SUITABILITY OF MAGNESITE AS A SOURCE OF MAGNESIUM IN ACID RICE SOILS OF KERALA

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By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **Suitability of magnesite as a source of magnesium in acid rice 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.

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8th April, 1992.

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CERTIFICATE

Certified that this thesis entitled **Suitability of magnesite as a source of magnesium in acid rice soils of Kerala** is a record of research work done independently by **Miss Susan Varughese** 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.

Dr. A.I. Jose
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CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Miss Susan Varughese**, a candidate for the degree of Master of Science in Agriculture with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled **Suitability of magnesite as a source of magnesium in acid rice soils of Kerala** may be submitted by Miss Susan Varughese in partial fulfilment of the requirement for the degree.

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INTRODUCTION

Magnesium is the fifth major plant nutrient. It is the only mineral constituent of chlorophyll and, therefore, essential for photosynthesis. Magnesium is also an activator of many enzymes and takes part in protein synthesis. It acts as a P carrier and helps in better P utilization in crop plants. Magnesium increases resistance to harmful environmental influences such as drought and disease as it has positive influence on the swelling and strength of the cell walls and on the permeability of the cell membranes.

Magnesium is a major nutrient for animals, as well as for plants and much attention has been given to the Mg nutrition of ruminants in relation to the incidence of the metabolic disorder hypomagnesaemic tetany (grass tetany) caused by lower than normal Mg content of the herbage dry matter.

Magnesium deficiency has been reported in many crops like coconut, pepper, etc. Major deficiency symptoms are interveinal chlorosis mainly on older leaves producing a streaked patchy effect. In acute deficiency the affected tissue may dry up and die. Leaves usually become small, brittle in final stages and curve upwards at margin.

Magnesium deficiencies are most commonly encountered on light, sandy soils, particularly under continued cropping with the use of concentrated NPK fertilizers. Under these conditions it appears inevitable that replenishment of exchangeable Mg by weathering of soil minerals will be unable to keep pace with the outgoings by drainage and crop removal. Reports of Mg deficiency on soils of heavier texture also appear to be increasing, particularly on strongly weathered and leached soils depleted of primary ferromagnesian minerals and 2:1 lattice clays alike. The above cases generally fall into the category of 'absolute' deficiencies which is aggravated by soil acidity, i.e., a low pH. Instances of Mg deficiency on loamy soils heavily fertilised for arable or horticultural crops are less common, and generally fall into the category of 'induced' deficiencies, where high exchangeable potassium and/or calcium and high base saturation are concomitant factors.

Magnesium deficiency in Indian soils is not of the same magnitude as that of primary nutrients (N, P and K). However, a considerable amount of Mg is removed by crops and lost through runoff and leaching gradually depleting the native magnesium. Fertilizers, manures, soil amendments, industrial wastes, sewage sludges, ground water etc. partially replenish soil magnesium. The partial replenishment cannot go on for long without deleterious effects on crop production. Suitable measures need to be taken to prevent the high loss of magnesium through runoff and leaching and need-based application has to be encouraged.

The importance of magnesium becomes more evident in acid soils (Prasad et al., 1983). Therefore, the use of ameliorating agents such as liming materials bring about a congenial chemical environment in those soils. It has been estimated that acid soils in India comprise about 50 million hectares accounting for 30 per cent of the total land area. Except a small patch of neutral to alkaline soils of Chittoor, the entire state of Kerala comprises of acid soils of varying intensities of acidity.

The acid soils of Kerala, in general, are very poor in magnesium and deficiency of this plant nutrient is very common in many crops in the state. The principal magnesium 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 magnesium. But it contains no water soluble magnesium. However, magnesite is soluble under acid conditions.

Rice, the major food crop of Kerala is mainly grown in a flooded condition. So a knowledge regarding the transformation of various magnesium fertilizers under this condition will be essential for evaluating their efficiency.

Kuttanad alluvium (karappadam) and laterite soils are the two main rice growing tracts of Kerala. The behaviour of the various magnesium fertilizers in these soils should be known for a better magnesium fertilizer management. The mode of transformation of various Mg sources like magnesite, dolomite and magnesium sulphate which were used in this study may vary widely. Hence the present study was taken up with the objectives to study the transformation of magnesium from various Mg sources under submerged condition, to compare the direct and residual effect of magnesite, dolomite and magnesium sulphate on nutrient uptake and yield of rice at different levels of application and to determine whether the costly magnesium sulphate can be replaced by the cheap magnesite in acid rice soils of Kerala.

Review of Literature

REVIEW OF LITERATURE

1. Transformation of Mg in soil

Magnesium is the fifth element in the group of six macronutrients. 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 of oxidation and the radii of ions capable of readily entering into particular crystalline structures of soil minerals (Cooper et al., 1947). According to Clark, as quoted by Jacob (1958), the solid earth crust contains 2.68 per cent Mg on the average. The Mg content of most soils generally lies in the range of 0.05 per cent for sandy soils to 0.5 per cent for clay soils.

1.1 Forms of magnesium in soil

Prince et al. (1947) stated that Mg in soils occurred in water soluble, exchangeable, lattice and primary mineral forms. According to Salmon (1963), the Mg in soils is mainly contained in silicate minerals, and smaller amounts are in exchangeable and water soluble forms. Magnesium carbonate is sometimes present, and some Mg may be held by organic matter in other than exchangeable forms. All these various forms are in equilibrium with each other.

1.1.1 Magnesium bearing minerals

Silicate minerals serve as the main reservoir of soil Mg (Salmon, 1963; Rice and Kamprath, 1968; Mokwunye and Melsted, 1972).

Total Mg in soils is related to mineralogy and hence is a potential indicator of pedological properties and processes. Mg is present in relatively easily weatherable ferromagnesian minerals, such as olivines, pyroxenes, hornblendes and serpentines; and micas such as biotites (trioctahedral). Silicate minerals with Mg as a major constituent are associated mainly with intermediate to basic and ultrabasic igneous rocks. Hence, they are abundant only in relatively young soils, or in regions of slow weathering (Beeson, 1959).

Some soils contain Mg as magnesium carbonate ($MgCO_3$) or dolomite ($CaCO_3 MgCO_3$). In arid or semiarid regions, soils may contain large amounts of Mg as magnesium sulphate ($MgSO_4$) (Metson, 1974). Aderikhin and Belyayev (1974) stated that Mg formed part of clay minerals namely hydromica, montmorillonite and chlorite. In addition it occurred in secondary clay minerals including chlorite, vermiculite, illite and montmorillonite (Kirkby and Mengel, 1976).

1.1.2 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.

Alston (1972) observed a higher content of exchangeable Mg in the soils derived from basaltic parent material. Loganathan (1973) reported exchangeable Mg content of 6.8 to 24, 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.

1.1.3 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 the 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 m M. 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^{2+} for Al^{3+} 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 in the Mg^{2+} ion form.

1.2 Magnesium fractions in soil

Mokwunye and Melsted (1972) devised a scheme for the systematic determination of chemical forms of Mg in the soil by fractionating soil Mg into (1) primary mineral, (2) acid soluble, (3) exchangeable and (4) organic complexed Mg and the distribution of different forms was ranked in the above decreasing order. This scheme was patterned after the potassium fractionation procedures of Rouse and Bertramson (1950).

Stahlberg (1960) stated that chlorites and non-vermiculites followed by illites were the main forms of the acid soluble Mg in Swedish soils. Some of the tropical soils (Moa, Sierra Loene, alluvial complex from South East Asia) had relatively high amounts of acid soluble Mg (Mokwunye and Melsted, 1972). Metson (1974) suggested that the acid soluble fraction played a vital role in replenishing levels of exchangeable Mg in soils. Metson and Brooks (1975) considered this fraction as a measure of the reserve of potentially available non-exchangeable Mg in the soils and it ranged from less than one to about 20 cmol (+) kg^{-1} and comprised 5 to 24 per cent of the total Mg in the soils studied. Metson (1977) reported that acid soluble Mg averaged to about 35 to 40 per cent of the total Mg, but varied from <10 to >60 per cent according to parent material.

Mokwunye and Melsted (1972) and Metson and Gibson (1977) reported that only a small fraction of the total Mg (0.05 to 2.8 per cent) occurred in organic complexed form. The work on this fraction is meagre.

1.3 Effect of soil characters on Mg transformations 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.

1.3.1 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.

In general, a strongly acid soil is low base saturated. Exchangeable Mg is therefore likely to be low, along with other basic cations like Ca, K and Na. It is therefore difficult, if not impossible, to distinguish between an acidity effect involving low pH and/or toxic levels of exchangeable Al, and an absolute deficiency of Mg in soils of low pH and low base saturation. In fact, Salmon (1963) stated that the well known release of Al from acid clays into the soil solution implied that lattice Mg will also be released, that would explain the increased Mg saturation of soils with increased leaching and acidification.

Wiklander and Anderson (1963) observed that exchangeable ions influenced the release of mineral bound ions, and H^+ 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.

1.3.2 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 increase in exchangeable Mg content of the soil in the following order: heath > sandy soils > other sandy soils > clay soils. Chu and Johnson (1985) reported that sand and silt but not clay were the important sources of exchangeable Mg.

1.3.3 Magnesium saturation

Exchangeable Mg expressed as a percentage of the total exchangeable bases determined the availability of Mg to plants and was observed to be a better guide (Alston, 1972).

1.3.4 Organic matter

Due to higher organic matter content of certain acid soils, less exchangeable Mg was lost by leaching (Carolus, 1933). In the Broadbalk wheat experiment at Rothamsted from 1865 to 1966, the exchangeable Mg increased during the first 50 years but decreased since 1914 in the farmyard manure plots (Bolton, 1972). From three year experiments, During and Weeda (1973) reported that dung application to soils increased exchangeable Mg content.

1.3.5 Cation exchange capacity

A positive relationship between exchangeable Mg and CEC of acid soil was observed by Boynton (1947). Martin and Page (1969) stated that exchangeable Ca and exchangeable Mg formed about 5 to 10 per cent of the CEC and these cations played a major role in soil reaction. Kirkby and Mengel (1976) reported that 4 to 20 per cent of the CEC was constituted by exchangeable Mg.

1.4 Availability of Mg in acid sulphate soils

Deficiencies of Ca and Mg have been suggested to be the constraints on rice growth in acid sulphate soils.

Although Ca and Mg are not directly involved in redox reactions in soils, their concentrations in water soluble fraction have been shown to increase following flooding (Ponnamperuma, 1972; Islam and Islam, 1973). Lindsay (1979) stated that most Mg minerals were too soluble to persist in acid soils and indicated that exchange reactions maintained the level of Mg in soil solution at low pH. Rorison (1973) suggested that deficiencies of Ca and Mg were probably important factors associated with poor plant growth in acid sulphate soils. This was supported by Attanandana <u>et al</u>. (1982).

Howeler (1973), Ottow <u>et al</u>. (1983) and Benckiser <u>et al</u>. (1984) claimed that Ca and Mg played an important role in Fe toxicity in rice. They indicated that a multiple nutritional stress was the main cause of Fe toxicity in rice.

Moore and Patrick (1989) reported that the acid sulphate soils were generally undersaturated with respect to Ca and Mg minerals. Cation exchange reactions probably governed the solubility of Ca^{2+} and Mg^{2+} in acid sulphate soils.

Pal <u>et al</u>. (1991) observed that most of the acid sulphate soils are base unsaturated. Of the exchangeable cations, Ca is the highest, followed by Mg.

In rice soils of Kerala, significant increase in soil pH was observed consequent on the addition of Ca and Mg compounds (Varghese, 1963). Potculture experiments on paddy conducted by Varghese and Money (1965) with Vellayani sandy clay loam and by Padmaja and Verghese (1966) with Vellayani red loam indicated that Mg either alone or in combination with Ca and Si, appreciably improved crop growth and significantly increased grain yield and soil pH. Hence it was considered likely that this element may be a seriously limiting factor in crop production in these soils. Liming red loam soils of Kerala at the rate of 2.5 t ha^{-1} of CaO raised the soil pH by 1 to 1.5 units. Liming with CaO and $MgCO_3$ was more effective than liming with CaO alone (Padmaja and Verghese, 1972a). Kuttanad soils showed significant response to liming, depending on the acidity of soils. In karappadam and kari soils 1/4 to 1/2 the lime requirement gave response (Panicker, 1980).

2. Magnesium in crop nutrition

Magnesium plays 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}. Generally the uptake by root crops is about double that of cereals. Deficiencies occur particularly in highly leached humus acid soils or on sandy soils which have been given heavy dressings of lime.

2.1 Magnesium 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, although for the same crop the agreement is quite good, allowing for the variations in yield normally found from soil to soil.

The contents of Mg in plant tissues were usually in the order of 0.1 to 0.5 per cent of the dry matter (Kirkby and Mengel, 1976).

According to Teichman (1957) cereals removed 21 kg ha^{-1} of Mg, the value for fodder beets being 33 kg ha^{-1}. In cereals, the Mg content of the grains was higher than that of the straw. The figures of Jacob (1958) indicated a low uptake (5-8 kg ha^{-1} year^{-1}) for cereals, and low to medium uptake (2-18 kg ha^{-1}) for a range of vegetable crops. Grass and clover hays, grassland clovers and lucerne crops generally showed a moderate uptake of about 7-26 kg ha^{-1} year^{-1}. Sugarbeet and marigolds recorded comparatively high uptake of 30-50 kg ha^{-1}.

Application of Mg increased N uptake by crops (Subramanian et al., 1975; Narayana and Rao, 1982). Beneficial effects of Mg in the presence of K and S in maize and cowpea have been reported (Nad and Goswami, 1983). There was about

9 per cent increase in the mean yield of jute as a result of addition of 40 kg MgO ha^{-1} over no Mg (Kumar and Borthakur, 1980).

Carolus (1933) reported high uptake of Mg by the potato crops at 50-80 days after planting. In India, deficiency of Mg has been observed in potato in acid soils of Nilgiris (Mathan et al., 1973) and also in cabbage and cauliflower at the Vegetable Research Substation (IARI), Katrain (Shukla and Banerjee, 1980).

In a trial with young coconut palms grown in sandy soil, application of Mg increased trunk growth, total number of leaves, palm height, flowering percentage and cumulative nut yield (Kamalakshiamma and Pillai, 1980). A foliar level of 0.2 per cent Mg in frond 14 might be considered as critical for regulating the Mg nutrition of the palm. The increase in yield of nuts on correction could be as high as 40 per cent. Quantitatively, the amount of Mg removed by the palm was, on an average, 50 per cent more than of P. Thus Mg is an important element in the nutrition of the palm and is mostly required for the effective functioning of the leaves, and through its photosynthetic function, it regulates the growth as well as the productivity of the palm (Cecil, 1991).

2.1.1 Magnesium nutrition in rice

Magnesium increased the ratio of grain to chaff. The P_2O_5 content in grain was a maximum for the Mg applied plants (Varghese and Money, 1965).

The form or level of Mg had no significant effect on tillering. The yields of grain and straw were not significantly influenced by the different forms of Mg at the rates of 25 and 50 kg MgO ha^{-1}. However, the Mg treatments tended to increase the yield of rice over control (Nayar and Koshy, 1966). Magnesium was found to produce a more extensive root system (Padmaja and Verghese, 1966).

Magnesium depressed the absorption of K by the rice plant indicating a K/Mg antagonism. An increase in the absorption of Mg was generally accompanied by a decrease in the uptake of Ca (Nayar and Koshy, 1969; Narayana and Rao, 1982). The quality of grain and straw as indicated by their protein content was markedly increased by the application of soil amendments like CaO or $MgCO_3$ (Padmaja and Verghese, 1972b).

Application of steatite resulted in decreased per cent of N, P, K and Ca in both grain and straw, while a significant increase in Mg and Si contents was observed (Panicker, 1980).

Nutrients identified as necessary to produce high dry matter in upland rice in Nigera'a humid tropics were N, K, Mg and Si. Among these nutrients, Mg and Si were found to be involved in the protection of rice plants against grain discolouration and their application increased the grain yield of three rice varieties by an average of 34 per cent (Yamauchi and Winslow, 1989).

2.2 Soil factors influencing Mg uptake

The capacity of a soil to supply Mg to plants can be expected, in the first instance, to depend on the levels of exchangeable Mg in the soil and the rate at which it can be replenished. Secondly, it will be affected by the levels of other exchangeable cations that may have an antagonistic effect on Mg uptake. A third factor is the nature of the crop, which determines the amount of Mg needed and the rate at which it is required and also, to some extent, the efficiency with which it is extracted from the soil. Thus the above factors may be broadly classified into (1) absolute Mg deficiency and (2) induced Mg deficiency.

2.2.1 Absolute Mg deficiency

Several authors have observed that the limiting values increase as the soil texture becomes heavier (Schachtschabel, 1954, 1957; Brugger, 1961 and Holmes, 1962). However, most reports of Mg deficiency have been associated with sandy soils in which exchangeable Mg was about 0.2 to 0.3 cmol (+) kg^{-1} (Hester et al., 1947; Semb and Tragethon, 1958; Welte and Werner, 1963 and Reith, 1963).

Instead of using exchangeable Mg as a measure of soil Mg levels for plants, some authors proposed exchangeable Mg as a percentage of cation exchange capacity (CEC) or of total exchangeable bases (TEB) (Prince et al., 1947). By this, it is hoped to make allowance for the clay or organic matter content of the soil, and for the presence of excess antagonistic ions. Bear and Toth (1948) reported a value of 6 per cent of CEC or 7 per cent of TEB for chlorotic plants for response to applied Mg, while Yamasaki et al. (1956) proposed a value of 10 per cent CEC as the ideal to aim for Mg deficient soils.

2.2.2 Induced dificiencies

This situation usually arises as a result of competition from some antagonistic cations such as K and Ca. This occurred most frequently in intensively cultivated and heavily fertilized horticultural soils.

2.2.2.1 Potassium/magnesium

Garner et al. (1923) reported that 'sand drown' was accentuated by the use of potassic fertilizers. High exchangeable K depressed the uptake of Mg (Walsh and O'Donohoe, 1945; Boynton, 1947; Camp, 1947; Prince et al., 1947; Bear and Toth, 1948; Johannesson, 1951; Mc Naught and Gdanitz, 1952; Jacob, 1958; Doll and Hossner, 1964 and Dejou and de Montard, 1982).

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

Salmon (1964) found decrease in the Mg concentrations by increasing K applications in grass which was then correlated (r = 0.99) with the activity ratios in the soil according to the formula $\sqrt{a_{Mg}} / \sqrt{a_{Ca+Mg}} + B.a_K$ (proportionality factor B being determined experimentally). Birch _et_ _al_. (1966) observed that the depressed yield due to heavy applications of K fertilizers to cereals, potatoes and sugarbeets, in 43 experiments was not caused by K/Mg interaction. Magnesium depressed the absorption of K by the rice plant indicating a K-Mg antagonism (Nayar and Koshy, 1969). Hossner and Doll (1970) stated that when the Mg/K ratio fell below 0.8, there was response to Mg application. Draycott and Durrant (1970) observed that the K/Mg ratio in the soil was poorly related to the percentage yield response to Mg. Increasing K fertilizer highly significantly reduced total and water soluble Mg and increased the fibre Mg content of the grass (McIntosh _et_ _al_., 1973a). Holcomb and White (1974) and Sekhon _et_ _al_. (1975) stated that low concentration of Mg in the chrysanthemum and wheat fields respectively might be due to high availability of K in the soils.

Mg uptake was increased with increasing K concentration up to 511 μ _M_. At higher concentrations of K there was a decrease in Mg uptake rate (Fageria, 1983). Osiname and Kang (1986) reported an increased rate of loss of Mg by leaching due to K application.

Application of Ca and/or Mg increased the concentration of K^+ in soil solution but decreased exchangeable K

(Bandyopadhyay and Goswami, 1988). Rate of Mg uptake was doubled when the K concentration at the root surface decreased below 20 μ M (Seggewiss and Jungk, 1988). Jayaraman (1988) observed that added Mg did not show any marked variations in the availabilities of K, Mg, Fe and Mn.

2.2.2.2 Calicum/magnesium

Loew in 1892 was the first to propose in Ca-Mg ratio hypothesis (Moser, 1933).

The effect of the ratio of lime to Mg was much more stronger at higher concentrations of these salts than at lower levels (Gile, 1913). Many of the authors like Mehlich (1946), Johnson *et al*. (1957), Halstead *et al*. (1958) and Berry and Ulrich (1970) have stressed that Mg deficiency symptoms were reduced to a minimum when the exchangeable Ca to Mg ratio in the soil was kept at the optimum level of 3:1, while Jacoby (1961) reported that the Ca/Mg ratio should not exceed eight. Ca/Mg ratio is an important factor for an optimum yield in Karnataka soils also (Krishnappa *et al*., 1974). But Russell (1973) observed that Ca-Mg ratio had very little influence on soil productivity, as very good and very poor soils were shown to have identical ratios.

At a constant level of exchangeable K, the Mg concentration in the grass was linearly related to the soil activity ratio, $\sqrt{a_{Mg}/\ a_{Ca+Mg}}$ (Salmon, 1964).

McNaught (1964) while reviewing the results of fertilizer trials in pastures stated that small depression in herbage Mg could be expected from the application of ground limestone. Liming acid soils might influence Mg uptake either because of associated pH factor or because of Ca levels (Christenson et al., 1973). According to Fageria (1983) increasing the Ca concentration increased Mg absorption upto 250 μ M, while at higher concentrations, Mg absorption was decreased. Edmeades et al. (1985) and Myers et al. (1988) were of the opinion that liming reduced exchangeable Mg in acid soils. Application of lime resulted in the release of non-exchangeable K and slight Mg fixation in most of the acid soils of Portugal (Gama, 1987). Mohebbi and Mahler (1988) reported that the extractable Mg decreased slightly as pH increased from 3.3 to 7 on liming. In the absence of applied K and Mg, the addition of $Ca(OH)_2$ increased the leaching loss of K and Mg initially present in the soil (Phillips et al., 1988).

2.2.2.3 Hydrogen/magnesium

The specific effects of soil acidity or of the exchangeable H/Mg ratio, on plant uptake of Mg have been little studied. Welte and Werner (1963) suggested that the H/Mg antagonism was more intense than the more recognised K/Mg antagonism, Christenson et al. (1973) reported that soil pH level appeared to effect Mg uptake by oats more than did the level of soil Ca.

3. Magnesium source

Magnesium is found widely distributed in a variety of minerals. Among the more commercially important ones are magnesite, brucite, dolomite and magnesium sulphate and $MgCl_2$ salts often found in natural brines. These minerals are the raw materials for a host of products including fertilizers (Wicken and Duncan, 1983).

Varying results were obtained with regard to the suitability of magnesite as a source of Mg in comparison to other sources.

In sandy soils of pH near 7, calcined magnesite containing about 90 per cent MgO was a good source of Mg for beans, but yield was sometimes depressed when the material was applied to the soil just before planting. Yields were not depressed when the material was applied 10 days before seeding or was mixed with the fertilizer (Wolf, 1963).

Vasil'eva (1966) in long term field experiments on acid sandy-loamy soils reported that lime + Mg gave higher crop yields than either alone. Mg fertilizers, particularly alkaline ones like magnesite enabled less lime to be applied and improved yields and crop quality.

Application of 45 kg of Mg as $MgCO_3$ and 11 kg of Si as sodium silicate over and above the normal schedule of N, P and K considerably increased all the productive factors, such as tillering, height of plants, earhead length and 1000 grain weight of rice in Kerala (Padmaja and Verghese, 1966). Studies conducted in the acid soils of the Kuttanad rice tract of Kerala showed that $MgCO_3$ did not have any influence on the yield and tiller production in paddy, variety Ptb 10 (Kurup and Ramankutty, 1969). Application of 250 and 500 kg $MgCO_3$ per hectare to groundnut increased the yield and nodulation (Tajuddin, 1970). Liming with CaO and $MgCO_3$ was more effective than liming with CaO alone in red loam soils of Kerala (Padmaja and Verghese, 1972a). The quality of grain and straw as indicated by their protein content was markedly increased by the application of soil amendments like CaO or $MgCO_3$ (Padmaja and Verghese, 1972b).

During (1972) and Hogg and Toxopeus (1973), on the basis of field trials on pasture considered magnesite the perfect source of Mg for moderately acid soils under moderate to high rainfalls (>900 mm). Application of 2 per cent magnesium sulphate was found to increase the grain yield of rice by 17 per cent (Mahapatra and Gupta, 1978).

3.1 Comparison between Mg sources

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). 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 magnesium sulphate. Plants treated with $MgCO_3$ gave the highest percentage of N in the grain while the P content of grain was the highest under the $MgSO_4$ treatment and lowest under $MgCO_3$ treatment (Nayar and Koshy, 1966). During (1972) considered imported magnesite approximately equivalent to the soluble sulphate minerals as a source of Mg for pasture on moderately acid soils. McIntosh et al. (1973b) found calcined magnesite approximately equivalent to epsom salts or magnesium ammonium phosphate in raising the Mg concentration of a mixed (grass-clover) sward. Magnesium in magnesium sulphate is more rapidly effective than Mg in the carbonate form (Zehler, 1982). Effect of $CaCO_3$ and $MgCO_3$ on the yield of soybean and gram has been found to be superior to other salts of Ca and Mg (chloride, nitrate and sulphate) in acid soils of Ranchi, Bihar (Prasad et al., 1983).

3.1.2 Dolomite and magnesium sulphate

Munk (1961) reported that powdered dolomite was superior to magnesium sulphate under acid conditions up to 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) magnesium sulphate (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 magnesium sulphate. In strongly acid soil, the Mg uptake by potato was greater from half burned dolomite than from magnesium sulphate, in weakly acid soil both magnesium sulphate and half burned dolomite supplied similar amounts of Mg to fodder beet, while at nearly neutral reaction magnesium sulphate was distinctly superior and crude dolomite rather inefficient.

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

3.1.3 Magnesite, dolomite and magnesium sulphate

Vasil'eva (1965) reported that magnesite and dolomite were more effective on acid soils while magnesium sulphate and schoenite ($K_2SO_4MgSO_46H_2O$) were more effective for crops of greater acid tolerance (flax, winter rye, potatoes, oats).

3.2 Residual effect of Mg sources

Efficiency of magnesium sulphate and dolomite was the highest in the year of application, and decreased to 75 per cent and 35 per cent of the original effect in the second and third residual years respectively. Residual effect of dolomite on potatoes was similar to that of magnesium sulphate + lime (Jaskowski, 1969).

The main loss of Mg was by leaching. The level of exchangeable Mg declined until the loss from leaching was balanced by that released by clay mineral weathering. The amount of available Mg is likely to be unsatisfactorily low for sensitive crops like sugarbeet, carrots and potatoes in sandy soils, but satisfactory in heavier soils. Most of the fertilizer Mg remained in the exchangeable form. The Mg of Mg fertilizers and Mg limestone was easily lost by leaching (Harrod, 1971).

Materials and Methods

MATERIALS AND METHODS

The study consisted of two experiments namely,

1. an incubation study with two acid rice soils of Kerala, three sources of Mg (magnesite, dolomite and magnesium sulphate) and two levels of Mg (25 and 50 kg MgO ha^{-1}) to study the transformation of Mg from the different sources under waterlogged condition;

2. a potculture experiment with the same soils, Mg sources and levels using rice as the test crop grown continuously for two seasons to study the direct and residual effects of added Mg under rice culture in waterlogged condition.

Collection of soil samples

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

INCUBATION STUDY

A laboratory incubation study was carried out with two soils (the karappadam and laterite), three sources of Mg namely magnesite ($MgCO_3$) containing 27.00 per cent MgO, dolomite ($CaMg(CO_3)_2$) with 15.36 per cent MgO and magnesium sulphate ($MgSO_4\ 7H_2O$) with 15.95 per cent MgO and two levels of Mg (25 and 50 kg MgO ha^{-1}) in a completely randomised design with two replications. The treatment combinations were

Treatment number	Treatment notation	Forms and levels of MgO, kg ha^{-1}	Soil
1	T_1	No Mg (control)	Karappadam
2	T_2	Magnesite 25	"
3	T_3	Magnesite 50	"
4	T_4	Dolomite 25	"
5	T_5	Dolomite 50	"
6	T_6	Magnesium sulphate 25	"
7	T_7	Magnesium sulphate 50	"
8	T_8	No Mg (control)	Laterite
9	T_9	Magnesite 25	"
10	T_{10}	Magnesite 50	"
11	T_{11}	Dolomite 25	"
12	T_{12}	Dolomite 50	"
13	T_{13}	Magnesium sulphate 25	"
14	T_{14}	Magnesium sulphate 50	"

1. Experimental procedure

The soils were weighed (700 g) and transferred into plastic containers of 1 kg capacity. The basic properties of the soils are given in Table 1. The magnesium sources as per the treatments described above were added and thoroughly mixed with the soil. The soils were continuously waterlogged, maintaining water at the level of 2 cm above the soil and incubated at room temperature (28 - 31°C) for 180 days. Soil samples were drawn regularly at 15 days interval throughout the period of incubation for chemical analyses.

2. Analytical procedure

The particle size analysis of the soils was carried out by the international pipette method (Piper, 1942). pH was determined using an Elico pH meter in a soil water suspension of 1:2.5 ratio. Specific conductance of 1:2.5 soil water extract was measured using a conductivity bridge.

The organic carbon was determined by Walkley and Black method as described by Jackson (1958). Cation exchange capacity of the soil was determined by the method of Peech et al. (1947).

Total elemental analysis of P, K, Ca and Mg was done using diacid ($HClO_4$ and 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 EDTA 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 and water soluble Ca and Mg were determined by EDTA titration method (Hesse, 1971).

Fractionation of Mg was carried out using the procedure of Mokwunye and Melsted (1972). The procedure was as follows:

Exchangeable Mg

This was extracted by shaking 1 g soil with 20 ml of 1 N neutral ammonium acetate for 40-60 min followed by centrifuging for 10 min at 2000 rpm and the supernatant was decanted. Additional 20 ml aliquots of ammonium acetate were used with 10 min shaking periods followed by centrifuging until a total of 100 ml of the supernatant solution was collected.

Organic complexed Mg

The residue obtained from the above ammonium acetate extraction was oxidised with 10 per cent hydrogen peroxide. The oxidised mixture was centrifuged, decanted, and the residue was washed with successive 1 N neutral ammonium acetate aliquots until 100 ml of the supernatent solution was obtained.

Acid soluble Mg

The acid-soluble Mg was extracted from the residue from the peroxide treatment with 30 ml of 1 N nitric acid. The mixture was boiled gently for 15 min on an electric hot plate and then filtered. The residue was then washed with aliquots of 0.2 N nitric acid until a total of 100 ml of extract was obtained.

Mineral Mg

The residue from the previous extraction including the filter paper was transferred to a 250 ml beaker and digested with 25 ml of the triple acid mixture (23 parts of conc. nitric acid, 23 parts of phosphoric acid, and 54 parts of perchloric acid). The digested mixture was cooled after which 5 ml of 5 N hydrochloric acid was added and the mixture filtered and washed with distilled water until 100 ml of combined filtrate was collected.

Magnesium in the various extracts was estimated with the Carl-Zeiss Atomic Absorption Spectrophotometer (λ = 285.2 nm). Interference by other ions was suppressed by the addition of 5 ml of 4000 ppm Sr in 50 ml of total solution.

POTCULTURE EXPERIMENT

A potculture experiment was conducted with two soils, three sources of Mg and two levels of Mg using a photoinsensitive variety of rice (Annapoorna) to study the direct and residual effect of magnesite in comparison to dolomite and magnesium sulphate under conditions of plant growth. The soils, sources of Mg and levels of Mg were the same as that described under the incubation study. The experiment was laid out in a completely randomised design with eight replications. Rice was grown continuously for two seasons (from July 1990 to January 1991). The treatment combinations were the same as that described under the incubation study.

The residual effect of magnesite was assessed by continuing the experiment for the second season without the application of magnesium fertilizers.

1. Experimental procedure

Earthen pots of uniform size (30 x 30 cm) were used for the study. These pots were filled with 10 kg of dried and powdered soil. Sufficient water was added to the pots to wet the soil and to bring out a puddled condition. Application of N, P, K, lime and organic matter was followed as per the package of practices (70 kg N, 35 kg P_2O_5, 35 kg K_2O, 600 kg lime and 5 t organic matter per ha) recommended by the Kerala Agricultural University (Anon., 1989). Magnesium was added in different forms and levels as per the treatment combinations. These fertilizers were mixed thoroughly with the soil.

Rice seedlings were raised by wet method using the seeds obtained from the Agricultural Research Station, Mannuthy. Seedlings (20 days old) were transplanted at the rate of four hills per pot. Plant protection and other inter-cultural operations were carried out as per the recommendations of the Kerala Agricultural University (Anon., 1989). Standing water was maintained till 15 days before harvest. Soil and plant samples were drawn at 15 days interval for chemical analyses. The grain and straw were harvested at full maturity.

2. Collection of soil and plant samples for analyses

Soil samples were collected at 15 days interval in both the seasons of crop growth. The collected soil samples were air-dried, ground and passed through 2 mm sieve and stored in polythene bags for chemical analyses.

Plant samples were collected at 15 days interval in both the seasons. These samples were dried and ground in a mechanical grinder and preserved in separate containers to study the uptake of nutrients.

3. Analytical procedure

3.1 Soil sample

Forms of Ca and Mg, available K, pH, EC and organic carbon of the air dried sample were determined as in the incubation study.

3.2 Plant sample

For the determination of P, K, Ca and Mg, 1 g of powdered plant sample was digested with a triacid mixture (HNO_3:H_2SO_4:$HClO_4$ in 10:1:4 ratio). The P content from this extract was determined colorimetrically by the vanadomolybdophosphoric yellow colour method in nitric acid system (Jackson, 1958). For the determination of K, the extract was diluted and read in an EEL flame photometer. Total Ca and Mg were determined by EDTA titration method (Hesse, 1971). Nitrogen content was determined by the microkjeldahl digestion-distillation method as described by Jackson (1958).

Statistical analysis of the data

Statistical analysis of the data was carried out by adopting the standard methods described by Panse and Sukhatme (1967).

Results and Discussion

RESULTS AND DISCUSSION

In order to assess the suitability of magnesite as a source of magnesium in acid rice soils of Kerala, a laboratory incubation study and potculture experiment were conducted the results of which are discussed hereunder.

INCUBATION STUDY

In this experiment, two acid rice soils of Kerala namely karappadam and laterite were incubated under submerged condition for a period of 180 days with and without the addition of magnesite, dolomite and magnesium sulphate at the rate of 25 and 50 kg MgO ha^{-1}. Soil samples were collected at fortnightly intervals (numbered as periods 1-12) and analysed for Mg fractions, available Ca and K, pH and EC.

1. General characteristics of the soil selected for the study

Two important soils of the state, namely an alluvium of Kuttanad (karappadam) collected from Moncompu, Alapuzha 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 1.

The karappadam soil was sandy loam in texture, non-saline (EC = 1.309 dS m^{-1}) and acidic (pH = 5.0). According to

Table 1. General characteristics of the soil

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	5.0	5.4
Specific conductance, dS m^{-1}	1.309	0.612
Organic carbon, %	1.85	1.16
Cation exchange capacity, cmol (+) kg^{-1}	20.68	16.03
Total N, %	0.266	0.168
Total P, %	0.083	0.292
Total K, %	0.088	0.138
Total Ca, %	1.169	0.835
Total Mg, %	0.108	0.087
Available N, kg ha^{-1}	365.2	409.2
Available P, kg ha^{-1}	16.80	76.16
Available K, kg ha^{-1}	280.0	420.0
Available Ca, kg ha^{-1}	4175	3666
Available Mg, kg ha^{-1}	1136	700
Water soluble Mg, ppm	Traces	Traces
Exchangeable Mg, ppm	230.46	140.28
Organic complexed Mg, ppm	16.85	11.53
Acid soluble Mg, ppm	315.20	299.45
Mineral Mg, ppm	411.25	321.80

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 feature of the Kuttanad alluvium. As regards the distribution of Mg fractions in the soil, it contained 230.5 ppm of NH_4OAc extractable Mg, 16.9 ppm of organic complexed Mg, 315.2 ppm of acid soluble Mg and 411.3 ppm of mineral Mg. The content of water soluble Mg was negligible. The relative contribution of Mg fractions to the total Mg status of the soil shows that the insoluble mineral fractions dominate over the soluble fraction. The NH_4OAc extractable Mg content was only 23.7 per cent of the total whereas the acid soluble and mineral fractions contributed 32.4 and 42.2 per cent respectively.

The laterite soil was sandy clay loam in texture and less acidic (pH = 5.4) than the karappadam soil and contained less 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 contents of different Mg fractions and total Mg were lower than those of the karappadam soil probably due to the decreased content of organic matter in this soil. As in the case of karappadam soil insoluble fractions dominated over the soluble fractions. Exchangeable Mg contributed only 18.2 per cent of the total Mg and the content of water soluble Mg was practically nil.

2. Magnesium fractions

2.1 Water soluble Mg

The values of water soluble Mg as influenced by the treatments at different periods of incubation are presented in Table 2. The mean values for Mg sources, soil types and Mg levels are given in Table 3 and 4. The coefficients of linear correlation among Mg fractions and soil chemical characteristics have been 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 under submergence with and without the addition of Mg fertilizers at two different levels. Therefore, the levels of Mg fractions and the most important soil characteristics which are expected to decisively influence the transformation of soil Mg were monitored at close intervals of 15 days for a period of six months.

The overall trend of changes in water soluble Mg revealed that the content of water soluble Mg gradually increased as a consequent of incubation under submergence up to the fifth stage (two and a half months) and thereafter declined

Table 2. Water soluble Mg in soil as influenced by the treatments at different periods of incubation, ppm

Treatment	Period of incubation, fortnights												
	1	2	3	4	5	6	7	8	9	10	11	12	Mean
T_1	0.0	4.51	18.04	34.07	72.14	24.05	38.08	19.94	32.06	40.08	31.09	20.04	27.84
T_2	0.0	15.69	20.04	100.20	108.20	31.10	60.12	5.37	42.39	51.16	60.12	75.11	47.46
T_3	0.0	33.05	34.07	136.30	160.30	38.08	56.11	9.07	48.10	64.13	70.22	78.37	60.65
T_4	0.0	58.11	32.06	31.09	86.17	48.10	92.18	19.32	31.44	50.10	42.08	16.87	42.30
T_5	0.0	48.39	42.08	36.07	126.40	69.41	126.35	24.02	38.12	94.19	52.10	45.63	58.56
T_6	0.0	24.87	36.07	102.20	106.20	106.20	70.14	30.12	59.16	60.12	76.15	109.48	65.06
T_7	0.0	32.92	46.09	108.20	124.30	91.53	98.20	31.23	62.12	76.15	89.25	108.69	72.39
T_8	0.0	8.02	10.02	31.09	42.08	18.04	50.10	4.54	18.18	32.06	30.12	22.04	22.19
T_9	0.0	22.30	26.05	60.12	62.12	54.11	57.11	13.27	52.10	46.09	49.32	52.10	41.23
T_{10}	0.0	31.90	59.13	84.17	86.17	74.15	72.14	34.45	62.12	88.18	74.14	61.09	60.64
T_{11}	0.0	6.54	46.09	156.30	168.30	28.06	140.25	9.45	49.11	56.11	34.07	16.03	59.20
T_{12}	0.0	9.79	60.12	146.30	134.30	58.12	134.27	16.03	60.12	60.12	40.08	25.17	62.03
T_{13}	0.0	21.30	18.04	96.19	92.18	126.30	184.37	20.86	71.40	88.18	89.25	91.36	74.95
T_{14}	0.0	35.63	42.08	152.30	94.19	142.28	160.29	29.31	88.18	94.19	94.89	100.20	86.13
Mean	0.0	25.22	35.00	91.04	104.50	64.97	95.69	19.07	51.04	64.35	59.50	58.73	55.76

in a fluctuating pattern to reach a minimum level at the eighth stage (four months). Then, the level again gradually increased and remained rather stable at the tenth, eleventh and twelth stages. It is observed that the pattern of changes in water soluble Mg during different stages in control plots which received no addition of Mg fertilizers was same as that of those which received Mg treatments. This is because the amount of Mg added through the sources is rather insignificant as compared to the total quantity of Mg originally present in the soil. In other words the overall changes during the incubation under submergence are dominated by the dynamics of the transformation of forms of Mg derived from the native soil Mg. However, the contribution to water soluble Mg in certain stages by the Mg sources was substantial. The initial increase in the content of water soluble Mg with the advancing period of incubation can be attributed to release of water soluble Mg from the added Mg sources as well as mineral Mg originally present in the soil. Decrease in the content of water soluble Mg at the eighth stage is indicative of the conversion of water soluble 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 containig minerals of low solubility. This has been further evidenced by the relatively high content of acid soluble Mg noticed in the soil at the fourth month. These observations tend to state that the transformation of Mg in soil is highly dynamic and the release and fixation exist

Table 3. Mean values of Mg fractions, NH$_4$OAc extractable Ca, available K, pH and EC as influenced by Mg sources and soil

Soil	Control	Magnesite	Dolomite	Magnesium sulphate	
Karappadam	27.84	54.06	50.43	68.73	Water soluble Mg, ppm
Laterite	22.19	50.94	60.62	80.54	
Karappadam	2.106	2.543	2.341	2.546	NH$_4$OAc extractable Mg, cmol (+) kg^{-1}
Laterite	0.546	0.751	0.803	0.977	
Karappadam	12.05	14.19	15.36	12.88	Organic complexed Mg, ppm
Laterite	9.38	14.18	12.98	11.22	
Karappadam	404.0	442.7	441.4	434.1	Acid soluble Mg, ppm
Laterite	317.0	312.6	323.4	324.2	
Karappadam	395.2	390.8	386.0	378.2	Mineral Mg, ppm
Laterite	323.0	355.9	338.6	335.3	
Karappadam	6.638	6.774	7.000	7.795	NH$_4$OAc extractable Ca, cmol (+) kg^{-1}
Laterite	6.277	5.685	6.617	5.759	
Karappadam	283.3	282.7	276.4	301.4	Available K, kg ha^{-1}
Laterite	375.8	365.7	375.4	364.1	
Karappadam	5.6	5.7	5.6	5.6	pH
Laterite	6.3	6.3	6.3	6.2	
Karappadam	0.256	0.243	0.234	0.262	Specific conductance, dS m^{-1}
Laterite	0.097	0.112	0.144	0.197	

side by side, the equilibrium being decided by the dominance of the nature of the reaction involved.

There was considerable increase in water soluble Mg of the soil on Mg application in all the periods of incubation (Table 2 and 3). In karappadam this increase was from 27.84 ppm to 57.44 ppm while in laterite it was from 22.19 ppm to 64.03 ppm. This is understandably due to the increased availability of Mg in the soil from the applied sources.

On comparing the different Mg sources, it was found that magnesium sulphate gave the maximum water soluble Mg in both the soils (68.73 and 80.54 ppm in karappadam and laterite soils respectively) (Table 3). The difference between magnesite and dolomite was inconsistent. Magnesite was 78.66 and 63.25 per cent as efficient as magnesium sulphate with regard to the release of water soluble Mg in karappadam and laterite soils respectively. The higher efficiency of magnesium sulphate when compared to the carbonate forms of Mg is due to the lesser content of water soluble Mg in magnesite and dolomite. The reported solubility for magnesium sulphate with a dissociation log K° of 8.15 reflects a very high solubility for this mineral. It is much too soluble to form in well drained soils. The carbonates of Mg decrease in solubility in the order magnesite (log K° = 10.69) > dolomite (log K° = 18.46) (Lindsay, 1979).

Table 4. Mean values of Mg fractions, NH_4OAc extractable Ca, available K, pH and EC as influenced by levels of Mg application

Levels of MgO	Soil		Sources of Mg			
kg ha^{-1}	Karappadam	Laterite	Magnesite	Dolomite	Magnesium sulphate	
25	51.61	58.46	44.35	50.75	70.01	Water soluble Mg, ppm
50	63.87	69.60	60.65	50.30	79.26	
25	2.326	0.716	1.478	1.426	1.659	NH_4OAc extractable Mg, cmol (+) kg^{-1}
50	2.627	0.971	1.816	1.719	1.864	
25	13.59	11.73	13.44	13.43	11.12	Organic complexed Mg, ppm
50	14.69	13.85	14.94	14.91	12.98	
25	435.2	322.4	370.6	379.3	386.7	Acid soluble Mg, ppm
50	443.6	317.8	384.8	385.5	371.7	
25	389.5	345.7	381.7	358.9	362.3	Mineral Mg, ppm
50	380.4	340.8	365.0	365.7	351.2	
25	7.413	5.843	6.117	6.593	7.175	NH_4OAc extractable Ca, cmol (+) kg^{-1}
50	6.966	6.197	6.343	7.024	6.379	
25	289.7	369.8	328.1	322.4	338.8	Available K, kg ha^{-1}
50	283.9	367.0	320.2	329.4	326.7	
25	5.6	6.3	6.0	5.9	5.9	pH
50	5.7	6.3	6.0	6.0	6.0	
25	0.238	0.129	0.177	0.204	0.172	Specific conductance, dS m^{-1}
50	0.254	0.112	0.178	0.174	0.198	

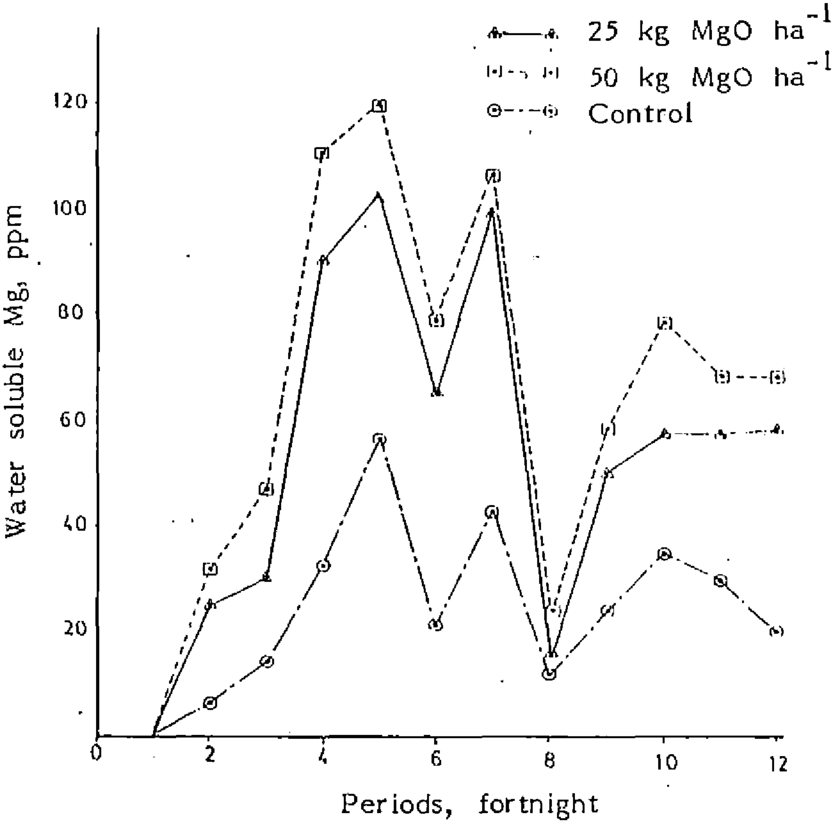

Fig. 1 Water soluble Mg at different periods of incubation as influenced by levels of Mg application

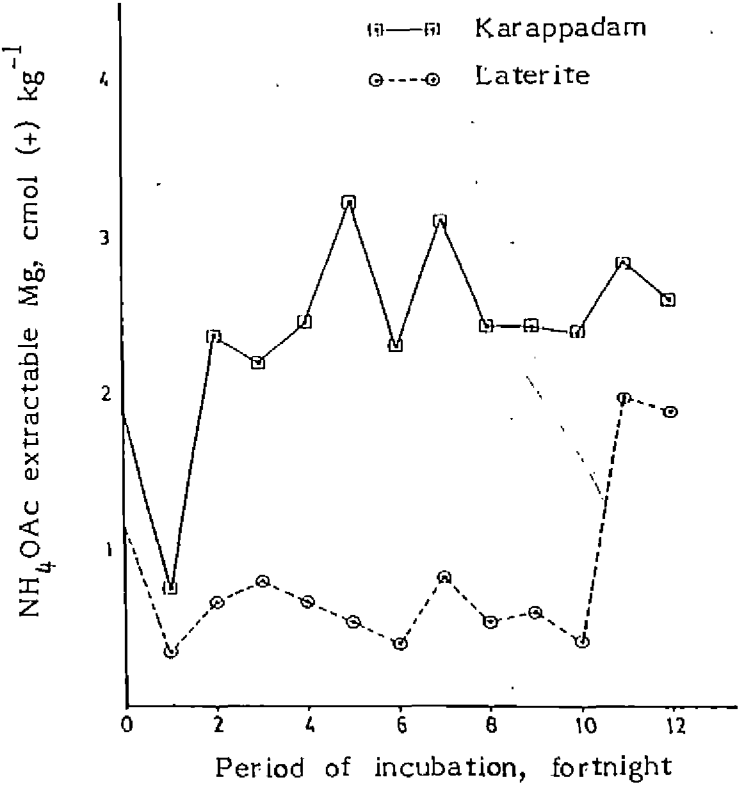

Fig.2 NH$_4$OAc extractable Mg at different periods of incubation as influenced by soils

Water soluble Mg increased with higher levels of Mg application in both the soils and in the case of all the three sources (Table 4 and Fig.1). This can be attributed to the increased release of Mg from Mg sources at the higher levels of application.

2.2 Ammonium acetate extractable Mg

Data on the influences of various treatments on NH_4OAc extractable Mg at different periods of incubation in karappadam and laterite soils are presented in Tables 3, 4, 5 and 13.

During the first fortnight of incubation, there was a marked decrease in the NH_4OAc extractable Mg. This may be due to the dilution effect consequent to flooding. Then there was a sharp increase in NH_4OAc extractable Mg content probably due to the release of exchangeable Mg from the applied sources. After the initial rapid increase, NH_4OAc extractable Mg content remained more or less the same till the fifth month of submergence in a slightly fluctuating manner. After that there was again a marked increase in NH_4OAc extractable Mg content. This may be attributed to the release of Mg from nonexchangeable to exchangeable form with prolonged period of flooding.

Ammonium acetate extractable Mg content of the karappadam soil was significantly higher than that of the laterite soil in all the stages of sampling (Fig.2). This may

Table 5. Ammonium acetate extractable Mg in soil as influenced by treatments at different periods of incubation, cmol (+) kg^{-1}

Treatment	Periods, fortnights											
	1	2	3	4	5	6	7	8	9	10	11	12
T_1	0.501	1.503	1.169	2.182	3.340	1.879	3.006	2.338	2.338	2.338	2.338	2.338
T_2	0.585	1.670	2.422	2.004	3.424	2.314	3.090	2.171	2.386	2.420	2.692	2.672
T_3	1.169	3.674	1.754	2.839	4.008	2.301	3.424	2.589	2.592	2.672	3.090	3.065
T_4	0.835	2.923	1.837	2.222	3.006	2.464	2.672	2.086	1.971	1.637	2.422	2.422
T_5	0.585	1.670	2.753	2.839	3.424	2.427	2.422	2.338	2.377	2.589	3.257	3.006
T_6	1.086	2.505	2.505	2.505	2.171	2.304	3.424	2.672	2.589	2.672	2.762	2.192
T_7	0.501	2.670	3.006	2.589	3.173	2.340	3.591	2.754	2.786	2.398	3.340	2.561
T_8	0.418	0.585	0.668	0.500	0.251	0.167	0.919	0.167	0.251	0.587	0.752	1.284
T_9	0.418	0.167	1.002	0.919	0.334	0.207	0.585	0.585	0.418	0.167	1.252	1.561
T_{10}	0.251	0.334	0.835	0.334	0.668	0.501	0.919	1.002	0.919	0.373	2.255	2.004
T_{11}	0.167	0.418	0.768	0.668	0.334	0.167	0.501	0.251	0.334	0.180	2.505	1.421
T_{12}	0.501	0.667	0.668	0.818	0.585	0.334	0.919	0.420	0.752	0.884	2.589	2.422
T_{13}	0.418	1.002	0.752	0.668	0.668	0.752	0.752	0.501	0.585	0.364	2.088	1.878
T_{14}	0.167	1.420	0.835	0.752	0.919	0.668	1.169	0.874	0.919	0.203	2.422	2.672
Mean	0.543	1.515	1.498	1.560	1.879	1.344	1.956	1.482	1.515	1.392	2.411	2.250

be due to the high native Mg in the karappadam soil as compared to that of the laterite. Even in the absence of added Mg, NH_4OAc extractable Mg of the karappadam was much higher than that of the laterite (Table 3). Ammonium acetate extractable Mg was found to increase considerably on Mg application, from 2.106 to 2.477 cmol (+) kg^{-1} in karappadam and from 0.546 to 0.844 cmol (+) kg^{-1} in laterite soil. This is obviously due to the increased availability of Mg in the soils.

On comparing the different forms of Mg used, magnesium sulphate supplied the maximum NH_4OAc extractable Mg in both the soils. In karappadam soil, magnesite (99.9%) and domomite (95.3%) were almost as efficient as magnesium sulphate. Their suitability in laterite soil was such that the magnesite and dolomite were 76.9 and 82.2 per cent as efficient as magnesium sulphate (Table 3). The higher efficiency of carbonate forms of Mg fertilizers in karappadam soil may be attributed to the high acidic condition prevailing in that soil leading to their increased solubility. On the 180th day of submergence, all the three Mg sources were on par, because of the increased release of Mg from carbonate forms on prolonged waterlogging.

Ammonium acetate extractable Mg content increased with the increased level of Mg applied in both the soils and in the case of all the three Mg sources (Table 4). This is due to the increased availability of applied Mg in the soils. Significant difference between the two levels of Mg applied on NH_4OAc

extractable Mg was mainly noticed during the later stages of submergence. This is due to the fact that during the initial stages of incubation solubility of the applied material is practically nil irrespective of the level of the applied Mg. But when the material is waterlogged exchangeable Mg is released and the difference between the levels becomes conspicuous.

Regression equations were worked out to establish the relationship between NH_4OAc extractable Mg and other Mg fractions and also with other soil nutrients and pH (Table 14). Simple linear regression equations showing the degree of change in acid soluble Mg, mineral Mg and available K at different periods of incubation with NH_4OAc extractable Mg are given in Fig.5, 6 and 7.

2.3 Organic complexed Mg

Results on the effect of sources and levels of applied Mg on the organic complexed Mg at different periods of incubation in karappadam and laterite soils of Kerala are presented in Tables, 3, 4, 6 and 13.

The organic complexed Mg constituted only 1.61 per cent of the total Mg in the soil. This was in line with the reports of Mokwunye and Melsted (1972) that it formed only 0.05 to 2.8 per cent of the total Mg. Also it was not significantly correlated to other Mg fractions, Ca or K. The level of organic complexed Mg of the soil was found to fluctuate with the

Table 6. Organic complexed Mg in soil as influenced by treatments at different periods of incubation, ppm

Treatments	Periods, month						
	1	2	3	4	5	6	Mean
T_1	10.74	11.97	13.42	11.11	12.06	13.01	12.05
T_2	8.13	17.02	16.73	11.15	11.93	17.72	13.78
T_3	10.15	18.68	18.12	11.22	12.27	17.18	14.60
T_4	6.83	17.35	18.97	14.15	12.48	18.34	14.69
T_5	7.37	20.08	19.30	14.43	13.89	21.13	16.03
T_6	8.98	11.16	14.79	13.09	12.94	12.93	12.31
T_7	10.32	11.92	17.37	13.68	11.77	15.65	13.45
T_8	6.14	8.62	9.99	9.89	7.89	13.74	9.38
T_9	8.86	10.50	12.66	19.86	11.04	15.61	13.09
T_{10}	13.51	11.64	15.18	18.48	15.88	16.94	15.27
T_{11}	8.61	9.75	11.73	11.36	11.97	19.65	12.17
T_{12}	9.15	13.08	15.22	13.16	13.38	18.70	13.78
T_{13}	10.97	11.67	10.60	7.65	9.82	8.78	9.92
T_{14}	10.83	15.91	14.19	10.84	12.08	11.19	12.51
Mean	9.33	13.52	14.88	12.86	12.10	15.75	13.07

advancement of the period of incubation (Table 6). This may be related to the changes taking place to the organic matter in the soil under submerged condition.

There was significant difference between the soils in respect of their organic complexed Mg content. It was much higher in karappadam soil than in the laterite, which may be attributed to the high organic matter content and native organic complexed Mg content of the karappadam soil.

On comparing the influence of various Mg fertilizers on organic complexed Mg content of the soil, it was found that the content of organic complexed Mg was higher in samples supplied with carbonate forms of Mg (Fig.3). In karappadam soil, release of organic complexed Mg was the highest in dolomite applied soils (15.36 ppm) followed by magnesite (14.18 ppm), while in laterite soil it was in the order of magnesite (14.18 ppm) and then dolomite (12.98 ppm) (Table 3). This is apparently due to the better efficiency of the carbonate forms to raise the pH of the soil because of their alkaline nature; thus creating a more favourable condition for the decomposition of organic matter and release of Mg from the complexed form.

There was a significant increase in the organic complexed Mg of the soils with increase in the levels of applied Mg. Also there was a marked increase in the organic complexed Mg on Mg addition, from 12.05 to 14.14 ppm in karappadam and

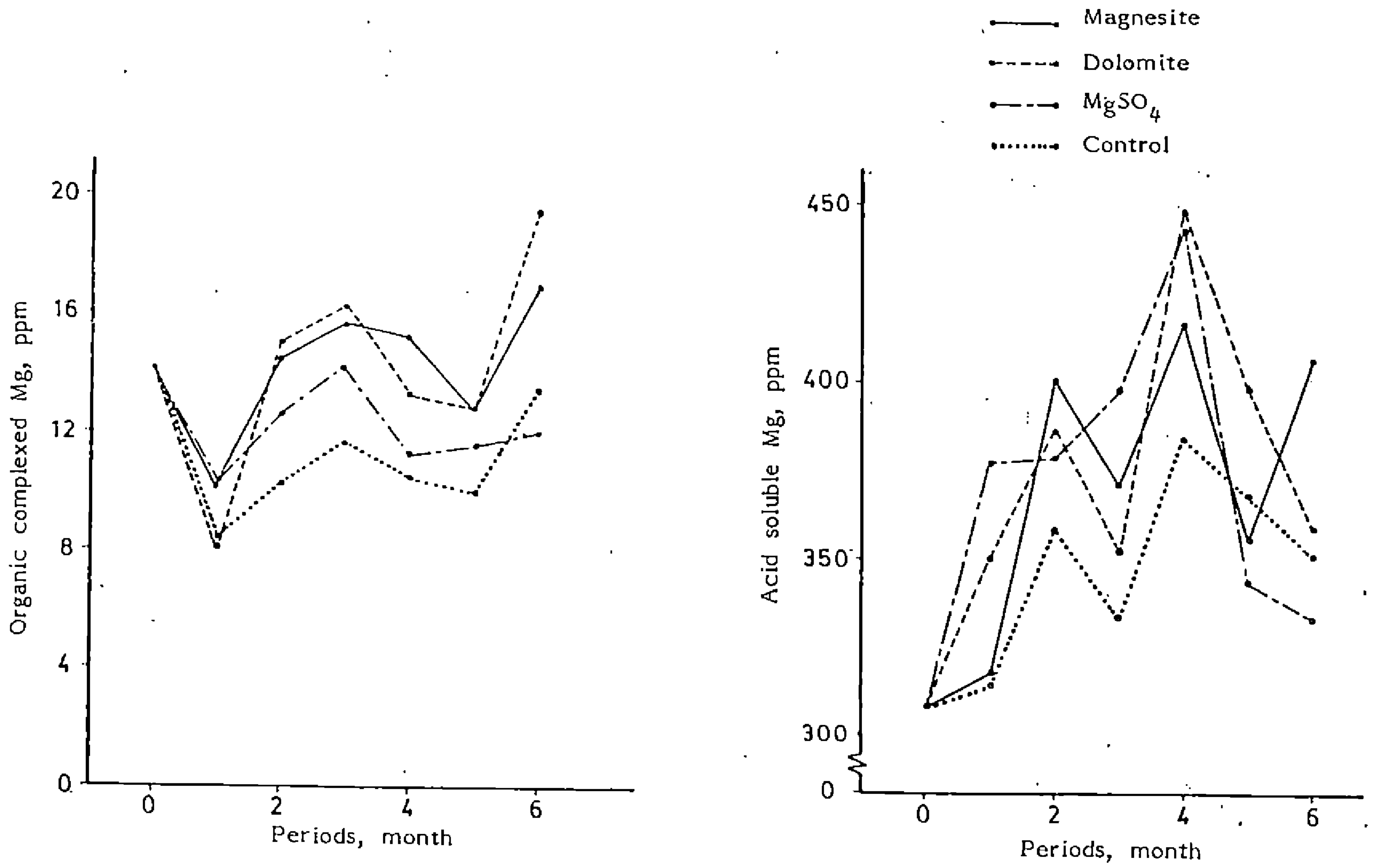

Fig.3 Mg fractions at different periods of incubation as influenced by forms of Mg fertilizers

from 9.38 to 12.79 ppm in laterite. This is understandably due to the increased availability of Mg in the soils as a result of which Mg ions would have been complexed with soil organic matter.

2.4 Acid soluble Mg

Acid soluble Mg as influenced by various treatments in karappadam and laterite soils is presented in Tables 3, 4, and 7.

Acid soluble Mg refers to that part of soil Mg which is not immediately available to the plants. It is a function of the type of clay present and particle size distribution. Metson (1974) suggested that this fractions plays a vital role in replenishing the levels of exchangeable Mg in soils.

The general trend of changes in acid soluble Mg revealed that its content increased as a consequence of incubation under submergence up to the eighth stage (fourth month) and thereafter declined. This increase in acid soluble Mg on incubation may be correlated to the raised pH on submergence. The reduced acidity consequent to flooding may result in decreased solubility of Mg resulting in enhanced acid soluble Mg content.

Even in the absence of added Mg, there was an increase in acid soluble Mg from 315.2 to 404.0 ppm in karappadam soil and from 299.5 to 316.99 ppm in laterite on incubation. The reason may be the same as that cited above. On Mg addition, it

Table 7. Acid soluble Mg in soil as influenced by treatment at different periods of incubation, ppm

Treatments	Periods, month						
	1	2	3	4	5	6	Mean
T_1	312.1	391.2	387.2	464.6	488.1	380.1	404.0
T_2	323.2	502.7	380.4	458.3	447.6	470.1	430.4
T_3	315.6	515.8	478.4	511.8	410.7	498.3	455.1
T_4	391.9	480.7	368.9	473.5	488.2	359.5	427.1
T_5	396.1	496.2	451.9	499.6	474.7	415.5	455.7
T_6	438.8	469.6	497.0	523.2	399.7	361.2	448.3
T_7	418.8	451.2	461.1	560.1	328.9	299.7	420.0
T_8	315.5	324.0	279.2	304.1	357.4	321.9	317.0
T_9	328.8	276.1	304.6	318.9	290.2	346.1	310.8
T_{10}	299.1	308.2	323.7	375.8	270.3	312.4	314.5
T_{11}	303.3	291.1	311.7	428.3	319.9	334.3	331.4
T_{12}	306.9	281.3	277.9	391.6	311.8	322.9	315.4
T_{13}	288.6	320.6	330.9	308.8	358.9	342.8	325.1
T_{14}	363.6	274.0	300.6	381.5	290.5	329.9	323.4
Mean	343.00	384.5	368.2	428.6	374.1	363.9	377.0

was further increased to 439.4 ppm in karappadam and to 320.1 ppm in laterite which may be the contribution from the added sources.

Acid soluble Mg content of the karappadam soil was significantly higher than that of the laterite soil both in the presence and absence of added Mg. This may be attributed to the high native acid soluble Mg of the karappadam soil.

Different sources of Mg used had significant influence on acid soluble Mg in the soil (Fig.3). In karappadam soil, acid soluble Mg was higher in samples supplied with magnesite and dolomite than in those supplied with magnesium sulphate. This may be due to the lesser water soluble Mg content in magnesite and dolomite. So the acid soluble fraction will be higher.

There was no significant difference between the two levels of Mg applied on acid soluble Mg during the initial two months, thereafter there was a significant difference. This may be due to the fact that during initial stages of incubation solubility of the applied material is negligible. But as a result of waterlogging, Mg release is increased and the difference between the levels becomes marked.

Acid soluble Mg was positively correlated with NH_4OAc extractable Mg (r = 0.97**) which is in line with Metson's (1974) finding that this fraction plays a vital role in replenishing the levels of exchangeable Mg in soils. It is also positively correlated with mineral Mg (r = 0.818**), NH_4OAc extractable Ca (r = 0.726**) and EC (r = 0.926**) of the soil. It is negatively correlated with available K (r = -0.947**) and pH (r = -0.961**). Regression equation giving the relationship between acid soluble Mg and NH_4OAc extractable Mg is given in Table 14 and Fig.5.

2.5 Mineral Mg

Influence of various treatments on mineral Mg in karappadam and laterite soil under submerged condition is presented in Tables 3, 4 and 8.

There was a sharp decline in mineral Mg content during the initial two fortnights. After that there was a gradual increase. The initial sharp decrease may be attributed to the sudden release of the other Mg fractions on submergence. This is supported by the reports of Lindsay (1979) that many of the Mg minerals under submerged condition get dissociated into Mg^{2+} ions and silicic acid.

eg. $Mg_3Si_4O_{10}(OH)_2$ (talc) $+ 4H_2O + 6H^+ \rightleftharpoons 3Mg^{2+} + 4H_4SiO_4$

$Mg_3Si_4O_{10}(OH)_2\ 2H_2O$ (vermiculite) $+ 2H_2O + 6H^+ \rightleftharpoons 3Mg^{+2} + 4H_4SiO_4$

In the absence of added Mg, mineral Mg decreased from 411.25 ppm to 395.15 ppm in karappadam soil. The reason may be the dissolution of native mineral Mg to more available forms on

Table 8. Mineral Mg in soil as influenced by treatments at different periods of incubation, ppm

Treatments	Periods, month						
	1	2	3	4	5	6	Mean
T_1	303.5	372.7	378.0	428.4	447.7	440.7	395.2
T_2	311.1	368.8	475.3	399.5	442.5	463.1	410.0
T_3	248.2	355.5	379.4	379.8	470.9	395.2	371.5
T_4	288.2	338.1	426.0	427.8	415.3	392.8	381.4
T_5	312.1	367.6	396.9	460.0	426.1	380.7	390.6
T_6	245.9	375.6	405.8	339.6	437.5	458.6	377.2
T_7	211.1	337.1	413.2	396.2	461.3	456.3	379.2
T_8	278.7	324.3	276.5	326.4	304.4	427.5	323.0
T_9	352.8	284.2	313.4	411.9	326.3	431.1	353.3
T_{10}	318.9	348.6	337.3	403.9	333.8	408.2	358.5
T_{11}	253.5	360.2	320.2	323.6	331.6	429.6	336.4
T_{12}	277.1	328.4	342.2	347.6	338.1	411.8	340.8
T_{13}	290.6	341.8	350.5	319.2	360.6	421.6	347.4
T_{14}	219.8	304.6	339.9	376.2	319.6	380.0	323.2
Mean	279.4	343.4	367.8	381.4	386.8	421.1	363.3

incubation under submerged condition. In the laterite soil there was not much difference in mineral Mg content on incubation without Mg addition.

On Mg addition, mineral Mg increased from 322.95 to 343.3 ppm in laterite soil. This may be the result of the fixation of added Mg as mineral Mg. But in karappadam soil, no such increase was noticed which may be due to the higher dissolution of mineral Mg under more acidic condition prevailing in the karappadam soil.

Mineral Mg content was significantly higher in karappadam than in laterite soil which may be attributed to the high native mineral Mg in the karappadam soil.

In general when the effect of various sources on mineral Mg content of the soil was studied, it was found that mineral Mg was maximum in samples supplied with magnesite, followed by dolomite and then magnesium sulphate in both the soils (Fig.4). This may be due to the fact that Mg is present in relatively easily soluble form in magnesium sulphate, so the chances of getting converted to mineral form is less. But in carbonate Mg sources, Mg in not so easily soluble, so may get fixed to mineral form in course of time.

Mineral Mg was positively correlated with NH_4OAc extractable Mg (r = 0.817**), acid soluble Mg (r = 0.818**), NH_4OAc extractable Ca (r = 0.548*) and EC (r = 0.818**) and

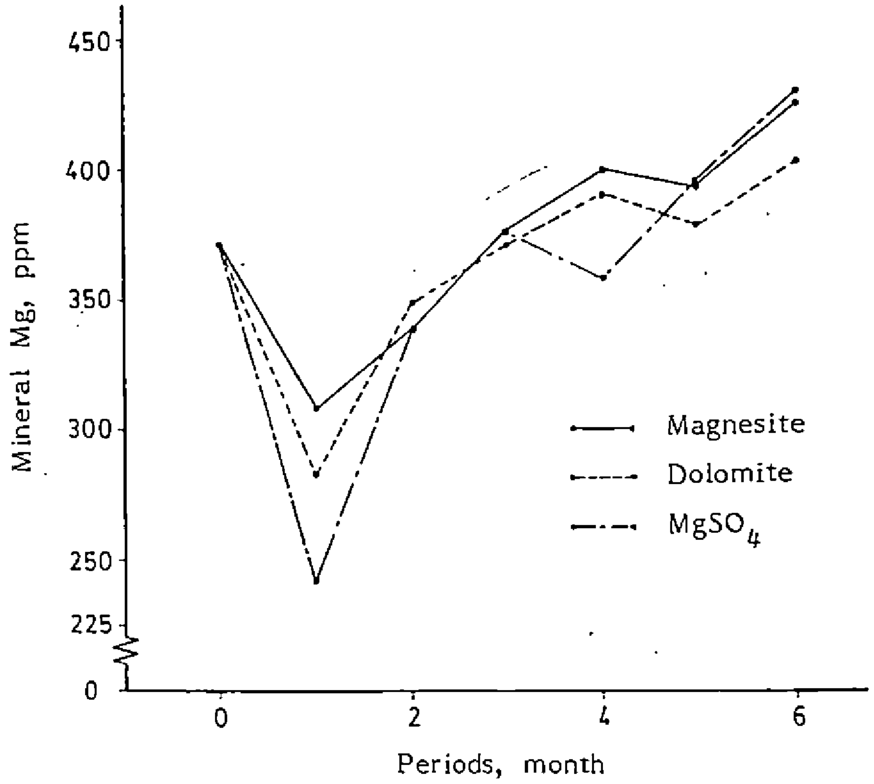

Fig.4 Mineral Mg at different periods of incubation as influenced by forms of Mg fertilizers

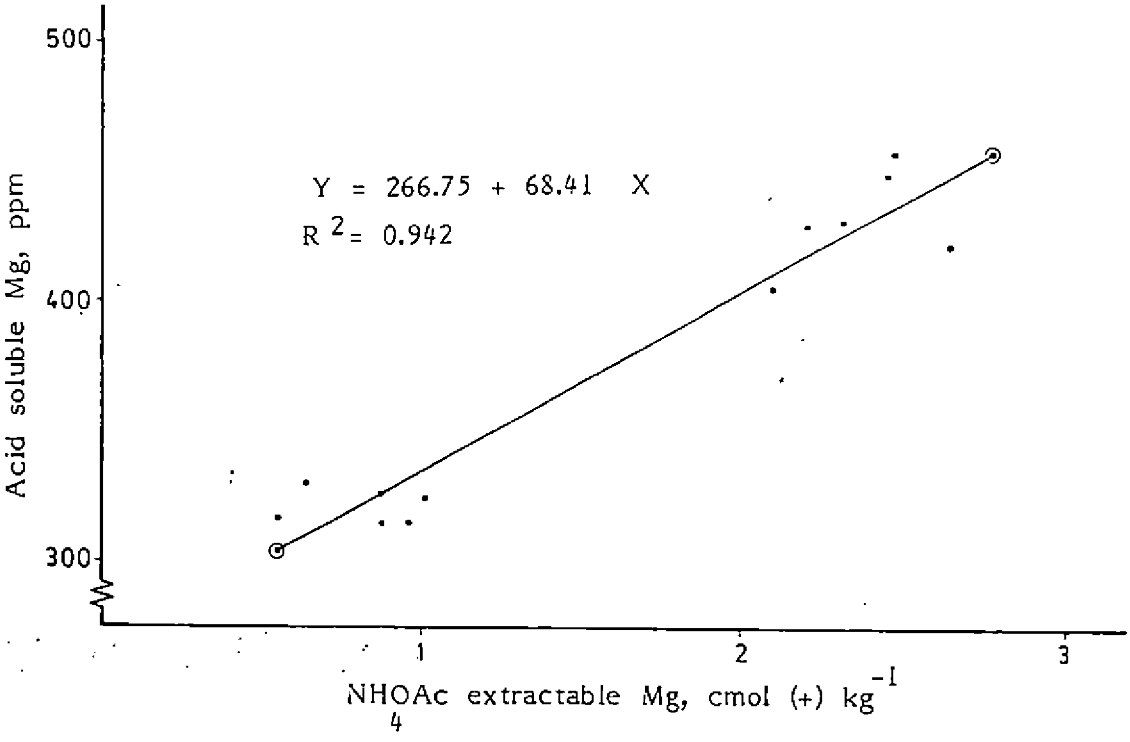

Fig.5 Relationship between NH_4OAc extractable Mg and acid soluble Mg (incubation study)

negatively correlated with available K (r = -0.881**) and pH (r = -0.850**). Regression equations showing the relationship between mineral Mg and other soil characters are given in Table 14. The relationship between mineral Mg and NH_4OAc extractable Mg is given in Fig.6.

2.6 Ammonium acetate extractable Ca

Data on the influence of various treatments on the NH_4OAc extractable Ca content in karappadam and laterite soils at different periods are given in 3, 4, 9 and 13.

There was a slight decline in NH_4OAc extractable Ca in the first fortnight may be due to the dilution effect due to submergence. Then there was a sudden increase and decrease in the NH_4OAc extractable Ca content during the initial stages of incubation. This can be attributed to sudden release and fixation of Ca from the native sources. After that there was not much variation in the NH_4OAc extractable Ca content since it would have attained an equilibrium condition by that time. In general, Ca content increased on incubation under submerged condition due to the release from native sources. Ammonium acetate extractable Ca was significantly higher in karappadam soil than in laterite soil. This can be assigned to the high native exchangeable Ca of the karappadam soil.

The difference between the various Mg sources with regard to the NH_4OAc extractable Ca content of the soil was inconsistent.

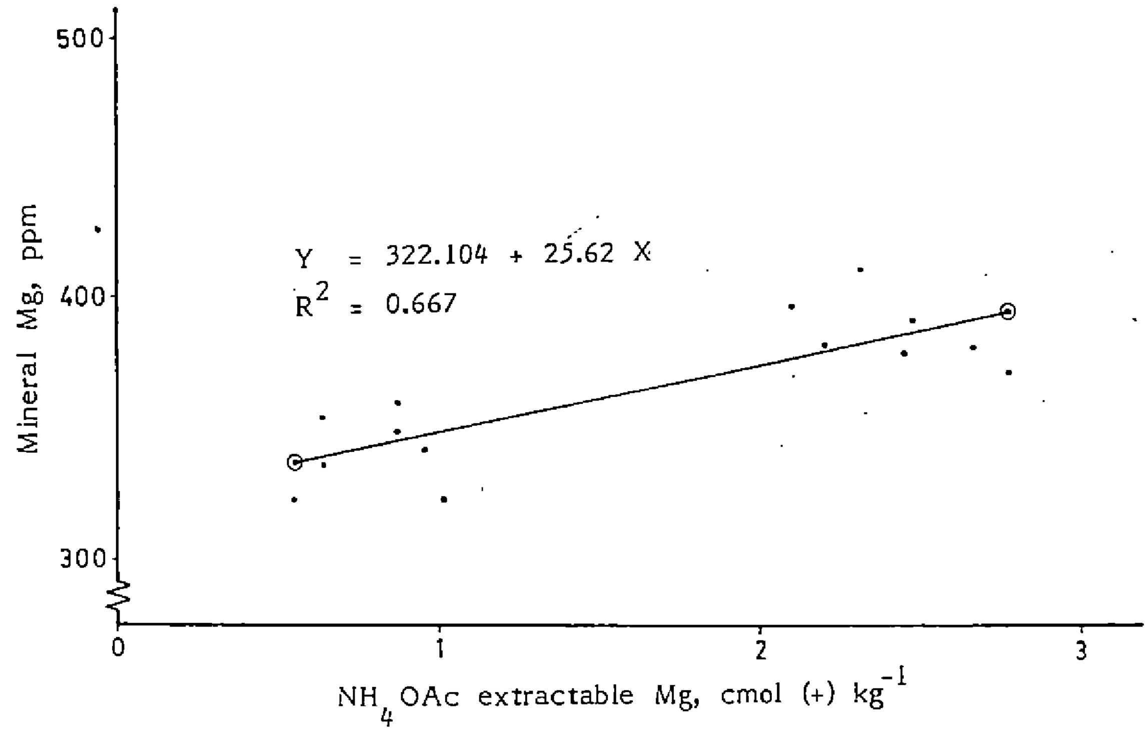

Fig.6 Relationship between NH_4OAc extractable Mg and mineral Mg (incubation study)

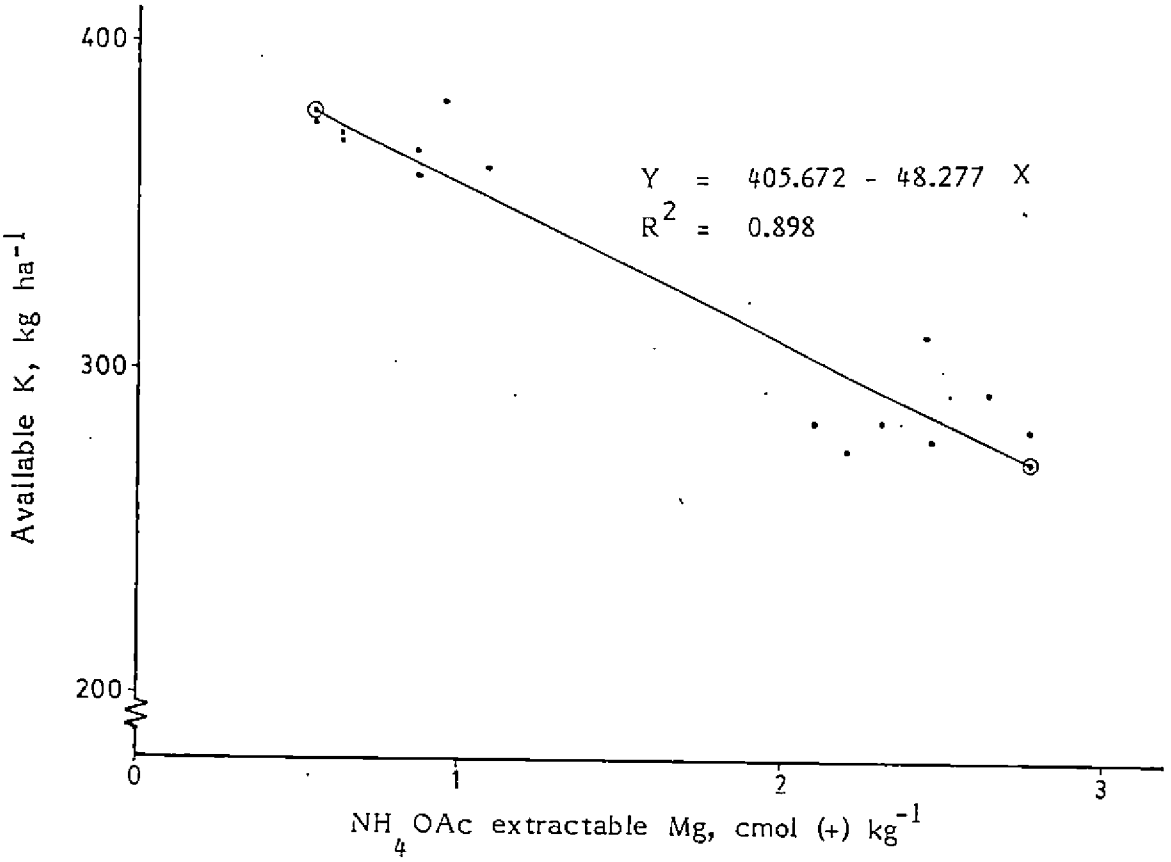

Fig.7 Relationship between NH_4OAc extractable Mg and available K (incubation study)

Table 9. Ammonium acetate extractable Ca as influenced by treatments at different periods of incubation, cmol (+) kg^{-1}

Treatment	Periods, fortnight												
	1	2	3	4	5	6	7	8	9	10	11	12	Mean
T_1	4.01	10.02	5.01	6.35	8.18	6.68	7.18	7.01	6.68	5.34	6.01	7.68	6.64
T_2	4.18	13.36	5.51	7.01	7.52	6.85	7.01	6.85	6.35	5.43	6.60	7.35	7.00
T_3	4.01	9.85	6.01	6.18	7.35	6.35	7.18	6.85	5.93	5.51	6.18	7.18	6.55
T_4	4.01	9.52	6.01	5.68	7.68	6.85	7.52	7.52	6.35	6.01	6.51	7.01	6.76
T_5	4.34	11.86	5.34	7.18	8.68	7.01	7.43	7.43	6.85	5.51	6.68	7.52	7.24
T_6	4.01	18.37	7.55	6.85	8.68	6.68	7.27	7.77	7.01	7.18	6.35	7.18	3.48
T_7	4.34	13.36	6.93	6.35	7.68	6.35	6.93	7.18	6.68	7.04	6.01	6.51	7.11
T_8	2.92	11.19	5.26	5.68	6.10	5.51	5.43	6.01	6.01	6.01	7.18	8.02	6.28
T_9	2.92	11.52	5.26	6.18	6.01	5.68	4.59	7.60	6.68	6.35	7.47	7.85	5.03
T_{10}	3.09	9.52	5.34	5.51	5.34	5.51	5.26	7.52	6.18	5.85	7.01	7.52	5.14
T_{11}	3.42	10.02	5.60	6.01	5.68	5.01	5.85	6.76	6.35	6.51	7.35	8.52	6.42
T_{12}	3.17	11.86	5.85	7.35	5.85	5.34	5.43	7.18	6.68	6.68	7.85	8.50	6.81
T_{13}	3.17	6.86	5.51	6.35	5.51	5.60	5.26	5.85	5.68	6.01	7.18	7.52	5.87
T_{14}	3.34	5.51	4.84	5.85	6.18	5.18	5.68	5.68	5.43	5.85	6.85	7.35	5.64
Mean	3.64	10.92	5.70	6.32	6.89	6.04	6.29	6.94	6.35	6.16	6.80	7.55	6.58

The two levels of Mg applied did not have any significant influence on NH_4OAc extractable Ca of the soil.

2.7 Available K

Data on the influence of various sources and levels of Mg on available K of the soil under submerged condition are presented in Tables 3, 4 and 10.

In the first fortnight of incubation, there was a decrease in available K content, may be due to the dilution effect. Then there was a sharp increase, which can be attributed to the release of K from fixed forms under submerged condition. Thereafternot much change in available K content was observed.

Available K content was significantly higher in laterite soil than in karappadam which can be assigned to the higher native K content and relatively neutral condition prevailing in laterite soil. On Mg addition there was not much change in the available K of the karappadam soil, but in laterite there was a decrease in available K content from 375.83 to 368.4 kg ha^{-1} indicating a K/Mg antagonism.

Available K of the soils decreased with increase in the levels of applied Mg from 25 to 50 kg MgO ha^{-1}. This decrease was from 289.7 to 283.9 kg ha^{-1} in karappadam and from 369.8 to 366.95 kg ha^{-1} in laterite. Also it was found that available K

Table 10. Available K in soil as influenced by treatments at different periods of incubation, kg ha^{-1}

Treatment	Periods, fortnight												
	1	2	3	4	5	6	7	8	9	10	11	12	Mean
T_1	143.4	344.4	162.4	311.6	319.2	277.2	308.0	316.4	280.0	260.4	327.7	348.6	283.3
T_2	155.7	358.4	224.0	319.2	280.0	285.6	305.2	313.6	270.6	249.2	311.9	336.0	284.1
T_3	152.3	341.6	232.4	313.2	316.4	280.0	302.4	316.4	256.9	257.6	291.6	313.6	281.2
T_4	141.1	313.6	238.0	277.2	294.0	263.2	294.0	299.8	308.2	282.8	288.4	295.7	294.7
T_5	142.2	313.6	229.6	280.0	299.6	274.4	294.0	311.9	296.8	288.4	285.6	322.4	278.2
T_6	156.8	380.6	318.6	327.6	302.4	280.0	310.8	347.2	340.9	3424.8	314.6	319.2	310.4
T_7	147.8	347.2	280.0	324.8	288.4	268.8	324.8	322.0	319.1	291.2	298.5	295.7	292.4
T_8	170.2	425.6	330.4	396.4	341.6	364.2	341.6	406.4	388.9	335.6	460.3	548.3	375.6
T_9	161.3	403.2	333.2	380.8	330.4	355.6	316.4	483.7	372.4	364.0	442.4	520.3	372.0
T_{10}	153.4	422.8	291.2	372.4	282.8	352.8	319.2	470.4	358.4	347.2	425.6	515.2	359.3
T_{11}	179.2	465.8	338.8	372.4	308.0	296.8	324.8	377.7	361.3	383.6	471.9	561.4	370.1
T_{12}	177.0	431.2	344.4	407.6	347.2	341.6	330.4	411.6	340.7	420.0	434.2	581.5	380.6
T_{13}	171.4	417.2	347.2	369.6	291.2	388.7	338.8	364.0	371.1	396.4	412.6	537.6	367.1
T_{14}	170.2	400.4	308.0	358.4	338.8	350.0	341.6	369.6	358.4	397.6	400.8	537.6	361.0
Mean	158.7	383.3	284.2	343.7	310.0	312.8	318.0	365.0	330.3	328.5	369.0	431.0	327.9

in the soil was highly negatively correlated with NH_4OAc extractable Mg (r = -0.948**), giving a clear evidence of K/Mg antagonism (Table 13). Figure 7 illustrates the negative relationship between available K and NH_4OAc extractable Mg.

2.8 pH

Data on the effect of various sources and levels of applied Mg on pH of the soil are presented in Tables 3, 4 and 11.

pH of the soils was found to increase considerably on incubation, from 5.0 to 5.6 in karappadam and from 5.4 to 6.26 in laterite in the absence of added Mg. On Mg addition, it was further increased to 5.64 in karappadam and to 6.3 in laterite. This is due to the neutralisation of soil reaction under submerged condition. Mg, a basic cation, further increased the pH.

On comparing the different Mg sources it was found that pH was maximum in soils supplied with magnesite indicating that it is a better source of Mg in acid soils. Efficiency of different sources in correcting soil reaction was in the order of magnesite > dolomite > 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.

Table 11. Soil pH as influenced by treatments at different periods of incubation

Treatment	Periods, fortnight												
	1	2	3	4	5	6	7	8	9	10	11	12	Mean
T_1	5.3	5.6	5.6	5.6	5.7	5.8	5.9	6.1	5.6	5.1	5.3	5.5	5.6
T_2	5.4	5.3	5.6	5.8	5.8	5.8	5.9	6.0	5.7	5.3	5.5	5.6	5.6
T_3	5.5	5.6	5.8	5.9	5.9	5.8	5.9	6.0	5.7	5.3	5.4	5.6	5.7
T_4	5.3	5.4	5.6	5.7	5.7	5.8	5.8	5.9	6.6	5.3	5.5	5.7	5.6
T_5	5.4	5.5	5.7	5.8	5.8	5.9	5.9	6.0	5.6	5.3	5.5	5.7	5.7
T_6	5.3	5.5	5.7	5.8	5.8	5.9	5.9	6.0	5.5	5.0	5.2	5.5	5.6
T_7	5.3	5.6	5.8	5.9	5.9	5.8	6.0	6.1	5.6	5.3	5.4	5.6	5.7
T_8	5.5	6.0	6.1	6.2	6.2	6.3	6.4	6.6	6.5	6.4	6.5	6.6	6.3
T_9	5.9	6.2	6.2	6.3	6.3	6.2	6.3	6.5	6.4	6.3	6.3	6.5	6.3
T_{10}	6.0	6.3	6.4	6.5	6.4	6.2	6.4	6.5	6.5	6.5	6.5	6.5	6.4
T_{11}	6.0	5.6	6.1	6.3	6.3	6.1	6.4	6.5	6.3	6.2	6.3	6.5	6.2
T_{12}	6.1	6.3	6.2	6.1	6.1	6.1	6.4	6.6	6.4	6.3	6.4	6.6	6.3
T_{13}	5.6	6.4	6.4	6.4	6.3	6.2	6.3	6.4	6.3	6.2	6.3	6.4	6.3
T_{14}	5.9	6.0	6.2	6.2	6.2	6.2	6.4	6.5	6.4	6.2	6.3	6.4	6.2
Mean	5.6	5.8	5.9	6.0	6.0	6.0	6.1	6.3	6.0	5.8	5.9	6.0	6.0

pH was positively correlated with available K of the soil (r = 0.955**) and negatively correlated with NH_4OAc extractable Mg (r = -0.947**), acid soluble Mg (r = -0.961**), mineral Mg (r = -0.850**), NH_4OAc extractable Ca (r = -0.707**) and EC (r = -0.949**) (Table 13).

2.9 Electrical conductance

Effect of various treatments on specific conductance of karappadam and laterite soils under submerged condition is presented in Tables 3, 4 and 12.

In general, the specific conductance of the soils on incubation was found to fluctuate in an irregular manner.

EC of the karappadam soil was significantly higher than that of the laterite soil during incubation, may be due to the higher native specific conductance of karappadam soil.

Influence of various sources and levels on EC of the soils was found to be inconsistent.

EC was positively correlated with NH_4OAc extractable Mg (r = 0.924**), acid soluble Mg (r = 0.926**), mineral Mg (r = 0.818**), NH_4OAc extractable Ca (r = 0.689**) and negatively correlated with available K (r = -0.919**) and pH (r = -0.949**).

Table 12. Specific conductance of the soil as influenced by treatments at different periods of incubation, dS m^{-1}

Treatment	Periods, fortnight												
	1	2	3	4	5	6	7	8	9	10	11	12	Mean
T_1	0.343	0.270	0.281	0.332	0.223	0.132	0.140	0.159	0.255	0.342	0.313	0.282	0.256
T_2	0.177	0.287	0.289	0.299	0.249	0.170	0.193	0.202	0.243	0.282	0.257	0.237	0.240
T_3	0.179	0.363	0.341	0.350	0.267	0.153	0.209	0.218	0.266	0.316	0.272	0.210	0.245
T_4	0.224	0.229	0.246	0.282	0.212	0.129	0.183	0.210	0.250	0.302	0.259	0.211	0.228
T_5	0.227	0.239	0.261	0.315	0.256	0.173	0.209	0.217	0.258	0.230	0.271	0.218	0.240
T_6	0.179	0.367	0.339	0.326	0.261	0.194	0.146	0.208	0.216	0.224	0.232	0.272	0.247
T_7	0.296	0.390	0.389	0.377	0.292	0.196	0.172	0.183	0.231	0.294	0.257	0.248	0.277
T_8	0.116	0.103	0.111	0.122	0.105	0.071	0.069	0.077	0.081	0.094	0.106	0.105	0.097
T_9	0.094	0.084	0.088	0.236	0.167	0.088	0.092	0.108	0.092	0.082	0.116	0.115	0.113
T_{10}	0.099	0.079	0.092	0.174	0.109	0.055	0.107	0.105	0.108	0.101	0.136	0.158	0.110
T_{11}	0.164	0.092	0.103	0.148	0.112	0.083	0.105	0.103	0.093	0.110	0.092	0.114	0.179
T_{12}	0.093	0.103	0.120	0.134	0.132	0.062	0.126	0.154	0.103	0.076	0.106	0.096	0.109
T_{13}	0.147	0.084	0.094	0.116	0.086	0.054	0.087	0.090	0.084	0.082	0.109	0.120	0.906
T_{14}	0.130	0.080	0.116	0.213	0.118	0.071	0.104	0.121	0.093	0.094	0.123	0.151	0.118
Mean	0.176	0.198	0.205	0.245	0.185	0.116	0.139	0.154	0.169	0.188	0.189	0.181	

Table 13. Inter-relationships of Mg fractions, NH_4OAc extractable Ca, available K, pH and EC during incubation

(Coefficients of simple linear correlation)

	Water soluble Mg	NH_4OAc extractable Mg	Organic complexed Mg	Acid soluble Mg	Mineral Mg	NH_4OAc extractable Ca	Available K	pH	EC
Water soluble Mg	--	0.069	0.170	-0.027	-0.205	0.038	0.131	0.146	-0.065
NH_4OAc extractable Mg		--	0.488	0.971**	0.817**	0.685**	-0.948**	-0.947**	0.924**
Organic complexed Mg			--	0.454	0.507	0.227	-0.500	-0.340	0.407
Acid soluble Mg				--	0.818**	0.726**	-0.947**	-0.961**	0.926**
Mineral Mg					--	0.548*	-0.881**	-0.850**	0.818**
NH_4OAc extractable Ca						--	-0.563*	-0.707**	0.689**
Available K							--	0.955**	-0.919**
pH								--	-0.949**
EC									--

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 14. Relationships between Mg fractions and soil characteristics (incubation study)

X	Y	Regression equation	R^2
NH_4OAc extractable Mg	Acid soluble Mg	$Y = 266.75 + 68.41\ X$	0.942
"	Mineral Mg	$Y = 322.10 + 25.62\ X$	0.667
"	NH_4OAc extractable Ca	$Y = 5.578 + 0.624\ X$	0.470
"	Available K	$Y = 405.7 - 48.28\ X$	0.898
pH	Available K	$Y = -161.7 + 81.28\ X$	0.448
"	NH_4OAc extractable Mg	$Y = 11.63 - 1.664\ X$	0.448
"	Acid soluble Mg	$Y = 1085.3 - 117.6\ X$	0.490
"	Mineral Mg	$Y = 552.4 - 31.38\ X$	0.176
"	NH_4OAc extractable Ca	$Y = 13.64 - 1.171\ X$	0.291
"	Specific conductance	$Y = 1.001 - 1.137\ X$	0.493

POTCULTURE EXPERIMENT

A potculture experiment was conducted to assess the direct and residual effect of magnesite in comparison with dolomite and the water soluble magnesium sulphate in karappadam and laterite soils of Kerala. The same two soils used in the incubation study were used for the potculture experiment. Magnesium fertilizers were applied at two levels (25 and 50 kg MgO ha^{-1}) and applications of N, P and K were done uniformly in all the treatments. Soil and plant samples were drawn regularly at 15 days interval to study the release of Mg from the Mg sources and the uptake of major nutrients. The residual effect of magnesite was assessed by continuing the experiment for the second season without the application of Mg fertilizers.

A. First Crop

1. Nutrient uptake

1.1 Nitrogen

1.1.1 Nitrogen per cent of straw

Results on the effect of various sources and levels of applied Mg on N per cent of straw at different growth stages in karappadam and laterite soils are presented in Tables 15, 16 and 17.

The N per cent of the straw was found to decrease continuously from the time of planting till harvest. This can be assigned to the increase in the dry matter production with

Table 15. Nitrogen per cent and uptake in straw as influenced by the treatments at different periods of crop growth (first crop)

Treatment	N %						N uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	3.951	.045	2.352	1.349	1.160	2.571	0.024	0.247	1.021	1.616	0.430	0.668
T_2	3.826	3.842	1.317	1.662	1.051	2.340	0.021	0.476	0.637	1.739	0.451	0.665
T_3	3.559	2.854	1.709	1.599	1.505	2.245	0.014	0.206	1.357	1.343	0.599	0.704
T_4	4.045	3.387	2.744	1.364	1.223	2.553	0.024	0.339	1.592	1.239	0.485	0.736
T_5	3.826	3.230	1.427	1.254	1.568	2.261	0.034	0.200	0.602	0.762	0.508	0.421
T_6	3.716	3.105	1.317	1.584	1.301	2.205	0.022	0.307	0.906	1.153	0.660	0.610
T_7	3.810	2.242	1.584	1.803	1.709	2.230	0.023	0.121	0.444	1.428	0.702	0.544
T_8	4.200	2.791	1.552	2.023	1.396	2.392	0.025	0.154	0.472	1.987	0.628	0.653
T_9	4.547	3.575	2.195	1.678	1.019	2.603	0.026	0.322	0.966	0.923	0.381	0.524
T_{10}	3.701	3.653	1.443	1.631	1.396	2.365	0.022	0.292	0.257	0.476	0.420	0.293
T_{11}	4.281	3.420	1.223	1.317	0.909	2.230	0.017	0.171	0.435	0.387	0.223	0.247
T_{12}	4.061	1.913	1.599	1.317	1.396	2.057	0.016	0.086	0.326	0.609	0.372	0.282
T_{13}	3.528	2.054	1.051	1.129	0.537	1.860	0.021	0.086	0.252	0.371	0.487	0.243
T_{14}	4.045	3.512	1.145	1.270	1.129	2.220	0.019	0.278	0.325	0.460	0.340	0.284
Mean	3.940	3.120	1.620	1.500	1.310	2.298	0.026	0.235	0.688	1.035	0.478	0.492

Table 16. Mean values of nutrient per cent, nutrient uptake, straw yield, grain yield, soil nutrient content, pH and EC as influenced by Mg sources and soil (first crop)

Soil	Control	Magnesite	Dolomite	Magnesium sulphate	
Karappadam	1.160	1.278	1.396	1.505	N % of straw at harvest
Laterite	1.396	1.208	1.153	1.333	
Karappadam	0.430	0.525	0.497	0.681	N uptake by straw at harvest, g pot^{-1}
Laterite	0.628	0.401	0.298	0.414	
Karappadam	0.465	0.738	0.652	0.588	N uptake by grain g pot^{-1}
Laterite	0.719	0.499	0.409	0.602	
Karappadam	0.895	1.262	1.148	1.269	Total N uptake at harvest, g pot^{-1}
Laterite	1.347	0.899	0.706	1.015	
Karappadam	0.615	0.450	0.395	0.505	P % of straw at harvest
Laterite	0.585	0.510	0.530	0.510	
Karappadam	0.228	0.184	0.140	0.229	P uptake by straw at harvest, g pot^{-1}
Laterite	0.263	0.171	0.137	0.157	
Karappadam	0.277	0.361	0.299	0.310	P uptake by grain, g pot^{-1}
Laterite	0.315	0.250	0.222	0.299	
Karappadam	0.505	0.545	0.439	0.540	Total P uptake at harvest, g pot^{-1}
Laterite	0.579	0.421	0.358	0.456	
Karappadam	1.90	2.30	2.25	1.98	K % of straw at harvest
Laterite	2.35	2.50	2.40	3.00	
Karappadam	0.704	0.952	0.803	0.901	K uptake by straw at harvest, g pot^{-1}
Laterite	1.057	0.835	0.615	0.923	
Karappadam	0.125	0.147	0.120	0.154	K uptake by grain, g pot^{-1}
Laterite	0.194	0.131	0.096	0.127	
Karappadam	0.830	1.098	0.923	1.055	Total K uptake at harvest, g pot^{-1}
Laterite	1.251	0.965	0.711	1.050	
Karappadam	0.614	0.799	0.729	0.807	Ca % of straw at harvest
Laterite	0.998	0.922	0.806	0.768	
Karappadam	0.228	0.331	0.264	0.373	Ca uptake by straw at harvest, g pot^{-1}
Laterite	0.449	0.317	0.205	0.237	
Karappadam	0.091	0.107	0.148	0.079	Ca uptake by grain, g pot^{-1}
Laterite	0.100	0.094	0.073	0.101	

Contd.

Table 16 (Contd.)

Soil	Control	Magnesite	Dolomite	Magnesium sulphate	
Karappadam	0.318	0.437	0.412	0.451	Total Ca uptake at harvest, g pot^{-1}
Laterite	0.548	0.411	0.278	0.338	
Karappadam	0.323	0.396	0.369	0.446	Mg % of straw at harvest
Laterite	0.369	0.369	0.323	0.370	
Karappadam	0.120	0.263	0.132	0.162	Mg uptake by straw at harvest, g pot^{-1}
Laterite	0.116	0.150	0.082	0.114	
Karappadam	0.030	0.066	0.048	0.080	Mg uptake by grain, g pot^{-1}
Laterite	0.040	0.033	0.038	0.063	
Karappadam	0.150	0.329	0.180	0.242	Total Mg uptake at harvest, g pot^{-1}
Laterite	0.056	0.183	0.121	0.177	
Karappadam	37.08	41.33	36.02	45.91	Straw yield at harvest g pot^{-1}
Laterite	44.98	33.74	25.61	30.90	
Karappadam	35.75	42.79	39.89	36.11	Grain yield, g pot^{-1}
Laterite	43.20	32.43	25.60	36.25	
Karappadam	3.414	3.534	3.758	3.325	NH_4OAc extractable Mg, cmol (+) kg^{-1}
Laterite	1.965	1.952	1.931	2.069	
Karappadam	72.43	76.89	72.92	86.36	Water soluble Mg, ppm
Laterite	77.85	89.99	86.88	97.57	
Karappadam	8.274	8.206	7.051	7.465	NH_4OAc extractable Ca, cmol (+) kg^{-1}
Laterite	5.930	6.370	5.614	5.965	
Karappadam	212.8	189.8	190.4	190.4	Available K, kg ha^{-1}
Laterite	246.4	271.5	255.4	254.2	
Karappadam	5.8	5.7	5.6	5.4	pH
Laterite	6.2	6.5	6.3	6.3	
Karappadam	0.117	0.113	0.117	0.105	Specific conductance, dS m^{-1}
Laterite	0.080	0.104	0.071	0.104	

less vigorous nutrient absorption resulting in the dilution of nutrient concentration.

In the absence of added Mg, the mean N per cent of the straw at harvest was 1.160 and 1.396 respectively in karappadam and laterite soils. On Mg addition, this value increased to 1.393 in karappadam soil. But there was no positive response in laterite soil. This may be due to the high native organic matter content and total N in the karappadam soil. Also the soil reaction was more acidic in karappadam soil. So the addition of Mg fertilizers might have resulted in a more favourable condition leading to the enhanced absorption of other nutrients like N and increased dry matter production in karappadam soil.

Similar results were observed on increasing the level of applied Mg from from 25 to 50 kg MgO ha^{-1}. In karappadam soil the N per cent increased from 1.192 to 1.594 while in laterite there was no positive response. Reason may be the same as described earlier.

Nitrogen per cent of the straw was the highest in samples supplied with magnesium sulphate. This may be attributed to the higher solubility of magnesium sulphate when compared to that of the carbonate sources. The reported solubility for magnesium sulphate with a dissociation of K° of 8.15 reflects a very high solubility for this mineral.

Table 17. Mean values of nutrient per cent, nutrient uptake, straw yield, grain yield, soil nutrient content, pH and EC as influenced by levels of Mg application (first crop)

Levels of MgO kg ha^{-1}	Soil		Sources of Mg			
	Karappadam	Laterite	Magnesite	Dolomite	Magnesium sulphate	
25	1.192	1.488	1.035	1.066	1.419	N % of straw at harvest
50	1.594	1.307	1.451	1.482	1.419	
25	0.532	0.364	0.416	0.354	0.573	N uptake by straw at harvest, g pot^{-1},
50	0.603	0.377	0.510	0.440	0.521	
25	0.661	0.520	0.666	0.453	0.620	N uptake by grain, g pot^{-1}
50	0.658	0.486	0.570	0.608	0.537	
25	1.192	0.884	1.082	0.807	1.225	Total N uptake at harvest, g pot^{-1}
50	1.260	0.863	1.080	1.047	1.058	
25	0.405	0.453	0.458	0.388	0.443	P % of straw at harvest
50	0.492	0.580	0.498	0.538	0.573	
25	0.182	0.142	0.184	0.120	0.183	P uptake by straw at harvest, g pot^{-1}
50	0.187	0.167	0.172	0.157	0.203	
25	0.353	0.266	0.361	0.230	0.337	P uptake by grain g pot^{-1}
50	0.294	0.248	0.250	0.290	0.272	
25	0.535	0.407	0.544	0.350	0.520	Total P uptake at harvest, g pot^{-1}
50	0.480	0.416	0.422	0.447	0.476	
25	2.08	2.40	2.40	2.20	2.13	K % of straw at harvest
50	2.27	2.85	2.38	2.45	2.85	
25	0.92	0.75	0.96	0.70	0.85	K uptake by straw at harvest, g pot^{-1}
50	0.85	0.83	0.82	0.72	1.36	
25	0.154	0.134	0.173	0.096	0.163	K uptake by grain, g pot^{-1}
50	0.127	0.102	0.106	0.119	0.119	
25	1.073	0.885	1.134	0.792	1.012	Total K uptake at harvest, g pot^{-1}
50	0.977	0.932	0.929	0.842	1.093	
25	0.819	0.923	0.960	0.845	0.807	Ca % of straw at harvest
50	0.737	0.742	0.760	0.690	0.768	
25	0.385	0.291	0.382	0.266	0.336	Ca uptake by straw at harvest, g pot^{-1}
50	0.279	0.215	0.265	0.204	0.274	

Contd.

Table 17 (Contd.)

Levels of MgO kg ha^{-1}	Soil		Sources of Mg			
	Karappadam	Laterite	Magnesite	Dolomite	Magnesium sulphate	
25	0.132	0.094	0.100	0.147	0.092	Ca uptake by grain, g pot^{-1}
50	0.090	0.084	0.101	0.074	0.087	
25	0.497	0.384	0.482	0.412	0.428	Total Ca uptake at harvest, g pot^{-1}
50	0.369	0.299	0.366	0.277	0.361	
25	0.369	0.308	0.369	0.300	0.346	Mg % of straw at harvest
50	0.438	0.400	0.396	0.392	0.470	
25	0.166	0.098	0.148	0.098	0.150	Mg uptake by straw at harvest, g pot^{-1}
50	0.233	0.133	0.264	0.117	0.168	
25	0.082	0.057	0.069	0.036	0.104	Mg uptake by grain, g pot^{-1}
50	0.047	0.033	0.030	0.050	0.039	
25	0.126	0.081	0.112	0.097	0.100	Total Mg uptake at harvest, g pot^{-1}
50	0.147	0.075	0.124	0.093	0.115	
25	44.41	31.21	40.13	32.12	41.19	Straw yield at harvest, g pot^{-1}
50	37.75	28.95	34.94	29.15	35.62	
25	42.75	32.04	42.46	31.48	38.25	Grain yield, g pot^{-1}
50	36.44	30.81	32.75	34.01	34.11	
25	3.389	1.853	2.694	2.690	2.480	NH_4OAc extractable Mg, cmol (+) kg^{-1}
50	3.689	2.115	2.793	3.000	2.914	
25	72.74	82.05	81.71	70.85	79.64	Water soluble Mg, ppm
50	71.37	100.91	65.16	88.95	104.30	
25	7.494	5.805	7.025	6.148	6.775	NH_4OAc extractable Ca, cmol (+) kg^{-1}
50	7.654	6.160	7.551	6.517	6.655	
25	193.4	274.3	241.2	228.5	231.8	Available K, kg ha^{-1}
50	187.0	246.4	220.1	217.3	212.8	
25	5.5	6.3	6.1	5.9	5.8	pH
50	5.6	6.4	6.1	6.0	5.9	
25	0.106	0.083	0.105	0.084	0.095	Specific conductance, dS m^{-1}
50	0.117	0.103	0.113	0.104	0.113	

Solubility of magnesite (log K° = 10.69) and dolomite (log k° = 18.46) are lesser than that of magnesium sulphate (Lindsay, 1979). Magnesium sulphate supplies S in addition to Mg and therefore the possible beneficial role of S in rice nutrition can not be ruled out.

1.1.2 Uptake of nitrogen by the straw

Data on the effect of various sources and levels of Mg on the uptake of N by the straw at different growth stages in karappadam and laterite soils are furnished in Tables 15, 16 and 17.

In all the treatments, the uptake of N by the straw was found to increase rapidly up to the fourth fortnight of planting and then decreased. This increase in the initial stages may be due to the increase in dry matter content and the decrease in the final stage can be assigned to the translocation of the nutrients to grain from the straw.

On Mg addition, N uptake by the straw at harvest increased from 0.430 to 0.568 g pot^{-1} in karappadam soil while in laterite soil there was no positive response. This positive response to Mg application in karappadan soil may be the result of high native organic matter content and total N in that soil. The addition of Mg fertilizers might have resulted in a more favourable condition in karappadam soil since pH was more acidic in that soil.

With regard to the N uptake by straw, magnesium sulphate was found to be the best source in both the soils. Probably the high solubility of magnesium sulphate and its ability to supply S would have resulted in increased dry matter production and in turn the N uptake by the crop would have increased.

Also there was an enhanced N uptake by the straw on increasing the level of Mg from 25 to 50 kg MgO ha^{-1} indicating that N uptake increased with the amount of Mg added. All these point to a synergestic relationship between Mg and N as indicated by Narayana and Rao (1982).

1.1.3 Uptake of N by the grain

Data on the influence of various sources and levels of applied Mg on the uptake of N by the grain in karappadam and laterite soils are presented in Tables 16, 17 and 18.

Magnesium application had a positive influence on N uptake in karappadam soil, but in laterite soil there was not such an influence. This positive influence noticed in karappadam soil may be attributed to the high native organic matter and total N in the soil and more acidic soil reaction prevailing in that soil. Application of Mg fertilizers might have resulted in a more favourable condition for plant growth in karappadam soil leading to increased grain yield.

Table 18. Straw yield, grain yield and nutrient uptake (g pot^{-1}) as influenced by the treatments (first crop)

Treatment	Straw yield	Grain yield	Total nutrient uptake at harvest					Nutrient uptake by the grain				
			N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_1	37.08	35.75	0.895	0.505	0.830	0.318	0.150	0.465	0.277	0.125	0.091	0.330
T_2	42.88	49.75	1.270	0.639	1.194	0.465	0.257	0.819	0.450	0.187	0.103	0.099
T_3	39.78	35.83	1.255	0.451	1.002	0.409	0.400	0.657	0.272	0.108	0.110	0.033
T_4	39.65	39.33	1.028	0.389	0.911	0.516	0.146	0.543	0.260	0.098	0.212	0.034
T_5	32.38	40.45	1.269	0.488	0.935	0.307	0.196	0.761	0.338	0.142	0.084	0.062
T_6	50.71	39.18	1.280	0.577	1.115	0.510	0.325	0.621	0.349	0.176	0.081	0.114
T_7	41.10	33.05	1.257	0.502	0.995	0.392	0.346	0.555	0.272	0.132	0.076	0.046
T_8	44.98	43.20	1.347	0.579	1.251	0.548	0.121	0.719	0.315	0.194	0.100	0.040
T_9	37.38	35.18	0.894	0.448	1.074	0.499	0.177	0.513	0.271	0.158	0.097	0.039
T_{10}	30.10	29.68	0.904	0.393	0.856	0.322	0.139	0.484	0.229	0.104	0.091	0.027
T_{11}	24.58	23.63	0.587	0.311	0.673	0.308	0.106	0.363	0.201	0.095	0.082	0.038
T_{12}	26.63	27.58	0.826	0.405	0.749	0.247	0.137	0.454	0.243	0.097	0.064	0.038
T_{13}	31.67	37.33	1.172	0.463	0.909	0.346	0.181	0.685	0.325	0.149	0.103	0.093
T_{14}	30.13	35.18	0.859	0.449	1.190	0.329	0.185	0.519	0.273	0.106	0.098	0.033

CD (0.05) for the comparison of soils for straw and grain yields and total Mg uptake are 8.875, 7.369 and 0.020 respectively. Other treatment effects are not significant.

1.1.4 Total uptake of N

Effect of various treatments on the total uptake of N by rice at harvest in karappadam and laterite soils are presented in Table 16, 17 and 18.

On Mg application, total N uptake by the rice plant at harvest was increased from 0.895 to 1.227 g pot^{-1} in karappadam soil, while in laterite soil there was not a positive response. This enhanced N uptake in karappadam soil may be due to increased straw and grain yield in that soil on Mg addition. Probably this may be the result of low pH, high native organic matter and total N in that soil. Total N uptake by the rice plant at harvest was positively correlated with straw yield (r = 0.751**) and grain yield (r = 0.764**) (Table 26).

Total N uptake at harvest was maximum in plants supplied with magnesium sulphate in both the soils (1.269 and 1.015 g pot^{-1} respectively in karappadam and laterite soils) closely followed by magnesite (1.262 and 0.891 g pot^{-1}) and dolomite (1.148 and 0.706 g pot^{-1}). This higher N uptake in plants supplied with magnesium sulphate may be due to the higher solubility of Mg from magnesium sulphate and also due to the availability of S from magnesium sulphate.

1.2 Phosphorus

1.2.1 Phosphorus per cent of straw

Results on the effect of various sources and levels of applied Mg on the P per cent of straw at different growth stages in karappadam and laterite soils are given in Table 16, 17 and 19.

Both in the presence and absence of added Mg, the level of P in the straw was maximum during the second fortnight which represented the maximum tillering stage. The decrease thereafter observed during the subsequent periods may be attributed to the dilution of nutrient concentration consequent to increase in dry matter production and the translocation of nutrient to the grains.

Phosphorus per cent of the straw at harvest was higher in laterite soil than the karappadam, may be due to the higher content of total as well as the available P in that soil.

Mg addition did not enhance the mean P per cent of the straw at harvest (Table 16). This was in agreement with the findings of Panicker (1980) that the application of steatite resulted in decreased per cent of P in the straw. The P per cent of the straw was relatively lower in treatments receiving dolomite. This may be attributed to the poor growth and low rate of absorption of nutrients recorded in the treatments receiving dolomite. Maximum P per cent was recorded in treatments receiving magnesium sulphate probably due to the higher solubility of magnesium sulphate and due to the presence of S in magnesium sulphate.

Table 19. Phosphorus per cent and uptake in straw as influenced by the treatments at different periods of crop growth (first crop)

Treatment	P %						P uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	0.775	1.020	0.530	0.595	0.615	0.707	0.005	0.062	0.230	0.713	0.228	0.248
T_2	0.750	0.880	0.455	0.655	0.440	0.636	0.004	0.109	0.220	0.685	0.189	0.241
T_3	0.815	0.655	0.525	0.580	0.450	0.605	0.003	0.047	0.417	0.487	0.179	0.227
T_4	0.750	1.040	0.565	0.640	0.325	0.664	0.005	0.104	0.328	0.581	0.129	0.229
T_5	0.810	0.860	0.490	0.790	0.464	0.683	0.008	0.053	0.207	0.480	0.151	0.180
T_6	0.750	0.745	0.560	0.535	0.450	0.608	0.005	0.074	0.385	0.390	0.228	0.216
T_7	0.790	0.905	0.485	0.660	0.560	0.680	0.005	0.049	0.136	0.523	0.230	0.189
T_8	0.750	1.090	0.505	0.750	0.585	0.736	0.004	0.060	0.154	0.737	0.263	0.244
T_9	0.715	0.670	0.705	0.615	0.475	0.636	0.004	0.060	0.310	0.338	0.178	0.178
T_{10}	0.760	0.725	0.795	0.645	0.545	0.694	0.005	0.058	0.142	0.188	0.164	0.111
T_{11}	0.690	0.955	0.685	0.705	0.450	0.697	0.003	0.048	0.244	0.207	0.111	0.123
T_{12}	0.715	0.865	0.640	0.720	0.610	0.770	0.003	0.039	0.131	0.333	0.162	0.134
T_{13}	0.700	0.880	0.630	0.810	0.435	0.691	0.004	0.037	0.151	0.267	0.138	0.119
T_{14}	0.645	0.890	0.695	0.590	0.585	0.681	0.003	0.070	0.197	0.214	0.176	0.132
Mean	0.744	0.870	0.590	0.664	0.499	0.673	0.004	0.062	0.232	0.439	0.180	0.183

Phosphorus per cent of the straw at harvest increased with increasing levels of Mg application from 25 to 50 kg MgO ha^{-1} in both the soils and also in the case of all the three sources. This was in line with the observations of Nayar and Koshy (1969) that P content of rice increased with increase in the rate of Mg. This may be because of the fact that Mg acts as the P carrier.

1.2.2 Phosphorus uptake by straw

Data on the effect of various sources and levels of applied Mg on P uptake by straw at different growth stages in karappadam and laterite soils are presented in Tables 16, 17 and 19.

In general, both in the presence and absence of added Mg, P uptake by straw increased and reached a maximum value of 0.439 g pot^{-1} in the fourth fortnight which may be due to the increase in dry matter production with the advancement of the stages. During the harvesting stage, P content of the straw was low, which can be explained as due to the translocation to the grains.

Phosphorus uptake by the straw at harvest was not enhanced by the application of Mg sources. This is in agreement with the observations of Jayaraman (1988) that P availability decreased with increasing levels of Mg. The uptake of P was relatively low in treatments receiving dolomite. This may be attributed to the low straw yield recorded in this treatment.

Maximum P uptake was obtained in magnesium sulphate applied treatment. Probably this may be due to the higher solubility of magnesium sulphate and the presence of S in magnesium sulphate.

On increasing the level of applied Mg from 25 to 50 kg MgO ha^{-1}, P uptake by the straw at harvest was found to increase. This may be due to the fact that Mg acts as a P carrier.

1.2.3 Phosphorus uptake by grain

Data on the influence of various sources and levels of applied Mg on P uptake by grain in karappadam and laterite soils are presented in Table 16, 17 and 18.

The uptake of P by the grain in the absence of added Mg was 0.277 and 0.315 g pot^{-1} in karappadam and laterite soils respectively. On Mg addition it was increased to 0.323 g pot^{-1} in karappadam soil. But there was no positive response in laterite soil. This can be attributed to the high organic matter content and low pH of the karappadam soil. Magnesium sources might have raised the pH to a favourable level and enhanced the grain yield as well as the grain P uptake.

There was no conspicuous increase in P uptake by grain on increasing the level of Mg from 25 kg to 50 kg MgO ha^{-1}.

1.2.4 Total P uptake

Data on the effect of various treatments on total P uptake by rice at harvest in karappadam and laterite soils are presented in Tables 16, 17 and 18.

Total P uptake increased on Mg addition in karappadam soil, while in laterite soil a decreasing trend was noticed. Total P uptake was positively correlated with straw yield (r = 0.773**) and grain yield (r = 0.838**) (Table 26). Due to the combined effect of low pH and high organic matter content of the karappadam soil, Mg addition might have resulted in enhanced growth and yield in that soil, subsequently increasing the total P uptake. No such response was noticed in laterite soil.

1.3 Potassium

1.3.1 Potassium per cent of straw

Data on the influence of various treatments on K per cent of straw in karappadam and laterite soils are given in Tables 16, 17 and 20.

Potassium per cent of the straw was maximum during the second fortnight representing the maximum tillering stage. Thereafter, there was a decrease in K content of the straw, may

Table 20. Potassium per cent and uptake in straw as influenced by the treatments at different periods of crop growth (first crop)

Treatment	K%						K uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	2.05	4.00	1.90	1.55	1.90	2.28	0.012	0.244	0.825	1.857	0.704	0.728
T_2	1.70	3.60	1.70	2.00	2.35	2.27	0.010	0.446	0.823	2.092	1.008	0.876
T_3	2.20	3.10	1.75	1.50	2.25	2.16	0.009	0.223	1.390	1.260	0.895	0.772
T_4	2.15	3.50	2.10	1.55	2.05	2.27	0.013	0.350	1.218	1.407	0.813	0.760
T_5	2.40	3.30	1.90	2.10	2.45	2.43	0.022	0.205	0.802	1.277	0.793	0.620
T_6	1.70	3.50	1.95	1.30	1.85	2.06	0.010	0.347	1.342	0.946	0.938	0.717
T_7	1.75	3.50	1.90	1.90	2.10	2.23	0.011	0.189	0.532	1.505	0.863	0.620
T_8	2.20	4.00	1.90	1.95	2.35	2.48	0.013	0.220	0.578	1.915	1.057	0.757
T_9	2.15	2.90	2.25	1.55	2.45	2.26	0.013	0.260	0.990	0.853	0.916	0.606
T_{10}	2.25	3.00	2.50	1.50	2.50	2.35	0.014	0.240	0.445	0.438	0.753	0.378
T_{11}	2.45	3.20	2.35	2.05	2.35	2.48	0.010	0.160	0.837	0.603	0.578	0.438
T_{12}	2.05	3.80	2.00	1.85	2.45	2.43	0.008	0.171	0.408	0.855	0.652	0.419
T_{13}	2.10	3.00	1.95	1.75	2.40	2.24	0.012	0.126	0.468	0.576	0.760	0.388
T_{14}	2.00	3.50	2.05	1.80	3.60	2.59	0.009	0.277	0.582	0.652	1.085	0.521
Mean	2.08	3.42	2.01	1.74	2.37	2.32	0.012	0.247	0.803	1.160	0.844	0.613

be due to the increased dry matter production leading to nutrient dilution. Then there was an increase in K per cent of straw from the fourth fortnight to the fifth one.

In the absence of added Mg, K per cent of the straw at harvest was 1.90 and 2.35 per cent respectively in karappadam and laterite soils. On Mg addition, these values increased to 2.18 and 2.63 respectively. The beneficial effects of Mg on the crop performance would have resulted in the high absorption of K from soil. Similar results were observed on increasing the level of applied Mg from 25 to 50 kg MgO ha^{-1}. The lack of any antagonistic reaction between K and Mg might be due to the low levels of Mg (25 and 50 kg MgO ha^{-1}) tried in the present experiment.

Potassium per cent of the straw was higher in laterite soil than in karappadam, probably due to the higher native K content of the laterite soil.

1.3.2 Potassium uptake by the straw

Influence of various treatments on K uptake by straw during different periods is presented in Tables 16, 17 and 20.

Both in the presence and absence of added Mg, K uptake by straw was found to increase steadily up to the fourth fortnight and then decrease at the time of harvest. Steady rise in K uptake during the initial stages may be the result of increased dry matter production and the decline during the harvesting stage may be due to the translocation of K to the grains.

On Mg addition, K uptake by the straw at harvest showed an increasing trend in karappadam soil, while a decreasing trend was observed in the laterite soil. Due to the combined effect of high organic matter, high total N and relatively low pH value, addition of Mg fertilizers might have resulted in a more favourable condition in karappadam soil leading to increased yield and uptake of nutrients like K.

K uptake by the straw at harvest was higher in laterite soil, may be due to the higher native K content of that soil.

Influence of the various levels of Mg applied on K uptake by the straw was inconsistent.

1.3.3 Uptake of K by the grain

Uptake of K by the grain as affected by various sources and levels of applied Mg in karappadam and laterite soils is presented in Tables 16, 17 and 18.

The K uptake by the grain increased on Mg addition in karappadam soil, which can be attributed to the increase in grain yield on Mg addition in that soil. No such response was observed in laterite soil. Positive response in karappadam soil may be due to the high organic matter content and N content of that soil.

The K uptake by grain decreased with increasing levels of Mg in both the soils, showing a K-Mg antagonism.

1.3.4 Total potassium uptake

Data on the influence of various sources and levels of applied Mg on total K uptake by the rice plant at harvest are presented in Tables 16, 17 and 18.

On Mg application, total K uptake by the rice plant increased in karappadam soil, while in laterite soil it showed a declining trend. This may be due to the highly significant positive correlation observed between the total K uptake and straw yield (r = 0.684**) and grain yield (r = 0.752**) (Table 26). Yields increased on Mg application in karappadam soil, may be due to the low pH value and high organic matter and N content of that soil.

1.4 Calcium

1.4.1 Calcium per cent of the straw

Influence of various treatments on calcium per cent of the straw in karappadam and laterite soils is presented in Tables 16, 17 and 21.

Table 21. Calcium per cent and uptake in straw as influenced by treatments at different periods of crop growth (first crop)

Treatment	Ca %						Ca uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	0.769	0.923	0.768	0.461	0.614	0.707	0.005	0.006	0.333	0.552	0.228	0.225
T_2	0.669	0.692	0.690	0.768	0.845	0.753	0.004	0.085	0.334	0.803	0.362	0.318
T_3	0.690	0.768	0.461	0.690	0.752	0.672	0.003	0.055	0.366	0.580	0.299	0.261
T_4	1.154	0.922	0.690	0.845	0.768	0.876	0.007	0.092	0.400	0.867	0.305	0.314
T_5	0.517	0.845	0.546	0.690	0.690	0.658	0.005	0.052	0.230	0.420	0.223	0.186
T_6	0.862	0.922	0.768	0.768	0.845	0.833	0.005	0.091	0.528	0.559	0.429	0.322
T_7	0.962	0.614	0.614	0.845	0.768	0.761	0.006	0.033	0.172	0.669	0.316	0.239
T_8	0.769	0.614	0.690	0.922	0.998	0.799	0.005	0.034	0.210	0.905	0.449	0.321
T_9	0.690	0.922	0.845	0.768	0.075	0.860	0.004	0.083	0.372	0.422	0.402	0.257
T_{10}	0.862	0.845	0.768	0.690	0.768	0.787	0.005	0.068	0.137	0.202	0.231	0.129
T_{11}	0.769	0.768	0.845	0.768	0.922	0.814	0.003	0.038	0.301	0.226	0.227	0.159
T_{12}	0.517	0.768	0.768	0.922	0.690	0.733	0.002	0.035	0.157	0.426	0.184	0.161
T_{13}	0.962	0.690	0.614	0.768	0.768	0.760	0.006	0.029	0.147	0.215	0.243	0.136
T_{14}	1.154	0.845	0.845	0.768	0.768	0.876	0.005	0.067	0.240	0.278	0.231	0.164
Mean	0.818	0.796	0.708	0.762	0.805	0.778	0.005	0.055	0.281	0.505	0.295	0.228

Calcium per cent of the straw decreased continuously from the time of planting till the third fortnight. This may be due to the dilution effect on increasing the dry matter production. After the third fortnight, there was an increase in Ca per cent of the straw till harvest. This can be attributed to the increased Ca uptake with dry matter production. Rate of Ca uptake might have exceeded the rate of dry matter production in the later stages, resulting in increased Ca per cent of the straw.

Calcium per cent of the straw was much higher in laterite soil when compared to that in the karappadam soil. This may be due to the higher Mg content of the karappadam soil. So due to the antagonistic effect of Mg, uptake of Ca by the plants might have been depressed in the karappadam soil eventhough the Ca content was higher in that soil. Also the higher pH in the laterite soil might have favoured the Ca uptake in the laterite soil.

Calcium per cent of the straw decreased with increasing the levels of Mg from 25 to 50 kg MgO ha^{-1}, indicating a Ca-Mg antagonism.

1.4.2 Calcium uptake by the straw

Data on the influence of various sources and levels of applied Mg on Ca uptake by the straw in karappadam and laterite soils are given in Tables16, 17 and 21.

In all the treatments, the uptake of Ca by the straw was found to increase up to the fourth fortnight and then decreased. This increase in the initial stages can be attributed to the increased dry matter production and the decrease in the fifth period may be due to the translocation of Ca from straw to the grain.

Calcium uptake by the straw at harvest was higher in laterite soil than in karappadam, which may be the result of the higher native Mg content of the karappadam soil causing an antagonistic effect on the Ca uptake in karappadam soil.

Calcium uptake by the straw was found to decrease on Mg application, indicating a Ca-Mg antagonism. On increasing the levels of applied Mg from 25 to 50 kg MgO ha^{-1}, Ca uptake by straw decreased by 0.086 g pot^{-1} in karappadam and by 0.076 g pot^{-1} in laterite soils. This increase in the case of different Mg fertilizers used were 0.117, 0.062 and 0.062 g pot^{-1} for magnesite, dolomite and magnesium sulphate respectively, clearly indicating a Ca-Mg antagonism.

1.4.3 Uptake of Ca by the grain

Influence of various sources and levels of applied Mg on the uptake of Ca by the grain is presented in Tables 16, 17 and 18.

On Mg application, Ca uptake by the grain increased from 0.091 to 0.111 g pot^{-1} in karappadam soil, while in laterite soil it showed a declining trend. This can be assigned to the increase in grain yield on Mg application in karappadam soil, may be due to the higher native organic matter, total N, Ca and Mg content of that soil.

Calcium uptake by the grain was found to decrease with increase in the level of applied Mg from 25 to 50 kg MgO ha^{-1} in all the soils and the sources of Mg used for the study, indicating the antagonistic effect of Mg on Ca uptake.

1.4.4 Total Ca uptake

Data on the influence of various sources and levels of applied Mg on total Ca uptake by the rice plant at harvest are presented in Tables 16, 17 and 18.

On Mg application, total Ca uptake by the rice plant increased in karappadam soil, while in laterite soil no positive response was observed. This can be assigned to the significant positive correlation of total Ca uptake with straw yield (r = 0.834**), grain yield (r = 0.624**) and total K uptake (r = 0.682**) (Table 26). Similar results were obtained in the case of total K uptake also. Yield increased on Mg application in karappadam soil due to the relatively low pH value and high organic matter and N, Ca and Mg contents of that soil.

Total Ca uptake at harvest decreased with increasing levels of Mg from 25 to 50 kg MgO ha^{-1} pointing to a competitive relationship between Ca and Mg.

1.5 Magnesium

1.5.1 Magnesium per cent of the straw

Data on the influence of various sources and levels of applied Mg on Mg per cent of the straw in karappadam and laterite soils are given in Tables 16, 17 and 22.

Magnesium per cent of the straw increased from the time of planting till the second fortnight representing the maximum tillering stage. Then there was a decline in Mg per cent of straw during the next fortnight, may be due to the dilution effect as dry matter production was increased during this period. Again there was an increase in Mg per cent of the straw in the later stages, may be because the rate of Mg uptake by straw exceeded the rate of dry matter production.

Both in the presence and absence of added Mg, the per cent of Mg in straw was higher in karappadam soil which can be attributed to the higher native Mg content of that soil.

In general, the Mg per cent of the straw at harvest was found to increase on Mg application from 0.346 to 0.379 per cent, understandably due to the increased availability of the applied Mg.

On comparing the efficiency of different Mg fertilizers used in maintaining the level of Mg in straw it was found that the magnesium sulphate was the best source (0.408 per cent) followed by magnesite (0.383 per cent) and dolomite (0.346 per cent). This may be attributed to the solubility of these Mg sources, which is in the decreasing order of magnesium sulphate, magnesite and dolomite (Lindsay, 1979). In the acid soils used in this study it was found that magnesite was 93.9 per cent and dolomite 84.8 per cent as efficient as magnesium sulphate with regard to the straw Mg per cent.

The Mg per cent of the straw was found to increase as the level of added Mg was increased from 25 to 50 kg MgO ha^{-1} in both the soils and also in the case of all the sources, obviously due to the higher availability of Mg from the applied sources.

1.5.2 Uptake of Mg by the straw

Uptake of Mg by the straw as influenced by the sources and levels of applied Mg in karappadam and laterite soils is presented in Tables 16, 17 and 22.

In all the treatments, the uptake of Mg by the straw was found to increase rapidly up to the fourth period and then gradually decreased. This increase in the initial stages may be attributed to the increase in the dry matter production and the decrease after the fourth period may be due to the translocation of the nutrients to grain from the straw.

Table 22. Magnesium per cent and uptake in straw as influenced by the treatments at different periods of crop growth (first crop)

Treatment	Mg %						Mg uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	0.207	0.692	0.231	0.323	0.323	0.355	0.001	0.042	0.100	0.387	0.120	0.130
T_2	0.207	0.508	0.139	0.231	0.369	0.291	0.001	0.063	0.067	0.241	0.158	0.106
T_3	0.207	0.692	0.231	0.323	0.423	0.475	0.001	0.050	0.183	0.271	0.367	0.175
T_4	0.207	0.646	0.277	0.277	0.323	0.346	0.001	0.065	0.161	0.251	0.128	0.121
T_5	0.207	0.646	0.185	0.369	0.415	0.364	0.001	0.040	0.078	0.225	0.135	0.096
T_6	0.104	0.415	0.092	0.277	0.415	0.261	0.001	0.041	0.064	0.202	0.211	0.104
T_7	0.155	0.462	0.185	0.415	0.477	0.339	0.001	0.025	0.052	0.329	0.114	0.121
T_8	0.155	0.646	0.185	0.277	0.369	0.326	0.001	0.036	0.056	0.272	0.116	0.096
T_9	0.207	0.508	0.323	0.231	0.369	0.328	0.001	0.046	0.142	0.127	0.138	0.091
T_{10}	0.104	0.415	0.323	0.369	0.369	0.316	0.001	0.033	0.058	0.108	0.161	0.062
T_{11}	0.207	0.462	0.323	0.323	0.277	0.318	0.001	0.023	0.115	0.095	0.068	0.060
T_{12}	0.310	0.369	0.231	0.415	0.369	0.339	0.001	0.017	0.047	0.192	0.098	0.071
T_{13}	0.104	0.508	0.231	0.323	0.277	0.289	0.001	0.021	0.055	0.106	0.088	0.054
T_{14}	0.104	0.323	0.231	0.323	0.462	0.289	0.001	0.026	0.066	0.117	0.139	0.070
Mean	0.177	0.521	0.228	0.320	0.410	0.331	0.001	0.038	0.089	0.209	0.152	0.098

For Mg uptake, CD (0.05) for the comparison of soils is 0.020. Other treatment effects are not significant

Both in the presence and the absence of added Mg, uptake of Mg by the straw at harvest was higher in karappadam soil than in laterite soil, which may be the result of higher native Mg of that soil.

On Mg addition, Mg uptake by the straw at harvest was found to increase from 0.118 to 0.151 g pot^{-1}, understandably due to the increased availability of Mg from the applied sources.

On increasing the level of applied Mg from 25 to 50 kg MgO ha^{-1}, Mg uptake was found to increase in both the soils as well as in the case of all the sources.

Magnesium uptake by the straw at harvest was maximum in samples supplied with magnesite in both the soils used for the study which may be due to its better efficiency in acid soils than magnesium sulphate. Soils receiving magnesium sulphate application were more acidic than that of magnesite. Probably the increased uptake of Mg from magnesite would have resulted by the improvement of soil reaction consequent to the addition of magnesite. Magnesium uptake was minimum in samples supplied with dolomite in both the soils. This can be assigned to the competition between Ca and Mg present in dolomite.

1.5.3 Magnesium uptake by the grain

Results on the effect of various sources and levels of applied Mg on the uptake of Mg by grain in karappadam and laterite soils are presented in Tables 16, 17 and 18.

In the absence of applied Mg, its uptake by grain in karappadam and laterite soils was 0.030 and 0.040 g pot^{-1} respectively. These values increased to 0.065 and 0.045 g pot^{-1} respectively on Mg addition obviously due to the increased Mg availability.

Among the various Mg sources, application of Mg as magnesium sulphate gave the best response with respect to the Mg uptake by the grain in both karappadam (0.080 g pot^{-1}) and laterite soils (0.063 g pot^{-1}). This may be assigned to the higher solubility of Mg from sulphate form than from carbonate forms.

1.5.4 Total Mg uptake

Data on the influence of various sources and levels of applied Mg on the total Mg uptake by the rice plant at various stages of crop growth in karappadam and laterite soils are given in Tables 16, 17 and 18.

There was significant difference between the two soils with regard to the total Mg uptake. Total Mg uptake was much higher in karappadam soil than in laterite soil, which may be due to the higher native Mg content of that soil. Total Mg uptake by rice was very significantly correlated with NH_4OAc extractable Mg in the soil (r = 0.622**) (Table 26).

There was so significant difference between the various sources used, though magnesite was found to be the best one in both the soils (0.154 and 0.083 g pot^{-1} in karappadam and laterite soils respectively) as well as for both the levels. This may be due to the fact that magnesite is a better source of Mg in acid soils than magnesium sulphate as confirmed by the works of Shieh et al. (1965) and Vasil'eva (1965).

Total Mg uptake was significantly correlated with straw yield (r = 0.566*) and negatively correlated with available K in the soil (r = ¯0.614*) indicating a K-Mg antagonism.

Simple linear regression equations giving the relationship between total Mg uptake and straw yield and other soil characters are given in Table 27.

2. Yield of straw and grain

2.1 Yield of straw

Effects of various sources and levels of applied Mg on the yield of straw at harvest in karappadam and laterite soils are given in Tables 16, 17 and 18.

There was significant difference between the two soils used in this experiment with regard to the yield of straw. Straw yield was higher in karappadam soil than in the laterite soil. This may be attributed to the overall effects of higher organic matter, total N, Ca and Mg contents in that soil.

On Mg addition, straw yield at harvest was found to increase in karappadam soil, while in laterite soil a declining trend was noticed. Reason may be the same as that cited earlier for significantly higher yield of straw in karappadam soil.

There was no significant difference between the various Mg sources used with regard to the straw yield. But magnesium sulphate (38.41 g pot^{-1}) was found to perform better closely followed by magnesite (37.54 g pot^{-1}) and dolomite (30.82 g pot^{-1}) when both the soils were taken together. Magnesite was 97.7 per cent and dolomite 80.2 per cent as efficient as magnesium sulphate.

Different levels of Mg applied did not have any significant influence on the straw yield of the crop at harvest. This may be the result of relatively low level of Mg (25 and 50 kg MgO ha^{-1}) tried in this study.

Mean straw yield of the rice plant at harvest was highly significantly correlated with grain yield ($r = 0.697^{**}$) and total N ($r = 0.751^{**}$), P ($r = 0.773^{**}$), K ($r = 0.683^{**}$), Ca ($r = 0.834^{**}$) and Mg ($r = 0.566^{**}$) uptakes (Table 26). Regression equations were also worked out (Table 27).

2.2 Yield of grain

Influence of various treatments on the yield of grain in karappadam and laterite soils of Kerala is presented in Tables 16, 17 and 18.

The two soils used for the study differed significantly in their influence on grain yield. Grain yield was higher in karappadam soil when compared to that in the laterite soil. On Mg application, grain yield increased in karappadam soil, while in laterite soil a decreasing trend was noticed. This may be due to the combined effect of higher organic matter content and total N, Ca and Mg in the karappadam soil. Soil reaction was acidic in karappadam soil, so the addition of Mg sources might have improved the soil condition and yield.

There was no significant difference between the different Mg sources used on grain yield, though magnesite was found to be a better source in karappadam soil and magnesium sulphate in laterite soil. This may be due to the more acidic condition prevailing in karappadam soil. Magnesite is found to be a better source of Mg in acid soils than soluble forms, while in neutral to less acidic soils, magnesium sulphate is a better source (Shieh et al., 1965 and Vasil'eva, 1965).

There was no significant difference between the two levels of Mg applied (25 and 50 kg MgO ha^{-1}) on grain yield, may be due to the very low dose of the applied Mg when compared to the native available Mg content (862.11 and 524.76 kg MgO ha^{-1} in karappadam and laterite soils respectively).

Grain yield was highly significantly correlated with straw yield (r = 0.697**), total N uptake (r = 0.764**), total P uptake (r = 0.838**), total K uptake (r = 0.752**) and total Ca upake (r = 0.624*) (Table 26).

3. Soil analysis

3.1 Ammonium acetate extractable magnesium

Data on the content of NH_4OAc extractable Mg as affected by various sources and levels of applied Mg in karappadam and laterite soils are presented in Tables 16, 17 and 23.

In general, both in the presence and absence of added Mg, the content of NH_4OAc extractable Mg in the soils decreased with the advancement of crop growth up to the third fortnight. Higher level of NH_4OAc extractable Mg observed during the early stages of sampling may be due to the release of Mg from the native as well as from the added sources, and at the same time the absorption of Mg by the plant might have been relatively low during that period. The decrease observed in the subsequent periods may be due to the absorption of Mg by the plant. The increase in NH_4OAc extractable Mg in the fourth and fifth fortnights can be attributed to the increased release of Mg from native as well as added sources with enhanced period of waterlogging.

In the absence of added Mg, values for NH_4OAc extractable Mg in the karappadam and laterite soils were 3.414 and 1.965 cmol (+) kg^{-1} respectively, which on Mg addition

Table 23. Ammonium acetate extractable and water soluble Mg of soil as influenced by the treatments at different periods of crop growth (first crop)

Treatment	Ammonium acetate extractable Mg, cmol (+) kg^{-1}					Water soluble Mg, ppm				
	Periods, fortnight					Periods, fortnight				
	1	2	3	4	5	1	2	3	4	5
T_1	4.138	3.448	2.414	3.620	3.448	20.69	82.75	103.44	51.92	103.44
T_2	6.206	3.448	2.414	2.931	2.931	103.44	103.44	62.06	25.86	51.72
T_3	5.172	3.448	3.103	2.414	3.276	20.69	41.38	20.69	77.58	62.06
T_4	4.482	3.103	2.414	3.448	3.965	62.06	20.69	103.44	25.86	77.58
T_5	5.172	4.482	2.931	3.793	3.793	62.06	62.06	62.06	129.30	124.13
T_6	4.482	2.931	2.931	2.758	2.391	144.82	82.75	62.06	103.44	62.06
T_7	5.689	3.276	2.241	3.793	2.758	103.44	103.44	20.69	155.16	86.25
T_8	2.414	2.069	1.724	1.896	1.724	104.82	62.06	82.75	62.06	77.58
T_9	1.724	1.552	1.034	1.940	2.758	103.44	41.38	206.88	77.58	41.38
T_{10}	2.414	2.586	1.379	2.069	2.069	124.13	62.06	82.75	77.58	82.75
T_{11}	3.103	1.724	1.552	1.552	1.552	103.44	82.75	165.50	25.86	41.38
T_{12}	3.448	1.207	1.552	2.069	1.552	186.19	124.13	20.69	77.58	41.38
T_{13}	2.586	1.724	1.552	1.552	1.896	103.44	103.44	41.38	51.72	41.38
T_{14}	2.758	2.414	1.552	2.414	2.241	182.75	162.06	82.75	103.44	103.44

For NH_4OAc extractable Mg, CD (0.05) for the comparison of soils and levels is 0.2712. Other treatment effects are not significant increased to 3.54 and 1.98 cmol (+) kg^{-1}, quite understandably due to the increased Mg availability in the soil from added sources. The soils differed significantly with regard to their NH_4OAc extractable Mg content. It was much higher in karappadam soil than in laterite soil, which may be the result of higher native Mg content of that soil.

Though the sources did not differ significantly with regard to their contribution to NH_4OAc extractable Mg in the soil, carbonate forms of Mg sources were found to be better than magnesium sulphate. This is in line with the observations of many workers like Munk (1961); Kuhn (1962); Sheih et al. (1965); Vasil'eva (1965) and Jokineu (1982) that the carbonate forms of Mg performed better than magnesium sulphate in acid soil.

There was a significant increase in the NH_4OAc extractable Mg of the soils with increase in the levels of applied Mg. This is evidently due to the increased level of Mg in the soil with increase in the level of applied Mg.

Ammonium acetate extractable Mg in the soil is highly positively correlated with total Mg uptake by the plant ($r = 0.662^{**}$) and negatively correlated with pH ($r = -0.749^{**}$) and available K ($r = -0.728^{**}$) expressing a K-Mg antagonism. Regression equations are given in Table 27.

3.2 Water soluble magnesium

Influence of various treatments on the content of water soluble Mg in the karappadam and laterite soils is shown in Tables 16, 17 and 23.

In general, both in the presence and absence of added Mg, the content of water soluble Mg decreased with the advancement of crop growth. The maximum quantity of water soluble Mg was observed during the first fortnight of sampling and then gradually decreased up to the time of harvest (Table 23). Higher level of water soluble Mg observed during the first fortnight of sampling was due to the release of large quantity of soluble Mg on flooding from the native Mg in addition to that from the added Mg, and at the same time the absorption of Mg by the plant was relatively low during this period. The decrease observed in the subsequent periods may be due to the increased absorption of Mg by the plant.

In the absence of added Mg, values for water soluble Mg in the karappadam and laterite were 72.43 and 77.85 ppm respectively which on Mg addition increased to 72.66 and 91.48 ppm which may be due to the increased Mg availability from the added sources.

Though the various Mg sources did not differ significantly in their contribution to the water soluble Mg in the soil, magnesium sulphate was the best source providing 86.36 ppm in karappadam and 97.57 ppm in laterite soil. This can be attributed to the high water soluble Mg content of magnesium sulphate when compared to other Mg sources.

3.3 Ammonium acetate extractable calcium

Contents of NH_4OAc extractable Ca as influenced by various sources and levels of applied Mg in karappadam and laterite soils are presented in Tables 16, 17 and 24.

General trend both in the presence and absence of added Mg was that, NH_4OAc extractable Ca content increased with the advancement of crop growth up to the third fortnight and then decreased. This trend was just the opposite to that shown by NH_4OAc extractable Mg revealing that there existed a Ca-Mg antagonism.

Ammonium acetate extractable Ca in the karappadam soil was significantly higher than that in the laterite soil. This may be attributed to the high native Ca content of the karappadam soil.

3.4 Available K

Influence of various treatments on the available K content of the karappadam and laterite soils is presented in Tables 16, 17 and 24.

Table 24. Ammonium acetate extractable Ca and available K of soil as influenced by the treatments at different periods of crop growth (first crop)

Treatment	Ammonium acetate extractable Ca, cmol (+) kg^{-1}					Available K, kg ha^{-1}				
	Periods, fortnight					Periods, fortnight				
	1	2	3	4	5	1	2	3	4	5
T_1	9.999	7.586	10.344	7.241	6.206	403.2	268.8	145.6	134.4	112.0
T_2	9.654	9.350	8.620	6.551	6.206	369.6	240.8	156.8	123.2	100.8
T_3	7.930	8.620	11.034	8.275	5.862	358.4	207.2	112.0	134.4	95.2
T_4	6.896	6.896	6.551	5.862	8.792	336.0	201.6	145.6	145.6	151.2
T_5	7.930	8.620	8.620	4.827	5.517	358.4	179.2	162.4	123.2	100.8
T_6	7.241	8.275	7.930	7.241	6.379	358.4	168.0	145.6	179.2	78.4
T_7	7.241	7.240	9.310	6.896	6.896	330.4	268.8	151.2	106.4	117.6
T_8	5.517	8.275	6.206	4.482	5.172	436.8	257.6	257.6	168.0	112.0
T_9	6.206	6.551	6.206	4.741	6.206	425.6	347.2	229.6	217.0	201.6
T_{10}	6.896	6.896	9.654	5.172	5.172	442.4	280.0	201.6	201.6	268.0
T_{11}	6.140	6.206	4.138	5.000	5.000	448.0	274.4	246.4	201.6	134.4
T_{12}	7.240	6.206	7.586	3.793	4.827	375.2	252.0	224.0	179.2	218.4
T_{13}	5.517	8.965	5.862	4.310	6.034	403.2	313.6	257.6	246.4	168.0
T_{14}	5.517	5.862	7.586	5.172	4.827	358.4	257.6	224.0	190.4	123.2

For NH_4OAc extractable Ca, CD (0.05) for the comparison of soils and sources are 0.5549 and 0.6796 respectively

For available K, CD (0.05) for the comparison of soils and levels is 14.303. Other treatment effects are not significant.

Available K content of the soil decreased with the advancement of crop growth both in the presence and absence of added Mg. Higher level of available K observed during the first fortnight of sampling may be due to the release of large quantity of available K on flooding from the native K in addition to that from added K, and at the same time the absorption of K by the plant was relatively low during this period. The decrease observed in the subsequent periods may be due to the absorption of K by the plant.

Available K content of the laterite soil was significantly higher than that of the karappadam soil.

A significant decrease in available K content was observed in both the soils on increasing the level of applied Mg from 25 to 50 kg MgO ha^{-1}, showing a K-Mg antagonism. Available K in the soil was negatively correlated with NH_4OAc extractable Mg (r = 0.728**) in the soil and also with total Mg uptake (r = 0.614*) by the plant, confirming K-Mg antagonism.

3.5 pH

Effect of various Mg sources and their levels on soil reaction is presented in Tables 16, 17 and 25.

There was highly significant difference between the two soils used in the study with respect to pH. pH of the laterite soil was much higher than that of the karappadam soil. A highly

Table 25. pH and specific conductance of soil as influenced by the treatments at different periods of crop growth (first crop)

Treatment	pH					Specific conductance, dS m^{-1}				
	Periods, fortnight					Periods, fortnight				
	1	2	3	4	5	1	2	3	4	5
T_1	6.3	5.8	5.3	5.6	5.9	0.177	0.135	0.106	0.092	0.077
T_2	6.1	5.9	5.6	5.5	5.7	0.153	0.121	0.094	0.091	0.090
T_3	5.9	5.5	5.2	5.5	5.7	0.188	0.152	0.118	0.082	0.039
T_4	5.6	5.2	5.1	5.8	5.6	0.141	0.127	0.118	0.093	0.077
T_5	6.1	5.6	5.3	5.6	5.7	0.177	0.134	0.118	0.092	0.090
T_6	5.9	5.4	4.9	5.3	5.7	0.118	0.119	0.129	0.074	0.039
T_7	5.7	5.3	5.1	5.4	5.7	0.153	0.136	0.129	0.083	0.064
T_8	6.5	6.2	5.9	6.2	6.5	0.106	0.092	0.071	0.069	0.064
T_9	6.4	6.4	6.1	6.3	6.6	0.106	0.092	0.082	0.099	0.116
T_{10}	6.7	6.5	6.4	6.5	6.8	0.130	0.114	0.129	0.094	0.077
T_{11}	6.4	6.3	6.0	6.3	6.6	0.094	0.072	0.059	0.031	0.026
T_{12}	6.1	6.5	6.3	6.6	6.4	0.141	0.119	0.071	0.058	0.039
T_{13}	6.3	6.1	5.8	6.2	6.6	0.094	0.087	0.082	0.092	0.116
T_{14}	6.4	6.2	6.3	6.5	6.4	0.118	0.113	0.118	0.101	0.116

For pH, CD (0.05) for the comparison of soils and sources are 0.086 and 0.105 respectively. Other treatment effects are not significant.

significant difference was observed between the various sources used with regard to the pH of the soil. Soils treated with magnesite recorded the highest pH (5.7 and 6.5 in karappadam and laterite soils respectively) followed by dolomite (5.6 and 6.3) and then magnesium sulphate (5.4 and 6.4). Carbonate forms on dissociation gives CO_3 which produces only weak acid, while magnesium sulphate on dissociation gives SO_4 which produces strong acid. This may be the reason for recording higher pH with magnesite and lower with magnesium sulphate.

pH of the soil increased with the level of applied Mg in both the soils and also in the case of all the three sources. This may be due to the higher Mg content at higher levels, leading to increased pH.

3.6 Specific conductance

Data on the influence of different treatments on specific conductance of soil during different periods of crop growth (first crop) are furnished in Table 25 and their mean values in Tables 16 and 17.

The specific conductance of the soil was found to decrease with the progress of crop growth both in the presence and absence of added Mg, which may be due to the increased salt uptake by the crop.

The specific conductance was much higher in karappadam soil than in the laterite soil, which may be attributed to the higher native EC of that soil.

The influence of various Mg sources on specific conductance was inconsistent.

The EC of both the soils used in the study increased on raising the level of applied Mg from 25 to 50kg MgO ha^{-1}, which is obviously due to the increased availability of salt or ions in the soil.

Table 26. Inter-relationships of soil nutrient content, pH, straw yield, grain yield and total nutrient uptake at the time of harvest, first crop

(Coefficients of simple linear correlation)

	NH_4OAc extractable Mg	Water soluble Mg	NH_4OAc extractable Ca	Available K	pH	Straw yield	Grain yield	Total N uptake	Total P uptake	Total K uptake	Total Ca uptake	Total Mg uptake
NH_4OAc extractable Mg	--	-0.374	0.709**	-0.728**	-0.749**	0.403	0.411	0.507	0.419	0.086	0.062	0.662**
Water soluble Mg		--	-0.492	0.042	0.284	-0.236	-0.244	-0.257	-0.049	0.144	-0.162	-0.263
NH_4OAc extractable Mg			--	-0.289	-0.354	0.252	0.316	0.176	0.390	-0.100	-0.107	0.367
Available K				--	0.851**	-0.340	-0.321	-0.437	-0.248	-0.219	-0.090	-0.614*
pH					--	-0.472	-0.265	-0.409	-0.161	-0.030	-0.031	-0.608*
Straw yield						--	-0.697**	0.751**	0.773**	0.684**	0.834**	0.566*
Grain yield							--	0.764**	0.838**	0.752**	0.624*	0.264
Total N uptake								--	0.772**	0.630*	0.524	0.588*
Total P uptake									--	0.756**	0.502	0.428
Total K uptake										--	0.682**	0.332
Total Ca uptake											--	0.220
Total Mg uptake												--

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 27. Relationships between straw yield, nutrient uptake and soil characteristics (potculture experiment)

X	Y	Regression equation	R^2
	First crop		
NH_4OAc extractable Mg	NH_4OAc extractable Ca	Y = 4.409 + 0.710 X	0.503
"	Available K	Y = 465.9 - 20.8 X	0.530
pH	"	Y = -307.1 + 112.6 X	0.725
"	NH_4OAc extractable Mg	Y = 25.21 - 3.47 X	0.562
"	Total Mg uptake	Y = 1.327 - 0.182 X	0.369
Straw yield	"	Y = -0.043 0.007 X	0.320
NH_4OAc extractable Mg	"	Y = 0.043 + 0.043 X	0.438
	Second crop		
NH_4OAc extractable Mg	NH_4OAc extractable Ca	Y = 0.438 + 2.494 X	0.659
"	Total Mg uptake	Y = 0.329 - 0.052 X	0.379
Straw yield	"	Y = -0.089 + 0.007 X	0.607
NH_4OAc extractable Ca	"	Y = 1.007 - 0.137 X	0.493
Total K uptake	"	Y = 0.079 + 0.263 X	0.616

B. Second crop

The residual effect of Mg sources was assessed by studying the nutrient uptake and yield (straw and grain) of the second crop without the application of Mg treatments. The soil nutrient status was also studied during this period.

1. Nutrient uptake

1.1 Nitrogen

1.1.1 Nitrogen per cent of the straw

Results on the effect of various sources and levels of applied Mg on N per cent of the straw in karappadam and laterite soils are presented in Tables 28, 29 and 30.

The N per cent of the straw during the second crop period showed declining tendency with increasing period of crop growth except during the third fortnight representing the panicle initiation stage. This decrease in N per cent of the straw with the advancement of crop growth may be due to the dilution effect resulting from increased dry matter production.

On comparing the different sources of Mg with regard to their influence on N per cent of the straw magnesium sulphate was found to be the best one responsible for 1.27 and 1.51 per cent in karappadam and laterite soils respectively. This may be due to the higher solubility of Mg from magnesium sulphate..

Table 28. Nitrogen per cent and uptake in straw as influenced by the treatments at different periods of crop growth (second crop)

Treatment	N %						N uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	2.301	1.490	1.411	1.599	1.444	1.649	0.046	0.194	0.457	0.684	0.678	0.412
T_2	2.141	1.662	1.521	1.678	1.160	1.632	0.064	0.179	0.353	0.973	0.446	0.403
T_3	2.452	1.301	1.443	1.364	1.066	1.525	0.049	0.130	0.274	0.458	0.390	0.260
T_4	2.064	1.474	1.693	1.521	1.035	1.557	0.041	0.175	0.589	0.694	0.366	0.373
T_5	2.175	1.364	1.725	1.364	1.035	1.533	0.044	0.109	0.380	0.557	0.498	0.317
T_6	2.529	1.254	1.396	1.505	1.807	1.578	0.076	0.151	0.335	0.933	0.391	0.377
T_7	2.634	1.443	1.148	1.599	1.333	1.831	0.074	0.152	0.816	0.630	0.443	0.423
T_8	2.826	1.819	1.662	1.552	1.443	1.860	0.079	0.127	0.459	0.652	0.549	0.373
T_9	2.817	1.615	1.458	1.396	1.349	1.727	0.101	0.279	0.303	0.343	0.579	0.321
T_{10}	2.953	1.098	1.913	1.725	1.035	1.745	0.106	0.112	0.536	0.511	0.433	0.340
T_{11}	2.262	1.223	1.693	1.411	1.223	1.562	0.059	0.142	0.501	0.550	0.403	0.331
T_{12}	2.571	1.270	1.568	1.599	1.207	1.643	0.051	0.144	0.627	0.752	0.426	0.400
T_{13}	2.437	1.317	1.458	2.070	1.270	1.710	0.061	0.158	0.639	1.014	0.552	0.485
T_{14}	2.644	1.866	1.725	1.788	1.741	1.953	0.101	0.182	0.315	0.833	0.800	0.446
Mean	2.490	1.440	1.630	1.580	1.250	1.678	0.068	0.160	0.470	0.685	0.497	0.376

Table 29. Mean values of nutrient per cent, nutrient uptake, straw yield, grain yield, soil nutrient content, pH and EC as influenced by Mg sources and soil (second crop)

Soil	Control	Magnesite	Dolomite	Magnesium sulphate	
Karappadam	1.444	1.113	1.035	1.270	N % of straw at harvest
Laterite	1.443	1.192	1.215	1.510	
Karappadam	0.678	0.418	0.432	0.417	N uptake by straw at harvest, g pot^{-1}
Laterite	0.549	0.506	0.414	0.676	
Karappadam	0.422	0.464	0.447	0.377	N uptake by grain, g pot^{-1}
Laterite	0.515	0.570	0.449	0.379	
Karappadam	1.100	0.882	0.879	0.794	Total N uptake at harvest, g pot^{-1}
Laterite	1.064	1.076	0.863	1.055	
Karappadam	0.530	0.478	0.468	0.460	P % of straw at harvest
Laterite	0.360	0.440	0.518	0.450	
Karappadam	0.185	0.179	0.199	0.149	P uptake by straw at harvest, g pot^{-1}
Laterite	0.137	0.187	0.178	0.199	
Karappadam	0.199	0.190	0.195	0.197	P uptake by grain, g pot^{-1}
Laterite	0.242	0.257	0.213	0.232	
Karappadam	0.384	0.369	0.394	0.346	Total P uptake at harvest, g pot^{-1}
Laterite	0.379	0.444	0.391	0.431	
Karappadam	1.88	2.21	1.93	2.04	K % of straw at harvest
Laterite	2.55	2.28	2.60	2.17	
Karappadam	0.655	0.827	0.802	0.669	K uptake by straw at harvest, g pot^{-1}
Laterite	0.970	0.965	0.886	0.967	
Karappadam	0.158	0.189	0.160	0.146	K uptake by grain, g pot^{-1}
Laterite	0.169	0.183	0.177	0.184	
Karappadam	0.813	1.016	0.962	0.814	Total K uptake at harvest, g pot^{-1}
Laterite	1.139	1.148	1.063	1.151	
Karappadam	0.896	0.866	0.931	0.897	Ca % of straw at harvest
Laterite	0.828	0.932	0.931	0.759	
Karappadam	0.312	0.325	0.391	0.294	Ca uptake by straw at harvest, g pot^{-1}
Laterite	0.315	0.396	0.318	0.339	

Contd.

Table 29 (Contd.)

Soil	Control	Magnesite	Dolomite	Magnesium sulphate	
Karappadam	0.087	0.112	0.077	0.070	Ca uptake by grain, g pot^{-1}
Laterite	0.067	0.087	0.08	0.079	
Karappadam	0.399	0.437	0.468	0.364	Total Ca uptake at harvest, g pot^{-1}
Laterite	0.409	0.483	0.399	0.418	
Karappadam	0.232	0.321	0.388	0.293	Mg % of straw at harvest
Laterite	0.334	0.411	0.423	0.468	
Karappadam	0.081	0.120	0.162	0.096	Mg uptake by straw at harvest, g pot^{-1}
Laterite	0.127	0.174	0.149	0.209	
Karappadam	0.006	0.041	0.028	0.031	Mg uptake by grain, g pot^{-1}
Laterite	0.035	0.051	0.044	0.050	
Karappadam	0.087	0.161	0.190	0.127	Total Mg uptake at harvest, g pot^{-1}
Laterite	0.162	0.224	0.193	0.259	
Karappadam	34.85	37.50	41.78	32.79	Straw yield at harvest, g pot^{-1}
Laterite	38.05	42.38	34.11	44.70	
Karappadam	31.63	35.63	32.01	28.98	Grain yield, g pot^{-1}
Laterite	32.20	36.67	31.32	32.47	
Karappadam	3.034	3.951	3.586	3.379	NH_4OAc extractable Mg, cmol (+) kg^{-1}
Laterite	2.057	2.258	2.448	2.670	
Karappadam	77.57	94.12	86.88	77.57	Water soluble Mg, ppm
Laterite	100.32	86.88	62.06	76.54	
Karappadam	11.000	10.948	9.068	11.258	NH_4OAc extractable Ca, cmol (+) kg^{-1}
Laterite	7.354	5.775	6.913	7.258	
Karappadam	209.4	216.1	196.6	196.6	Available K, kg h^{-1}
Laterite	240.8	212.8	e226.3	199.9	
Karappadam	6.2	6.1	5.8	5.9	pH
Laterite	6.3	6.3	6.4	6.5	
Karappadam	0.097	0.083	0.071	0.079	Specific conductance, dS m^{-1}
Laterite	0.085	0.082	0.084	0.077	

Also the S in magnesium sulphate might have contributed to a favourable condition leading to increased N per cent of the straw.

1.1.2 Uptake of N by the straw

Results on the effect of various sources and levels of Mg on the uptake of N by the straw at harvest in karappadam and laterite soils are presented in Tables 28, 29 and 30.

Irrespective of Mg treatments, N uptake by the straw increased up to the fourth fortnight and then decreased. This decrease in the fifth fortnight may be due to the N removal by grain.

Nitrogen uptake by the straw at harvest showed no positive response to Mg applicable in both the soils. It was in line with the reports of Panicker (1980) and Jayaraman (1988) that Mg application decreased the N level of the plants.

Among the various Mg sources tried in this experiment, magnesium sulphate was found to perform better. This may be attributed to the better solubility of Mg from magnesium sulphate and also the presence of S in magnesium sulphate.

1.1.3 Nitrogen uptake by the grain

Data on the influence of various sources and levels of applied Mg on uptake of N by the grain in karappadam and laterite soils are presented in Tables 29, 30 and 31.

Table 30. Mean values of nutrient per cent, nutrient uptake, straw yield, grain yield, soil nutrient content, pH and EC as influenced by levels of Mg application (second crop)

Levels of MgO kg ha^{-1}	Soil		Sources of Mg			
	Karappadam	Laterite	Magnesite	Dolomite	Magnesium sulphate	
25	1.134	1.281	1.255	1.130	1.240	N % of straw at harvest
50	1.145	1.327	1.051	1.120	1.540	
25	0.401	0.511	0.513	0.385	0.472	N uptake by straw at harvest, g pot^{-1}
50	0.444	0.553	0.412	0.462	0.622	
25	0.442	0.445	0.550	0.391	0.389	N uptake by grain, g pot^{-1}
50	0.417	0.487	0.484	0.506	0.367	
25	0.843	0.956	1.063	0.776	0.861	Total N uptake at harvest, g pot^{-1}
50	0.861	1.040	0.896	0.968	0.989	
25	0.448	0.440	0.460	0.418	0.450	P % of straw at harvest
50	0.485	0.498	0.458	0.568	0.450	
25	0.159	0.174	0.187	0.143	0.170	P upake by straw at harvest, g pot^{-1}
50	0.193	0.202	0.179	0.234	0.179	
25	0.186	0.229	0.218	0.191	0.212	P uptake by grain, g pot^{-1}
50	0.202	0.239	0.228	0.218	0.216	
25	0.345	0.403	0.405	0.334	0.382	Total P uptake at harvest, g potl-1
50	0.395	0.441	0.407	0.452	0.395	
25	2.05	2.37	2.21	2.37	2.07	K % of straw at harvest
50	2.06	2.33	2.28	2.17	2.14	
25	0.729	0.929	0.898	0.804	0.785	K uptake by straw at harvest, g pot^{-1}
50	0.803	0.949	0.895	0.883	0.850	
25	0.166	0.172	0.200	0.156	0.152	K uptake by grain, g pot^{-1}
50	0.164	0.191	0.172	0.181	0.179	
25	0.895	1.101	1.098	0.960	0.937	Total K uptake at harvest, g pot^{-1}
50	0.967	1.140	1.067	1.064	1.029	
25	0.919	0.920	0.966	0.896	0.897	Ca % of straw at harvest
50	0.877	0.828	0.832	0.966	0.759	
25	0.325	0.367	0.395	0.306	0.336	Ca uptake by straw at harvest, g pot^{-1}
50	0.349	0.335	0.326	0.403	0.296	

Contd.

Table 30 (Contd.)

Levels of MgO kg ha^{-1}	Soil		Sources of Mg			
	Karappadam	Laterite	Magnesite	Dolomite	Magnesium sulphate	
25	0.101	0.091	0.115	0.084	0.088	Ca uptake by grain, g pot^{-1}
50	0.072	0.074	0.084	0.116	0.061	
25	0.426	0.458	0.510	0.390	0.424	Total Ca uptake at harvest, g pot^{-1}
50	0.421	0.409	0.410	0.519	0.357	
25	0.310	0.464	0.390	0.409	0.362	Mg % of straw at harvest
50	0.357	0.403	0.341	0.402	0.398	
25	0.110	0.189	0.161	0.144	0.143	Mg uptake by straw at harvest, g pot^{-1}
50	0.142	0.166	0.133	0.167	0.162	
25	0.028	0.049	0.053	0.034	0.029	Mg uptake by grain, g pot^{-1}
50	0.038	0.047	0.038	0.038	0.052	
25	0.138	0.238	0.214	0.178	0.172	Total Mg uptake at harvest, g pot^{-1}
50	0.180	0.213	0.171	0.205	0.214	
25	35.39	39.78	40.68	34.18	37.89	Straw yield at harvest, g pot^{-1}
50	39.32	41.02	39.20	41.70	39.60	
25	33.22	33.06	37.05	30.37	31.99	grain yield, g pot^{-1}
50	31.19	33.91	35.24	32.96	29.45	
25	3.506	2.483	3.069	2.983	2.931	NH_4OAc extractable Mg, cmol (+) kg^{-1}
50	3.772	2.435	3.141	3.052	3.119	
25	92.05	82.74	90.49	78.60	93.09	Water soluble Mg, ppm
50	80.33	67.58	90.50	70.33	61.02	
25	10.643	6.494	8.379	8.172	9.145	NH_4OAc extractable Ca, cmol (+) kg^{-1}
50	10.206	6.804	8.345	7.810	9.361	
25	196.0	221.8	203.3	217.3	206.1	Available K, kg ha^{-1}
50	210.1	204.3	225.6	205.6	190.4	
25	6.0	6.4	6.2	6.2	6.2	pH
50	5.9	6.4	6.3	6.0	6.2	
25	0.085	0.083	0.094	0.079	0.080	Specific conductance dS m^{-1}
50	0.070	0.078	0.070	0.076	0.076	

Nitrogen uptake by the grain was high in Mg treated pots (0.429 g pot^{-1}) over control (0.422 g pot^{-1}) in the case of karappadam soil while in laterite soil such a positive response was not seen. This increased uptake from karappadam soil may be assigned to favourable conditions like high organic matter, total N, Ca and Mg content existed in that soil.

Nitrogen uptake by the grain was maximum in pots supplied with magnesite in both the soils (0.464 and 0.570 g pot^{-1} in karappadam and laterite soils respectively) followed by dolomite (0.447 and 0.449 g pot^{-1}) and then magnesium sulphate (0.377 and 0.379 g pot^{-1}). Higher N uptake in plants supplied with carbonate forms of Mg may be correlated with their better residual efficiency in acid soils. When compared to that of magnesium sulphate, pH was comparatively higher in soils supplied with magnesite and dolomite. This is in conformity with the observations of Shieh et al. (1965) and Vasil'eva (1965) that magnesite and dolomite were more effective in acid soils than magnesium sulphate.

Nitrogen uptake by grain increased with the levels of Mg applied (25 and 50 kg MgO ha^{-1}) showing a synergestic relationship between N and Mg.

1.1.4 Total N uptake

Influence of various sources and levels of Mg applied during the first crop season on total N uptake by the second crop at harvest is presented in Tables 29, 30 and 31.

Table 31. Straw yield, grain yield and nutrient uptake, g pot^{-1} as influenced by the treatments (second crop)

Treatment	Straw yield	Grain yield	Total nutrient uptake at harvest					Nutrient uptake by the grain				
			N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_1	34.85	31.63	1.099	0.384	0.813	0.400	0.157	0.422	0.199	0.158	0.087	0.006
T_2	38.43	39.60	0.967	0.362	1.065	0.481	0.159	0.522	0.181	0.228	0.137	0.046
T_3	36.58	31.65	0.797	0.375	0.966	0.393	0.163	0.407	0.198	0.150	0.087	0.035
T_4	35.40	30.38	0.786	0.327	0.851	0.401	0.156	0.419	0.184	0.152	0.084	0.020
T_5	48.15	33.65	0.973	0.462	1.071	0.535	0.224	0.475	0.207	0.168	0.070	0.036
T_6	32.35	29.68	0.777	0.344	0.766	0.394	0.101	0.386	0.191	0.119	0.082	0.019
T_7	33.23	28.28	0.811	0.348	0.863	0.334	0.154	0.368	0.202	0.173	0.059	0.043
T_8	38.05	32.20	1.064	0.379	1.139	0.382	0.191	0.515	0.242	0.169	0.067	0.035
T_9	42.93	34.50	1.158	0.449	1.130	0.539	0.269	0.579	0.255	0.173	0.094	0.060
T_{10}	41.83	38.83	0.993	0.438	1.167	0.427	0.181	0.560	0.258	0.194	0.080	0.041
T_{11}	32.97	30.37	0.765	0.339	1.066	0.379	0.200	0.362	0.197	0.160	0.084	0.048
T_{12}	35.25	32.28	0.962	0.443	1.057	0.418	0.185	0.537	0.229	0.194	0.078	0.039
T_{13}	43.43	34.30	0.944	0.420	1.107	0.454	0.244	0.393	0.233	0.184	0.095	0.038
T_{14}	45.97	30.63	1.166	0.441	1.195	0.380	0.263	0.365	0.230	0.184	0.063	0.061

For straw yield, CD (0.05) for the comparison of soil x source interaction is 3.651.

For grain yield, CD (0.05) for the comparison of sources is 3.007. Other treatment effects are not significant.

Total N uptake at harvest showed no positive response to Mg application, which may be due to the similar trend shown by N per cent of straw and grain on Mg addition.

Among the different Mg sources tried, magnesite was the most suited one for total N uptake by paddy. This may be assigned to the higher neutralising value of magnesite helping it to perform better in acid soils.

On raising the level of applied Mg from 25 to 50 kg MgO ha^{-1}, total N uptake by the crop increased. This may be due to the beneficial effect of applied Mg in the soil. Magnesium application raises the pH of the soil, thus creating a more favourable condition for the uptake of nutrients like N.

Total N uptake by the rice plant at harvest was positively correlated with total P uptake (r = 0.684**), total K uptake (r = 0.547*) and total Mg uptake (r = 0.632*) and negatively correlated with exchangeable Mg (r = -0.674**) in the soil (Table 39).

1.2 Phosphorus

1.2.1 Phosphorus per cent of the straw

Data on the effect of various sources and levels of Mg (applied during the first crop season) on P per cent of the straw (second crop) in karappadam and laterite soils are presented in Tables 29, 30 and 32.

Table 32. Phosphorus per cent and uptake in straw as influenced by the treatments at different periods of crop growth (second crop)

Treatment	P %						P uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	0.830	0.890	0.820	0.720	0.530	0.758	0.017	0.116	0.266	0.308	0.185	0.178
T_2	0.690	0.710	0.895	0.655	0.470	0.684	0.021	0.076	0.208	0.380	0.181	0.173
T_3	0.620	0.640	0.955	0.650	0.485	0.670	0.012	0.064	0.182	0.218	0.177	0.131
T_4	0.890	0.930	0.960	0.670	0.405	0.771	0.018	0.111	0.334	0.306	0.143	0.182
T_5	0.920	0.960	0.970	0.725	0.530	0.821	0.018	0.077	0.213	0.296	0.255	0.172
T_6	0.810	0.860	0.965	0.730	0.470	0.767	0.024	0.103	0.232	0.453	0.152	0.193
T_7	0.790	0.860	0.860	0.805	0.440	0.751	0.022	0.090	0.327	0.317	0.146	0.181
T_8	0.720	0.770	0.960	0.810	0.360	0.724	0.020	0.054	0.265	0.340	0.137	0.167
T_9	0.710	0.735	0.920	0.780	0.450	0.719	0.026	0.127	0.191	0.192	0.193	0.146
T_{10}	0.880	0.930	0.985	0.800	0.430	0.805	0.032	0.095	0.276	0.237	0.180	0.164
T_{11}	0.810	0.850	0.930	0.715	0.430	0.747	0.021	0.099	0.275	0.279	0.142	0.163
T_{12}	0.830	0.880	0.910	0.610	0.605	0.767	0.017	0.099	0.364	0.287	0.213	0.196
T_{13}	0.770	0.810	0.830	0.570	0.430	0.682	0.019	0.097	0.364	0.279	0.187	0.189
T_{14}	0.815	0.835	0.680	0.850	0.460	0.728	0.031	0.081	0.147	0.396	0.212	0.173
Mean	0.790	0.840	0.900	0.720	0.470	0.744	0.021	0.092	0.260	0.306	0.179	0.172

Phosphorus per cent of the straw was maximum during the second and third fortnights indicating the maximum tillering stage and panicle initiation stage. Thereafter there was a decline in P per cent of the straw, may be due to the dilution effect resulting from increased dry matter production.

Magnesium addition raised the P per cent of the straw from 0.360 per cent to 0.469 per cent in laterite soil while in karappadam soil, no positive response was obtained. Higher P per cent in the laterite soil may be due to the release of P from native sources as well as due to the beneficial effects of added Mg which may have become available only during the second crop season, since this rise in P per cent was not noticed during the first crop season.

Phosphorus per cent of the straw at harvest increased with the levels of Mg in both the soils. This is obviously due to beneficial effect of higher dose of Mg applied on P uptake, which is in line with the conclusions of many workers that Mg acts as a P carrier.

1.2.2 Phosphorus uptake by the straw

Influence of various treatments on P uptake by straw at harvest in karappadam and laterite soils is furnished in Tables 29, 30 and 32.

Phosphorus uptake by the straw increased continuously from the time of planting till the fourth fortnight and then decreased during the final stage. This increase in the initial stages may be attributed to the increased dry matter production and the decrease at the time of harvest may be due to the translocation to grains.

On Mg addition, P uptake by the straw at harvest increased from 0.13 to 0.188 g pot^{-1} in laterite soil, while in karappadam soil no positive response was noticed. This increased P uptake in laterite soil may be due to the release of P from native sources under submerged condition. Native P content was relatively higher in laterite soil.

Phosphorus uptake by the straw at harvest was the highest in samples supplied with dolomite, followed by magnesite and magnesium sulphate. This may be correlated with the solubilities of the three Mg sources used in this experiment. Solubility increased in the order of dolomite < magnesite < magnesium sulphate (Lindsay, 1979). Due to the low solubility, Mg release from dolomite might have taken place slowly and so during the second crop season Mg availability might have been the highest in dolomite added samples. This can be supported by the highest total Mg uptake by the samples supplied with dolomite (0.19 g pot^{-1}) in karappadam soil. Since Mg acts as a P carrier, P uptake might have increased in plants supplied with dolomite.

During the second crop season, P uptake by the straw at harvest showed a increasing trend on raising the level of applied Mg from 25 to 50 kg MgO ha^{-1}. This again reveals the importance of Mg in P nutrition.

1.2.3 Phosphorus uptake by the grain

Data on the influence of various treatments on P uptake by the grain during the second crop season is furnished in Tables 29, 30 and 31.

Magnesium application did not have any positive effect on P uptake by the grain during the second crop. But on increasing the level of applied Mg from 25 to 50 kg MgO ha^{-1}, P uptake increased in both the soils and also in the case of all the three sources (Table 30) revealing the essential role of Mg in P nutrition. This was in agreement with observations of Nayar and Koshy (1969) that the P content of paddy increased with the rate of Mg application.

1.2.4 Total P uptake

Total P uptake as influenced by various treatments during the second crop season is presented in Tables 29, 30 and 31.

Both in the presence and absence of applied Mg total P uptake by the rice at harvest was more in laterite soil. This is due to the high native P content of the laterite soil.

On Mg application, total P uptake increased in laterite soil, while in karappadam no positive response was noticed. This may be due to the higher native P content of the laterite soil. Waterlogging and the addition of Mg fertilizers might have helped the release of P from native sources.

Total P uptake increased with the levels of Mg application from 25 to 50 kg MgO ha^{-1} emphasising the importance of Mg in P nutrition as a P carrier.

Total P uptake was highly positively correlated with straw yield (r = 0.814**), total N uptake (r = 0.684**), total K uptake (r = 0.673**), total Ca uptake (r = 0.588*) and total Mg uptake (r = 0.725**) (Table 39).

1.3 Potassium

1.3.1 Potassium per cent of the straw

Data on the residual effects of the sources and levels of applied Mg on K per cent of the straw in karappadam and laterite soils are presented in Tables 29, 30 and 33.

On Mg application, K per cent of the straw at harvest showed a decreasing trend in the laterite soil, while in karappadam soil an increasing trend was noticed. This may be correlated with the pH of the two soils. Due to the more acidic reaction of the karappaddam soil, Mg added might have become readily soluble in the first crop season itself and so only a

Table 33. Potassium per cent and uptake in straw as influenced by the treatments at different periods of crop growth (second crop)

Treatment	K per cent						K uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	1.80	2.90	1.75	1.75	1.88	2.02	0.036	0.377	0.567	0.749	0.655	0.477
T_2	1.92	2.28	1.88	1.60	2.18	1.97	0.058	0.245	0.436	0.928	0.838	0.501
T_3	1.72	2.28	1.85	1.78	2.23	1.97	0.035	0.228	0.352	0.528	0.816	0.392
T_4	1.88	2.80	1.78	1.60	1.98	2.01	0.038	0.333	0.619	0.730	0.701	0.484
T_5	1.98	2.10	2.00	1.80	1.88	1.95	0.040	0.168	0.440	0.734	0.903	0.457
T_6	1.96	2.40	2.00	1.65	2.00	2.00	0.059	0.288	0.480	1.023	0.647	0.499
T_7	1.82	2.85	1.85	1.75	2.08	2.07	0.051	0.299	0.703	0.690	0.689	0.486
T_8	1.80	2.03	1.80	1.83	2.55	2.00	0.050	0.142	0.497	0.769	0.970	0.486
T_9	1.90	2.45	1.88	1.85	2.23	2.06	0.068	0.424	0.391	0.455	0.957	0.459
T_{10}	1.75	2.35	1.85	1.85	2.33	2.03	0.063	0.240	0.518	0.548	0.973	0.468
T_{11}	1.72	2.15	1.65	2.00	2.75	2.05	0.045	0.249	0.488	0.780	0.907	0.494
T_{12}	1.84	2.40	1.78	1.80	2.45	2.05	0.037	0.271	0.712	0.846	0.864	0.546
T_{13}	1.89	2.45	1.83	1.73	2.13	2.01	0.047	0.294	0.802	0.848	0.923	0.583
T_{14}	1.90	2.30	1.83	1.70	2.20	1.99	0.072	0.224	0.395	0.792	1.011	0.499
Mean	1.85	2.41	1.84	1.76	2.21	2.01	0.050	0.270	0.529	0.744	0.847	0.488

small portion might be remaining in the second crop season. But in laterite soil due to relatively higher pH condition, release of Mg from their sources might have taken place relatively slowly so sufficient quantity might have remained in the soil during the second crop season to cause K-Mg antagonism. This is supported by much higher total Mg uptake noted in laterite soil (0.21 g pot^{-1}) than the karappadam (0.14 g pot^{-1}).

1.3.2 Potassium uptake by the straw

Influence of various treatments on K uptake by the straw during the second crop season is presented in Tables 29, 30 and 33.

Potassium uptake by the straw showed a continuously increasing trend during the crop growth season, it may be due to the increase in the dry matter production.

On Mg application, K uptake by the straw increased in karappadam soil, while in laterite soil it decreased. This may be correlated with the K per cent of the straw at harvest.

Potassium uptake by the straw was higher in laterite soil than in karappadam, evidently due to the higher native K content in the laterite soil.

1.3.3 Potassium uptake by the grain

Uptake of K by grain as influenced by various treatments is presented in Tables 29, 30 and 31.

Laterite soil marked higher K uptake of grain than karappadam soil both in the presence and absence of added Mg, may be due to the higher native K in laterite soil.

Potassium uptake by grain increased from 0.158 to 0.165 g pot^{-1} in karappadam soil and from 0.169 to 0.181 g pot^{-1} in laterite soil. This increase may be attributed to the correction of soil pH to near neutral condition on addition of Mg fertilizers. Probably this condition may have favoured the uptake of other nutrients like N.

Different levels of Mg applied did not have any marked influence on K uptake by the grain.

1.3.4 Total K uptake

Effect of various sources and levels of applied Mg on total K uptake by the rice plant at harvest during the second crop period is given in Tables 29, 30 and 31.

Total K uptake was higher in plants grown in laterite soil than in karappadam, obviously due to the higher native K content of that soil.

In general total K uptake by the rice plants was found to increase on Mg addition. Total K uptake increased with the level of applied Mg. This may be assigned to the favourable condition created in acid soil on Mg addition, increasing the uptake of other nutrients like K.

Total K uptake by the rice during the second crop season was positively correlated with straw yield (r = 0.698**), grain yield (r = 0.534*), total N uptake (r = 0.547*), total P uptake (r = 0.673**) and total Mg uptake (r = 0.780**) (Table 39).

1.4 Calcium

1.4.1 Calcium per cent of the straw

Influence of various treatments on Ca per cent of the straw during the second crop season in karappadam and laterite soils is presented in Tables 29, 30 and 34.

Studies on Ca per cent of the straw at harvest revealed that it was much higher in karappadam soil than in laterite soil, may be due to the higher native Ca content of the karappadam soil.

Calcium per cent of the straw was the highest in samples supplied with dolomite in both the soils, obviously due to the Ca present in dolomite.

On increasing the level of Mg application from 25 to 50 kg MgO ha^{-1}, in general, Ca per cent of the straw was found to decrease from 0.919 to 0.877 per cent in karappadam soil and from 0.920 to 828 per cent in laterite soil, expressing a Ca-Mg antagonism. But in the case of dolomite, Ca per cent increased on raising the level of applied Mg from 25 to 50 MgO ha^{-1}, may be due to the presence of Ca in dolomite.

Table 34. Calcium per cent and uptake in straw as influenced by the treatments at different periods of crop growth (second crop)

Treatment	Ca per cent						Ca uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	0.743	0.620	0.656	0.758	0.896	0.735	0.015	0.081	0.213	0.324	0.312	0.189
T_2	0.726	0.758	0.656	0.690	0.896	0.745	0.022	0.085	0.152	0.400	0.344	0.200
T_3	0.682	0.620	0.552	0.620	0.836	0.662	0.014	0.062	0.105	0.208	0.306	0.139
T_4	0.769	0.656	0.620	0.758	0.896	0.740	0.015	0.078	0.216	0.456	0.317	0.217
T_5	0.696	0.690	0.620	0.758	0.966	0.746	0.014	0.052	0.136	0.309	0.465	0.195
T_6	0.625	0.483	0.656	0.896	0.966	0.835	0.020	0.058	0.157	0.556	0.313	0.221
T_7	0.634	0.586	0.620	0.690	0.828	0.672	0.018	0.062	0.236	0.272	0.275	0.172
T_8	0.736	0.724	0.620	0.756	0.828	0.733	0.021	0.051	0.171	0.318	0.315	0.175
T_9	0.672	0.586	0.620	0.828	1.036	0.748	0.024	0.101	0.129	0.204	0.445	0.181
T_{10}	0.656	0.586	0.758	0.758	0.828	0.717	0.024	0.060	0.212	0.224	0.346	0.173
T_{11}	0.796	0.758	0.828	0.690	0.896	0.794	0.021	0.088	0.245	0.269	0.295	0.184
T_{12}	0.682	0.552	0.758	0.690	0.966	0.730	0.014	0.062	0.303	0.324	0.341	0.209
T_{13}	0.712	0.690	0.828	0.690	0.828	0.750	0.018	0.083	0.363	0.338	0.360	0.232
T_{14}	0.698	0.690	0.586	0.828	0.690	0.698	0.027	0.067	0.127	0.386	0.317	0.185
Mean	0.706	0.643	0.716	0.750	0.880	0.739	0.019	0.071	0.198	0.328	0.339	0.191

1.4.2 Calcium uptake by the straw

Effect of various treatments on Ca uptake by the straw at harvest during the second crop season is given in Tables 29, 30 and 34.

Calcium uptake by the straw was found to increase gradually with the advancement of crop growth, which may be assigned to the increase in dry matter production.

In Mg applied pots Ca level of the straw at harvest was higher than that of the control in both the soils during the second crop season. Probably this may be due to the low Mg content in the soil during the second crop season to cause any antagonism between Ca and Mg.

Calcium uptake by the straw at harvest was the highest in pots supplied with dolimite, understandably due to the residual effect of dolomite in supplying calcium.

Different levels of Mg tried did not have any marked influence on Ca uptake by the straw. This may be due to the relatively low dose of Mg applied (25 and 50 kg MgO ha^{-1}).

1.4.3 Calcium uptake by the grain

Data on the influence of various treatments on calcium uptake by grain are furnished in Tables 29, 30 and 31.

Grain Ca level was higher in karappadam soil than in laterite, probably due to the higher native Ca of that soil.

Calcium uptake by grains decreased with increasing levels of Mg, indicating a negative interaction between Ca and Mg.

1.4.4 Total Ca uptake

Total Ca uptake as influenced by various sources and levels of applied Mg is presented in Tables 29, 30 and 31.

Magnesium application raised the total Ca uptake at harvest. Reason may be the same as cited for increased Ca uptake by straw and grain on Mg application. Also the total Ca uptake by rice was positively correlated with straw yield (r = 0.649*) and grain yield (r = 0.630*) (Table 39) which were also increased on Mg application during the second crop season.

Total Ca uptake showed a decreasing trend on increasing the level of Mg application from 25 to 50 kg MgO ha^{-1} revealing antagonism between Ca and Mg.

1.5 Magnesium

1.5.1 Magnesium per cent of the straw

Data on the influence of various sources and levels of Mg applied to the first crop on Mg per cent of the straw during the second crop season in karappadam and laterite soils are given in tables 29, 30 and 35.

Table 35. Magnesium per cent and uptake in straw as influenced by the treatments at different periods of crop growth (second crop)

Treatment	Mg per cent						Mg uptake, g pot^{-1}					
	Periods, fortnight						Periods, fortnight					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
T_1	0.193	0.367	0.391	0.330	0.232	0.303	0.004	0.048	0.127	0.141	0.081	0.080
T_2	0.246	0.284	0.391	0.280	0.293	0.299	0.007	0.031	0.091	0.162	0.113	0.081
T_3	0.325	0.458	0.363	0.274	0.348	0.354	0.007	0.046	0.069	0.092	0.127	0.068
T_4	0.227	0.300	0.274	0.421	0.385	0.321	0.005	0.036	0.095	0.192	0.136	0.093
T_5	0.315	0.372	0.322	0.330	0.390	0.346	0.006	0.030	0.071	0.135	0.188	0.086
T_6	0.310	0.540	0.391	0.247	0.251	0.348	0.009	0.065	0.094	0.153	0.081	0.081
T_7	0.347	0.619	0.504	0.371	0.334	0.435	0.010	0.065	0.192	0.146	0.111	0.105
T_8	0.129	0.535	0.458	0.421	0.334	0.375	0.004	0.038	0.127	0.177	0.127	0.094
T_9	0.216	0.343	0.322	0.379	0.487	0.349	0.008	0.059	0.067	0.093	0.209	0.087
T_{10}	0.254	0.389	0.330	0.330	0.334	0.327	0.009	0.040	0.092	0.098	0.140	0.076
T_{11}	0.209	0.420	0.379	0.280	0.432	0.344	0.005	0.049	0.112	0.109	0.152	0.086
T_{12}	0.229	0.362	0.284	0.371	0.414	0.332	0.005	0.041	0.114	0.174	0.146	0.096
T_{13}	0.257	0.325	0.288	0.232	0.473	0.315	0.006	0.039	0.126	0.114	0.205	0.098
T_{14}	0.272	0.462	0.478	0.334	0.462	0.402	0.010	0.045	0.103	0.156	0.213	0.105
Mean	0.254	0.410	0.370	0.330	0.370	0.347	0.007	0.045	0.106	0.147	0.145	0.090

The trend shown by the Mg per cent of the straw during the different stages of crop growth was inconsistent.

During the second crop season, at the time of harvest, Mg per cent of the straw showed a conspicuous increase over control in both the soils. This observed increase was from 0.232 to 0.334 per cent in karappadam soil and from 0.334 to 0.434 per cent in laterite soil. This is clearly due to the uptake of Mg from residual sources in the soil.

The laterite soil recorded higher Mg per cent in the straw at harvest than that of the karappadam soil in the second crop season (0.409 and 0.309 per cent respectively in laterite and karappadam soils). But during the first crop period an opposite trend was noticed. Magnesium per cent of the straw was higher in karappadam soil (0.384 per cent) than the laterite (0.358 per cent). This showed that the residual value of Mg sources was higher in laterite soil which may be attributed to the pH values of these soils. Due to the low pH of the karappadam soil, Mg might have become more readily soluble in the first crop season itself. So very small quantity may be remaining for the subsequent season. In the case of laterite soil, due to the slower release of Mg from added sources, relatively larger amounts may be remaining in the second crop season for uptake.

In karappadam soil, Mg per cent of the straw was the highest in samples supplied with dolomite, followed by magnesite and magnesium sulphate. This may be assigned to their solubility which is inversely proportional to the residual effect.

In laterite soil, Mg per cent of the straw was the highest in samples supplied with magnesium sulphate. This may be due to the fact that the removal of Mg by the first crop was relatively lower in laterite soil and since no provision for drainage was made in the potculture experiment, whatever Mg that was retained after uptake in the first crop season might have become available for use in the subsequent season.

Different levels of Mg used did not have any marked influence on Mg per cent of the straw.

1.5.2 Magnesium uptake by the straw

Effect of various treatments on Mg uptake by the straw during the second crop season is presented in Tables 29, 30 and 35.

Magnesium uptake by the straw was found to increase with the advancement of crop season till the fourth stage, may be due to the increase in dry matter production. During the harvesting stage, there was a decrease in Mg uptake by the straw, may be the result of translocation to the grains.

Among the two soils used in the study, laterite recorded higher Mg uptake than karappadam. This showed that the residual value of Mg sources applied was higher in laterite soil than in karappadam soil. Reason may be the same as that for higher Mg per cent of the straw in the laterite soil.

Uptake of Mg by the straw was higher in Mg applied samples than control in both the soils; obviously due to the uptake of Mg from residual sources.

On comparing the performance of various Mg sources in karappadam soil, dolomite recorded the highest Mg uptake. This may be due to its higher residual value and low water solubility. But in laterite soil magnesium sulphate recorded the highest Mg uptake at harvest. As explained in the case of Mg per cent of the straw, this can be attributed to the retention of water soluble Mg in magnesium sulphate treated pots since there was no chance of leaching loss of Mg from the experimental pots and that the removal of Mg by the first crop was more from the karappadam soil.

1.5.3 Magnesium uptake by the grain

Data on the influence of various Mg sources on Mg uptake by the grain are furnished in Tables 29, 30 and 31.

There was a marked increase in Mg uptake by the grain on Mg application in both the soils. This increase was from 0.006 to 0.033 g pot^{-1} in karappadam soil and from 0.035 to 0.048 g pot^{-1} in laterite. This may be correlated to the increased grain yield on Mg addition, which emphasises the importance of Mg in grain nutrition. Similar observations were made by Sheng and Yuan (1963) and Narayana and Rao (1982).

Uptake of Mg by the grain was higher in laterite soil than in karappadam soil. This may be due to the larger amount of Mg released in this soil during the second crop season.

Magnesium uptake by the grain increased with the levels of Mg applied from 25 to 50 kg MgO h^{-1}, obviously due to the increased Mg availability from higher dose.

1.5.4 Total Mg uptake

Effect of various treatments on total Mg uptake by rice plant during the second crop season in karappadam and laterite soils is given in Tables 29, 30 and 31.

Total Mg uptake by the rice plant increased markedly on Mg application from 0.087 to 0.159 g pot^{-1} in karappadam soil and from 0.162 to 0.225 g pot^{-1} in laterite soil. This is understandably due to the availability of Mg from residual sources in the soil.

Both in the presence and absence of added Mg, total Mg uptake by the rice plant was more from laterite soil than from karappadam soil. As stated in the case of higher Mg per cent of the straw in laterite soil, this can be attributed to pH value of the two soils. Due to relatively higher pH of the laterite soil, release of Mg from added sources might have taken place slowly and so more Mg may be remaining for absorption by plants during the second crop period.

There was no significant difference between the different Mg sources used with regard to total Mg uptake by the rice plant at harvest. This showed that the amount of Mg that was made available from different sources in the second crop period was almost the same. This may be due to the fact that no provision for drainage was made in the pots used for this experiment. So whatever Mg that was released might have remained in the pots for absorption in the second crop season.

In general, total Mg uptake was found to increase with the levels of Mg applied; obviously due to the increased availability of Mg from added sources.

Total Mg uptake by rice plant was positively correlated with straw yield (r = 0.799**), total N uptake (r = 0.632*), total P uptake (r = 0.725**) and total K uptake (r = 0.780**) and negatively correlated with NH_4OAc extractable Mg in the soil (r = -0.616*) (Table 39).

2 Yield of straw and grain

2.1 Yield of straw

Results on the influence of sources and levels of applied Mg on the yield of straw in karappadam and laterite soils are given in Tables29, 30 and 31.

On Mg application, straw yield increased over control from 34.85 to 37.35 g pot^{-1} in karappadam soil and from 38.05 to 40.4 g pot^{-1} in laterite soil at harvest. This is clearly due to the beneficial influence of added Mg.

Though there was no significant difference between the two soils used for the study with respect to straw yield in the second crop season, plants grown in laterite soil was found to perform better. This may be due to the more favourable pH condition prevailing in the laterite soil.

There was no significant difference between the Mg sources used on straw yield. Straw yield was found to increase on raising the level of applied Mg from 25 to 50 kg MgO ha^{-1}, evidently due to the increased availability of Mg.

Straw yield was positively correlated with total N uptake (r = 0.619*), total P uptake (r = 0.814**), total K uptake (r = 0.698**), total Ca uptake (r = 0.649*) and total Mg uptake (r = 0.779**) (Table 39).

2.2 Yield of grain

Influence of various treatments on yield of grain during the second crop season is presented in Tables 29, 30 and 31.

Different sources of Mg applied had significant influence on grain yield in the second crop season. Among the sources magnestie was found to be the best one in both the soils responsible for a grain yield of 35.63 and 36.67 g pot^{-1} in karappadam and laterite soils respectively. Next one was dolomite, giving on yield of 32.01 and 31.32 g pot^{-1} respectively in both the soils. From magnesium sulphate, it was 28.98 and 32.47 g pot^{-1} respectively. The higher grain yield from samples supplied with carbonate forms of Mg may be attributed to the enhanced release of Mg from these sources on prolonging the period of submergence.

Grain yield increased in both the soils on Mg application. This may be due to the influence of Mg on grain yield and was in line with the reports of Sheng and Yuan (1963).

Different levels of Mg tried did not have any significant influence on grain yield.

Grain yield in the second crop season was positively correlated with water soluble Mg (r = 0.607*), total K uptake (r = 0.534*) and total Ca uptake (r = 0.63*) (Table 39).

3 Soil analysis

3.1 Ammonium acetate extractable Mg

Effect of different sources and levels of Mg applied on NH_4OAc extractable Mg of karappadam and laterite soils during the second crop season is presented in Tables 29, 30 and 36.

Table 36. Ammonium acetate extractable and water soluble Mg of soil as influenced by the treatments at different periods of crop growth (second crop)

Treatment	Ammonium acetate extractable Mg, cmol (+) kg^{-1}					Water soluble Mg, ppm				
	Periods, fortnight					Periods, fortnight				
	1	2	3	4	5	1	2	3	4	5
T_1	2.069	3.276	3.793	3.103	2.931	77.58	103.44	82.75	82.75	41.38
T_2	3.448	3.793	3.448	4.655	3.448	129.30	103.44	103.44	82.75	103.44
T_3	3.448	4.827	4.482	3.414	4.551	129.30	124.13	62.06	62.06	41.38
T_4	3.276	3.965	4.827	3.448	2.414	77.58	82.75	82.75	20.69	109.44
T_5	3.103	3.793	3.276	3.620	4.138	129.30	103.44	62.06	124.13	20.69
T_6	3.448	3.103	2.241	4.138	2.931	77.58	82.75	82.75	82.75	103.44
T_7	2.931	4.138	3.793	3.448	3.620	77.58	82.75	103.44	41.38	41.38
T_8	2.241	1.724	1.896	2.181	2.241	129.30	103.44	103.44	124.13	41.38
T_9	2.069	2.069	2.069	2.241	3.448	51.72	82.75	62.06	82.75	103.44
T_{10}	2.241	1.896	1.896	2.586	2.069	155.16	103.44	82.75	103.44	41.38
T_{11}	2.414	2.758	1.724	2.241	2.758	25.86	103.44	82.75	103.44	41.38
T_{12}	2.414	2.586	2.586	2.758	2.241	77.58	20.69	41.38	82.75	41.38
T_{13}	2.241	2.758	2.414	3.448	2.586	129.30	144.82	103.44	82.75	41.38
T_{14}	2.224	2.241	3.103	2.758	2.931	27.58	103.44	20.69	41.38	20.69

For NH_4OAc extractable Mg, CD (0.05) for the comparison of soils and soil x source interaction are 0.2596 and 0.4497 respectively. Other treatment effects are not significant.

There was significant difference between the two soils used for the study with regard to their NH_4OAc extractable Mg content. It was significantly higher in karappadam soil than that of the laterite. This may be due to the higher initial NH_4OAc extractable Mg content of that soil.

On Mg applied pots, NH_4OAc extractable Mg content was significantly higher than that of the control by 0.605 cmol (+) kg^{-1} in karappadam soil and by 0.402 cmol (+) kg^{-1} in laterite soil. This may be attributed to the increased availability of Mg from added sources.

There was no significant difference between the sources with regard to the NH_4OAc extractable Mg in the soil.

Different levels of Mg applied did not have significant influence on NH_4OAc extractable Mg content of the soil.

Ammonium acetate extractable Mg was negatively correlated with total Mg uptake ($r = -0.616^*$).

3.2 Water soluble Mg

Influence of various treatments on water soluble Mg content of the soils is presented in Tables 29, 30 and 36.

On Mg addition, water soluble Mg of the karappadam soil increased from 71.57 to 86.19 ppm, but in laterite soil no positive response was observed. This may be attributed to the relatively low pH of the karappadam soil in which added Mg might have become more soluble.

There was no significant influence for the sources or levels of added Mg on water soluble Mg of the soil.

Water soluble Mg was positively correlated with grain yield (r = 0.607*).

3.3 Ammonium acetate extractable Ca

Influence of various treatments on NH_4OAc extractable Ca in the soil is presented in Tables 29, 30 and 37.

The two soils used for the study differed significantly in their NH_4OAc extractable Ca content. It was much higher in karappadam soil, may be due to the higher native Ca content of that soil.

On Mg application, NH_4OAc extractable Ca was found to decrease from 11 to 10.42 cmol (+) kg^{-1} in karappadam soil and from 7.35 to 6.65 cmol (+) kg^{-1} in laterite soil, indicating a Ca-Mg antagonism.

Ammonium acetate extractable Ca of the soil was positively correlated with NH_4OAc extractable Mg (r = 0.812**) and negatively correlated with total Mg uptake (r = -0.735*), total P uptake (r = -0.603*) and total K uptake (r = -0.631*) (Table 39).

Table 37. Ammonium acetate extractable Ca and available K of soil as influenced by the treatments at different periods of crop growth (second crop)

Treatment	Ca, cmol (+) kg^{-1}					Available K, kg ha^{-1}				
	Periods, fortnight					Periods, fortnight				
	1	2	3	4	5	1	2	3	4	5
T_1	7.586	8.969	14.826	12.413	13.206	257.6	212.8	263.2	190.4	123.2
T_2	9.999	12.413	11.378	12.068	7.241	285.6	229.6	179.2	168.0	100.8
T_3	8.965	15.171	11.378	8.344	12.516	263.2	358.4	235.2	172.5	168.0
T_4	9.310	9.999	9.654	11.034	9.310	296.8	196.0	257.6	168.0	123.2
T_5	6.551	8.965	7.241	8.620	9.999	179.2	252.0	179.2	168.0	145.6
T_6	9.999	18.619	9.654	9.999	8.965	229.6	190.4	224.0	179.2	112.0
T_7	6.206	17.930	12.068	10.344	8.792	179.2	285.6	240.8	168.0	156.8
T_8	6.551	13.792	5.344	4.362	6.724	285.6	442.4	179.2	128.8	168.0
T_9	5.862	5.172	5.517	6.896	7.241	229.6	168.0	257.6	212.8	201.6
T_{10}	5.517	4.482	5.000	6.896	5.172	207.2	291.2	218.4	201.6	140.0
T_{11}	5.689	5.172	5.000	8.965	7.586	268.8	212.8	196.0	280.0	173.6
T_{12}	6.551	6.206	4.310	11.378	8.275	236.0	190.4	263.2	280.0	162.4
T_{13}	5.517	7.241	5.344	9.654	6.551	268.8	240.8	224.0	235.2	156.8
T_{14}	5.517	7.242	7.586	5.551	11.378	212.8	201.6	207.2	134.4	117.6

For NH_4OAc extractable Ca, CD (0.05) for the comparison of soils is 1.214. Other treatment effects are not significant.

3.4. Available K

Effect of various treatments on available K content of the soil during the second crop season is presented in Tables 29, 30 and 37.

Available K content of the soil showed a decreasing trend with the advancement of crop growth during the second crop season. This may be due to the increased uptake of K by the rice plant with increase in dry matter production.

On Mg addition, available K content of the soil decreased from 209.44 to 203.06 kg ha^{-1} in karappadam soil and from 240.8 to 213.01 kg ha^{-1} in laterite, revealing a K-Mg antagonism.

3.5 pH

Data on the effect of different sources and levels of applied Mg on pH in karappadam and laterite soils are presented in Tables 29, 30 and 38.

pH of the soils increased continuously on prolonging the period of submergence. The difference in pH between the stages was significant. This was in agreement with the reports of many workers like Ponnamperuma (1972) that the submerged condition tends the pH of the acid soil to near neutral condition. This may also be due to the influence of added Mg fertilizers.

Table 38. pH and specific conductance of soil as influenced by the treatments at different periods of crop growth (second crop)

Treatment	pH					Specific conductance, dS m^{-1}				
	Periods, fortnight					Periods, fortnight				
	1	2	3	4	5	1	2	3	4	5
T_1	5.7	6.2	6.6	6.4	6.3	0.059	0.091	0.129	0.114	0.090
T_2	6.2	6.1	6.0	5.8	6.0	0.129	0.115	0.106	0.083	0.039
T_3	6.0	6.1	6.2	6.3	6.5	0.094	0.086	0.082	0.052	0.039
T_4	6.0	6.0	6.0	5.8	6.1	0.082	0.084	0.106	0.062	0.039
T_5	5.4	5.3	5.5	5.8	6.3	0.059	0.053	0.059	0.063	0.103
T_6	6.2	6.0	5.8	5.9	6.0	0.129	0.109	0.082	0.061	0.051
T_7	5.6	5.8	6.0	5.9	5.9	0.094	0.087	0.082	0.051	0.039
T_8	6.3	6.2	6.1	6.3	6.5	0.129	0.092	0.071	0.069	0.064
T_9	6.3	6.2	6.2	6.4	6.7	0.129	0.082	0.047	0.072	0.141
T_{10}	6.3	6.1	6.2	6.3	6.7	0.106	0.079	0.035	0.060	0.064
T_{11}	6.2	6.2	6.2	6.4	6.7	0.071	0.073	0.071	0.092	0.103
T_{12}	6.3	6.2	6.1	6.5	6.8	0.094	0.075	0.059	0.081	0.116
T_{13}	6.4	6.2	6.2	6.5	6.8	0.047	0.062	0.082	0.083	0.090
T_{14}	6.2	6.5	6.6	6.8	6.9	0.082	0.082	0.094	0.084	0.064

For pH, CD (0.05) for the comparison of soils, sources, soil x source and soil x source x level interactions are 0.092, 0.112, 0.159 and 0.225 respectively. Other treatment effects are not significant.

There was highly significant difference between the two soils in their pH. This is apparently due to the relatively low pH of the karappadam soil when compared to that of the laterite.

The sources differed significantly in their contribution to soil pH. In karappadam soil the highest pH was marked by magnesite (6.1) while dolomite (5.8) and magnesium sulphate (5.9) were on par. In laterite soil pH was maximum in soils supplied with magnesium sulphate (6.5), while magnesite (6.3) and dolomite (6.4) were on par. This difference in behaviour of the Mg sources in the two soil may be related to the original pH of the soils. In acid soils, magnesite was a better source of Mg than soluble forms while in near neutral soils, magnesium sulphate performed better than carbonate forms of Mg (Shieh et al., 1965).

Different levels of Mg applied did not have any significant influence on soil pH. This may be due to the relatively low level of Mg (25 and 50 kg MgO ha^{-1}) tried in this experiment.

3.6 Specific conductance

Effect of various sources and levels of applied Mg on specific conductance of karappadam and laterite soils during different periods of crop growth in the second crop season is presented in Tables 29, 30 and 38.

Table 39. Inter-relationships of soil nutrient content, pH, straw yield, grain yield and toal nutrient uptake at the time of harvest, second crop

(Coefficient of simple linear correlation)

	NH_4OAc extract-able Mg	Water soluble Mg	NH_4OAc extract-able Ca	Avail-able K	pH	Straw yield	Grain yield	Total N uptake	Total P uptake	Total K uptake	Total Ca uptake	Total Mg uptake
NH_4OAc extractable Mg	--	0.188	0.812**	0.074	-0.324	-0.279	-0.074	-0.674**	-0.503	-0.501	-0.024	-0.616*
Water soluble Mg		--	0.100	-0.013	0.003	0.426	0.607*	0.103	0.293	0.286	0.221	-0.062
NH_4OAc extractable Ca			--	0.426	-0.110	-0.453	-0.003	-0.430	-0.603*	-0.631*	-0.044	-0.735**
Available K				--	0.465	-0.344	0.108	-0.140	-0.494	-0.064	-0.106	-0.173
pH					--	0.014	0.319	0.155	0.077	0.472	-0.006	0.208
Straw yield						--	0.458	0.619*	0.814**	0.698**	0.649*	0.779**
Grain yield							--	0.358	0.408	0.534*	0.630*	0.193
Total N uptake								--	0.684**	0.547*	0.396	0.632*
Total P uptake									--	0.673*	0.588*	0.725**
Total K uptake										--	0.373	0.780**
Total Ca uptake											--	0.472
Total Mg uptake												--

* Significant at 5 per cent level ** Significant at 1 per cent level

The EC of the soils was found to decrease with the advancement of crop growth which may be due to the increased uptake by the crop.

The three different Mg sources used in this experiment and the two levels at which they were tried did not have any conspicuous influence on specific conductance of the soils.

C. Pooled analysis of data for the two seasons

1 Yield

1.1 Straw yield

Data on the mean values of straw yield for the first and second rice crop season are given in Tables 18 and 31.

For the first crop mean straw yield on Mg application was 35.59 g pot^{-1}. During the second crop season it increased to 38.88 g pot^{-1}. It may be due to the slow dissolution of the added Mg sources so that Mg availability would have been more during the second crop season.

On comparing the two soils used in the study for both the seasons, it was found that during the first crop yield was higher from karappadam soil, while for the second crop it was higher from laterite soil. This may be correlated with the pH of the soils. Due to the relatively low pH of the karappadam soil, Mg added might have dissolved more readily making Mg available during the first crop season itself. While in laterite soil, because of the less acidic reaction, dissolution of Mg fertilizers might have taken place more slowly making more of the Mg available during the second crop season.

On comparing the performance of different Mg sources for the two seasons it was found that during the second season straw yield was higher for the samples supplied with magnesite and dolomite. The increase in straw yield during the second crop season was most pronounced for samples supplied with dolomite. It was from 30.82 to 37.95 g pot^{-1} while for magnesite, this was from 37.54 to 39.94 g pot^{-1} only. This higher residual effect of dolomite may be due to the lower solubility of dolomite than magnesite. In pots supplied with magnesium sulphate, straw yield was almost the same for both the seasons (38.41 and 38.75 g pot^{-1}) which may be due to the presence of readily water soluble Mg in magnesium sulphate.

Influence of different levels of applied Mg on straw yield of the two seasons was inconsistent.

1.2 Grain yield

Mean values of grain yield for the two seasons in karappadam and laterite soils are presented in Tables 18 and 31.

Mean grain yield in Mg applied pots during the first crop was 35.51 g pot^{-1}. It decreased to 33.02 g pot^{-1} in the second crop. This indicates that residual Mg in the soil had no influence on grain yield of the second crop.

This reduction in grain yield during the second crop season was mostpronounced in the case of magnesium sulphate, may be due to the lesser availability Mg in the second crop. In the case of magnesite and dolomite reduction in grain yield during the second crop season was not marked. This may be due to the relatively higher residual value of magnesite and dolomite than magnesium sulphate.

In karappadam soil, grain yield was higher during the first crop season than the second crop season. This may be attributed to the faster dissolution of Mg fertilizers in that soil making large amount of Mg available in the first crop season itself. But in laterite soil, grain yield was higher during the second crop than the first crop. This may be correlated with the slower release of Mg from the sources in that soil.

2 Total Mg uptake

Data on the mean values of total Mg uptake for the two seasons are presented in Tables 18 and 31 and in Fig.8.

There was no marked difference in total Mg uptake between the first and second crop, though a slight decrease from 0.205 to 0.193 g pot^{-1} was noticed. This shows that a substantial amount of Mg remained in the soil for uptake in the second crop season.

Total Mg uptake decreased from 0.225 to 0.142 g pot^{-1} in karappadam soil, while in laterite soil it increased from 0.160 to 0.210 g pot^{-1}. These changes may be attributed to pH of the soils. In karappadam soil due to low pH Mg fertilizers added might have dissolved quickly, making Mg available in sufficient quantities during the first crop season self. But in laterite soil due to relatively higher pH, dissolution may have taken place slowly prolonging the release of Mg.

On comparing the performance of Mg sources during the two seasons it was found that in samples supplied with dolomite there was an increase in total Mg uptake from 0.151 to 0.192 g pot^{-1}. This may be due to the lower water solubility and higher residual value for dolomite.

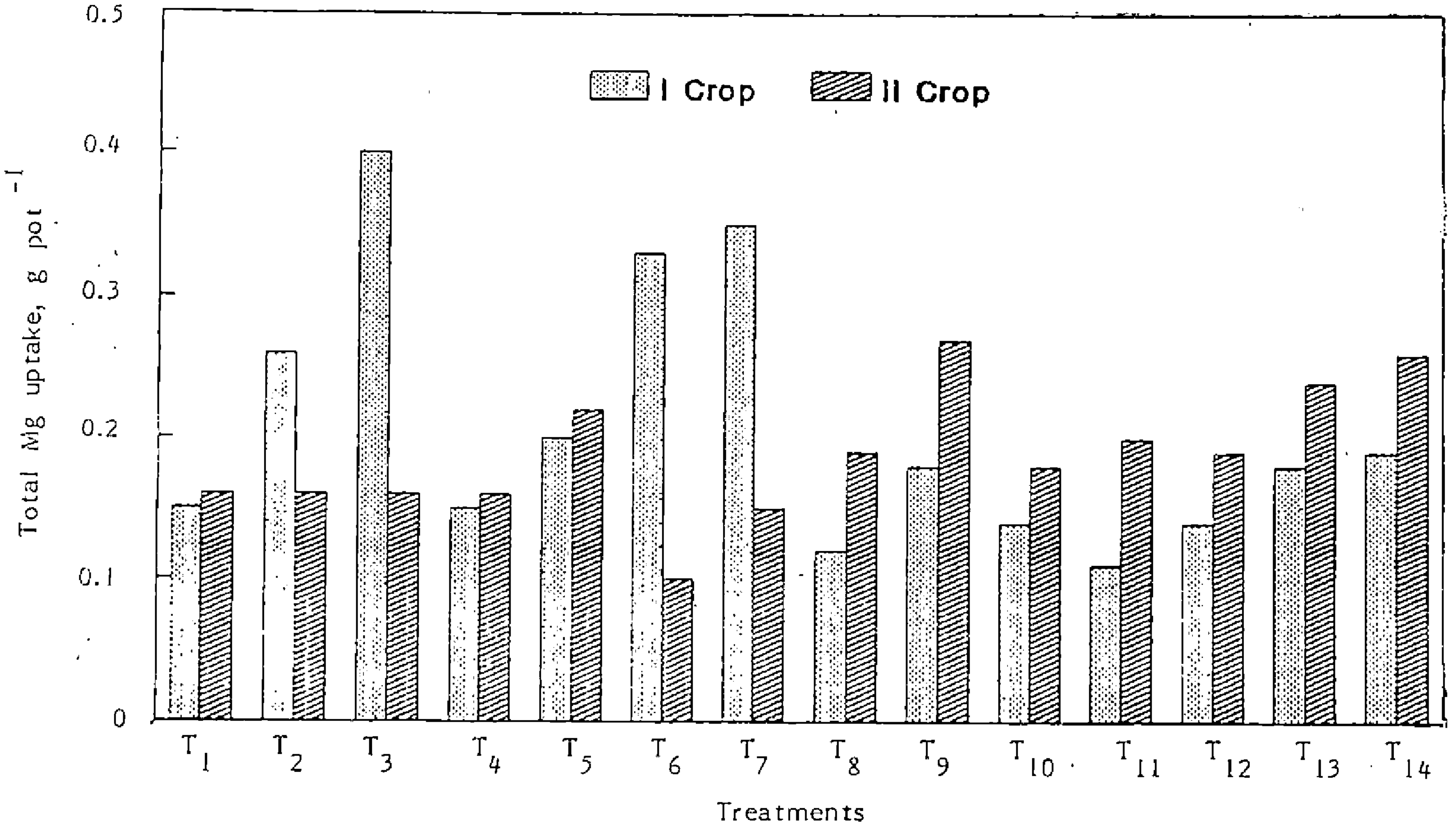

Fig.8 Total Mg uptake at harvest as influenced by fertilizer treatments

Summary

SUMMARY

An incubation study and a potculture experiment were conducted to assess the suitability of magnesite in comparison with that of magnesium sulphate and dolomite in karappadam and laterite soils of Kerala. In the incubation study, these three Mg sources were tried at the rate of 25 and 50 kg MgO ha^{-1} and their transformations under submergence were studied for 180 days. In the potculture experiment using rice (Annapoorna) as the test crop, the direct and residual effects of magnesite, dolomite and magnesium sulphate were studied. The soils and levels of Mg application were the same as in the incubation study. The residual effect of Mg fertilizers was assessed by continuing the experiment for the second season without the addition of Mg fertilizers.

1. The karappadam soil was sandy loam in texture, non-saline, 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 insoluble Mg fractions dominated over the soluble fractions. Among the various Mg fractions, mineral Mg was the dominant one in both the soils accounting to 42.23 and

41.63 per cent of total Mg in karappadam and laterite soils respectively. Acid soluble Mg was the second most abundant fraction representing 32.37 and 38.74 per cent of the total Mg status. Ammonium acetate extractable Mg of the soils was 23.67 and 18.15 per cent. The content of organic complexed Mg was very low and that of water soluble Mg was practically nil. Total Mg content as well as the content of various Mg fractions was higher in karappadam soil than the laterite soil.

3. 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.

4. The soluble Mg fractions were higher in samples supplied with magnesium sulphate while the insoluble Mg fractions were higher in samples supplied with carbonate forms of Mg.

5. Magnesite was 78.66 and 63.25 per cent as efficient as magnesium sulphate with regard to the release of water soluble Mg in karappadam and laterite soils respectively. In karappadam soil, magnesite (99.9 per cent) and dolomite (95.3 per cent) were almost as efficient as magnesium sulphate in their ability to release NH_4OAc extractable Mg. In laterite soil, their relative efficiency was 76.9 and 82.2 per cent.

6. Ammonium acetate extractable Mg was highly positively correlated with acid soluble Mg ($r = 0.971^{**}$), mineral Mg ($r = 0.817^{**}$) and negatively correlated with available K ($r = -0.948^{**}$). The organic complexed Mg constituted only 1.61 per cent of the total Mg and it was not significantly correlated with other Mg fractions and available Ca and K.

7. Ammonium acetate extractable Ca was significantly higher in karappadam soil than in laterite soil but the different sources and levels of Mg applied did not have any significant influence on NH_4OAc extractable Ca during incubation.

8. Available K of the soils decreased with increase in the levels of applied Mg from 25 to 50 kg MgO ha^{-1}. This decrease was from 289.70 to 283.90 kg ha^{-1} in karappadam soil and from 369.80 to 366.95 kg ha^{-1} in laterite soil. Available K in the soil was highly negatively correlated with the Mg fractions, indicating a K-Mg antagonism.

9. Even in the absence of added Mg, pH of the soils increased on incubation. On Mg addition, this rise in pH became more conspicuous. Increasing the level of applied Mg enhanced the pH of the soil. Efficiency of different Mg sources in correcting the acidic soil reaction was in the order of magnesite > dolomite > magnesium sulphate.

10. In the potculture experiment, nutrient per cent of the straw decreased with the advancement of crop growth. Phosphorus, K and Mg per cent of the straw was maximum during the second fortnight representing the maximum tillering stage.

11. The straw nutrient uptake increased till the fourth fortnight of planting and then decreased at the time of harvest due to the translocation of the nutrients to the grains.

12. During the first crop season, N per cent and uptake increased on Mg addition in the karappadam soil while in laterite soil no positive response was observed. Similar results were obtained on increasing the level of applied Mg from 25 to 50 kg MgO ha^{-1}. But during the second crop season, N uptake by the straw decreased on Mg application in both the soils, while the grain N level showed the same tendency as that shown by the first crop.

13. Uptake of N and P were maximum in samples supplied with magnesium sulphate.

14. Addition of Mg did not enhance the mean P per cent and uptake in the straw at harvest during the first crop season. But during the second crop season, P per cent increased from 0.36 to 0.47 per cent in laterite soil, while in karappadam soil no positive response was noticed.

15. Total P uptake as well as the P uptake by grain increased on Mg addition in karappadam soil while in laterite soil a declining trend was noticed during the first crop season. Just opposite tendency was noticed during the second crop season.

16. The level and uptake of Ca in the straw and grain decreased with increasing the level of applied Mg, indicating a Ca-Mg antagonism.

17. Uptake and level of Mg in the straw increased with the levels of applied Mg. It was the highest in samples supplied with magnesium sulphate, while magnesite and dolomite were almost as efficient as magnesium sulphate. Grain Mg uptake increased markedly on Mg addition.

18. Though there was no significant difference between the various Mg sources with regard to the total Mg uptake, magnesite was found to be the best one in both the soils as well as for the two levels.

19. Total Mg uptake at harvest (first crop) was positively correlated with NH_4OAc extractable Mg in the soil ($r = 0.662^{**}$) and straw yield ($r = 0.566^{*}$) and negatively correlated with available K in the soil ($r = -0.614^{*}$).

20. During the first crop season, the performance of the rice plant with respect to their yield and Mg content was higher in karappadam soil. But in the second crop season, it was higher in laterite soil.

21. The Mg sources did not differ significantly in their contribution to straw yield. But magnesium sulphate was found to perform better closely followed by magnesite and then dolomite. Magnesite was 97.7 per cent and dolomite 80.2 per cent as efficient as magnesium sulphate. During the second crop season also, different Mg sources were on par with regard to the straw yield. Straw yield did not differ significantly with different levels of Mg tried in both the seasons.

22. During the first crop season, grain yield was higher in karappadam soil than in the laterite soil. On Mg addition, grain yield increased in the karappadam soil, while in laterite soil no such response was noticed.

23. There was no significant difference between the different Mg sources on grain yield during the first crop season, though magnesite was found to perform better in karappadam soil and magnesium sulphate in laterite soil. But during the second crop season, Mg sources differed significantly. Best source was the magnesite followed by dolomite and magnesium sulphate.

24. The level of NH_4OAc extractable Mg, water soluble Mg and available K in soil was found to decrease with the advancement of crop growth.

25. Ammonium acetate extractable Mg in soils increased on Mg addition in both the seasons

26. The sources did not differ significantly with regard to their contribution to NH_4OAc extractable Mg in the soil. But during the first crop season, carbonate forms of Mg were found to perform better than magnesium sulphate.

27. Though sources and levels of added Mg did not have significant influence on water soluble Mg in the soil, magnesium sulphate was found to be the best source during the first crop season.

28. A negative relationship was observed between NH_4OAc extractable Ca and Mg during potculture experiment.

29. A significant decrease in available K content of the soil was observed on increasing the level of applied Mg. Available K was negatively correlated with NH_4OAc extractable Mg ($r = -0.728^{**}$) in soil and total Mg uptake ($r = -0.614^{**}$) by the plant, confirming K-Mg antagonism.

30. pH of the soils differed significantly with the source. During the first crop, pH was maximum in pots supplied with magnesite (5.7 and 6.5), then dolomite (5.6 and 6.3) and magnesium sulphate (5.4 and 6.3). But in the second crop seaon, magnesite performed better in karappadam soil and magnesium sulphate in laterite soil.

31. Various sources and levels of Mg did not have any significant influence on specific conductance of the soil in the potculture experiment as well as in the incubation study.

32. For the first crop, mean straw yield on Mg application was 35.59 g pot^{-1}. But during the second crop season it increased to 38.88 g pot^{-1}. It was greater by 2.43 g pot^{-1} over control for the second crop. This shows that the beneficial effect of Mg on straw yield was more apparent during the second crop season due to the slow dissolution of added Mg sources.

33. The mean grain yield decreased during the second crop season to 33.02 g pot^{-1} from 35.51 g pot^{-1} in the first crop. This reduction was most pronounced in the case of magnesium sulphate while for magnesite and dolomite this reduction was not marked, may be due to their relatively higher residual effect.

34. On comparing the performance of different Mg sources it was found that for the samples supplied with magnesite and dolomite the straw yield was higher during the second crop season. For the pots supplied with magnesium sulphate straw yield was almost the same for both the seasons.

35. Total Mg uptake by the rice plants decreased from 0.225 g pot^{-1} (first crop) to 0.142 g pot^{-1} (second crop) in karappadam soil, while in laterite soil it increased from 0.160 to 0.210 g pot^{-1}. Similar trend was noticed for Mg per cent of the straw also.

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SUITABILITY OF MAGNESITE AS A SOURCE OF MAGNESIUM IN ACID RICE SOILS OF KERALA

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ABSTRACT

An incubation study and a potculture experiment were conducted to assess the suitability of magnesite in comparison with that of magnesium sulphate and dolomite in karappadam (Moncompu, Alappuzha district) and laterite (Vellanikkara, Thrissur district) soils of Kerala. In the incubation study, these three Mg sources were added to the two soils at the rate of 25 and 50 kg MgO ha^{-1} and their transformations under submergence were studied for 180 days drawing samples at regular intervals of 15 days. The samples were analysed for Mg fractions, available Ca and K, pH and EC. In the potculture experiment using rice (Annapoorna) as the test crop, the direct and residual effect of magnesite, dolomite and magnesium sulphate were studied. The soils and levels of Mg application were the same as in the incubation study. Application of N, P and K was done uniformly in all the treatments. Soil and plant samples were taken at 15 days interval for the determination of uptake and availability of nutrients, pH and EC. The residual effect of Mg fertilizers was assessed by continuing the experiment for the second season without the addition of Mg fertilizers.

The karappadam soil was sandy loam in texture, non-saline, 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. The insoluble Mg fractions dominated over the soluble ones in these soils. Among them, mineral Mg was the most abundant one and acid soluble Mg the second most common form. Ammonium acetate extractable Mg content in the karappadam and laterite soils was 23.67 and 18.15 per cent respectively. The content of organic complexed Mg and water soluble Mg was very low. The total Mg content as well as the content of various Mg fractions was higher in karappadam soil than in the laterite soil.

The soluble Mg fractions were higher in samples supplied with magnesium sulphate while the insoluble fractions were higher in samples supplied with carbonate forms of Mg. Magnesite was 78.66 and 63.25 per cent as efficient as magnesium sulphate with regard to the release of water soluble Mg in karappadam and laterite soils respectively. In karappadam soil, mangesite and dolomite were almost as efficient as magnesium sulphate in their ability to release the NH_4OAc extractable Mg. In laterite soil, their relative efficiency was 76.9 and 82.2 per cent. Ammonium acetate extractable Mg was highly positively correlated with acid soluble Mg ($r = 0.971^{**}$), mineral Mg ($r = 0.817^{**}$) and negatively correlated with available K ($r = -0.948^{**}$). The acid soluble and mineral Mg also showed similar relationships.

The organic complexed Mg constituted only 1.61 per cent of the total Mg and it was not significantly correlated with other Mg fractions and soil characteristics.

Ammonium acetate extractable Ca was significantly higher in karappadam soil than in laterite soil. But sources and levels Mg did not have any significant influence on NH_4OAc extractable Ca. Available K of the soils decreased with increase in the levels of applied Mg. Also the soil K was highly negatively correlated with the Mg fractions, indicating a K-Mg antagonism.

Incubation under submerged condition raised the pH of the soils. Magnesium addition further increased the pH. There was a positive correlation between the level of applied Mg and soil pH. Effectiveness of different Mg sources in correcting the acidic soil reaction was in the order of magnesite > dolomite > magnesium sulphate.

In the potculture experiment, nutrient per cent of the straw decreased with the advancement of crop growth due to the dilution effect. Many of the nutrients like P, K and Mg were maximum during the maximum tillering stage (second fortnight). The straw nutrient uptake increased till the fourth fortnight of planting and then decreased at the time of harvest due to the translocation of the nutrients to the grains.

On Mg addition, N per cent and uptake in the straw and grain increased in the karappadam soil, while in laterite soil no positive response was noticed during the first crop season. But in the second crop, straw N uptake decreased in karappadam soil and in laterite soil, the same tendency as shown in the first crop was noted.

Magnesium addition did not enhance the mean P per cent and uptake in the straw at harvest during the first crop season. But during the second crop season, P per cent increased from 0.36 to 0.47 per cent in laterite soil, while in karappadam soil no positive response was noticed. Total P uptake as well as the P uptake by the grain increased on Mg addition in karappadam soil while in laterite soil a decreasing trend was noticed during the first crop season. Just the opposite tendency was noted during the second crop season.

Calcium per cent and uptake in the straw and grain decreased with increasing the level of applied Mg, indicating a Ca-Mg antagonism.

Magnesium per cent of the straw was found to increase on Mg application. It was the highest in samples supplied with magnesium sulphate, while magnesite and dolomite were almost as efficient as magnesium sulphate. Uptake of Mg by the straw and grain increased markedly on Mg addition. Though the sources did not differ significantly with regard to the total Mg uptake, magnesite was found to be the best one in both the soils as well as for the two levels.

The performance of the rice plant with respect to their yield and Mg uptake was higher in karappadam soil during the first crop season. But in the second crop season, it was higher in laterite soil, may be due to the higher residual value of Mg sources in the laterite soil.

Though there was no significant difference between the sources with regard to the straw yield, magnesium sulphate was found to perform better closely followed by magnesite and dolomite. During the second crop season also, the different sources were on par.

There was no significant difference between the different Mg sources on grain yield during the first crop season, though magnesite was found to perform better in karappadam soil and magnesium sulphate in laterite soil. But during the second crop season, different Mg sources differed significantly. The best one was magnesite followed by dolomite and magnesium sulphate.

Ammonimum acetate extractable Mg in soil increased on Mg addition in both the crops and there was no significant difference between the sources with respect to NH_4OAc extractable Mg. But the carbonate forms of Mg were found to perform better during the first crop season. The forms and levels of added Mg did not have any significant influence on water soluble Mg in soil.

Negative relationship was observed between NH_4OAc extractable Ca and Mg during the potculture experiment.

A significant decrease in available K content of the soil was observed on increasing the level of applied Mg. Available K was negatively correlated with NH_4OAc extractable Mg ($r = -0.728^{**}$) in soil and total Mg uptake ($r = -0.614^{*}$) by the plant, revealing K-Mg antagonism.

pH of the soils differed significantly with the sources. During the first crop, pH was the maximum for soils supplied with magnesite (5.7 and 6.5 in karappadam and laterite soils respectively), then dolomite (5.6 and 6.3) and magnesium sulphate (5.4 and 6.3). But in the second crop season, magnesite performed better in karappadam soil and magnesium sulphate in laterite soil.

Various sources and levels of Mg did not have any significant influence on specific conductance of the soil in the potculture experiment as well as in the incubation study.

Straw yield was higher during the second crop season than the first crop, but just the opposite was the case with the grain yield. It decreased during the second crop season.

Straw yield was higher during the second crop season in pots supplied with carbonate forms of Mg, but in pots supplied with magnesium sulphate, straw yield was almost the same for both the seasons.