are presented in Table 43. The treatments did not differ significantly in their effect on uptake of Mg by leaves.

The uptake of Mg by leaves was seen correlated with Mg content of leaf (r = 0.9766**). It also correlated positively with Mg uptake by finger (r = 0.4288*) and with total Mg uptake (r = 0.8780**), as these parameters are inter-related.

2. Uptake and distribution of Ca and Mg by different plant parts

Data on the influence of different treatments on the per cent and uptake of Ca and Mg by different plant parts at the time of harvest are furnished in Table 45. The treatments did not

Table 45. Percentage and uptake of Ca and Mg by different plant parts of banana and total uptake at the time of harvest (mean of three replications)

Treatment	Percentage in rhizome		Uptake by rhizome, g $plant^{-1}$		Percentage in psuedostem		Uptake by psuedostem, g $plant^{-1}$	
	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg
T_1	0.333	0.100	3.449	1.207	0.291	0.125	3.534	1.199
T_2	0.250	0.233	2.946	2.629	0.250	0.216	2.494	2.128
T_3	0.264	0.208	1.930	1.331	0.264	0.233	2.463	2.197
T_4	0.389	0.200	2.284	1.065	0.555	0.200	4.215	1.410
T_5	0.458	0.184	4.457	1.743	0.291	0.075	3.083	0.780
T_6	0.305	0.133	2.749	1.806	0.333	0.117	3.161	1.083
T_7	0.333	0.325	2.557	3.128	0.361	0.141	3.052	1.418
T_8	0.291	0.125	1.868	0.893	0.333	0.067	3.398	1.626
T_9	0.319	0.075	2.537	0.584	0.319	0.108	3.735	1.274
T_{10}	0.416	0.142	3.705	1.216	0.292	0.092	2.808	0.863
Mean	0.336	0.173	2.848	1.560	0.329	0.137	3.194	1.398

Treatment effects are not significant

Contd.

Table 45 Continued

Treatment	Percentage in finger		Uptake by finger g plant^{-1}		Percentage in leaf		Uptake by leaf g plant^{-1}		Total uptake g plant^{-1}	
	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg
T_1	0.125	0.058	3.671	1.785	1.414	0.058	55.68	2.243	66.33	6.434
T_2	0.138	0.050	3.791	1.396	1.193	0.150	51.45	6.452	60.68	12.610
T_3	0.097	0.067	3.007	2.261	1.886	0.216	75.55	8.745	82.95	14.710
T_4	0.139	0.058	3.759	1.560	1.692	0.092	57.47	3.426	67.73	7.462
T_5	0.111	0.033	3.745	1.200	1.872	0.150	72.30	5.864	83.59	9.496
T_6	0.125	0.050	3.310	1.150	1.178	0.075	32.30	2.044	41.52	5.903
T_7	0.138	0.092	3.976	2.564	1.483	0.233	58.29	8.924	67.88	16.040
T_8	0.125	0.025	3.774	0.746	1.317	0.083	44.86	2.849	53.90	6.114
T_9	0.097	0.025	2.708	0.690	1.803	0.083	68.36	3.635	77.34	6.182
T_{10}	0.139	0.050	4.017	1.396	1.844	0.067	73.14	2.390	83.67	5.864
Mean	0.123	0.051	3.576	1.475	1.568	0.121	58.94	4.657	68.56	9.082

For uptake of Ca by leaves, CD (0.05) for comparison of treatments is 25.4979 and for total Mg uptake, CD (0.01) is 8.1902.

differ significantly except in the case of total uptake of Mg.

Of the total Ca uptake, 85 per cent was observed in leaves. The rest was distributed as 5 per cent in the rhizome, 5 per cent in the psuedostem and 5 per cent in the fingers. The contribution of Mg uptake by leaves was 51.3 per cent. About 17.2 per cent was contributed by rhizome, 15.3 per cent by psuedostem and 16.2 per cent by fingers.

Mean value of the total uptake of Ca was 68.56 g plant^{-1} and that of Mg was 9.082 g plant^{-1}. The average Mg uptake by the rhizome, psuedostem, fingers and leaves were 1.56, 1.398, 1.475 and 4.657 g plant^{-1} respectively.

The uptakes of Ca and Mg by different plant parts were found positively correlated with their respective per cent in the plant part (Table 49). This is obvious because the uptake increases as the per cent of nutrient increases at a constant dry matter production.

The per cent of Ca and uptake in one plant part was found positively correlated with per cent and uptake of Ca in other plant parts (Table 49). Similarly, positive correlations were observed between Mg per cent in one part of the plant with the per cent Mg and uptake of other plant parts (Table 49).

The Ca and Mg per cent and uptake in different parts of the plant showed negative correlations (Table 49) indicating antagonism between Ca and Mg.

The total uptake of Mg was significantly influenced by the treatments. The lowest uptake (5.864 g plant^{-1}) was in the treatment with 1500 g MgO given as dolomite and the maximum (16.04 g plant^{-1}) in the treatment with 1500 g MgO as magnesite. The lowest uptake in the treatment with dolomite may be due to its lower solubility compared to magnesite. Though magnesium sulphate is highly soluble compared to magnesite and dolomite, a considerable amount of Mg in the soluble form might have been lost by leaching, since the location of the experiment site enjoys a typical tropical climate. Magnesite, being slowly soluble in acid conditions, releases Mg so that a good amount of it can be taken up by the plant, making the released Mg less susceptible to leaching. Thus the total Mg uptake from treatment with magnesite at the highest level of MgO might have reached the highest compared to other treatments.

There was significant difference between the effect of sources on uptake of Mg. While comparing the mean total uptake of Mg among different sources, the uptake was highest in the treatments with magnesium sulphate closely followed by treatments with magnesite. Only the treatments with dolomite differed significantly, showing lower uptake. This shows that on comparing the different sources of Mg, magnesite in acid soil is as good as magnesium sulphate.

Within the sources, the levels of Mg had significant influence on the total uptake of Mg, only in the case of magnesite. The uptake was maximum in the highest level of MgO (1500 g MgO $plant^{-1}$).

The total Mg uptake correlated positively with Mg content of leaf (r = 0.8597**), rhizome (r = 0.4435*), psuedostem (r = 0.4557*), finger (r = 0.5266**), uptake of Mg by rhizome (r = 0.4580*), psuedostem (r = 0.4275*), finger (r = 0.5995**) and with uptake of Mg by leaf (r = 0.8780**), showing the contribution of Mg content and uptake by different plant parts to total Mg uptake.

C. Soil analysis

1. Organic carbon

Influence of various treatments on organic carbon content of soil is presented in Tables 33, 36, 39 and 44 at different growth stages of banana. The mean values at different stages ranged from 0.394 to 0.461 per cent. The treatments could not decisively influence the organic carbon content of soil.

Positive correlation between organic carbon and K content of leaf (r = 0.3682*) and between organic carbon and available

P (r = 0.5473**) were observed at late vegetative stage. The increased organic carbon increases the availability of nutrients by way of decomposition and mineralisation, thus causing an increased K uptake and higher available P content of soil.

At the time of harvest, organic carbon was positively correlated with CEC (r = 0.3872*) and with exchangeable Mg (r= 0.4116*). Organic matter increases the CEC of soil and thus increases the retention of exchangeable cations.

2. Total N in soil

Effect of various treatments on the total N content in soil is given in Tables 33, 36, 39 and 44. The overall mean values of total N at early vegetative stage, late vegetative stage, at the time of shooting and harvest were 0.165, 0.165, 0.126 and 0.189 per cent respectively. Statistical analysis of the data at each stage of growth showed that the treatments did not differ significantly.

A negative correlation was observed between the total N in soil and N content of leaf (r = -0.4292*) at late vegetative stage. This may be due to the reduction in total N in soil as a result of uptake of N by leaves.

At the time of shooting, total N in soil positively correlated with total chlorophyll (r = 0.4390*) and with chlorophyll 'b' (r = 0.4498*). Nitrogen being an essential constituent of chlorophyll, the increased availability of N in soil might have caused an increased uptake of N and an increased production of chlorophyll pigments.

3. Available P

Data on the influence of treatments on available P are furnished in Table 33, 36, 39 and 44. The mean values at different stages ranged from 186.4 to 296.4 kg ha^{-1} and no significant difference between treatments was observed at any stage of growth.

In the late vegetative stage, organic carbon correlated positively with available P (r = 0.5473**). Decomposition of organic matter results in an increase in available P of the soil.

At the time of shooting, positive correlation was observed between available P and P content of leaf (r = 0.5540**). Available P also correlated with total number of leaves (r = 0.3984*). At the time of harvest, positive correlation was observed between available P and height of plants (r = 0.4207*). This shows the influence of P in vegetative growth of the plant.

At the time of harvest positive correlation was observed between available P and pH (r = 0.3624*). The increase in pH to near neutrality increases the available P content of soil.

4. Available K

The data on available K in soil as influenced by the treatments are presented in Tables 33, 36, 39 and 44. The available K ranged from 294.6 to 1065 kg ha^{-1}. The conspicuous increase in available K at late vegetative stage may be due to the application of K fertilizer at the fourth month.

In the early vegetative stage available K correlated positively with exchangeable K (r = 0.879**).

When more K^+ ions are in the available form, a part of them will go to exchange sites and vice versa. This is because, the available K is in equilibrium with exchangeable K in soil. The correlation between available K and exchangeable K was also observed at the time of shooting (r = 0.7059**) and at the time of harvest (r = 0.5144**).

Height of the plants was significantly correlated with available K (r = 0.4523*). This explains the role of K in the growth of plant which is again supported by the positive correlation between available K and weight of finger (r = 0.3910*) emphasising the role of K in banana nutrition.

Positive correlation was also observed between available K and pH (r = 0.4724**). The increase in soil pH to near neutrality causes better availability of K.

5. Available Mg

Effect of various treatments on available Mg in soil is furnished in Tables 33, 36, 39 and 44. The available Mg in soil first decreased till the late vegetative stage and then increased up to the stage of harvest. This decrease may be due to the higher utilisation of Mg in the vegetative stage and increase may be due to release of Mg from insoluble sources.

The statistical analysis of the data showed that the available Mg in soil was decisively influenced by the treatments at early vegetative stage, late vegetative stage and at the time of shooting.

In the early vegetative stage, the minimum amount of available Mg (417.7 kg ha^{-1}) was observed in T_1 (control) and the maximum (5072 kg ha^{-1}) in T_4 (1500 g MgO as magnesium sulphate). This is obvious since magnesium sulphate ranks first in solubility in the order of magnesium sulphate, magnesite and dolomite (Lindsay, 1979). The available Mg in soil in the absence of added Mg was significantly lower than that in the rest of the treatments.

While comparing the difference between treatments with the three sources, the treatments with magnesite and dolomite were on par. The treatments with dolomite and magnesium sulphate were also on par, while the treatments with magnesite and magnesium sulphate differed significantly.

The levels within the source could influence the amount of available Mg only in the case of magnesium sulphate. The maximum amount (5072 kg ha^{-1}) was seen in T_4 (1500 g MgO plant^{-1} as magnesium sulphate), and the minimum (2267 kg ha^{-1}) in T_2 (500 g MgO plant^{-1} as magnesium sulphate). The amount of available Mg increased with increasing level of MgO. In the case of magnesium sulphate, the average Mg in soil increased with increasing level of application. Such a decisive influence of level of MgO was not shown at this stage in the case of dolomite and magnesite applications because of their insoluble nature. The release of Mg from these sources is expected only at a very slow rate.

In the late vegetative stage, the treatments differed significantly in the amount of available Mg in control (no added Mg) from the rest of the treatments. The lowest amount was in control (238.7 kg ha^{-1}) and the highest in the treatment of 1500 g of MgO given as dolomite (2626 kg ha^{-1}). No significant difference was observed between treatments in various sources or levels within sources.

At the time of shooting, the treatments had highly significant influence on available Mg in soil. The lowest amount (298.4 kg ha^{-1}) was seen in T_5 (500 g MgO plant^{-1} as magnesite) and the highest (4508 kg ha^{-1}) in T_3 (1000 g MgO plant^{-1} as magnesium sulphate). A relatively higher level of available Mg is expected in plots receiving the highest level of Mg application as magnesium sulphate due to the high solubility of this source as compared to other sources.

There was significant difference between the treatments with different sources. The treatments of magnesite showed minimum amount of available Mg (775.7 kg ha^{-1}) whereas the treatments of magnesium sulphate showed the highest amount (2784.6 kg ha^{-1}). The treatments with magnesite and dolomite formed a group and the treatments with dolomite and magnesium sulphate were on par. But the treatments with magnesite and magnesium sulphate differed significantly.

No significant difference was observed in the available Mg content due to the difference in level of MgO applied within a source. It is probable that the removal of available Mg from the soil due to crop growth would have restricted the possible difference in available Mg due to different levels of application.

In the early vegetative stage, available Mg correlated positively with EC (r = 0.3988*). This is obvious from the fact that soluble salts increase salinity and thus the specific conductance of the soil.

6. Exchangeable Mg

Data on the influence of treatments on exchangeable Mg are given in Tables 33, 36, 39 and 44. In general, exchangeable Mg decreased according to the growth of the crop. This may be the outcome of increased use of Mg with advancing plant growth.

The treatments could significantly influence the exchangeable Mg in soil only at the early vegetative stage and at the time of shooting. The minimum amount of exchangeable Mg (0.67 cmol(+) kg^{-1}) was registered in T_1 (control) and the maximum (7.10 cmol(+) kg^{-1}) in T_4 (1500 g MgO $plant^{-1}$ as magnesium sulphate). This might have resulted from the increased solubility of magnesium sulphate. As the number of Mg^{++} ions in soil solution increases, the number reaching the exchange site also increases to keep the equilibrium between exchangeable Mg and soil solution Mg.

There was significant difference between sources. Magnesium sulphate registered the maximum value (5.55 cmol(+) kg^{-1}), and differed significantly from others. The minimum value (1.407 cmol(+) kg^{-1}) was registered by magnesite. The treatments of magnesite and dolomite were on par. This can again be attributed to the higher solubility of magnesium sulphate.

The exchangeable Mg in the control differed significantly from that of the rest of the treatments, showing that the added levels of Mg are sufficient to cause significant difference in exchangeable Mg content of soil.

Within the treatments with magnesium sulphate, the exchangeable Mg increased with increasing levels of MgO.

At the time of shooting, the treatments differed significantly in their influence on exchangeable Mg. The minimum amount of exchangeable Mg (0.67 cmol(+) kg^{-1}) was seen in treatment with no added Mg (T_1) and the maximum amount (2.66 cmol(+) kg^{-1}) in the treatment with 1500 g MgO plant^{-1} given as magnesium sulphate.

Exchangeable Mg was found positively correlated with available Mg (r = 0.5593**), EC (r = 0.618**) and with CEC (r= 0.4064*) at early vegetative stage. Soils with greater CEC are found to have more exchangeable Mg as more exchange sites are occupied by Mg ions. Exchangeable Mg was seen negatively correlated with Ca in leaf (r = -0.5687**) and with exchangeable Ca (r = -0.4015*) showing antagonism between Ca and Mg.

Positive correlation between exchangeable Mg and EC was observed in the late vegetative stage (r = 0.4368*) and at the time of shooting (r = 0.4168*).

At the time of harvest organic carbon and exchangeable Mg were significantly correlated (r = 0.4116*). This is evidently due to the ability of organic matter in retaining exchangeable cations.

7. Exchangeable Ca

Effect of treatments on exchangeable Ca is furnished in Tables 33, 36, 39 and 44. The exchangeable Ca content of soil in general, decreased with advancing stages of plant growth.

The treatments differed significantly in their influence on exchangeable Ca in the early vegetative stage. The treatment T_4 (1500 g MgO plant^{-1} as magnesium sulphate) showed the minimum amount of exchangeable Ca (5.1 cmol(+) kg^{-1}). This could be attributed to the antagonism between Ca and Mg since the maximum amount of exchangeable Mg was observed under this treatment. The maximum amount (13.99 cmol(+) kg^{-1}) was seen in T_{10} (1500 g MgO plant^{-1} as dolomite). This may be because of the higher Ca content of dolomite itself.

There was significant difference between sources in their influence on exchangeable Ca. Treatments with dolomite exhibited the maximum amount (10.952 cmol(+) kg^{-1}) due to the presence of Ca in dolomite and the minimum was in treatments with magnesium sulphate. Within the treatments with dolomite, there was significant difference among levels of MgO. When the levels of MgO increased, the exchangeable Ca also increased and the maximum was in T_{10} (1500 g MgO plant^{-1} as dolomite) and the minimum in T_8 (500 g MgO as dolomite). This is due to the increased addition of Ca through dolomite at higher levels.

Exchangeable Ca was found negatively correlated with height of plants, girth of plants and total number of leaves in the early and late vegetative stages (Tables 46 and 47). This indicates the utilisation of Ca in the vegetative growth.

Antagonism between Ca and Mg was exhibited by the negative correlation between exchangeable Ca and exchangeable Mg (r = -0.4015*) in the early vegetative stage.

At the time of harvest, exchangeable Ca was found positively correlated with height of plants (r = 0.4537*), girth (r = 0.5053**) and weight of finger (r = 0.4288*). This may be due to the decreased absorption of Ca during the stage of harvest.

Exchangeable Ca and pH were found positively correlated at all growth stages (Tables 46 to 49). This emphasises the role of Ca in increasing pH by way of increasing base saturation. Exchangeable calcium correlated positively with available K, exchangeable K and exchangeable Na at late vegetative stage and at the time of harvest (Tables 47 and 49). This may be attributed to the increase in pH caused by an increase in exchangeable Ca. Exchangeable Ca was found positively correlated with EC at late vegetative stage (r = 0.4751*) and also at harvest (r = 0.5418**). An increase in exchangeable Ca will contribute more number of Ca^{++} ions into soil solution to maintain the equilibrium between the ions in exchange sites and in soil solution. More number of ions in soil solution increase the specific conductance.

8. Exchangeable K

Results on the influence of treatments on exchangeable K are furnished in Tables 33, 36, 39 and 44. The mean value of exchangeable K increased in the late vegetative stage and then decreased till harvest. The increase in this stage may be due to the second dose of fertilizer application. The treatments could not decisively influence the content of exchangeable K in soil at any stage of growth.

Exchangeable K correlated positively with available K in early vegetative stage (r = 0.879**), at the time of shooting (r = 0.7059**) and also at harvest (r = 0.5144**).

In the late vegetative stage negative correlation was observed between exchangeable K and height of plants (r = -0.7503**), girth of plants (r = -0.6687**), total number of leaves (r = -0.6094**), total chlorophyll (r = -0.4395*), chlorophyll 'a' (r = -0.5091**) and with chlorophyll 'b' (r = -0.4855**). The essentiality of potassium in vegetative growth is stressed by these correlations. As K helps in the formation of chlorophyll, its increased use with increase in chlorophyll contents causes a decrease in its level in soil.

Positive correlation was observed between exchangeable K and exchangeable Ca (r = 0.6908**), N content of leaf (r = 0.3638*), exchangeable Na (r = 0.5881**), pH (r = 0.6181**) and

EC (r = 0.6303**) at late vegetative stage. Nitrogen uptake was found to increase in the presence of K exhibiting synergism between the two. An increase in exchangeable K causes an increase in base saturation leading to increased pH. The reserve K in exchange site may come into solution increasing the salinity and specific conductance. The correlation between exchangeable K and pH may inturn cause more Ca ions from soil solution to come to exchange sites, causing an increase in exchangeable Ca with increase in exchangeable K. Exchangeable Na may also be increased in a similar way.

9. Exchangeable Na

Influence of various treatments on exchangeable Na is given in Tables 33, 36, 39 and 44. The overall mean values of exchangeable Na at different growth stages showed that there was no considerable variation in the values except for a reduction at the time of harvest. The treatments could not decisively influence exchangeable Na content within the stages.

Exchangeable Na was found positively correlated with exchangeable Ca, in the early vegetative stage (r = 0.4543*), in the late vegetative stage (r = 0.6913**) and at the time of harvest (r = 0.3655*), probably due to the effect of exchangeable Na in increasing pH.

A positive correlation was observed between exchangeable Na and pH in the early vegetative stage (r = 0.4254*) and in the late vegetative stage (r = 0.6273**). The Na in the exchange site increases pH as it replaces H^+ ion and the Na^+ ions on hydrolysis yield OH^- ions.

10. pH

Effect of different treatments on pH of the soil is presented in Tables 33, 36, 39 and 44. The pH at different stages did not vary considerably.

The treatments differed conspicuously in their influence on pH at early vegetative stage and at late vegetative stage.

At the first stage, the lowest pH (4.73) was exhibited in T_4 (1500 g MgO plant^{-1} as magnesium sulphate) and the highest (6.04) in T_{10} (1500 g MgO as dolomite). In general, the treatments with magnesium sulphate showed lower pH. This is because of the fact that magnesium sulphate on hydrolysis yields SO_4^{--} ions which leads to the formation of H_2SO_4. The pH of the control plot (no added Mg) was on par with these treatments. This is because of original lower pH of the soil. The treatments with magnesite increased the pH of soil but were on par with the treatments with magnesium sulphate on statistical analysis. Only the treatment T_{10} (1500 g MgO plant^{-1} as dolomite) showed significant increase in pH. This might have resulted from the increase in the exchangeable Ca.

There was significant difference in the influence of sources on pH. The treatments with magnesium sulphate showed lowest pH whereas treatments with magnesite and dolomite showed higher pH. The pH was maximum in the case of dolomite. Magnesite being magnesium carbonate on solubilisation yields CO_2 and forms H_2CO_3 which is a weak acid. But magnesium sulphate yields SO_4^{--} ions leading to formation of H_2SO_4 which is a strong acid. So the pH in treatments with magnesite is higher than that in treatments with magnesium sulphate. Dolomite which is a double carbonate of Ca and Mg, supplies Ca^{++} ions in addition to the Mg^{++} ions to the exchange site of the soil. So the pH is maximum in plots treated with dolomite. This is further evidenced by the positive correlation between pH and exchangeable Ca at various stages of growth.

Within the source, significant increase in pH was observed at the highest level of MgO (1500 g MgO plant^{-1} as dolomite).

In the late vegetative stage, lowest pH was observed in T_3 (1000 g MgO plant^{-1} as magnesium sulphate) and the highest in T_{10} (1500 g MgO plant^{-1} as dolomite).

Significant difference between sources was observed in their influence on pH of soil. As in the previous stage, lowest pH was exhibited by treatments with magnesium sulphate and the highest by treatments with dolomite. The treatments with magnesite and dolomite were on par, but the treatments with magnesium sulphate differed significantly from them.

The pH was positively correlated with exchangeable Ca at early vegetative stage ($r = 0.7813^{**}$), at late vegetative stage ($r = 0.7587^{**}$), at the time of shooting ($r = 0.5237^{**}$) and at the time of harvest ($r = 0.5564^{**}$). Exchangeable Na was found positively correlated with pH at early vegetative stage ($r = 0.4254^{**}$) and at late vegetative stage ($r = 0.6273^{**}$). The pH was found positively correlated with exchangeable K at late vegetative stage ($r = 0.6181^{**}$) and with available K ($r = 0.4724^{**}$) at the time of harvest. These cations increase base saturation leading to increased pH thus explaining these correlations.

Positive correlation between P content of leaf and pH at early vegetative stage ($r = 0.4688^{**}$) shows the increased P utilisation by the crop at near neutral pH. The correlation between available P and pH at the time of harvest ($r = 0.3624^{*}$) also supports increased availability of P at near neutral pH.

pH and EC correlated negatively at the time of shooting ($r = -0.3837^{*}$). The negative correlation may be due to the fact that at low pH the Fe and Al compounds in the soil get solubilised.

11. Specific conductance

Influence of various treatments on specific conductance is furnished in Tables 33, 36, 39 and 44. The overall mean values of specific conductance increase upto late vegetative stage and then decrease till harvest. The statistical analysis of the data showed that the treatments differed significantly in their influence on specific conductance only at the time of shooting.

At the time of shooting the lowest value of specific conductance (0.247 dS m^{-1}) was exhibited by T_8 (500 g MgO $plant^{-1}$ as dolomite) and the highest (0.451 dS m^{-1}) by T_4 (1500 g MgO $plant^{-1}$ as magnesium sulphate). Significant difference between sources was observed in their influence on specific conductance. The treatments with magnesium sulphate differed significantly from others. The treatments with magnesite and dolomite were on par. This is because of the higher solubility of magnesium sulphate than the other two sources. The order of solubility is magnesium sulphate > magnesite > dolomite (Lindsay, 1979).

Specific conductance was found to correlate positively with available Mg (r = 0.3988*) and with exchangeable Mg (r = 0.618**) at early vegetative stage, with exchangeable Mg (r= 0.4368*), exchangeable Ca (r = 0.4751**), exchangeable K (r = 0.6303**) and exchangeable Na (r = 0.5969**) at late vegetative stage and with exchangeable Mg (r = 0.4168*) at the time of shooting. The cations in the exchange site come to solution and increase the salinity and thus the specific conductance.

pH and EC correlated negatively at the time of shooting (r = -0.3837*) probably because of the solubilisation of Fe and Al compounds in the laterite soil, at low pH.

12. Cation exchange capacity

Data on the effect of various treatments on the CEC of soil at various stages are presented in Tables 33, 36, 39 and 44. The overall mean values of CEC at various stages ranged from 9.197 cmol(+) kg^{-1} to 16.27 cmol(+) kg^{-1}.

The treatments did not differ significantly in their influence on CEC, at any stage.

A positive correlation was observed between CEC and exchangeable Mg (r = 0.4064*) at early vegetative stage. Similar observations of an increase in exchangeable Mg with increase in CEC of acid soils was reported by Boynton (1947).

In the late vegetative stage, the Mg content of leaf correlated positively with CEC (r = 0.3665*). This may be due to the increased uptake of Mg when a considerable amount is present in exchangeable form.

At the time of harvest CEC correlated positively with Ca content of leaf ($r = 0.3642^{*}$), Ca content of rhizome ($r = 3911^{*}$), Ca content of finger ($r = 0.3929^{*}$) and with uptake of Ca by finger ($r = 0.5047^{**}$). These correlations indicate the better uptake of Ca by different plant parts at higher CEC.

Thus the field experiment on banana with different sources and levels of Mg tends to conclude that the vegetative characters and yield characters of the plant are not significantly influenced by the application of the treatments. However, maximum uptake of Mg was observed when the highest level of MgO as magnesite was applied to the soil. Magnesite which is a cheaper source of Mg thus appears to be equally or marginally more efficient than the soluble, but costlier source of Mg namely magnesium sulphate.

Table 46. Correlation coefficients (r) between various characteristics in the field experiment, at early vegetative stage of banana

Sl. No.	X	Y	r
1	Height	Girth	0.9445**
2	"	Total number of leaves	0.6878**
3	Girth	"	0.6701**
4	Total chlorophyll	Chlorophyll 'a'	0.3772*
5	"	Chlorophyll 'b'	0.9067**
6	Per cent P in leaf	Height	-0.6468**
7	"	Girth	-0.6737**
8	Per cent Mg in leaf	Per cent Ca in leaf	-0.4909**
9	Available P	Per cent K in leaf	0.4029*
10	Available K	Exchangeable K	0.879**
11	Available Mg	EC	0.3988*
12	Exchangeable Mg	Per cent Ca in leaf	-0.5687**
13	"	Available Mg	0.5593**
14	"	Exchangeable Ca	-0.4015*
15	"	EC	0.6180**
16	"	CEC	0.4064*
17	Exchangeable Ca	Height	-0.6529**
18	"	Girth	-0.5756**
19	"	P per cent in leaf	0.5202**
20	"	Exchangeable Na	0.4543*
21	"	pH	0.7813**
22	Exchangeable Na	"	0.4254*
23	pH	P per cent in leaf	0.4688**

* Significant at 5% level

** Significant at 1% level

Table 47. Correlation coefficients (r) between various characteristics in the field experiment, at late vegetative stage of banana

Sl. No.	X	Y	r
1	Height	Girth	0.9338**
2	"	Total number of leaves	0.7947**
3	Girth	"	0.7978**
4	Total chlorophyll	Height	0.4235*
5	"	Chlorophyll 'a'	0.9181**
6	"	Chlorophyll 'b'	0.9481**
7	Chlorophyll 'a'	Height	0.4646**
8	"	Chlorophyll 'b'	0.9656**
9	Chlorophyll 'b'	Height	0.4621*
10	Per cent N in leaf	"	-0.4106*
11	"	Total number of leaves	-0.3700*
12	"	Per cent P in leaf	0.6081**
13	Per cent P in leaf	Chlorophyll 'a'	-0.3662*
14	"	Chlorophyll 'b'	-0.3841*
15	Per cent Mg in leaf	Per cent K in leaf	-0.3957*
16	"	Per cent Ca in leaf	-0.4615*
17	Organic carbon	Per cent K in leaf	0.3682*
18	"	Available P	0.5473**
19	Total N in soil	Per cent N in leaf	-0.4292*
20	Exchangeable Mg	EC	0.4368*

Contd.

Table 47 Continued

Sl. No.	X	Y	r
21	Exchangeable Ca	Height	-0.7249**
22	"	Girth	-0.6605**
23	"	Total number of leaves	-0.5852**
24	"	Per cent P in leaf	0.4064*
25	"	Exchangeable K	0.6908**
26	"	Exchangeable Na	0.6913**
27	"	pH	0.7587**
28	"	EC	0.4751**
29	Exchangeable K	Height	-0.7503**
30	"	Girth	-0.6687**
31	"	Total number of leaves	-0.6094**
32	"	Total chlorophyll	-0.4395*
33	"	Chlorophyll 'a'	-0.5091**
34	"	Chlorophyll 'b'	-0.4855**
35	"	Per cent N in leaf	0.3638*
36	"	Exchangeable Na	0.5881**
37	"	pH	0.6181**
38	"	EC	0.6303**
39	Exchangeable Na	pH	0.6273**
40	"	EC	0.5969**
41	CEC	Per cent Mg in leaf	0.36645*

* Significant at 5% level
** Signficant at 1% level

Table 48. Correlation coefficients (r) between various characteristics in the field experiment, at the time of shooting

Sl. No.	X	Y	r
1	Height	Girth	0.4430*
2	Total chlorophyll	Days to flower	-0.5216**
3	Chlorophyll 'a'	Days to flower	-0.5792**
4	Chlorophyll 'b'	Days to flower	-0.4805**
5	Per cent P in leaf	Height of plant	0.3814*
6	"	Total number of leaves	0.4557*
7	Available P	Per cent P in leaf	0.5540**
8	"	Total number of leaves	0.3984*
9	Per cent K in leaf	"	-0.4125*
10	"	Per cent Ca in leaf	-0.4868**
11	Per cent Mg in leaf	Total chlorophyll	0.3616*
12	"	Per cent Ca in leaf	-0.5893**
13	Organic carbon	Exchangeable Na	0.4223*
14	Total N in soil	Total chlorophyll	0.4391*
15	"	Chlorophyll 'b'	0.4498*
16	Available K	Exchangeable K	0.7059**
17	Exchangeable Mg	EC	0.4168*
18	Exchangeable Ca	Per cent P in leaf	0.3545*
19	"	pH	0.5237**
20	Exchangeable K	Height	-0.4187*
21	Total chlorophyll	Chlorophyll 'a'	0.7823**
22	"	Chlorophyll 'b'	0.8799**
23	Chlorophyll 'a'	Chlorophyll 'b'	0.4079*
24	pH	EC	-0.3837*

* Significant at 5% level
** Significant at 1% level

Table 49. Correlation coefficients (r) between various characteristics in the field experiment, at the time of harvest

Sl. No.	X	Y	r
1	Height	Girth	0.6379**
2	"	Weight of bunch	0.6112**
3	"	Number of fingers per bunch	0.4115*
4	Girth	Weight of bunch	0.6939**
5	"	Number of fingers per bunch	0.5324**
6	"	Weight of finger	0.3862*
7	Number of fingers per bunch	"	0.4496*
8	"	Weight of bunch	0.7822**
9	Weight of finger	"	0.7008**
10	Chlorophyll 'a'	Total chlorophyll	0.9541**
11	"	Chlorophyll 'b'	0.8682**
12	Chlorophyll 'b'	Total chlorophyll	0.965**
13	Per cent N in leaf	Weight of finger	-0.3683*
14	"	Ca uptake of leaf	-0.3661*
15	Per cent P in leaf	Girth	0.4432*
16	Per cent Ca in leaf	Uptake of Ca by leaf	0.8386**
17	Per cent Mg in leaf	Uptake of Ca by finger	0.4059*
18	"	Uptake of Mg by leaf	0.9766**
19	"	Total Mg uptake	0.8597**
20	Per cent Ca in rhizome	Per cent Ca in psuedostem	0.5305**
21	"	"	-0.4462*
22	"	Uptake of Ca by rhizome	0.7644**
23	"	Uptake of Ca by psuedostem	0.4798**
24	"	Uptake of Mg by psuedostem	-0.4889**

Contd.

Table 49 Continued

Sl. No.	X	Y	r
25	Per cent Mg in rhizome	Per cent Mg in psuedostem	0.5044**
26	"	Per cent Mg in finger	0.4106*
27	"	Uptake of Mg by rhizome	0.9212**
28	"	Total Mg uptake	0.4435*
29	Per cent Ca in psuedostem	Per cent Mg in psuedostem	-0.3767*
30	"	Uptake of Ca by psuedostem	0.8705**
31	"	Uptake of Mg by psuedostem	0.3748*
32	Per cent Mg in psuedostem	Uptake of Mg by rhizome	0.5342**
33	"	Uptake of Ca by psuedostem	-0.5013**
34	"	Uptake of Mg by psuedostem	0.7597**
35	"	Total Mg uptake	0.4557*
36	Per cent Mg in finger	Uptake of Mg by finger	0.9562**
37	Per cent Mg in leaf	Total Mg uptake	0.5266**
38	Organic carbon	CEC	0.3872*
39	"	Exchangeable Mg	0.4116*
40	Available P	pH	0.3624*
41	"	Height	0.4207*
42	Available K	"	0.4523*
43	"	Weight of finger	0.3910*
44	"	Exchangeable K	0.5144**
45	"	pH	0.4724**
46	"	EC	0.4779**
47	Exchangeable Ca	Height	0.4537*
48	"	Girth	0.5053**
49	"	Weight of finger	0.4288*

Contd.

Table 49 Continued

Sl. No.	X	Y	r
50	Exchangeable Ca	Per cent P in leaf	0.3965*
51	"	Available K	0.6917**
52	"	Exchangeable K	0.3665*
53	"	Exchangeable Na	0.3655*
54	"	pH	0.5564**
55	"	EC	0.5418**
56	Exchangeable Na	Per cent P in leaf	0.5332**
57	CEC	Per cent Ca in leaf	0.3642*
58	"	Per cent Ca in rhizome	0.3911*
59	"	Per cent Ca in finger	0.3929*
60	"	Uptake of Ca by finger	0.5047**
61	Mg uptake by rhizome	Uptake of Mg by finger	0.3773*
62	"	Total Mg uptake	0.4580*
63	Mg uptake by psuedostem	"	0.4275*
64	Uptake of Ca by finger	Number of fingers of bunch	0.3727*
65	"	Total chlorophyll	-0.4000*
66	"	Chlorophyll 'a'	-0.3985*
67	Per cent Ca in finger	Uptake of Ca by finger	0.8249**
68	Uptake of Mg by finger	Total uptake of Mg	0.5995**
69	Uptake of Ca by leaf	Height	0.4374*
70	"	Girth	0.4244*
71	"	Weight of bunch	0.3966*
72	Uptake of Mg by leaf	Uptake of Mg by finger	0.4289*
73	"	Total uptake of Mg	0.8780**

* Significant at 5% level
** Significant at 1% level

Summary

SUMMARY

The present experiment consisted of four parts, namely (1) the Mg status of soils of Kerala, (2) evaluation of laboratory indices of Mg availability, (3) transformation of applied Mg in soil and (4) pattern of Mg uptake by banana from different sources at different levels.

In part 1, one hundred and fifty surface samples (0-15 cm) were collected from all over the State of Kerala, to study the status of Mg as well as properties in relation to the behaviour of Mg in these soils. In part 2, some selected chemical agents were tried in twenty selected soils of Kerala in order to evolve a suitable extractant for available Mg for the soils of Kerala. In part 3, two acid rice soils of Kerala namely, karappadam and laterite were incubated at field capacity for a period of 180 days, with and without the addition of magnesium sulphate, magnesite and dolomite at the rate of 1250, 2500 and 3750 kg MgO ha^{-1}, to monitor the pattern of release of Mg from applied sources. Soil samples were drawn regularly at 15 days interval for the determination of available Mg and at 60 days interval for determination of other important chemical properties. In part 4, a field experiment was conducted to study the response of applied Mg on the uptake, growth and yield of banana (variety Nendran) under irrigated condition. Three sources of Mg were applied at three levels viz., 500, 1000 and 1500 g MgO per plant per year. The

sources of Mg applied were $MgSO_4.7H_2O$, magnesite and dolomite. Soil and plant samples were drawn at early vegetative stage, late vegetative stage, at the time of shooting and at the time of harvest of banana. The salient results of these experiments are summarised below.

Part 1

1. The soils were medium in their organic carbon content. Most of the soils were acidic, except the black soils which were alkaline. With the exception of black soils, all the soils exhibited low CEC and were poor in exchangeable bases.

2. In general, the soils of Kerala were found to be deficient in total Mg reserves. The mean content of total Mg of soils selected for this study was only 963.7 ppm. Of the 150 soils selected for the study, 61 per cent were deficient with regard to the total Mg content in soil. Only the black soils were relatively rich in total Mg with the mean value of 5452 ppm.

3. The available Mg content of the soils selected for the study varied from 13.08 to 915.6 ppm, with an average of 231.6 ppm. The black soils contained the highest amount of available Mg (638.3 ppm) and the alluvial soils showed the least (184.6 ppm). The laterite group was in between (231.9 ppm).

4. The relationship between available Mg and exchangeable Mg showed that in general the content of available Mg is almost double the quantity of exchangeable Mg.

5. Ten per cent of the soils in Group 1 (red, laterite and brown hydromorphic) and 34 per cent of the soils in Group 2 (alluvium) were deficient in available Mg. Altogether 17 per cent of the soils were deficient in available Mg. All the black soils (Group 3) were sufficient in available Mg. Mainly sandy loam soils of coastal alluvium were deficient.

6. The average content of exchangeable Mg of selected soil samples was 0.902 cmol(+) kg^{-1}. The alluvial soils showed the lowest values and the black soils contained the maximum.

7. Twenty five per cent of the total soils selected for study were deficient in exchangeable Mg and another 25 per cent was marginal being within the range of 25 to 50 ppm. The remaining 50 per cent can be considered as sufficient in exchangeable Mg.

8. The inter-relationships among total, available and exchangeable Mg were found significant and positive. Exchangeable Mg was found positively correlated with other exchangeable cations.

9. In general, the acid soils of Kerala are deficient in total Mg reserves. About 24 per cent of the total Mg was considered as available Mg. In terms of magnitude of available Mg in soil, the acid soils of the State were deficient whereas all the black soils were rated as sufficient. This trend was also seen in the distribution of exchangeable Mg in soil.

Part 2

1. Wide variation was observed in the organic carbon content, pH, EC, CEC, exchangeable Ca, exchangeable K, exchangeable Na, total Mg, exchangeable Mg and available Mg content of the twenty selected soils.

2. The various extractants showed the following decreasing order in their efficiency for extracting Mg: 0.005 *M* DTPA + 0.005 *M* $CaCl_2$ (374.1 ppm) > Mathew's triacid (300.9 ppm) > 0.1 *M* acetic acid + 0.04 *M* Ca lactate (296.9 ppm) > Reith's reagent (272.1 ppm) > 0.0125 *M* $CaCl_2$ (259.6 ppm) > 1 *N* NH_4OAc (242 ppm) > 0.05 *M* HCl (213.2 ppm) > 0.005 *M* DTPA (160.9 ppm).

3. The amount of Mg extracted by various extractants failed to correlate significantly with the Mg uptake of test crop (rice) as well as the per cent Mg in the crop. The performance of 0.05 *M* HCl was promising with respect to the pattern of release, degree of variability due to varying periods of equilibration and the magnitude of Mg extracted at the optimum period of equilibration.

Part 3

1. The karappadam soil was sandy loam in texture, nonsaline, acidic, high in organic carbon, medium in available P and high in available K. The laterite soil was sandy clay loam

in texture, less acidic and contained less soluble salts. The content of organic carbon was relatively low, while available P and K ratings were higher than that of the karappadam soil.

2. The available Mg content dominated over the exchangeable Mg content.

3. The availability of Mg gradually increased upto 3 months and then decreased in karappadam soil. In laterite, the variation in available Mg with the advancing period of incubation was not so conspicuous. The treatments showed a general trend of increase in available Mg upto the fifth stage and thereafter the levels were inconsistent.

4. The rate of release of Mg from different sources was fastest in samples located with magnesium sulphate. The degree of solubility was in the order magnesium sulphate > magnesite > dolomite.

5. The available Mg content was in the decreasing order in treatments with magnesium sulphate > magnesite > dolomite. But treatments with magnesite retained higher amounts of available Mg after six months of incubation. The magnitude of release of Mg was more in karappadam soil than in laterite.

6. The available Mg content was found to increase with increased levels of application of MgO, given as different forms of Mg fertilizers.

7. While comparing the efficiency of different Mg fertilizers to supply available Mg after six months of incubation, magnesite was found superior in both soils (49.8 per cent efficiency in karappadam and 36.1 per cent efficiency in laterite soil). The efficiency of magnesium sulphate was 40.5 per cent in karappadam and 30.4 per cent in laterite. The corresponding values of dolomite were 27.8 in karappadam and 4.96 per cent in laterite, at field capacity.

8. Available Mg in the control was found to be significantly lower than that in treatments.

9. At different stages of incubation available Mg was positively correlated with exchangeable Mg and negatively correlated with exchangeable Ca. Negative correlation was also observed between available Mg and pH.

10. In general, the exchangeable Mg content of both soils was found to increase upto four months and then it started to decline.

11. The exchangeable Mg content was the highest in treatments with magnesium sulphate followed by magnesite and dolomite

after four months of incubation. But with the advancing period of incubation, treatments with magnesite retained more Mg in the exchangeable form.

12. The karappadam soil contained more exchangeable Mg in the control as well as in treatments with different sources, compared to laterite.

13. The exchangeable Mg content increased with increasing levels of MgO applied.

14. On comparison of the efficiency of the different Mg fertilizers in the contribution of exchangeable Mg, magnesite was found superior (25.7 per cent in karappadam and 24.02 per cent in laterite soil). Magnesium sulphate was second (15.2 per cent in karappadam and 19.6 per cent in laterite). The least efficient was dolomite (11.4 per cent in karappadam and 5.3 per cent in laterite).

15. There was significant difference between the control and treatments in the content of exchangeable Mg in soil.

16. There was an increase in pH of karappadam soil after two months of incubation and thereafter there was no considerable variation in pH with advancing period of incubation. A similar trend was followed by laterite soil.

17. The soil reaction was influenced by the different sources of Mg. The increase in pH of soil with the addition of Mg sources were in the order dolomite > magnesite > magnesium sulphate.

18.. The pH of the karappadam soil was lower than that of laterite, in the control as well as in treatments.

19. The pH in treatments was higher than that of the control.

20. Increasing the level of Mg increased the pH of the soil.

21. In karappadam, the specific conductance increased upto two months. Thereafter it remained more or less stable upto fourth month and then declined after six months of incubation. Corresponding change in the laterite soil was inconsistent.

22. On comparing the effect of different sources of Mg on specific conductance, magnesium sulphate increased specific conductance compared to the other two sources upto fourth month of incubation. After six months of incubation, there was no considerable variation in the specific conductance in samples treated with any of the sources.

23. Magnesium in slowly available form was influenced by the different sources of Mg and the highest amount was seen in samples treated with dolomite and the lowest in magnesite.

24. Increasing levels of applied Mg increased the content in the slowly available form.

Part 4

1. The Mg treatments failed to influence the vegetative characters namely, mean height of plants, girth of plants, total number of leaves, total number of suckers, days to flower, days to mature and total duration of the crop.
2. The effect of treatments on yield and yield characteristics such as weight of bunch, length of bunch, number of hands per bunch, weight of finger and length and girth of finger, was not significant.
3. Yield was positively correlated with per cent Ca in leaf.
4. No significant difference between treatments was observed in the content of chlorophyll.
5. Total chlorophyll content was positively correlated with per cent Mg in leaf ($r = 0.3616^{*}$).
6. The treatments did not differ significantly in the percentage of N and P in the plant.
7. The Mg content of leaf was decisively influenced by the treatments at the late vegetative stage and at the time of shooting. The treatments differed significantly in their influence on per cent Ca in leaf at early vegetative stage.

8. Of the total Ca uptake 85 per cent was contributed by leaves. The rest of the amount was distributed as 5 per cent in the rhizome, 5 per cent in the psuedostem and 5 per cent in the finger. The uptake of Ca by leaves was significantly influenced by the treatments.

9. The contribution to Mg uptake by leaves was 51.3 per cent. About 17.2 per cent was contributed by rhizome, 15.3 per cent by psuedostem and 16.2 per cent by finger.

10. The total uptake of Mg was significantly influenced by the treatments. The maximum uptake (16.04 g plant^{-1}) was in the treatment with 1500 g MgO given as magnesite and the minimum uptake (5.864 g plant^{-1}) was in the treatment with 1500 g MgO as dolomite.

11. Magnesite was found to be as good as magnesium sulphate in the supply of Mg in acid soils.

12. The uptake of Mg was found to increase with increased levels of application of MgO.

13. The available Mg content of soil was decisively influenced by the treatments.

14. The available Mg in soil in the absence of added Mg was significantly lower than that in the rest of the treatments.

15. While comparing the difference between treatments with the three sources, the treatments with magnesite and dolomite were on par. The treatments with dolomite and magnesium sulphate were also on par, while the treatments with magnesite and magnesium sulphate differed significantly.

16. The available Mg content of soil increased with increasing levels of MgO supplied as magnesium sulphate.

17. The treatments could decisively influence the content of exchangeable Mg at the early vegetative stage and at the time of shooting.

18. The treatments with magnesium sulphate showed highest amount of exchangeable Mg.

19. Exchangeable Mg was positively correlated with available Mg ($r = 0.5593^{**}$).

20. The treatments differed significantly in their influence of exchangeable Ca in the early vegetative stage. The minimum amount of exchangeable Ca was observed in soil supplied with 1500 g MgO plant^{-1} in the form of magnesium sulphate.

21. Antagonism between Ca and Mg was observed in the treatment with highest dose of magnesium sulphate (1500 g MgO plant^{-1}).

22. The soil reaction was decisively influenced by the treatments.

23. The treatment with magnesium sulphate exhibited lower pH and the pH was maximum in treatments with dolomite supplying 1500 g MgO plant^{-1}.

References

REFERENCES

Adams, F. and Henderson, J.B. 1962. Magnesium availability as affected by deficient and adequate levels of potassium and lime. *Proc. Soil Sci. Soc. Am.* 26:65-68.

Aderikhin, P.G. and Belyayev, A.B. 1974. Chemical composition of chernozem separates in the central regions. *Soviet Soil Sci.* **6**:191-202.

Albrecht, W.M.A., Pettyjohn, W.M.J. and McLean, N.J. 1943. Magnesium depletion in relation to some cropping systems. *Soil Sci.* **55**:447-455.

Alston, A.M. 1972. Availability of magnesium in soils. *J. agric. Sci.* **79**:197-204.

Ananthanarayana, R. and Rao, B.V.V. 1979. Studies on dynamics of magnesium in soils and crops of Karnataka: II. Magnesium nutrition of groundnut. *Mysore J. agric. Sci.* **13**: 420-425.

Ananthanarayana, R. and Rao, B.V.V. 1980. Effect of magnesium on total chlorophyll content of hybrid maize. *Curr. Res.* **9**: 8-9.

Ananthanarayana, R. and Rao, B.V.V. 1982. Magnesium fertilization of rice on a red sandy loam soil. *J. Indian Soc. Soil Sci.* **30**:569-571.

Anonymous, 1979. Magnesium important for production of pineapples. *Information Bulletin,* Citrus and Subtropical Fruit Research Institute, South Africa, No.85, 3.

AOAC. 1960. *Official Methods of Analysis.* Association of Official Agricultural Chemists, Washington, D.C., p.225-226.

Asiegbu, J.E. and Uzo, J.O. 1983. Effects of lime and magnesium on tomato (*Lycopersicon esculentum* Mill.) grown in a ferrallitic sandy loam tropical soil. *Pl. Soil* 74:53-60.

Attanandana, T., Vacharotayan, S. and Kyuma, K. 1982. Chemical characteristics and fertility status of acid sulphate soils of Thailand. *Int. Symp. on Acid sulphate soils,* Bangkok, Thailand, 18-24 Jan. 1981. Int. Inst. for Land Reclamation and Improvement Publ. Wageningen, The Netherlands, p. 137-156.

Awada, M. and Suehisa, R.H. 1985. Sodium, potassium and magnesium effects on growth, petiole composition and elemental distribution in young papaya plants in sand culture. *Research Series,* College of Tropical Agriculture and Human Resources, University of Hawaii, No.039:20.

Bandyopadhyay, B.K. and Goswami, N.N. 1988. Dynamics of potassium in soil as influenced by levels of added K, Ca and Mg. *J. Indian Soc. Soil Sci.* 36:471-475.

Barshad, I. 1960. Significance of the presence of exchangeable magnesium ions in acidified clays. *Science* 131:988-989.

Bear, F.E. and Toth, S.J. 1948. Influence of calcium on availability of other soil cations. *Soil Sci.* 65:69-75.

Beeson, K.C. 1959. Magnesium in soils-sources, availability and zonal distribution. *Proc. Symposium Magnesium and Agriculture,* West Virginia University, p.217.

Berry, W.L. and Ulrich, A. 1970. Calcium nutrition of sugarbeets as affected by potassium. *Soil Sci.* **110**:389-394.

Birch, J.A., Davine, J.R. and Holmes, M.R.J. 1966. Field experiments on the magnesium requirement of cereals, potatoes and sugarbeet in relation to nitrogen and potassium application. *J. Sci. Fd Agric.* **17**:76-81.

Biswas, B.C., Yadav, D.S. and Maheswari, S. 1985. Role of calcium and magnesium in Indian agriculture. *Fert. News* **30**(7):14-35.

Bolton, J. 1972. Changes in magnesium and calcium in soils of Broadbalk wheat experiment at Rothamsted from 1865 to 1966. *J. agric. Sci.* **79**:217-223.

Bolton, J. 1973. Sources of magnesium for sugarbeet, potatoes and wheat grown on acid sandy soil at Woburn beds. *J. agric. Sci.* **81**:553-555.

Bolton, J. and Slope, D.B. 1971. Effects of magnesium on cereals, potatoes and leys grown on the continuous cereals site at Woburn. *J. agric. Sci. Camb.* **77**:253-259.

Boratynski, K., Roszykowa, S. and Zietecka, M. 1964. Investigations on the magnesium content of soils III. Soil reaction and sorption capacity and magnesium contents. *Roczn gleobosu* **14**: 27-41.

Bower, C.A., Reitemeier, R.F. and Fireman, M. 1952. Exchageable cation analysis of saline and alkali soils. *Soil Sci.* **73**:251-261.

Boynton, D. 1947. Magnesium nutrition of apple trees. *Soil Sci.* **63**: 53-68.

Brugger, G. 1961. Magnesium deficiency in heavy soils in Wurttenberg, *Kali-Briefe* **1**(10):1-8. Abstracted in *Chemical Abstr.* **55**: 127-129.

Camp, A.F. 1947. Magnesium in citrus fertilization in Florida. *Soil Sci.* **63**:43-52.

Carolus, R.L. 1933. Some factors affecting the absorption of magnesium by the potato plant. *Proc. Am. Soc. hort. Sci.* **30**: 480-484.

Cecil, S.R. 1991. Calcium and magnesium nutrition of coconut palm. *Coconut Breeding and Management.* Kerala Agric. Univ., Trichur, p.219-224.

Chandramony, D. and George, M.K. 1975. Nutritional effects of calcium, magnesium, silica and sodium chloride on certain anatomical characters of rice plant related to lodging. *Agric. Res. J. Kerala* **13**(1):39-42.

Chinea, E.T., Martin, Q.D. and Crispin, E.C. 1986. Influence of zinc, magnesium and filter press cake on yields and quality of pineapple cv. Red Spanish. *Centro Agricola* **13**(2):74-79.

Christenson, D.R. and Doll, E.C. 1973. Release of magnesium from soil clay and silt fractions during cropping. *Soil Sci.* **116**: 59-63.

Christenson, D.R., White, R.P. and Doll, E.C. 1973. Yield and magnesium uptake by plants as affected by soil pH and calcium levels. *Agron. J.* **65**:205-206.

Chu, C.H. and Johnson, L.J. 1985. Relationship between exchangeable and total magnesium in Pennsylvania soils. *Clays Clay Minerals* **33**:340-344.

Cline, R.A. 1987. Calcium and magnesium effects on rachis necrosis of interspecific hybrids of *Euvitis grapes* cv. Canada Muscat and cv. Himiod grapes. *J. Pl. Nutr.* **10**(16):1897-1905.

Colapietra, M. 1987. The effect of increasing rates of plant nutrients on the qualitative and quantitative yield of grape vines. A comparison of fertigation and manually applied fertilizer. *Rivista di Viticoltura e di Enolgia* **40**(6):223-249.

Cooper, H.P., Paden, W.R. and Garman, W.H. 1947. Some factors influencing the availability of magnesium in soil and the magnesium content of certain crop plants. *Soil Sci.* **63**:27-41.

Dejou, J. and DeMontard, F.X. 1982. The positive effect of potassium and magnesium fertilizing treatments on the volcanic soils of the Massif Central of France. *Potash Rev.* Suite **32**(3).

DeMello, F.A.F. and Arzolla, S. 1970. Solubility of dolomitic limestone in soil: II. Pot experiments with tobacco. *Anais da Escola Superior de Agricultura Luiz de Queiroz.* **27**:359-365. Abstracted in *Soil Fert.* **35**:726.

During, C. 1972. *Fertilizers and Soils in New Zealand Farming.* 2nd ed., N.Z. Dep. Agric. Bull. 409:312.

During, C. and Weeda, W.C. 1973. Some effects of cattle dung on soil properties, pasture production and nutrient uptake: II. Influence of dung and fertilizers on sulphate sorption, pH, cation exchange capacity and the potassium, magnesium, calcium and nitrogen economy. *N.Z. J. agric. Res.* **16**:431-438.

Edmeades, D.C., Wheeler, D.M. and Crouchly, G. 1985. Effects of liming on soil magnesium in some soils in New Zealand. *Commun. Soil Sci. Pl. Anal.* 16:727-739.

Elamin, O.M. and Wilcox, G.E. 1985. Effect of magnesium fertilization on yield and leaf composition of tomato plants. *J. Pl. Nutr.* 8(11):999-1012.

Elamin, O.M. and Wilcox, G.E. 1986. Effect of magnesium and manganese nutrition on water-melon growth and manganese toxicity. *J. Am. Soc. hort. Sci.* 111(4):588-593.

Estrada, G.E. and Guerrero, R.R. 1985. Magnesium status and its availability in Andian soils of Cundinamarca, Colombia *Ciencia del Suelo* 3(1-2):30-38.

Fageria, N. 1983. Ionic interactions in rice plants from dilute solutions. *Pl. Soil* 70:309-316.

Fecenko, J., Bizik, J. and Chomanicova, A. 1986. Effect of magnesium, copper, manganese and zinc fertilizer application on yield, formation and quality of spring barley and winter wheat. *Rostlinna Vyroba* 32(10):1055-1062.

Ferrari, J. and Sluijsmans, C.M.J. 1955. Mottling and magnesium deficiency in oats and their dependence on various factors. *Pl. Soil* 6:262-299.

Fischer, R. 1956. Magnesium deficiency and its causes. *Hopfenrundschau* 7:15. Abstracted in *Soil Fert.* 19:1446.

Foy, C.D. and Barber, S.A. 1958. Magnesium deficiency and corn yield in two acid Indiana soils. *Proc. Soil Sci. Soc. Am.* 22: 145-148.

Frolich, W. 1987. Whole plant and grain yields of European maize hybrids grown under summer drought conditions in Southern Chile in relation to the supply of mineral nutrients. *Tropenlandwirt* **88**:11-26.

Gajbhiye, K.S. and Goswami, N.N. 1980. Changes in the status of secondary and micronutrients in soil with wheat and bajra cultivation. *J. Indian Soc. Soil Sci.***28**:501-506.

Gama, M.V. 1987. Effect of calcium carbonate on the mobilisation of potassium and magnesium in twenty samples of acid soils derived from granite. *Agronomia Lusitana* **42**(3-4):285-300. Abstracted in *Soil Fert.* **52**:140-141.

Gartel, W. 1962. *Landw. Forsch. Sonderh.* **16**:133. Quoted by Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis.* Chemical Publishing Co., Inc., New York, p.106-125.

George, C.M. and Sreedharan, C. 1966. Studies on the effect of calcium and magnesium carbonate and sodium silicate on paddy in kayal lands at Vellayani. *Agric. Res. J. Kerala* .**4**(2): 73-77.

Gerzabek, M.H. and Schaffer, K. 1987. Determination of plant available Mg by an experiment with small pots. *OEFZS - Berichte* No.4409.

Gerzabek, M. Von. 1988a. Plant availability of magnesium. Part I: A comparison of various soil extraction methods. *Bodenkulter* **39**(2):117-124.

Gerzabek, M. Von. 1988b. Plant availability of magnesium. Part II. Relations between the Mg content of the soil and plant uptake. *Bodenkultur* 39(3):207-216.

Giessler, T. and Kurnoth, P. 1960. *Wiss. Z. Humboldt. Univ. Berlin nathnaturwiss Reihe* **9**:795. Quoted by Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis.* Chemical Publishing Co., Inc., New York, p.106-125.

Gile, P.L. 1913. Lime - magnesia ratio as influenced by concentration. *Porto Rico agric. exp. Stn. Bull.* **12**:1-24.

Godziashvili, B.A. and Peterburgsky, A.V. 1985. Potassium and magnesium nutrition of tea on the red soils of Georgia. *Potash Rev.* Subject 27, 114th suite, No.8. p.6.

Goswami, N.N. and Sahrawat, K.L. 1982. Nutrient Transformation in soils - Macronutrients. *Review of Soil Research in India, Part I.* 12th Int. Cong. Soil Sci. New Delhi, India. p.140-141.

Gottreich, M., Bradu, D. and Halevy, Y. 1964. A simple method of determining average banana fruit weight. *Ktavini* **14**: 161-162.

Graham, E.R., Powell, S. and Carter, M. 1956. *Miss. agric. Exp. Stn Res. Bull.* 607. Quoted by Hesse, P.R. 1971. *A Text Book of Soil Chemical Analaysis.* Chemical Publishing Co., Inc., New York, p.106-125.

Grant, C.A. and Racz, G.J. 1987. The effect of Ca and Mg concentrations in nutrient solution on the dry matter yield and Ca, Mg and K content of barley (*Hordeum vulgare* L.). *Can. J. Soil Sci.* **67**:857-865.

Gray, G. 1910. On the dissolved matter contained in rain water collected at Lincoln, New Zealand. Canterbury Agricultural College Magazine **24**:18-95. Quoted by Metson, A.J. 1974. *N. Z. J. exp. Agric.* **2**:277-319.

Grimme, H. 1983. Aluminium induced magnesium deficiency in oats. *Z. Pfl-Ernahr. Dung. Bodenk.* **146**:666-676.

Halstead, R.L., McLean, A.J. and Nielsen, K.F. 1958. Ca : Mg ratios in soil and yield and composition of alfalfa. *Can. J. Soil Sci.* **38**:85-87.

Hane, J.W. and Woodruff, J.R. 1976. Potassium/magnesium ratios in subsoils as related to Mg availability to plants. *Agron. Abstr.* 68:146.

Hanlon, E.A. and Johnson, G.V. 1984. Bray/Kurtz, Mehlich III, AB/D and ammonium acetate extractions of P, K and Mg in four Oklohoma soils. *Commun. Soil Sci. Pl. Anal.* **15**(3): 277-294.

Hara, T. and Sonoda, Y. 1981. The role of macronutrients in cabbage-head formation: II. Contribution to cabbage-head formation of calcium, magnesium or sulfur supplied at different growth stages. *Soil Sci. Pl. Nutr.* **27**:45-54.

Harbone, J.B. 1973. *Phyotochemical Methods - A guide to Modern Techniques of Plant Analysis.* International edition, Chapman and Hall, London, p.205-209.

Harrison, H.C. and Bergman, E.L. 1981. Calcium, magnesium and potassium interrelationships affecting cabbage production. *J. Am. Soc. hort. Sci.* **106**:501-503.

Hecht-Buchholz, C., Jorns, C.A., Keil, P. 1987. Effect of excess aluminium and manganese on Norway spruce seedlings as related to magnesium nutrition. *J. Pl. Nutr.* **10**:1103-1110.

Heenan, D.P. and Campbell, L.C. 1981. Influence of potassium and manganese on growth and uptake of magnesium by soybean (*Glycine max* (L) Merr. C.V. Bragg). *Pl. Soil* **61**:447-455.

Hendriksen, A. 1970. The magnesium balance in Danish agricultural soils. *Tidsakrift for Plantearl* **74**:224-233.

Hendriksen, A. 1971. Availability of magnesium reserves in soil. *Tiddskrift for Plantearl* **75**:647-663. Abstracted in *Soil Fert.* 35:1929.

Hesse, P.R. 1971. Calcium and magnesium. *A Text Book of Soil Chemical Analysis.* Chemical Publishing Co., Inc., New York, p.106-125.

Hester, J.B., Smith, G.E. and Shelton, F.A. 1947. The relation of rainfall, soil type and replaceable magnesium to deficiency symptoms. *Proc. Am. Soc. hort. Sci.* **49**:304-308.

Hewitt, C.W. 1955. Leaf analysis as a guide to the nutrition of bananas. *Emp. J. exp. Agric.* 23:11-16.

Hogg, D.E. and Toxopeus, M.R.J. 1973. Effect on magnesium oxide responses of particle size and combination with superphosphate. *N.Z. J. exp. Agric.* 1:191-194.

Holcomb, E.J. and White, J.W. 1974. Potassium fertilization of chrysanthemums using a constant drip fertilizer solution. *Pl. Soil* **41**:271-278.

Holmes, M.R.J. 1962. Field experiments on the magnesium requirements of potatoes in Great Britain. *J. agric. Sci.* **58**:281-285.

Hossner, L.R. and Doll, E.C. 1970. Magnesium fertilization of potatoes as related to liming and potassium. *Proc. Soil Sci. Soc. Am.* **34**:772-774.

Howeler, R.H. 1973. Iron-induced oranging disease of rice in relation to physico-chemical changes in a flooded Oxisol. *Proc. Soil Sci. Soc. Am.* 37:898-901.

Islam, A. and Islam, W. 1973. Chemistry of submerged soils and growth and yield of rice: 1. Benefits from submergence. *Pl. Soil* 39:555-564.

Jackson, M.L. 1958. *Soil Chemical Analysis.* Prentice - Hall Inc., London, p.82-110.

Jackson, M.L. 1969. *Soil Chemical Analysis, Advanced Course.* 2nd ed., L.B. Publishers and Distributors (P) Ltd., Bangalore, p.252-286.

Jacob, A. 1958. *Magnesium - The Fifth Major Plant Nutrient* Translated from the German by Dr.Norman Walker. Staples Press Ltd., London.

Jaffries, C.D. and White, J.E. 1938. Some mineralogical and chemical characteristics of a Hagerstown soil profiles. *Proc. Soil Sci. Soc. Am.* 2:133-141.

Jayaraman, C. 1988. Studies on soil magnesium. Ph.D. thesis, Tamil Nadu Agric. Univ., Coimbatore.

Johannesson, J.K. 1951. Magnesium deficiency in tomato leaves. *N.Z. J. Sci. Tech.* A 33:52-57.

Johansson, O.A.H. and Halilin, J.M. 1977. Potassium/magnesium balance in soil for maximum yield. *Proceedings, International Seminar on Soil Environment and Fertility Management in Intensive Agriculture (SEFMIA) Japan, 1977.* Society of the Science of Soil and Manure, Tokyo, Japan. p.487-495.

Johnson, K.E.E., Davis, J.F. and Benne, E.J. 1957. Control of magnesium deficiency in Utah IOB celery on organic soil. *Proc. Soil Sci. Soc. Am.* **21**:528-532.

Jokinen, R. 1977a. Effect of added magnesium, potassium, lime and nitrogen on oats: I. Yields. *J. Sci. agric. Soc. Finland* **49**(4):283-295.

Jokinen, R. 1977b. Effect of added magnesium, potassium, lime and nitrogen on oats: II. *J. Sci. agric. Soc. Finland* **49**(4): 296-314.

Jokinen, R. 1982. Effects of liming on the value of magnesium sulphate and two dolomitic limestones as Mg sources for rye grass. *J. Sci. agric. Soc. Finland* 54(1):77-78.

Kabeerathumma, S. 1969. Effect of liming on exchangeable cations and availability of nutrients in acid soils of Kuttanad. M.Sc.(Ag.) thesis, Kerala Univ., Trivandrum.

Kabeerathumma, S., Sasidhar, V.K., Kunj, U.M. and Sadanandan, N. 1977. A note on the effect of magnesium and molybdenum on soybean yield. *Agric. Res. J. Kerala* **15**(2):197-199.

Kamalakshiamma, P.G. and Pillai, N.G. 1980. Role of magnesium in coconut nutrition. *Indian Cocon. J.* **11**(3):1-2.

Kanwar, J.S. 1976. *Soil Fertility - Theory and Practice.* I.C.A.R., New Delhi, p.422-424.

KAU. 1989. *Package of Practices Recommendations.* Kerala Agricultural University, Directorate of Extension, Mannuthy, Kerala, p.1-40.

Kerschberger, M., Righter, D. and Pfleger, D. 1986. Determination of the plant available magnesium supply in field soils of the German Democratic Republic. *Archiv fur Ackerund Pflanzenban und Bodenkunde* 30(4):243-250.

Kirkby, K.A. and Mengel, K. 1976. The role of magnesium in plant nutrition. *Z. Pfl-Ernahr. Dung.***2**:209-222.

Kiss, 'A.S. 1979. Effect of magnesium fertilization on capsicum and tomato yield. *Kertgazdasag* **11**(5):65-68.

Kiss, A.S. 1981. Magnesium and its role in plants. *Magnesium Bulletin* **3**(1A):6-12.

Kondrat'ev, M.N. and Kondrat'eva, V.A. 1978. Contents of nitrates and ammonia in wheat and *Phaseolus vulgaris* plants grown under magnesium and calcium deficiency. *R.Zh.***2**:55-64.

Krishnamurthy, R., Mathan, H.B., Balakrishnan, N., Raman, S. and Samboornaraman, S. 1979. Refining the dose of magnesium sulphate for potato. *Indian J. Agron.* **24**: 455-457.

Krishnappa, M., Gajanan, G.N., Mithyantha, M.S. and Perur, N.G. 1974. Calcium-magnesium exchange equilibrium in three soils of Karnataka. *Mysore J. agric. Sci.* **8**:97-102.

Krstic, Z., Mrda, S. and Pandurovic, L. 1981. Magnesium application on maize in alluvial soil. *Agrohemija* 1-2, 75-80.

Kuhn, H. 1962. The magnesium effect of dolomitic limestones. *Bodenkultur.* **13**:226-239. Abstracted in *Soil Fert.* **26**:194.

Kuleza, W. and Szafranek, R.C. 1978. The effect of fertilizers on the growth and yield of apple. *Roczniki Nauk Rolniczych,* A. **103**(3):79-92.

Kumar, V., Bhatia, B.K. and Shukla, U.C. 1981. Magnesium and zinc relationship in relation to dry matter yield and the concentration and uptake of nutrients in wheat. *Soil Sci.* **131**: 151-155.

Kurup, K.R. and Ramankutty, M.N. 1969. Influence of magnesium silicate, sodium silicate and magnesium carbonate on the growth and yield of rice in the Kuttanad soils of Kerala. *Agric. Res. J. Kerala* 7(2):80-83.

Lea, R., Ballard, R. and Wells, C.G. 1980. Amounts of nutrients removed from forest soils by two extractants and their relationship to *Pinus taeda* foliage concentrations. *Commun. Soil Sci. Pl. Anal.* **11**:957-967.

Lightemberg, L.A. and Malburg, J.L. 1984. Occurrence of magnesium deficiency in a banana plantation in southern Brazil - Technical communication. In. *Anais do VII Congresso Brasilerio de Fruiticultura* Florianopolis, Brazil; Empresa catarinense de Pesquisa Agropecuriasa S.A. Volume 1, 276-282.

Lindsay, W.L. 1979. Magnesium. *Chemical Equilibrium in Soils.* Wiley Interscience, New York, p.106-116.

Loch, J. 1964. Problems of the methods of determining plant available Mg. *Debr. agrartud Foisk tud Kozl.* 1963, **9**:223-231. Abstracted in *Soil Fert.* **28**:3013.

Loganathan, S. 1973. Studies on certain aspects of calcium in the soils of South India. Ph.D. thesis, Tamil Nadu Agric. Univ., Coimbatore.

Lombin, L.G. 1979. Evaluation of magnesium supplying powers of the Nigerian savannah soils. *Soil Sci. Pl. Nutr.* **25**:477-492.

Lombin, L.G. and Fayemi, A.A. 1975. Critical level of Mg in Western Nigeria soils as estimated under green house conditions. *Agron. J.* **67**:272-275.

Low, A.J. and Armitage, E.R. 1970. The composition of the leachate through cropped and uncropped soils in lysimeters compared with that of rain. *Pl. Soil* **33**:393-411.

Mahapatra, I.C. and Gupta, S.K. 1978. Foliar application of macro and micro nutrients on rice. *Indian J. Agron.* **23**:369-371.

Mahler, R.L., Liu, C.T. and Menser, H.A. 1986. Evaluation of a salt fluxing residue as a potential potassium-magnesium fertilizer in the Pacific North West. *Commun. Soil Sci. Pl. Anal.* **17**:679-695.

Martin, J.P. and Page, A.L. 1969. Influence of exchangeable calcium and magnesium and of per cent base saturation on the growth of citrus plants. *Soil Sci.* **107**:39-46.

Mathan, K.K. 1964. Study of distribution, availability and fixation of phosphorus in Nilgiri soils. M.Sc.(Ag.) dessertation, Madras Univ., Madras.

Mathan, K.K. 1979. Studies on magnesium in acid soils of Nilgiris. Ph.D. thesis, Tamil Nadu Agric. Univ., Coimbatore.

Mathan, K.K., Samboornaraman, S., Balakrishnan, N. and Nehru, M.S. 1973. Magnesium fertilization of Nilgiris soils. *Madras agric. J.* **60**:1069-1070.

Mazayeva, M.M. 1965. Distribution of magnesium deficiency in coarse textured soils of the Sod podzolic zone. *Soviet Soil Sci.* **7**:809-815.

McColloch, R.C., Bingham, F.T. and Aldrich, D.G. 1957. Relation of soil potassium and magnesiumm to nutrition of citurs. *Proc. Soil Sci. Soc. Am.* **21**:85-88.

McIntosh, S., Crooks, P. and Simpson, K. 1973a. The effects applied N, K and Mg on the distribution of Mg in the plant. *Pl. Soil* **39**:389-397.

McIntosh, S., Crooks, P. and Simpson, K. 1973b. Sources of magnesium for grasslands. *J. agric. Sci.* **81**:507-511.

McMurtrey, J.E. 1947. Effect of magnesium on growth and composition of tobacco. *Soil Sci.* **63**:59-67.

McNaught, K.J. 1964. Grass staggers in leaf cattle. Effect of fertilizer and season on magnesium levels in pastures. *N. Z. J. Agric.* **109**:49-53.

McNaught, K.J. and Gdanitz, L.C. 1952. Magnesium deficiency in glass house tomatoes. *N.Z. J. Agric. Tech.* A **34**:82-91.

Mehlich, A. 1946. Soil properties affecting the proportionate amounts of Ca, Mg and K in plants and HCl extracts. *Soil Sci.* **62**:393-409.

Messing, J.H.L. 1974. Long term changes in potassium, magnesium and calcium content of banana plants and soils in the Windward Islands. *Trop. Agric.* 51:154-160.

Metson, A.J. 1974. Magnesium in New Zealand soils: I. Some factors governing the availability of soil magnesium : a review. *N. Z. J. exp. Agric.* **2**:277-319.

Metson, A.J. and Gibson, E.J. 1977. Magnesium in New Zealand soils. V. Distribution of exchangeables, "reserve" and total magnesium in some representative soil profiles. *N.Z. J. agric. Res.* **20**:163-184.

Mohebbi, S. and Mahler, R.L. 1988. The effect of soil pH manipulation on chemical properties of an agricultural soil from Northern Idaho. *Commun. Soil Sci. Pl. Anal.* **19**:1795-1812.

Mokwunye, A.U. and Melsted, S.W. 1972. Magnesium forms in selected temperate and tropical soils. *Proc. Soil Sci. Soc. Am.* **36**:762-764.

Moore, Jr. P.A. and Patrick, Jr. W.H. 1989. Calcium and magnesium availability and uptake by rice in acid sulphate soils. *Soil Sci. Soc. Am. J.* **53**:816-822.

Moreira, R.S. and Hiroce, R. 1978. Diagnosis of banana plant 'blue' in the South Coastal Region of Sao Paulo. *Bragantia* **37**(1):59-63.

Moser, F. 1933. The calcium-magnesium ratio in soils and its relation to crop growth. *J. Am. Soc. Agron.* **25**:365-377.

Munk, H. 1961. The effects of magnesium as dolomite and sulphate. *Z. Pfl-Ernahr. Dung.* **92**:36-46. Abstracted in *Soil Fert.* **24**:222.

Muralidharan, P. 1992. Response of rice to application of micronutrients. M.Sc.(Ag.) thesis, Kerala Agric. Univ., Trichur.

Myers, J.A., McLean, E.O. and Bigham, J.M. 1988. Reductions in exchangeable magnesium with liming of acid Ohio soils. *Soil Sci. Soc. Am. J.* **52**:131-135.

Nad, B.K. and Goswami, N.N. 1983. Response of legume and oil seed crops to different sources of sulphur and magnesium in some alluvial soils. *J. Indian Soc. Soil Sci.* **31**:60-64.

Nambiar, E.P. 1972. Variation in the nutrient ratios within the plant as a function of the ratios within the soil. Ph.D. thesis, Kerala Univ. Trivandrum.

Nambiar, P.K.D. 1963. Investigations on the possible relationship between the nutritional status of soils and the incidence of bunchytop disease of banana (*Musa* sp.). M.Sc.(Ag.) thesis, Kerala Univ., Trivandrum.

Nartea, R.N. and Castro, V.G. 1977. Magnesium release characteristics of some Philippine soils. *Proceedings 16th Congress, International Society of Sugarcane Technologists*, p.1203-1210.

Narwal, R.P., Kumar, V. and Singh, J.P. 1985. Potassium and magnesium relationship in cowpea (*Vigna ungiculata* (L) Walp). *Pl. Soil* **86**:129-134.

Nayar, M.A. and Koshy, M.M. 1966. The influence of different forms and levels of magnesium on the growth and yield of rice. *Agric. Res. J. Kerala* **4**(2):32-38.

Nayar, M.A. and Koshy, M.M. 1969. Influence of the forms and doses of magnesium on the uptake of nutrients by rice. *Agric. Res. J. Kerala* **7**(1):14-20.

Onuwaje, O.V. 1983. Yield response of rubber (*Hevea brasiliensis*) to fertilizers on an Ultisol in Nigeria. *Fert. Res.* **4**:357-360.

Osiname, O.A. and Kang, B.T. 1986. The effect of potassium fertilization on maize yield and Ca, Mg and K status in an oxic paleustaff in South Western Nigeria. *Potash Rev.* Suite 68, Subject 9, No.5.

Ottow, J.C.G., Benckiser, G., Watanabe, K. and Santiago, S. 1983. Multiple nutritional stress as the prerequisite for iron toxicity of wet land rice (*Oryza sativa* L.). *Trop. Agric.* (*Trinidad*) **60**:102-106.

Padmaja, P. and Verghese, E.J. 1966. Effect of Ca, Mg and Si on soil reaction and N and P status of the red loam soils of Kerala. *Agric. Res. J. Kerala* **4**:31-38.

Padmaja, P. and Verghese, E.J. 1972a. Effect of Ca, Mg and Si on soil reaction and N and P status of the red loam soils of Kerala. *Agric. Res. J. Kerala* **10**(1):14-19.

Padmaja, P. and Verghese, E.J. 1972b. Effect of Ca, Mg and Si on the uptake of plant nutrients and quality of straw and grain of paddy. *Agric. Res. J. Kerala.* **10**(2):100-105.

Pal, S. Laskar, B.K., De, G.K. and Debnath, N.C. 1991. Nature of some acid sulphate soils occurring in the coastal areas of West Bengal. *J. Indian Soc. Soil Sci.* **39**:59-62.

Panak, H. and Wojnowska, T. 1977. Effect of intensive mineral fertilization of pasture on plant pigments and magnesium and calcium contents of cocks foot. *Olsztynie* **175**(22):41-51.

Panicker, N.K. 1980. The utility of an indegenous source of magnesium silicate for rice in Kuttanad soils. M.Sc.(Ag.) thesis, Kerala Agric. Univ., Trichur.

Panse, V.G. and Sukhatme, P.V. 1985. *Statistical Methods for Agricultural Workers.* 4th ed. Indian Council of Agricultural Research, New Delhi, p.347.

Pedersen, B.F. and Vang-Petersen, O. 1984. Application of magnesium to apple trees: II. *Tidsskrift for Planteavl* 88(4): 405-412.

Peech, M. and English, L. 1944. Rapid microchemical soil tests. *Soil Sci.* **57**:167-196.

Phillips, I.R., Black, A.S. and Cameron, K.C. 1988. Effect of cation exchange on the distribution and movement of cations in soils with variable charge: II. Effect of lime or phosphate on K and Mg leaching. *Fert. Res.***17**:31-46.

Pillai, K.S. 1965. Nutritional status of soils and the incidence of bunchytop disease of banana (*Mussa*sp.). Part II. Significance of Ca/Mg ratio in the nutritional medium and in the plants. M.Sc.(Ag.) thesis, Kerala Univ., Trivandrum.

Piper, C.S. 1942. *Soil and Plant Analysis.* Asian reprint 1966, Hans Publishers, Bombay, p.368.

Ponnamperuma, F.N. 1972. The chemistry of submerged soils. *Adv. Agron.* **24**:29-96.

Pope, D.T. and Munger, H.M. 1953. Heredity and nutrition in relation to magnesium deficiency chlorosis in celery. *Proc. Am. Soc. hort. Sci.* 61:472-480.

Prasad, B., Prasad, R. and Verma, M.K. 1983. Effect of Ca and Mg on gram and soybean crops in acid soil. *J. Indian Soc. Soil Sci.* 31:229-232.

Prince, A.L., Zimmerman, M. and Bear, F.E. 1947. The magnesium supplying power of twenty New Jersey soils. *Soil Sci.* **63**:69-78.

Prohaszka, K. 1980. Effect of certain soil characteristics on the magnesium content of soil and plant. *Novenyternceles* **29** (2):183-190.

Qui, X.C., Zhang, Y.S. and Zhu, Y.Q. 1984. A new reagent for the spectrophotometric determination of magnesium (II) *Chemie* **318**(7):505-508.

Rahmatullah and Baker, D.E. 1981. Magnesium accumulation by corn (*Zea mays* L.) as a function of potassium, magnesium exchange in soils. *Soil Sci. Soc. Am. J.* **45**:899-903.

Raij, B. Van., Quaggio, J.A., Silva, N.M. Da. 1986. Extraction of phosphorus, potassium, calcium and magnesium from soils by an ion exchange resin procedure. *Commun. Soil Sci. Pl. Anal.* **17**(5):547-566.

Ramanathan, G. 1974. Studies on the physico-chemical properties of soils of Tamil Nadu in relation to clay mineralogy. Ph.D. thesis, Tamil Nadu Agric. Univ., Coimbatore.

Razeto, B. and Salas, a. 1986. Magnesium, manganese and zinc sprays on orage trees (*Citrus sinensis* (L) Osbeck). *Foliar Fertilization* (ed. Alexander, A.) Developments in Plant and Soil Sciences Vol.22. Dordrecht, Netherlands Martinus Nijhoff Publishers, 255-270.

Reith, J.W. 1963. The magnesium contents of soils and crops. *J. Sci. Fd Agric.* **14**:417-426.

Rice, H.B. and Kamprath, E.J. 1968. Availability of exchangeable and non-exchangeable magnesium in sandy coastal plain soils. *Proc. Soil Sci. Soc. Am.* **32**:386-388.

Rorison, I.H. 1973. The effect of extreme soil acidity on the nutrient uptake and physiology of plants. *Proc. of the Int. Symp. on Acid sulphate soils,* Int. Inst. for Land Reclamation and Improvement, Wageningen, The Netherlands, p.223-254.

Russell, E.W. 1973. *Soil Conditions and Plant Growth.* 10th ed., The English Language Book Society and Longman, p.59.

Salmon, R.C. 1963. Magnesium relationships in soils and plants. *J. Sci. Fd Agric.* **14**:605-610.

Salmon, R.C. 1964. Cation activity ratios in equilibrium soil solution and the availability of magnesium. *Soil Sci.* **98**:213 -221.

Sanchez, L.F. 1984. Aspects of magnesium nutrition of rice in in the eastern plains of Colombia. *Ravista Institute Colombiano Agropecuario* **19**(3):361-369.

Schachtschabel, P. 1954. Plant available magnesium in soil and its determination. *Z. Pfl-Ernahr. Dung. Bodenk.* **67** : 9-23. Abstracted in *Soil Fert.* **18**:64.

Schachtschabel, P. 1957. Magnesium content of soil in northern Germany and the occurrence of symptoms of magnesium deficiency in potatoes. *Landw. Forsch. Sonderheft* **9**:101-105.

Schroeder, D. and Zahiroleslam, S. 1963. The magnesium content of soils in Schleswig-Holstein. *Z. Pfl-Ernahr. Dung.* **100** : 207-215.

Schweder, P. 1983. Studies on mineral reserves in soils. *Archiv fur Acker - und Pflanzenban und Bodenkunde* **27**(10):655-661.

Seggewiss, B. and Jungk, A. 1988. Influence of potassium dynamics at the soil root interface on Mg uptake by plants. *Z. Pfl-Ernahr. Dung. Bodenk.* **157**(2) : 91-96. Abstracted in *Soil Fert.* **52**:810.

Sekhon, G.S., Arora, C.L. and Soni, S.K. 1975. Nutrient status of wheat crop in Ludhiana. *Commun. Soil Sci. Pl. Anal.* **6**: 609-618.

Semb, G. and Tragethon, O. 1958. Investigations on magnesium deficiency in the districts Rygge and Rade, Ostfold Country. *Tidsskrift for det norske landbruk.* **62** :230-244. Abstracted in *Chemical Abstr.* **52**:1960.

Sharma, R.C., Lal, S.S., Sahota, T.S. and Sharma, A.K. 1981. Effect of magnesium and phosphorus on the yield and composition of potato tubers in acid soils of Shillong and Simla. *J. Indian Potato Assoc.* **8**(4):183-189.

Shieh, C.C., Ma, M.T. and Chu, Y.C. 1965. Studies on the effect of Mg fertilizers on the soils in South China. *Acta Pedol. sin.* **13**:377-386. Abstracted in *Soil Fert.* **29**:383.

Shukla, L.M. and Banerjee, N.K. 1980. Effect of zinc and magnesium on the growth and seed yield of cabbage and cauliflower. *Indian J. Agron.* **25**:497-500.

Simmonds, N.N. 1959. *Bananas*. 1st ed. Longman, London, p.1-431.

Simon, J.E., Wilcox, G.E., Simini, M., Elamin, O.M. and Decotean, R.D. 1986. Identification of manganese toxicity and magnesium deficiency on melons grown in low pH soils. *Hort. Sci.* **21**:1383-1386.

Simpson, K. 1983. *Soil*, Longman, London, p.120.

Singh, L. and Balasubramanian, V. 1985. Response of irrigated wheat to N, P and K fertilizers in the Nigerian savanna. *Samara J. agric. Res.* **3**:31-38.

Snedecor, G.W. and Cochran, W.G. 1967. *Statistical Methods*, 6th ed., Oxford and IBH Pub. Co., Calcutta, p.593.

Sonneveld, C. 1987. Magnesium deficiency in rock wool grown tomatoes as affected by climatic conditions and plant nutrition. *J. Pl. Nutr.* **10**:1591-1604.

Spear, S.N., Edwards, D.G. and Asher, C.J. 1978. Response of cassava, sunflower and maize to potassium concentration in solution: III. Interaction between potassium, calcium and magnesium. *Field Crops Res.* **1**:375-389.

Stahlberg, S. 1960. Studies on the release of bases from minerals and soils: IV. The release of calcium and magnesium by boiling normal hydrochloric acid. *Acta Agric. scand.* **10**: 448-456.

Stahlberg, S. 1980. A new extraction method for estimation of plant available P, K and Mg. A trial application in Swedish cultivated soils. *Acta. Agric. scand.* **30**:93-107.

Stout, W.L. and Bennet, O.L. 1983. Effect of Mg and Zn fertilization on soil test levels, ear-leaf composition and yields of corn in northern West Virginia. *Commun. Soil Sci. Pl. Anal.* **14**:601-613.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci.* **29**:259-260.

Subramanian, R.M., Manickam, T.S. and Krishnamoorthy, K.K. 1975. Studies on the effect of magnesium on the progressive changes of nutrients of groundnut (POL 1) in two red soils of Tamil Nadu. *Madras agric. J.* **62**:550-554.

Sudhir, K., Ananthanarayana, R. and Deshpande, P.B. 1987. Influence of calcium, magnesium and potassium fertilization of groundnut on the yield attributes, uptake of nutrients and soil chemical characteristics. *Mysore J. agric. sci.* **21**: 164-168.

Sumner, M.E., Farina, P.M.W. and Hurst, V.J. 1978. Magnesium fixation - a possible cause of negative yield responses to lime applications. *Commun. Soil Sci. Pl. Anal.* **9**:995-1007.

Tajuddin, E. 1970. Effect of lime and magnesium on the yield and quality of groundnut in the acid soils of Kerala. *Agric. Res. J. Kerala* 8(2):89-92.

Teichman, W. 1957. Symptoms of magnesium deficiency in cereals in the early stages of growth. *Landwirtschaftsblattfur Weser - Ens.* **104**:645. Abstracted in *Soil Fert.* **20**:2232.

Thomas, A. and Koshy, M.M. 1977. Response of rice variety Triveni to graded doses of magnesium silicate. *Agric. Res. J. Kerala* **15**(1):83-84.

Tisdale, S.L., Nelson, W.L. and Beaton, J.D. 1985. *Soil Fertility and Fertilizers* 4th ed. Macmillan Publishing Company, New York, p.754.

Tomar, V.S. and Verma, G.P. 1970. Available magnesium status of Madhya Pradesh soils. *Indian J. agric. Chem.* **3**:29-34.

Trueby, P. and Aldinger, E. 1989. A method for the determination of exchangeable cations in forest soils. *Z. Pfl-Ernahr. Bodenk.* **152**:301-306.

Turner, D.W. and Barkus, B. 1983. The uptake and distribution of mineral nutrients in banana in response to supply of K, Mg and Mn. *Fert. Res.* **4**:89-99.

Varghese, T. 1963. Influence of Ca and Mg in increasing the efficiency of fertilizers for rice and Ca and Mg status of some typical rice soils of Kerala. M.Sc.(Ag.) thesis, Kerala Agric. Univ., Trichur.

Varghese, T. and Money, N.S. 1965. Influence of Ca and Mg in increasing the efficiency of fertilizers for rice in Kerala. *Agric. Res. J. Kerala* **3**(1):40-45.

Varkey, T., Kamalakshiamma, P.G., Ramanandan, P.L. and Nambiar, P.T.N. 1979. Foliar yellowing of coconut palms in healthy and root (wilt) affected areas. *J. Plant. Crops* **7**(2):117-120.

Varughese, S. 1992. Suitability of magnesite as a source of magnesium in acid rice soils of Kerala. M.Sc.(Ag.) thesis, Kerala Agric. Univ., Thrissur.

Vasil'eva, L.V. 1965. Effectiveness of magnesium fertilizers on light podzolic soils. *Trudy Solikam - sel - Khoz. Opyt. Sta.* **3**:171-228. Abstracted in *Soil Fert.* **30**:588.

Vasil'eva, L.V. 1966. Interaction of effectiveness of magnesium and calcium on light dernopodzolic soils. *Pochvovedenie* **5**: 79-88. Abstracted in *Soil Fert.* **29**:469.

Venugopal, V.K. and Koshy, M.M. 1976. Exchangeable cations of some important soil profiles of Kerala. *Agric. Res. J. Kerala* **14**(1):37-42.

Walsh, T. and O'Donoboe, T.F. 1945. Magnesium deficiency in some crop plants in relation to the level of potassium nutrition. *J. agric. Sci.* **35**:254-263.

Watanabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. *Proc. Soil Sci. Soc. Am.* **29**:677-78.

Welte, E. and Werner, W. 1963. Potassium-magnesium antagonism in soils and crops. *J. Sci. Fd Agric.* **14**:180-186.

Welte, E., Werner, W. and Niederbudde, E.A. 1960. *Trans. 7th Int. Congr. Soil Sci.* 2:246. Quoted by Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis.*Chemical Publishing Co., Inc., New York, p.116-117.

Wicken, O.M. and Duncan, L.R. 1983. Magnesite and related minerals. *Industrial Minerals and Rocks.* **2**:881-896.

Wiklander, L. and Anderson, E.K. 1963. Influence of exchangeable ions on release of mineral based ions. *Soil Sci.* **95**:9-15.

Wolf, B. 1963. Evaluation of calcined magnesite as a source of magnesium for plants. *Agron. J.* **55**:261-262.

Yamasaki, T., Kamishikiryo, S. and Terashima, M. 1956. Magnesium defecient soil and magnesium deficiency in crops. *Tokai-Kinki Nogyo Shikenjo Kenkgu Hokoku* **3**:73-106. Abstracted in *Soil Fert.* **20**:791.

Yamauchi, M. and Winslow, M.D. 1989. Effect of silica and magnesium on yield of upland rice in the humid tropics. *Pl. Soil* **113**:265-269.

Yang, P.S. and Pao, P.T. 1962. Studies on the effect of potash on banana. *Potash Rev.* Sub **27**(4):31-37.

Yordanov, I.T., Stoyanov, I.G. and Chichev, P.N. 1978. Pigment contents and lamellar chloroplast protein composition of maize plants, grown at Mg deficiency. *Doklady Bulgarskor Akademii Nauk* **30**:1625-1628.

Ystaas, J. and Steenberg, K. 1978. Pear nutrition - 3. Competition between fruit and leaves for magnesium and calcium. *Forskning og Forsk i Landbruket* **29**(5):409-420.

Zehler. E. 1982. Potassium and magnesium sulphate fertilizers : advantages over non-sulphate forms in terms of crop quality and yield. *Sulphur* **1**:525-543.

Appendices

Apppendix 1. Details of soil samples collected for the study of Mg status of Kerala soils

	Soil sample Number	Location	District
Group I Red, laterite and brown hydromorphic soils	1	Ajanur	Kasaragod
	2	Uduma	,,
	3	Mancheswar	,,
	4	Periya	,,
	5	Balal	,,
	6	Rajapuram	,,
	7	Tellichery	Kannoor
	8	Vengad	,,
	9	Panoor	,,
	10	Muzhakkunnam	,,
	11	Periyaram	,,
	12	Eranjholi	,,
	13	Chirakkal	,,
	14	Kunnathuparambu	,,
	15	Chittariparambu	,,
	16	Azhikodu	,,
	17	Chempilodu	,,
	18	Mokeri	,,
	19	Koothuparambu	,,
	20	Parangadu	,,
	21	Kathiroor	,,
	22	Kolanchery	,,
	23	Elayavoor	,,
	24	Thalakkulathur	Kozhikode
	25	Kakkoor	,,
	26	Payyampra	,,
	27	West Hill	,,
	28	Nanminda	,,

Contd.

Appendix 1 Continued

Soil sample Number	Location	District
29	Punnoor	Kozhikode
30	Balussery	,,
31	Naduvannoor	,,
32	Ulleri	,,
33	Chelannoor	,,
34	Cheruvannoor	,,
35	Kallupuram	,,
36	Thenjippalam	Malappuram
37	Kattuparuthy	,,
38	Valanchery	,,
39	Pulamanthol	,,
40	Puzhakkathiri	,,
41	Kuruva	,,
42	Moorkanad	,,
43	Edappal	,,
44	Athuvanad	,,
45	Kooriyadu	,,
46	Ollur	Thrissur
47	Pananchery	,,
48	Nelluvai	,,
49	Chalakkudy	,,
50	Koratty	,,
51	Choondal	,,
52	Puthukkadu	,,
53	Kolazhy	,,
54	Vadavannoor	,,
55	Kaiparamba	,,
56	Annamanada	,,
57	Thali	,,

Contd.

Appendix 1 Continued

Soil sample Number	Location	District
58	Meloor	Thrissur
59	Karalam	,,
60	Velokkara	,,
61	Arthat	,,
62	Erumappetty	,,
63	Nadavarambu	,,
64	Cherpu	,,
65	Thiruvazhiyodu	Palakkad
66	Vadakkumcheri	,,
67	Ayaloor	,,
68	Kozhinjampara	,,
69	Thirumaradi	Ernakulam
70	Palakkuzha	,,
71	Muthumanoor	,,
72	Arakkuzha	,,
73	Poothrikka	,,
74	Kadachira	,,
75	Moovattupuzha	,,
76	Thiruvankulam	,,
77	Vellore	Kottayam
78	Marangattupilli	,,
79	Mulakkulam	,,
80	Thalayolaparamba	,,
81	Njeezhoor	,,
82	Kanakkary	,,
83	Kaduthuruthy	,,
84	Keezhoor	,,
85	Maravanthuruthu	,,
86	Elakkadu	,,

Contd.

Appendix 1 Continued

	Soil sample Number	Location	District
	87	Mannar	Kottayam
	88	Murikkasseri	Idukki
	89	Parathodu	,,
	90	Puramattom	Pathanamthitta
	91	Punaloor	Quilon
	92	Mylom	,,
	93	Perinad	,,
	94	Edathara	,,
	95	Poothakkulam	,,
	96	Kunnathukal	Thiruvananthapuram
	97	Nemom	,,
	98	Nagarur	,,
	99	Nanniyodu	,,
	100	Tholikkodu	,,
	101	Chemmaruthy	,,
Group II - Alluvium	102	Nileswar	Kasaragod
	103	Pallikkara	,,
	104	Pilicode	,,
	105	Padna	,,
	106	Cheruvathoor	,,
	107	Cherukunnu	Kannur
	108	Mazhupilangad	,,
	109	Valapatanam	,,
	110	Thannyam	Thrissur
	111	Chattukulam	,,
	112	Kadvanthra	Ernakulam
	113	Udayamperoor	,,
	114	Thripunithura	,,
	115	Cochin	,,

Contd.

Appendix 1 Continued

Soil sample Number	Location	District
116	Haripad	Alappuzha
117	Kuthiathodu	,,
118	Mannar	,,
119	Kayamkulam	,,
120	Muhamma	,,
121	Chennithala	,,
122	Mararikulam North	,,
123	Aroor	,,
124	Alappuzha	,,
125	Moncompu	,,
126	Krishnapuram	,,
127	Mannanchery	,,
128	Pathiyoor	,,
129	Pollathai	,,
130	Kalavoor	,,
131	Kulasekharapuram	Quilon
132	Ochira	,,
133	Pallikkal	,,
134	Puthanambalam	,,
135	Pali	,,
136	Patharam	,,
137	Kulathupuzha	,,
138	Sooranad South	,,
139	Aruvikkara	Thiruvananthapuram
140	Kadakkarapilli	,,
141	Kalhinamkulam	,,
142	Thiruvallam	,,
143	Chempu	Kottayam

Contd.

Appendix 1 Continued

	Soil sample Number	Location	District
	144	Kudaveehoor	Kottayam
	145	Udayanapuram	,,
Group III - Black soil	146	Athikkodu	Palakkad
	147	Kozhippara	,,
	148	Venthapalayam	,,
	149	Menonpara	,,
	150	Muthalamada	,,

Appendix 2. Details of soils selected for the evaluation of laboratory indices for available magnesium

Sl. No.	Soil sample Number	Location	District
1	103	Pallikkara	Kasaragod
2	6	Rajapuram	''
3	80	Thalayolaparambu	Kottayam
4	143	Chempu	''
5	113	Udayamperoor	Ernakulam
6	123	Aroor	Alappuzha
7	24	Thalakkulathoor	Kozhikod
8	25	Kakkoor	''
9	26	Payyampra	''
10	146	Athikodu	Palakkad
11	147	Kozhippara	''
12	125	Moncompu	Alappuzha
13	31	Naduvannoor	Kozhikod
14	47	Pananchery	Thrissur
15	54	Vadavannoor	''
16	57	Thali	''
17	59	Karalam	''
18	60	Velokkara	''
19	61	Arthat	''
20	64	Cherpu	''

Appendix 3. Weather data (monthly average) during the cropping period (from October 1990 to October 1991)

Month and year	Total rainfall, mm	Temperature (mean)		Relative humidity %		Sunshine hours (mean)
		Maximum °C	Minimum °C	Forenoon	Afternoon	
October, 1990	350.2	34.20	29.00	92	69	6.5
November "	85.1	34.40	29.80	87	62	6.0
December "	3.2	34.00	30.00	72	45	10.2
January, 1991	Nil	33.22	19.27	74	41	8.9
February "	Nil	35.59	16.77	74	28	10.1
March "	0.6	36.21	19.97	84	47	8.7
April "	92.4	36.02	20.10	83	53	8.9
May "	42.8	35.61	18.48	85	55	7.5
June "	922.1	30.92	18.34	94	82	4.8
July "	1073.5	29.84	17.11	94	79	2.5
August "	584.1	30.14	16.25	95	78	2.8
September "	70.1	31.86	18.61	91	64	7.3
October "	198.7	32.03	18.04	90	74	4.3

Source: CPCRI Research Centre, Kannara

Plates

Plate 1. A general view of the field experiment at early vegetative stage

Plate 2. A general view of the field experiment at the time of harvest

STATUS, AVAILABILITY AND TRANSFORMATION OF MAGNESIUM IN ACID SOILS OF KERALA

By

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ABSTRACT OF A THESIS

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ABSTRACT

The investigation consisted of four parts, namely (1) magnesium status of soils of Kerala, (2) evaluation of laboratory indices of Mg availability, (3) transformation of applied Mg in soil and (4) pattern of Mg uptake by banana from different sources at different levels. In Part 1, one hundred and fifty surface samples were collected from all over the State of Kerala, to study the status of Mg as well as properties in relation to the behaviour of Mg in these soils. In Part 2, some selected chemical agents were tried in twenty selected soils in order to evolve a suitable extractant for available Mg. In Part 3, two acid rice soils of Kerala namely, karappadam and laterite were incubated at field capacity for a period of 180 days with and without the addition of magnesium sulphate, magnesite and dolomite at the rate of 1250, 2500 and 3750 kg MgO ha^{-1}, to monitor the pattern of release of Mg from applied sources. Soil samples were drawn regularly at 15 days interval for the determination of available Mg and at 60 days interval for the determination of other important chemical properties. In Part 4, a field experiment on banana was conducted to study the response to applied Mg.

In the first experiment (Part 1), the soils were medium in their organic carbon content. Most of the soils were acidic except the black soils which were alkaline. With the exception

of black soils, all the soils were low in CEC and poor in exchangeable cations. In general, the soils of Kerala were found to be deficient in total Mg reserves, with a mean value of 963.7 ppm. Of the 150 soils selected for the study, 61 per cent were deficient with regard to the total Mg content in soil. Only the black soils were relatively rich in total Mg with the mean value of 5452 ppm. The average content of available Mg was 231.6 ppm. The black soils contained the highest amount and the alluvial soils, the least. The laterite group was in between. The available Mg content was almost double that of exchangeable Mg. Altogether 17 per cent of the soils studied were found to be deficient in available Mg. The sandy loam soils of coastal alluvium were in general, dificient in available Mg. But all the black soils were rated as sufficient in available Mg. The distribution of exchangeable Mg was similar to that of available Mg. Twenty five per cent of the total soils selected for the study were deficient in exchangeable Mg. Black soils were rather rich in exchangeable Mg. The most deficient were the sandy loam soils of coastal alluvium. The interrelationships among total available and exchangeable Mg were found to be significant and positive. Exchangeable Mg was found positively correlated with other exchangeable cations. In general, about 24 per cent of total Mg reserve in the soils under study was considered available and 11 per cent of total Mg was considered exchangeable. The total Mg reserves in Kerala soils were found to be poor and Mg can be considered as a critical element in acid soils of Kerala.

In the second experiment (Part 2), wide variation was observed in the organic carbon content, pH, EC, CEC, exchangeable Ca, exchangeable K, exchangeable Na, total Mg, exchangeable Mg and available Mg content of the twenty selected soils. The various extractants showed the following decreasing order in their efficiency for extracting Mg: 0.005 *M* DTPA + 0.005 *M* $CaCl_2$ > Mathew's triacid > 0.1 *M* acetic acid + 0.04 *M* Ca lactate > Reith's reagent > 0.0125 *M* $CaCl_2$ > 1 *N* NH_4OAc > 0.05 *M* HCl > 0.005 *M* DTPA. The amount of Mg extracted by various extractants failed to correlate significantly with the Mg uptake of test crop (rice) as well as the per cent Mg in the crop. The performance of 0.05 *M* HCl was promising with respect to the pattern of release, degree of variability due to varying periods of equilibration and the magnitude of Mg extracted at the optimum period of equilibration.

In the third experiment (Part 3), the karappadam soil was sandy loam in texture, nonsaline, acidic, high in organic carbon, medium in available P and high in available K. The laterite soil was sandy clay loam in texture, less acidic and contained less soluble salts. The content of organic carbon was relatively low, while available P and K ratings were higher than that of karappadam soil. The availability of Mg gradually increased upto three months and then it decreased in karappadam soil. In laterite, the variation in available Mg with the advancing periods of incubation was not so conspicuous. The treatments showed a general trend of increase in available Mg upto the fifth stage (two and a half months) and thereafter the levels were inconsistent. The rate of release of Mg from different source of Mg was fastest in samples treated with magnesium sulphate. The degree of solubility was in the order magnesium sulphate > magnesite > dolomite. Treatments with magnesite retained higher amounts of available Mg after six months of incubation. The magnitude of release of Mg was more in karappadam soil than in laterite. The available Mg content was found to increase with increased levels of application of MgO given in different forms of fertilizers. While comparing the efficiency of different Mg fertilizers to supply available Mg after six months of incubation, magnesite was found superior in both soils (49.8 per cent efficiency in karappadam and 36.1 per cent efficiency in laterite soil). The efficiency of magnesium sulphate was 40.5 per cent in karappadam and 30.4 per cent in laterite. The corresponding values of dolomite were 27.8 in karappadam and 4.96 per cent in laterite at field capacity. Available Mg in control was found to be significantly lower than that in Mg treatments. At different stages of incubation, available Mg was positively correlated with exchangeable Mg and negatively correlated with exchangeable Ca. Negative correlation was also observed between available Mg and pH. The dynamics of exchangeable Mg followed the similar trend as in the case of available Mg. On comparison of the efficiency of the different Mg fertilizers in the contribution of exchangeable Mg, magnesite was found superior

(25.7 per cent in karappadam and 24.02 per cent in laterite soil). Magnesium sulphate was second (15.2 per cent in karappadam and 19.6 per cent in laterite). The least efficient was dolomite (11.4 per cent in karappadam and 5.3 per cent in laterite). There was an increase in pH of karappadam after two months of incubation and thereafter there was no considerable variation in pH with advancing periods of incubation. A similar trend was followed by laterite soil. The soil reaction was influenced by the different sources of Mg. The increase in pH of soil with the addition of Mg sources was in the order of dolomite > magnesite > magnesium sulphate. The pH of karappadam soil was lower than that of laterite, in the control as well as in Mg treatments. The pH in Mg treatments was higher than that of the control. Increasing the level of Mg increased the pH of the soil. The specific conductance of soil increased upto two months of incubation both in karappadam and laterite soils. Thereafter in karappadam soil there was no considerable variation in the specific conductance upto four months and then there was a considerable decrease. Corresponding change in specific conductance in laterite soil was inconsistent. On comparing the effect of different sources of Mg on specific conductance, magnesium sulphate increased specific conductance compared to the other two sources upto fourth month of incubation. After six months of incubation, there was no considerable variation in the specific conductance in samples treated with any of the sources. The total Mg content of karappadam was found to be higher than that of laterite. The slowly available

Mg was seen influenced by the different sources of Mg and the lowest amount was seen in samples treated with magnesite and the highest in samples treated with dolomite. Increasing levels of applied Mg increased the slowly available Mg.

In the field experiment with banana (Part 4), the Mg treatments failed to influence the vegetative characters, viz., mean height of plants, girth of plants, total number of leaves, total number of suckers, days to flower, days to mature and total duration of the crop. The effect of treatments on yield and yield characteristics such as weight and length of bunch, number of hands per bunch, weight, length and girth of finger was not significant. Yield was positively correlated with per cent Ca in leaf. No significant difference between treatments was observed in the content of chlorophyll. Total chlorophyll content positively correlated with per cent Mg in leaf (r = 0.3616*). The treatments did not differ significantly in the percentage of N and P by the plant. The Mg content of leaf was decisively influenced by the treatments at the late vegetative stage and at the time of shooting. The treatments differed significantly in their influence on per cent Ca in leaf at early vegetative stage. Of the total Ca uptake, 85 per cent was contributed by leaves. The rest of the amount was distributed as 5 per cent in the rhizome, 5 per cent in the psuedostem and 5 per cent in the fingers. The uptake of Ca by leaves was significantly influenced by the treatments. The contribution of Mg uptake by leaves was 51.3 per cent. About 17.2 per cent was contributed by rhizome, 15.3 per cent by psuedostem and 16.2 per cent by finger. The total uptake of Mg was significantly influenced by the treatments. The maximum uptake was in the treatment with 1500 g MgO given as magnesite. Magnesite was found as good as magnesium sulphate in the supply of Mg in acid soils. The uptake of Mg was found to increase with increased levels of application of MgO. The available Mg content of soil was decisively influenced by the treatments. The available Mg in soil in the absence of added Mg was significantly lower than that in the rest of the treatments. The available Mg content of soil increased with increasing levels of MgO supplied as magnesium sulphate. The treatments could decisively influence the content of exchangeable Mg at the early vegetative stage and at the time of shooting. The treatments with magnesium sulphate showed the highest amount of exchangeable Mg. Exchangeable Mg positively correlated with available Mg ($r = 0.5593^{**}$). The treatments differed significantly in their influence of exchangeable Ca in the early vegetative stage and antagonism between Ca and Mg was observed in the treatment with highest dose of magnesium sulphate. The soil reaction was decisively influenced by the treatments. The treatments with magnesium sulphate exhibited lower pH and the pH was maximum in treatments with dolomite.