DYNAMICS OF POTASSIUM, MAGNESIUM AND SULPHUR IN PLANT AND SOIL WITH SPECIAL REFERENCE TO THE APPLICATION OF LANGBEINITE

By

B. RANI

THESIS

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Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
COLLEGE OF HORTICULTURE
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DECLARATION

I hereby declare that the thesis entitled "***Dynamics of potassium magnesium and sulphur in plant and soil with special reference to the application of langbeinite***" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship, associateship or other similar title of any other University of Society.

Vellanikkara

B. Rani

Dr. A.I.JOSE
Associate Dean
College of Horticulture
Vellanikkara

CERTIFICATE

Certified that the thesis entitled "***Dynamics of potassium, magnesium and sulphur in plant and soil with special reference to the application of langbeinite***" is a record of research work done independently by **Smt. B. Rani** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or assoicateship.

Vellanikkara

A.I. Jose
Chairman, Advisory Committee

CERTIFICATE

We, the undersigned members of the Advisory Committee of Smt. B. Rani, a candidate for the degree of Doctor of Philosophy in Agriculture, with major in soil science and Agricultural Chemistry, agree that the thesis entitled "***Dynamics of potassium, magnesium and sulphur in plant and soil with special reference to the application of langbeinite***" may be submitted by Smt. B. Rani, in partial fulfillment of the requirement for the degree.

Dr. A.I. Jose
(Chairman, Advisory Committee)
Associate Dean
College of Horticulture
Vellanikkara

Dr. N.P. Chinnamma
Professor and Head
Department of Soil Science and Agrl. Chemistry
College of Horticulture
Vellanikkara
(Member)

Dr. V.K. Venugopal
Professor
Department of Soil Science and Agrl. Chemistry
College of Agriculture
Vellayani
(Member)

Dr. R. Vikraman Nair
Professor
Associate Director of Research (South zone)
NARP
College of Agriculture
Vellayani
(Member)

Dr. V.K.G. Unnithan
Associate Professor
Department of Agrl. Statistics
College of Horticulture
Vellanikkara
(Member)

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DMP	-	Dry matter production
HCN	-	Hydrocyanic acid
m.a.p.	-	Months after planting
MOP	-	Muriate of potash
SPM	-	Sul-Po-Mag

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To my
Parents and Husband

CONTENTS

Introduction

INTRODUCTION

It is well known that potassium deficiency occurs in the highly leached acid soils of the tropics due to high rainfall and temperature which increase the leaching and release of soil potassium. Such soils are also deficient or low in magnesium and sulphur. The use of high analysis fertilizers and intensive cropping systems lead to deficiencies in secondary and micro nutrients in soil. This necessitates the use of fertilizers which can supply secondary nutrients in addition to nitrogen, phosphorus and potassium to soil.

The acid laterite soils of Kerala are deficient both in potassium as well as magnesium. Crops cultivated in Kerala, in general, respond to the application of magnesium. Application of potassium to an inherently magnesium deficient soil increases magnesium deficiency due to the antagonism between these nutrients in plant and soil.

Many of the cultivated soils are found to be deficient in available magnesium and in many cases, crop growth is found to be limited by magnesium deficiency. Therefore, the application of magnesium fertilizers has been an accepted management practice for a few important crops of the state. The total magnesium reserves in Kerala soils are poor and thus magnesium can be considered as a critical element in the acid soils of Kerala (Prema, 1992). The intensive use of soil, multiple cropping and the increased use of sulphur free fertilizers coupled with the adoption of high yielding varieties of crops have resulted in reduced sulphur content in soils and thus there is need of sulphur application to satisfy crop needs. Moreover, many soils in the tropics are deficient in sulphur and sulphur shortage often limits crop yields since sulphur is a very important plant food and plants take up sulphur in amounts almost equal to that of phosphorus. It is therefore necessary to apply magnesium and sulphur to the soil in addition to potassium, to satisfy crop needs.

Langbeinite is a naturally occurring mineral which is a mixture of K_2SO_4 and $MgSO_4$, containing 22 per cent K_2O and 18.5 per cent MgO in addition to 22 per cent sulphur, marketed under the trade names Sul-Po-Mag and K-Mag. Sul-Po-Mag has been reported to increase the nutrient content of soil, thus resulting in increased crop yields. Field experiments with Sul-Po-Mag in more than 20 different crops in China showed that significant response occurred with most crops, resulting in yield and quality improvements (Kincheloe and Xie, 1992). This fertilizer would be of more significance in Kerala soils, which are highly leached and acidic. The induced deficiency of magnesium due to the application of potassium fertilizers can also be minimized. Thus Sul-Po-Mag can probably be a substitute or can complement the potassium fertilizers already used in the state. Hence the suitability of langbeinite as a potassium-cum-magnesium fertilizer in the acid laterite soils of Kerala is evaluated using tapioca and bhindi as test crops.

Cassava (*Manihot esculenta* Crantz) forms an important cheap source of energy in the tropical countries, and is the most important subsidiary food crop of Kerala. It is also gaining importance as an industrial crop as well as a source of cattle feed. Cassava is an exhausting crop and an efficient utilizer of plant food elements. When grown, there is a significant drain on the soil nutrient reserves especially potassium, which if not replenished through balanced fertilization coupled with agronomic practices, will result in severe reduction in growth and yield of the succeeding crop. The laterite soils of Kerala, ideally suited for this crop are generally deficient in potassium although the requirement is very high. Cassava has also been reported to respond significantly to the application of magnesium (Thampan, 1979) and sulphur (Korah *et al.*, 1988) in the acid soils of Kerala.

The importance of vegetables in human nutrition is well known as it is a rich and comparatively cheap source of vitamins and minerals. Among vegetables, bhindi (*Abelmoschus esculentus* Moench) occupies an important place on account of its tender green fruits. In addition to its role as a vegetable, it also has nutritional, economic and medicinal importance (CSIR, 1959). Like other vegetable crops, bhindi generally responds to high doses of fertilizer application.

The relationship between potassium in solid phase and in solution phase of soil plays a key role in determining the ability of the soil to supply potassium to plant, which in turn is influenced by the relative abundance of other cations and the type and quantity of clay minerals present in soil. It is therefore necessary to study the dynamics of potassium and magnesium in relation to the other.

Thus the present study was undertaken with the following objectives

i) To examine the dynamics of potassium, magnesium and sulphur in soil plant system

ii) To evaluate the pattern of release of potassium, magnesium and sulphur in soil, as influenced by the application of langbeinite; and

iii) To assess the suitability of langbeinite as a potassium- cum-magnesium fertilizer in the acid laterite soils of Kerala using tapioca and bhindi as test crops. The study will also reveal the mechanism of interaction between potassium, magnesium and sulphur in soil and plant system.

Review of Literature

REVIEW OF LITERATURE

The extensively leached soils of the tropics are high in acidity and low in available nutrients. These soils, due to their low fertility, lead to poor crop yields. When crops are grown in these soils, a significant drain on the soil nutrient reserves occurs, which if not replenished through balanced fertilization, coupled with agronomic practices will result in severe reduction in growth and yield of the succeeding crop. Application of K to an inherently Mg deficient soil increases Mg deficiency due to the antagonism between these nutrients in soil and plant. During the past few years, sulphur has also been receiving increasing attention world-wide. While reports of S deficiency and crop responses to S application are increasing, the contribution from traditional sources of S is on the decline. Thus it becomes necessary to review the importance of K, Mg and S in crops, their transformations in soils and their interactions in soils and crops.

1. *Potassium, magnesium and sulphur in plant nutrition*

Of the sixteen essential elements required for plant growth, K is the third macronutrient utilized by plants. The requirement of plants for this element is quite high. Concentration of K in plants ranges from one to five per cent. K exists in the mobile ionic form and its function appears to be primarily catalytic in nature. It is the predominant cation in the plant and determines to a large extent the osmotic concentration in the plant and upon which water uptake and turgor pressure are in turn dependent. It is involved in the activation of several enzymes and is required for the synthesis of ATP, for the translocation of assimilates and plays an important role in photosynthesis. K is also involved in protein and starch synthesis and is required for the uptake of nitrogen (Tisdale *et al.*, 1995).

Magnesium also plays a vital role in crop nutrition. Plants generally contain about 0.1 to 0.4 per cent Mg. Magnesium increases the chlorophyll content of plants (Ananthanarayana and Rao, 1980 and Kiss, 1981) and its deficiency decreases the biosynthesis of pigments to one third of their original level (Yordanov *et al.*, 1978). Magnesium activates several enzyme systems involved in carbohydrate metabolism (Kondratev and Kondrateva, 1978). One of the major nutritional functions ascribed to Mg is that of a carrier of P in plants (Jacob, 1958). It promotes the uptake and translocation of P and also helps in better P utilization by crops (Varghese and Money, 1965 and Subramanian *et al.*, 1976). The increase in P uptake by Mg application is because of enhanced P assimilation by Mg (Waddrowska and Jania, 1951). Ananthanarayana and Rao (1982) and Subramanian *et al.* (1975) found that Mg also increased the N uptake by crops.

Sulphur is one of the three principal anions necessary for plants. The typical concentration in plants is 0.1 to 0.4 per cent. It is required for the synthesis of sulphur containing amino acids and is a component of many substances important in plant metabolism. It is also required for chlorophyll synthesis and its presence imparts the characteristic taste and smell of plants in the mustard and onion families.

A deficiency of sulphur has a pronounced retarding effect on plant growth. Sulphur deficiency disturbs the balance of nutritional environment in plants which results in the biological inactivation of life processes of plants and the development of chlorosis in them (Singh *et al.*, 1976). Sulphur deficient plants have poor utilization of N, P and K at all stages of growth till maturity compared to those which are supplied with S (Kumar and Singh, 1994). Plants deficient in sulphur accumulate non-protein N in the form of amides and nitrate in contrast to their very low levels of sulphate. Sulphur deficiency occurs because of the increased use of high analysis fertilizers containing little or no sulphur, higher yielding crops and multiple cropping systems which remove greater amounts of S from soil, and the declining reserves of S in surface soils caused by loss of organic matter through erosion and mineralization.

2. Potassium, magnesium and sulphur in soils

Potassium is present in relatively large quantities in soils as compared to other major nutrients. The content of K in the earth's crust averages about 1.9 per cent. In Kerala soils, the total K_2O content ranges from 0.04 to 0.54 per cent (Praseedom, 1970) whereas the values for many Indian soils range from 0.5 to 3.0 per cent (Tandon and Sekhon, 1988). The available K of soils ranges from 0.32 per cent of total K (Singh *et al.*, 1983) to 0.69 per cent of total K (Singh and Datta, 1986).

Magnesium, on an average, constitutes about 1.93 per cent of the earth's crust. The total Mg content ranges from 0.1 per cent in sandy soils to about four percent in fine textured soils. Magnesium deficiency apparently occurs under at least two conditions: where exchangeable Mg in the soil exists at a level too low to support normal plant growth and where K in the soil is sufficiently high to limit Mg absorption by plant roots. Since most fertilizer materials do not contain Mg in appreciable quantities, soils hitherto considered to be adequately supplied with Mg may show up Mg deficiency. Owing to the imbalance created in the nutrient supplying capacity of the soils, crops grown in such situations may suffer from the deficiency of secondary nutrients. The amount of Mg required annually by many of the arable crops is in the range of 10 to 25 kg ha^{-1}. Deficiencies occur particularly in the highly leached humus acid soils or on sandy soils, which have been given heavy dressings of lime (Tisdale *et al.*, 1995).

Thus magnesium deficiency in plants is most common in acid sandy soils (Jacob, 1958 and Embleton, 1966) especially following periods of excessive rainfall (Mc Murtrey, 1947). Low yield under acid soil conditions is caused by low Mg availability (Christensen *et al.*, 1973). Several studies have indicated that exchangeable soil Mg contents below about four to ten per cent are deficient for a number of crops (Prince *et al.*, 1947; Graham *et al.*, 1956 and Adams and Hendersen, 1962). Mg deficiency is most evident on light sandy soils and following periods of excessive rainfall (Mc Murtrey, 1947).

The average sulphur content of the earth's crust is 0.06 to 0.1 per cent. The total S status of the surface soils of India vary from 191 to 3836 ppm (Tandon, 1991) while available S constitutes about 11.7 per cent (Karwasra *et al.*, 1986) to 15 per cent of total S (Balasubramanian and Kothandaraman, 1985). There are reports of widespread occurrence of S deficiency in Indian soils (Tandon, 1991). Appearance of S deficiency in soil due to the extensive use of S free high analysis fertilizers has been reported (Aulakh *et al.*, 1977 and Hagstrom, 1990).

3. Sources of K, Mg and S fertilisers

To overcome the deficiency of nutrients, fertilizer application schedule is to be adjusted. Fertilization of soils can increase the nutrient concentration in soil solution to relatively high levels due to exchange reaction, solubilization of soil constituents, and increase in ionic strength of solution (Sparks, 1984).

Potassium: The main sources of K fertilisers are muriate of potash and potassium sulphate. Use of Sul-Po-Mag (langbeinite) as a potassium source is also increasing rapidly, primarily because of the greater need to include sulphur and magnesium in fertilizer programmes. In general, root vegetables are less tolerant to chlorine than leaf vegetables since chlorides promote foliage formation and sulphates promote root growth (Hagstrom, 1990).

Magnesium: The type of magnesium fertilizer used varies according to the soil type. The different Mg fertilizers used are magnesite, dolomite, epsom salts, calcined magnesite, shoenite etc.. In acid soils, $MgCO_3$ is more effective than soluble magnesium salts (Shieh *et al.*, 1965). Powdered dolomite is superior to $MgSO_4$ under acid conditions up to pH 5.5 (Munk, 1961) but the solubility and efficiency decreases as the soil is limed and Mg-Ca antagonism begins to operate. Vasil'eva (1965) reported that magnesite and dolomite were more effective on acid soils while $MgSO_4$ and shoenite (K_2SO_4 $MgSO_4.6H_2O$) were more effective for crops of greater acid tolerance.

Sulphur: Responses to plant nutrient sulphur are increasing in many areas of the world due to the fact that the fertilizer industry is replacing low analysis materials such as ammonium sulphate and normal super phosphate with high analysis materials which are sulphur free. It has been shown that potassium sulphate is the best source of sulphur for plants, thereafter in the order of sulphur efficiency follow ammonia, sodium, magnesium and calcium sulphates (Perny, 1979). Gypsum, pyrites and elemental sulphur when applied to crops like potato, radish and carrot gave positive yield response. Among the different sources, gypsum was the best with respect to yield and content of sulphur in vegetable crops (Prakash *et al.*, 1997).

3.1 Comparative effects of potassium chloride and potassium sulphate

The ability to retain KCl and K_2SO_4 vary with soils. It was reported that the ability of humic and hydrol humic latosols to retain K from KCl was slight and from K_2SO_4 considerable (Ayres and Hagihara, 1953). In soils or irrigation water with high levels of chloride, sulphate sources of K are preferred (Davide *et al.*, 1986). Sulphate sources of plant nutrients have often been shown to be superior under naturally occurring high levels of chlorine in soil / irrigation water when fertilizer application rates are high especially with high value crops like vegetables. A comparison of KCl and K_2SO_4 show that K_2SO_4 outyields KCl when applied to crops (Bakhsh *et al.*, 1986 and Loue', 1985). Application of K_2SO_4 accelerated tuber development, increased starch content, protein content and dry matter production in plants (Loue', 1985).

Certain highly fertilized vegetable crops like potatoes, soybean etc. have also been shown to benefit from sulphate rather than chloride sources of plant nutrients (Parker *et al.*, 1986). There are also studies to indicate that coffee prefers potassium sulphate to potassium chloride as a potash source. Arana (1968) observed that chloride toxicity occurs when KCl is applied to coffee and that the P uptake was increased when sulphate rather than chloride was the K_2O source.

3.2 Effect of Sul-Po-Mag on crops

The fertilizer material Sul-Po-Mag has produced excellent results when applied to crops in many areas of the world. Sul-Po-Mag is a highly water-soluble source of magnesium (11% Mg), sulphur (22 % S) and potassium (22 % K_2O), but its rate of solubility is somewhat slower than that of the other potassium materials such as muriate of potash. Sul-Po-Mag is considered as a non-chloride source of plant nutrient. The product is guaranteed to contain less than 1 % Cl. Results of a greenhouse trial by Welte and Werner (1963) where increasing rates of K were applied as KCl and Sul-Po-Mag showed that not only were yields consistently higher with Sul-Po-Mag application, but yields were actually depressed when the highest rate of K was applied as KCl.

Sul-Po-Mag has long been preferred over KCl as potash source for tobacco in the United States (Hagstrom, 1990). Studies from various pineapple growing areas of China have clearly shown that Sul-Po-Mag is preferred over muriate of potash with respect to yield and crop quality (Xie, 1989). Studies in China also have shown that citrus responds positively to the application of Sul-Po-Mag giving higher yields when compared to muriate of potash. Field experiments with Sul-Po-Mag in more than 20 different crops in China showed that significant response occurred with most crops resulting in yield and quality improvements (Kincheloe and Xie, 1992). Experiments carried out in Germany and Switzerland have shown that both yield and starch content of potato tubers were significantly higher with Sul-Po-Mag when compared to muriate of potash and K_2SO_4 alone (Hagstrom, 1990).

4. Nutrient interactions

Nutrient absorption by plants is usually referred to as ion uptake or ion absorption because it is in the ionic form in which nutrients are absorbed. Cations and anions may be absorbed independently and may not be absorbed in equal quantities. Electroneutrality must be maintained within reasonable limits in the plant and in the growth medium because ionic relationship achieve major importance in plant nutrition (Fageria, 1983).

Uptake of nutrients by a plant is a function of the nutrient concentration at the root surface and also the rate of uptake. The concentration of nutrients at the root surface is in turn dependent upon the initial concentration at the start of the vegetative period. It is in particular affected by the rate of uptake and by the rate at which the nutrients are supplied to the roots by mass flow and diffusion (Grimme *et.al.*,1977).

The variation of nutrient elements in the plant tissue relates not only to the rate of absorption from the soil but also to the degree of utilization of the nutrient constituents in the plant tissue for the synthesis of various end products. Thus the ultimate nutrition of a plant including yields and quality depends both on the levels of individual nutrients and their relative quantities in the plant tissues.

Apart from the availability of adequate quantities of nutrients in the soil, it is also important to have a proper balance between the nutrient constituents present both in the soil and the plant. It is well known that all the essential and other beneficial elements are involved in mutual interaction among themselves. Interaction between nutrient elements can be synergistic or antagonistic and the type of interation is usually characteristic of the plant species (Emmert, 1961). Increasing the content of one cation in a plant usually decreases the content of other cations and the total cation equivalents are not greatly changed unless other conditions like nitrate supply are also changed. These interactions of nutrient elements in the soil affect their absorption and utilization by the plant.

Thus the factors influencing nutrient uptake may be broadly classified into those causing i) absolute deficiency and ii) induced deficiency. A number of studies have reported that antagonistic and synergistic responses exist among nutrient elements, especially among K, Mg and Ca (Breson, 1946; Bear and Toth, 1948; Bould, 1972; Christensen *et.al.*, 1973 and Ohki and Ulrich, 1975). Interactions of K, Mg and S among each other and with other nutrients are reviewed hereunder.

Uptake of nutrients, particularly cations is seriously influenced by K fertilization. Thus K has been shown to affect the absorption, translocation and distribution of other cations (Epstien, 1972).

Potassium and nitrogen: Potassium is essential for the large-scale uptake of nitrate. Interruptions or inhibitions of nitrate uptake controlled by K^+ results in decreased dry matter production. A limitation of K^+ ions even in the presence of relatively high level of N and P fertilizer will inhibit the utilization of N, decrease photosynthesis and the export of photosynthetic products from leaf. This situation will result in smaller plants giving significantly reduced yields. An adequate supply of K constitutes the key for the efficient utilization of N fertilizers as well as for the operation of photosynthetic system at optimal rates (Wicke, 1968). Thus potassium addition increased the nitrogen uptake by plants (Gupta *et al.*, 1971; Muthuswamy *et al.*, 1974; Singh and Singh, 1987; Rajdhar, 1989; Hegde and Srinivas, 1991 and Menon and Marykutty, 1993). The positive effect of K on the absorption of N may be attributed to the ability of K to reduce fixation of NH_4^+ in soils.

In some cases, increased K supply decreased N uptake (Turner and Barkus, 1983; Garita and Jarmillo, 1984; Taharieva and Raomheld, 1991 and Sindu, 1997). Added K sometimes showed no effect on N uptake (Sheela and Aravindakshan, 1990).

Potassium and phosphorus: Increasing concentration of applied K increased P uptake by plants (Muthuswamy *et al.*, 1974; De Datta and Gomez, 1982; Turner and Barkus, 1983; Rajdhar, 1989; Sheela and Aravindakshan, 1990 and Sindu, 1997) while a decrease in P uptake by K application was observed by Fageria (1983). Wicke (1968) observed that added K did not affect P uptake.

Potassium and calcium: Increased K supply decreased the uptake of Ca (Harrison and Bergman, 1981; Fageria, 1983; Turner and Barkus, 1983; Narwal *et al.*, 1985; Rajdhar, 1989; Oshima *et al.*, 1990, Taharieva and Romheld, 1991 and Sindu, 1997). Absorption of K is stimulated by Ca ions at low concentrations and decreased at high concentrations (Fageria, 1983 and Sudhir *et al.*,1987) while little effect of Ca:Mg on K uptake was reported by Salmon (1964). But Harrison and Bergman (1981) and Sudhir *et al.*(1987) reported lower plant K in high Ca soils. This demonstrates the

K – Ca antagonism described by Van Itallie (1938). Antagonistic interaction between K and Ca were also reported by Barber (1986), Taharieva and Romheld (1991) and Sindu (1997), while Alvarenga and Loper, (1988) and Menon and Marykutty (1993) observed an increase in exchangeable Ca with the addition of K.

Potassium and magnesium: Heavy dressings of K decreased the uptake of Mg (Wicke, 1968; Pushpadas *et al.*, 1976; Yang, 1992 and Sindu 1997). Since increasing K fertilizers highly significantly decreased the total Mg of plants and since increasing the exchangeable Mg in soil increased the plant Mg content, maintaining a reasonable level of exchangeable soil Mg can affect to some extent the adverse effects of high fertilizer K application on plant Mg concentration (Mc Intosh *et al.*, 1973). Since increasing K decreased the uptake of Mg, plant Mg deficiency is most common in acid sandy soils containing relatively high percentages of extractable K (Jacob, 1958 and Embleton, 1966).

An increase in Mg uptake by K fertilization has also been reported by many workers (Adams and Hendersen, 1962; Fageria, 1983 and Narwal *et al.*, 1985). There are also reports that in Mg deficient soils the availability of Mg to crops is greater at higher levels of K and in Mg sufficient soils, the availability of Mg is less at higher K levels (Adams and Hendersen, 1962).

Decrease in Mg uptake from Mg sufficient soils at higher K in spite of increased plant growth is because of a decrease in the Mg concentration of plants. The increase in total Mg uptake by the addition of K is because less of available Mg was absorbed by plants moderately deficient in K due to less vigorous plant growth and due to the increase in Mg availability by the addition of K which displaces exchangeable Mg into solution. But at low soil K and at sufficient exchangeable Mg levels, uptake of Mg is not hindered (Mc Colloch *et al.*, 1957).

Generally there is a decrease in potassium uptake with increase in magnesium concentration. Thus high magnesium in solution decrease the concentration and rate of uptake of potassium (Landua *et al.*, 1973; Aulakh and Pasricha, 1978; Schwartz and Kafkafi, 1978; Kumar *et al.*, 1981; Fageria, 1983; Shukla and Mukhi, 1979; Bandyopadhyay and Goswami, 1988; Muralidharan, 1992 and Varughese, 1992). Increased K supply in soils reduced the supply of Mg and uptake by crops (Prince *et.al.*, 1947; Johanneson, 1951; Jacob, 1958; Birch *et.al.*, 1966; Nayar and Koshy, 1969; Hossner and Doll, 1970; Mc Intosh *et al.*, 1973; Sekhon *et.al.*, 1975; Spear *et.al.*, 1978; Heenan and Campbell, 1981; Turner and Barkus, 1983; Rajdhar, 1989; Taharieva and Romheld, 1991; Yang, 1992 and Sindu, 1997).

In some cases, magnesium had no effect on the uptake of potassium (Perumal, 1972; Subramanian *et al.*, 1976 and Grant and Racz, 1987). In red soil no significant effect of different levels of magnesium application was observed on potassium uptake while high magnesium slightly decreased the uptake. The antagonistic effect of magnesium on potassium is mainly on solution concentration rather than uptake, which is dependent on the magnitude of yield (Anathanarayana and Rao, 1979).

Synergistic interaction between K and Mg was also observed by many workers (Fageria, 1983; Narwal *et.al.*, 1985; Grant and Racz, 1987 and Sudhir *et.al.*; 1987), while a lack of response of added K on the availability of Mg was reported by Jayaraman (1988) and Menon and Marykutty (1993). Increase in K in tissue with increasing Mg in solution is because of the decreased dry matter production associated with high magnesium in solution.

Potassium and sulphur: An Increase in total potassium in sulphur deficient plants occurs since potassium is not properly utilized (Kumar and Singh, 1994). Jaggi *et al.* (1995) has reported an increase in potassium concentration in plants due to sulphur application.

Magnesium and nitrogen: Synergistic effect between Mg and N exists in plants. In Mg deficient plants, N metabolism is disturbed and subsequent protein metabolism is affected (Mulder, 1958). But Kumar *et al.* (1981) has reported that the uptake of N increased at low Mg and decreased as the Mg addition increased.

Magnesium and phosphorus: Due to the greater solubilzation of phosphorus and the carrier effect on phosphorus, magnesium application increases phosphorus availability (Jacob, 1958). But Kumar *et al.* (1981) has reported that at low magnesium application rates, the uptake of phosphorus was not affected and at high magnesium, there was a decrease in phosphorus uptake.

Magnesium and calcium: Ca - Mg ratio hypothesis was first proposed by Loew in 1892 (Moser, 1933). This ratio was found to be an important factor in plant nutrition (Mehlich, 1946; Johnson *et al.*, 1957; Halstead *et al.*, 1958 and Krishnappa *et al.*, 1974). Excess Mg over Ca decreases the productivity of crops. Roots become unhealthy with excess Mg and loose turgidity and root cells become inactive (Wolf, 1864). But Ca in suitable concentrations effectively overcomes the toxicity of Mg. In the absence of Ca, high Mg causes toxicity. Thus Mg is toxic when an adequate supply of Ca is not present (Atterberg, 1892). A decrease in barley yield in both soil and solution culture was reported by Carter *et al.* (1979) when Mg / Ca ratios were increased, suggesting that the high concentration of Mg present in solution induced a Ca deficiency. Antagonistic effects of Ca and Mg were also observed by Halstead *et al.* (1958); Christensen *et al.*, (1973); Fageria (1983); Ohno and Grunes (1985); Myers *et al.* (1988); Phillips *et al.* (1988) and Varughese (1992). Thus high Mg restricts the accumulation of Ca in tissues and vice versa. Uptake of calcium increased at low magnesium and decreased at high magnesium levels (Kumar *et al.*, 1981). The antagonistic effect of magnesium on calcium uptake was apparent only when the absolute amounts of potassium and calcium were low (Ananthanarayana and Rao, 1979). This decrease in tissue concentration and uptake of calcium with increasing concentrations of magnesium in solution is presumably due to the replacement of magnesium for calcium for the neutralization of negative charges within the vacuole and on the exchange sites in the apoplast.

A reduction in magnesium uptake at higher concentration of calcium also occur because of antagonism (Fageria, 1983). He reported that the uptake of magnesium was not increased by the addition of $CaSO_4$. But calcium decreases the movement of magnesium from root to shoot. Hence with higher calcium concentrations, magnesium in root increases and in shoot decreases. But since uptake is a function of dry matter production, factors influencing dry matter production also influence uptake.

It appears however that growth of most plants is not significantly influenced if the exchangeable calcium exceeds magnesium. Martin and Page (1965) noticed little evidence of strong Ca – Mg or Mg – Ca antagonism. Higher exchangeable Ca did not decrease Mg absorption from low Mg soils. Until there was Mg excess, growth of plants increased either with increasing exchangeable Ca or Mg. Increasing exchangeable Ca from about 20 per cent to 90 per cent while maintaining Mg at lowest level had little or no effect on leaf Mg concentration.

Magnesium and sulphur: Increased addition of magnesium also increases sulphur uptake (Ananthanarayana and Rao, 1979).

Sulphur and nitrogen: Total N was significantly high in sulphur deficient plants than in sulphur sufficient ones (Kumar and Singh, 1994). In sulphur deficient plants, accumulation of nitrate nitrogen occurs (Lund and Murdock, 1978). Thus sulphur deficiency cause poor utilization of nitrogen in plants which in turn result in an increase in total nitrogen content.

Sulphur and phosphorus: Under sulphur deficient conditions phosphorus in plants is not properly utilized and hence an increase in total phosphorus occurs (Kumar and Singh, 1994). Chapman and Brown (1941) and Coic (1961) have reported that there was no change in the absorption of phosphorus due to sulphur deficiency but a deep effect occurs on the utilization of phosphorus in plant metabolism.

Sulphur and calcium: As calcium increased in plant, sulphur uptake also increased. Thus there is a synergistic effect which can be attributed to the fact that as both are absorbed as anions, higher application of phosphorus might have resulted in an increase in sulphur content in soil solution as a result of anion exchange, ultimately resulting in higher sulphur absorption (Aulakh and Dev, 1978).

5. Response of crops to potassium

Yield: Potassium influences many of the processes that are important for the formation of yield in plants such as water economy, synthesis of carbohydrates and the transport of assimilates (Mengel and Kirkby, 1982). Application of potassium results in increased yield in a number of crops (Wicke, 1968 and Roy and Kumar, 1990). K addition in small quantities increased yield while large additions affected yield very little (Salmon, 1964). Since potassium ions are essential for the large-scale uptake of nitrate, a limitation of K^+ even in the presence of relatively high level of N will inhibit the utilization of N, reduce photosynthesis and the export of photosynthetic products from leaf. This situation will result in smaller plants giving significantly reduced yields (Wicke, 1968).

Dry matter production: A decrease in dry matter content of potato tubers with increase in K and a decrease in K with increase in dry matter production occur. This is mainly because of dilution (Terman *et al.*, 1953). A decrease in dry matter production in plants due to the application of high levels of K was also reported by Loue' (1985). Inadequate supply of K^+ results in low water content and decreased growth rate of plants and the dry matter production decreases (Scherar *et al.*, 1983). An increase in dry matter yield was also reported in cowpea due to high levels of K application (Narwal *et al.*, 1985).

5.1 Response of cassava to potassium

The K requirement of most of the tuber crops is as high as N. Cassava, with its bulk storage organs is a heavy extractor of plant food elements from the soil, particularly potash (Thampan, 1979). The role of K is associated with starch synthesis leading to the promotion of tuber growth through the accelerated translocation of photosynthates from leaves to tuber (Obigbesan, 1973 and Mukhopadhyay *et al*., 1993).

Plant growth: Application of K increases plant height and girth of stem in cassava (Ngongi, 1976; Ashokan and Sreedharan, 1977; Ngongi *et al.*, 1977; Nair, 1982 and Nair and Aiyer, 1985). Potassium application seems to have not much influence on leaf production and hence vegetative growth (Nair, 1982 and Nair and Aiyer, 1985). The percentage of leaves retained was positively correlated and the percentage of leaves shed was negatively correlated with the level of K application (Nair and Aiyer, 1985). A decrease in number of leaves produced at higher levels of K was observed by Pillai (1967) where as Natarajan (1975) found an increase in leaf number of cassava by K application. According to Edwards (1982) potash fertilization increased the tolerance of plants to water stress. Thus leaf fall is minimum and leaf retention maximum in plants receiving higher levels of K application.

Dry matter production: When the level of K increased, starch synthesis also increased and hence an increase in the dry matter content of tubers occurred (Pushpadas and Aiyer, 1976; Ashokan and Sreedharan, 1977; Pillai and George 1978 and Nair and Aiyer, 1985). The total dry matter production also increased by K application (Ashokan and Sreedharan, 1977). This dry matter increase may be due to the beneficial effect of K in the synthesis and accumulation of carbohydrates.

Yield: Uptake of K is positively and significantly correlated with tuber yield of cassava (Mohankumar *et al*., 1971; Rajendran *et al*., 1976; Muthuswamy, 1978 and Nair and Aiyer, 1985). But Maglhaes *et al*., (1980) could not find any effect on root number and weight due to K application.

Quality attributes

Starch: Potassium application increased the starch content of cassava (Pillai, 1967; Natarajan, 1975; Ashokan and Sreedharan, 1977 and Muthuswamy and Rao, 1981). This may be because of the fact that K acts as a co-factor for a number of enzymatic reactions in carbohydrate metabolism, particularly the polymerisation of glucose to starch (Evans and Sorger, 1966).

Hydrocyanic acid: One of the objections for the extensive use of cassava for human consumption is the presence of HCN in tuber. Application of K decreased the HCN content of tubers (Gopal and Sadasivam, 1973; Kurian *et al*., 1976; Ashokan and Sreedharan, 1977 and Muthuswamy and Rao, 1981). When K availability in the soil is low in relation to N it causes the accumulation of non-protein N compounds in the plant tissue consequent to the failure in their elaboration into protein. This may help in the increased synthesis of cyanogenic glucosides and their increased HCN content (Thampan, 1979). But Nair *et al*. (1980) found that K did not show much influence on the starch content of tubers.

5.2 *Response of bhindi to potassium*

Application of K increased the content of K in the bhindi plant (Asif and Greig, 1972). Bhindi responds to K application up to 100 kg ha^{-1} with no difference between sources either KCl or K_2SO_4.

Plant growth: Height of bhindi increased by K application (Singh, 1979 and Subramanian 1980). But in certain cases, K application did not have any marked effect on the growth of the bhindi plant (Chonkar and Singh, 1963; Sutton, 1963; Chandrasekharan, 1965 and Singh, 1979).

Dry matter production: Maximum dry matter production of bhindi was recorded at the highest level of 50 kg K_2O ha^{-1} (Subramaniam, 1980). Higher doses of K significantly increased the total dry matter yield per plant in chilli while Chougule and Mahajan (1979) indicated that in chilli, the dry matter content of leaves and branches was not affected by potassium.

Yield: Application of K did not influence the total yield of bhindi (Sutton, 1963; Chandrasekharan, 1965; Singh and Singh, 1966 and Singh *et al.*, 1967). Ahamed and Reid (1968), Asif and Greig (1972) and Mani and Ramanathan (1980) reported significant influence of K on the total yield of bhindi. But very high K levels decreased the yield of bhindi (Kamalanathan *et al.*, 1970 and Verma *et al.*, 1970).

Quality attributes

Crude protein content of bhindi fruits is decreased by the application of K (Subramaniam, 1980) and at higher levels of K, there was no significant influence on the crude protein content (Chandrasekharan, 1965). A decrease in ascorbic acid content of bhindi fruits is observed with decrease in level of K application (Rani, 1992). In bhindi, the fibre percentage increased by increased potassium fertilizer application (Singh, 1979 and Mani and Ramanathan, 1982).

6. Response of crops to magnesium

Kerschberger *et al.* (1986) observed that the yield response to Mg decreased in the order cereals > forage plants > potatoes. Positive beneficial effect of Mg on rice was noted by many workers (Varghese and Money, 1965; Nayar and Koshy, 1969; Padmaja and Verghese, 1972; Chandramony and George, 1975; Thomas and Koshy, 1977; Panicker, 1980; Sanchez, 1984; Moore and Patrick, 1989; Yamauchi and Winslow, 1989 and Varughese, 1992). Application of Mg showed positive response in oats (Jokinen, 1977 and Mahler *et al.*, 1986), in maize (Krstic *et al.*, 1981; Stout and Bennet, 1983 and Frolich, 1987), in wheat (Kumar *et al.*, 1981; Singh and Balasubrammanian, 1985; Fecenko *et al.*, 1986 and Mahler *et al.*, 1986) and in barley (Fecenko *et al.*, 1986; Mahler *et al.*, 1986 and Grant and Racz, 1987).

Potato responded well to Mg application in acid soils (Carolus, 1933; Mathan *et al.*, 1973; Krishnamoorthy *et al.*, 1979 and Sharma *et al.*, 1981). Beneficial effects of Mg have been reported in cowpea (Nad and Goswami, 1983) and in groundnut (Tajuddin, 1970). In coconut, favourable response to the application of Mg was observed by Varkey *et al.* (1979), Kamalakshiamma and Pillai (1980) and Cecil (1991). Magnesium increased the yield of rubber (Onuwaje, 1983) and of tea (Godziashvill and Peterburgsky, 1985).

A good response to applied Mg was exhibited by vegetable crops such as capsicum (Kiss, 1979), tomatoes (Kiss, 1979; Asiegbu and Uzo, 1983; Elamin and Wilcox, 1985 and Sonneveld, 1987), cabbage (Shukla and Banerjee, 1980; Hara and Sonoda, 1981 and Harrison and Bergman, 1981), cauliflower (Shukla and Banerjee, 1980) and melons (Elamin and Wilcox, 1986 and Simon *et al.*, 1986).

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

But there were also reports of lack of decisive favourable response of applied Mg in crops. George and Sreedharan (1966) found that application of Ca - Mg carbonate either alone or in combination with Na - Mg silicate did not have any significant effect on the yield of grain and straw in rice. Yields of grain and tiller production in paddy were not influenced by the application of Mg silicate and $MgCO_3$ in Kuttanad soils of Kerala (Kurup and Ramankutty, 1969). Varughese (1992) and Muralidharan (1992) also reported similar observations on the effect of Mg on rice in laterite soil. Pedersen and Yang-Petersen (1984) have also found that fruit yield and fruit size in apple were not affected by Mg applications.

There are also reports that cassava responds favourably to the application of Mg. To produce 36 t of tuber, cassava removed 55 kg Mg ha^{-1} from soil (Thampan, 1979). Higher rates of NPK application reduced total dry matter production in cassava due to Ca and Mg deficiency (Ngongi, 1976). Positive response of potato to $MgSO_4$ was also reported by Sharma *et al.*, (1981).

7. Response of crops to sulphur

During the past few years, S has been receiving increasing attention worldwide. While reports of S deficiency and crop responses to S application are increasing, the contribution from traditional sources of S is on the decline. Several workers have investigated the relationship between different forms of S in the soil and crop growth and yield (Williams and Steinberg, 1959 and Bansal *et al.*, 1979). Sulphur shows synergistic effect on the yield of crops (Kumar *et al.*, 1985 and Aulakh *et al.*, 1990). Application of S resulted in yield increases in crops like wheat, rice, tea, sugarcane etc. (Tandon, 1991). Mohankumar and Nair (1983) and Tandon (1991) have reported significant positive yield response to S application in cassava. Sulphur application increased the yield of crops like carrot, cauliflower and radish (Prakash *et al.*, 1997), in potato (Tandon, 1991 and Prakash *et al.*, 1997), ground nut (Singh *et al.*, 1996), sorghum (Kumawat and Bansal, 1996), cluster bean (Sekhawat *et al.*, 1996) and cowpea (Kaushik *et al.*, 1996). Available S at three and six months after planting had significant positive correlation with tuber yield of cassava (Korah *et al.*, 1988). S application is also found to decrease the HCN content of cassava (Saalbach, 1973 and Mohankumar and Nair, 1983). Sharma *et al.* (1994) observed only a marginal increase in the yield of paddy due to increased S application.

The total S content of plants varies from 0.05 to 0.5 per cent depending on S supply (Randall, 1988). The total sulphur content shows significant positive correlation with dry matter production (Rychlicka, 1989 and Turker and Dikshit, 1994). Above a certain level, growth of plants is impaired because an excess of S contained in the plant is not metabolized to proteinaceous S (Rawat and Shriniwas, 1979). An increase in non-protein organic S and a corresponding decrease in protein S occur as a result of S application. The increase in non-metabolic form of S in the plant tissue might be considered to decrease dry matter production (Dhillon and Dev, 1980).

8. Transformation of K, Mg and S in soil

8.1 Potassium

Potassium resources and their availability to plants largely depend on the mineralogy and degree of weathering which in turn determine the dynamic equilibrium between the non exchangeable, exchangeable and water soluble forms (Ranganathan and Satyanarayana, 1980). The K releasing power of soils refers to the total availability of K in the soil and the K supplying power refers to the actual uptake by the plant (Ramanathan and Krishnamurthy, 1982). Exchangeable K decreases with cropping and hence the contribution of soil reserve K towards K nutrition of plants is considerable (Yadav and Swami, 1988).

Occurrence of potassium in soil

Potassium in soil originates from the disintegration and decomposition of rocks containing potassium-bearing minerals. The minerals that are generally considered to be the original sources of K are the K feldspars orthoclase and microcline, muscovite, biotite and phlogopite. Micas and K feldspars account for the major portion of K in soils (Syers, 1995). In the non-clay component of soil, feldspar K was more than mica clay (Dubey *et al.*, 1988). K bearing minerals in alluvial soils of India (Entisols and Inceptisols) are micas which are fine grained and concentrated mainly in the clay fraction. K is also found in secondary clay minerals like illites, vermiculites, chlorites and interstratified minerals (Tisdale *et al.*, 1995).

Forms of soil potassium

Potassium in soil occur in the water soluble, exchangeable, non-exchangeable (fixed or difficultly available) and mineral forms. The different forms of K exist in dynamic equilibrium in soil. The increasing order of availability of different forms of K is mineral - non exchangeable - exchangeable and solution K (Martin and Sparks, 1985 and Tisdale *et al.*, 1995)

Water soluble potassium: Soil solution K ranges from 1 to 10 ppm in soils and constitutes about 0.1 to 2 per cent of total K. Mishra *et al.* (1993) has reported that water soluble K accounts for about 0.05 per cent of total K while Venkatesh and Satyanarayana (1994) reported that water soluble K accounts for 0.02 % of total K. Das *et al.* (1993) has reported that water soluble K accounts for 1.8 to 17.4 % of available K.

In the laterite soils of Kerala and Tamil Nadu, the water soluble K ranged from 0.028 to 0.248 cmol (p^+) kg^{-1} (Nambiar, 1972) while in the laterite soils of Maharashtra, water soluble K ranged from 6 to 30 ppm (Sutar *et al.*, 1992). Levels of water soluble K in soils of humid regions varied from one to eighty ppm (Tisdale *et al.*, 1995). Water-soluble K is positively and significantly correlated with exchangeable or available K (Devi *et al.*, 1990).

Exchangeable potassium: Exchangeable K constitutes about 1 to 10 per cent of total K and is generally less than one per cent of total K. Das *et al.* (1993) has reported that exchangeable K constitutes about 80 to 98.2 per cent of available K. According to Mishra *et al.* (1993) available K and exchangeable K constituted about 0.64 and 0.59 % of total K respectively while Venkatesh and Satyanarayana (1994) reported that exchangeable K constituted about 2.6 % of total K.

Kaolinite dominated soils are low in exchangeable K reserves, smectite medium and illite high (Rao *et al.*, 1993). Laterite and non-laterite soils of humid regions are comparatively low in available K (Patil *et al.*, 1993). The variation in the distribution of K depends on the mineral present, particle size and the degree of weathering.

Dynamics of applied potassium in soil

Potassium applied in soils gets transformed into non-exchangeable K, followed by exchangeable and water soluble forms (Deshmukh *et al.*, 1991). The K fixation capacity varies with soils. K fixation capacity was found to be 11.92 to 51.52 per cent in an UP soil. On incubation, only 4 to 6.2 % of added K remained in water soluble form and exchangeable K content increased with increasing level of K application (Mishra and Shanker, 1971). Fixation of K was more under alternate wetting and drying conditions than under constant moisture levels in laterite soils. The increased addition of K increased the quantity of K in exchange complex which in turn increased the quantity of fixed K (Ramanathan *et al.*, 1981). In general, soils fixed more K under dry conditions and subsoils fixed more K than surface soils (Ano *et al.*, 1992).

Exchangeable K in texturally different soils increases with increasing levels of K and decrease with passage of time. Similarly the amount of K fixed increase with levels and passage of time (Prakash and Singh, 1989). K fixation in laterite soils varied between 2.35 to 27 per cent. This low fixation is due to the presence of 1:1 type clay minerals (Ningappa and Vasuki, 1989).

Higher levels of KCl increased the amount of solution and exchangeable K. Under high rates of application, water soluble K exceeded exchangeable K in soil (Chakravorti, 1992). The content of water soluble and exchangeable K shows a marked rise with K_2O application in soils with low and moderate K releasing capacity while non exchangeable and total K increased conspicuously in those having high releasing power (Prasad and Rajamannar, 1987).

On incubation of Mollisols of UP, available and fixed K showed a slight increase in the first two weeks and a sudden decrease in the fourth week. Generally more fixed K was released under submerged condition than at field capacity (Singh and Singh, 1992). In a study on the effect of added K and incubation time on the transformation of available K and non exchangeable K in different soils of Maharashtra, the exchangeable K fraction increased with increase in the amount of added K and decreased with increase in the period of incubation while the non exchangeable K increased with increase in incubation period (Talele *et al.*, 1993). Longer period of incubation decreased the retention of K in alluvial soils (Rao and Khera, 1995).

Effect of soil characters on potassium transformation in soil

pH: Retention of applied K in soils is dependent on soil pH. A positive correlation also exists between pH and different forms of K (Bolan and Ramulu, 1981 and Cuttle, 1983). It is also reported that significant positive correlation exists between K fixing capacity of soils and pH (Singh and Singh, 1979; Ranganathan and Satyanarayana, 1980; Sahu and Gupta, 1987 and Talele *et al.*, 1993).

Particle size distribution: Potassium status of soils is influenced by soil texture. The K content of alluvial soils was found to be a function of clay + silt content (Kansal and Sekhon, 1976 and Chakravarthy *et al.*, 1979). The total K was greatest in silt fraction followed by fine sand > clay > coarse sand (Lepsch *et al.*, 1978). Sharma and Mishra (1986) obtained higher content of exchangeable and non exchangeable K in fine textured soils compared to coarse textured soils which were high in water soluble K. Talele *et al.* (1993) observed that fixation of K in different soils had significant positive relationship with clay and silt and negative correlation with sand.

Cation exchange capacity: A positive relationship was observed between all forms of K and CEC (Cuttle, 1983; Ravikumar *et al.*, 1987; Ningappa and Vasuki, 1989 and Talele *et al.*, 1993).

Organic matter: A positive correlation of organic carbon existed with water soluble, exchangeable, available and fixed K (Mercykutty *et al.*, 1990) while Singh and Singh (1986) obtained significant positive correlation of organic carbon with total K and water soluble K. K fixation was not significantly correlated with organic matter (Ano *et al.*, 1992). Talele *et al.* (1993) reported a negative correlation between K fixation and organic carbon of soils.

Other cations: Significant positive correlation of K fixing capacity exists with exchangeable Ca and Mg (Singh and Singh, 1979; Ranganathan and Satyanarayana 1980; Sahu and Gupta, 1987; Ningappa and Vasuki, 1989 and Talele *et al.*, 1993). A positive correlation between exchangeable Ca and Mg with different forms of K was also reported by Bolan and Ramulu (1981).

8.2 Magnesium

Magnesium, on an average, constitutes about 1.93 % of the earth's crust (Tisdale *et al.*, 1995). The total Mg content of soils ranges from 0.1 % in sandy soils to about 4 % in fine textured soils. The distribution and availability of Mg in soils are influenced by the segregation and concentration during the geochemical evolution of the globe, characteristics of the valence electronic shells and free energy oxidation and the radii of ions capable of readily entering into particular crystalline structures of soil minerals (Cooper *et al.*, 1947).

Occurrence of magnesium in soil

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

Forms of soil magnesium

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

Exchangeable Mg: Exchangeable Mg is usually in the order of about five per cent of the total Mg and four to twenty per cent of the cation exchange capacity. This fraction along with the water soluble Mg is of greater importance in the supply of Mg to plants. Barshad (1960) found that Mg ions account for a large percentage of the total exchangeable ions in HCl acidified clays and considered this to explain the high percentage of exchangeable Mg present in solonetz soils and in near neutral soils derived from serpentine rocks. Alston (1972) observed a higher content of exchangeable Mg in soils derived from basaltic parent material. Loganathan (1973) reported exchangeable Mg contents of 6.8 to 24.0, 2.8 to 19.1, 4.2 to 10.6 and 1.3 to 2.5 cmol(+)kg^{-1} for black, red, alluvial and laterite soils respectively.

Soil solution Mg:

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

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

Magnesium was found to be highly susceptible to leaching (Kanwar, 1976; Gajbhiye and Goswami, 1980 and Goswami and Sahrawat, 1982). The release of Mg from soils and minerals was found to be inversely related to particle size (Stahlberg, 1960). Nartea and Castro (1977) found that low Mg soils release Mg more easily than high Mg soils. Reduction in Mg uptake due to liming of soils to neutrality is due to Mg fixation which reduces the amount of exchangeable Mg (Summer *et al.*, 1978). The transformation of Mg in soil under submerged conditions was highly dynamic, release and fixation existed side by side, the equilibrium being decided by the dominance of the nature of the reaction involved (Varughese, 1992).

Effect of soil characters on magnesium transformation in soil

Among the various soil factors that influence 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.

pH: Carolus (1933) reported that increased acidity of the soil did not interfere markedly with the exchangeable Mg content. Pope and Munger (1953), Ferrari and Sluijsmans (1955), Fischer (1956), Adams and Henderson (1962), Metson (1974) and Simpson (1983) observed that the amount of exchangeable Mg was influenced by soil pH. Low pH of soil tended to promote Mg deficiency. Salmon (1963) stated that the well known release of Al from acid clays into the soil solution implied that lattice Mg would also be released, that would explain the increased leaching and acidification. Wiklander and Anderson (1963) found that H^+ ions strongly enhanced the mobility of Mg.

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

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

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

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

Cation exchange capacity: A positive relationship was observed between exchangeable Mg and CEC. Exchangeable Mg constitutes about 5 to 10 per cent of the CEC (Martin and Page, 1969). Kirkby and Mengel (1976) reported that exchangeable Mg constituted 4 to 20 per cent of the CEC.

Other cations: Magnesium absorption by plants is affected by several factors other than the absolute level of Mg in soils, the level of other cations in the soil being the most important.

i. Potassium: One of the stronger antagonisms encountered in plant nutrition is that of K on the absorption of Mg. Instances of K induced Mg deficiencies have been reported worldwide under diverse soil and cropping conditions. Freeman (1965) observed some marked reduction in Mg content of several varieties of maize due to high application of K. Fischer (1956) and Salmon (1963) have observed that soils rich in potassium showed deficiency of Mg, though exchangeable Mg content was found adequate. The interaction between Mg and K was more marked than that between Mg and Ca.

ii. Calcium: Ca has also been reported to depress plant absorption of Mg though the inhibitory effect of Ca is less than that of K. A value of 65-75 per cent Ca saturation has long been suggested (Bear *et al.*, 1945) in some soils. Nevertheless, many experiments have shown that Ca has very little effect on Mg uptake (Christenson *et al.*, 1973).

iii. Nitrogen: Ammonium nitrogen also inhibits the absorption of Mg (Wilcox *et al.*, 1973; Boswell *et al.*, 1967). But this antagonistic effect of NH_4 is not as important as is the effect of K. This is due to the fact that NH_4 in soils is usually converted quite readily to nitrate by soil bacteria.

iv. Aluminium: Evidence is rapidly accumulating showing that Al strongly depresses plant absorption of Mg. This antagonistic effect would be of greater consequence under acid soil conditions where levels of soluble Al can be high. Mayland and Grunes (1979) and Grimme (1983) reported experiments that showed a drastic decrease in tissue Mg of wheat when treated with increasing levels of Al.

8.3 Sulphur

Occurrence of sulphur in soil

Sulphur in soil occurs in the elemental form, as sulfides, sulphates and in organic combination with carbon and nitrogen. It is present in the S bearing minerals like gypsum, epsomite, mirabilite, pyrite, marcasite, chalcopyrite etc. A review of studies investigating organic or inorganic forms of S in soils world-wide, revealed that in the majority of cases, organic S contributed about 90 % of the total S (Freney, 1986).

Forms of soil sulphur

Sulphur is present in the soil as soluble sulphate and adsorbed sulphate which represents the plant available sulphur, insoluble sulphate coprecipitated with calcium carbonate,the reduced inorganic S compounds and organic sulphur.

Total sulphur: The total S status of surface soils of India vary from 191 ppm to 3836 ppm (Tandon, 1991). The sandy and laterite soils of Kerala were reported to contain 671 and 1037 ppm respectively of total sulphur (Leela 1967). The light textured red, laterite and alluvial soils with low clay content contain less total S as compared to soils of other group (Mishra *et al.*, 1990). Of the various soil types of India, the mean content of total S was 273 ppm in red, 329 ppm in alluvial, 350 ppm in laterite, 456 ppm in hill and 530 ppm in black soils (Hegde *et al.*, 1980). There can be wide variations in total S of soils depending on organic matter status and texture (Virmani and Kanwar, 1971and Ruhal and Paliwal, 1978).

Available sulphur: Available sulphur constitutes about 15 per cent of total S (Balasubramanian and Kothandaraman, 1985) while Karwasra *et al.* (1986) has reported that available S constitutes about 11.7 per cent of total S. Naik and Das (1964) reported that available S content of Indian soils is less than 40 ppm.

Effect of soil characters on sulphur transformation

Sulphur availability is influenced by soil pH, soluble salt content, calcium carbonate and clay content (Balanagoundar and Satyanarayana, 1990a). In some tropical soils where the surface charge is variable and depends on pH, SO_4^{2-} is adsorbed on soil colloids if soil pH is sufficiently acid. This is due to the fact that as pH is lowered in these soils the net negative charge on the solid phase decreases to zero and then the net charge become positive when the pH is still lowered (Uehara and Kang, 1975). Sulphur content is higher in acid soils than in alkaline soils (Kanwar, 1976) and shows an increase as the acidity increases (Singh *et al.* 1976 and Palaniappan *et al.*, 1978) since acid soils are high in free Al and Fe oxides which have high adsorption capacity for sulphate.

Water-soluble and sulphate sulphur are positively correlated with clay content while organic S is correlated with organic carbon (Balanagoundar and Satyanarayana, 1990b). Organic S is highest in red soils followed by lateritic and least in black soils (Reddy and Mehta, 1970; Bhan and Tripathi, 1973; Patil *et al.*, 1981 and Prasad *et al.*, 1983).

Total S in most of the soils of India have been shown to be significantly and positively interrelated with soil organic matter (Kanwar and Takkar, 1963; Kanwar and Mohan, 1964 and Virmani and Kanwar, 1971) and with organic carbon (Bhan and Tripathi, 1973; Palaniappan *et al.*, 1978; Singh and Sharma, 1983; Singh *et al.*, 1985 and Arora and Takur, 1988). Total S is also a function of clay content of soil mainly due to the association of organic matter with the clay fraction of the soils (Ruhal and Paliwal, 1980; Patil *et al.*, 1981 and Arora and Takkur, 1985). Total S and water soluble S has positive significant relation with calcium carbonate (Karle *et al.*, 1985). Sulphate sulphur is positively correlated with salt content in soil (Singh and Chibba, 1987) while Pandey *et al.*, 1989 and Balanagoundar and Satyanarayana, 1990b have reported that sulphate sulphur is positively and total S negatively correlated with electrical conductivity of soil.

Total S and available S has positive correlation with total N, P, K, Ca, and Mg (Ananthanarayana and Rao, 1979 and Krishnappa *et al.*, 1989). The ratio of available S to total S is higher in virgin soils than in cultivated soils possibly due to crop removal and the consequent high rate of depletion in cultivated soils.

Application of S to soil increases the soil sulphate content (Rychlicka, 1989). The total S contents of soils decrease with depth (Bhardwaj and Pathak, 1969 and Mukhopadhyay and Mukhopadhyay, 1980) and hence will be more in surface soils. Similar results were obtained by Arora *et al.* (1989) who reported that S content was higher in plough layer and decreased with soil depth. But in a study on soil columns with different types of soils added with ^{35}S labelled K_2SO_4, Malik *et al.* (1992) found that movement of S increased with depth and the total per cent recovery of S was more in vertisol and less in oxisol.

Sulphate adsorption rates vary from one soil to another with about 56 to 75 per cent of applied S adsorbed at the initial stage, the rate becoming slower thereafter. The amount of sulphate adsorbed was found to be higher at the initial period of adsorption.

9. Retention and release of potassium, magnesium and sulphur by soils

9.1 Potassium

Exchangeable K of soils reflects closely the K applied (Mc Lean and Simon 1958). No apparent relationship was found between the capacity of soils to release K from non exchangeable forms and either the total K content or its distribution among the particle size separates (Pearson, 1952). Surface soils are rich in exchangeable K while subsoils are always low in exchangeable K. This decrease in exchangeable K with depth varies with topographical site (Hanway *et al.*, 1962 and Riversat, 1974). Contrary to this, Bosewell and Anderson (1968) and Sparks *et al.* (1983) observed an increased exchangeable K in A_2 and B_2 horizons in soils due to leaching of K to clayey subsoil horizons.

Considerable movement of K occurs in sandy and sandy loam soil. About 75 per cent of K moved more than 40 cm depth whereas in loamy soil, about 80 per cent of K remained within the top 15 cm (Prasad *et al.*, 1981). The leaching loss of K is much less than that of N in acid subsoils (Kabeerathumma and George, 1993) with only about 30 to 40 per cent of available K being retained in the top 0 to 30 cm.

High rates of K application is reported to increase the available K in surface soils (Subbarao *et al.*, 1993 and Talele *et al.*, 1993).

Exchangeable K in soils show an increase with increase in the amount of K added to the soil and decrease with period of incubation (Talele *et al.*, 1993). Bhattacharya and Poonia (1996) found that the equilibrium of K release from acidic soils in NH_4 OAc solution took about six weeks and that the rate of release of K gradually decreased with time.

Considerable amount of added K^+ ions undergo fixation depending upon the nature of clay size fraction present in the soil (Kardos, 1964). The fixation and availability of K^+ and NH_4^+ are somewhat interdependent and prior fixation of K^+ or NH_4^+ has a depressing effect on subsequent fixation of the other since the ionic diameters of both are very close and the mechanism of lattice fixation of the two ions similar (Stanford and Pierre, 1947; Hanway *et al.*, 1957; Raju and Mukhopadhyay, 1973 and Kar *et al.*, 1975).

9.2 Magnesium

Magnesium availability increases with increased levels of Mg application in laterite soils of Kerala. A negative relationship exists between available K and Mg fractions in soil (Varughese and Jose, 1994). But Jayaraman (1988) reported that added Mg did not show any marked variation in the available K on incubation.

In a comparison of the amount of MgO added by treatments with the increased amount recovered in the leachate and found in potato plant, Carolus (1933) reported that either epsom salts or hydrated dolomite lime is more easily leached and much more easily available for plant absorption than sulphate of potash-magnesia.

9.3 Sulphur

Total S contents in soils gradually decreases with depth and thus is higher in the plough layer (Mukhopadhyay and Mukhopadhyay, 1980 and Arora *et al.*, 1989). In a study on soil columns with different types of soils added with ^{35}S labeled K_2SO_4, Malik *et al.*(1992) found that movement of ^{35}S increased with depth and that the total per cent recovery of ^{35}S was more in vertisol and less in oxisol. The kinetics of sulphate adsorption was studied in calciorthents using K_2SO_4 (Bhogal *et al.*, 1996). The amount of sulphate adsorbed varied from one soil to another and was found to increase with time but the rate was higher at the initial period of adsorption. In a green house experiment, leaching of S increased with increasing amount of gypsum applied to the soil (Braga *et al.*, 1995).

Materials and Methods

MATERIALS AND METHODS

A study was undertaken to examine the dynamics of potassium, magnesium and sulphur in soil plant system, to evaluate the pattern of release of potassium, magnesium and sulphur in soil as influenced by the application of langbeinite and to assess the suitability of langbeinite as a potassium-cum-magnesium fertilizer for the acid laterite soils of Kerala using tapioca and bhindi as test crops. Langbeinite ($K_2SO_4.2MgSO_4$), the potassium-cum-magnesium fertilizer is a naturally occurring mineral, which is a mixture of potassium sulphate and magnesium sulphate containing 22 per cent K_2O and 18.5 per cent MgO in addition to 22 per cent sulphur.

The study comprised of three parts

a) A field experiment to investigate the suitability of Sul-Po-Mag as a potassium-cum-magnesium fertilizer for tapioca in Kerala

b) A laboratory incubation study using two soils namely laterite and alluvial, to estimate the pattern of release of potassium, magnesium and sulphur in soil as influenced by Sul-Po-Mag

c) A pot culture experiment to study the potassium-magnesium interaction in soil-plant system using bhindi as test crop.

1. Field experiment

A field experiment was laid out to study the suitability of Sul-Po-Mag as a potassium-cum-magnesium fertilizer for tapioca.

1.1 Experimental site

The experiment was laid out at the Instructional Farm, College of Horticulture, Vellanikkara, Thrissur.

1.2 Planting material

The cassava hybrid H-1687 (Sree Vishakam), a semi branched medium tall variety of ten month duration was used for the study. Mature stem harvested and preserved in shade during the previous season was cut to setts of 15 to 20 cm length from the middle portion of the stem and used for planting.

1.3 Layout

The experiment was laid out in randomized block design adopting a spacing of 90 x 90 cm and a gross plot size of 5.4 x 5.4 m. The outer rows in each plot was considered as border rows giving a net plot size of 4.5 x 4.5 m. The lay out of the experiment is given in Appendix 2.

1.4 Season

The crop was planted during April 1994 and harvested during February 1995, ten months after planting. The data on the weather parameters during the crop period is given in Appendix 1.

1.5 Treatments

The treatments included a no-fertilizer control, supply of N, P and K in the form of urea, diammonium phosphate and muriate of potash at the rate recommended by the Kerala Agricultural University (100 kg N, 100 kg P_2O_5 and 100 kg K_2O per hectare) and treatments in which the requirements of K_2O was substituted by Sul-Po-Mag to the extent of 25 per cent, 50 per cent and 100 per cent respectively. N and K were applied in three splits 1/3rd basal, 1/3rd two months after planting and 1/3rd three months after planting. Full dose of P was applied as basal.

The treatment combinations used were the following:

Sl. no.	Treatment notations	Treatment details
1	C	Control (No fertilizer)
2	NPK (MOP)	Recommended dose of N, P and K as urea, diammonium phosphate and muriate of potash
3	NPK (SPM)	N and P as urea and diammonium phosphate Sul-Po-Mag to supply 100 per cent K_2O requirement
4	NPK (½ MOP + ½ SPM)	N and P as urea and diammonium phosphate, Sul-Po-Mag to supply 50 per cent K_2O and the remaining 50 per cent K_2O as muriate of potash
5	NPK (¾ MOP + ¼ SPM)	N and P as urea and diammonium phosphate, Sul-Po-Mag to supply 25 per cent K_2O and the remaining 75 per cent K_2O as muriate of potash
6	NPK + Mg	Recommended dose of N, P and K as urea, diammonium phosphate and muriate of potash + MgO equivalent to that in Sul-Po-Mag supplied by Treatment 3.
7	NPK + ½ Mg	Recommended dose of N, P and K as urea, diammonium phosphate and muriate of potash + MgO equivalent to that in Sul-Po-Mag supplied by Treatment 4.
8	NPK + ¼ Mg	Recommended dose of N, P and K as urea, diammonium phospahte and muriate of potash + MgO equivalent to that in Sul-Po-Mag supplied by Treatment 5.
9	NPK + S	Recommended dose of N, P and K as urea, diammonium phosphate and muriate of potash + sulphur equivalent to that in Sul-Po-Mag in Treatment 3.
10	NPK + ½ S	Recommended dose of N, P and K as urea, diammonium phosphate and muriate of potash + sulphur equivalent to that in Sul-Po-Mag in Treatment 4.
11	NPK + ¼ S	Recommended dose of N, P and K as urea, diammonium phosphate and muriate of potash + sulphur equivalent to that in Sul-Po-Mag in Treatment 5.
12	NPK + Mg + S	Recommended dose of N, P and K as urea, diammonium phosphate and muriate of potash and MgO + sulphur equivalent to that in Sul-Po-Mag in Treatment 3.
13	NPK + ½ Mg + ½ S	Recommended dose of nitrogen phosphorus potassium as urea, diammonium phosphate and muriate of potash and MgO + sulphur equivalent to that in Sul-Po-Mag in Treatment 4.
14	NPK + ¼ Mg + ¼ S	Recommended dose of nitrogen phosphorus potassium as urea, diammonium phosphate and muriate of potash and MgO + sulphur equivalent to that in Sul-Po-Mag in Treatment 5.

The sources of MgO and sulphur in treatments six through fourteen were gypsum for sulphur and magnesium carbonate for Mg.

1.6 Field culture

Cultural practices were done as per the package of practices recommended by the Kerala Agricultural University (KAU, 1993).

The experimental area was ploughed twice and was divided into blocks. Plots of 5.4 m x 5.4 m were laid out and were separated by bunds of about 50 cm width and 25 cm height. After the application of the basal dose of fertilizers, three noded setts were planted vertically on the centre of mounds of 45 cm height taken 90 cm apart on either way. Top dressing of fertilizers was done according to the treatments fixed, in bands taken around the middle of each mound. Sprouting of setts was satisfactory and gap filling was done ten days after planting.

1.7 Biometric observations

Number of leaves, girth of stem and height of plant

Five plants each in the net plot area were selected for taking biometric observations and the average value was recorded. The number of fully opened leaves, girth at a uniform height of 30 cm from ground level and height of the tallest stem of each plant measured from the base of first sprout to the top of unopened bud were recorded at 2, 4, 6 and 10 months after planting.

Dry matter production

One representative plant of each plot from the net area was uprooted at 3 months and 6 months after planting and at harvest stage of the crop. From each plant the laminae, petioles, stem and tubers were separated and weighed. Representative samples from each of the plant parts were taken, wiped with damp cloth to remove adhering dust particles, and were dried in air oven at 70°C till constant weights were recorded. From the dry weight of the samples, the total plant dry weight was computed.

Tuber yield

The total fresh weight of tubers of five representative plants from each plot was recorded after harvest of the crop and the yield per plant was worked out.

1.8 Uptake of nutrients by the plant

The uptakes of nutrients were computed from the dry weight and nutrient concentration in the different plant parts. The total plant uptake was then worked out.

1.9 Quality attributes

The hydrocyanic acid content of fresh tubers was estimated on the same day of harvest. The dried flesh was powdered and analysed for starch content.

1.10 Soil analysis

Soil samples were analysed for available nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. Studies on soil properties were conducted before planting and after harvest of the crop.

2. Soil Incubation study

A laboratory incubation study was taken up using two soils namely laterite (Vellanikkara) and alluvial (Kannara) to estimate the pattern of release of potassium, magnesium and sulphur in soil as influenced by the application of Sul-Po-Mag.

2.1 *Treatments*

The treatments included in the study were

Sl. no	Treatment notations	Treatment details
1	T_0	Control
2	L_1	Langbeinite to supply 50 kg K_2O ha^{-1}
3	L_2	Langbeinite to supply 100 kg K_2O ha^{-1}
4	L_3	Langbeinite to supply 150 kg K_2O ha^{-1}
5	K_1	Muriate of potash to supply 50 kg K_2O ha^{-1}
6	K_2	Muriate of potash to supply 100 kg K_2O ha^{-1}
7	K_3	Muriate of potash to supply 150 kg K_2O ha^{-1}
8	Mg_1	$MgSO_4$ equivalent to Mg in L_1
9	Mg_2	$MgSO_4$ equivalent to Mg in L_2
10	Mg_3	$MgSO_4$ equivalent to Mg in L_3
11	$K_1 + Mg_1$	Combination of treatments K_1 and Mg_1
12	$K_2 + Mg_2$	Combination of treatments K_2 and Mg_2
13	$K_3 + Mg_3$	Combination of treatments K_3 and Mg_3

2.2 *Layout*

The experiment was laid out in the laboratory in completely randomized design with two soils (laterite and alluvial) and three replication. The soils after the addition of fertilizers as per the treatments were incubated for 90 days in plastic containers provided with an outlet for collecting the leachate.

Soil and leachate were collected on the 1st, 2nd, 4th, 8th, 15th, 30th, 45th, 60th and 90th day after incubation. The soil and leachate were analysed for N, P, K, Ca, Mg and S. The physicochemical properties of the soils used for the study were examined prior to the application of the treatments.

3. **Pot culture experiment**

A pot culture experiment using two soils namely laterite (Vellanikkara) and alluvial (Kannara), four levels of potassium, four levels of magnesium and four levels of Sul-Po-Mag was carried out with bhindi as the test crop to study the interaction between potassium and magnesium in soil and plant at different levels of these nutrients. N and P were supplied to all the treatments except absolute control according to the package of practices recommended by the Kerala Agricultural University.

3.1 *Planting material*

The bhindi variety Arka Anamika was used for the study. The seeds were soaked overnight before sowing.

3.2 *Season*

Sowing was done during July 1995. Harvesting of fruits was started during August and continued till October.

3.3 *Treatments*

Factorial combinations of four levels of potassium and four levels of magnesium in addition to four levels of Sul-Po-Mag were applied to the pots. The treatment details are given below.

Levels of K

K_0	MOP to supply 0 kg K_2O ha^{-1}
K_1	MOP to supply 15 kg K_2O ha^{-1}
K_2	MOP to supply 30 kg K_2O ha^{-1}
K_3	MOP to supply 45 kg K_2O ha^{-1}

Levels of Mg

Mg_0	$MgSO_4$ to supply 0 kg Mg ha^{-1}
Mg_1	$MgSO_4$ to supply 10 kg Mg ha^{-1}
Mg_2	$MgSO_4$ to supply 20 kg Mg ha^{-1}
Mg_3	$MgSO_4$ to supply 30 kg Mg ha^{-1}

The sixteen treatment combinations were

$K_0 Mg_0$	$K_0 Mg_1$	$K_0 Mg_2$	$K_0 Mg_3$
$K_1 Mg_0$	$K_1 Mg_1$	$K_1 Mg_2$	$K_1 Mg_3$
$K_2 Mg_0$	$K_2 Mg_1$	$K_2 Mg_2$	$K_2 Mg_3$
$K_3 Mg_0$	$K_3 Mg_1$	$K_3 Mg_2$	$K_3 Mg_3$

Levels of Sul-Po-Mag

L_0	Equivalent to K_oMg_o
L_1	Sul-Po-Mag to supply 15 kg K_2O ha^{-1}
L_2	Sul-Po-Mag to supply 30 kg K_2O ha^{-1}
L_3	Sul-Po-Mag to supply 45 kg K_2O ha^{-1}

Thus there were 21 treatments including an absolute control and a treatment receiving nitrogen, phosphorus potassium according to the package of practices recommended by the Kerala Agricultural University. N and P were applied to all treatments except absolute control.

3.4 Fertilizer application

Split doses of fertilizers were applied according to the package of practices recommended by the Kerala Agricultural University (N:P:K 50:8:25 kg ha^{-1}). Half dose of nitrogen, full P_2O_5, full K_2O and full MgO were given as basal and the remaining half dose of nitrogen was given one month after planting.

4. Analytical procedures

4.1 Soil

Particle size distribution of the soil was determined by the international pipette method as outlined by Piper (1950).

Chemical properties: The pH of soil water suspension (1:2.5) was determined using a pH meter. Electrical conductivity of the supernatant liquid of soil water suspension was read with the help of a conductivity bridge (Jackson, 1958). Organic carbon was estimated by the method of Walkley and Black (1934).

Available nutrients: Available N was estimated by alkaline permanganate method (Subbiah and Asija, 1956). Available P was extracted by Bray No.1 extractant (0.025*N* HCl + 0.03*N* NH_4F with a soil: solution ratio of 1:10 and period of extraction 5 minutes) and the P content was determined colorimetrically by the ascorbic acid reduced molybdophosphoric blue colour method in hydrochloric acid system (Watanabe and Olsen, 1965).

Available K, Ca and Mg were determined from the neutral normal ammonium acetate extract of the soil. The K content of samples were determined using a flame photometer (Jackson, 1958). Ca and Mg were determined by the versenate titration method (Hesse, 1971).

Available S was extracted with Morgan's reagent (pH 4.5) and estimated turbidimetrically (Chesnin and Yien, 1951). Soil and Morgan's reagent (100 g sodium acetate and 30 ml 99.5 per cent acetic acid dissolved in 500 ml of water and made up to one litre) in the ratio 1:10 were shaken for half an hour and the suspension was filtered and S content in the aliquot of the extract was determined turbidimetrically.

Cation exchange capacity was determined by neutral normal ammonium acetate method (Jackson, 1958).

Total nutrients: Total N was estimated by Kjeldahl digestion and distillation method (Jackson, 1958). Total P, K, Ca, Mg and S were determined from the nitric-perchloric acid digest. The soil was digested with nitric and perchloric acids in the ratio 2:1 and made up to a constant volume (Hesse, 1971). From the extract, P was determined by vanadomolybdate yellow colour method in nitric acid system (Jackson, 1958). The total K, Ca, Mg and S from the extract were determined by analytical techniques described under available nutrients.

4.2 Leachate

The collected leachate was analysed for N, P, K, Ca, Mg and S. Nitrogen content of the leachate was determined by macrokjeldahl distillation method (Bremner and Keeney, 1965). The water soluble P, K, Ca, Mg and S were determined by the analytical techniques described under available nutrients.

4.3 Plant analysis

Nitrogen in the H_2SO_4 digested plant sample was estimated by the microkjeldahl method as described by Jackson (1958). For the estimation of other elements the plant samples were digested with nitric-perchloric acid mixture (Wilde *et al.*, 1972). P, K, Ca, Mg and S were estimated from this acid extract.

P was estimated by the vanadomolybdate yellow colour method (Jackson, 1958), K by the flame photometer method (Jackson, 1958), Ca and Mg by versenate titration method (Cheng and Bray, 1951) and sulphur by the method of Chesnin and Yien (1951). From the concentration of nutrients in different plant parts and the dry weight, the uptake of nutrients were computed.

4.4 Quality attributes

Starch content of tubers was determined by titration of the sugar solution using ferricyanide ion in alkaline solution using methylene blue as indicator (Aminoff *et al.*, 1970).

The protein content of fruits was computed from the nitrogen content of plant sample determined by microkjeldhal method (Jackson, 1958) and multiplying with the factor 6.25 (Simpson *et al.*, 1965).

Fibre content of bhindi fruits was determined by AOAC method (AOAC, 1960).

Hydrocyanic acid content of fresh tuber was determined by the method suggested by Indira and Sinha (1969).

The ascorbic acid content of bhindi fruits was estimated titrimetrically (Gyorgy and Pearson, 1967).

4.5 Statistical analysis

The results obtained were statistically analysed using methods described by Snedecor and Cochran (1967). The data were analysed using the Duncan's Multiple Range Test, where the values coming under the same alphabet are statistically on par.

Results and Discussion

RESULTS AND DISCUSSION

An investigation was conducted with three experiments to examine the dynamics of potassium, magnesium and sulphur in soil plant system, to evaluate the pattern of release of potassium, magnesium and sulphur in soil as influenced by the application of langbeinite and to assess the suitability of langbeinite as a potassium-cum-magnesium fertilizer using tapioca and bhindi as test crops. The salient results of this study are presented and discussed hereunder.

PART I

SUITABILITY OF SUL-PO-MAG AS A POTASSIUM-CUM-MAGNESIUM FERTILIZER FOR TAPIOCA IN KERALA

A field experiment was conducted at the Instructional Farm, College of Horticulture, Vellanikkara, Thrissur, using Sul-Po-Mag as a source of K_2O, MgO and S with tapioca as the test crop. The treatments included a no fertilizer control, supply of nitrogen, phosphorus and potassium in the form of urea, diammonium phosphate and muriate of potash at the rate recommended by the Kerala Agricultural University (100 kg N, 100 kg P_2O_5 and 100 kg K_2O ha^{-1}) and treatments in which the requirement of K_2O is substituted by Sul-Po-Mag to the extent of 25 per cent, 50 per cent and 100 per cent respectively.

1. General characteristics of the soil selected for the study

Data on the general characteristics of the soil selected for the study are presented in Table 1.

Table 1. General characteristics of the soil selected for the study

Characteristics	
Coarse sand %	28.25
Fine sand %	19.55
Silt %	20.80
Clay %	31.10
pH	4.50
Specific conductance dS m^{-1}	0.59
Organic carbon %	0.47
CEC cmol(+) kg^{-1}	12.15
Total N %	0.18
Total P %	0.07
Total K %	0.16
Total Ca %	0.20
Total Mg %	0.07
Total S %	0.04
Available N kg ha^{-1}	220.80
Available P kg ha^{-1}	24.60
Available K kg ha^{-1}	291.00
Exchangeable Ca cmol(+)kg^{-1}	2.90
Exchangeable Mg cmol(+)kg^{-1}	1.60
Available S kg ha^{-1}	14.00

The soil was sandy clay loam in texture, non saline (EC = 0.59 dS m^{-1}) and acidic (pH = 4.5). According to the fertility ratings followed by the soil testing laboratories in Kerala, this soil was low in organic carbon and high in available P and K contents. Thus the soil of the study area was highly acidic in nature, with low cation exchange capacity (12.15 cmol (+) kg^{-1}) and organic carbon content, typical of the laterite soils of Kerala. Since the cation exchange capacity of the area is generally low, the fertilizer use efficiency is also low and hence a substantial increase in fertilizer use efficiency is considered to be difficult in the area under study. The available nitrogen content of the soil was low corresponding to the low organic carbon content. The ratings for both available P and K were high probably since the soil has been put under continuous fertilization.

2. Growth characteristics

Studies on the growth characters of the crop were conducted and the results are presented in Tables 2, 3 and 4.

1. Height of plant (Table 2)

A comparison of the plant height of different treatments showed that the treatment effects except the no fertilizer control failed to influence significantly the plant height at all stages except at the later stage where the treatment receiving 100 per cent K_2O as Sul-Po-Mag and the treatment receiving muriate of potash + Mg + S equivalent to that in treatment five gave significantly higher height of stem than the other treatments. Thus during the initial stages of growth, the treatments receiving Sul-Po-Mag to the full and half requirement of K_2O gave relatively higher values for plant height than the treatments receiving muriate of potash, even though the differences were not to the extent of giving statistical significance. All the treatments except control was found to fall in one group without any significant difference till six months after planting.

When the crop attained four months duration, the treatments receiving Mg and S at the lowest level in addition to 100 per cent K_2O as muriate of potash gave higher values for plant height than the Sul-Po-Mag treatments. Thus the presence of Mg or S failed to influence significantly the height of plant during the early stages but during the later stages, addition of Mg and S at the lowest level along with muriate of potash was found to be as effective as the application of Sul-Po-Mag alone.

Table 2. Height of stem (cm) of cassava plant at different stages of growth

Treatments	2 m.a.p.	4 m.a.p.	6 m.a.p.	harvest
1	34.95^{B}	51.85^{B}	115.20^{B}	125.50^{H}
2	62.80^{A}	100.30^{A}	188.90^{A}	200.4^{BCD}
3	67.20^{A}	99.30^{A}	204.30^{A}	213.6^{AB}
4	76.45^{A}	114.50^{A}	191.70^{A}	203.5^{ABC}
5	60.85^{A}	83.70^{AB}	193.50^{A}	207.1^{ABC}
6	63.50^{A}	91.40^{A}	171.60^{A}	182.3^{EFG}
7	61.25^{A}	98.00^{A}	198.60^{A}	209.5^{AB}
8	66.40^{A}	100.70^{A}	183.10^{A}	192.1^{DEF}
9	60.40^{A}	87.25^{AB}	167.90^{AB}	179.7^{FG}
10	59.80^{A}	94.60^{A}	187.60^{A}	200.2^{BCD}
11	64.70^{A}	95.20^{A}	182.10^{A}	194.3^{CDE}
12	64.55^{A}	84.80^{AB}	163.70^{AB}	175.2^{G}
13	72.90^{A}	109.70^{A}	190.40^{A}	204.5^{BCD}
14	66.80^{A}	102.80^{A}	208.70^{A}	217.8^{A}

2. Number of leaves (Table 3)

The number of leaves remained unaffected due to the application of the treatments during the initial stages of growth, except for the control plants. But when harvest approached, the leaf number was significantly higher for the treatments receiving muriate of potash alone than that receiving Sul-Po-Mag. Hence the leaves retained on the plant at harvest stage was significantly higher for the treatments receiving muriate of potash. This was reflected in the yield also since the highest yield was recorded for the treatment receiving muriate of potash alone. Hence it can be inferred that when more number of leaves are retained in the plant, the tuber production is also increased.

Table 3. Number of leaves of cassava plant at different stages of growth

Treat-ments	2 m.a.p.	4 m.a.p.	6 m.a.p.	harvest
1	17.9^{B}	54.5^{C}	125.3^{C}	41.2^{F}
2	27.8^{A}	89.6^{A}	236.5^{A}	79.5^{A}
3	26.9^{AB}	85.9^{AB}	214.3^{A}	68.2^{BCD}
4	27.7^{A}	82.7^{AB}	191.9^{AB}	63.9^{CDE}
5	22.4^{AB}	73.2^{ABC}	184.5^{AB}	63.1^{CDE}
6	28.9^{A}	74.5^{ABC}	193.1^{AB}	59.3^{E}
7	24.4^{AB}	60.5^{BC}	151.0^{BC}	58.5^{E}
8	23.6^{AB}	84.8^{AB}	202.4^{AB}	70.8^{BC}
9	23.4^{AB}	76.1^{ABC}	230.2^{A}	74.5^{AB}
10	23.3^{AB}	73.8^{ABC}	196.7^{AB}	67.3^{BCD}
11	21.7^{AB}	81.2^{AB}	187.0^{AB}	67.0^{BCD}
12	25.4^{AB}	67.7^{ABC}	178.4^{ABC}	61.3^{DE}
13	30.1^{A}	69.1^{ABC}	196.7^{AB}	67.8^{BCDE}
14	25.0^{AB}	79.7^{ABC}	184.4^{AB}	63.4^{CDE}

Mg application does not seem to influence significantly the leaf production in cassava except at the early vegetative stage. As growth advanced, the treatments receiving no Mg or Mg at low levels are found to give values for leaf number on par with the treatments which were given sufficient Mg. Thus Mg application affects leaf production only during the initial stages of growth.

3. Girth of stem (Table 4)

As with the case of the number of leaves and the height of plant, the treatment effects failed to influence the girth of stem during the initial stages. Only the control treatment receiving no fertilizers gave statistically low values for stem girth. During the later stages, though the treatment receiving muriate of potash alone gave higher values for stem girth it was on par with the 100 per cent Sul-Po-Mag treatment.

Table 4. Girth of stem (cm) of cassava plant at different stages of growth

Treat-ments	2 m.a.p.	4 m.a.p.	6 m.a.p.	harvest
1	3.31^{B}	4.52^{B}	5.63^{D}	5.52^{E}
2	5.5^{A}	6.85^{A}	8.2^{A}	8.13^{A}
3	5.53^{A}	5.83^{AB}	7.94^{AB}	7.81^{AB}
4	5.6^{A}	6.95^{A}	7.41^{ABC}	7.29^{BCD}
5	4.95^{A}	5.56^{AB}	7.12^{BC}	7.10^{CD}
6	5.35^{A}	6.58^{AB}	7.68^{AB}	7.61^{ABC}
7	5.25^{A}	6.76^{AB}	7.44^{ABC}	7.38^{BC}
8	5.41^{A}	6.07^{AB}	7.11^{BC}	7.04^{CD}
9	4.8^{A}	5.83^{AB}	6.77^{C}	6.71^{D}
10	4.89^{A}	6.32^{AB}	7.64^{ABC}	7.60^{ABC}
11	5.34^{A}	6.38^{AB}	7.48^{ABC}	7.41^{BC}
12	5.29^{A}	5.54^{AB}	7.08^{BC}	7.00^{CD}
13	5.38^{A}	6.14^{AB}	7.84^{AB}	7.76^{AB}
14	5.49^{A}	6.61^{AB}	7.42^{ABC}	7.37^{BC}

Application of S as gypsum alone or along with Mg at higher levels was found to depress the values of stem girth at all stages of growth. Thus the presence of Mg along with gypsum is not able to counteract the negative effect of gypsum application on the girth of stem. But Mg application along with muriate of potash is seen to increase the girth of stem when compared to gypsum application.

3. Dry matter production

Data on the dry matter produced by the plant at different growth stages are presented in Table 5.

Table 5. Dry matter production and tuber yield of cassava (kg / plant)

Treatments	Dry matter production			Tuber yield
	3 m.a.p.	6 m.a.p.	harvest	
1	0.510^{D}	0.590^{G}	0.825^{C}	1.310^{C}
2	1.370^{ABC}	1.460^{CDEF}	2.060^{A}	3.655^{A}
3	1.725^{A}	2.132^{B}	2.080^{A}	3.630^{A}
4	1.110^{ABC}	2.655^{A}	1.985^{A}	3.125^{AB}
5	1.100^{BC}	1.837^{BC}	1.865^{AB}	3.020^{AB}
6	1.100^{BC}	1.765^{BC}	1.960^{A}	3.230^{AB}
7	1.330^{ABC}	1.287^{DEF}	1.650^{AB}	2.840^{AB}
8	1.190^{BC}	1.170^{EF}	1.710^{AB}	2.750^{AB}
9	1.355^{ABC}	1.650^{CD}	1.785^{AB}	2.620^{AB}
10	1.295^{BC}	1.765^{BC}	1.600^{AB}	2.415^{B}
11	1.075^{BC}	1.070^{F}	1.410^{B}	2.452^{B}
12	0.960^{C}	1.145^{EF}	1.610^{AB}	2.635^{AB}
13	1.475^{AB}	1.585^{CD}	1.590^{AB}	2.605^{AB}
14	0.995^{C}	1.495^{CDE}	1.875^{AB}	2.625^{AB}

At all stages of growth, the Sul-Po-Mag treated plots gave higher dry matter production. During the initial stages of growth and at harvest stage, the dry matter produced by the treatments receiving muriate of potash did not vary significantly. But at six months after planting there was higher dry matter production for the Sul-Po-Mag treatment than the muriate of potash treatment. This may be due to the decreased stem height for the plots receiving muriate of potash alone at that stage. The Sul-Po-Mag treatments and the Mg or gypsum applied treatments were able to withstand better the temporary water logging which occurred just after the initial stage of growth. After this period the crop was able to recover and an increase in dry matter production was observed. As growth advanced the different treatments in general showed an increasing trend for dry matter production.

Though the dry matter production was comparatively low for the muriate of potash treatment than the Sul-Po-Mag treatment, the treatment receiving muriate of potash alone gave higher values for yield of tuber.

It is seen that gypsum addition decreases dry matter production while Mg addition increases dry matter production. This can be due to the Ca-Mg antagonism effect. In the presence of gypsum all levels of Mg gave lower dry matter production when compared to the treatments receiving Mg without gypsum addition. This suppressing effect is not seen in the case of Sul-Po-Mag which does not contain Ca and hence the Ca-Mg antagonism effect does not operate when Sul-Po-Mag is applied.

Correlation studies also showed that at all stages of growth, the dry matter production was positively and significantly correlated with tuber yield ($r = 0.610^{*}$, 0.603^{*} and 0.942^{**} respectively at the three stages of sampling).

4. Tuber yield

Yield of tuber was highest for the treatment receiving muriate of potash alone (Table 5). This was on par with the Sul-Po-Mag treatment and the treatment receiving muriate of potash + Mg. The treatment receiving gypsum along with muriate of potash without Mg addition gave significantly lower yield when compared to the treatments receiving muriate of potash or muriate of potash + Mg. Application of Mg at different levels along with muriate of potash also gave tuber yields statistically on par with that of the muriate of potash and Sul-Po-Mag treatments.

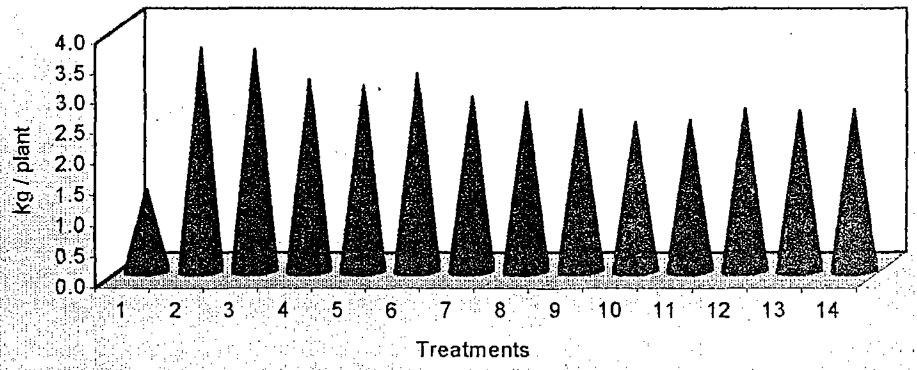


Fig.1 Yield of cassava (kg / plant)

The higher yield for the muriate of potash treatments corresponds to the higher leaf production by the plants receiving muriate of potash alone during the different stages. The higher leaf production has contributed to the increased tuber yield for the treatment receiving muriate of potash alone.

The lower yield recorded by the treatments receiving gypsum and gypsum + Mg (Fig.1) when compared to those receiving muriate of potash, Sul-Po-Mag or muriate of potash + Mg treatments may be due to the Ca- Mg antagonism effect by which Ca suppresses the activity of Mg.

There was no significant influence due to the addition of Mg over the muriate of potash treatment but addition of gypsum along with Mg is found to decrease the yield of tuber. Yield responses to Mg fertilizers is related to both level of exchangeable soil Mg and to soil Mg / K ratio. At sufficient inherent soil Mg, yields were not affected by the increased application of Mg (Hossner and Doll, 1970).

Thus it is inferred that the inherent Mg and S in soil would have been sufficient to retain the production of tuber. The presence of Mg and S in Sul-Po-Mag did not influence tuber production but the presence of gypsum with muriate of potash decreased tuber production probably because of the presence of Ca which induced a Ca-Mg antagonism effect.

Correlation studies showed that tuber yield was positively correlated with dry matter production at all stages of growth (r = 0.942** at harvest stage). The nutrient uptake at all stages also showed positive correlation with yield. Significant positive correlation existed between tuber yield and plant nutrient uptake. Thus N, P and K uptake showed significant positive correlation with yield at harvest stage (r = 0.799**, 0.743** and 0.890** respectively). Uptake of Ca, Mg and S also gave significant positive correlation with yield (r = 0.748**, 0.818** and 0.797** respectively).

5. Quality attributes

Table 6 presents the influence of Sul-Po-Mag on the quality attributes of tubers at harvest stage.

1. Starch

The starch content of the tubers ranged from 66.32 per cent to 72.71 per cent. There was no

Plate 1: Cassava crop at active growth stage

Plate 2: Cassava crop at harvest stage

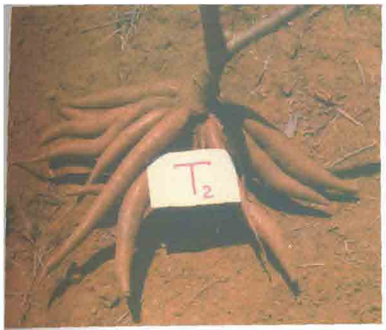


Plate 3: Muriate of Potash(100% K)

Plate 4: Sul-Po-Mag (100%K)

Plate 5: Sul-Po-Mag (50% K) + Muriate of Potash (50%K)

Plate 6: Muriate of Potash (100% K) + Mg as in T_3

Plate 7: Muriate of Potash (100 % K) + S as in T_3

Plate 8: Muriate of Potash (100 % K) + Mg + S as in T_3

significant difference in starch content among the Sul-Po-Mag treatments at different levels and the treatment receiving muriate of potash to the extent of 100 per cent K_2O requirement. But there was a significant increase in starch content for the different treatments over control.

Application of gypsum at different levels gave significantly lower starch contents when compared to the treatments receiving muriate of potash alone and those receiving Sul-Po-Mag or muriate of potash + Mg. Similar results were reported by Pushpadas *et al.* (1975), who stated that Mg application increased starch contents. Korah *et al.* (1988) and Ngongi *et al.* (1977) also had reported that at harvest stage, available S had significant negative effect on the starch content of cassava tubers.

Table 6. Quality attributes of cassava tuber at harvest stage

Treatments	Starch (%)	HCN (ppm)
1	66.315^{E}	139.850^{A}
2	71.825^{ABC}	137.65^{B}
3	71.975^{ABC}	135.85^{B}
4	72.115^{AB}	136.65^{B}
5	72.705^{A}	137.7^{AB}
6	71.135^{BCD}	136.00^{B}
7	70.970^{BCD}	138.60^{A}
8	71.355^{BCD}	137.8^{AB}
9	70.100^{D}	138.95^{A}
10	70.560^{CD}	138.50^{A}
11	71.125^{BCD}	137.65^{AB}
12	71.110^{BCD}	138.25^{A}
13	71.430^{ABCD}	138.00^{AB}
14	71.655^{ABC}	137.40^{B}

Correlation studies showed that a significant positive correlation (r = 0.698**) existed between yield and starch content of cassava tubers. The dry matter production at the three stages of growth and the starch content were also positively correlated (r = 0.559*, 0.601* and 0.764** respectively).

2.Hydrocyanic acid

The hydrocyanic acid content was highest for the control plots receiving no fertilizer. It is seen that with fertilization there was a reduction in hydrocyanic acid content, though the effect was not significant. But hydrocyanic acid content of tubers in plots treated with 100 per cent and 50 per cent Sul-Po-Mag recorded lower values than the plots treated with muriate of potash. Application of magnesium did not influence the hydrocyanic acid content while gypsum application increased the hydrocyanic acid content. This may be due to the reason that with fertilization the total dry matter and yield increased and hence there could be a dilution of hydrocyanic acid content. This justifies the reduced hydrocyanic acid content for the treatments receiving muriate of potash, Sul-Po-Mag and muriate of potash + Mg. Control plots gave the highest value for hydrocyanic acid content. The reduction of hydrocyanic acid content due to potassium application may be due to the fact that potassium is a cofactor for a number of enzymatic reactions in carbohydrate metabolism, particularly the polymerisation of glucose to starch (Evans and Sorger, 1966). Since glucose would be required for the synthesis of cyanoglucosides, its diversion to starch synthesis might result in the reduction of cyanoglucoside synthesis.

A negative correlation existed between the hydrocyanic acid content of tubers at harvest stage with tuber yield (r = −0.611*), and dry matter production of plants at the three stages of growth (r = −0.398, −0.633* and −0.633* respectively). The starch content of tubers and the uptake values for nitrogen, phosphorus, potassium, calcium, magnesium and sulphur also showed a negative correlation with the tuber hydrocyanic acid content. It is also seen that the exchangeable Ca of soil at harvest stage had positive correlation with the hydrocyanic acid content of tubers (r = 0.495). But available N, P, K, exchangeable Mg and available S of soil at harvest showed negative correlation with the hydrocyanic acid content (r = −0.232, −0.177, −0.310, −0.571* and −0.445 respectively). The results are in line with the observation of Korah *et al.* (1988) who reported that available sulphur has negative correlation with hydrocyanic acid content.

6. Uptake of nutrients

1.Nitrogen (Table 7)

Nitrogen was taken up in significantly higher quantities by the treatment receiving Sul-Po-Mag to the full requirement of K_2O. The muriate of potash treated plants gave lower N uptake values than the Sul-Po-Mag treated ones but this was significant at the initial stages only. Similar observations were made by Loue' (1985) who reported that application of K_2SO_4 significantly increased the N uptake by plants when compared to the KCl applied ones. In the presence of KCl, at low Mg levels, uptake of N was not significantly affected. But higher Mg levels in combination with KCl further decreased the N uptake. Similar results were obtained by Kumar *et al.* (1981) who reported that the uptake of N increased at low Mg and decreased at high Mg application rates.

When K was applied as Sul-Po-Mag, the N uptake values showed a significant increase during the initial stages. But during the harvest stage, there was no significant difference in N uptake between the Sul-Po-Mag and muriate of potash treatments. Application of gypsum decreased N uptake. This was reflected in the tuber yield also where the muriate of potash and Sul-Po-Mag treatments gave higher and comparable yields than the treatments receiving gypsum + muriate of potash.

Sulphur deficiency has been reported to result in poor utilization of N and a consequent increase in total N content (Lund and Murdock, 1978). But in this study, since the treatment two receiving muriate of potash alone gave the highest yield which was on par with the treatment receiving Sul-Po-Mag, it can be inferred that the inherent S content of the soil used for the study was sufficient to bring about a high yield for cassava and hence a deficiency of S was not felt so as to result in an impaired N metabolism.

Correlation studies show that the nitrogen uptake by the plant was positively correlated with yield at the three stages of growth (r = 0.592*, 0.510 and 0.799** respectively).

2.Phosphorus (Table 7)

The Sul-Po-Mag applied plots gave significantly higher values for phosphorus uptake when compared to the muriate of potash applied ones during the initial stages of growth but at harvest stage there was no significant difference between the Sul-Po-Mag and muriate of potash treatments. Thus there was an increase in P uptake when magnesium was in combination with K_2SO_4. Due to the greater solubilization of P and the carrier effect on P, Mg application increases P availability (Jacob, 1958). A decrease in P uptake at higher rates of Mg application was also

Table 7. Uptake of nitrogen, phosphorus and potassium by cassava (g / pl)

Treat-ments	Nitrogen			Phosphorus			Potassium		
	3 m.a.p.	6 m.a.p.	harvest	3 m.a.p.	6 m.a.p.	harvest	3 m.a.p.	6 m.a.p.	harvest
1	4.64^{D}	35.35^{A}	4.62^{G}	0.709^{D}	0.535^{F}	0.844^{E}	6.01^{C}	5.97^{F}	8.00^{D}
2	18.65^{BC}	13.00^{CDEF}	17.55^{ABC}	3.505^{BC}	2.845^{C}	3.375^{A}	20.33^{AB}	20.08^{D}	22.24^{AB}
3	27.19^{A}	19.51^{AB}	20.11^{A}	3.775^{A}	4.000^{B}	3.105^{AB}	24.63^{A}	29.79^{AB}	25.63^{A}
4	17.45^{BC}	22.89^{A}	17.51^{ABC}	3.565^{AB}	5.560^{A}	1.660^{DE}	18.74^{AB}	34.26^{A}	21.36^{ABC}
5	16.45^{BC}	14.57^{CD}	15.63^{BCD}	2.590^{BC}	5.925^{A}	2.490^{ABCD}	15.57^{B}	28.40^{AB}	22.63^{AB}
6	12.46^{C}	12.74^{CDEF}	13.71^{DE}	2.135^{C}	2.835^{C}	2.800^{ABC}	13.04^{B}	27.36^{BC}	20.58^{ABC}
7	17.38^{BC}	10.10^{EFG}	14.65^{CDE}	2.917^{ABC}	1.485^{DEF}	2.255^{BCD}	16.58^{B}	16.59^{DE}	17.68^{BC}
8	12.94^{C}	8.52^{G}	11.31^{EF}	2.160^{C}	1.715^{DE}	1.980^{CD}	14.09^{B}	16.34^{DE}	18.64^{BC}
9	16.85^{BC}	12.81^{CDEF}	12.30^{DEF}	2.910^{ABC}	3.055^{BC}	2.650^{ABCD}	18.15^{AB}	20.60^{D}	19.51^{ABC}
10	18.19^{BC}	13.47^{CDE}	12.23^{EF}	2.485^{BC}	2.465^{CD}	2.390^{ABCD}	17.42^{AB}	21.83^{CD}	16.24^{BC}
11	16.52^{BC}	8.82^{FG}	9.04^{F}	2.100^{C}	1.125^{EF}	1.680^{DE}	13.30^{B}	11.14^{EF}	14.97^{C}
12	16.33^{BC}	11.25^{DEFG}	14.24^{CDE}	2.060^{C}	$.910^{EF}$	2.170^{BCD}	15.11^{A}	12.76^{E}	18.10^{BC}
13	22.24^{AB}	16.02^{BC}	14.13^{DE}	2.555^{BC}	1.695^{DE}	2.320^{ABCD}	20.00^{AB}	21.82^{CD}	18.14^{BC}
14	14.50^{BC}	16.15^{BC}	18.05^{AB}	1.795^{C}	2.440^{CD}	2.485^{ABCD}	14.00^{B}	16.91^{DE}	20.91^{ABC}

reported by Kumar *et al.* (1981).

Addition of gypsum or Mg to muriate of potash decreased P uptake. It is seen that though the values for available P was high for the plots receiving both Mg and gypsum along with muriate of potash there was a corresponding decrease in P uptake values for these treatments. Correlation studies also show significant positive relation between P uptake at the three stages and tuber yield (r = 0.650**, 0.493 and 0.743** respectively).

3.Potassium (Table 7)

The muriate of potash treated plants generally did not show significant difference in K uptake from the Sul-Po-Mag treated plants at different stages of growth but the values were lower for the muriate of potash treatment (Fig.2). Addition of Mg + muriate of potash did not influence the uptake of K by the plant. This is reflected in the yield also since Mg application gave comparable yields with the muriate of potash applied treatments. Sulphur application as gypsum also gave significantly lower K uptake values. This may be due to the inhibition of K uptake by the added Ca as gypsum (Fageria, 1983 and Sudhir *et al.*, 1987). Tuber yield and K uptake at the three stages were positively and significantly correlated (r = 0.690**, 0.648** and 0.890** respectively).

4.Calcium (Table 8)

During the initial stages, Ca uptake was higher for the Sul-Po-Mag treatment, which also gave higher values for K uptake. But when crop growth advanced Ca uptake values increased for the treatments receiving muriate of potash alone and hence the addition of Mg or S decreased Ca

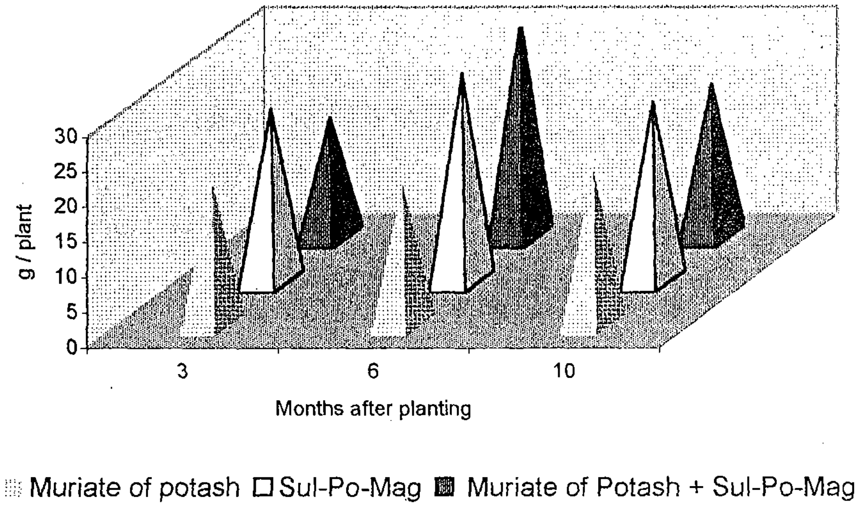


Fig. 2 Uptake of potassium by cassava plant (g / pl)

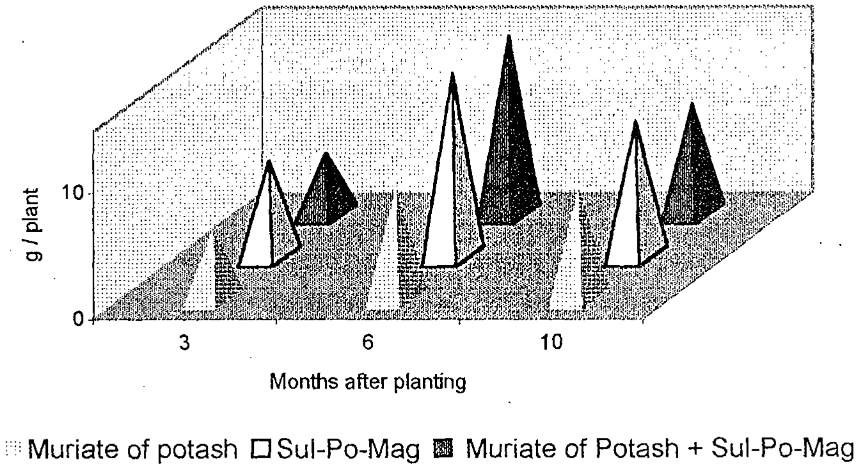


Fig. 3 Uptake of magnesium by cassava plant (g/pl)

Table 8. Uptake of calcium, magnesium and sulphur by cassava (g / pl)

Treat-ments	Calcium			Magnesium			Sulphur		
	3 m.a.p.	6 m.a.p.	harvest	3 m.a.p.	6 m.a.p.	harvest	3 m.a.p.	6 m.a.p.	harvest
1	3.689^{E}	3.011^{A}	6.720^{E}	1.973^{E}	2.069^{H}	2.852^{DE}	0.653^{E}	0.289^{E}	0.747^{D}
2	12.311^{AB}	9.539^{CDE}	27.161^{A}	5.462^{BC}	8.711^{DE}	8.763^{AB}	1.69^{BCD}	0.691^{BCDE}	2.759^{ABC}
3	14.167^{A}	13.608^{B}	23.230^{AB}	7.648^{A}	14.663^{B}	10.768^{A}	2.782^{A}	1.504^{A}	2.432^{AB}
4	13.535^{A}	16.620^{A}	25.848^{A}	5.929^{B}	16.811^{A}	9.278^{AB}	2.238^{ABC}	1.480^{A}	2.563^{A}
5	8.913^{CD}	12.27^{BC}	23.503^{AB}	3.952^{CD}	11.785^{C}	8.348^{AB}	1.643^{BCD}	0.931^{BC}	2.433^{AB}
6	7.557^{D}	8.839^{DEF}	14.117^{D}	4.064^{CD}	10.489^{CD}	9.579^{A}	1.473^{CD}	0.781^{BCD}	2.165^{ABC}
7	9.892^{BCD}	7.165^{EFG}	15.522^{CD}	4.796^{BCD}	8.164^{EF}	7.249^{BC}	2.226^{ABC}	0.509^{DE}	1.927^{ABC}
8	8.699^{CD}	7.204^{EFG}	15.687^{CD}	4.077^{CD}	7.117^{EF}	7.185^{BC}	1.588^{CD}	0.495^{DE}	2.131^{ABC}
9	11.354^{ABC}	10.056^{CDE}	18.429^{BCD}	4.417^{BCD}	6.474^{FG}	3.933^{DE}	2.459^{AB}	1.081^{B}	1.850^{BC}
10	8.976^{CD}	10.219^{CD}	18.481^{BCD}	5.210^{BC}	8.740^{DE}	3.364^{DE}	1.783^{BCD}	0.964^{B}	1.637^{C}
11	8.394^{CD}	6.235^{FG}	17.159^{BCD}	4.687^{BCD}	4.520^{G}	2.592^{E}	1.675^{BCD}	0.535^{CDE}	1.663^{C}
12	7.215^{D}	5.556^{GH}	16.209^{CD}	4.160^{CD}	6.750^{EF}	5.455^{CD}	1.353^{DE}	0.672^{BCDE}	1.814^{BC}
13	9.137^{CD}	9.010^{DEF}	17.503^{BCD}	4.93^{BCD}	10.418^{CD}	5.363^{CDE}	2.082^{ABCD}	0.891^{BCD}	1.786^{BC}
14	6.911^{D}	8.572^{DEF}	21.085^{ABC}	3.377^{DE}	6.902^{EF}	5.424^{CDE}	1.248^{DE}	0.711^{BCD}	2.211^{ABC}

uptake. This is because of the existence of Ca-Mg antagonism.

Either gypsum or Mg application with muriate of potash did not increase Ca uptake but Mg at higher levels along with KCl significantly decreased uptake. Similar results were obtained by Kumar *et al.* (1981) who reported that the uptake of Ca increased at low Mg levels and decreased at high Mg levels. The antagonistic effect of Mg on Ca uptake was apparent only when the absolute amounts of K and Ca were low (Ananthanarayana and Rao, 1979). Uptake values of Ca for the muriate of potash treatment was lower than the Sul-Po-Mag 100 and 50 per cent treatments but no significant difference was observed. The uptake of Ca at the three growth stages was positively and significantly correlated with yield (r = 0.700**, 0.589* and 0.748** respectively).

5.Magnesium (Table 8)

Uptake of magnesium increased during the active growth period of the cassava plant and thereafter showed a decrease when the harvest stage approached. The increased vegetative growth during the initial stages and the increased leaf fall during the later stages might have resulted in this pattern of uptake values. This is evidenced by the positive correlation obtained between dry matter production and Mg uptake at different stages (Table 11.2). The uptake values for the muriate of potash treatment remained low throughout the growth period (Fig.3) when compared to the Sul-Po-Mag and muriate of potash + Sul-Po-Mag treatments. Generally the plants treated with Sul-Po-Mag gave higher Mg uptake values than those treated with muriate of potash. The uptake values were significantly higher for the Sul-Po-Mag treatments during the

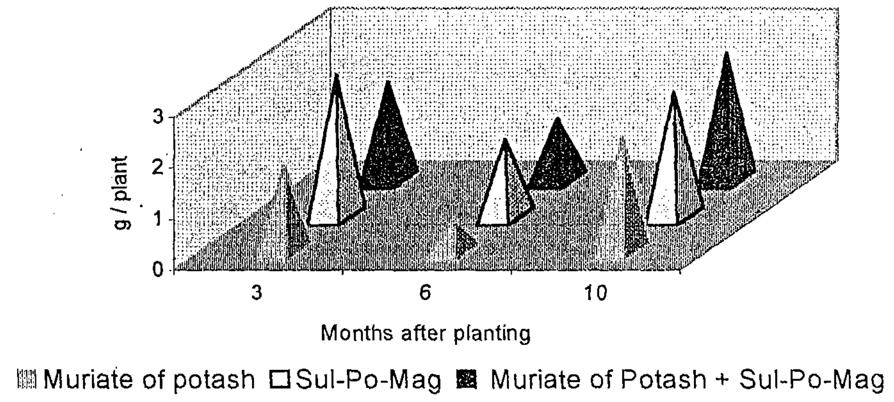


Fig. 4 Uptake of sulphur by cassava plant (g/pl)

initial stages. During the later stages, though the Sul-Po-Mag treatment gave higher values for Mg uptake, there was no significant difference. Mg uptake was also higher for the highest level of Mg applied along with KCl. Loue' (1985) have reported that KCl treatment results in significantly higher Mg uptake values without Mg addition when compared to the K_2SO_4 treatment. In this study, since langbeinite contains $MgSO_4$ in addition to K_2SO_4, this effect is compensated.

All the Sul-Po-Mag treatments gave higher Mg uptake values than the muriate of potash treatment but when muriate of potash was applied along with Mg and gypsum, lower Mg uptake values were observed except for the treatment receiving the highest level of Mg along with muriate of potash. Here, addition of gypsum did not increase Mg uptake but actually decreased it. This may be because of the antagonism existing between Ca and Mg (Fageria, 1983). Uptake of Mg is not increased by the addition of gypsum. This may be due to the presence of Ca which might have decreased the movement of Mg from root to shoot. The uptake is also found to be a function of dry matter production. Mg uptake at the three stages were positively and significantly correlated with yield (r = 0.597*, 0.629* and 0.818** respectively)

6.Sulphur (Table 8)

Uptake of S was generally lower for the muriate of potash treatment when compared to the Sul-Po-Mag applied ones (Fig.4) Application of Sul-Po-Mag and gypsum at the highest level gave significantly higher S uptake values. Treatments receiving Mg and gypsum in addition to KCl gave S uptake values statistically on par with the plots receiving muriate of potash alone. It can be seen that in the presence of K_2SO_4, increasing Mg gave significantly higher S uptake values. S uptake was statistically higher for the gypsum applied plots during the initial stages. But during the harvest stage, there was a reduction in sulphur uptake for the gypsum applied plots. This may be due to a reduction in dry matter production because of increased leaf fall and the unaccountability of their higher S contents. A positive correlation existed between the dry matter production and S uptake values at all stages of growth (Table 11.2). S is absorbed more during the early growth period. The sulphur requirement decreases with age probably because at the later stage, the slow growth rate of the plant allows more translocation of S from the older tissues to the meristem, thus permitting more efficient utilization of indigenous S for plant growth (Singh and Chibba, 1987).

There is an initial decrease in sulphur uptake by the plants for all treatments. This may be due to the high rainfall that occurred during that growth period which resulted in leaching of the sulphate anion beyond the root zone. As plant growth advanced more sulphur could be absorbed since the plants could utilize much of the lost sulphur. It is also seen that sulphur uptake at the three growth stages showed significant positive correlation with tuber yield (r = 0.470, 0.521* and 0.797** respectively).

7. Soil available nutrients

Data on the available nutrient content of soil at harvest stage is presented in Table 9.

1. Nitrogen

At harvest stage, the different treatments did not influence the N content of soil except for the treatment receiving Mg at the highest dose along with muriate of potash and control, where the available N content was significantly low. But the presence of Mg in Sul-Po-Mag did not decrease the N availability at harvest stage significantly though N was highest for the treatment receiving muriate of potash alone.

The treatments receiving Sul-Po-Mag and those receiving gypsum / gypsum + Mg along with muriate of potash gave available N values statistically on par with each other. When Mg was applied at different levels along with muriate of potash, significantly lower available N content was recorded than the treatment receiving muriate of potash alone. Similar observation was made by Kumar *et al.* (1981) who reported that the uptake of N increased at low Mg and decreased as Mg addition increased.

2. Phosphorus

Available phosphorus was significantly lower for the plots receiving Sul-Po-Mag, muriate of potash and Mg than those receiving gypsum / gypsum + Mg along with muriate of potash. Thus the application of Mg and gypsum increased the availability of soil P and this was more pronounced when Mg and gypsum were in combination with muriate of potash when compared to muriate of potash + Mg or Sul-Po-Mag. Thus Mg application along with muriate of potash or as Sul-Po-Mag gave significantly low available P content. But Mg and gypsum in combination increased significantly the P availability over the other treatments. Hence the application of Mg alone along with muriate of potash could not increase P availability but when gypsum was in combination with Mg, the P availability increased. Sulphur in Sul-Po-Mag also could not increase the P availability significantly over the muriate of potash treatment. Similar results were obtained by Kumar *et al.* (1981) who found that at low Mg application rates, the uptake of P was not affected and at high Mg levels, there was a decrease in available P.

3.Potassium

Application of higher doses of Mg or gypsum along with muriate of potash gave increased available K content of soil at harvest. But treatments receiving 100 per cent muriate of potash or Sul-Po-Mag gave significantly low available K contents. The K uptake values for

Table 9. Available nutrient content in soil at harvest stage of cassava

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Exch. Ca cmol (+) kg^{-1}	Exch. Mg cmol (+) kg^{-1}	Available S (kg ha^{-1})
1	182.300^{C}	15.700^{H}	134.40^{F}	2.50^{AB}	1.47^{BCDE}	13.385^{E}
2	244.850^{A}	47.500^{FG}	231.84^{DE}	2.39^{BC}	1.31^{E}	18.150^{E}
3	226.350^{AB}	58.500^{EFG}	225.12^{E}	2.36^{BC}	2.13^{A}	53.05^{A}
4	227.900^{AB}	62.250^{DEF}	276.64^{BC}	2.33^{C}	1.96^{ABCD}	48.75^{AB}
5	243.30^{A}	55.200^{EFG}	246.40^{CDE}	2.38^{BC}	1.73^{ABCDE}	45.05^{B}
6	203.25^{BC}	67.500^{DE}	355.04^{A}	2.40^{AB}	2.1^{AB}	19.00^{E}
7	210.95^{ABC}	57.250^{EFG}	272.16^{BCD}	2.43^{AB}	1.97^{ABC}	18.50^{E}
8	212.10^{ABC}	43.500^{G}	249.76^{CDE}	2.37^{BC}	1.77^{ABCDE}	19.00^{E}
9	230.90^{AB}	48.500^{FG}	296.80^{B}	2.82^{A}	1.32^{DE}	34.45^{C}
10	231.00^{AB}	93.500^{B}	351.68^{A}	2.73^{AB}	01.49^{ABCD}	27.00^{D}
11	232.00^{AB}	76.000^{CD}	211.68^{E}	2.67^{AB}	1.46^{CDE}	32.40^{CD}
12	217.15^{AB}	131.000^{A}	240.80^{CDE}	2.76^{AB}	1.99^{ABC}	34.00^{CD}
13	223.30^{AB}	98.500^{B}	254.24^{CDE}	2.67^{AB}	1.86^{ABCDE}	30.50^{CD}
14	221.75	88.500^{BC}	250.88^{CDE}	2.61^{AB}	1.68^{ABCDE}	28.25^{CD}

these treatments were high throughout the growth period though the available K at harvest was low. Since the uptake values for the Mg and gypsum applied plots were low compared to the muriate of potash and Sul-Po-Mag applied ones, it could be inferred that the high content of available K at harvest stage for these treatments may be due to the reduced uptake. A synergistic interaction between K and Mg was also obtained by Fageria (1983) and Narwal *et al.*(1985).

4.Calcium

High Ca values of soil were recorded by the treatments receiving gypsum. With incremental additions of gypsum, there was an increase in exchangeable Ca level, but significantly lower values were recorded for the treatments receiving Mg when compared to the treatments receiving gypsum at higher levels. When Mg was supplemented with calcium (as gypsum), this antagonism was overcome to some extent. The treatments receiving muriate of potash also gave significantly lower Ca levels. The Ca availability decreased with Mg addition because the higher solution concentration of Mg suppresses the Ca activity in soil. Similar results were obtained by Grimme *et al.* (1977) and Ohno and Grunes (1985). Antagonistic effect of Ca and Mg were also observed by Myers *et al.* (1988), Phillips *et al.*(1988) and Varughese (1992).

5. Magnesium

Exchangeable Mg was found to increase with Mg addition with no difference among sources. Similar results were obtained by Hossner and Doll (1970) and Ananthanarayana and Rao (1979). The treatments receiving the highest amount of Mg gave the highest values for Mg availability of soil. Application of gypsum along with K at all doses increased Ca in soil while its application at all levels decreased Mg in soil. This may be due to the existence of Ca-Mg antagonism. This antagonism was apparent only when the absolute amounts of Mg was low, i.e., when no Mg was applied.

Thus the addition of Ca as gypsum resulted only in an increase in the Ca content of the soil but did not appreciably increase the Mg availability of soil and therefore was of little value in making Mg available to the plant, since no significant increase in available Mg was observed between treatment two (100 per cent K_2O as MOP) and the treatments receiving gypsum. Ananthanarayana and Rao (1979) also reported an increase in Mg availability by Mg addition.

6.Sulphur

Available sulphur also increased with increase in sulphur application as Sul-Po-Mag or gypsum. Plants receiving muriate of potash and muriate of potash + Mg gave significantly low available S values than those receiving Sul-Po-Mag or gypsum. This is in contrast to the observation of Ananthanarayana and Rao (1979) who reported that magnesium addition increases the available S contents. Plots receiving muriate of potash gave still lower S content which was on par statistically with the control plots.

Correlation studies showed that positive relation existed between available nutrient contents of soils at harvest stage and the tuber yield but there was no significance (Table 11.1).

Table 10. Total nutrient content in soil at harvest stage of cassava (ppm)

Treatments	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulphur
1	1765^{A}	695^{A}	1605^{A}	1965^{B}	660^{B}	415^{D}
2	1845^{A}	735^{A}	1650^{A}	2065^{AB}	660^{B}	465^{BCD}
3	1820^{A}	765^{A}	1655^{A}	2150^{AB}	740^{A}	525^{AB}
4	1860^{A}	730^{A}	1645^{A}	2145^{AB}	725^{AB}	500^{ABC}
5	1890^{A}	735^{A}	1625^{A}	2145^{AB}	710^{AB}	483^{ABC}
6	1880^{A}	725^{A}	1635^{A}	2130^{AB}	735^{A}	440^{CD}
7	1805^{A}	740^{A}	1645^{A}	2120^{AB}	715^{AB}	470^{ABCD}
8	1830^{A}	730^{A}	1615^{A}	2115^{AB}	705^{AB}	440^{CD}
9	1835^{A}	750^{A}	1615^{A}	2217^{A}	665^{B}	525^{AB}
10	1860^{A}	730^{A}	1635^{A}	2215^{A}	655^{B}	500^{ABC}
11	1900^{A}	745^{A}	1626^{A}	2190^{AB}	665^{B}	495^{ABC}
12	1880^{A}	725^{A}	1640^{A}	2300^{A}	740^{A}	528^{A}
13	1855^{A}	740^{A}	1665^{A}	2250^{A}	720^{AB}	513^{AB}
14	1895^{A}	725^{A}	1650^{A}	2200^{A}	695^{AB}	500^{ABC}

8. Total nutrients

The data on the total nutrient content of soil at harvest stage is presented in Table 10. Total N, P and K in soil did not show significant difference among the treatments. But total Mg was significantly higher for the treatments receiving Sul-Po-Mag or Mg. The treatments receiving the highest level of Mg (3, 6 and 12) gave total Mg values significantly higher than the treatments receiving muriate of potash and those receiving gypsum without Mg. Thus the application of gypsum decreased significantly the total Mg of soil. This can be due to the action of Ca-Mg antagonism effect by which Ca might have replaced Mg from the soil. The leaching of the displaced Mg must have led to comparatively low Mg values for the gypsum applied plots. Though the treatments receiving Sul-Po-Mag and those receiving gypsum gave total S contents higher than the muriate of potash and Mg treatments, it was seen that significant difference did not generally exist. The treatment receiving no fertilizers (control) recorded significantly lower total S than all other treatments.

Table 11.1 Correlation matrix showing interrelationships among various plant characteristics and soil nutrient contents

Charact-eristics	DMP 3 m.a.p.	DMP 6 m.a.p.	DMP harvest	Yield	Avail-able N	Avail-able P	Avail-able K	Exch. Ca	Exch. Mg	Avail-able S
DMP-1map	1.000									
DMP-2map	0.596*	1.000								
DMP-3map	0.610*	0.705**	1.000							
Yield	0.610*	0.603*	0.942**	1.000						
Avail. N	0.437	0.455	0.476	0.474	1.000					
Avail. P	0.086	0.103	0.097	0.007	0.194	1.000				
Avail. K	0.347	0.488	0.479	0.346	0.200	0.313	1.000			
Exch. Ca	-0.119	-0.271	-0.310	-0.403	0.052	0.519*	0.112	1.000		
Exch. Mg	0.225	0.388	0.323	0.351	-0.231	0.266	0.213	-0.414	1.000	
Avail. S	0.433	0.690**	0.437	0.394	0.485	0.195	0.044	-0.015	0.330	1.000

* Significant at 5 % level   ** Significant at 1 % level   DMP - Dry Matter Production
m.a.p. - months after planting

Table 11.2 Correlation matrix showing interrelationships among different plant characteristics and nutrient uptake

DMP 3m.a.p.	DMP 6m.a.p.	DMP harvest	Yield	Starch	HCN	Plant N 3m.a.p.	Plant N 6m.a.p.	Plant N harvest	Plant P 3m.a.p.	Plant P 6m.a.p.	Plant P harvest	Plant K 3m.a.p.	Plant K 6m.a.p.	Plant K harvest	Plant Ca 3m.a.p.	Plant Ca 6m.a.p.	Plant Ca harvest	Plant Mg 3m.a.p.	Plant Mg 6m.a.p.	Plant Mg harvest	Plant S 3m.a.p.	Plant S 6m.a.p.	Plant S harvest
1.000																							
0.596 *	1.000																						
0.610 *	0.705 **	1.000																					
0.610 **	0.603 *	0.942 **	1.000																				
0.559 *	0.601 *	0.764 **	0.698 **	1.000																			
-0.398	-0.633 *	-0.633 *	0.611 *	-0.660 **	1.000																		
0.905 **	0.530 *	0.579 *	0.592 *	0.586 *	-0.410	1.000																	
0.591 *	0.910 **	0.638 *	0.510	0.676 **	-0.647 **	0.582 *	1.000																
0.631 *	0.699 **	0.866 **	0.799 **	0.771 **	-0.640 *	0.676 **	0.780 **	1.000															
0.887 **	0.700 **	0.666 **	0.650 **	0.579 *	-0.426	0.807 **	0.640 *	0.670 **	1.000														
0.327	0.826 **	0.594 *	0.493	0.569 *	-0.529 *	0.277	0.738 **	0.579 *	0.513	1.000													
0.488	0.366	0.761 **	0.743 **	0.589 *	-0.447	0.483	0.391	0.707 **	0.441	0.343	1.000												
0.885 **	0.583 *	0.693 **	0.690 **	0.559 *	-0.415	0.914 **	0.583 *	0.718 **	0.864 **	0.379	0.560 *	1.000											
0.566 *	0.945 **	0.724 **	0.648 **	0.648 **	-0.674 **	0.476	0.852 **	0.678 **	0.655 **	0.868 **	0.461	0.535 *	1.000										
0.665 **	0.681 **	0.938 **	0.890 **	0.780 **	-0.599 *	0.687 **	0.658 **	0.874 **	0.707 **	0.609 *	0.719 **	0.726 **	0.723 **	1.000									
0.857 **	0.686 **	0.694 **	0.700 **	0.539 *	-0.447	0.770 **	0.639 *	0.671 **	0.891 **	0.539 *	0.466	0.861 **	0.640 *	0.694 **	1.000								
0.613 *	0.944 **	0.678 **	0.589 *	0.616 *	-0.574 *	0.525 *	0.880 **	0.681 **	0.719 **	0.873 **	0.362	0.592 *	0.930 **	0.690 **	0.757 **	1.000							
0.527 *	0.657 **	0.805 **	0.748 **	0.747 **	-0.484	0.575 *	0.670 **	0.795 **	0.637 *	0.679 **	0.591 *	0.712 **	0.621 *	0.777 **	0.723 **	0.713 **	1.000						
0.903 **	0.613 *	0.562 *	0.597 *	0.555 *	-0.513 *	0.885 **	0.626 *	0.631 *	0.862 **	0.354	0.423	0.837 **	0.571 *	0.644 **	0.862 **	0.642 **	0.574 *	1.000					
0.595 *	0.911 **	0.676 **	0.629 *	0.679 **	-0.711 **	0.554 *	0.881 **	0.739 **	0.712 **	0.801 **	0.397	0.603 *	0.940 **	0.702 **	0.680 **	0.896 **	0.651 **	0.665 **	1.000				
0.449	0.616 *	0.766 **	0.818 **	0.580 *	-0.711 **	0.364	0.539 *	0.730 **	0.539 *	0.595 *	0.541 *	0.472	0.725 **	0.751 **	0.557 *	0.605 *	0.554 *	0.479	0.764 **	1.000			
0.875 **	0.549 *	0.484	0.470	0.459	-0.334	0.811 **	0.526 *	0.515 *	0.874 **	0.364	0.363	0.814 **	0.516 *	0.534 *	0.838 **	0.574 *	0.458	0.809 **	0.545 *	0.332	1.000		
0.634 *	0.902 **	0.592 *	0.521 *	0.458	-0.508	0.591 *	0.847 **	0.600 *	0.713 **	0.701 **	0.284	0.618 *	0.839 **	0.617 *	0.702 **	0.895 **	0.566 *	0.669 **	0.798 **	0.493	0.614 *	1.000	
0.576 *	0.702 **	0.882 **	0.797 **	0.867 **	-0.669 **	0.562 *	0.704 **	0.844 **	0.660 **	0.687 **	0.597 *	0.591 *	0.750 **	0.913 **	0.645 **	0.712 **	0.768 **	0.575 *	0.751 **	0.738 **	0.508 *	0.549 *	1.00

* Significant at 5 % level ** Significant at 1 % level DMP - Dry Matter Production HCN - Hydrocyanic acid m.a.p. - months after planting

PART II

PATTERN OF RELEASE OF K, Mg AND S IN SOIL AS INFLUENCED BY SUL-PO-MAG

In this experiment, two soil types of Kerala, namely alluvial and laterite were incubated under submerged conditions for a period of 90 days, after the addition of three levels of Sul-Po-Mag and three levels of muriate of potash to supply 50, 100 and 150 kg K_2O ha^{-1}, three levels of $MgSO_4$ to supply Mg equivalent to that supplied by the Sul-Po-Mag treatments, and applications of K and Mg as muriate of potash and $MgSO_4$ equivalent to a combination of the K and Mg treatments. Soil samples and leachate were drawn on the 1st, 2nd, 4th 8th, 15th, 30th, 45th, 60th and 90th day after incubation for studying the pattern of release of K, Mg, S and other macro nutrients.

1. *General characteristics of the soils selected for the study*

Two soil types of Kerala, namely the alluvium from Kannara, and the laterite from the Instructional farm Vellanikkara, Thrissur district were made use of for the incubation study. The data on the general characteristics of the two soils are presented in Table 12.

The laterite soil was sandy clay loam in texture, non saline (EC = 0.64 dS m^{-1}) and less acidic (pH = 4.6) than the alluvial soil. According to the fertility ratings followed in the soil testing laboratories in Kerala, the soil was high in organic carbon, medium in available P and K. It contained 1.61 c mol (+) kg^{-1} exchangeable Mg and 47.05 kg ha^{-1} available S.

The alluvial soil was sandy clay in texture and acidic (pH = 4.9). The soil was high in organic carbon, medium in available P and K. This soil contained 2.92 c mol (+) kg^{-1} exchangeable Mg and 44 kg ha^{-1} available S.

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

Characteristics	Alluvial	Laterite
Coarse sand (%)	17.06	29.35
Fine sand (%)	9.25	18.65
Silt (%)	33.11	21.20
Clay (%)	40.07	30.45
pH	4.90	4.60
Specific conductance (dS m^{-1})	0.64	0.52
Organic carbon (%)	1.62	1.12
Cation exchange capacity (c mol (+) kg^{-1})	6.40	9.38
Total N (%)	0.144	0.185
Total P (%)	0.036	0.078
Total K (%)	0.091	1.58
Total Ca (%)	0.028	0.027
Total Mg (%)	0.105	0.107
Total S (%)	0.061	0.049
Available N (kg ha^{-1})	368.10	351.30
Available P (kg ha^{-1})	11.27	20.88
Available K (kg ha^{-1})	128.8	200.48
Exchangeable Ca (c mol (+) kg^{-1})	4.45	4.80
Exchangeable Mg (c mol (+) kg^{-1})	2.92	1.61
Available S (kg ha^{-1})	44.00	47.05

The incubation study was programmed with the intention of delineating the pattern of release of K, Mg and S during the course of incubation under submerged conditions, after the addition of Sul-Po-Mag, muriate of potash, $MgSO_4$ and a combination of muriate of potash and $MgSO_4$, at three different levels of these fertilizers. At each stage of incubation, the soil samples were collected after collecting the leachate and the soils were again submerged. The pattern of release of N, P and Ca were also studied in addition to K, Mg and S. The results obtained from the study are presented and discussed hereunder.

2.1 Potassium

i) Available K (Table 13)

Application of K fertilizers resulted in a significant increase in the available K of both soils. This is due to the increased availability of K to the soil from the fertilizers. But the application of $MgSO_4$ did not cause any significant effect on the available K content.

The effect of different treatments on the pattern of release of K in alluvial soil during the incubation period is presented in Table 13.1. The overall trend of changes show that the available K first increased till 15 days after incubation and then decreased to a stable value at the end of incubation (Fig.5). When considering the individual treatments, all treatments receiving Mg showed an increase during the initial periods of incubation, then showed a decrease at eight days after incubation and then again increased in a fluctuating pattern to attain a stable value. Thus the $MgSO_4$ treatment though caused a reduction in available K at the initial stages, gave increased values towards the end of incubation. During the later stages of incubation, the values for muriate of potash and muriate of potash+$MgSO_4$ were less than the corresponding initial values but in Sul-Po-Mag the available K was found to increase gradually during the later stages also. Thus not much variation was observed in the available K content of samples treated with Sul-Po-Mag. But for the muriate of potash + $MgSO_4$ and the muriate of potash treatments, the available K was found to decrease after 15 days of incubation whereas for the Sul-Po-Mag treated samples, the available K showed an increase after 45 days after incubation. The decrease for the K + Mg treatments may be due to the displacement of K^+ ions from the exchange sites by the released Mg^{++} ions. But for the Sul-Po-Mag treated samples, an increase was seen during the later stages when compared to K+$MgSO_4$ probably because of the continued release of K from Sul-Po-Mag due to its metered solubility whereas due to the higher solubility of muriate of potash, all the K from the muriate of potash treatments must have been solubilized and lost through the leachate water. During the later stages of incubation, the solubility of Sul-Po-Mag might have increased so that release of K must have taken place, which must have then occupied the exchange sites.

The lower available K values for the muriate of potash + $MgSO_4$ and the $MgSO_4$ treatments might be due to the replacement of K^+ from the exchange sites by Mg which must have reduced the K availability of the soil. The presence of K in the muriate of potash + $MgSO_4$ treatment resulted in the comparatively higher values for exchangeable Mg than the samples treated with $MgSO_4$ alone.

Thus when Mg was applied along with K (Sul-Po-Mag or muriate of potash + $MgSO_4$) the available K values were significantly lower than those receiving K alone (muriate of potash treatment), but when K was supplied through Sul-Po-Mag, the available K values were higher than that supplied by

Table 13. 1 Available K at different periods of incubation in alluvial soil (kg ha^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	118.72^{G}	112.00^{H}	113.49^{G}	101.54^{F}	134.40^{GH}	138.13^{GH}	138.88^{G}	124.69^{H}	143.36^{FG}
L_1	173.22^{D}	173.24^{E}	196.36^{CD}	139.62^{E}	199.35^{D}	182.19^{E}	149.33^{FG}	167.26^{E}	191.14^{C}
L_2	190.39^{C}	209.06^{D}	207.57^{C}	214.28^{C}	275.51^{B}	213.55^{E}	194.88^{D}	200.11^{C}	200.85^{B}
L_3	211.30^{B}	291.24^{B}	286.76^{A}	249.37^{B}	297.17^{A}	272.54^{B}	245.17^{A}	238.18^{B}	232.21^{A}
K_1	149.33^{E}	180.70^{E}	198.60^{CD}	147.83^{DE}	196.39^{D}	185.17^{E}	187.41^{DE}	169.50^{E}	150.83^{E}
K_2	205.33^{B}	252.37^{C}	274.78^{B}	223.25^{C}	245.92^{C}	226.24^{C}	213.54^{C}	183.69^{D}	168.75^{D}
K_3	286.72^{A}	306.88^{A}	295.72^{A}	274.77^{A}	287.48^{B}	294.93^{A}	230.71^{B}	248.64^{A}	186.67^{C}
Mg_1	125.44^{FG}	132.90^{F}	130.66^{F}	112.00^{F}	141.87^{G}	138.88^{GH}	141.12^{G}	141.12^{G}	156.06^{E}
Mg_2	118.72^{G}	117.28^{GH}	115.73^{G}	103.79^{F}	128.42^{H}	125.44^{I}	138.88^{G}	130.66^{H}	139.63^{G}
Mg_3	116.48^{G}	122.45^{G}	110.51^{G}	105.28^{F}	135.88^{GH}	132.16^{HI}	147.84^{FG}	147.84^{G}	141.12^{FG}
K_1+ Mg_1	131.41^{F}	137.38^{F}	149.33^{E}	105.28^{F}	152.32^{F}	143.36^{G}	138.88^{G}	129.91^{H}	145.60^{FG}
K_2+ Mg_2	178.45^{D}	181.44^{E}	191.88^{D}	141.11^{DE}	172.49^{E}	168.00^{F}	156.80^{F}	146.35^{G}	149.33^{EF}
K_3+ Mg_3	207.57^{B}	206.07^{D}	208.32^{C}	155.30^{D}	203.11^{D}	172.48^{F}	176.96^{E}	155.31^{F}	182.93^{C}
Mean L	191.70^{B}	224.50^{B}	230.20^{B}	200.80^{B}	258.90^{A}	222.60^{B}	196.70^{B}	202.00^{A}	208.00^{A}
K	213.67^{A}	246.50^{A}	256.25^{A}	215.90^{A}	243.50^{B}	235.40^{A}	210.50^{A}	200.50^{A}	168.70^{B}
Mg	120.30^{D}	124.10^{D}	119.10^{D}	107.20^{C}	135.30^{D}	132.40^{D}	142.40^{D}	140.00^{B}	145.70^{D}
K + Mg	172.20^{C}	174.80^{C}	183.30^{C}	133.91^{C}	176.10^{C}	161.20^{C}	157.50^{C}	143.90^{B}	159.30^{C}
Overall mean	170.16	186.30	190.76	192.90	198.13	184.08	173.86	167.90	168.75

K + $MgSO_4$. Thus the available K was increased to a great extent in the treatments receiving Sul-Po-Mag when compared to those receiving muriate of potash + $MgSO_4$. For the control treatment, the available K show decreased values at eight days after incubation and then showed an increase.

In laterite soil, the available K values were higher when compared to the alluvial soil. The available K values for the control treatment increased and decreased in a fluctuating manner throughout the incubation period (Table 13.2). All the treatments showed an increase in available K at the start of incubation. The available K then decreased gradually from four days after incubation, the decrease being more for the treatment receiving muriate of potash than the samples treated with Sul-Po-Mag (Fig.5). The higher solubility of muriate of potash must have resulted in the initial increase in available K. But the available K for the Sul-Po-Mag treatment was maintained in a stable manner over a prolonged period when compared to the muriate of potash + Mg SO_4 treatments. At the end of incubation all the treatments showed almost equal values for available K. This is because of the attainment of equilibrium between the applied fertilizers and the soil. The presence of Mg in Sul-Po-Mag and the K + Mg SO_4 treatments resulted in the lower values for available K when compared to the treatments receiving muriate of potash alone.

The two soils behaved differently with regard to the content of available K probably due to the difference in the K supplying power of these two soils. With advancing period of incubation, the available K content in samples treated with various levels of K increased and decreased in a fluctuating manner possibly because release and fixation of K^1 occurred side by side so that at the end of incubation all treatments reached a more or less stable value especially in laterite soil.

In both soils, the available K was found to decrease with incremental additions of $MgSO_4$ especially during the initial stages of incubation. This may be due to the displacement of K^+ ions by Mg^{++} ions because of the higher solution concentrations of Mg^{++} which suppresses the K activity in soil (Grimme *et al*., 1977). This decrease in available K with incremental additions of Mg^{++} occurred only in the absence of K^+ addition. When K was added to the soil either as Sul-Po-Mag or as muriate of potash, this decrease was overcome.

Available K was higher in laterite soil when compared to alluvial soil. This may be due to the higher native K of the soil. Significant difference existed in available K between the control and the soils treated with Mg. As the level of K application increased either as muriate of potash or as Sul-Po-Mag, the available K also showed an increase in both soils. This is understandably because of the increase in the magnitude of release of K^+ from the applied fertilizers at higher levels. The available K was high for the highest level of K application for both the fertilizers throughout the incubation period. The quantity of available K for the control treatment was lower than that for the K applied treatments during the course of incubation. This shows that the transformation of K in soil is dominated by the dynamics of applied K rather than the native K. The increase in available K with increased levels of application of K fertilizer was narrow during the initial stages of incubation and then became more conspicuous and again the

Table 13. 2 Available K at different periods of incubation in laterite soil (kg ha $^{-1}$)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	207.57^{F}	227.72^{H}	268.05^{G}	289.71^{GH}	307.62^{EF}	286.72^{D}	253.86^{G}	231.45^{J}	204.58^{DE}
L_1	306.87^{E}	327.03^{D}	365.12^{D}	301.65^{FG}	286.72^{F}	313.59^{C}	312.10^{E}	279.25^{GH}	283.05^{GH}
L_2	343.46^{C}	381.54^{C}	396.48^{C}	325.54^{DE}	383.78^{B}	313.59^{C}	356.90^{C}	294.93EF	296.49^{EF}
L_3	399.46^{B}	434.55^{D}	448.74^{A}	364.37^{B}	396.49^{B}	356.90^{A}	407.67^{B}	319.57^{C}	320.38^{BC}
K_1	311.36^{DE}	378.55^{D}	336.00^{F}	313.60^{DEF}	333.02^{DE}	275.52^{D}	316.59^{E}	285.95^{FG}	279.25^{GH}
K_2	361.39^{C}	381.54^{CD}	344.22^{E}	327.79^{D}	344.22^{CD}	306.88^{C}	251.62^{G}	312.83^{CD}	311.36^{CD}
K_3	468.91^{A}	462.18^{A}	440.53^{A}	395.00^{A}	458.45^{A}	369.60^{A}	446.50^{A}	364.35^{A}	323.31^{B}
Mg_1	298.66^{E}	348.68^{E}	293.44^{G}	300.16^{FGH}	323.31^{E}	284.47^{D}	285.23^{F}	307.60^{D}	350.19^{A}
Mg_2	294.18^{E}	294.93^{G}	283.73^{G}	290.45^{GH}	328.54^{DE}	255.35^{E}	266.55^{G}	304.61^{DE}	244.97^{I}
Mg_3	293.43^{E}	313.59^{F}	311.36^{F}	284.48^{H}	281.48^{F}	285.22^{D}	291.19^{F}	266.56^{I}	289.02^{FG}
K_1+ Mg_1	292.69^{E}	371.83^{F}	308.37^{F}	325.55^{DE}	357.66^{C}	284.48^{D}	321.07^{DE}	266.54^{I}	275.52^{H}
K_2+ Mg_2	335.26^{CD}	399.45^{D}	384.53^{C}	344.22^{C}	341.98^{D}	336.75^{B}	333.76^{D}	335.23^{B}	350.19^{A}
K_3+ Mg_3	410.67^{B}	438.28^{B}	414.40^{B}	365.87^{B}	453.22^{A}	309.12^{C}	421.86^{B}	341.95^{B}	313.60^{BCD}
Mean L	350.10^{B}	381.02^{C}	403.40^{A}	330.40^{B}	355.60^{B}	327.80^{A}	281.00^{C}	297.90^{B}	300.20^{BC}
K	380.53^{A}	407.33^{A}	373.50^{A}	345.47^{A}	378.51^{A}	317.13^{B}	338.24^{B}	320.71^{A}	304.70^{B}
Mg	295.50^{D}	315.80^{D}	296.10^{C}	291.60^{C}	311.30^{C}	275.10^{C}	323.60^{B}	292.80^{B}	294.60^{C}
K + Mg	346.21^{C}	403.00^{B}	369.31^{B}	345.20^{A}	384.20^{A}	310.18^{B}	358.80^{A}	314.36^{A}	313.26^{A}
Overall mean	332.60	365.30	353.50	325.20	353.50	306.00	319.80	300.60	295.60

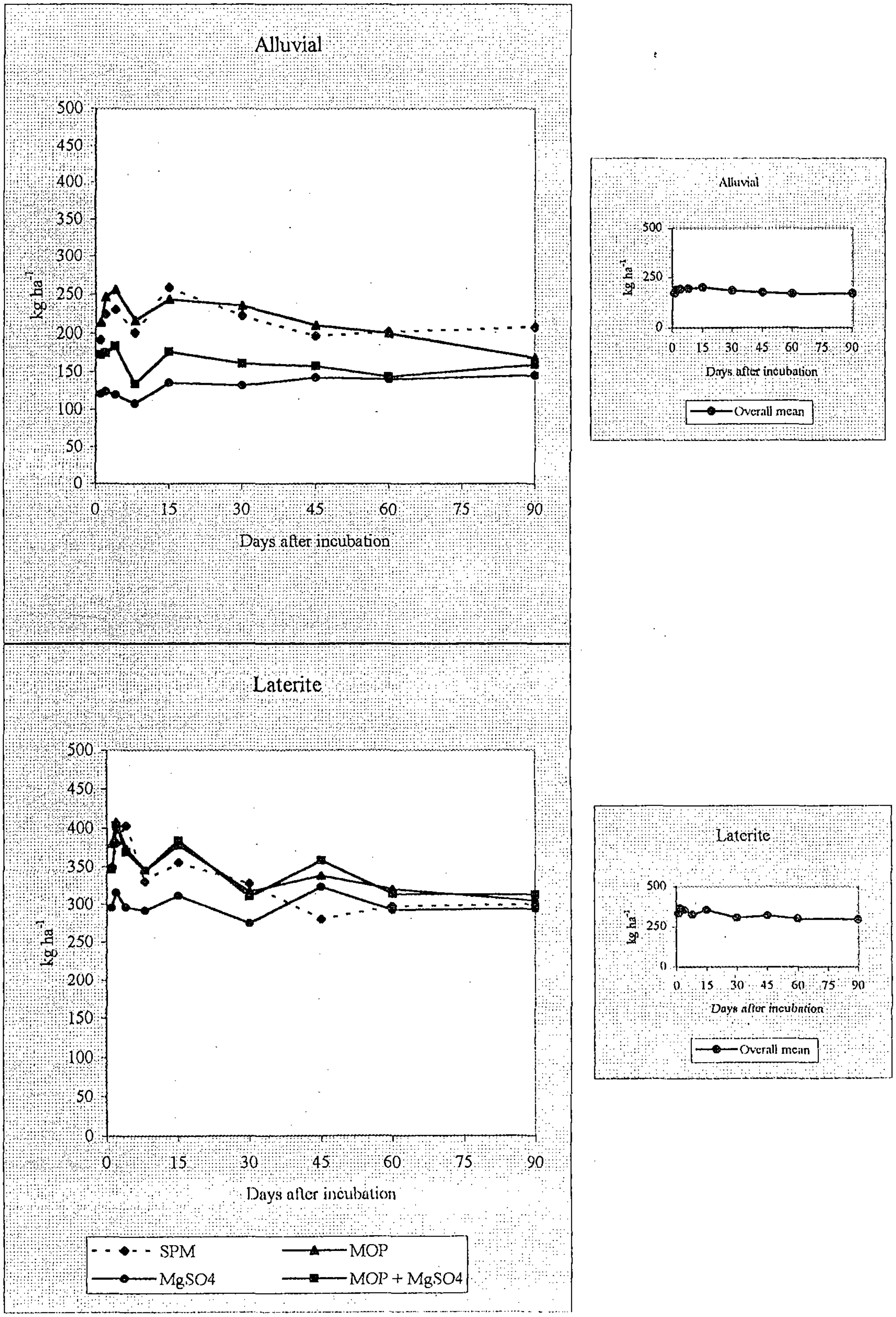


Fig. 5 Available K at different periods of incubation

difference narrowed down. This trend is in line with the general increase and subsequent decrease in available K with advancing stages of incubation.

ii) Leachate potassium (Table 14)

At different stages of sampling during the incubation study, the leachate was also collected at each stage and analysed for the different nutrients to determine the amount of nutrients lost through leachate water after the application of the different treatments at each stage of sampling.

The quantity of K present in the leachate differed in the two soils with the alluvial soil giving comparatively very low amounts of K in the leachate for all the treatments when compared to the laterite soil, which gave higher amounts of K.

The trend of changes of leachate K in the soils due to the effect of the different treatments is given in Fig.6. The overall trend of changes in both soils show that the change was in a fluctuating manner (Tables 14.1 and 14.2). The leachate K showed a steep decrease during the initial periods of incubation up to 4 days in both the soils. Thereafter the amount of K in the leachate got stabilized. After 30 days of incubation a gradual increase in leachate K was observed in the laterite soil and a steep increase in alluvial soil. At eight days after incubation, an increase in leachate K was observed in alluvial soil corresponding to the decrease in available K during that stage. This pattern of change was similar for all the treatments throughout the period of incubation in both the soils. Thus the change in leachate K for the different treatments during the incubation period was similar to the overall trend of change. Significantly higher K in leachate was obtained for the treatments receiving $MgSO_4$+muriate of potash and that receiving muriate of potash alone in alluvial soil, while the Sul-Po-Mag and $MgSO_4$ treatments generally gave lower K in the leachate with the minimum registered by the treatments receiving different levels of $MgSO_4$ alone. This is understandably because of the absence of K addition for that treatment because of which the soil contained relatively low amounts of K. But it is seen that the treatments receiving $MgSO_4$ alone registered high values for leachate K at one day after incubation. This could be because of the replacement of K^+ in the exchange sites by Mg due to which the K in the soil must have been released and leached down. The high content of leachate K in the muriate of potash and the muriate of potash + $MgSO_4$ treatments might be due to the application of K and due to the presence of Mg which displaces some of the K^+ from the exchange sites of the soil. The reduction in leachate K for the treatments receiving Sul-Po-Mag could be due to the relatively low solubility of Sul-Po-Mag and the ability of Sul-Po-Mag to resist leaching when compared to muriate of potash.

Increasing the level of application of the different treatments containing K caused a progressive increase in the leachate K in both soils. This is because of the increased supply of K through the fertilizers. The laterite soil also showed the same pattern as in alluvial soil except that the leachate K was comparatively higher at all stages of incubation when compared to the alluvial soil. This reduction in leachate K in alluvial soil is understandably due to the relatively low content of available K in the soil when compared to that of the laterite soil.

Table 14.1 Leachate K at different periods of incubation in alluvial soil (ppm)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	8.443^{CDE}	1.540^{H}	0.817^{G}	2.300^{EF}	1.127^{D}	1.020^{G}	1.623^{CD}	2.667^{CDE}	4.847^{CD}
L_1	7.767^{E}	2.453^{G}	1.180^{F}	2.920^{B}	1.413^{CD}	1.050^{FG}	1.897^{CD}	1.967^{EF}	7.790^{A}
L_2	9.300^{BC}	3.197^{DE}	1.577^{E}	2.720^{BCD}	1.817^{BC}	2.090^{BC}	3.533^{B}	4.767^{B}	5.860^{BC}
L_3	8.813^{BCDE}	3.793^{BC}	2.920^{A}	3.650^{A}	1.740^{BC}	2.530^{A}	3.027^{B}	3.323^{C}	7.367^{AB}
K_1	8.110^{DE}	4.053^{B}	2.203^{BC}	1.857^{F}	2.570^{A}	1.737^{CDE}	1.363^{CD}	2.010^{EF}	5.377^{C}
K_2	8.667^{BCDE}	4.120^{AB}	3.037^{A}	2.850^{BC}	1.867^{B}	2.010^{CD}	1.443^{CD}	2.913^{CD}	5.947^{BC}
K_3	9.493^{BC}	4.520^{A}	2.277^{BC}	3.343^{A}	2.490^{A}	2.433^{AB}	1.227^{D}	6.780^{A}	7.943^{A}
Mg_1	9.140^{BCD}	1.537^{H}	1.117^{F}	2.453^{BCDE}	1.067^{D}	1.08^{FG}	3.097^{B}	1.477^{F}	5.787^{BC}
Mg_2	9.650^{B}	2.690^{FG}	1.733^{E}	2.550^{BCD}	1.587^{BC}	0.973^{G}	1.990^{C}	3.067^{C}	8.367^{A}
Mg_3	10.713^{A}	3.076^{EF}	1.700^{E}	1.853^{F}	1.660^{BC}	1.420^{EF}	1.690^{CD}	4.467^{B}	5.113^{CD}
K_1+Mg_1	9.107^{BCD}	2.740^{EFG}	2.143^{CD}	2.340^{DE}	1.613^{BC}	1.270^{FG}	3.343^{B}	3.003^{CD}	2.840^{E}
K_2+Mg_2	9.550^{BC}	3.576^{CD}	1.977^{D}	2.393^{CDE}	1.770^{BC}	1.650^{DE}	7.107^{A}	2.600^{CDE}	3.680^{DE}
K_3+Mg_3	11.057^{A}	3.783^{BC}	2.420^{A}	2.703^{BCD}	2.440^{A}	1.790^{CDE}	3.137^{B}	2.140^{DEF}	7.467^{AB}
Mean L	8.627^{B}	3.148^{B}	1.892^{C}	3.097^{A}	1.657^{C}	1.890^{A}	2.819^{B}	3.352^{B}	7.066^{A}
K	8.757^{B}	4.231^{A}	2.506^{A}	2.683^{B}	2.309^{A}	2.060^{A}	1.361^{D}	3.901^{A}	6.422^{A}
Mg	9.834^{A}	2.433^{C}	1.517^{D}	2.286^{C}	1.438^{D}	1.160^{C}	2.259^{C}	3.003^{BC}	6.422^{A}
K + Mg	9.904^{A}	3.366^{B}	2.180^{B}	2.479^{BC}	1.941^{B}	1.570^{B}	4.529^{A}	2.581^{C}	4.662^{B}
Overall mean	9.216	3.160	1.931	2.608	1.782	1.620	2.656	3.168	6.029

Table 14.2 Leachate K at different periods of incubation in laterite soil (ppm)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	78.667^{CDE}	35.773^{EF}	28.373^{CD}	25.933^{EF}	20.300^{C}	28.913^{C}	27.000^{EF}	23.467^{F}	43.783^{B}
L_1	75.413^{DEF}	45.547^{D}	32.393^{C}	28.580^{DE}	32.673^{B}	35.033^{AB}	24.783^{F}	34.160^{CD}	38.667^{BC}
L_2	98.333^{A}	26.827^{F}	22.613^{D}	24.833^{EF}	29.687^{B}	25.667^{C}	31.640^{CDE}	28.293^{EF}	42.047^{B}
L_3	75.093^{DEF}	36.320^{E}	29.333^{CD}	32.600^{CD}	30.633^{B}	30.500^{ABC}	30.153^{DEF}	36.900^{BC}	23.200^{D}
K_1	80.333^{CD}	31.633^{EF}	28.327^{CD}	39.367^{B}	29.720^{B}	27.500^{C}	35.627^{BCD}	34.293^{CD}	27.333^{CD}
K_2	79.667^{CD}	55.900^{BC}	42.600^{B}	36.933^{BC}	43.847^{A}	27.810^{C}	41.210^{B}	40.107^{AB}	49.147^{AB}
K_3	90.467^{AB}	53.090^{CD}	43.157^{B}	53.280^{A}	48.013^{A}	29.287^{BC}	57.780^{A}	42.980^{A}	58.267^{A}
Mg_1	61.740^{G}	32.360^{EF}	23.193^{D}	21.907^{FG}	26.207^{BC}	30.653^{ABC}	25.567^{F}	30.700^{DE}	50.383^{AB}
Mg_2	70.147^{EFG}	37.060^{E}	33.120^{C}	17.260^{G}	31.167^{B}	28.727^{C}	27.393^{EF}	31.707^{CDE}	38.240^{BC}
Mg_3	70.253^{EFG}	33.900^{EF}	23.460^{D}	34.233^{BCD}	32.467^{B}	35.913^{A}	24.147^{F}	35.473^{BCD}	28.900^{CD}
K_1+ Mg_1	67.000^{FG}	58.493^{BC}	46.730^{B}	29.333^{DE}	18.387^{C}	29.847^{BC}	27.160^{EF}	29.777^{DE}	45.390^{B}
K_2+ Mg_2	84.007^{BCD}	67.593^{A}	57.873^{A}	25.500^{EF}	19.773^{C}	29.723^{BC}	28.810^{EF}	23.067^{F}	39.380^{BC}
K_3+ Mg_3	87.507^{BC}	62.367^{AB}	57.300^{A}	34.500^{BCD}	33.620^{B}	25.967^{C}	36.980^{BC}	44.760^{A}	45.973^{B}
Mean L	82.95^{A}	36.23^{C}	28.11^{C}	28.67^{B}	31.00^{B}	30.40^{AB}	28.86^{B}	33.12^{B}	34.64^{B}
K	83.49^{A}	46.87^{B}	38.03^{B}	43.19^{A}	40.53^{A}	28.20^{B}	44.87^{A}	39.13^{A}	44.92^{A}
Mg	67.38^{B}	34.44^{C}	26.59^{C}	24.47^{C}	29.95^{B}	31.76^{A}	25.70^{C}	32.63^{B}	39.17^{AB}
K + Mg	79.50^{A}	62.82^{A}	53.94^{A}	29.94^{B}	23.93^{C}	28.51^{B}	30.98^{B}	32.53^{B}	43.58^{A}
Overall mean	78.36	44.37	36.04	31.13	30.50	29.66	32.17	33.52	40.82

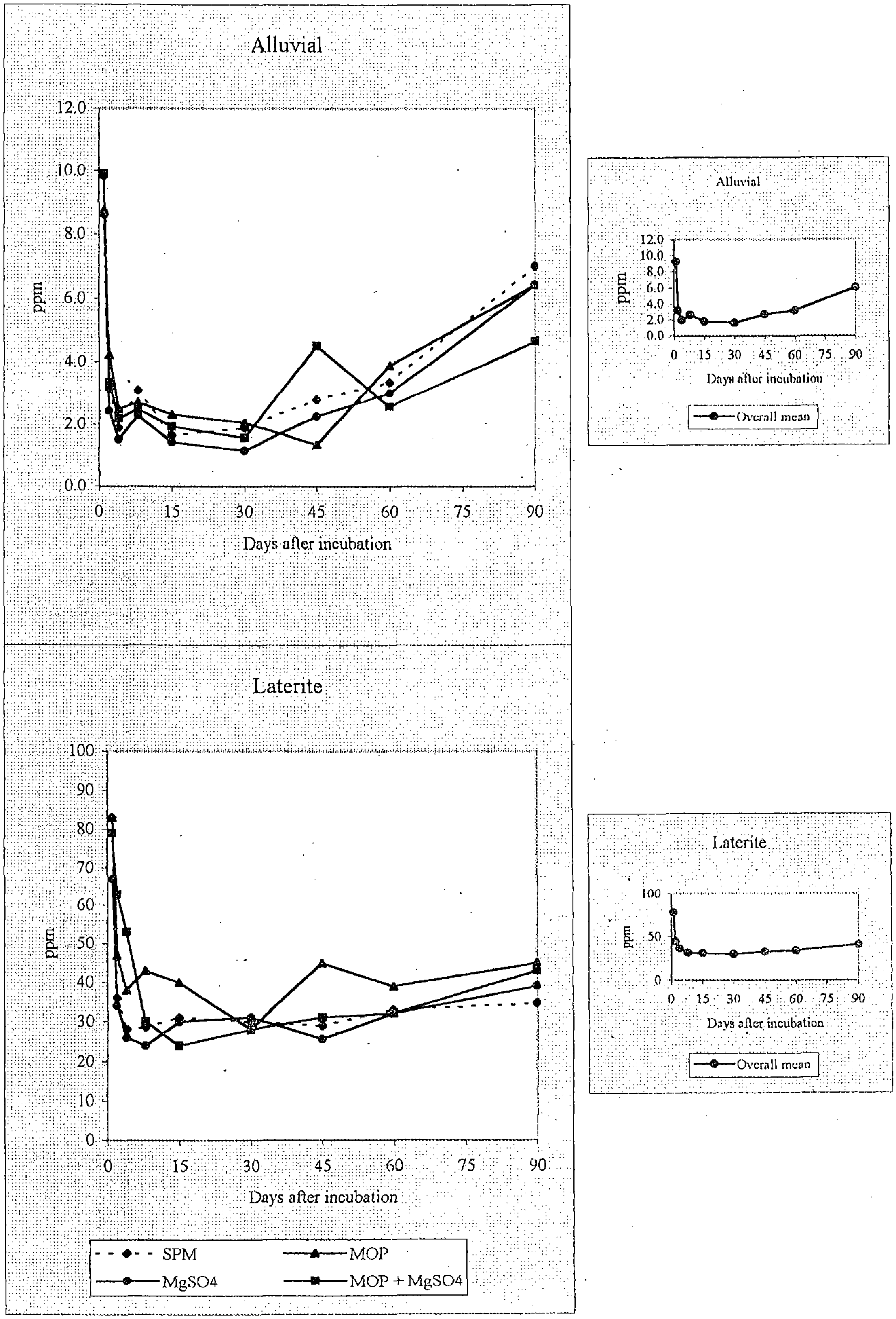


Fig. 6 Leachate K at different periods of incubation

2.2 *Magnesium*

i) Exchangeable Mg (Table 15)

Application of Mg containing fertilizers resulted in a significant increase in the exchangeable Mg of both the alluvial and the laterite soil throughout the period of incubation (Table 15.1 and 15.2). This is due to the increased availability of Mg in the soil from the applied sources. The overall trend of changes in exchangeable Mg revealed that the change was in a fluctuating pattern. In alluvial soil, the treatments showed an increase in exchangeable Mg in a fluctuating manner till the end of incubation. This is obviously due to the release of Mg from the applied sources. At eight days after incubation the $MgSO_4$ and K + $MgSO_4$ treatments showed a decline in exchangeable Mg. The Sul-Po-Mag and $MgSO_4$ treatments showed increased Mg gradually till 90 days after incubation. The Sul-Po-Mag treatment gave higher exchangeable Mg values at the end of the incubation period. This is because of the gradual release of Mg from the applied Sul-Po-Mag. The control treatment showed a decrease at two days after incubation and then increased till 30 days and thereafter remained stable till 90 days after incubation. The initial decrease could be due to the release of exchangeable Mg from the soil into the leachate and later the release of Mg from the soil components must have occurred which raised exchangeable Mg till 30 days. After 30 days the Mg remained stable which could be attributed to the attainment of equilibrium between the soil and the solution and due to the reduction in solubility of the soil Mg components due to the transformation of different forms of Mg.

The trend of changes of exchangeable Mg due to the effect of different treatments is given in Fig.7. It is seen that the exchangeable Mg for Sul-Po-Mag treatment is highest at 90 days after incubation indicating the gradual release of Mg from the fertilizer when compared to $MgSO_4$. Thus the Mg from Sul-Po-Mag is released over a prolonged period when compared to $MgSO_4$. This is because of its granular form which dissolves slowly so as to provide adequate Mg through a prolonged period. This metered solubility of Sul-Po-Mag is a beneficial property particularly in many areas of the humid tropics where leaching losses of fertilizer nutrients can be a problem. The comparative reduction of exchangeable Mg for the $MgSO_4$ treatments than the Sul-Po-Mag treatments towards the end of incubation is because of the high solubility of $MgSO_4$. The reported solubility of magnesium sulphate with a dissociation log K^0 of 8.15 reflects a very high solubility for this mineral. It is much too soluble to be retained in well-drained soils. Though Sul-Po-Mag is also highly soluble, the rate of release of Mg is slower when compared to magnesium sulphate. The released Mg from the $MgSO_4$ treatment could have been converted to insoluble forms by the process of fixation which may involve the interlocking of Mg in the crystal lattice of clay minerals as well as the formation of Mg containing minerals of low solubility, or the Mg might have been leached down. The release of Mg from Sul-Po-Mag was at a slower rate than from that of $MgSO_4$ indicated by the lower content of exchangeable Mg in the samples treated with Sul-Po-Mag during the initial periods. This is because of the slower rate of release of Mg from Sul-Po-Mag when compared to $MgSO_4$.

The trend of changes was different in laterite soil when compared to alluvial soil. In laterite soil, the exchangeable Mg due to the different

Table 15.1 Excangeable Mg at different periods of incubation in alluvial soil (c mol (+) kg^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	2.58^{D}	2.08^{G}	3.25^{E}	3.25^{F}	2.50^{D}	4.25^{DE}	4.25^{B}	4.50^{DEF}	4.40^{CD}
L_1	3.75^{BC}	4.08^{BCD}	4.75^{BC}	4.25^{BCD}	5.33^{A}	5.58^{A}	5.33^{A}	5.58^{D}	6.00^{B}
L_2	4.08^{ABC}	3.83^{DE}	4.66^{BCD}	4.83^{AB}	4.75^{ABC}	4.41^{DE}	5.16^{A}	4.66^{CDE}	7.00^{A}
L_3	3.75^{C}	4.00^{CD}	4.33^{CD}	5.00^{A}	4.58^{ABC}	5.08^{BC}	5.25^{A}	7.41^{A}	6.25^{AB}
K_1	2.67^{D}	2.92^{F}	3.75^{CD}	4.17^{BCD}	3.83^{C}	4.25^{DE}	4.41^{B}	4.33^{DEFG}	4.50^{CD}
K_2	2.58^{D}	3.17^{F}	3.15^{E}	4.58^{ABC}	4.17^{BC}	4.08^{E}	4.17^{B}	3.58^{FG}	5.00^{C}
K_3	3.83^{ABC}	3.33^{EF}	4.17^{CD}	3.58^{DEF}	4.58^{ABC}	4.33^{DE}	4.33^{B}	4.83^{BCDE}	5.00^{C}
Mg_1	3.42^{C}	4.66^{AB}	4.00^{D}	4.00^{CDE}	5.25^{A}	4.66^{CD}	4.58^{B}	5.50^{BC}	5.75^{B}
Mg_2	4.08^{ABC}	5.00^{A}	6.83^{D}	4.41^{ABC}	5.00^{AB}	4.33^{DE}	4.25^{B}	5.50^{BC}	6.33^{AB}
Mg_3	4.58^{A}	4.83^{A}	6.08^{A}	4.00^{CDE}	4.91^{AB}	4.75^{BCD}	5.08^{A}	4.58^{DE}	6.16^{B}
K_1+ Mg_1	4.58^{AB}	4.17^{BCD}	4.58^{BCD}	3.42^{EF}	4.58^{ABC}	4.33^{DE}	3.75^{C}	4.91^{BCD}	4.58^{CD}
K_2+ Mg_2	3.91^{ABC}	4.58^{ABC}	4.50^{BCD}	4.33^{ABC}	4.91^{AB}	5.08^{BC}	4.41^{B}	4.00^{EFG}	4.75^{C}
K_3+ Mg_3	4.00^{ABC}	4.83^{A}	4.08^{CD}	4.50^{ABC}	4.91^{AB}	5.25^{AB}	5.16^{A}	3.50^{G}	3.92^{D}
Mean L	3.83^{A}	4.58^{A}	4.58^{B}	4.66^{A}	4.91^{A}	5.00^{A}	5.25^{A}	5.91^{A}	6.41^{A}
K	3.00^{B}	3.17^{B}	3.83^{C}	4.08^{B}	4.17^{A}	4.33^{B}	4.33^{B}	4.25^{B}	4.83^{B}
Mg	4.08^{A}	4.83^{A}	5.08^{A}	4.17^{B}	5.08^{A}	4.58^{AB}	5.00^{AB}	5.16^{A}	6.08^{A}
K + Mg	4.17^{A}	4.50^{A}	4.42^{B}	4.08^{B}	4.83^{A}	4.91^{A}	4.41^{B}	4.25^{B}	4.41^{B}
Overall mean	3.67	4.17	4.33	4.17	4.58	4.66	4.66	4.83	5.33

Table 15.2 Excangeable Mg at different periods of incubation in laterite soil (c mol (+) kg^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	1.58^{C}	1.75^{B}	1.92^{C}	2.00^{CD}	2.00^{DE}	2.42^{BCD}	2.50^{C}	2.50^{EFG}	2.42^{E}
L_1	2.58^{ABC}	2.17^{AB}	3.00^{AB}	3.00^{ABCD}	2.42^{BCD}	2.25^{CD}	2.50^{C}	3.00^{CDEFG}	2.92^{BCDE}
L_2	3.00^{AB}	2.17^{AB}	3.00^{AB}	3.50^{ABC}	2.42^{BCD}	2.00^{DE}	2.83^{ABC}	3.58^{ABC}	3.33^{ABC}
L_3	2.75^{ABC}	2.83^{AB}	2.67^{ABC}	3.50^{ABC}	2.67^{ABC}	1.92^{DE}	2.58^{BCD}	3.17^{BCD}	3.58^{A}
K_1	2.33^{BC}	2.33^{AB}	1.83^{C}	2.00^{D}	1.83^{E}	1.50^{E}	2.42^{C}	3.00^{DEFG}	2.70^{DE}
K_2	2.33^{BC}	1.83^{B}	2.17^{BC}	3.42^{ABC}	1.75^{E}	1.50^{E}	2.92^{ABC}	2.45^{BCD}	2.83^{BCDE}
K_3	2.25^{BC}	2.33^{AB}	2.00^{C}	2.67^{BCD}	2.08^{DE}	2.05^{CD}	2.83^{ABC}	3.08^{BCDEF}	2.75^{CDE}
Mg_1	2.42^{ABC}	2.25^{AB}	2.75^{ABC}	3.58^{AB}	2.25^{CDE}	2.83^{AB}	2.58^{BC}	3.67^{BCD}	2.92^{BCDE}
Mg_2	2.67^{ABC}	2.42^{AB}	3.00^{AB}	3.67^{AB}	2.08^{DE}	2.58^{BC}	2.58^{BC}	3.33^{ABC}	3.42^{AB}
Mg_3	2.67^{ABC}	2.67^{AB}	3.50^{A}	3.83^{A}	2.00^{DE}	2.42^{BCD}	3.25^{A}	4.08^{A}	3.17^{ABCD}
K_1+ Mg_1	3.00^{AB}	2.25^{AB}	2.58^{BC}	3.17^{ABC}	3.08^{CDE}	2.00^{DE}	3.67^{ABC}	2.42^{G}	2.67^{DE}
K_2+ Mg_2	3.25^{A}	2.67^{AB}	1.92^{C}	3.25^{ABC}	2.92^{AB}	2.17^{CD}	3.17^{AB}	3.08^{BCDEFG}	3.08^{ABCD}
K_3+ Mg_3	3.00^{AB}	3.58^{A}	2.17^{BC}	3.67^{AB}	3.17^{A}	3.25^{A}	2.83^{ABC}	2.50^{FG}	3.25^{ABCD}
Mean L	2.75^{AB}	2.42^{BC}	2.92^{A}	4.17^{A}	2.50^{A}	2.08^{B}	2.67^{A}	3.25^{B}	3.25^{A}
K	2.33^{B}	2.17^{C}	2.00^{B}	3.35^{A}	1.91^{B}	1.67^{C}	2.75^{A}	3.08^{B}	2.75^{B}
Mg	2.58^{B}	2.58^{AB}	3.08^{A}	3.75^{A}	2.08^{B}	2.58^{A}	2.83^{A}	3.67^{A}	3.17^{A}
K + Mg	3.08^{A}	2.83^{A}	2.25^{B}	3.33^{A}	2.75^{A}	2.50^{A}	2.92^{A}	2.67^{C}	3.00^{AB}
Overall mean	2.60	2.42	3.25	3.50	2.33	2.25	2.75	3.08	3.00

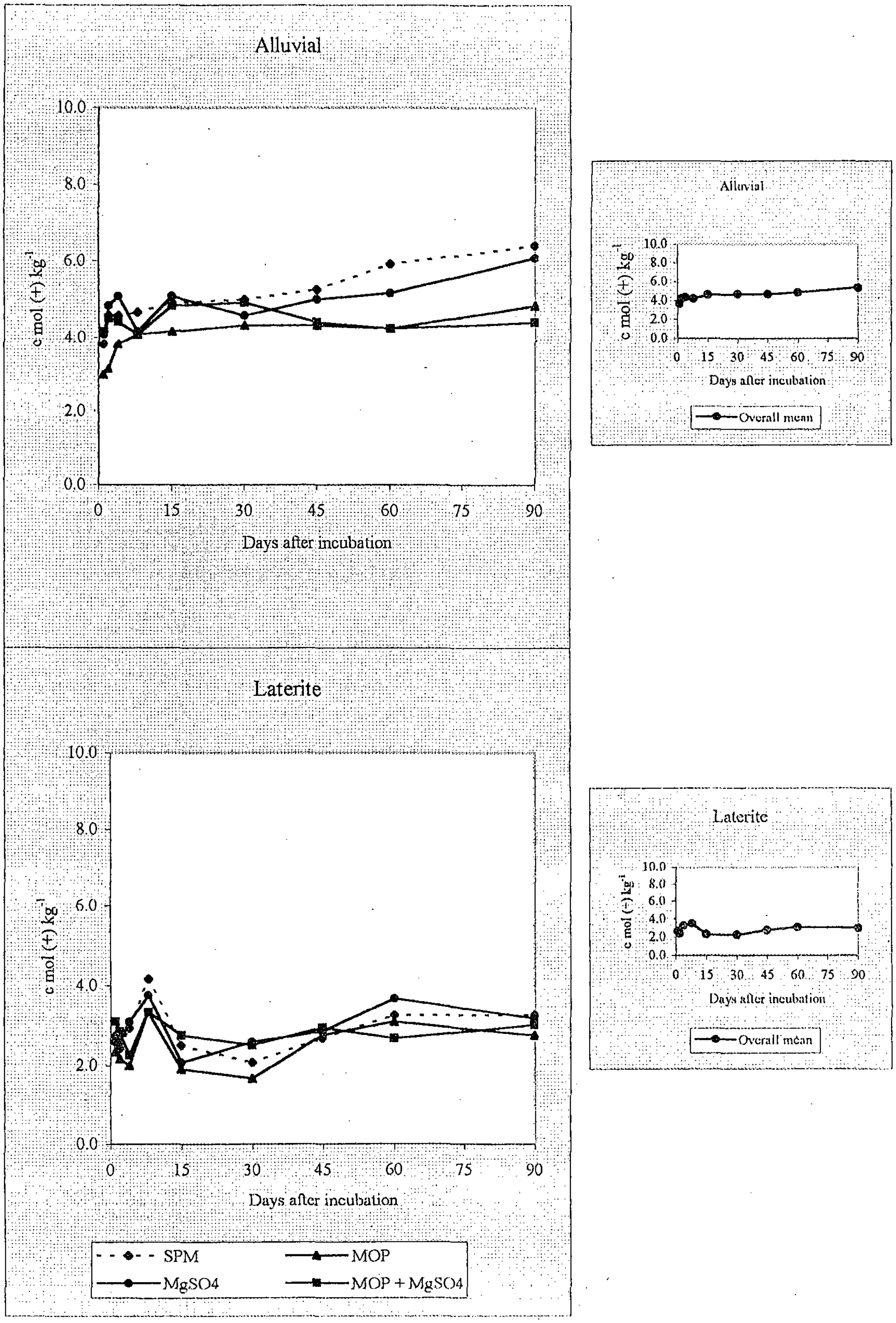


Fig. 7 Exchangeable Mg at different periods of incubation

treatments showed a slight decrease upto two days after incubation and then showed a steep increase at eight days followed by a decrease and increase in a fluctuating manner. When comparing the effect of different treatments on the availability of Mg during the incubation period it can be seen that the control receiving no Mg and the three muriate of potash treatments gave significantly low values as in the case of alluvial soil. The control showed a decrease during the first 15 days and then slightly increased and thereafter the exchangeable Mg remained stable till the end of incubation. The initial decrease may be due to the reduction in solubility of the soil Mg components due to the transformation of different forms of Mg. The further increase in availability is due to the gradual release from the soil. The pattern of release of Mg was almost similar for the treatments receiving Mg either as Sul-Po-Mag or as $MgSO_4$, with a peak value at eight days after incubation and a steep decrease at 15 days and then increasing and decreasing in a fluctuating manner till the end of incubation. But the Sul-Po-Mag treatments gave slightly higher values during the final stage of incubation. Generally, the exchangeable Mg was less for the absolute control and the treatments receiving muriate of potash alone. The presence of K along with Mg in Sul-Po-Mag and the K+Mg treatments did not affect significantly the exchangeable Mg values of soil. This could be because of the relatively high level of Mg, which balances the K in the fertilizers so that K does not affect the exchangeable Mg values in soil.

ii) Leachate magnesium (Table 16)

The leachate Mg showed a steep decrease during the initial stages and then showed an increase after eight days of incubation in both soils (Tables 16.1 and 16.2). The increase was in a more stable manner in laterite soil and fluctuated in alluvial soil (Fig. 8). Thus the attainment of equilibrium between the soil and solution after the addition of fertilizers was faster in laterite than in alluvial soil. The leachate Mg decreased till 30 days in laterite soil and then showed an increase. In alluvial soil, after the initial decree, the leachate Mg increased and decreased in a fluctuating manner till the end of incubation but values were generally lower when compared to the initial value. The magnitude of increase and decrease was more in alluvial than in laterite soil. After 30 days, the Mg in leachate from laterite soil again increased slightly till the end of incubation. Thus in general there was a gradual increase in leachate Mg till the end of incubation in both soils after the initial steep decline though in alluvial soil, during the later stages, an increase was noticed, the magnitude of which was higher than that of laterite soil. The reduction in leachate Mg during the initial period of incubation may be due to the decreased solubility of the fertilizers and the attainment of equilibrium between the applied fertilizers and the soil solution. Thereafter the solubility remained almost stable in laterite soil and increased slightly in alluvial soil and hence the corresponding change in leachate Mg.

When considering the different fertilizers, there was a steep decline in the leachate Mg for the treatments receiving magnesium sulphate and muriate of potash alone and in combination, but for the treatments receiving Sul-Po-Mag, the decline was gradual in laterite soil but in alluvial soil a steep decline was noticed for all the treatments.

Table 16.1 Leachate Mg at different periods of incubation in alluvial soil (%)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Content	0.0152^{CDE}	0.0035^{AB}	0.0048^{FG}	0.0030^{E}	0.0048^{EF}	0.0064^{CD}	0.0078^{DEFG}	0.0121^{ABC}	0.0100^{B}
L_1	0.0189^{BCD}	0.0034^{AB}	0.0096^{BC}	0.0058^{D}	0.0040^{F}	0.0051^{E}	0.0085^{DEF}	0.0069^{F}	0.0063^{DE}
L_2	0.0145^{CDE}	0.0045^{AB}	0.0077^{DE}	0.0066^{D}	0.0097^{A}	0.0052^{DE}	0.0105^{CD}	0.0109^{BCDE}	0.0055^{E}
L_3	0.0136^{DE}	0.0046^{AB}	0.0089^{CD}	0.0061^{B}	0.0089^{AB}	0.0068^{C}	0.0090^{DE}	0.0130^{A}	0.0114^{A}
K_1	0.0120^{E}	0.0057^{AB}	0.0080^{A}	0.0032^{E}	0.0068^{C}	0.0086^{D}	0.0071^{EFG}	0.0097^{DE}	0.0071^{CD}
K_2	0.0133^{DE}	0.0069^{AB}	0.0081^{DE}	0.0040^{E}	0.0065^{CD}	0.0049^{EF}	0.0055^{GH}	0.0092^{E}	0.0038^{G}
K_3	0.0287^{A}	0.0046^{AB}	0.0046^{FG}	0.0055^{D}	0.0078^{B}	0.0039^{F}	0.0057^{FGH}	0.0103^{CDE}	0.0039^{G}
Mg_1	0.0175^{BCDE}	0.0030^{B}	0.0071^{E}	0.0060^{D}	0.0082^{B}	0.0053^{DE}	0.0042^{H}	0.0113^{ABCD}	0.0025^{H}
Mg_2	0.0202^{BC}	0.0047^{AB}	0.0097^{BC}	0.0099^{AB}	0.0065^{CD}	0.0060^{CDE}	0.0082^{DEFG}	0.0109^{BCDE}	0.0041^{FG}
Mg_3	0.0200^{BC}	0.0046^{AB}	0.0098^{BC}	0.0100^{AB}	0.0048^{EF}	0.0105^{C}	0.0119^{C}	0.0123^{AB}	0.0053^{EF}
$K_1 + Mg_1$	0.0233^{B}	0.0056^{AB}	0.0034^{G}	0.0096^{BC}	0.0019^{CD}	0.0053^{DE}	0.0174^{B}	0.0110^{BCDE}	0.0080^{C}
$K_2 + Mg_2$	0.0228^{B}	0.0054^{AB}	0.0055^{F}	0.0086^{C}	0.0047^{EF}	0.0061^{CDE}	0.0177^{B}	0.0097^{DE}	0.0073^{CD}
$K_3 + Mg_3$	0.0230^{B}	0.0093^{A}	0.0106^{B}	0.0109^{A}	0.0055^{DE}	0.0101^{A}	0.0216^{A}	0.0058^{F}	0.0103^{AB}
Mean L	0.0156^{C}	0.0042^{A}	0.0087^{B}	0.0062^{C}	0.0075^{A}	0.0057^{B}	0.0093^{B}	0.0103^{B}	0.0077^{B}
K	0.0180^{BC}	0.0058^{A}	0.0069^{A}	0.0042^{D}	0.0070^{AB}	0.0058^{B}	0.0061^{C}	0.0098^{BC}	0.0049^{C}
Mg	0.0192^{B}	0.0041^{A}	0.0089^{B}	0.0086^{B}	0.0065^{B}	0.0073^{A}	0.0081^{B}	0.0115^{A}	0.0040^{D}
K + Mg	0.0230^{A}	0.0068^{A}	0.0065^{C}	0.0097^{A}	0.0040^{C}	0.0072^{A}	0.0189^{A}	0.0088^{C}	0.0085^{A}
Overall mean	0.0187	0.0051	0.0075	0.0069	0.0062	0.0065	0.0089	0.0102	0.0066

Table 16.2 Leachate Mg at different periods of incubation in laterite soil (%)

Treatments		Days after incubation							
	1	2	4	8	15	30	45	60	90
Control	0.0130^{CD}	0.0047^{CD}	0.0037^{E}	0.0040^{DEF}	0.0039^{GH}	0.0059^{CDE}	0.0087^{C}	0.0096^{A}	0.0112^{A}
L_1	0.0140^{BCD}	0.0122^{A}	0.0105^{B}	0.0034^{EFG}	0.0032^{H}	0.0049^{EF}	0.0091^{BC}	0.0057^{E}	0.0128^{A}
L_2	0.0130^{CD}	0.0102^{B}	0.0070^{C}	0.0040^{DEF}	0.0031^{H}	0.0053^{DEF}	0.0073^{DE}	0.0074^{BCD}	0.0123^{A}
L_3	0.0200^{ABC}	0.0097^{B}	0.0053^{CDE}	0.0039^{DEF}	0.0076^{A}	0.0070^{ABC}	0.0098^{BC}	0.0084^{AB}	0.0107^{AB}
K_1	0.0100^{D}	0.0096^{B}	0.0030^{E}	0.0042^{DEF}	0.0042^{FG}	0.0053^{DEF}	0.0093^{BC}	0.0066^{CDE}	0.0091^{BC}
K_2	0.0190^{BC}	0.0065^{C}	0.0049^{DE}	0.0025^{G}	0.0051^{E}	0.0047^{F}	0.0059^{F}	0.0061^{DE}	0.0059^{D}
K_3	0.0170^{BCD}	0.0054^{CD}	0.0065^{CD}	0.0047^{DE}	0.0055^{DE}	0.0073^{AB}	0.0061^{EF}	0.0072^{BCD}	0.0047^{D}
Mg_1	0.0170^{BCD}	0.0051^{CD}	0.0053^{CDE}	0.0064^{C}	0.0060^{CD}	0.0055^{DEF}	0.0058^{F}	0.0076^{BCD}	0.0080^{C}
Mg_2	0.0210^{AB}	0.0047^{CD}	0.0047^{CDE}	0.0080^{B}	0.0047^{EF}	0.0056^{DEF}	0.0075^{D}	0.0078^{BC}	0.0044^{D}
Mg_3	0.0200^{ABC}	0.0057^{CD}	0.0013^{A}	0.0109^{A}	0.0039^{GH}	0.0074^{A}	0.0073^{DE}	0.0080^{BC}	0.0054^{D}
$K_1 + Mg_1$	0.0170^{BCD}	0.0040^{D}	0.0045^{CDE}	0.0048^{D}	0.0034^{H}	0.0059^{CDEF}	0.0091^{BC}	0.0066^{CDE}	0.0045^{D}
$K_2 + Mg_2$	0.0120^{AB}	0.0086^{B}	0.0045^{CDE}	0.0032^{FG}	0.0067^{BC}	0.0053^{DEF}	0.0103^{B}	0.0069^{CDE}	0.0086^{C}
$K_3 + Mg_3$	0.0260^{A}	0.0097^{B}	0.0138^{A}	0.0023^{G}	0.0071^{AB}	0.0062^{BCD}	0.0123^{A}	0.0066^{CDE}	0.0092^{BC}
Mean L	0.0155^{B}	0.0107^{A}	0.0076^{A}	0.0037^{B}	0.0046^{B}	0.0058^{A}	0.0087^{B}	0.0071^{AB}	0.0119^{A}
K	0.0154^{B}	0.0071^{B}	0.0048^{B}	0.0038^{B}	0.0049^{B}	0.0057^{A}	0.0071^{C}	0.0067^{B}	0.0066^{BC}
Mg	0.0193^{AB}	0.0052^{C}	0.0077^{A}	0.0084^{A}	0.0049^{B}	0.0062^{A}	0.0069^{C}	0.0078^{A}	0.0059^{C}
K + Mg	0.0213^{A}	0.0074^{B}	0.0076^{A}	0.0034^{B}	0.0057^{A}	0.0052^{A}	0.0105^{A}	0.0067^{B}	0.0074^{B}
Overall mean	0.0175	0.0074	0.0067	0.0048	0.0049	0.0059	0.0083	0.0073	0.0082

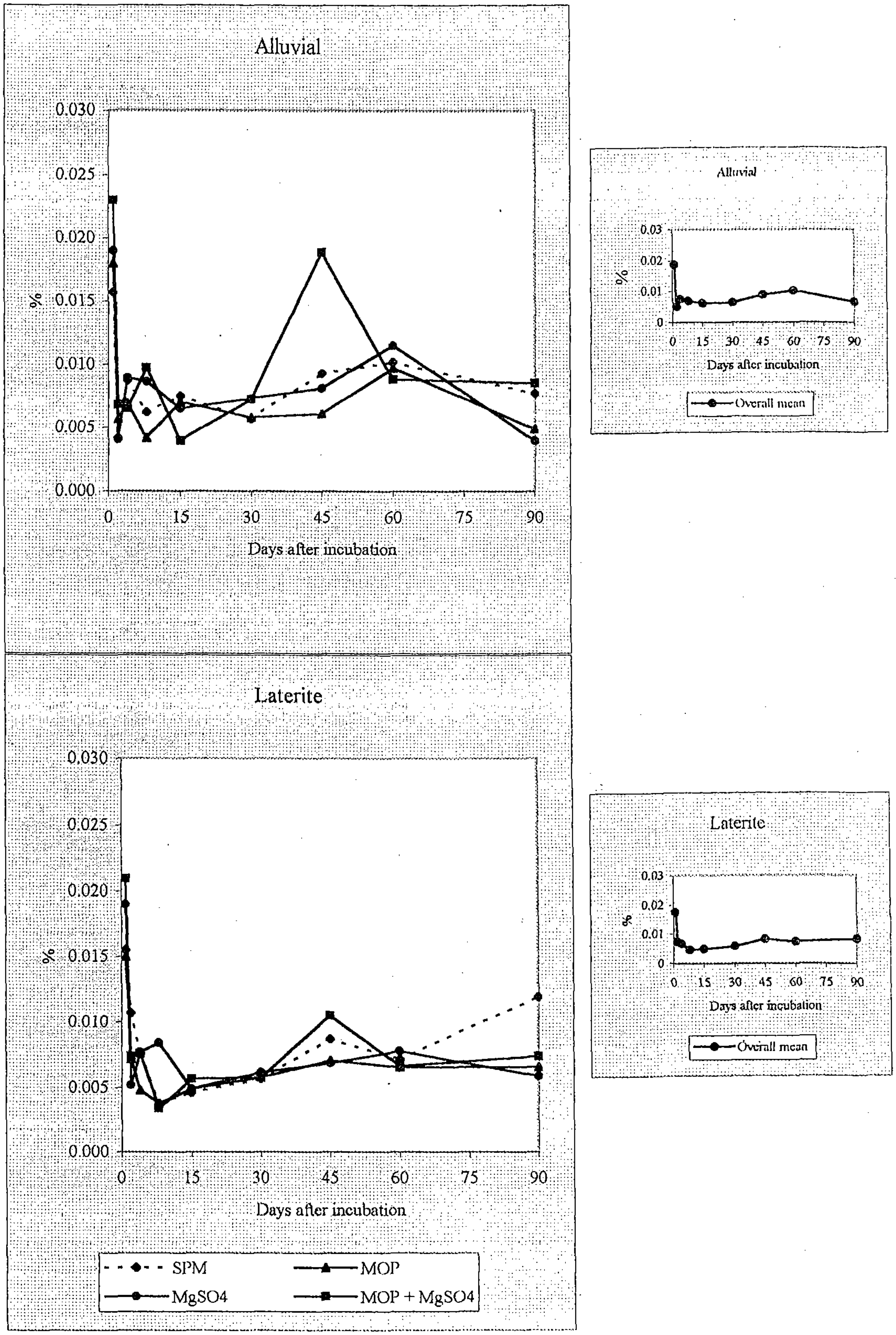


Fig. 8 Leachate Mg at different periods of incubation

Thus, the trend of changes for the different treatments was identical to the overall trend in both soils but in alluvial soil the treatments receiving muriate of potash and magnesium sulphate in combination showed a steep increase in leachate Mg at 45 days after incubation which was found to correspond to the decrease in exchangeable Mg at the same period. This may be because of the increased release of Mg to the soil in alluvial soil due to the transformation of different forms of Mg at that stage.

As the level of different Mg fertilizers increased there was a significant increase in the leachate Mg. In treatments receiving Sul-Po-Mag, this increase was not seen during the final stages of incubation. Leachate Mg was significantly higher for the treatments receiving muriate of potash + $MgSO_4$ than the Sul-Po-Mag treatments in both laterite and alluvial soils.

2.3 Sulphur

i) Available Sulphur (Table 17)

The alluvial and laterite soils did not vary much in their available S contents. Thus the transformations of S in the two soils was always almost similar throughout the period of incubation. Application of magnesium sulphate or Sul-Po-Mag resulted in an increase in the available S content of soil throughout the incubation period in both the soils (Tables 17.1 and 17.2). This is due to the increased availability of S in the soil from the applied sources (Rychilka, 1989).

The overall trend of changes in available S revealed that the change was in a fluctuating manner (Fig.9). In both soils the pattern of release of S was almost similar with an initial slight increase, and a subsequent steep decrease which occurred till four days after incubation in alluvial and eight days after incubation in laterite soil and again an increase in both soils in a fluctuating manner till the end of incubation. In alluvial soil the magnitude of increase in available S during the later stages was more than that of laterite soil. At the end of incubation, there was an increase in available S values in the alluvial soil but in laterite soil there was a slight decrease. While comparing the sources, in both alluvial and laterite soils, the treatments receiving Sul-Po-Mag and $MgSO_4$ registered significantly higher values for available S at all stages of incubation followed by the treatments receiving K, which gave comparatively lower values than the Sul-Po-Mag or $MgSO_4$ treatments. The increased available S values for the treatments receiving Sul-Po-Mag and $MgSO_4$ is due to the increased supply of S to the soil by these treatments and due to the positive correlation of available S with K and Mg (Ananthanarayana and Rao, 1979 and Krishnappa *et al.*, 1989).

The control treatment showed an increase in available S till 15 days after incubation after which the values of available S got stabilised but in laterite soil, though available S was generally low for the control when compared to the other treatments, the pattern of change was similar to the overall trend.

Increasing the level of application of either Sul-Po-Mag or Mg SO_4 alone or in combination with muriate of potash caused a significant increase in the available S values. This could be due to the increased release from the fertilizers.

For all treatments in the two soils there was an increase in available S upto two days after

Table 17.1 Available S at different periods of incubation in alluvial soil (kg ha^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	40.34^{G}	45.04^{E}	40.20^{CD}	56.88^{E}	79.42^{BC}	74.18^{C}	68.00^{BCD}	58.12^{G}	72.42^{EFG}
L_1	69.30^{D}	91.16^{AB}	44.00^{ABC}	83.30^{A}	64.33^{F}	77.48^{ABC}	59.82^{EF}	90.14^{A}	81.35^{C}
L_2	70.75^{CD}	93.57^{A}	46.56^{A}	59.24^{DE}	86.42^{A}	82.31^{A}	104.57^{A}	73.29^{EF}	90.29^{B}
L_3	72.92^{BCD}	55.44^{D}	48.41^{A}	69.68^{B}	70.21^{DE}	75.92^{BC}	100.46^{A}	83.34^{BC}	107.00^{A}
K_1	69.89^{D}	57.67^{D}	45.96^{AB}	69.48^{B}	69.57^{DEF}	64.13^{D}	59.77^{EF}	69.14^{F}	75.37^{DEF}
K_2	66.08^{DE}	56.78^{D}	43.50^{ABC}	62.19^{CDE}	68.78^{EF}	62.60^{D}	71.34^{BC}	28.40^{H}	77.81^{CDE}
K_3	58.01^{F}	59.26^{D}	36.54^{D}	68.68^{BC}	67.05^{EF}	73.93^{C}	63.85^{CDE}	87.75^{AB}	78.92^{CD}
Mg_1	77.85^{ABC}	63.55^{D}	40.90^{BCD}	66.49^{BC}	74.65^{CD}	66.30^{D}	61.48^{DE}	71.90^{EF}	70.03^{FG}
Mg_2	80.05^{AB}	64.52^{D}	46.86^{A}	65.22^{BCD}	68.07^{EF}	67.59^{D}	63.51^{DE}	75.81^{DE}	68.03^{G}
Mg_3	81.35^{A}	83.10^{B}	47.48^{A}	66.87^{BC}	80.82^{B}	79.99^{AB}	67.83^{BCD}	80.07^{CD}	73.76^{DEF}
K_1+ Mg_1	52.83^{F}	64.42^{CD}	41.31^{BCD}	22.56^{F}	67.77^{EF}	81.53^{A}	75.16^{B}	77.90^{CDE}	91.88^{D}
K_2+ Mg_2	56.80^{F}	73.04^{C}	23.71^{E}	55.86^{E}	68.03^{EF}	75.23^{BC}	53.90^{F}	77.36^{DE}	82.88^{C}
K_3+ Mg_3	60.05^{EF}	61.84^{D}	38.21^{D}	70.87^{B}	71.05^{DE}	75.71^{BC}	75.17^{B}	76.98^{DE}	82.68^{C}
Mean L	70.99^{A}	80.05^{A}	46.30^{A}	70.74^{A}	73.66^{A}	78.57^{A}	88.28^{A}	82.26^{A}	92.89^{A}
K	64.66^{AB}	57.90^{B}	42.00^{B}	66.78^{B}	68.47^{B}	66.89^{C}	64.99^{B}	61.80^{C}	77.37^{C}
Mg	79.75^{A}	70.39^{A}	45.08^{A}	66.19^{B}	74.51^{A}	71.29^{B}	64.27^{B}	75.92^{B}	70.64^{D}
K + Mg	56.56^{BC}	64.43^{AB}	34.41^{C}	49.76^{C}	68.95^{B}	77.51^{A}	68.07^{B}	77.41^{B}	85.81^{B}
Overall mean	65.86	66.87	41.82	62.87	72.01	73.61	71.20	73.10	80.97

Table 17.2 Available S at different periods of incubation in laterite soil (kg ha^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	44.57^{H}	68.27^{G}	36.61^{E}	19.34^{B}	33.74^{H}	48.80^{F}	61.83^{CD}	34.16^{F}	44.65^{H}
L_1	79.76^{ABC}	73.99^{F}	44.61^{BC}	18.99^{B}	66.73^{BC}	64.28^{CD}	58.77^{EF}	75.83^{ABCD}	73.59^{CDE}
L_2	82.56^{AB}	85.66^{ABC}	43.64^{CD}	19.13^{B}	61.97^{CDE}	64.95^{C}	73.91^{A}	67.84^{DE}	72.63^{DE}
L_3	83.25^{A}	80.53^{CDE}	45.03^{BC}	43.03^{A}	59.50^{DE}	88.30^{A}	69.76^{ABC}	80.26^{AB}	73.54^{CDE}
K_1	61.97^{FG}	91.24^{A}	39.03^{DE}	18.48^{B}	43.37^{G}	58.32^{DE}	64.87^{CDE}	71.00^{CD}	72.61^{DE}
K_2	62.61^{EFG}	81.51^{BCD}	40.03^{CDE}	6.01^{D}	48.87^{F}	57.86^{DE}	60.22^{DEF}	71.69^{CD}	86.82^{A}
K_3	58.35^{G}	42.99^{H}	41.92^{CD}	7.45^{D}	69.64^{B}	63.38^{CD}	66.51^{BCD}	29.86^{F}	61.55^{G}
Mg_1	72.06^{BCDEF}	79.26^{DEF}	13.22^{G}	18.97^{B}	57.26^{E}	56.00^{E}	75.89^{A}	71.46^{CD}	64.32^{FG}
Mg_2	68.15^{DEFG}	79.41^{DEF}	29.87^{F}	22.06^{D}	60.71^{DE}	64.92^{C}	55.17^{F}	72.93^{BCD}	68.18^{EFG}
Mg_3	72.80^{ABCDE}	86.98^{AB}	42.99^{CD}	12.65^{C}	60.22^{DE}	7.66^{B}	60.22^{DEF}	78.87^{ABC}	77.01^{CD}
K_1+ Mg_1	69.28^{CDEF}	75.21^{EFG}	54.62^{A}	15.81^{B}	81.52^{A}	68.04^{BC}	72.36^{AB}	29.55^{F}	79.77^{BC}
K_2+ Mg_2	76.12^{ABCD}	79.45^{DEF}	49.04^{B}	8.87^{D}	63.17^{DE}	64.05^{CD}	65.01^{CDE}	62.97^{EF}	83.91^{AB}
K_3+ Mg_3	82.19^{A}	68.03^{CDE}	45.25^{BC}	6.15^{D}	61.66^{DE}	64.18^{CD}	66.00^{CD}	82.81^{A}	68.88^{EF}
Mean L	81.86^{A}	80.06^{A}	44.43^{AB}	27.05^{A}	62.73^{AB}	72.51^{A}	67.40^{A}	74.64^{A}	73.25^{B}
K	60.98^{B}	71.91^{B}	40.33^{B}	10.65^{B}	53.96^{B}	59.85^{B}	63.86^{B}	57.52^{B}	73.66^{AB}
Mg	71.00^{AB}	81.88^{A}	28.69_{C}	17.90^{AB}	59.40^{AB}	64.19^{B}	63.76^{B}	74.42^{A}	69.84^{B}
K + Mg	75.86^{A}	74.23^{AB}	49.64^{A}	10.28^{B}	68.78^{A}	65.42^{B}	67.79^{A}	58.44^{B}	77.52^{A}
Overall mean	70.28	76.35	40.45	16.69	59.10	64.21	65.42	63.79	71.34

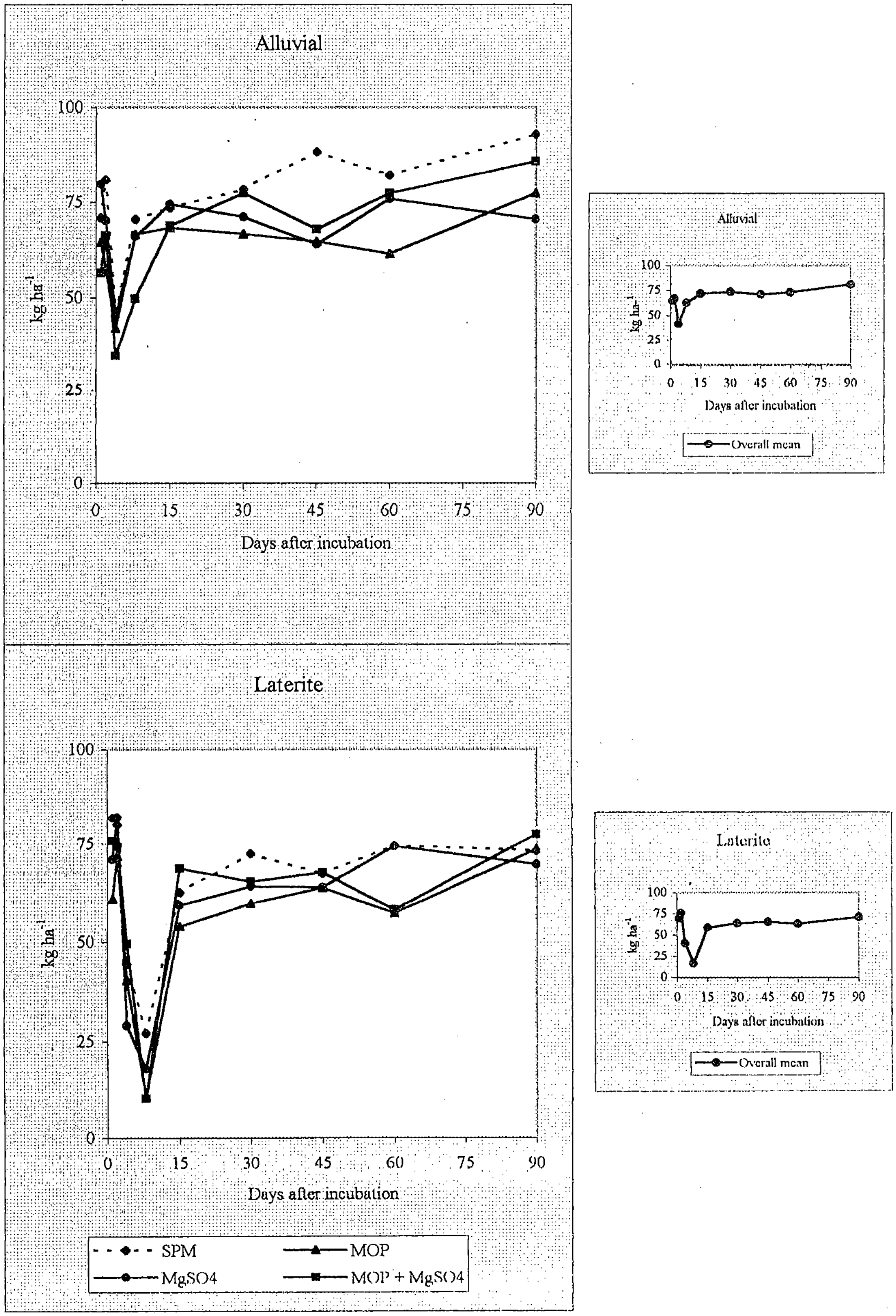


Fig. 9 Available S at different periods of incubation

incubation and then a steep decline at eight days after incubation; the available sulphur then increased at 15 days after incubation and thereafter attained an almost stable value. The decline in available S in the two soils is due to the effect caused by submergence by which the reduced sulphur must have reacted with heavy metals to give insoluble sulphides (Ponnamperuma, 1972) and also due to the release of SO_4^{2-} to the soil solution and a subsequent increase in the water soluble sulphate. A part of the sulphate must also have been strongly sorbed by clay and hydrous oxides of iron and aluminium. The further increase in available S from 15 days after incubation may be due to the subsequent oxidation to available forms by chemical or microbial means and the release of S from the soil and the applied fertilizers.

In both soils, the treatments receiving muriate of potash or MOP+$MgSO_4$ recorded significantly lower values for available S than the treatments receiving Sul-Po-Mag or $MgSO_4$ during the course of incubation. The low values for the treatment receiving muriate of potash alone are understandably due to the absence of SO_4 in the fertilizer. The comparative reduction in available S for the treatment receiving MOP +$MgSO_4$ might be due to the proportionately lower content of S when considering the amount of added fertilizers.

ii) Leachate sulphur (Table 18)

The overall trend of changes show that the leachate sulphur fluctuated throughout the incubation period in the two soils. The leachate S increased till four days after incubation in alluvial soil and then decreased to a stable value till 30 days after incubation. The leachate S again increased till 60 days after incubation and then decreased at the end of incubation. In laterite soil there was a steep decline in leachate sulphur at the start of incubation after which the values stabilized till 30 days after incubation. The leachate S then showed an increase till 60 days after incubation and then slightly decreased at the end of incubation (Tables 18.1 and 18.2). In both the laterite and alluvial soils there was an increase in leachate sulphur after 30 days after incubation which was sharper for the alluvial than the laterite soil. There was a decrease in leachate S at the end of incubation in both the soils (Fig.10)

Considering the mean of the values of different treatments, in laterite soil, the leachate sulphur of soils treated with muriate of potash alone (and control) were significantly less when compared to the treatments receiving magnesium sulphate and Sul-Po-Mag. With progress in the period of incubation, the sulphur present in leachate decreased in laterite soil till 30 days after incubation after which there was an increase. The decrease was steep during the initial stages and then gradual after which there was a steep increase till 60 days after incubation and again a decrease at the end of incubation. But in alluvial soil, there was an initial increase in leachate S till four days after incubation and then decreased at eight days after incubation to reach a minimum value at 30 days after incubation after an increase at 15 days after incubation for Sul-Po-Mag and MOP +$MgSO_4$ and a decrease for the treatments receiving Mg SO_4 and muriate of potash alone without Mg or K in combination. The leachate S then increased till 60 days and then decreased to a stable value at 90 days after incubation.

Table 18.1 Leachate S at different periods of incubation in alluvial soil (ppm)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	69.933^{C}	29.217^{F}	55.067^{G}	26.667^{E}	21.297^{G}	47.054^{CD}	111.597^{E}	154.200^{C}	112.187^{A}
L_1	80.057^{B}	41.540^{E}	34.073^{H}	43.893^{C}	48.267^{D}	60.467^{AB}	76.143^{FG}	40.323^{G}	61.703^{E}
L_2	56.000^{DE}	78.393^{B}	93.533^{C}	46.300^{C}	63.380^{C}	26.190^{GH}	144.693^{D}	91.167^{EF}	58.813^{E}
L_3	54.447^{DE}	79.560^{B}	125.433^{A}	42.130^{CD}	58.900^{C}	28.297^{GH}	145.763^{D}	190.267^{B}	76.050^{CD}
K_1	49.513^{E}	42.093^{E}	61.767^{FG}	27.067^{E}	38.140^{E}	21.887^{HI}	95.990^{EF}	92.103^{EF}	36.257^{G}
K_2	35.863^{F}	45.947^{DE}	77.833^{DE}	53.420^{B}	24.933^{FG}	25.700^{GHI}	94.470^{EF}	102.840^{E}	54.413^{EF}
K_3	23.690^{G}	44.547^{E}	58.670^{FG}	62.073^{A}	26.860^{FG}	39.057^{EF}	86.460^{F}	106.973^{DE}	45.243^{FG}
Mg_1	29.927^{FG}	55.690^{D}	69.300^{EF}	34.720^{D}	31.873^{EF}	17.600^{I}	64.223^{G}	111.187^{DE}	67.780^{DE}
Mg_2	38.013^{F}	67.327^{C}	87.500^{CD}	35.260^{D}	34.737^{E}	32.153^{FG}	157.960^{CD}	183.713^{B}	55.780^{EF}
Mg_3	60.373^{D}	116.380^{A}	90.150^{C}	65.213^{A}	62.906^{C}	62.280^{A}	171.773^{C}	242.557^{A}	61.227^{E}
K_1+ Mg_1	61.633^{D}	79.970^{B}	77.963^{DE}	42.277^{CD}	91.483^{A}	22.780^{HI}	204.277^{B}	128.220^{D}	82.260^{BC}
K_2+ Mg_2	60.707^{D}	78.933^{B}	109.900^{B}	41.720^{CD}	78.033^{D}	44.260^{DE}	221.090^{B}	77.490^{F}	93.383^{B}
K_3+ Mg_3	110.230^{A}	111.443^{A}	105.920^{B}	46.150^{BC}	47.913^{D}	53.553^{BC}	259.640^{A}	90.653^{EF}	106.567^{A}
Mean L	63.50^{B}	66.50^{C}	84.35^{B}	44.11^{A}	56.85^{B}	38.32^{A}	122.20^{B}	107.30^{B}	65.52^{B}
K	36.36^{D}	44.20^{D}	66.09^{C}	47.52^{A}	29.98^{D}	28.88^{B}	92.31^{C}	100.60^{B}	45.30^{C}
Mg	42.77^{C}	79.80^{B}	82.32^{B}	45.10^{A}	43.17^{C}	37.34^{A}	131.30^{B}	179.20^{A}	61.60^{B}
K + Mg	77.52^{A}	90.12^{A}	97.93^{A}	43.42^{A}	72.48^{A}	40.20^{A}	228.30^{A}	98.79^{B}	94.07^{A}
Overall mean	56.18	67.01	80.55	43.62	48.36	37.02	141.07	124.00	70.13

Table 18.2 Leachate S at different periods of incubation in laterite soil (ppm)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	133.700^{E}	59.057^{E}	51.653^{F}	39.773^{CD}	36.500^{D}	26.507^{CDE}	67.333^{DEF}	67.867^{G}	128.100^{A}
L_1	171.357^{D}	87.953^{D}	63.473^{DEF}	36.867^{DE}	44.283^{BC}	21.447^{DE}	80.650^{CD}	92.327^{EF}	120.920^{A}
L_2	201.233^{C}	91.753^{D}	59.850^{EF}	45.133^{BC}	45.447^{BC}	29.573^{CD}	70.213^{DE}	108.773^{DE}	93.067^{C}
L_3	214.560^{C}	98.233^{C}	73.613^{CD}	47.107^{AB}	74.467^{A}	29.447^{CD}	94.073^{BC}	180.540^{AB}	57.307^{EF}
K_1	100.923^{F}	46.940^{F}	68.993^{CDE}	29.283^{FG}	45.050^{BC}	19.637^{E}	62.537^{DEF}	92.490^{EF}	66.187^{DEF}
K_2	102.230^{F}	51.160^{F}	69.987^{CDE}	28.613^{FG}	48.380^{B}	22.517^{DE}	56.007^{EF}	84.680^{FG}	73.680^{D}
K_3	97.797^{F}	47.560^{F}	78.230^{C}	31.710^{EF}	43.743^{BC}	33.887^{BC}	49.057^{F}	81.813^{FG}	65.650^{DEF}
Mg_1	171.167^{D}	90.660^{D}	91.790^{B}	25.127^{G}	41.003^{CD}	45.417^{A}	69.853^{DE}	169.407^{B}	68.463^{DE}
Mg_2	295.300_{A}	91.573^{D}	90.580^{B}	37.347^{DE}	41.603^{CD}	24.703^{CDE}	104.560^{B}	160.937^{B}	68.397^{DE}
Mg_3	257.513^{B}	102.267^{BC}	117.687^{A}	50.930^{A}	44.373^{BC}	28.790^{CDE}	108.077^{B}	191.620^{A}	61.007^{EF}
K_1+ Mg_1	172.223^{D}	59.650^{E}	62.667^{DEF}	28.583^{FG}	43.370^{BC}	29.887^{CD}	103.807^{B}	117.733^{CD}	55.747^{F}
K_2+ Mg_2	203.073^{C}	106.640^{B}	60.800^{DEF}	29.197^{FG}	46.037^{BC}	27.453^{CDE}	106.273^{B}	121.333^{CD}	74.643^{D}
K_3+ Mg_3	304.300^{A}	142.363^{A}	51.373^{F}	32.550^{EF}	76.227^{A}	39.790^{AB}	160.693^{A}	130.017^{C}	107.253^{D}
Mean L	195.70^{C}	92.65^{B}	65.65^{B}	43.04^{A}	54.73^{A}	26.82^{B}	81.65^{C}	127.20^{B}	90.43^{A}
K	100.30^{D}	48.55^{C}	71.74^{B}	29.87^{C}	45.72^{B}	25.35^{B}	55.87^{D}	86.33^{C}	68.51^{B}
Mg	241.30^{A}	94.83^{B}	100.00^{A}	37.80^{B}	42.33^{C}	32.97^{A}	94.16^{B}	174.00^{A}	65.96^{B}
K + Mg	226.50^{B}	102.90^{A}	58.28^{C}	30.11^{C}	55.21^{A}	32.38^{A}	123.60^{A}	123.00^{C}	79.21^{AB}
Overall mean	186.55	82.76	72.20	35.56	48.50	29.16	87.17	123.04	80.03

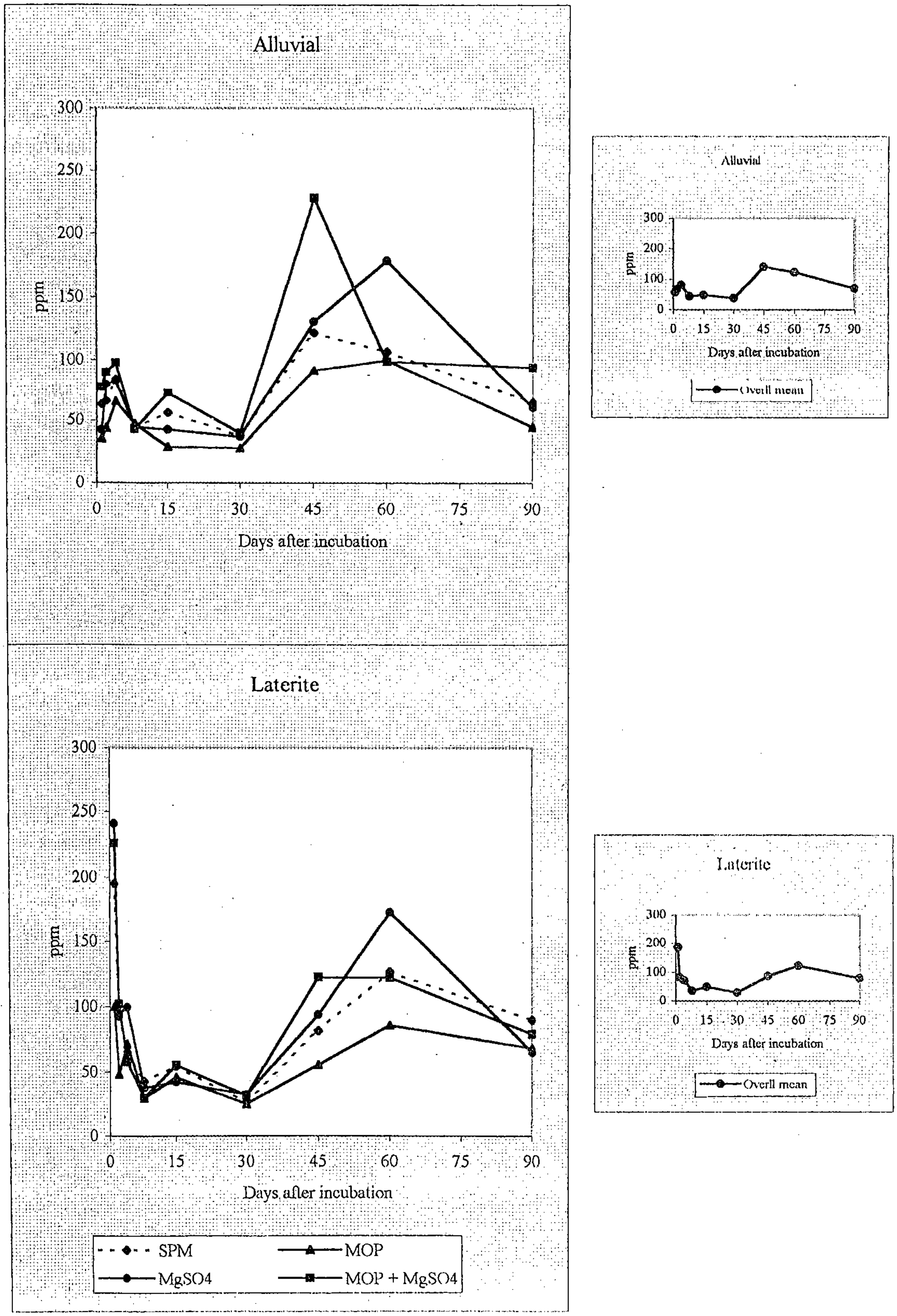


Fig. 10 Leachate S at different periods of incubation

As the level of S application as Sul-Po-Mag or Mg SO_4 increased, there was an increase in the leachate S in laterite soil. The difference among the levels narrowed down with progress in the period of incubation except for the treatments receiving MOP +Mg SO_4, whereas the level of fertilizer application increased, an increase in leachate sulphur occurred till the end of incubation. This decrease in the magnitude of difference is because of the increased release of S from the fertilizers at higher levels than the lower level during the initial stages of incubation, so that the release of S from the treatments at higher levels was at a faster rate than from the treatments at lower levels.

2.4 Nitrogen

i. Available Nitrogen (Table 19)

In the control treatment the available N was found to decrease during the first four to eight days in the two soils and then showed an almost stable value till the end of incubation. The initial decrease in available N could be due to the effect of submergence by which denitrification results in the loss of some part of nitrogen (Ponnamperuma, 1972). Application of K and Mg fertilizers as Sul-Po-Mag, muriate of potash or Mg SO_4 resulted in a significant increase in the available N of both soils when compared to control especially for the treatments receiving Mg (Tables 19.1 and 19.2). But there was no significant difference among the fertilizer treatments in the available N content at any stage of incubation. During the course of incubation, the available N remained almost stable till 30 days after incubation after which an increase was seen for all the treatments. The two soils behaved similarly in the available N content of samples throughout the period of incubation.

The treatments receiving K and Mg either as Sul-Po-Mag or as MOP +Mg SO_4 were found to give higher values for available N than the treatments receiving Mg alone though there was no significance. The least available N values were shown by the treatment receiving K alone as muriate of potash in the alluvial soil. The laterite soil also showed the same pattern of changes but there was a decrease in available N at two days after incubation for the fertilizer treated samples. This decrease may be due to the loss of nitrate through the leachate water. There was a further increase in available N again till eight days after incubation and thereafter the available N showed a gradual decrease till 45 days and then showed a slight increase.

ii) Leachate nitrogen (Table 20)

The overall trend of changes show that the nitrogen content in leachate was generally higher during the initial stages in both soils and decreased gradually till 45 days after incubation in laterite soil after which there was a slight increase (Tables 20.1 and 20.2). In alluvial soil, increasing the level of K or K and Mg generally increased the N in leachate but as the level of Mg application increased there was a decrease in leachate N. In laterite soil, higher levels of fertilizer application was found to decrease the leachate N content. But the trend of changes in leachate N was similar in both alluvial and laterite soils.

2.5 Phosphorus

i) Available P (Table 21)

The available P was found to increase progressively during the initial stages of incubation soils and then showed a decrease. This pattern of change was similar in both soils

Table 19.1 Available N at different periods of incubation in alluvial soil (kg ha^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	357.60^{AB}	349.20^{AB}	352.30^{AB}	340.90^{A}	330.40^{B}	333.60^{B}	341.90^{C}	351.30^{B}	334.60^{B}
L_1	351.30^{AB}	354.50^{AB}	354.50^{AB}	358.70^{A}	345.10^{AB}	356.60^{A}	357.60^{ABC}	369.10^{AB}	364.90^{A}
L_2	337.70^{B}	351.30^{AB}	358.70^{A}	362.80^{A}	354.40^{A}	354.50^{AB}	370.10^{AB}	369.10^{AB}	378.50^{A}
L_3	363.90^{A}	354.50^{AB}	357.60^{A}	362.80^{A}	357.60^{A}	356.60^{A}	366.00^{AB}	373.30^{AB}	377.50^{A}
K_1	345.10^{AB}	346.10^{AB}	352.40^{AB}	357.60^{A}	348.20^{A}	353.40^{AB}	363.90^{AB}	330.40^{C}	362.80^{A}
K_2	351.30^{AB}	338.80^{B}	353.40^{AB}	356.60^{A}	346.10^{AB}	356.60^{A}	358.70^{ABC}	364.90^{AB}	376.40^{A}
K_3	351.30^{AB}	351.30^{AB}	333.60^{B}	349.20^{A}	344.00^{AB}	367.00^{A}	361.80^{ABC}	366.00^{AB}	370.10^{A}
Mg_1	360.70^{A}	348.20^{AB}	348.20^{AB}	353.40^{A}	354.50^{A}	349.20^{AB}	354.50^{ABC}	355.50^{AB}	366.00^{A}
Mg_2	353.40^{AB}	364.90^{AB}	353.40^{AB}	355.50^{A}	355.50^{A}	357.60^{A}	366.00^{AB}	375.40^{AB}	372.20^{A}
Mg_3	357.60^{AB}	369.10^{A}	360.70^{A}	353.40^{A}	358.70^{A}	360.70^{A}	375.40^{A}	371.20^{AB}	377.50^{A}
K_1+Mg_1	353.40^{AB}	363.90^{AB}	359.70^{A}	355.50^{A}	355.50^{A}	352.40^{AB}	353.40^{BC}	364.90^{AB}	369.10^{A}
K_2+Mg_2	358.70^{AB}	368.00^{A}	362.80^{A}	357.60^{A}	358.70^{A}	358.70^{A}	364.90^{AB}	370.10^{A}	377.50^{A}
K_3+Mg_3	364.90^{A}	370.10^{A}	359.70^{A}	355.50^{A}	358.70^{A}	366.00^{A}	372.20^{AB}	370.10^{A}	372.20^{A}
Mean L	350.96^{A}	353.40^{AB}	356.90^{A}	361.10^{A}	352.50^{AB}	355.60^{A}	364.90^{A}	370.80^{A}	373.70^{A}
K	349.20^{A}	345.40^{B}	346.46^{B}	354.40^{A}	346.30^{B}	359.01^{A}	360.90^{A}	353.90^{B}	369.90^{A}
Mg	357.20^{A}	360.70^{AB}	354.10^{A}	354.30^{A}	356.00^{A}	355.60^{A}	365.20^{A}	367.50^{A}	371.60^{A}
K + Mg	359.00^{A}	367.30^{A}	360.70^{A}	356.20^{A}	357.20^{A}	359.20^{A}	363.60^{A}	371.10^{A}	373.00^{A}
Overall mean	354.10	356.12	354.34	355.25	357.26	355.47	361.90	364.75	369.22

Table 19.2 Available N at different periods of incubation in laterite soil (kg ha^{-1})

Treatment	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	360.73^{AB}	349.20^{ABC}	337.70^{B}	340.90^{B}	333.60^{B}	334.60^{B}	344.00^{C}	333.60^{E}	340.90^{D}
L_1	348.20^{B}	353.40^{ABC}	357.60^{AB}	360.70^{AB}	352.40^{AB}	340.90^{AB}	353.40^{ABC}	343.00^{DE}	348.20^{CD}
L_2	366.00^{AB}	344.00^{BC}	367.00^{A}	361.80^{AB}	357.60^{A}	352.40^{AB}	358.70^{ABC}	358.70^{BCD}	352.40^{CD}
L_3	369.10^{AB}	362.80^{AB}	368.10^{A}	369.10^{A}	357.60^{A}	353.40^{AB}	353.40^{ABC}	359.70^{ABCD}	354.50^{BCD}
K_1	364.90^{AB}	346.10^{BC}	363.90^{AB}	364.90^{AB}	352.40^{AB}	349.20^{AB}	347.20^{BC}	350.30^{CDE}	369.10^{ABC}
K_2	361.80^{AB}	333.60^{C}	364.90^{AB}	364.90^{AB}	349.20^{AB}	351.30^{AB}	363.90^{ABC}	352.40^{CD}	376.40^{AB}
K_3	368.10^{AB}	355.50^{AB}	366.00^{A}	369.10^{A}	353.40^{AB}	353.40^{AB}	363.90^{ABC}	367.00^{ABC}	369.10^{ABC}
Mg_1	367.00^{AB}	358.70^{AB}	369.10^{A}	369.10^{A}	354.50^{A}	353.40^{AB}	353.40^{ABC}	356.60^{CD}	363.90^{ABC}
Mg_2	372.20^{A}	358.70^{AB}	377.50^{A}	371.20^{A}	357.60^{A}	358.70^{A}	353.40^{ABC}	368.10^{ABC}	377.50^{A}
Mg_3	372.20^{A}	363.90^{AB}	377.50^{A}	372.20^{A}	357.60^{A}	355.50^{AB}	358.70^{ABC}	378.50^{A}	382.70^{A}
K_1+ Mg_1	369.00^{AB}	353.40^{ABC}	358.70^{AB}	364.90^{AB}	355.50^{A}	345.10^{AB}	359.70^{ABC}	358.70^{BCD}	354.50^{CD}
K_2+ Mg_2	367.00^{AB}	354.50^{ABC}	354.50^{AB}	366.00^{A}	359.70^{A}	350.30^{AB}	371.20^{A}	377.50^{A}	363.90^{ABC}
K_3+ Mg_3	375.40^{A}	369.10^{A}	360.70^{AB}	371.20^{A}	357.60^{A}	354.50^{AB}	364.90^{ABC}	369.10^{ABC}	378.50^{A}
Mean L	361.06^{A}	353.40^{A}	364.20^{AB}	363.80^{A}	355.40^{A}	348.80^{A}	355.00^{A}	353.90^{B}	351.60^{B}
K	364.90^{A}	345.06^{B}	364.90^{AB}	366.00^{A}	351.50^{A}	351.40^{A}	358.40^{A}	356.90^{B}	371.70^{A}
Mg	370.50^{A}	360.40^{A}	374.70^{A}	371.20^{A}	356.50^{A}	355.70^{A}	355.00^{A}	367.90^{A}	374.20^{A}
K + Mg	375.50^{A}	359.00^{A}	357.90^{B}	361.30^{A}	357.20^{A}	350.10^{A}	363.20^{A}	368.20^{A}	365.40^{A}
Overall mean	366.26	354.05	363.36	363.68	353.51	350.15	357.28	359.58	363.76

Table 20.1 Leachate N at different periods of incubation in alluvial soil (ppm)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	52.000^{AB}	48.667^{A}	44.667^{A}	41.000^{AB}	33.333^{A}	31.000^{A}	30.000^{A}	42.667^{A}	40.000^{AB}
L_1	56.000^{A}	51.000^{A}	47.333^{A}	42.667^{A}	35.667^{A}	31.000^{A}	30.000^{A}	42.000^{A}	41.000^{AB}
L_2	53.333^{AB}	50.667^{A}	45.333^{A}	39.333^{ABCD}	31.667^{A}	28.000^{A}	27.000^{A}	41.000^{A}	37.667^{B}
L_3	49.000^{BCD}	51.333^{A}	44.667^{A}	39.667^{ABC}	34.000^{A}	29.667^{A}	30.667^{A}	43.000^{A}	42.667^{A}
K_1	48.667^{BCD}	49.667^{A}	46.667^{A}	43.000^{A}	32.000^{A}	27.000^{A}	28.000^{A}	40.000^{A}	40.667^{AB}
K_2	54.333^{AB}	49.667^{A}	46.000^{A}	36.333^{BCDE}	31.667^{A}	26.000^{A}	28.667^{A}	42.667^{A}	42.333^{A}
K_3	45.333^{CDE}	47.333^{AB}	43.667^{A}	38.333^{ABCD}	32.333^{A}	28.667^{A}	30.000^{A}	43.333^{A}	41.000^{AB}
Mg_1	48.667^{BCD}	47.000^{AB}	43.667^{A}	34.333^{CDE}	30.667^{A}	29.000^{A}	26.333^{A}	40.333^{A}	39.000^{AB}
Mg_2	52.667^{AB}	50.000^{A}	45.000^{A}	40.000^{AB}	32.000^{A}	30.333^{A}	28.667^{A}	40.333^{A}	40.667^{AB}
Mg_3	43.000^{DE}	45.333^{AB}	42.667^{A}	37.000^{BCDE}	31.000^{A}	27.000^{A}	26.667^{A}	41.000^{A}	38.667^{AB}
K_1+Mg_1	40.667^{E}	41.667^{B}	41.000^{A}	32.667^{E}	31.333^{A}	27.333^{A}	29.333^{A}	42.000^{A}	41.000^{AB}
K_2+Mg_2	50.667^{ABC}	45.333^{AB}	44.000^{A}	34.000^{DE}	30.333^{A}	28.000^{A}	30.333^{A}	43.667^{A}	42.667^{A}
K_3+Mg_3	52.667^{AB}	49.333^{A}	47.333^{A}	39.000^{ABCD}	33.667^{A}	29.000^{A}	30.333^{A}	43.000^{A}	41.330^{AB}
Mean L	52.78^{A}	51.00^{A}	45.78^{A}	40.56^{A}	33.78^{A}	29.56^{A}	29.22^{AB}	42.00^{A}	40.44^{A}
K	49.44^{B}	48.89^{AB}	45.44^{A}	39.22^{AB}	32.00^{A}	27.22^{A}	28.89^{AB}	42.00^{A}	41.33^{A}
Mg	48.11^{B}	47.44^{AB}	43.78^{A}	37.11^{BC}	31.22^{A}	28.78^{A}	27.22^{B}	40.56^{A}	39.44^{A}
K + Mg	48.00^{B}	45.44^{B}	44.00^{A}	35.22^{C}	31.78^{A}	28.11^{A}	30.00^{A}	42.89^{A}	41.67^{A}
Overall mean	49.77	48.97	44.74	38.26	32.82	28.62	28.92	41.92	40.66

Table 20.2 Leachate N at different periods of incubation in laterite soil (ppm)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	52.667^{BC}	49.667^{ABC}	50.000^{AB}	44.000^{AB}	34.333^{A}	30.000^{A}	33.000^{A}	38.667^{A}	37.333^{C}
L_1	57.000^{ABC}	53.00^{AB}	50.667^{AB}	46.333^{A}	35.667^{A}	32.000^{A}	31.667^{AB}	41.333^{A}	39.667^{ABC}
L_2	56.333^{ABC}	52.333^{AB}	49.333^{AB}	43.000^{AB}	34.000^{A}	29.667^{A}	32.667^{A}	42.667^{A}	42.000^{AB}
L_3	50.667^{CD}	48.333^{BC}	45.667^{B}	41.333^{AB}	32.333^{A}	28.000^{A}	29.000^{AB}	39.667^{A}	37.667^{BC}
K_1	55.333^{ABC}	50.000^{ABC}	46.667^{B}	44.667^{AB}	33.000^{A}	30.000^{A}	30.667^{AB}	42.333^{A}	39.333^{ABC}
K_2	51.667^{BCD}	51.333^{ABC}	50.000^{AB}	43.000^{AB}	32.000^{A}	29.333^{A}	28.500^{AB}	40.667^{A}	40.667^{ABC}
K_3	45.667^{D}	45.000^{C}	46.667^{B}	40.000^{D}	33.000^{A}	30.667^{A}	31.933^{AB}	44.000^{A}	43.000^{A}
Mg_1	58.667^{AB}	54.333^{AB}	50.000^{AB}	45.333^{AB}	36.333^{A}	30.000^{A}	30.667^{AB}	42.667^{A}	41.667^{ABC}
Mg_2	0.867^{A}	56.667^{A}	54.000^{A}	43.333^{AB}	33.333^{A}	30.667^{A}	32.667^{A}	43.667^{A}	42.000^{AB}
Mg_3	57.867^{ABC}	55.000^{AB}	51.667^{AB}	43.000^{AB}	31.667^{A}	28.667^{A}	29.667^{AB}	40.000^{A}	41.333^{ABC}
K_1+Mg_1	3.900^{ABC}	52.000^{AB}	49.000^{AB}	41.333^{AB}	33.000^{A}	29.000^{A}	27.500^{B}	42.667^{A}	40.000^{ABC}
K_2+Mg_2	58.333^{AB}	53.667^{AB}	54.000^{A}	46.333^{A}	35.667^{A}	32.000^{A}	30.000^{AB}	41.667^{A}	39.667^{ABC}
K_3+Mg_3	52.333^{BCD}	50.667^{ABC}	48.667^{AB}	41.000^{AB}	33.333^{A}	31.333^{A}	30.667^{AB}	41.333^{A}	41.000^{ABC}
Mean L	54.67^{B}	51.22^{B}	48.56^{AB}	43.56^{A}	34.00^{A}	29.89^{A}	31.11^{A}	41.22^{A}	39.78^{A}
K	50.89^{C}	48.78^{B}	47.78^{B}	42.56^{A}	32.67^{A}	30.00^{A}	30.37^{A}	42.33^{A}	41.00^{A}
Mg	59.13^{A}	55.33^{A}	51.89^{A}	43.89^{A}	33.78^{A}	29.78^{A}	31.00^{A}	42.11^{A}	41.67^{A}
K + Mg	54.86^{B}	52.11^{AB}	50.56^{B}	42.89^{A}	34.00^{A}	30.78^{A}	29.59^{A}	41.89^{A}	40.22^{A}
Overall mean	54.72	51.69	49.72	43.28	33.67	30.10	30.71	41.64	40.41

(Tables 21.1 and 21.2) but in laterite soil, the peak value of available P was attained later (30 days after incubation) than in alluvial soil (15 days after incubation). The increase in P is due to the release of phosphate from iron and aluminium phosphates with increase in soil pH due to submergence (Ponnamperma, 1972). This results in an increase in the concentration of water-soluble and available P. The decrease in available P during the later stages may be due to the resorption of phosphate ions by the soil components.

Application of different fertilizers did not result in much deviation from the original pattern of P release and sorption in both the soils. The different fertilizers also did not affect significantly the amount of available P though it was seen that the treatments receiving K and Mg as KCl and Mg SO_4 gave comparatively lower values than Sul-Po-Mag after the initial stages of incubation. But it was seen that increasing the level of fertilizer application either as Sul-Po-Mag or muriate of potash or Mg SO_4 resulted in significant increase in the available P especially during 30-45 days after incubation when the P availability was maximum in laterite soil and from 15-30 days after incubation in alluvial soil. It was seen that the available P values of laterite soil were much higher than the alluvial soil.

ii) Leachate P (Table 22)

The P contained in the leachate of alluvial soil was only in traces when compared to that of the laterite soil. A slight increase was observed in the leachate P after 15 days after incubation in the laterite soil. This is because of the increase in water soluble P during these stages. The increase in solubility of P in laterite soil is associated with the hydrolysis of Fe(III) and Al phosphates, release of P held by anion exchange sites on clay and hydrous oxides of Fe(III) and Al and the reduction of Fe (III) to Fe (II) with the liberation of sorbed and chemically bonded P (Ponnamperuma, 1972). The further decrease in leachate P is because of the resorption of the released P by clay and hydrous oxides of Al or due to reprecipitation of the solubilised P. It was seen that the P in leachate of laterite soil was significantly low for the treatments receiving Mg when compared to the muriate of potash treatments.

2.6 Calcium

i) Exchangeable Ca (Table 23)

The values of exchangeable Ca remained almost stable till four days after incubation and then showed an increase at eight days after incubation to decrease gradually till the end of the incubation period in both soils (Tables 23.1 and 23.2). In laterite soil, a decrease in Ca content was observed at eight days after incubation which again increased till 30 days after incubation and then showed a decrease. The reduction in Ca content may be due to the fixation of the native Ca present in the soil and due to the occupation of the exchange sites by Mg and increase in the exchangeable Mg content during that period. When the exchangeable Mg content decreased, the corresponding increase was observed in the Ca content of the soil. The exchangeable Ca was slightly higher in the alluvial soil when compared to the laterite soil. In alluvial soil the exchangeable Ca fluctuated and came to a high value at eight days after incubation and then remained stable till 30 days after incubation. The exchangeable Ca again showed a decrease till the end of incubation.

Table 21.1 Available P at different periods of incubation in alluvial soil (kg ha^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	11.433^{AB}	10.333^{CD}	11.067^{C}	16.300^{D}	19.567^{DE}	10.510^{DE}	11.367^{BCDE}	9.63^{CD}	9.800^{BC}
L_1	10.400^{BC}	11.433^{BC}	11.433^{BC}	17.470^{CD}	18.033^{EF}	11.733^{CD}	10.867^{DE}	10.47^{BC}	12.533^{A}
L_2	9.773^{C}	12.100^{ABC}	11.733^{BC}	21.733^{A}	23.773^{AB}	12.867^{ABC}	10.933^{DE}	10.33^{BC}	12.467^{A}
L_3	11.367^{AB}	10.633^{CD}	12.700^{ABC}	22.367^{A}	24.233^{A}	13.300^{ABC}	11.567^{BCDE}	11.33^{AB}	9.767^{BC}
K_1	11.567^{AB}	12.033^{ABC}	12.900^{ABC}	18.767^{BC}	16.633^{F}	12.700^{ABC}	12.200^{ABCD}	9.83^{BC}	11.333^{AB}
K_2	10.167^{BC}	9.167^{D}	13.567^{AB}	18.200^{C}	24.367^{A}	12.100^{CD}	12.567^{ABCD}	9.30^{CD}	11.033^{ABC}
K_3	12.400^{A}	14.000^{A}	13.733^{AB}	19.800^{B}	21.900^{BC}	13.133^{ABC}	11.200^{CDE}	9.20^{CD}	10.967^{ABC}
Mg_1	9.333^{C}	11.467^{BC}	11.533^{BC}	14.200^{E}	22.423^{ABC}	13.200^{ABC}	13.067^{AB}	12.23^{A}	9.433^{C}
Mg_2	10.167^{BC}	13.433^{AB}	13.667^{AB}	13.700^{EF}	18.800^{DEF}	12.833^{ABC}	12.733^{ABC}	9.97^{BC}	5.433^{D}
Mg_3	9.267^{C}	13.467^{AB}	14.967^{A}	17.400^{CD}	19.000^{DE}	12.500^{BC}	10.200^{E}	9.30^{CD}	5.700^{D}
K_1+ Mg_1	11.333^{AB}	12.000^{ABC}	11.633^{BC}	14.667^{E}	18.100^{EF}	13.670^{ABC}	11.300^{CDE}	9.90^{BC}	6.733^{D}
K_2+ Mg_2	9.700^{C}	11.267^{C}	12.333^{BC}	12.433^{F}	21.000^{CD}	14.167^{AB}	13.367^{A}	11.63^{AB}	5.833^{D}
K_3+ Mg_3	12.167^{A}	10.567^{CD}	10.967^{C}	13.333^{EF}	19.300^{DE}	14.600^{A}	12.867^{ABC}	8.03^{B}	6.100^{D}
Mean L	11.38^{A}	11.73^{AB}	11.96^{B}	20.52^{A}	22.00^{A}	12.63^{B}	11.12^{B}	10.60^{A}	11.59^{A}
K	9.59^{C}	12.79^{A}	13.40^{A}	18.92^{B}	20.97^{AB}	12.64^{B}	11.99^{AB}	9.44^{B}	11.11^{A}
Mg	11.07^{AB}	11.28^{B}	13.39^{A}	15.10^{C}	20.09^{BC}	12.84^{B}	12.00^{AB}	10.50^{A}	6.86^{B}
K + Mg	10.70^{B}	11.68^{AB}	11.64^{B}	13.48^{D}	19.50^{C}	14.01^{A}	12.51^{A}	9.86^{B}	6.22^{B}
Overall mean	10.74	11.75	12.40	16.86	20.56	12.84	11.86	10.06	9.01

Table 21.2 Available P at different periods of incubation in laterite soil (kg ha^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	21.51^{AB}	23.10^{ABC}	25.91^{A}	26.40^{AB}	30.36^{AB}	50.53^{E}	51.58^{AB}	30.68^{AB}	27.09^{CD}
L_1	23.22^{A}	21.35^{C}	26.48^{A}	20.58^{B}	30.04^{AB}	51.66^{DE}	51.98^{AB}	28.73^{BCD}	30.59^{AB}
L_2	22.98^{A}	17.67^{BC}	27.11^{A}	28.21^{AB}	28.00^{B}	51.13^{DE}	50.58^{B}	28.53^{BCD}	31.56^{A}
L_3	21.78^{AB}	23.38^{ABC}	27.96^{A}	27.74^{AB}	22.28^{C}	56.12^{A}	54.56^{A}	28.49^{BCD}	28.13^{BCD}
K_1	24.55^{A}	22.94^{BC}	26.62^{A}	26.97^{AB}	29.72^{AB}	54.33^{B}	49.84^{B}	29.08^{BCD}	28.40^{BCD}
K_2	21.92^{AB}	23.16^{ABC}	27.25^{A}	29.23^{A}	30.93^{AB}	50.34^{E}	51.87^{AB}	31.98^{A}	26.95^{CD}
K_3	21.77^{AB}	24.88^{AB}	26.16^{A}	24.48^{AB}	32.38^{A}	55.27^{AB}	52.12^{AB}	30.99^{AB}	26.07^{D}
Mg_1	23.28^{A}	25.66^{A}	26.14^{A}	29.06^{A}	32.49^{A}	51.85^{DE}	49.98^{B}	26.16^{D}	27.98^{BCD}
Mg_2	22.02^{AB}	23.01^{ABC}	24.87^{A}	27.08^{AB}	29.79^{AB}	54.03^{BC}	44.48^{CD}	27.60^{CD}	30.53^{AB}
Mg_3	22.74^{AB}	23.33^{ABC}	27.13^{A}	28.30^{AB}	28.45^{AB}	54.37^{B}	46.66^{C}	21.64^{E}	26.35^{D}
K_1+Mg_1	19.21^{B}	21.87^{C}	22.74^{A}	29.13^{A}	31.48^{AB}	50.85^{E}	43.38^{D}	28.38^{BCD}	27.83^{BCD}
K_2+Mg_2	21.82^{AB}	22.73^{BC}	24.65^{A}	24.78^{AB}	31.28^{AB}	50.60^{E}	44.28^{CD}	30.12^{ABC}	29.60^{ABC}
K_3+Mg_3	22.04^{AB}	22.13^{C}	26.53^{A}	22.89^{AB}	31.26^{AB}	52.73^{CD}	46.35^{CD}	26.28^{D}	28.78^{BCD}
Mean L	22.66^{A}	22.47^{B}	27.18^{A}	25.50^{A}	26.78^{B}	52.98^{A}	52.38^{A}	28.58^{B}	30.10^{A}
K	22.75^{A}	23.66^{B}	26.70^{A}	26.90^{A}	31.00^{A}	53.33^{A}	51.28^{A}	30.68^{A}	27.15^{C}
Mg	22.68^{A}	24.00^{A}	26.05^{A}	28.15^{A}	30.08^{A}	53.40^{A}	47.05^{B}	25.13^{C}	28.28^{BC}
K + Mg	21.02^{A}	22.24^{B}	24.64^{A}	25.60^{A}	31.33^{A}	51.40^{B}	44.68^{C}	28.25^{B}	28.80^{AB}
Overall mean	22.22	23.09	26.12	26.52	29.84	52.61	49.05	28.35	28.50

Table 22. Leachate P at different periods of incubation in laterite soil (ppm)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	0.139^{BCD}	0.129^{CD}	0.289^{C}	0.148^{D}	0.127^{E}	0.630^{A}	0.342^{E}	0.137^{ABCD}	0.129^{DEF}
L_1	0.175^{A}	0.186^{A}	0.307^{B}	0.262^{A}	0.201^{A}	0.628^{A}	0.609^{A}	0.180^{AB}	0.182^{A}
L_2	0.130^{CDE}	0.129^{CD}	0.167^{G}	0.163^{CD}	0.141^{BCD}	0.478^{BC}	0.559^{B}	0.123^{CD}	0.120^{DEF}
L_3	0.145^{B}	0.137^{BC}	0.149^{H}	0.143^{D}	0.144^{BC}	0.438^{CD}	0.425^{C}	0.129^{BCD}	0.123^{EFG}
K_1	0.182^{A}	0.180^{A}	0.353^{A}	0.260^{A}	0.197^{A}	0.504^{B}	0.415^{CD}	0.178^{ABC}	0.167^{B}
K_2	0.186^{A}	0.190^{A}	0.287^{C}	0.206^{B}	0.194^{A}	0.276^{G}	0.394^{D}	0.185^{A}	0.178^{A}
K_3	0.147^{B}	0.139^{BC}	0.170^{E}	0.150^{D}	0.141^{BCD}	0.311^{FG}	0.134^{G}	0.123^{CD}	0.130^{DEF}
Mg_1	0.142^{BC}	0.141^{B}	0.174^{E}	0.161^{D}	0.142^{BCD}	0.466^{CD}	0.252^{F}	0.138^{ABCD}	0.134^{CD}
Mg_2	0.142^{BC}	0.143^{B}	0.203^{D}	0.183^{C}	0.151^{B}	0.647^{A}	0.153^{G}	0.143^{ABCD}	0.140^{C}
Mg_3	0.109^{F}	0.123^{D}	0.137^{I}	0.114^{E}	0.109^{F}	0.298^{G}	0.259^{F}	0.119^{D}	0.123^{EFG}
K_1+ Mg_1	0.119^{EF}	0.119^{D}	0.172^{E}	0.145^{D}	0.126^{E}	0.357^{EF}	0.412^{CD}	0.115^{D}	0.118^{G}
K_2+ Mg_2	0.125^{E}	0.124^{D}	0.172^{E}	0.146^{D}	0.131^{DE}	0.452^{BCD}	0.410^{CD}	0.121^{D}	0.121^{FG}
K_3+ Mg_3	0.128^{DE}	0.129^{CD}	0.165^{F}	0.145^{D}	0.136^{CDE}	0.399^{DE}	0.325^{E}	0.128^{BCD}	0.131^{CDE}
Mean L	0.150^{B}	0.151^{B}	0.206^{B}	0.189^{B}	0.162^{B}	0.515^{A}	0.531^{A}	0.144^{AB}	0.144^{B}
K	0.172^{A}	0.169^{A}	0.270^{A}	0.205^{A}	0.177^{A}	0.364^{D}	0.314^{C}	0.162^{A}	0.158^{A}
Mg	0.131^{C}	0.136^{C}	0.171^{C}	0.125^{C}	0.134^{C}	0.464^{B}	0.221^{D}	0.133^{AB}	0.133^{C}
K + Mg	0.124^{B}	0.124^{D}	0.170^{C}	0.145^{C}	0.131^{C}	0.402^{C}	0.382^{B}	0.121^{B}	0.124^{D}
Overall mean	0.144	0.144	0.211	0.171	0.149	0.451	0.361	0.140	0.139

Table 23.1 Exchangeable Ca at different periods of incubation in alluvial soil (c mol (+) kg^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	4.35^{BC}	4.15^{CD}	4.05^{ABC}	5.10^{A}	4.50^{D}	4.75^{D}	4.25^{DE}	4.15^{CD}	3.10^{C}
L_1	4.35^{BC}	4.80^{ABCD}	3.70^{C}	5.55^{A}	5.15^{A}	5.20^{AB}	4.65^{BCDE}	4.50^{ABC}	3.70^{F}
L_2	4.45^{BC}	4.85^{ABCD}	4.00^{ABC}	5.25^{A}	4.85^{ABCD}	5.05^{ABCD}	5.05^{B}	4.55^{A}	4.15^{DE}
L_3	4.15^{C}	4.45^{BCD}	3.95^{BC}	4.95^{A}	4.85^{ABCD}	5.25^{A}	4.20^{E}	4.35^{ABCD}	4.25^{BCD}
K_1	4.55^{BC}	4.25^{BCD}	3.90^{BC}	4.90^{A}	4.80^{ABCD}	4.80^{BCD}	4.85^{BC}	4.50^{ABC}	4.15^{DEF}
K_2	4.55^{BC}	4.95^{ABC}	3.85^{BC}	5.00^{A}	4.75^{BCD}	4.75^{CD}	4.25^{CDE}	4.50^{ABC}	4.20^{CD}
K_3	4.45^{BC}	4.15^{CD}	4.65^{A}	4.40^{A}	5.05^{AB}	4.35^{E}	4.80^{BC}	4.40^{ABCD}	3.75^{EF}
Mg_1	5.15^{A}	5.35^{A}	4.05^{ABC}	4.55^{A}	4.50^{D}	5.15^{ABC}	5.95^{A}	4.30^{ABCD}	4.90^{A}
Mg_2	4.45^{BC}	4.75^{ABCD}	3.95^{BC}	4.50^{A}	4.50^{A}	4.75^{CD}	4.80^{C}	4.25^{ABCD}	4.05^{DEF}
Mg_3	4.45^{BC}	4.35^{BCD}	4.55^{AB}	4.55^{A}	4.85^{ABCD}	3.85^{F}	4.65^{BCD}	4.55^{AB}	4.70^{AB}
K_1+ Mg_1	4.50^{BC}	4.60^{BCD}	4.45^{AB}	4.70^{A}	4.55^{CD}	5.10^{ABCD}	4.45^{CDE}	4.20^{BCD}	4.55^{BCD}
K_2+ Mg_2	4.60^{BC}	5.00^{AB}	4.35^{ABC}	4.95^{A}	5.00^{AB}	5.10^{ABCD}	4.25^{DE}	4.05^{D}	4.25^{CD}
K_3+ Mg_3	4.80^{AB}	5.00^{AB}	4.45^{AB}	4.55^{A}	4.90^{ABCD}	5.05^{ABCD}	4.45^{CDE}	4.20^{BCD}	4.65^{ABC}
Mean L	4.32^{B}	4.70^{AB}	3.88^{B}	5.25^{A}	4.95^{A}	5.16^{A}	4.64^{B}	4.48^{A}	4.05^{B}
K	4.52^{AB}	4.45^{B}	4.15^{AB}	4.75^{AB}	4.87^{A}	4.65^{B}	4.70^{B}	4.46^{A}	4.02^{B}
Mg	4.69^{A}	4.82^{AB}	4.19^{AB}	4.55^{B}	4.76^{A}	4.55^{B}	5.35^{A}	4.37^{A}	4.56^{A}
K + Mg	4.64^{A}	4.87^{A}	4.41^{A}	4.75^{AB}	4.82^{A}	5.07^{A}	4.39^{C}	4.16^{B}	4.49^{A}
Overall mean	4.53	4.65	4.15	4.85	4.80	4.85	4.65	4.35	4.15

Table 23.2 Exchangeable Ca at different periods of incubation in laterite soil (c mol (+) kg^{-1})

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	4.30^{BC}	3.90^{A}	4.30^{ABC}	3.80^{EF}	3.55^{G}	4.70^{A}	3.85^{A}	3.55^{EF}	3.85^{ABC}
L_1	4.45^{B}	4.55^{A}	4.40^{AB}	3.75^{F}	4.50^{BC}	4.85^{A}	4.05^{A}	3.55^{BCDEF}	3.95^{ABC}
L_2	5.50^{A}	3.70^{A}	3.95^{CD}	4.05^{CDEF}	4.15^{DE}	5.15^{A}	3.95^{A}	3.65^{EF}	3.60^{BC}
L_3	3.00^{E}	4.25^{A}	4.25^{ABC}	4.05^{CDEF}	4.90^{A}	4.40^{A}	4.50^{A}	3.95^{BCDE}	4.35^{A}
K_1	4.25^{BC}	4.15^{A}	3.65^{D}	4.25^{CDE}	3.90^{EF}	4.55^{A}	4.10^{A}	4.25^{AB}	4.25^{A}
K_2	3.30^{DE}	4.75^{A}	4.43^{AB}	4.15^{CDEF}	3.80^{FG}	4.75^{A}	4.20^{A}	4.20^{BC}	3.95^{ABC}
K_3	4.30^{BC}	4.50^{A}	4.50^{A}	4.75^{A}	3.75^{FG}	4.20^{A}	4.30^{A}	4.15^{BCD}	3.85^{ABC}
Mg_1	3.95^{BCD}	4.60^{A}	4.10^{BC}	4.45^{BC}	4.85^{A}	5.15^{A}	3.90^{A}	3.85^{BCDEF}	4.05^{ABC}
Mg_2	4.15^{BC}	4.25^{A}	3.65^{D}	3.95^{DEF}	4.15^{DE}	3.70^{A}	4.15^{A}	4.00^{BCDE}	3.60^{BC}
Mg_3	4.05^{BC}	3.45^{A}	4.15^{ABC}	4.75^{B}	4.25^{CD}	4.35^{A}	4.45^{A}	3.45^{F}	4.15^{AB}
K_1+ Mg_1	3.85^{BCD}	3.75^{A}	4.20^{ABC}	3.70^{F}	4.50^{BC}	4.25^{A}	4.25^{A}	3.75^{CDEF}	3.95^{ABC}
K_2+ Mg_2	3.85^{BCD}	4.00^{A}	4.20^{ABC}	4.45^{BC}	4.35^{BCD}	4.00^{A}	4.10^{A}	3.70^{DEF}	3.90^{ABC}
K_3+ Mg_3	3.60^{CDE}	3.95^{A}	4.25^{ABC}	4.45^{BCD}	4.65^{AB}	4.00^{A}	4.15^{A}	4.65^{A}	3.50^{C}
Mean L	4.30^{A}	4.18^{AB}	4.20^{A}	3.94^{C}	4.52^{A}	4.80^{A}	4.17^{A}	3.81^{BC}	3.98^{A}
K	3.94^{B}	4.45^{A}	4.20^{A}	4.38^{A}	3.82^{B}	4.51^{AB}	4.21^{A}	4.20^{A}	4.00^{A}
Mg	4.06^{B}	4.11^{AB}	3.98^{B}	4.39^{A}	4.40^{A}	4.39^{AB}	4.17^{A}	3.78^{C}	3.94^{A}
K + Mg	3.76^{C}	3.90^{B}	4.22^{A}	4.20^{B}	4.50^{A}	4.09^{B}	4.17^{A}	4.05^{AB}	3.79^{A}
Overall mean	4.04	4.15	4.11	4.20	4.26	4.47	4.15	3.93	3.93

Table 24.1 Leachate Ca at different periods of incubation in alluvial soil (%)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	0.0079^{BC}	0.0042^{EF}	0.0037^{EF}	0.0063^{BC}	0.0025^{D}	0.0063^{A}	0.0061^{CD}	0.0084^{BC}	0.0118^{DE}
L_1	0.0039^{HI}	0.0026^{G}	0.0032^{F}	0.0051^{C}	0.0023^{B}	0.0061^{A}	0.0058^{CD}	0.0078^{BCD}	0.0145^{BCD}
L_2	0.0049^{FGH}	0.0076^{C}	0.0067^{BC}	0.0055^{BC}	0.0047^{CD}	0.0760^{A}	0.0065^{C}	0.0093^{AB}	0.0132^{CDE}
L_3	0.0048^{FGH}	0.0054^{D}	0.0074^{B}	0.0051^{C}	0.0055^{BCD}	0.0076^{A}	0.0067^{C}	0.0048^{G}	0.0155^{BC}
K_1	0.0043^{GH}	0.0037^{EF}	0.0030^{F}	0.0093^{A}	0.0055^{BCD}	0.0066^{A}	0.0062^{CD}	0.0073^{CDEF}	0.0117^{DE}
K_2	0.0071^{CD}	0.0048^{DE}	0.0049^{DE}	0.0055^{BC}	0.0068^{BCD}	0.0068^{A}	0.0059^{CD}	0.0080^{BCD}	0.0152^{BC}
K_3	0.0067^{DE}	0.0088^{B}	0.0047^{DE}	0.0019^{E}	0.0078^{ABCD}	0.0067^{A}	0.0069^{B}	0.0108^{A}	0.0081_{A}
Mg_1	0.0099^{A}	0.0034^{FG}	0.0095^{A}	0.0033^{B}	0.0045^{CD}	0.0078^{A}	0.0030^{D}	0.0061^{EFG}	0.0110^{E}
Mg_2	0.0082^{B}	0.0042^{EF}	0.0056^{CD}	0.0032^{B}	0.0055^{BCD}	0.0060^{A}	0.0056^{CD}	0.0076^{CDE}	0.0130^{CDE}
Mg_3	0.0052^{FG}	0.0081^{BC}	0.0056^{CD}	0.0052^{C}	0.0078^{ABCD}	0.0007^{A}	0.0058^{CD}	0.0094^{AB}	0.0130^{CDE}
K_1+ Mg_1	0.0059^{EF}	0.0046^{DE}	0.0088^{A}	0.0065^{B}	0.0133^{A}	0.0096^{A}	0.0113^{B}	0.0057^{FG}	0.0121^{DE}
K_2+ Mg_2	0.0888^{HI}	0.0087^{BC}	0.0066^{BC}	0.0056^{BC}	0.0103^{ABC}	0.0101^{A}	0.0088^{BC}	0.0058^{FG}	0.0134^{CDE}
K_3+ Mg_3	0.0029^{I}	0.0111^{A}	0.0069^{BC}	0.0057^{BC}	0.0113^{AB}	0.0087^{A}	0.0167^{A}	0.0066^{DEF}	0.0167^{B}
Mean L	0.0045^{C}	0.0052^{B}	0.0058^{B}	0.0053^{A}	0.0042^{A}	0.0071^{B}	0.0063^{BC}	0.0073^{B}	0.0144^{A}
K	0.0060^{B}	0.0058^{B}	0.0042^{C}	0.0056^{A}	0.0067^{A}	0.0067^{B}	0.0075^{B}	0.0087^{A}	0.0164^{A}
Mg	0.0076^{A}	0.0052^{B}	0.0069^{A}	0.0039^{B}	0.0059^{A}	0.0069^{B}	0.0048^{C}	0.0077^{B}	0.0124^{A}
K + Mg	0.0042^{C}	0.0081^{A}	0.0074^{A}	0.0060^{A}	0.0117^{A}	0.0094^{A}	0.0123^{A}	0.0060^{C}	0.0141^{A}
Overall mean	0.0058	0.0059	0.0059	0.0053	0.0068	0.0072	0.0076	0.0075	0.0141

Table 24.2 Leachate Ca at different periods of incubation in laterite soil (%)

Treatments	Days after incubation								
	1	2	4	8	15	30	45	60	90
Control	0.0185^{CD}	0.0090^{G}	0.0065^{F}	0.0069^{CD}	0.0031^{H}	0.0076^{AB}	0.0073^{B}	0.0060^{FGH}	0.0074^{B}
L_1	0.0175^{D}	0.0110^{DEFG}	0.0098^{A}	0.0069^{CD}	0.0039^{GH}	0.0075^{AB}	0.0071^{B}	0.0046^{H}	0.0033^{B}
L_2	0.0140^{EF}	0.0170^{B}	0.0073^{EF}	0.0089^{B}	0.0044^{FGH}	0.0073^{BC}	0.0075^{B}	0.0067^{EFG}	0.0101^{A}
L_3	0.0215^{BC}	0.0240^{A}	0.0075^{DEF}	0.0093^{B}	0.0090^{B}	0.0056^{DE}	0.0082^{B}	0.0069^{DEFG}	0.0103^{A}
K_1	0.0105^{F}	0.0090^{FG}	0.0095^{CD}	0.0054^{D}	0.0069^{EFG}	0.0073^{BC}	0.0046^{D}	0.0073^{DEF}	0.0062^{C}
K_2	0.0165^{DE}	0.0130^{CDE}	0.0101^{C}	0.0057^{D}	0.0064^{D}	0.0053^{E}	0.0058^{C}	0.0054^{GH}	0.0047^{D}
K_3	0.0180^{D}	0.0120^{CDEFG}	0.0099^{C}	0.0094^{B}	0.0062^{D}	0.0077^{AB}	0.0058^{C}	0.0076^{CDE}	0.0030^{E}
Mg_1	0.0170^{DE}	0.0130^{CDEF}	0.0101^{C}	0.0068^{CD}	0.0069^{CD}	0.0090^{A}	0.0076^{CD}	0.0101^{A}	0.0098^{A}
Mg_2	0.0240^{AB}	0.0090^{EFG}	0.0131^{B}	0.0094^{B}	0.0059^{DE}	0.0057^{CDE}	0.0077^{B}	0.0084^{BCD}	0.0094^{A}
Mg_3	0.0240^{AB}	0.0160^{BC}	0.0009^{CD}	0.0082^{BC}	0.0079^{BC}	0.0027^{F}	0.0076^{B}	0.0090^{ABC}	0.0056^{CD}
K_1+ Mg_1	0.0230^{B}	0.0090^{EFG}	0.0089^{CDE}	0.0111^{A}	0.0056^{DEF}	0.0055^{DE}	0.0101^{A}	0.0096^{AB}	0.0047^{D}
K_2+ Mg_2	0.0235^{AB}	0.0140^{BCD}	0.0110^{C}	0.0112^{A}	0.0082^{BC}	0.0069^{BCDE}	0.0102^{A}	0.0103^{A}	0.0077^{B}
K_3+ Mg_3	0.0270^{A}	0.0160^{BC}	0.0075^{DEF}	0.0079^{BC}	0.0107^{A}	0.0071^{BCD}	0.0100^{A}	0.0060^{FGH}	0.0080^{B}
Mean L	0.0177^{C}	0.0172^{A}	0.0187^{A}	0.0084^{B}	0.0058^{C}	0.0068^{A}	0.0071^{B}	0.0061^{B}	0.0096^{A}
K	0.0150^{D}	0.0114^{B}	0.0098^{BC}	0.0068^{C}	0.0058^{C}	0.0068^{A}	0.0053^{D}	0.0068^{B}	0.0046^{D}
Mg	0.2170^{B}	0.0125^{B}	0.0109^{B}	0.0081^{B}	0.0069^{B}	0.0058^{B}	0.0069^{C}	0.0092^{A}	0.0083^{B}
K + Mg	0.0246^{A}	0.0128^{B}	0.0091^{C}	0.0101^{A}	0.0082^{A}	0.0065^{AB}	0.0101^{A}	0.0086^{A}	0.0068^{C}
Overall mean	0.0197	0.0131	0.0117	0.0082	0.0064	0.0066	0.0074	0.0076	0.0073

ii) Leachate Ca (Table 24)

The leachate Ca showed a decrease at eight days after incubation in alluvial soil corresponding to the increase in exchangeable Ca at that period, and increased gradually till 90 days after incubation when the leachate Ca was maximum and exchangeable Ca minimum. In laterite soil the leachate Ca remained almost stable throughout the incubation period. It was seen that the Ca in leachate was higher for the laterite soil than the alluvial soil throughout the incubation period (Tables 24.1 and 24.2). The leachate Ca was significantly high for the treatments receiving muriate of potash + $MgSO_4$ than the other treatments in general.

3. Total nutrient contents at different periods of incubation

Data on the total nutrient contents of the alluvial and laterite soils at different periods of incubation are presented in Tables 25 to 30.

The total N was found to be lower in alluvial soil than the laterite soil. There was a decrease in total N upto 30 days after incubation and then a slight increase was noticed. The different treatments failed to affect significantly the total N of soils at different periods of incubation (Table 25). It was seen that the various treatments did not show significant difference in the total N content of laterite soil at different periods of incubation especially during the initial stages. The treatments receiving K and Mg were found to give higher total N values though not significant. The treatments receiving K alone gave lower values for total N. It was seen that the total N decreased gradually with progress in the period of incubation in both soils.

The total P of alluvial soil did not show significant difference among the treatments though the control gave lower values (Table 26). In laterite soil the total P did not show significant difference during the initial stages but the control treatment gave generally higher values for total P. Application of Mg also did not affect the total P of laterite soil. There was a decrease in total P with incubation time in both soils. The total P was generally lower for alluvial soil than the laterite soil.

In alluvial soil, the total K was less than that of laterite soil. As K addition increased either as Sul-Po-Mag or as muriate of potash, the total K also was found to increase. The treatments without K (Mg_1, Mg_2, Mg_3 and control) gave significantly lower total K than the treatments with K addition (Table 27). The control treatments gave significantly lower total K values than the treatments receiving K. In laterite soil, the total K was significantly lower for control and the treatments receiving Mg alone than the treatments receiving K during the initial stages, but during the later stages of incubation, there was no significant difference. This may be due to the increased leaching of K from the treatments receiving K. The total K was found to decrease gradually with incubation period in both soils.

In both alluvial and laterite soils the total Ca did not show any significant difference among the treatments (Table 28).

In alluvial soil, the total Mg was significantly higher for the treatments receiving Mg at the highest level either as $MgSO_4$ or as Sul-Po-Mag, than the treatments receiving no Mg. But from 30 days after incubation, the various treatments did not show any significant dif-

Table 25. Total N at different periods of incubation (%)

Soil	Treatments	Days after incubation								
		1	2	4	8	15	30	45	60	90
Alluvial	Control	0.144^{A}	0.141^{A}	0.140^{A}	0.137^{A}	0.133^{A}	0.131^{C}	0.130^{B}	0.127^{B}	0.127^{B}
	L$_1$	0.155^{A}	0.153^{A}	0.151^{A}	0.148^{A}	0.146^{A}	0.146^{ABC}	0.148^{AB}	0.149^{A}	0.152^{A}
	L$_2$	0.156^{A}	0.150^{A}	0.152^{A}	0.148^{A}	0.148^{A}	0.148^{ABC}	0.148^{AB}	0.151^{A}	0.148^{AB}
	L$_3$	0.153^{A}	0.151^{A}	0.150^{A}	0.147^{A}	0.147^{A}	0.144^{ABC}	0.141^{AB}	0.141^{AB}	0.140^{AB}
	K$_1$	0.149^{A}	0.146^{A}	0.145^{A}	0.143^{A}	0.142^{A}	0.141^{ABC}	0.143^{AB}	0.144^{AB}	0.144^{AB}
	K$_2$	0.145^{A}	0.143^{A}	0.142^{A}	0.139^{A}	0.136^{A}	0.136^{ABC}	0.138^{AB}	0.140^{AB}	0.140^{AB}
	K$_3$	0.152^{A}	0.148^{A}	0.146^{A}	0.144^{A}	0.141^{A}	0.138^{ABC}	0.139^{AB}	0.140^{AB}	0.140^{AB}
	Mg$_1$	0.146^{A}	0.144^{A}	0.143^{A}	0.144^{A}	0.141^{A}	0.143^{A}	0.146^{AB}	0.146A	0.143^{AB}
	Mg$_2$	0.140^{A}	0.139^{A}	0.137^{A}	0.133^{A}	0.131^{A}	0.130^{C}	0.132^{B}	0.135^{AB}	0.137^{AB}
	Mg$_3$	0.142^{A}	0.137^{A}	0.135^{A}	0.133^{A}	0.132^{A}	0.133^{BC}	0.133^{AB}	0.133^{AB}	0.133^{AB}
	K$_1$+ Mg$_1$	0.144^{A}	0.143^{A}	0.146^{A}	0.138^{A}	0.132^{A}	0.132^{BC}	0.136^{AB}	0.135^{AB}	0.135^{AB}
	K$_2$+ Mg$_2$	0.157^{A}	0.156^{A}	0.154^{A}	0.151^{A}	0.149^{A}	0.151^{A}	0.152^{A}	0.150^{A}	0.149^{AB}
	K$_3$+ Mg$_3$	0.154^{A}	0.152^{A}	0.151^{A}	0.149^{A}	0.146^{A}	0.145^{ABC}	0.148^{AB}	0.145^{AB}	0.144^{AB}
Laterite	Control	0.185^{B}	0.182^{B}	0.181^{A}	0.179^{BC}	0.177^{BC}	0.177^{A}	0.176^{A}	0.173^{D}	0.173^{D}
	L$_1$	0.200^{AB}	0.194^{AB}	0.192^{A}	0.188^{ABC}	0.183^{ABC}	0.185^{A}	0.183^{A}	0.183^{ABCD}	0.187^{ABCD}
	L$_2$	0.212^{A}	0.206^{AB}	0.204^{A}	0.200^{A}	0.194^{ABC}	0.193^{A}	0.190^{A}	0.188^{ABCD}	0.188^{ABCD}
	L$_3$	0.190^{AB}	0.183^{AB}	0.180^{A}	0.176^{C}	0.175^{C}	0.176^{A}	0.176^{A}	0.174^{CD}	0.180^{ABCD}
	K$_1$	0.191^{AB}	0.186^{AB}	0.183^{A}	0.181BC	0.178^{BC}	0.177^{A}	0.178^{A}	0.175^{BCD}	0.179^{CD}
	K$_2$	0.198^{AB}	0.188^{AB}	0.185^{A}	0.182^{ABC}	0.180^{ABC}	0.181^{A}	0.182^{A}	0.180^{ABCD}	0.180^{BCD}
	K$_3$	0.201^{AB}	0.192^{AB}	0.190^{A}	0.187^{ABC}	0.186^{ABC}	0.188^{A}	0.188^{A}	0.187^{ABCD}	0.19^{ABCD}
	Mg$_1$	0.208^{AB}	0.200^{AB}	0.198^{A}	0.194^{ABC}	0.192^{ABC}	0.192^{A}	0.190^{A}	0.193^{AB}	0.192^{ABC}
	Mg$_2$	0.205^{AB}	0.198^{AB}	0.195^{A}	0.195^{ABC}	0.192^{ABC}	0.192^{A}	0.190^{A}	0.192^{ABC}	0.196^{ABC}
	Mg$_3$	0.211^{AB}	0.202^{AB}	0.198^{A}	0.196^{AB}	0.194^{ABC}	0.220^{A}	0.189^{A}	0.187^{ABCD}	0.187^{ABCD}
	K$_1$+ Mg$_1$	0.215^{A}	0.211^{A}	0.205^{A}	0.200^{A}	0.199^{A}	0.196^{A}	0.194^{A}	0.198^{A}	0.198^{A}
	K$_2$+ Mg$_2$	0.197^{AB}	0.195^{AB}	0.193^{A}	0.191^{ABC}	0.190^{ABC}	0.187^{A}	0.187^{A}	0.189^{ABCD}	0.193^{ABC}
	K$_3$+ Mg$_3$	0.215^{A}	0.208^{AB}	0.203^{A}	0.201^{A}	0.198^{AB}	0.197^{A}	0.191^{A}	0.194^{A}	0.198^{AB}

Table 26. Total P at different periods of incubation (%)

Soil	Treatments	Days after incubation								
		1	2	4	8	15	30	45	60	90
Alluvial	Control	0.0365^{A}	0.0367^{B}	0.0364^{B}	0.0364^{A}	0.0363^{B}	0.0380^{A}	0.0750^{ABC}	0.0369^{A}	0.0570^{A}
	L_1	0.0402^{A}	0.0396^{AB}	0.0388^{AB}	0.0385^{A}	0.0381^{AB}	0.0381^{A}	0.0384^{AB}	0.0380^{A}	0.0374^{A}
	L_2	0.0376^{A}	0.0380^{AB}	0.0378^{AB}	0.0372^{A}	0.0370^{AB}	0.0385^{A}	0.0372^{ABC}	0.0371^{A}	0.0369^{A}
	L_3	0.0394^{A}	0.0397^{AB}	0.0396^{AB}	0.0388^{A}	0.0383^{AB}	0.0387^{A}	0.0385^{AB}	0.0382^{A}	0.0373^{A}
	K_1	0.0399^{A}	0.0401^{AB}	0.0401^{AB}	0.0397^{A}	0.0396^{A}	0.0389^{A}	0.0386^{AB}	0.0388^{A}	0.0369^{A}
	K_2	0.0384^{A}	0.0377^{AB}	0.0379^{AB}	0.0377^{A}	0.0383^{AB}	0.0387^{A}	0.0386^{AB}	0.0384^{A}	0.0380^{A}
	K_3	0.0403^{A}	0.0402^{AB}	0.0404^{A}	0.0395^{A}	0.0396^{A}	0.0395^{A}	0.0393^{A}	0.0392^{A}	0.0400^{A}
	Mg_1	0.0366^{A}	0.0363^{B}	0.0364^{B}	0.0386^{A}	0.0383^{AB}	0.0386^{A}	0.0362^{ABC}	0.0392^{A}	0.0400^{A}
	Mg_2	0.0375^{A}	0.0377^{AB}	0.0364^{B}	0.0362^{A}	0.0359^{B}	0.0364^{A}	0.0354^{C}	0.0363^{A}	0.0367^{A}
	Mg_3	0.0360^{A}	0.0365^{B}	0.0377^{AB}	0.0360^{A}	0.0364^{B}	0.0368^{A}	0.0365^{ABC}	0.0362^{A}	0.0353^{A}
	K_1+ Mg_1	0.0373^{A}	0.0374^{AB}	0.0372^{AB}	0.0369^{A}	0.0372^{AB}	0.0367^{A}	0.0362^{ABC}	0.0355^{A}	0.0351^{A}
	K_2+ Mg_2	0.0365^{A}	0.0369^{AB}	0.0362^{B}	0.0380^{A}	0.0371^{B}	0.0370^{A}	0.0370^{ABC}	0.0370^{A}	0.0362^{A}
	K_3+ Mg_3	0.0365^{A}	0.0365^{B}	0.0363^{B}	0.0368^{A}	0.0364^{B}	0.0365^{A}	0.0360^{BC}	0.0359^{A}	0.0352^{A}
Laterite	Control	0.0785^{A}	0.0782^{A}	0.0767^{AB}	0.0711^{C}	0.0770^{A}	0.0774^{A}	0.0770^{A}	0.0769^{A}	0.0776^{A}
	L_1	0.0744^{A}	0.0745^{A}	0.0745^{BC}	0.0745^{ABC}	0.0755^{A}	0.0756^{AB}	0.0757^{AB}	0.0756^{AB}	0.0758^{A}
	L_2	0.7670^{A}	0.0767^{A}	0.0769^{AB}	0.0769^{AB}	0.0762^{A}	0.0762^{AB}	0.0762^{AB}	0.0759^{AB}	0.0758^{A}
	L_3	0.0740^{A}	0.0741^{A}	0.0735^{C}	0.0739^{BC}	0.0745^{A}	0.0745^{B}	0.0747^{B}	0.0747^{B}	0.0748^{A}
	K_1	0.0735^{A}	0.0735^{A}	0.0733^{C}	0.0728^{C}	0.0745^{A}	0.0748^{B}	0.0744^{B}	0.0745^{B}	0.0741^{A}
	K_2	0.0748^{A}	0.0749^{A}	0.0746^{ABC}	0.0744^{ABC}	0.0745^{A}	0.0756^{AB}	0.0755^{AB}	0.0750^{AB}	0.0753^{A}
	K_3	0.0766^{A}	0.0765^{A}	0.0758^{ABC}	0.0758^{ABC}	0.0750^{A}	0.0755^{AB}	0.0756^{AB}	0.0752^{AB}	0.0800^{A}
	Mg_1	0.0750^{A}	0.0758^{A}	0.0757^{ABC}	0.0755^{ABC}	0.0750^{A}	0.0749^{B}	0.0747^{B}	0.0750^{AB}	0.0749^{A}
	Mg_2	0.0770^{A}	0.0769^{A}	0.0763^{AB}	0.0761^{AB}	0.0759^{A}	0.0762^{AB}	0.0758^{AB}	0.0759^{AB}	0.0755^{A}
	Mg_3	0.0772^{A}	0.0771^{A}	0.0773^{A}	0.0765^{AB}	0.0764^{A}	0.0760^{AB}	0.0755^{AB}	0.0755^{AB}	0.0753^{A}
	K_1+ Mg_1	0.0755^{A}	0.0762^{A}	0.0758^{ABC}	0.0758^{ABC}	0.0756^{A}	0.0754^{AB}	0.0753^{AB}	0.0753^{AB}	0.0751^{A}
	K_2+ Mg_2	0.0749^{A}	0.0756^{A}	0.0752^{ABC}	0.0759^{ABC}	0.0752^{A}	0.0752^{B}	0.0749^{AB}	0.0747^{B}	0.0745^{A}
	K_3+ Mg_3	0.0761^{A}	0.0759^{A}	0.0754^{ABC}	0.0755^{ABC}	0.0751^{A}	0.0753^{AB}	0.0752^{AB}	0.0750^{AB}	0.0748^{A}

Table 27. Total K at different periods of incubation (%)

Soil	Treatments	Days after incubation								
		1	2	4	8	15	30	45	60	90
Alluvial	Control	0.090^{D}	0.090^{D}	0.089^{E}	0.087^{CD}	0.087^{DE}	0.087^{DE}	0.084^{D}	0.083^{BC}	0.081^{BC}
	L_1	0.105^{BCD}	0.100^{BCD}	0.095^{CDE}	0.094^{BC}	0.092^{CD}	0.092^{CD}	0.091^{BCD}	0.090^{ABC}	0.088^{ABC}
	L_2	0.116^{AB}	0.113^{AB}	0.110^{AB}	0.106^{A}	0.105^{AB}	0.102^{ABC}	0.098^{AB}	0.092^{ABC}	0.087^{ABC}
	L_3	0.126^{AB}	0.121^{A}	0.116^{A}	0.114^{A}	0.109^{A}	0.110^{A}	0.105^{A}	0.102^{A}	0.097^{AB}
	K_1	0.099^{CD}	0.096^{BCD}	0.090^{E}	0.088^{BCD}	0.088^{DE}	0.093^{CD}	0.096^{ABC}	0.096^{ABC}	0.093^{ABC}
	K_2	0.115^{AB}	0.115^{AB}	0.115^{A}	0.109^{A}	0.105^{AB}	0.102^{ABC}	0.091^{BCD}	0.091^{ABC}	0.088^{ABC}
	K_3	0.124^{A}	0.121^{A}	0.113^{A}	0.106^{A}	0.106^{AB}	0.109^{A}	0.101^{AB}	0.102^{A}	0.099^{A}
	Mg_1	0.093^{D}	0.091^{CD}	0.091^{DE}	0.088^{BCD}	0.088^{DE}	0.093^{CDE}	0.089^{BCD}	0.091^{ABC}	0.095^{ABC}
	Mg_2	0.092^{D}	0.090^{D}	0.085^{E}	0.084^{D}	0.082^{E}	0.081^{E}	0.080^{D}	0.079^{C}	0.082^{ABC}
	Mg_3	0.094^{D}	0.091^{CD}	0.087^{E}	0.088^{BCD}	0.087^{DE}	0.087^{DE}	0.085^{CD}	0.083^{BC}	0.079^{C}
	$K_1 \div Mg_1$	0.106^{BCD}	0.102^{ABCD}	0.102^{BCD}	0.096^{B}	0.097^{BC}	0.095^{BCD}	0.092^{BCD}	0.098^{AB}	0.086^{ABC}
	$K_2 \div Mg_2$	0.113^{ABC}	0.111^{ABC}	0.105^{ABC}	0.107^{A}	0.103^{AB}	0.105^{AB}	0.101^{AB}	0.098^{AB}	0.094^{ABC}
	$K_3 \div Mg_3$	0.122^{A}	0.116^{AB}	0.110^{AB}	0.109^{A}	0.105^{AB}	0.103^{ABC}	0.101^{AB}	0.099^{AB}	0.098^{AB}
Laterite	Control	0.158^{B}	0.156^{BC}	0.156^{CD}	0.155^{BC}	0.154^{BC}	0.154^{A}	0.156^{A}	0.153^{A}	0.152^{A}
	L_1	0.172^{AB}	0.169^{ABC}	0.168^{B}	0.163^{BC}	0.163^{ABC}	0.159^{A}	0.156^{A}	0.152^{A}	0.152^{A}
	L_2	0.180^{AB}	0.176^{ABC}	0.173^{AB}	0.170^{AB}	0.169^{ABC}	0.168^{A}	0.166^{A}	0.164^{A}	0.162^{A}
	L_3	0.188^{A}	0.182^{A}	0.182^{A}	0.183^{A}	0.180^{A}	0.179^{A}	0.175^{A}	0.176^{A}	0.176^{A}
	K_1	0.171^{AB}	0.167^{ABC}	0.171^{AB}	0.170^{AB}	0.168^{ABC}	0.165^{A}	0.160^{A}	0.159^{A}	0.158^{A}
	K_2	0.178^{AB}	0.174^{ABC}	0.170^{B}	0.167^{ABC}	0.165^{ABC}	0.162^{A}	0.163^{A}	0.161^{A}	0.159^{A}
	K_3	0.185^{A}	0.179^{AB}	0.175^{AB}	0.173^{AB}	0.172^{AB}	0.169^{A}	0.165^{A}	0.165^{A}	0.16^{A}
	Mg_1	0.160^{B}	0.155^{BC}	0.154^{CD}	0.151^{C}	0.152^{BC}	0.151^{A}	0.150^{A}	0.149^{A}	0.147^{A}
	Mg_2	0.158^{B}	0.151^{C}	0.151^{D}	0.151^{C}	0.149^{C}	0.146^{A}	0.148^{A}	0.146^{A}	0.147^{A}
	Mg_3	0.160^{B}	0.155^{BC}	0.152^{D}	0.150^{C}	0.150^{BC}	0.148^{A}	0.152^{A}	0.149^{A}	0.148^{A}
	$K_1 \div Mg_1$	0.171^{AB}	0.166^{ABC}	0.164^{BC}	0.160^{BC}	0.158^{ABC}	0.153^{A}	0.145^{A}	0.143^{A}	0.141^{A}
	$K_2 \div Mg_2$	0.177^{AB}	0.174^{ABC}	0.167^{B}	0.163^{BC}	0.159^{ABC}	0.156^{A}	0.153^{A}	0.152^{A}	0.149^{A}
	$K_3 \div Mg_3$	0.178^{AB}	0.178^{AB}	0.174^{AB}	0.171^{AB}	0.169^{ABC}	0.165^{A}	0.160^{A}	0.157^{A}	0.152^{A}

Table 28. Total Ca at different periods of incubation (%)

Soil	Treatments	Days after incubation								
		1	2	4	8	15	30	45	60	90
Alluvial	Control	0.279^{A}	0.278^{A}	0.274^{A}	0.267^{A}	0.261^{A}	0.249^{A}	0.242^{A}	0.235	0.230^{A}
	L_1	0.286^{A}	0.280^{A}	0.273^{A}	0.267^{A}	0.266^{A}	0.258^{A}	0.254^{A}	0.248	0.245^{A}
	L_2	0.288^{A}	0.282^{A}	0.280^{A}	0.267^{A}	0.301^{A}	0.256^{A}	0.252^{A}	0.250	0.246^{A}
	L_3	0.283^{A}	0.282^{A}	0.277^{A}	0.265^{A}	0.267^{A}	0.264^{A}	0.261^{A}	0.255	0.252^{A}
	K_1	0.245^{A}	0.241^{A}	0.235^{A}	0.263^{A}	0.229^{A}	0.226^{A}	0.221^{A}	0.221	0.219^{A}
	K_2	0.244^{A}	0.240^{A}	0.235^{A}	0.263^{A}	0.303^{A}	0.235^{A}	0.218^{A}	0.215	0.213^{A}
	K_3	0.246^{A}	0.246^{A}	0.243^{A}	0.240^{A}	0.234^{A}	0.231^{A}	0.230^{A}	0.228	0.226^{A}
	Mg_1	0.277^{A}	0.259^{A}	0.263^{A}	0.259^{A}	0.249^{A}	0.208^{A}	0.245^{A}	0.242	0.239^{A}
	Mg_2	0.285^{A}	0.277^{A}	0.271^{A}	0.268^{A}	0.240^{A}	0.260^{A}	0.255^{A}	0.254	0.251^{A}
	Mg_3	0.273^{A}	0.269^{A}	0.265^{A}	0.262^{A}	0.255^{A}	0.251^{A}	0.248^{A}	0.240	0.236^{A}
	K_1+ Mg_1	0.251^{A}	0.245^{A}	0.239^{A}	0.239^{A}	0.235^{A}	0.235^{A}	0.232^{A}	0.228^{A}	0.225^{A}
	K_2+ Mg_2	0.246^{A}	0.243^{A}	0.240^{A}	0.239^{A}	0.223^{A}	0.230^{A}	0.218^{A}	0.225^{A}	0.221^{A}
	K_3+ Mg_3	0.251^{A}	0.249^{A}	0.243^{A}	0.242^{A}	0.248^{A}	0.235^{A}	0.232^{A}	0.229^{A}	0.225^{A}
Laterite	Control	0.265^{A}	0.260^{A}	0.256^{A}	0.256^{A}	0.242^{A}	0.251^{A}	0.238^{A}	0.247^{A}	0.224^{A}
	L_1	0.292^{A}	0.286^{A}	0.282^{A}	0.277^{A}	0.272^{A}	0.269^{A}	0.266^{A}	0.263^{A}	0.259^{A}
	L_2	0.251^{A}	0.278^{A}	0.277^{A}	0.274^{A}	0.269^{A}	0.263^{A}	0.260^{A}	0.247^{A}	0.245^{A}
	L_3	0.263^{A}	0.287^{A}	0.280^{A}	0.275^{A}	0.270^{A}	0.267^{A}	0.264^{A}	0.261^{A}	0.257^{A}
	K_1	0.279^{A}	0.277^{A}	0.275^{A}	0.270^{A}	0.266^{A}	0.263^{A}	0.260^{A}	0.257^{A}	0.254^{A}
	K_2	0.255^{A}	0.253^{A}	0.251^{A}	0.251^{A}	0.243^{A}	0.242^{A}	0.240^{A}	0.237^{A}	0.234^{A}
	K_3	0.260^{A}	0.257^{A}	0.258^{A}	0.258^{A}	0.254^{A}	0.253^{A}	0.250^{A}	0.247^{A}	0.242^{A}
	Mg_1	0.279^{A}	0.275^{A}	0.266^{A}	0.262^{A}	0.253^{A}	0.241^{A}	0.246^{A}	0.243^{A}	0.241^{A}
	Mg_2	0.279^{A}	0.275^{A}	0.271^{A}	0.258^{A}	0.269^{A}	0.264^{A}	0.261^{A}	0.256^{A}	0.246^{A}
	Mg_3	0.282^{A}	0.277^{A}	0.274^{A}	0.272^{A}	0.265^{A}	0.262^{A}	0.258^{A}	0.252^{A}	0.235^{A}
	K_1+ Mg_1	0.257^{A}	0.253^{A}	0.250^{A}	0.249^{A}	0.247^{A}	0.243^{A}	0.242^{A}	0.238^{A}	0.234^{A}
	K_2+ Mg_2	0.257^{A}	0.252^{A}	0.246^{A}	0.244^{A}	0.241^{A}	0.235^{A}	0.233^{A}	0.231^{A}	0.233^{A}
	K_3+ Mg_3	0.254^{A}	0.247^{A}	0.238^{A}	0.240^{A}	0.237^{A}	0.233^{A}	0.234^{A}	0.232^{A}	0.233^{A}

Table 29. Total Mg at different periods of incubation (%)

Soil	Treatments	Days after incubation								
		1	2	4	8	15	30	45	60	90
Alluvial	Control	0.1048^{C}	0.1045^{C}	0.1042^{D}	0.1040^{D}	0.1038^{D}	0.1035^{A}	0.1033^{A}	0.1032^{A}	0.1030^{A}
	L_1	0.1060^{ABC}	0.1059^{AB}	0.1055^{ABC}	0.1055^{ABC}	0.1051^{ABC}	0.1046^{A}	0.1045^{A}	0.1041^{A}	0.1039^{A}
	L_2	0.1066^{ABC}	0.1062^{AB}	0.1060^{ABC}	0.1057^{ABC}	0.1053^{ABC}	0.1052^{A}	0.1052^{A}	0.1049^{A}	0.1046^{A}
	L_3	0.1072^{A}	0.1069^{A}	0.1067^{A}	0.1064^{A}	0.1061^{A}	0.1056^{A}	0.1057^{A}	0..1050^{A}	0.1050^{A}
	K_1	0.1058^{ABC}	0.1054^{B}	0.1052^{BCD}	0.1048^{CD}	0.1045^{CD}	0.1044^{A}	0.1045^{A}	0.1052^{A}	0.1039^{A}
	K_2	0.1054^{BC}	0.1054^{B}	0.1050^{CD}	0.1049^{CD}	0.1046^{CD}	0.1045^{A}	0.1043^{A}	0.1041^{A}	0.1039^{A}
	K_3	0.1056^{ABC}	0.1055^{B}	0.1052^{BCD}	0.1050^{BCD}	0.1046^{CD}	0.1043^{A}	0.1040^{A}	0.1038^{A}	0.1000^{A}
	Mg_1	0.1065^{ABC}	0.1059^{AB}	0.1054^{ABCD}	0.1052^{ABCD}	0.1049^{BCD}	0.1045^{A}	0.1043^{A}	0.1042^{A}	0.1040^{A}
	Mg_2	0.1065^{ABC}	0.1061^{AB}	0.1058^{ABC}	0.1057^{ABC}	0.1052^{ABC}	0.1049^{A}	0.1048^{A}	0.1045^{A}	0.1043^{A}
	Mg_3	0.1073^{A}	0.1069^{A}	0.1065^{AB}	0.1063^{A}	0.1059^{AB}	0.1054^{A}	0.1050^{A}	0.1049^{A}	10.45^{A}
	K_1+ Mg_1	0.1065^{ABC}	0.1059^{AB}	0.1054^{ABCD}	0.1053^{ABC}	0.1050^{ABC}	0.1045^{A}	0.1045^{A}	0.1042^{A}	0.1041^{A}
	K_2+ Mg_2	0.1068^{AB}	0.1062^{AB}	0.1057^{ABC}	0.1055^{ABC}	0.1051^{ABC}	0.1048^{A}	0.1040^{A}	0.1038^{A}	0.1036^{A}
	K_3+ Mg_3	0.1073^{A}	0.1068^{A}	0.1066^{A}	0.1062^{AB}	0.1058^{AB}	0.1056^{A}	0.1049^{A}	0.1047^{A}	0.1043^{A}
Laterite	Control	0.1061^{B}	0.1060^{E}	0.1058^{E}	0.1057^{E}	0.1054^{D}	0.1052^{D}	0.1049^{C}	0.1046^{A}	0.1043^{A}
	L_1	0.1079^{B}	0.1076^{CD}	0.1073^{CDE}	0.1069^{BCDE}	0.1065^{BCD}	0.1061^{BCD}	0.1057^{BC}	0.1055^{A}	0.1052^{A}
	L_2	0.1091^{AB}	0.1086^{BC}	0.1083^{ABC}	0.1082^{ABCD}	0.1077^{ABC}	0.1072^{ABC}	0.1068^{ABC}	0.1066^{A}	0.1063^{A}
	L_3	0.1075^{AB}	0.1090^{A}	0.1095^{A}	0.1093^{A}	0.1089^{A}	0.1086^{A}	0.1084^{A}	0.1073^{A}	0.1074^{A}
	K_1	0.1076^{B}	0.1067^{DE}	0.1065^{DE}	0.1064^{DE}	0.1062^{CD}	0.1058^{BCD}	0.1051^{C}	0.1047^{A}	0.1045^{A}
	K_2	0.1066^{B}	0.1063^{E}	0.1061^{E}	0.1061^{E}	0.1058^{D}	0.1055^{CD}	0.1054^{C}	0.1054^{A}	0.1048^{A}
	K_3	0.1062^{B}	0.1063^{E}	0.1058^{E}	0.1056^{E}	0.1054^{D}	0.1050^{D}	0.1049^{C}	0.1046^{A}	0.1000^{A}
	Mg_1	0.1081^{AB}	0.1078^{C}	0.1073^{CDE}	0.1068^{CDE}	0.1064^{BCD}	0.1064^{BCD}	0.1060^{BC}	0.1058^{A}	0.1055^{A}
	Mg_2	0.1087^{AB}	0.1083^{C}	0.1077^{BCD}	0.1072^{BCDE}	0.1069^{BCD}	0.1063^{BCD}	0.1061^{BC}	0.1057^{A}	0.1056^{A}
	Mg_3	0.1094^{AB}	0.1088^{AB}	0.1089^{AB}	0.1087^{AB}	0.1083^{AB}	0.1074^{ABC}	0.1068^{ABC}	0.1064^{A}	0.1061^{A}
	K_1+ Mg_1	0.1081^{AB}	0.1079^{C}	0.1077^{BCD}	0.1074^{BCDE}	0.1069^{BCD}	0.1065^{BCD}	0.1063^{BC}	0.1059^{A}	0.1058^{A}
	K_2+ Mg_2	0.1089^{AB}	0.1086^{BC}	0.1084^{ABC}	0.1081^{BCD}	0.1077^{ABC}	0.1069^{ABCD}	0.1068^{ABC}	0.1064^{A}	0.1060^{A}
	K_3+ Mg_3	0.1131^{A}	0.1096^{AB}	0.1086^{ABC}	0.1083^{ABC}	0.1032^{AB}	0.1077^{AB}	0.1073^{AB}	0.1070^{A}	0.1067^{A}

Table 30. Total S at different periods of incubation (%)

Soil	Treatments	Days after incubation								
		1	2	4	8	15	30	45	60	90
Alluvial	Control	0.062^{ABC}	0.056^{CD}	0.054^{CD}	0.052^{DE}	0.048^{CD}	0.045^{BC}	0.042^{B}	0.040^{A}	0.039^{A}
	L_1	0.072^{ABC}	0.068^{ABCD}	0.065^{ABCD}	0.061^{BCD}	0.058^{BC}	0.057^{ABC}	0.054^{A}	0.051^{A}	0.049^{A}
	L_2	0.079^{AB}	0.078^{AB}	0.074^{A}	0.068^{ABC}	0.066^{AB}	0.063^{A}	0.058^{A}	0.056^{A}	0.054^{A}
	L_3	0.008^{AB}	0.081^{A}	0.077^{A}	0.072^{A}	0.069^{A}	0.067^{A}	0.062^{A}	0.059^{A}	0.057^{A}
	K_1	0.064^{ABC}	0.063^{BCD}	0.060^{ABCD}	0.058^{CD}	0.056^{ABC}	0.054^{ABC}	0.051^{AB}	0.049^{A}	0.045^{A}
	K_2	0.054^{C}	0.052^{D}	0.049^{D}	0.045^{E}	0.044^{D}	0.043^{C}	0.040^{B}	0.039^{A}	0.038^{A}
	K_3	0.060^{BC}	0.058^{CD}	0.056^{BCD}	0.053^{DE}	0.052^{BCD}	0.050^{ABC}	0.050^{AB}	0.047^{A}	0.050^{A}
	Mg_1	0.069^{ABC}	0.066^{ABCD}	0.064^{ABCD}	0.060^{BCD}	0.058^{BC}	0.054^{ABC}	0.052^{AB}	0.051^{A}	0.050^{A}
	Mg_2	0.074^{ABC}	0.070^{ABC}	0.066^{ABCD}	0.064^{ABC}	0.060^{ABC}	0.055^{ABC}	0.052^{AB}	0.049^{A}	0.046^{A}
	Mg_3	0.079^{AB}	0.074^{AB}	0.072^{AB}	0.067^{ABC}	0.065^{AB}	0.040^{ABC}	0.055^{A}	0.055^{A}	0.052^{A}
	K_1+Mg_1	0.076^{AB}	0.069^{ABCD}	0.067^{ABC}	0.064^{ABC}	0.061^{ABC}	0.060^{ABC}	0.060^{A}	0.057^{A}	0.053^{A}
	K_2+Mg_2	0.080^{AB}	0.078^{AB}	0.075^{A}	0.070^{AB}	0.065^{AB}	0.061^{AB}	0.058^{A}	0.056^{A}	0.053^{A}
	K_3+Mg_3	0.082^{A}	0.078^{AB}	0.075^{A}	0.069^{AB}	0.065^{AB}	0.062^{AB}	0.059^{A}	0.056^{A}	0.054^{A}
Laterite	Control	0.048^{D}	0.046^{C}	0.044^{E}	0.042^{D}	0.040^{C}	0.037^{B}	0.034^{C}	0.034^{A}	0.030^{A}
	L_1	0.065^{AB}	0.063^{ABC}	0.059^{ABC}	0.051^{ABCD}	0.055^{ABC}	0.051B	0.049^{ABC}	0.047^{A}	0.043^{A}
	L_2	0.067^{AB}	0.065^{ABC}	0.063^{AB}	0.061^{AB}	0.056^{AB}	0.051B	0.048^{ABC}	0.047^{A}	0.044^{A}
	L_3	0.073^{A}	0.069^{AB}	0.066^{AB}	0.066^{A}	0.061^{A}	0.058B	0.054^{AB}	0.052^{A}	0.050^{A}
	K_1	0.053^{CD}	0.050^{BC}	0.049^{DE}	0.048^{BCD}	0.047^{ABC}	0.045B	0.040^{ABC}	0.038^{A}	0.037^{A}
	K_2	0.049^{D}	0.046^{C}	0.046^{E}	0.044^{D}	0.043^{BC}	0.042^{B}	0.039^{BC}	0.037^{A}	0.035^{A}
	K_3	0.053^{CD}	0.050^{BC}	0.048^{DE}	0.046^{CD}	0.043^{BC}	0.045^{AB}	0.044^{ABC}	0.041^{A}	0.04^{A}
	Mg_1	0.061^{BC}	0.059^{ABC}	0.055^{CD}	0.053^{ABCD}	0.049^{ABC}	0.046^{AB}	0.044^{ABC}	0.039^{A}	0.036^{A}
	Mg_2	0.069^{AB}	0.066^{ABC}	0.063^{AB}	0.062^{A}	0.059^{ABC}	0.058^{AB}	0.053^{AB}	0.051^{A}	0.049^{A}
	Mg_3	0.074^{A}	0.072^{A}	0.068^{A}	0.064^{A}	0.061^{A}	0.051^{AB}	0.055^{AB}	0.048^{A}	0.047^{A}
	K_1+Mg_1	0.065^{AB}	0.061^{ABC}	0.058^{BC}	0.055^{ABCD}	0.053^{ABC}	0.051^{AB}	0.050^{ABC}	0.046^{A}	0.043^{A}
	K_2+Mg_2	0.067^{AB}	0.063^{ABC}	0.059^{BC}	0.059^{ABC}	0.052^{ABC}	0.052^{AB}	0.049^{ABC}	0.047^{A}	0.044^{A}
	K_3+Mg_3	0.071^{A}	0.068^{AB}	0.066^{AB}	0.064^{A}	0.061^{A}	0.059^{A}	0.057^{A}	0.055^{A}	0.052^{A}

Plate 9: Soil incubation study

ference. In laterite soil, the total Mg was significantly higher for the treatments receiving the highest level of Mg either as Sul-Po-Mag or as $MgSO_4$ (Table 29). The treatments receiving K alone as muriate of potash gave significantly lower total Mg and on par with control. But towards the end of incubation, there was no significant difference among the treatments in their total Mg contents.

The total S was higher for alluvial soil than for the laterite soil. But the treatments did not show consistent variation in the total S in alluvial soil. But total S showed marked decrease with period of incubation (Table 30). In laterite soil, total S was significantly higher for the treatments receiving Sul-Po-Mag or $MgSO_4$ in combination with muriate of potash or $MgSO_4$ alone. The treatments receiving muriate of potash alone gave total S values significantly lower than those receiving Sul-Po-Mag or $MgSO_4$.

PART III

POT CULTURE: POTASSIUM- MAGNESIUM INTERACTION IN SOIL – PLANT SYSTEM

The pot culture experiment was undertaken to study the interaction of K and Mg in soil and plant at different levels of these nutrients. The experiment was conducted using two soils namely laterite (Vellanikkara) and alluvial (Kannara), with bhindi as the test crop. The fertilizer treatments given were factorial combinations of four levels of K (0, 15, 30 and 45 kg K_2O ha^{-1}) and four levels of Mg (0,10, 20 and 30 kg Mg ha^{-1}) in addition to four levels of Sul-Po-Mag (0, 15, 30 and 45 kg K_2O ha^{-1}). These treatments were applied to the plots along with the normal recommendation of N and P. There was also an NPK treatment receiving fertilizer dose equivalent to the package of practices recommended by the Kerala Agricultural University (KAU, 1993), and an absolute control. After the application of the treatments, the soil and plant samples were drawn at one month interval and analysed to get the following results.

1. *General characteristics of the soils selected for the study*

The general characteristics of the soils selected for the pot culture experiment are same as that for the incubation study (Table 12).

2. *Dry matter production, yield and quality attributes of bhindi*

1.1 Dry matter production (Table 31)

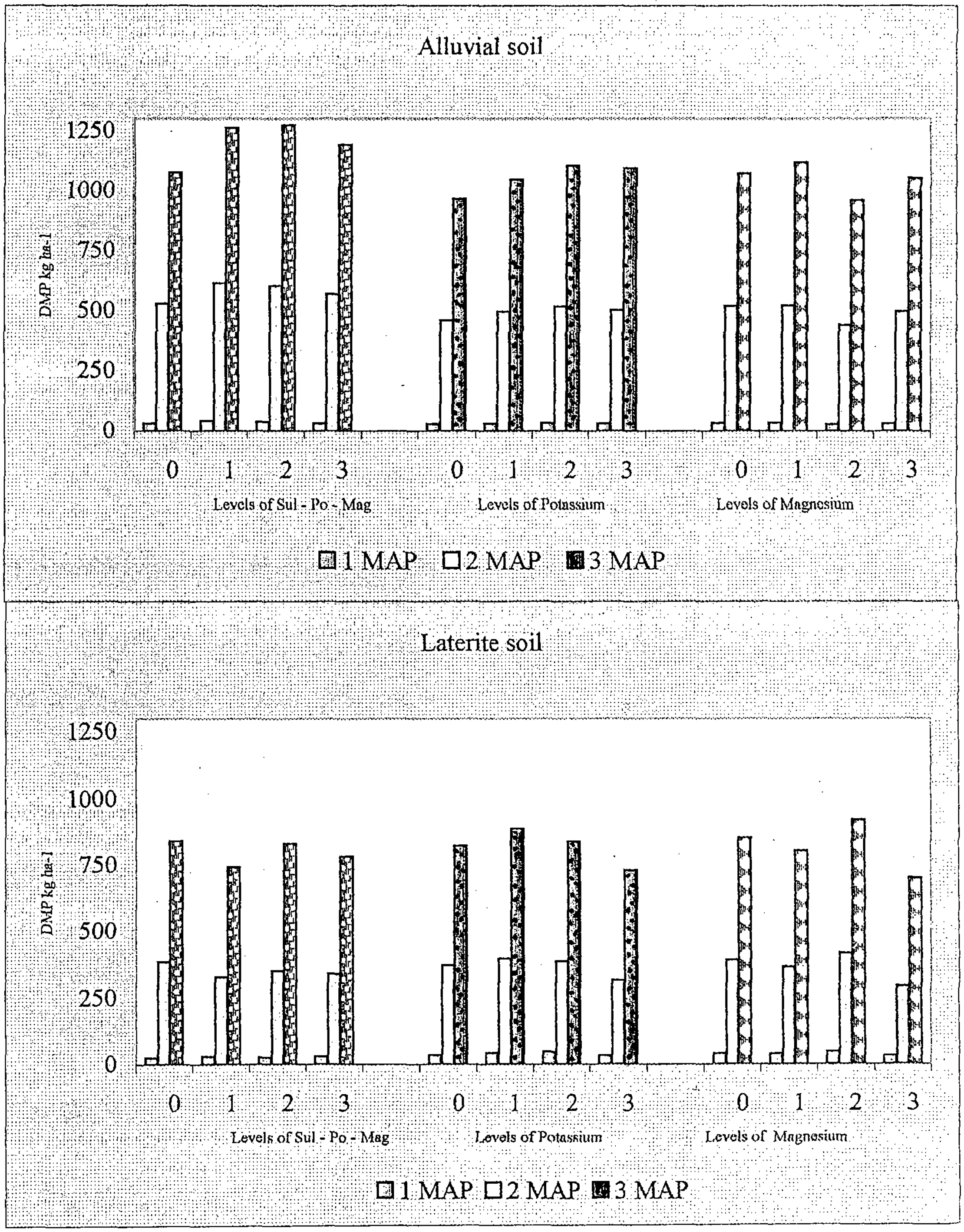
The effect of treatments on the dry matter produced by the bhindi crop grown in the alluvial and laterite soils at different stages of growth are presented and discussed hereunder.

In alluvial soil, as crop growth progressed, the dry matter production also showed a progressive increase for all the treatments. The Sul-Po-Mag applied plants gave relatively high dry matter production when compared to the

Table 31. Dry matter production of bhindi at different stages (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	24.85^{KL}	381.50^{I}	806.75^{K}	18.38^{HI}	295.75^{I}	636.05^{IJ}
$NPSPM_1$	42.88^{A}	612.50^{A}	1263.50^{AB}	29.93^{EFG}	328.00^{FGHI}	743.00^{FGH}
$NPSPM_2$	39.38^{B}	602.00^{A}	1275.75^{A}	26.63^{FG}	351.00^{EFG}	831.00^{DEF}
$NPSPM_3$	31.68^{FGHI}	568.75^{ABC}	1193.5^{BC}	28.88^{FG}	340.00^{FGH}	783.50^{DEF}
NPK	32.03^{FGH}	501.40^{DE}	1075.75^{EF}	36.75^{CDE}	341.25^{FGH}	790.50^{DEFG}
NPK_0Mg_0	30.65^{GHIJ}	528.50^{CDE}	1048.25^{FGHI}	24.68^{GHI}	385.00^{DE}	841.50^{DE}
NPK_1Mg_0	31.33^{FGHI}	486.50^{FGH}	1022.00^{FGHI}	39.38^{C}	390.50^{D}	870.85^{CD}
NPK_2Mg_0	32.73^{EFG}	507.50^{DE}	1072.75^{EF}	61.25^{A}	476.00^{AB}	988.10^{AB}
NPK_3Mg_0	36.75^{BCD}	547.75^{BCD}	1155.0^{CD}	35.00^{CDEF}	316.00^{FGHI}	723.00^{GH}
NPK_0Mg_1	26.25^{JKL}	406.00^{I}	8732.50^{K}	36.75^{CDE}	338.00^{EF}	784.20^{DEFGH}
NPK_1Mg_1	35.00^{CDEF}	539.00^{CD}	1128.75^{CDE}	49.88^{B}	448.00^{BC}	981.00^{AB}
NPK_2Mg_1	38.50^{BC}	567.00^{ABC}	1237.25^{AB}	37.63^{CD}	341.00^{FGH}	732.50^{GH}
NPK_3Mg_1	35.88^{BCDE}	567.00^{ABC}	1244.25^{AB}	35.00^{CDEF}	320.50^{FGHI}	715.00^{GHI}
NPK_0Mg_2	28.18^{IJK}	441.00^{HI}	950.25^{J}	47.25^{B}	441.00^{BC}	971.00^{AB}
NPK_1Mg_2	28.53^{HIJ}	453.25^{GHI}	974.75^{IJ}	46.38^{B}	428.00^{C}	944.50^{BC}
NPK_2Mg_2	28.88^{HIJ}	455.00^{FGHI}	987.00^{HIJ}	65.63^{A}	487.30^{A}	1084.50^{A}
NPK_3Mg_2	23.28^{L}	400.50^{FGHI}	945.00^{J}	32.55^{CDEF}	316.25^{FGHI}	741.55^{FGH}
NPK_0Mg_3	29.76^{GHIJ}	462.88^{FGH}	999.25^{GHIJ}	30.98^{DEFG}	309.00^{HI}	693.00^{HI}
NPK_1Mg_3	31.85^{FGHI}	501.40^{DEF}	105.85^{EFG}	36.75^{CDE}	319.75^{FGHI}	766.50^{EFGH}
NPK_2Mg_3	33.25^{DEFG}	537.25^{CD}	1121.75^{DE}	24.50^{GH}	238.00^{J}	601.50^{J}
NPK_3Mg_3	26.25^{JKL}	492.00^{EFG}	1038.25^{FGH}	30.63^{DEFG}	312.00^{GHI}	739.00^{GH}
Levels of K						
K_0	28.71	459.59	967.75	34.91	372.00	822.43
K_1	31.68	495.04	1046.06	43.09	396.56	889.46
K_2	33.34	516.69	1104.69	47.25	385.70	839.15
K_3	30.54	501.81	1095.63	33.29	316.26	729.75
CD (5 %)	1.36	17.73	26.87	2.68	14.00	32.91
Levels of Mg						
Mg_0	32.86	517.56	1074.50	40.08	391.88	854.61
Mg_1	33.91	519.75	1120.88	39.81	365.70	803.18
Mg_2	27.21	441.19	964.25	47.95	418.26	923.00
Mg_3	30.28	494.63	1054.50	13.71	294.69	700.00
CD (5%)	1.36	17.73	26.87	2.68	14.00	32.91
CD-K x Mg (5 %)	2.71	35.46	53.73	5.35	28.00	65.82

m.a.p. – Months after planting



MAP – Months after planting

Fig. 11 Drymatter production of bhindi at different levels of fertilizers other treatments at all stages (Fig.11) but a decrease in dry matter production was observed as the level of application increased. This reduction in dry matter production was significant only during the initial stages of growth. As growth progressed, though a decrease was noticed, significant reduction did not occur.

Application of increased levels of Mg as $MgSO_4$ caused an increase in the dry matter production only upto Mg_1 level and a further increase of Mg to Mg_2 and higher, caused a significant reduction in dry matter production. The initial increase in dry matter production by the addition of Mg at Mg_1 level may be due to an increase in the photosynthetic activity induced by the application of Mg (Terry and Ulrich, 1974). But further raising Mg to higher levels has detrimental effect on the dry matter production. It is also seen that at all K levels, (from K_1 to K_3) an increase was observed in the dry matter production as Mg increased from Mg_0 to Mg_1 but then a decrease in dry matter production occurred on further Mg addition.

As the rate of K application increased, a significant increase in dry matter production was observed at all stages of growth till K_2 but further increasing the K levels caused a reduction in dry matter production. This trend was shown by both the muriate of potash and the Sul-Po-Mag applied plants. Similar results were reported by Terman *et al.* (1953). This reduction in dry matter production at higher K levels may be because of the dilution effect due to the increase in fresh weight of the plant caused by an increase in water storage induced by high K levels. But the dry matter production remains low (Loue', 1985).

Increasing the K levels without the addition of Mg generally increased the dry matter production significantly during the growth period. This effect was more conspicuous during the initial and final stages of growth. But in the presence of Mg_1 significant increase in dry matter production was observed as K increased from K_0 to K_2 only and a further increase to K_3 did not cause any significant increase. This pattern of change was seen at each level of Mg with increasing K levels. Thus it is seen that the application of increased levels of K in the presence of Mg increased dry matter production significantly only upto K_2 level and further increasing K decreased the dry matter production especially when K_3 was combined with Mg at the highest level. Hence high levels of K and Mg in combination decreases the dry matter production of plants.

Only an initial increase in Mg increases dry matter production. Further addition of Mg is not beneficial but is seen to decrease significantly the dry matter production at all stages of growth. The initial increase in dry matter production by Mg addition also implies that S is needed for the increased dry matter production of plants since Mg was applied as Mg SO_4. Higher Mg SO_4 addition decreased dry matter production. This is because, above a certain level, growth of the plant is impaired because an excess of S contained in the plant is not metabolised to proteinaceous S (Dhillon and Dev, 1980). This may be the reason for the decrease in dry matter production at the highest level of Sul-Po-Mag application.

Thus it is seen that at low K levels, the dry matter production increased with increased addition of K and this was significant only when Mg was added at moderate levels. But at higher Mg levels, the dry matter production decreased as K application rates increased to the highest level. Similar results were obtained by Tiwari *et al.*(1982) and Narwal *et al.* (1985).

Though high rates of Mg addition decreased the dry matter production significantly, it is seen that the uptake of K is not inhibited. Thus the reduction in growth was directly caused by excessive levels of Mg and not due to a K deficiency induced by excess Mg. Sanchez Conde and Azuara (1980) have also reported that the application of Mg SO_4 decreased the dry weight of plants. Excess Mg may also interfere with the uptake of other nutrients like Zn or Mn by the plant thereby restricting plant growth (Fageria, 1983 and Kinzel, 1983).

In laterite soil, contrary to that in alluvial soil, the Sul-Po-Mag treatments did not give significantly high dry matter production when compared to the other treatments. It is also seen that though a general increase in dry matter production is seen by increasing the rate of Sul-Po-Mag application to SPM_2, statistical significance did not exist among the three treatments during the growth period of the crop.

When Mg was applied as $MgSO_4$ at different levels (Mg_0 to Mg_3), it is seen that increasing the rate of application of Mg from Mg_0 to Mg_2 increased the dry matter production significantly (Fig.11) but a further increase to higher Mg levels resulted in a significant decrease in dry matter production. This was similar to the trend observed in alluvial soil. Addition of Mg at Mg_2 level along with muriate of potash at different levels gave significantly high dry matter production than the corresponding Sul-Po-Mag treatments.

Increasing the levels of K_2O application as muriate of potash increased the dry matter production significantly from K_0 to K_2 during the initial stages and from K_0 to K_1 during the later stages of growth. Further increase in K to K_3 caused a reduction in dry matter production. Thus high K levels resulted in a decrease in dry matter production similar to the decrease in dry matter production by the application of high levels of Mg. The same trend was noticed when K and Mg were in combination. Thus increasing the K levels in the presence of moderate levels of Mg (upto Mg_2) increased the dry matter production but at higher Mg levels no significant increase in dry matter production was noticed.

Though K and Mg in combination gave significantly high dry matter production in laterite soil, the application of K + Mg as Sul-Po-Mag did not increase the dry matter production. The dry matter produced by the Sul-Po-Mag treatments were generally on par with that produced by the NPK treatments recommended by the package of practices of the Kerala Agricultural University. At all stages of growth, the highest dry matter production was for the treatment receiving K_2Mg_2. This was significantly higher than the Sul-Po-Mag treatment of comparable K and Mg.

Significant positive correlation existed between the dry matter production at different stages and N and P uptake in alluvial soil. But Mg uptake at initial stages showed negative correlation with dry matter production (Table 45). But in laterite soil the correlation between dry matter production and the nutrient uptake was not significant.

1.2 Fruit yield (Table 32)

Yield of bhindi fruits showed significant variation among the treatments in both alluvial and laterite soils. In alluvial soil, the Sul-Po-Mag treatments gave significantly higher fruit yield when compared to the treatments receiving K and Mg, with SPM_1 giving the highest yield (Fig.12). This increase in yield is also reflected in the dry matter production of the crop. The NPK treatment receiving the normal fertilizer dose recommended by the Kerala Agricultural University gave significantly lower yield when compared to the Sul-Po-Mag treatments and the treatments receiving K at different levels in combination with Mg at the lowest level (Mg_1). Thus addition of Mg at moderate levels (Mg_1) along with muriate of potash significantly increased the yield of bhindi fruits in alluvial soil, when compared to the treatments receiving K alone. The different levels of K as muriate of potash without the addition of Mg, corresponding to the three Sul-Po-Mag treatments gave significantly lower yields. But when Mg was added in addition to muriate of potash, a significant increase in yield occurred though yield did not increase to the level of the Sul-Po-Mag treatments.

The increase in yield by Sul-Po-Mag application over the muriate of potash treatments may be because of the occurrence of K as K_2SO_4 and due to the presence of Mg at levels comparable to that of K. Welte and Werner (1963) have also reported that when increasing rates of K were applied as KCl and Sul-Po-Mag, not only were yields consistently higher with the Sul-Po-Mag application, but yields were actually depressed when the highest rate of K was applied as KCl. A depression in yield of crops by KCl application when compared to K_2SO_4 application was also reported by Dibb and Thompson (1985).

As the level of application of Mg as $MgSO_4$ increased from Mg_0 to Mg_1, a significant increase in yield was observed but increasing Mg beyond that level caused significant reduction in yield in alluvial soil. This effect was more pronounced when K was not added. Here, the yields were generally low and significantly less when compared to the K applied pots. The decrease in yield with K_0 was overcome by the addition of Mg upto Mg_2 but further increasing the Mg level reduced the yield significantly. Positive beneficial effects of Mg application on the yield of vegetable crops have also been reported by Su (1969), Elamin and Wilcox (1985) and Sonneveld (1987). Thus Mg addition at moderate levels increased crop yield in the absence of K. But when K was applied at K_1 level, increasing levels of Mg did not significantly affect yield and there was a decreasing trend at higher levels of Mg application. The same trend was shown at K_2 and K_3 levels also with increasing Mg levels. Thus in general in the presence of K, increasing Mg reduced the yield of bhindi.

Increasing the level of K application increased the yield significantly upto K_2 level and thereafter showed a non significant decrease. It is also seen that at Mg_0 and Mg_1, the fruit yield increased significantly from K_0 to K_1 and on further increasing the level of K a non significant increase in yield was obtained. But as the level of Mg application was raised further it was seen that the application of high levels of K decreased yield significantly. Thus increasing the level of K from K_0 to K_3 in the presence of low levels of Mg caused a progressive increase in yield while at higher Mg

Table 32. Fruit yield and quality attributes of bhindi

Treatments	Alluvial				Laterite			
	Fruit yield (kg ha^{-1})	Crude protein (%)	Crude fibre (%)	Ascorbic acid (mg 100g^{-1})	Fruit yield (kg ha^{-1})	Crude protein (%)	Crude fibre (%)	Ascorbic acid (mg 100g^{-1})
$N_0P_0K_0Mg_0$	5810.00^{J}	17.28^{DEFGH}	14.13^{A}	17.99^{C}	5666.50^{G}	9.77^{B}	14.20^{A}	18.27^{B}
$NPSPM_1$	8400.00^{A}	21.40^{BCD}	13.34^{DEF}	19.49^{AB}	6422.50^{EF}	10.28^{B}	13.48^{CDE}	19.16^{A}
$NPSPM_2$	8330.00^{A}	14.99^{EFGH}	13.07^{F}	19.63^{AB}	7210.00^{AB}	10.98^{AB}	13.09^{E}	19.39^{A}
$NPSPM_3$	7935.00^{AB}	15.64^{EFGH}	13.40^{CDEF}	19.50^{AB}	6650.00^{DEF}	10.39^{AB}	13.41^{CDE}	19.32^{A}
NPK	7262.00^{CDE}	22.38^{ABC}	13.79^{ABCD}	19.07^{B}	6667.50^{CDEF}	11.87^{AB}	13.76^{ABC}	19.04^{A}
NPK_0Mg_0	6282.50^{J}	16.64^{DEFGH}	14.19^{A}	18.52^{C}	6282.50^{F}	11.49^{AB}	14.11^{AB}	18.74^{B}
NPK_1Mg_0	7070.00^{DEFG}	19.12^{CDEF}	13.93^{AB}	19.00^{B}	6755.00^{BCDE}	11.78^{AB}	13.86^{ABC}	19.05^{A}
NPK_2Mg_0	7210.00^{CDEF}	24.68^{AB}	13.68^{BCDE}	19.05^{B}	7140.00^{AB}	10.56^{AB}	13.56^{CDE}	19.00^{A}
NPK_3Mg_0	7490.00^{BCD}	26.54^{A}	13.29^{EF}	19.28^{AB}	6422.50^{EF}	10.08^{B}	13.49^{CDE}	19.34^{A}
NPK_0Mg_1	6720.00^{GHI}	14.64^{FGH}	13.63^{BCDE}	19.11^{B}	6825.00^{BCDE}	10.32^{B}	13.72^{BC}	18.92^{AB}
NPK_1Mg_1	7507.50^{BCD}	13.00^{GH}	13.43^{CDEF}	19.48^{AB}	7017.50^{ABCD}	10.83^{AB}	13.54^{CDE}	19.35^{A}
NPK_2Mg_1	7560.00^{BC}	16.10^{EFGH}	13.40^{CDEF}	19.97^{A}	6632.50^{DEF}	10.56^{AB}	13.40^{CDE}	19.40^{A}
NPK_3Mg_1	7682.50^{BC}	14.37^{FGH}	13.16^{F}	19.46^{AB}	6492.50^{EF}	12.30^{AB}	13.13^{E}	19.43^{A}
NPK_0Mg_2	6807.50^{EFGH}	20.08^{BCDE}	13.15^{F}	19.02^{B}	6825.00^{BCDE}	12.15^{AB}	13.19^{DE}	19.09^{A}
NPK_1Mg_2	7053.00^{DEFG}	22.95^{ABC}	13.17^{F}	19.03^{B}	7122.50^{ABC}	11.90^{AB}	13.13^{E}	18.94^{AB}
NPK_2Mg_2	7210.00^{CDEF}	16.30^{DEFGH}	13.22^{EF}	19.16^{B}	7472.50^{A}	13.85^{A}	13.14^{E}	19.15^{A}
NPK_3Mg_2	6758.00^{FGHI}	18.04^{CDEFG}	13.04^{F}	19.19^{B}	6545.00^{EF}	11.59^{AB}	13.09^{E}	19.20^{A}
NPK_0Mg_3	6475.00^{HI}	20.19^{BCDE}	13.81^{ABC}	19.18^{B}	6650.00^{DEF}	10.90^{AB}	13.65^{BCD}	19.08^{A}
NPK_1Mg_3	7070.00^{DEFG}	12.33^{HI}	13.67^{BCDE}	19.27^{AB}	6860.00^{BCDE}	12.30^{AB}	13.83^{ABC}	19.22^{A}
NPK_2Mg_3	7210.50^{CDEF}	15.31^{EFGH}	13.63^{BCDE}	19.13^{B}	5705.00^{G}	11.43^{AB}	13.65^{BCD}	19.10^{A}
NPK_3Mg_3	6475.00^{HI}	18.26^{CDEFG}	13.38^{CDEF}	19.30^{AB}	7070.00^{ABCD}	8.98^{B}	13.44^{CDE}	19.19^{A}
Levels of K								
K_0	6571.10	17.89	13.69	18.96	6645.63	11.22	13.69	18.96
K_1	7175.00	16.85	13.55	19.19	6938.75	11.70	13.59	19.14
K_2	7297.50	18.10	13.48	19.21	6737.50	11.60	13.44	19.16
K_3	7101.40	19.30	13.22	19.31	6632.50	10.71	13.22	19.28
CD (5%)	211.68	2.27	0.21	0.35	219.11	1.61	0.22	0.32
Levels of Mg								
Mg_0	7013.12	21.74	13.77	18.96	6650.00	10.98	13.75	19.03
Mg_1	7367.50	14.53	13.40	19.50	6741.88	11.33	13.45	19.27
Mg_2	6957.00	19.34	13.14	19.10	6991.25	12.37	13.13	19.09
Mg_3	6807.50	16.53	13.62	19.10	6571.25	10.90	13.64	19.15
CD (5%)	211.68	2.27	0.21	0.35	219.11	1.61	0.22	0.32
CD-K x Mg (5%)	423.35	4.54	0.42	0.70	438.21	3.22	0.43	0.644

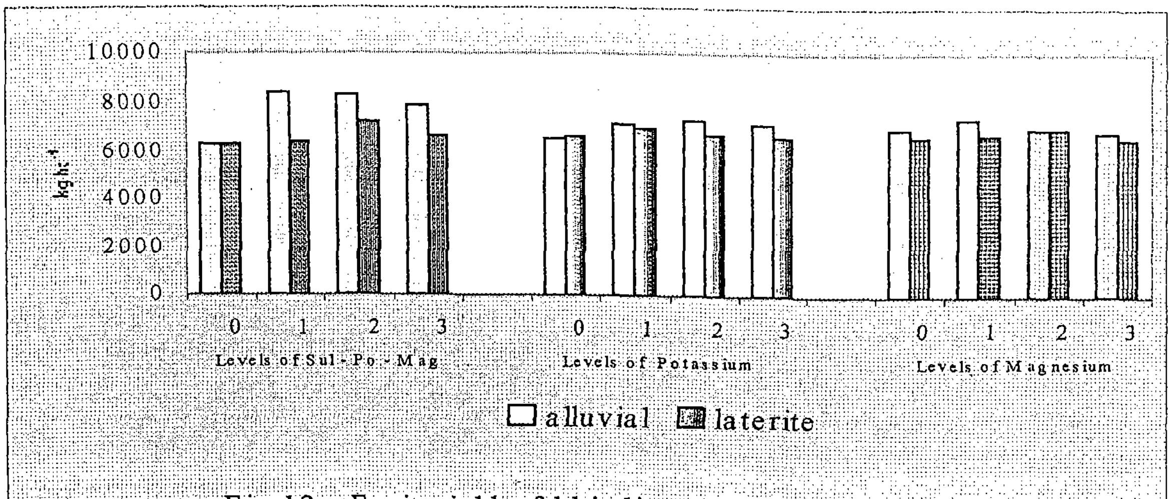


Fig.12 Fruit yield of bhindi at different levels of fertilizers

levels, increasing K to higher levels decreased yield. Thus high K and Mg results in yield reduction in alluvial soil. Positive significant influence on the yield of bhindi by K addition have also been reported by Ahmed and Reid (1968), Asif and Greig (1972) and Mani and Ramanathan (1980). A reduction in the yield of bhindi at very high levels of K has been reported by Kamalanathan *et al.*(1970) and Verma *et al.* (1970). Salmon (1964) has also reported that K addition in small quantities increased yield while large additions affected yield very little.

In laterite soil, the yields were generally lower than that in alluvial soil (Fig.12). Sul-Po-Mag at the second level (SPM_2) was found to give fruit yield significantly higher than Sul-Po-Mag at lower and higher levels. The NPK treatment gave significantly lower yield than SPM_2 but was on par with SPM_1 and SPM_3. Thus in laterite soil, Sul-Po-Mag at first level is as effective as the normal NPK recommendation.

As in alluvial soil, the addition of increased levels of Mg significantly increased the yield of bhindi upto Mg_2 and thereafter the yield was significantly reduced. Mg application at the lowest rate without the addition of K increased yield but further increasing the Mg level did not significantly increase yield. In the presence of K, increasing the level of Mg increased the yield significantly till Mg_2 but at higher K levels there was no significant increase in the yield on addition of higher levels of Mg. Thus the trend of changes in laterite soil was similar to that in alluvial soil.

Increasing the levels of K application significantly increased yield only upto K_1 and a further increase caused a reduction in yield which was significant at K_3 level. When K was applied at increasing rates without Mg application the fruit yield increased significantly upto K_2 and beyond that a significant decrease was noticed. Thus when K was applied at levels higher than the normal NPK recommendation, the yield was found to decrease in laterite soil, but the yield obtained for the different K levels without Mg application was less than that with Mg application. When Mg was applied at the lowest rate (Mg_1), a significant decrease in yield occurred when K was raised to K_3. But yield was higher than that with Mg_0. At Mg_2 also a significant reduction in yield occurred when K was raised to K_3. In the presence of Mg_3 yields were generally low and there was no significant increase as the K levels were raised. Thus application of K and Mg at high rates decreased significantly the yield of *bhindi* in laterite soil and application of moderate levels of Mg with K increased the yield.

In alluvial soil fruit yield was positively and significantly correlated with nutrient uptake but in laterite soil, significant correlation did not exist between fruit yield and nutrient uptake (Table 45).

2.3.Crude protein (Table 32)

In alluvial soil, increasing the rate of Sul-Po-Mag application resulted in a significant decrease in the crude protein content of fruits. The NPK treatment gave crude protein on par with the lowest Sul-Po-Mag treatment (SPM_1) and significantly higher than the Sul-Po-Mag treatments at higher levels (SPM_2 and SPM_3). The treatments receiving K as muriate of potash also gave crude protein on par with the NPK treatment. Thus the decrease in crude protein for the Sul-Po-Mag or K+Mg treatments at higher levels might be due to an increase in Mg or S.

The different K levels did not show significant effect on crude protein content. But when K was applied at increasing rates without Mg, the crude protein also increased and a significant increase was observed when K was raised to K_2 and higher level. Chandrasekharan (1965) has also reported that crude protein increased with K application in bhindi. This increasing trend was not observed when different levels of Mg were applied along with muriate of potash. Thus the application of Mg generally decreased significantly the crude protein content of harvested fruits. This may be the reason for the decrease in crude protein for the Sul-Po-Mag treatments.

In laterite soil, the different treatments did not seem to affect significantly the crude protein of fruits. The Sul-Po-Mag treatment at different levels were on par with each other and with the treatments receiving N, P and K with no Mg. Treatments receiving K and Mg at equal levels and equivalent to the level of K and Mg in the respective Sul-Po-Mag treatments were also on par in their crude protein content. Thus, increasing the levels of K or Mg did not significantly affect the crude protein of fruits in laterite soil.

Marschner (1986) has reported that addition of S increases the protein content. But in this study, though Sul-Po-Mag and $MgSO_4$ contain S, no increase in crude protein was noticed and in alluvial soil, application of Sul-Po-Mag or $MgSO_4$ actually decreased the crude protein content.

2.4.Crude fibre (Table 32)

In alluvial soil, Sul-Po-Mag application decreased significantly the crude fibre of fruits when compared to the NPK treatment. Addition of Mg as $MgSO_4$ also caused a significant decrease in the crude fibre content. But increasing the Sul-Po-Mag levels did not significantly affect the crude fibre of fruits. Increasing the rate of application of K also progressively and significantly decreased the crude fibre. The magnitude of decrease was increased in the presence of low levels of Mg. Though Mg addition decreased the crude fibre content, increasing the Mg level did not cause any significant reduction. Thus increased levels of K or Mg decreases crude fibre of fruits.

In laterite soil also the crude fibre content of fruits was found to decrease significantly with Mg addition. Increased levels of K application also decreased the crude fibre content significantly upto K_3. The three Sul-Po-Mag treatments were on par with each other and with the NPK treatment in the crude fibre content of fruits. As in alluvial soil, the decrease in crude fibre with increase in K application was found to be significant especially when K was in combination with Mg. Since the treatments without Mg or K gave significantly high crude fibre content than the Sul-Po-Mag or $K+Mg_2$ treatments, it can be concluded that addition of Mg cause a reduction in crude fibre. A negative correlation existed between crude fibre and nutrient uptake in both soils but generally there was no significance (Table 45).

2.5.Ascorbic acid (Table 32)

In alluvial soil, the three Sul-Po-Mag treatments and the treatment receiving NPK as recommended by the Kerala Agricultural University were on par in the ascorbic acid content of fruits. But the treatments receiving no fertilizers or only N and P without K gave significantly low ascorbic acid. A general increase in ascorbic acid was observed as K levels increased, but there was no significance. Increasing the level of Mg from Mg_0 to Mg_1 increased significantly the ascorbic acid content of fruits but further increasing the rate of Mg addition caused a significant decrease. At all levels of Mg, as the K application rate increased, the ascorbic acid content also showed an increasing trend. It is also seen that the application of Mg at the lowest level (Mg_1), without K addition significantly increased the ascorbic acid content. Further increasing the Mg level did not cause any significant effect. But in the presence of K, increasing the Mg level did not decrease the ascorbic acid content of fruits significantly. Thus the addition of K and Mg increased the ascorbic acid content of bhindi fruits.

As in alluvial soil, in laterite soil also the ascorbic acid content was on par for all the treatments except for the treatment receiving no K or Mg and these registered significantly low values. Application of K either as Sul-Po-Mag or as muriate of potash increased the ascorbic acid content. Increasing the K levels or the Mg levels did not significantly increase the ascorbic acid. The interaction between K and Mg also was not significant in laterite soil. Rani (1993) has also reported that in the presence of marginal levels of K, the ascorbic acid content of bhindi fruits is reduced. The reduction in ascorbic acid content due to the deficiency of K may be due to the involvement of K in the physiological processes leading to the synthesis of ascorbic acid.

In both alluvial and laterite soils, sulphur uptake was positively and significantly correlated with the ascorbic acid content of fruits (Table 45).

2. *Nutrient uptake by bhindi at different stages of growth*

The uptake of different nutrients by bhindi from the alluvial and laterite soils due to the application of the different treatments is presented and discussed below.

3.1. Nitrogen (Table 33)

Nitrogen uptake by bhindi grown in alluvial soil generally increased as growth of the crop progressed. During the initial stages, though the Sul-Po-Mag treatment at the lower level gave significantly higher N uptake values than the higher Sul-Po-Mag treatments, the uptake was found to decrease during the later stages. The higher levels of Sul-Po-Mag (SPM_2 and SPM_3), did not differ significantly in N uptake throughout the crop growth period. Thus increasing Sul-Po-Mag to levels beyond SPM_2 does not significantly affect the N uptake. The Sul-Po-Mag treatments registered higher N uptake values than the muriate of potash or the K+Mg treatments especially during the later stages of growth.

Thus higher levels of Sul-Po-Mag also showed a negative effect on N uptake especially at two months after planting. Application of Mg as $MgSO_4$ decreased the uptake of N by the crop. Similar results were reported by Kumar *et al.* (1981) who reported that increasing Mg caused a decrease in N uptake of plants.

As the level of K application as muriate of potash increased, the N uptake was also found to increase significantly upto K_2 and then showed a significant decrease as K application increased further.

The interaction between different levels of K and Mg was also found to be significant. As the level of Mg application increased without K addition the N uptake was found to decrease significantly at one month after planting but during the later stages such a consistent variation did not occur. The decrease in N uptake with Mg application was also noticed at K_1 during the initial stages of growth but during the later stages, as Mg application increased, N uptake also showed an increase. The decrease in N uptake with increased levels of Mg application during the initial stages of growth might be because of the decrease in dry matter production associated with high Mg.

It is seen that at Mg_0, increasing the K levels though decreased the N uptake at the initial stages, showed an increasing trend at two months after planting. At the later stages of growth, increasing the levels of K did not significantly influence N uptake. Thus increasing the K levels did not produce any consistent effect on N uptake. But increasing the level of K beyond K_2 in the presence of Mg significantly decreased the N uptake of the crop in alluvial soil.

When Mg was applied as Sul-Po-Mag, the N uptake was significantly higher than when a corresponding level of Mg and K were applied as $MgS0_4$ and K_2O respectively. This can be due to the effect of KCl application due to which the Cl^- ions might have interfered with the uptake of N when compared to sulphate. Thus for increased N uptake, K should be applied in the sulphate form. A similar decrease in N uptake by the application of KCl when compared to K_2SO_4 was also reported by Loue'(1985). Thus in alluvial soil, the application of K as K_2SO_4 increased the uptake of N when compared to KCl. But increasing the levels of K or Mg did not bring about a consistent variation in the N uptake by the bhindi crop.

In the laterite soil, the Sul-Po-Mag treatments gave significantly lower N uptake values especially with higher levels of application when compared to the MOP + Mg treatments at moderate levels (Mg_2) throughout the growth period. But the N uptake values were on par for the NPK treatment with the SPM_1,

Table 33. Nitrogen uptake by bhindi at different stages (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	0.89^{H}	11.85^{GHIJ}	14.10^{J}	0.63^{I}	4.44^{H}	9.62^{F}
$NPSPM_1$	1.85^{A}	21.64^{A}	20.59^{FGH}	1.20^{DEFG}	7.79^{DE}	10.72^{DEF}
$NPSPM_2$	1.54^{BC}	15.09^{DEF}	28.72^{AB}	0.77^{HI}	7.71^{DE}	12.22^{CDEF}
$NPSPM_3$	1.38^{CDEFG}	15.29^{DE}	29.25^{A}	1.12^{FGH}	6.81^{EFG}	9.29^{F}
NPK	1.57^{BC}	16.12^{CDE}	24.20^{BCDEF}	1.56^{CD}	8.87^{D}	13.52^{CD}
NPK_0Mg_0	1.52^{BCD}	11.92^{GHIJ}	25.48^{ABCDE}	0.99^{GH}	12.18^{BC}	13.17^{CDE}
NPK_1Mg_0	1.36^{CDEFG}	13.88^{DEFG}	20.84^{EFGH}	1.54^{CDE}	8.97^{D}	12.11^{CDEF}
NPK_2Mg_0	1.24^{FG}	18.64^{BC}	15.90^{IJ}	2.17^{A}	12.74^{ABC}	20.05^{B}
NPK_3Mg_0	1.36^{CDEFG}	20.17^{AB}	26.20^{ABCD}	1.54^{CDE}	5.99^{FG}	10.49^{EF}
NPK_0Mg_1	1.31^{DEFG}	11.44^{GHIJ}	18.21^{HIJ}	1.56^{CD}	7.74^{DE}	11.25^{DEF}
NPK_1Mg_1	1.43^{CDEF}	10.06^{IJ}	25.46^{ABCDE}	2.00^{AB}	13.37^{AB}	14.88^{C}
NPK_2Mg_1	1.77^{A}	13.61^{EFGH}	23.66^{CDEFG}	1.44^{DEF}	6.59^{EFG}	10.06^{DEF}
NPK_3Mg_1	1.68^{AB}	13.01^{EFGHI}	19.25^{GHI}	1.83^{ABC}	8.80^{D}	12.16^{CDEF}
NPK_0Mg_2	1.30^{EFG}	14.32^{DEFG}	20.72^{EFGH}	1.98^{AB}	11.84^{C}	21.27^{AB}
NPK_1Mg_2	1.47^{CDE}	16.79^{CD}	23.33^{CDEFG}	1.80^{BC}	11.55^{C}	22.00^{AB}
NPK_2Mg_2	1.37^{CDEFG}	10.69^{HIJ}	22.52^{DEFGH}	2.18^{A}	13.85^{A}	23.88^{A}
NPK_3Mg_2	1.17^{G}	9.77^{J}	19.42^{FGHI}	0.95^{GHI}	7.11^{EF}	13.07^{CDE}
NPK_0Mg_3	1.28^{EFG}	14.20^{DEFG}	19.42^{FGHI}	1.32^{DEFG}	5.59^{GH}	10.06^{F}
NPK_1Mg_3	1.31^{DEFG}	9.05^{J}	21.35^{EFGH}	1.43^{DEF}	6.44^{EFG}	13.15^{CDE}
NPK_2Mg_3	1.41^{CDEF}	12.00^{FGHIJ}	27.78^{ABC}	1.10^{FGH}	6.89^{EFG}	11.54^{DEF}
NPK_3Mg_3	1.21^{FG}	9.38^{J}	22.92^{DEFGH}	1.19^{EFG}	7.76^{DE}	10.21^{EF}
Levels of K						
K_0	1.35	12.97	20.95	1.46	9.34	13.93
K_1	1.39	12.44	22.74	1.69	10.08	15.53
K_2	1.44	13.73	22.46	1.72	10.02	16.63
K_3	1.35	13.08	21.95	1.38	7.41	11.48
CD (5%)	0.08	1.13	1.72	0.133	0.54	1.05
Levels of Mg						
Mg_0	1.37	16.15	22.10	1.56	9.97	13.95
Mg_1	1.55	12.03	21.65	1.71	9.12	12.34
Mg_2	1.33	12.89	21.49	1.73	11.09	20.05
Mg_3	1.30	11.15	22.86	1.26	6.67	11.24
CD (5%)	0.08	1.13	1.72	0.133	0.54	1.05
CD-K x Mg (5%)	0.15	2.26	3.45	0.265	1.08	2.11

m.a.p.– Months after planting

and SPM_2 treatments. Contrary to that in alluvial soil, the addition of Mg significantly increased the N uptake values.

Application of K as KCl along with $MgSO_4$ gave higher N uptake values at moderate levels of these nutrients than the application of K and Mg as Sul-Po-Mag. Thus in laterite soil, application of Sul-Po-Mag does not cause an increase the N uptake values contrary to that in alluvial soil where lower levels of Sul-Po-Mag gave increased N uptake.

As the level of K application increased, the N uptake also increased significantly at all stages but increasing K beyond K_2 level either as Sul-Po-Mag or as muriate of potash caused a reduction in the N uptake values which was significant when muriate of potash was used as the K source. An increase in N uptake by the addition of K at moderate levels was also reported by Singh and Singh (1987), Hegde and Srinivas (1991) and Menon and Marykutty (1993) in different crops. The positive effect of K on the absorption of N may be attributed to the ability of K to decrease N fixation in soils. But K application at higher levels was found to decrease significantly the N uptake. This decrease in uptake at higher rates of K was also noticed when Mg was applied at different levels. But at the highest level of Mg, increasing the K levels does not significantly affect N uptake though the N uptake was found to be lower compared to Mg application at moderate levels (Mg_2 and Mg_1).

Wicke (1968) has observed that a limitation of K^+ ions even in the presence of relatively high levels of N and P fertilizer will inhibit the uptake and utilization of N. But in this study, it is seen that an absence of K in the presence of N and P does not significantly affect N uptake since the values were equivalent to or higher than the NPK treatment from two months after planting onwards. The data on K uptake show that the values for the no K applied plots with N and P application were not significantly lower than the K applied ones. This may be the reason attributed to the fact that though K is not applied, the N uptake is not hindered.

3.2 Phosphorus (Table 34)

In alluvial soil, the Sul-Po-Mag treatments gave significantly high P uptake values but with incremental addition of Sul-Po-Mag, the P uptake decreased significantly. The NPK treatment receiving fertilizer dose as recommended by the package of practices, KAU gave P uptake values on par with SPM_3 and significantly less than SPM_1 and SPM_2 throughout the growth period.

Application of increasing levels of K resulted in increased P uptake values which was significant only upto K_2 level at two and three months after planting. Higher K levels, thus does not cause significant positive effect on the P uptake of bhindi crop, but is seen to decrease uptake. Similar results were obtained by Fageria (1983), Rajdhar (1989), Sheela and Arvindakshan (1990) and Sindu (1997) who reported that heavy application of K decreased P absorption by the plant.

Increasing the levels of K without Mg application resulted in a significant increase in P especially as growth progressed from the early to the later stages. When Mg was applied with increasing levels of K, no significant change was observed in the P uptake values. In the absence of Mg, an increase in P

Table 34. Phosphorus uptake by bhindi at different stages (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	0.55^{E}	0.97^{F}	2.11^{EFG}	0.06^{J}	1.21^{GH}	2.12^{I}
$NPSPM_1$	0.14^{A}	1.95^{A}	3.56^{A}	0.12^{H}	1.55^{BC}	2.96^{AB}
$NPSPM_2$	0.13^{AB}	1.84^{A}	3.49^{A}	0.17^{CDEF}	1.49^{BCD}	2.84^{ABCD}
$NPSPM_3$	0.10^{CD}	1.43^{BC}	2.73^{BC}	0.18^{CDE}	1.30^{DEFGH}	2.55^{DEFGH}
NPK	0.10^{CD}	1.47^{B}	2.81^{B}	0.12^{H}	1.27^{DEFGH}	2.48^{EFGH}
NPK_0Mg_0	0.10^{CD}	1.09^{EF}	2.33^{CDEFG}	0.08^{I}	1.56^{BC}	2.92^{ABC}
NPK_1Mg_0	0.10^{CD}	1.39^{BCDE}	2.64^{CDEF}	0.19^{CD}	1.18^{H}	2.31^{GHI}
NPK_2Mg_0	0.09^{D}	1.87^{A}	3.52^{A}	0.17^{CDEF}	1.84^{A}	2.52^{EFGH}
NPK_3Mg_0	0.11^{BC}	1.74^{A}	3.19^{A}	0.15^{EFGH}	1.19^{H}	2.22^{HI}
NPK_0Mg_1	0.09^{D}	1.05^{F}	1.94^{G}	0.15^{EFGH}	1.25^{GH}	2.43^{FGHI}
NPK_1Mg_1	0.10^{CD}	1.14^{CDEF}	2.15^{DEFG}	0.20^{BC}	1.65^{AB}	3.01^{A}
NPK_2Mg_1	0.12^{AB}	1.40^{BCD}	2.55^{BCD}	0.16^{DEFG}	$1.45^{BCDEFGH}$	2.83^{ABCD}
NPK_3Mg_1	0.12^{B}	1.21^{BCDEF}	2.49^{BCDE}	0.16^{DEF}	1.29^{DEFGH}	2.60^{CDEFG}
NPK_0Mg_2	0.10^{CD}	1.11^{DEF}	2.03^{FG}	0.22^{AB}	1.37^{CDEFGH}	$2.68^{ABCDEFH}$
NPK_1Mg_2	0.10^{CD}	1.37^{BCDE}	2.51^{BCDE}	0.19^{CD}	1.47^{BCDEF}	2.79^{ABCDE}
NPK_2Mg_2	0.09^{D}	1.33^{BCDEF}	2.32^{CDEFG}	0.25^{A}	1.48^{BCDE}	2.84^{ABCD}
NPK_3Mg_2	0.09^{D}	1.30^{BCDEF}	2.45^{BCDE}	0.14^{FGH}	1.36^{CDEFGH}	2.64^{BCDEFG}
NPK_0Mg_3	0.09^{D}	1.22^{BCDEF}	2.38^{BCDEF}	0.13^{GH}	1.19^{H}	2.42^{FGHI}
NPK_1Mg_3	0.10^{CD}	1.38^{BCDE}	2.69^{BC}	0.13^{H}	1.24^{EFGH}	2.39^{FGHI}
NPK_2Mg_3	0.10^{CD}	1.33^{BCDEF}	2.64^{BC}	0.18^{CDEF}	1.28^{DEFGH}	2.50^{EFGH}
NPK_3Mg_3	0.10^{CD}	1.27^{BCDEF}	2.48^{BCDE}	0.15^{EFGH}	1.24^{FGH}	2.42^{FGHI}
Levels of K						
K_0	0.095	1.12	2.17	0.15	1.33	2.61
K_1	0.098	1.32	2.43	0.18	1.38	2.62
K_2	0.101	1.45	2.76	0.19	1.51	2.67
K_3	0.108	1.38	2.65	0.15	1.27	2.47
CD (5%)	0.007	0.11	0.15	0.012	0.083	0.12
Levels of Mg						
Mg_0	0.102	1.52	2.85	0.15	1.44	2.49
Mg_1	0.110	1.20	2.28	0.17	1.40	2.71
Mg_2	0.093	1.24	2.33	0.20	1.42	2.74
Mg_3	0.096	1.30	2.55	0.15	1.24	2.43
CD (5%)	0.007	0.11	0.15	0.012	0.083	0.12
CD-K x Mg (5%)	0.014	0.22	0.30	0.023	0.167	0.25

m.a.p. – Months after planting

uptake was possible by the addition of increasing K levels but by the addition of Mg_1, significant increase in P uptake did not occur at any level of K. Thus Mg addition decreases the uptake of P by the plant. The application of high rates of Mg decreased the favourable effect of K on P uptake and hence Mg is seen to have an antagonistic effect on P uptake. This is in contrast with the results of Waddrowska and Jania (1951) and Jacob (1958) who reported that Mg has a favourable effect on P uptake since it acts as a carrier of P in plants. This reduction in P uptake inspite of increased P availability due to the addition of increased levels of Mg as Sul-Po-Mag or $MgSO_4$ might be due to the interference of SO_4^{2-} ions on the absorption of P by the plant.

In the laterite soil, the Sul-Po-Mag treatments at moderate levels (SPM_1 and SPM_2) gave significantly high P uptake values. As the level of Sul-Po-Mag application increased, a decrease in P uptake was observed especially during the later stages. The NPK treatment receiving fertilizer dose as recommended by the package of practices, Kerala Agricultural University, gave uptake values lower than the Sul-Po-Mag treatments in general but on par with SPM_3.

Increasing levels of K from K_0 to K_2 increased the P uptake at all stages and a further increase caused a reduction in uptake similar to that in alluvial soil. It was also seen that P uptake was not affected in the absence of K and Mg after the early growth period since K_0Mg_0 treatment applied with N and P gave comparatively higher P uptake values. The NPK_0Mg_0 treatment gave significantly higher P uptake values than the NPK treatment and on par with SPM_1 and SPM_2. Addition of increased levels of K without the application of Mg did not bring about a consistent effect on P uptake. Increasing the levels of Mg application without K addition also showed an inconsistent effect on P uptake. But K and Mg were found to interact significantly so as to affect the P uptake by the plant. At different levels of Mg (Mg_1 and Mg_3) , increasing the K levels increased significantly the P uptake values upto K_2 and a further increase in K caused a reduction in uptake. Increasing the Mg application rates upto Mg_2 at different levels of K also caused a significant increase in P uptake. But higher Mg levels significantly reduced uptake.

Hence in laterite soil though K or Mg alone did not bring about a consistent effect on P uptake, when applied together, they interacted to give significant effects. Thus the application of Mg_2 with different levels of K gave higher P uptake values on par with the Sul-Po-Mag treatments. But since the K_0Mg_0 treatment also recorded higher uptake values, it can be concluded that for proper P uptake, K or Mg does not play a significant role.

Since the application of Sul-Po-Mag at the highest level (SPM_3) and muriate of potash + $MgSO_4$ (Mg_3) gave significantly lower values for P uptake, when compared to the moderate Mg levels, it can be inferred that high application of $MgSO_4$ will lead to a reduction in the P uptake values.

Thus it is seen that though moderate levels of Sul-Po-Mag or Mg does not cause any significant increase in P uptake, their increased use can reduce the uptake values significantly. But K application is not found to significantly affect P uptake. Wicke (1968) also has reported that heavy application of K does not affect P uptake.

3.3 Potassium (Table 35)

Increasing the level of Sul-Po-Mag in alluvial soil increased the uptake of K throughout the growth period (Fig.13) but significant increase occurred only from two months after planting. SPM_1 gave significantly low K uptake values than the higher Sul-Po-Mag levels. It was seen that K uptake by the Sul-Po-Mag treated plants were in general higher than the muriate of potash treated ones. Similar results were obtained by Loue' (1985) who reported an increase in K^+ in the $K_2 SO_4$ treated plants. Increasing the K application rate as muriate of potash also increased the K uptake significantly. Similar increase in K uptake with increase in K application was reported by Harrison and Bergman (1981) and Sudhir *et al.* (1987). As the level of Mg application increased, the K uptake also increased contrary to the reports that K and Mg are antagonistic. Thus Mg might have diminished only the solution concentration of K in soil and not the uptake.

Significant interaction existed among the different levels of K and Mg. When K was applied at increasing rates without Mg, though K uptake increased upto K_3, significant increase occurred only from K_0 to K_1 and thereafter the different K levels were on par. Application of Mg at different levels also gave the same trend with increasing levels of K. Thus at a constant Mg level, increasing K above K_1 does not significantly increase uptake.

When Mg was applied at increasing rates either without K application or in the presence of K_1 no significant effect was noticed on the K uptake. But at higher levels of K, a significant increase in the K uptake was noticed as Mg levels were increased. Thus significant positive interaction occurred between K and Mg on the uptake of K. It was also observed that the treatments receiving Sul-Po-Mag and K + Mg at higher levels gave significantly higher K uptake values than the treatments receiving no Mg. Thus addition of Mg either as Sul-Po-Mag or as $MgSO_4$ favoured the uptake of K. Similar results were reported by Grant and Racz (1987) who observed an increase in K as Mg increased. This increase in K in tissue with increasing Mg might be because of the decreased dry matter production associated with high Mg. Since Sul-Po-Mag and $MgSO_4$ contains S, the increased S in soil might also have favoured K uptake. An increase in K uptake with increasing S level was also reported by Singh and Singh (1992) and Jaggi *et al.* (1995).

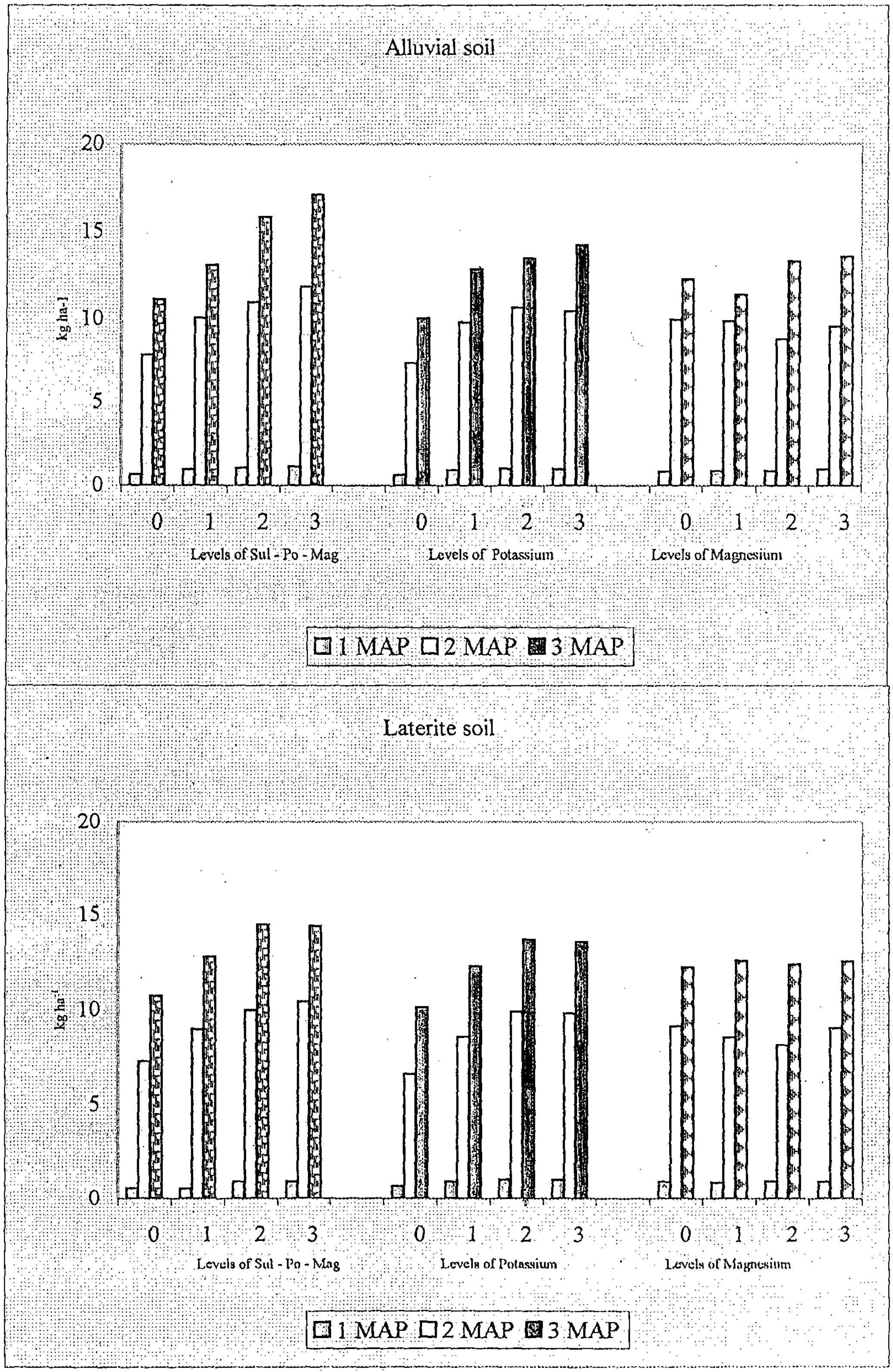
In laterite soil also application of Sul-Po-Mag gave higher K uptake values which were on par with the treatments receiving K + Mg. Increasing the Sul-Po-Mag levels significantly increased the K uptake only during the early stages of growth. During the later stages, the increase in K uptake was not significant. As the level of Sul-Po-Mag increased from SPM_2 to SPM_3, the magnitude of increase showed a decrease. But it is seen that the NPK treatment also gave K uptake values on par with in the SPM_2 and SPM_3 treatments and the different levels of K + Mg treatments at all stages of growth. It is also seen that in the absence of Mg, increased K levels gave significantly high K uptake values. The different Mg levels did not show significant effect on K uptake but increasing the K levels significantly increased the K uptake at all stages of growth.

Thus it is evident that Mg did not interfere in the uptake of K by the plant in laterite soil as

Table 35. Potassium uptake by bhindi at different stages (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	0.55^{I}	7.00^{HI}	9.01^{I}	0.38^{E}	6.48^{F}	9.75^{EF}
$NPSPM_1$	1.00^{CDEF}	10.05^{CDEFG}	13.11^{CDEF}	0.54^{DE}	8.99^{BCD}	12.73^{ABCD}
$NPSPM_2$	1.06^{ABCD}	10.95^{ABCD}	15.85^{AB}	0.90^{ABC}	9.98^{ABCD}	14.47^{AB}
$NPSPM_3$	1.14^{ABC}	11.85^{A}	17.11^{A}	0.91^{ABC}	10.43^{AB}	14.38^{ABC}
NPK	0.85^{G}	9.91^{DEFG}	12.78^{CDEF}	0.89^{ABCD}	9.30^{ABCD}	11.96^{BCDE}
NPK_0Mg_0	0.71^{H}	7.85^{H}	11.13^{FGH}	0.57^{CDE}	7.26^{F}	10.72^{DEF}
NPK_1Mg_0	0.92^{EFG}	10.41^{BCDEF}	12.55^{DEF}	1.00^{A}	9.17^{ABCD}	11.40^{DEF}
NPK_2Mg_0	0.90^{FG}	11.23^{ABC}	12.17^{EF}	1.01^{A}	10.22^{ABC}	12.73^{ABCD}
NPK_3Mg_0	0.96^{DEFG}	10.26^{BCDEF}	13.27^{CDEF}	1.04^{A}	9.92^{ABCD}	13.96^{ABC}
NPK_0Mg_1	0.64^{HI}	7.97^{H}	9.23^{HI}	0.62^{BCDE}	6.41^{F}	9.89^{EF}
NPK_1Mg_1	0.91^{EFG}	10.15^{CDEFG}	11.68^{FG}	0.81^{ABCD}	8.69^{DE}	13.26^{ABC}
NPK_2Mg_1	1.09^{ABCD}	10.78^{ABCDE}	12.27^{EF}	1.06^{A}	9.68^{ABCD}	14.84^{A}
NPK_3Mg_1	0.91^{EFG}	10.54^{BCDEF}	13.38^{DEF}	1.00^{A}	9.42^{ABCD}	12.18^{BCDE}
NPK_0Mg_2	0.71^{H}	7.04^{HI}	10.10^{GHI}	0.87^{ABCD}	6.41^{F}	9.36^{F}
NPK_1Mg_2	0.91^{EFG}	9.04^{G}	12.96^{CDEF}	0.94^{AB}	7.60^{EF}	12.39^{ABCD}
NPK_2Mg_2	1.04^{BCDE}	9.70^{EFG}	14.48^{BCD}	1.01^{A}	9.09^{BCD}	13.27^{ABC}
NPK_3Mg_2	1.01^{BCDEF}	9.48^{FG}	15.67^{AB}	0.96^{AB}	9.42^{ABCD}	14.30^{ABC}
NPK_0Mg_3	0.67^{H}	6.52^{I}	9.60^{HI}	0.74^{BCDE}	6.25^{F}	10.54^{DEF}
NPK_1Mg_3	1.04^{BCDE}	9.43^{FG}	14.13^{BCDE}	0.92^{ABC}	8.82^{CDE}	11.89^{CDE}
NPK_2Mg_3	1.14^{AB}	10.79^{ABCDE}	14.87^{BC}	1.02^{A}	10.64^{A}	13.81^{ABC}
NPK_3Mg_3	1.19^{A}	11.41^{AB}	15.64^{AB}	1.05^{A}	10.46^{AB}	13.76^{ABC}
Levels of K						
K_0	0.68	7.34	10.01	0.67	6.58	10.13
K_1	0.94	9.76	12.83	0.92	8.57	12.23
K_2	1.04	10.63	13.45	1.02	9.90	13.66
K_3	1.01	10.42	14.24	1.01	9.80	13.55
CD (5%)	0.05	0.43	0.78	0.131	0.522	0.91
Levels of Mg						
Mg_0	0.87	9.94	12.28	0.90	9.14	12.20
Mg_1	0.89	9.86	11.39	0.87	8.55	12.54
Mg_2	0.92	8.81	13.30	0.94	8.13	12.33
Mg_3	1.01	9.54	13.56	0.90	9.04	12.50
CD (5%)	0.05	0.43	0.78	0.131	0.522	0.91
CD-K x Mg (5%)	0.10	0.87	1.55	0.262	1.044	1.81

m.a.p.– Months after planting



MAP – Months after planting

Fig. 13 Uptake of potassium by bhindi at different levels of fertilizers compared to the alluvial soil. Subramaniam *et al.* (1976) also has reported that Mg does not affect the uptake of K by plants. But it is seen that high Mg application along with no or low K (K_0 and K_1) significantly reduced uptake. Thus the antagonistic effect of Mg on K uptake existed at low or marginal K levels in laterite soil but in alluvial soil even at low K levels, high Mg did not reduce uptake. Ananthanarayana and Rao (1979) have also reported that the antagonistic effect of Mg or K is mainly on solution concentration rather than on uptake.

3.4 Calcium (Table 36)

In alluvial soil, application of increased levels of Sul-Po-Mag did not produce a significant effect on the uptake of calcium by bhindi though a decreasing trend was noticed. The NPK treatment receiving no Mg also gave calcium uptake values on par with the Sul-Po-Mag treatments. Thus the presence of Mg in SPM did not hinder the uptake of calcium by the plant.

Increasing the K levels did not bring about a consistent change in the calcium uptake values during the initial stages but significantly reduced the uptake during later stages especially in the absence of Mg. Similar results were reported by Fageria (1983) and Narwal *et al.* (1985) who found an antagonistic effect of K application on calcium uptake. When applied with high levels of Mg though higher levels of K caused a reduction in the calcium uptake, no significant decrease was generally obtained.

It is seen that addition of $MgSO_4$ at increased levels decreased the calcium uptake significantly at one and two months after planting. Thus increased Mg levels must have hindered the absorption of calcium by the plant due to the action of the Ca-Mg antagonistic effect. Such antagonism of Mg on the uptake of calcium was also reported by Kumar *et al.* (1981). It is also seen that the antagonistic effect of increased levels of Mg occurred only in the absence of K. In the presence of increased levels of K, the antagonism of Mg on calcium was overcome. Ananthanarayana and Rao (1979) have also reported that the depressing effect of Mg on Ca uptake was apparent only when the absolute amounts of K and Ca were low. The decrease in tissue concentration and uptake of Ca with increasing concentration of Mg is presumably due to the replacement of Mg for Ca for the neutralisation of negative charges within the vacuole and on the exchange sites in the apoplast of the plant cell.

In laterite soil also increasing the level of Sul-Po-Mag did not significantly affect the calcium uptake values. The NPK treatment was on par with the Sul-Po-Mag treatments in calcium uptake.

Increasing the level of K application did not bring about a consistent effect on the calcium uptake by bhindi in laterite soil. Thus in the absence of Mg also incremental addition of K did not cause any significant effect on calcium uptake.

As in alluvial soil Mg at low levels did not significantly affect the calcium absorption by the plant in laterite soil but increasing Mg to higher levels (Mg_3) significantly decreased uptake especially when Mg_3 was in combination with high levels of K. Thus high levels of K associated with high Mg levels significantly reduced calcium uptake in laterite soil, but high K or Mg alone does not produce significant effect on calcium uptake.

Table 36. Calcium uptake by bhindi at different stages (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	0.67^{F}	13.90^{CDE}	16.94^{E}	0.56^{I}	7.39^{H}	8.01^{E}
$NPSPM_1$	1.07^{BC}	18.96^{A}	23.47^{AB}	0.95^{CDE}	8.71^{GH}	19.10^{ABC}
$NPSPM_2$	1.06^{BC}	15.90^{ABC}	19.63^{BCDE}	0.93^{CDE}	11.16^{DEFG}	18.24^{ABCD}
$NPSPM_3$	1.06^{BC}	16.11^{ABC}	18.04^{DE}	0.97^{BCD}	11.71^{CDEF}	16.03^{BCD}
NPK	1.01^{BCD}	11.86^{DE}	22.35^{ABCD}	0.93^{CDE}	13.12^{ABCDE}	16.83^{BCD}
NPK_0Mg_0	1.14^{AB}	18.16^{A}	26.78^{A}	0.75^{FGH}	14.80^{ABC}	19.46^{ABC}
NPK_1Mg_0	1.20^{AB}	15.21^{ABCD}	21.01^{BCDE}	1.08^{ABC}	13.76^{ABCD}	19.71^{ABC}
NPK_2Mg_0	1.07^{BC}	18.00^{AB}	21.53^{BCDE}	1.02^{BCD}	11.08^{DEFG}	17.04^{BCD}
NPK_3Mg_0	1.29^{A}	16.55^{ABC}	21.52^{BCDE}	1.18^{A}	10.09^{EFGH}	18.12^{ABCD}
NPK_0Mg_1	0.90^{CDE}	11.18^{E}	22.95^{ABC}	0.93^{CDE}	8.86^{FGH}	16.68^{BCD}
NPK_1Mg_1	0.99^{BCDE}	14.17^{BCDE}	21.82^{BCDE}	1.01^{BCD}	14.73^{ABC}	19.71^{ABC}
NPK_2Mg_1	1.14^{AB}	18.21^{A}	21.19^{BCDE}	1.17^{A}	14.50^{ABCD}	16.29^{BCD}
NPK_3Mg_1	1.16^{AB}	12.75^{CDE}	20.20^{BCDE}	1.11^{AB}	10.03^{EFGH}	19.59^{ABC}
NPK_0Mg_2	0.84^{DEF}	13.07^{CDE}	19.86^{BCDE}	0.72^{GH}	14.82^{ABC}	16.10^{BCD}
NPK_1Mg_2	1.04^{BCD}	16.42^{ABC}	22.70^{ABCD}	0.86^{DEFG}	15.38^{A}	21.27^{A}
NPK_2Mg_2	1.07^{BC}	13.06^{CDE}	18.47^{CDE}	0.96^{BCD}	15.04^{AB}	19.77^{AB}
NPK_3Mg_2	1.04^{BCD}	10.66^{EF}	18.08^{CDE}	0.97^{BCD}	11.91^{BCDEF}	21.24^{A}
NPK_0Mg_3	0.81^{EF}	10.34^{EF}	21.28^{BCDE}	0.69^{HI}	8.13^{GH}	20.46^{ABC}
NPK_1Mg_3	0.92^{CDE}	14.17^{BCDE}	20.29^{BCDE}	0.80^{EFGH}	10.52^{EFGH}	18.78^{ABC}
NPK_2Mg_3	1.03^{BCD}	13.01^{CDE}	18.87^{BCDE}	0.85^{DEF}	9.86^{FGH}	15.75^{CD}
NPK_3Mg_3	1.00^{BCDE}	11.79^{DE}	17.12^{E}	0.87^{DEFG}	11.31^{DEFG}	14.83^{D}
Levels of K						
K_0	0.92	13.19	22.71	0.77	11.65	17.83
K_1	1.03	14.99	21.45	0.94	13.59	19.87
K_2	1.07	15.57	20.01	1.00	12.54	17.21
K_3	1.12	13.19	19.23	1.03	10.83	18.45
CD (5%)	0.072	1.41	1.71	0.057	1.145	1.40
Levels of Mg						
Mg_0	1.17	16.98	22.71	1.0	12.43	18.58
Mg_1	1.05	14.33	21.54	1.05	11.96	18.07
Mg_2	1.00	13.30	19.77	0.88	14.28	19.59
Mg_3	0.93	12.32	19.39	0.81	9.95	17.11
CD (5%)	0.072	1.41	1.71	0.057	1.145	1.40
CD-K x Mg (5%)	0.144	2.82	3.42	0.114	2.289	2.80

m.a.p. – Months after planting

3.5 Magnesium (Table 37)

As Mg application to alluvial soil increased either as Sul-Po-Mag or as $MgSO_4$ the Mg uptake also increased (Fig. 14). Increasing the levels of Sul-Po-Mag increased the Mg uptake significantly especially after one month of planting. This increase in Mg uptake was reflected on the yield of the crop also. Application of Sul-Po-Mag gave relatively high Mg uptake values contrary to the observation of Loue'(1985) who reported that K_2SO_4 treatment decreased the uptake of Mg. This may be because of the presence of Mg also in comparable levels along with K_2SO_4 in Sul-Po-Mag. Thus the presence of K in Sul-Po-Mag did not interfere with the absorption of Mg by the plant.

The NPK treatment receiving fertilizer dose as recommended by the Package of Practices of the Kerala Agricultural University, gave significantly low Mg uptake values than SPM_2 and SPM_3 and the treatments receiving Mg along with muriate of potash especially at the later stages of growth.

Increasing the level of K application as muriate of potash decreased the Mg uptake values significantly at one and two months after planting. During the later stages of growth the K levels did not significantly influence the Mg uptake by the plant. With increase in the level of Mg, a progressive and significant increase occurred in the Mg uptake values throughout the growth period.

In the presence of Mg_0 or Mg_1 the different K levels did not influence significantly the Mg uptake by the plant. Adams and Hendersen (1962) have also reported that in Mg deficient soils, uptake of Mg by crops was greater or unchanged at higher K levels and in Mg sufficient soils the uptake was less at higher K levels. At Mg_2 increasing the K levels resulted in a general decrease in Mg which was significant at one month after planting and thereafter no significant decrease was noticed. At the highest level of Mg application (Mg_3) the decreasing trend in uptake was noticed with increasing K levels only during the initial stages of growth. The decrease in Mg uptake for the Mg sufficient soils at higher K levels in spite of increased plant growth is because of a decrease in the Mg concentration of the plant. It is also seen that any particular Mg level, heavy dressings of K decreased Mg uptake. Similar results were obtained by Salmon (1964), Wicke (1968), Harrison and Bergman (1981) and Fageria (1983).

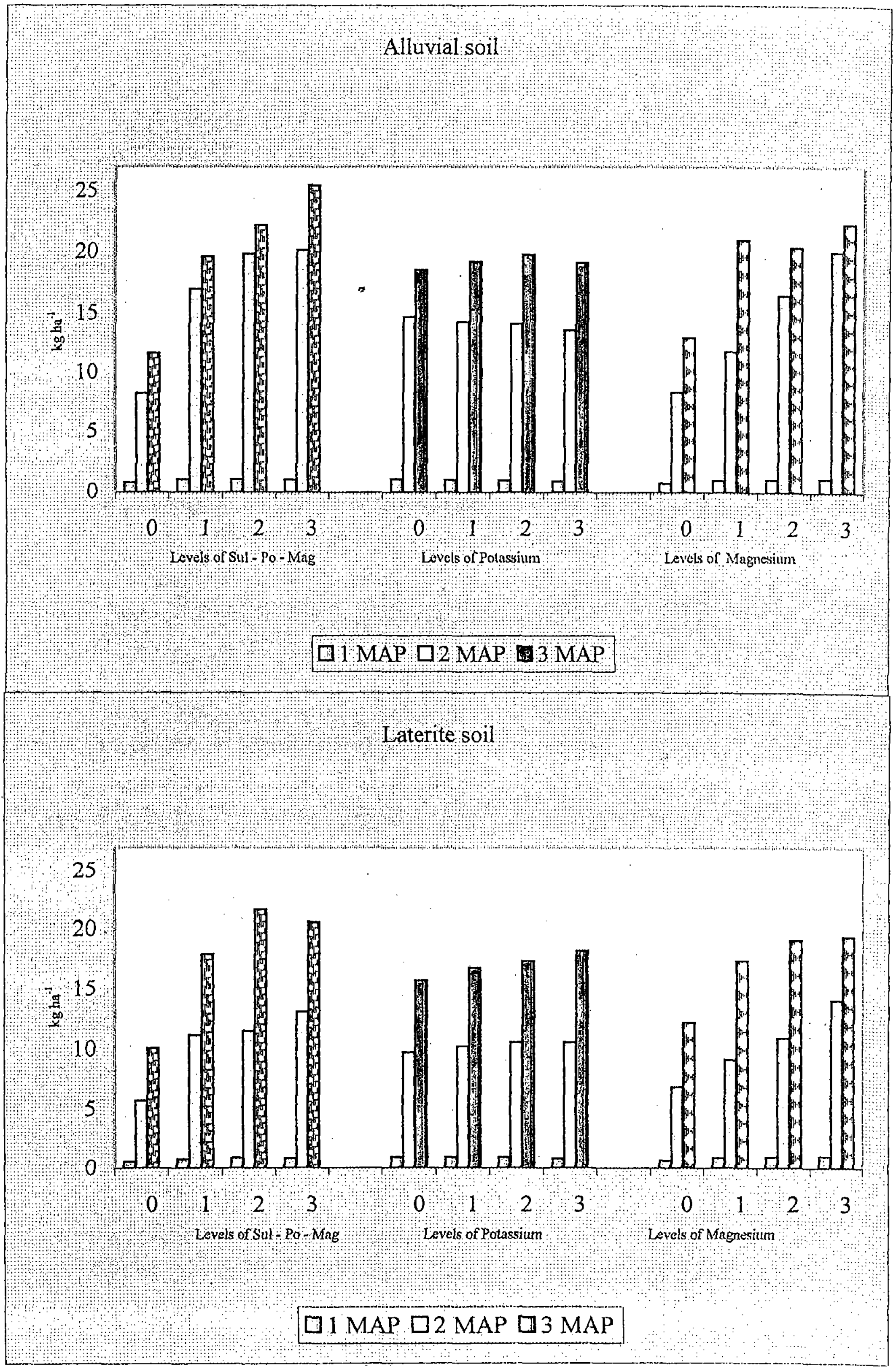
At low levels of K (K_0 and K_1) increasing the Mg levels significantly increased uptake. At higher K levels, significant increase in Mg uptake by increased application of Mg occurred only upto Mg_1 and thereafter the Mg levels were on par. Thus at any particular K level, as the Mg application rate increased, the uptake of Mg also increased but the significance of difference decreased as the K levels increased, i.e. at low K and sufficient Mg, uptake was not hindered (Mc Colloch, *et al.*, 1957) but high K decreased uptake (Dibb and Thompson, 1985; Yang, 1992 and Sindu, 1997).

The total Mg uptake increase by the addition of K is because less of available Mg was absorbed by the plants moderately deficient in K because of less vigorous plant growth or by increasing Mg availability by the addition of K which displaces exchangeable Mg into solution. At higher Mg levels, by supplying additional excess levels of K, the antagonism of additional K is great enough to repress Mg

Table 37. Magnesium uptake by bhindi at different stages (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	0.72^{FG}	7.45^{H}	9.72^{E}	0.41K	4.44^{J}	8.34^{J}
$NPSPM_1$	1.05^{BC}	17.00^{CD}	19.65^{BC}	0.76^{FGHI}	11.15^{CD}	17.94^{BCD}
$NPSPM_2$	1.06^{BC}	19.85^{AB}	22.25^{B}	0.88^{CDEFG}	11.50^{C}	21.65^{A}
$NPSPM_3$	1.00^{BCDE}	20.15^{AB}	25.46^{A}	0.82^{DEFGH}	13.05^{B}	20.58^{ABC}
NPK	0.72^{FG}	15.84^{DE}	18.17^{C}	0.65^{HIJ}	9.89^{DEF}	15.15^{EFG}
NPK_0Mg_0	0.78^{EFG}	8.27^{H}	11.68^{DE}	0.56^{J}K	5.75^{I}	10.12^{IJ}
NPK_1Mg_0	0.81^{DEFG}	8.02^{H}	12.33^{DE}	0.74^{GHI}	6.94^{H}	11.81^{HI}
NPK_2Mg_0	0.66^{G}	8.74^{GH}	14.73^{D}	0.76^{FGHI}	7.52^{GH}	12.74^{GH}
NPK_3Mg_0	0.81^{DEFG}	8.37^{H}	13.28^{D}	0.60^{IJ}	7.39^{GH}	14.18^{FGH}
NPK_0Mg_1	1.04^{BCD}	13.34^{EF}	19.70^{BC}	0.92^{BCDEF}	9.29^{F}	16.15^{DEF}
NPK_1Mg_1	0.90^{CDEF}	11.05^{FG}	21.96^{B}	0.89^{CDEFG}	8.60^{FG}	17.79^{CDE}
NPK_2Mg_1	0.98^{BCDE}	12.05^{F}	21.97^{B}	0.93^{ABCDEF}	9.25^{F}	17.77^{CDE}
NPK_3Mg_1	0.88^{CDEFG}	11.08^{FG}	20.39^{BC}	0.81^{EFGH}	9.55^{EF}	18.15^{BCD}
NPK_0Mg_2	1.17^{AB}	17.54^{BCD}	21.05^{BC}	1.03^{ABC}	11.11^{CD}	18.21^{BCD}
NPK_1Mg_2	1.04^{BCD}	16.45^{CD}	19.62^{BC}	0.96^{ABCDE}	10.02^{CD}	18.73^{BCD}
NPK_2Mg_2	1.05^{ABC}	16.96^{CD}	20.45^{BC}	0.97^{ABCDE}	10.71^{CDE}	19.65^{ABC}
NPK_3Mg_2	0.92^{CDEF}	15.19^{DE}	20.49^{BC}	0.89^{CDEFG}	10.99^{CD}	20.24^{ABC}
NPK_0Mg_3	1.30^{A}	20.24^{AB}	21.82^{B}	1.10^{A}	12.86^{B}	18.43^{BCD}
NPK_1Mg_3	1.20^{AB}	21.70^{A}	23.00^{AB}	1.07^{AB}	14.40^{A}	18.98^{ABC}
NPK_2Mg_3	1.04^{BCD}	18.90^{BC}	22.13^{B}	0.99^{ABCD}	14.81^{A}	19.50^{ABC}
NPK_3Mg_3	0.98^{BCDE}	19.91^{AB}	22.43^{AB}	0.95^{ABCDE}	14.36^{A}	20.75^{AB}
Levels of K						
K_0	1.07	14.72	18.56	0.90	9.75	15.73
K_1	0.99	14.30	19.23	0.92	10.24	16.82
K_2	0.95	14.16	19.82	0.91	10.57	17.41
K_3	0.89	13.63	19.15	0.81	10.57	18.24
CD (5%)	0.083	1.03	1.22	0.063	0.49	1.01
Levels of Mg						
Mg_0	0.76	8.35	13.000	0.66	6.90	12.21
Mg_1	0.95	11.88	21.00	0.89	9.17	17.46
Mg_2	1.05	16.53	20.40	0.96	10.96	19.12
Mg_3	1.13	20.06	22.34	1.03	14.11	19.42
CD (5%)	0.083	1.03	1.22	0.063	0.49	1.01
CD-K x Mg (5%)	0.17	2.10	2.44	0.126	0.98	2.02

m.a.p. – Months after planting



MAP – Months after planting

Fig. 14 Uptake of magnesium by bhindi at different levels of fertilizers absorption regardless of the Mg level. Thus at low soil K and sufficient exchangeable Mg levels, uptake of Mg is not hindered (Mc Colloch, *et al.*, 1957).

In laterite soil, the Sul-Po-Mag treatments gave comparatively lower Mg uptake values when compared to the muriate of potash treatments receiving Mg at moderate to high levels (Mg_2 and Mg_3). But as the level of Sul-Po-Mag application increased, a significant increase was observed in the Mg uptake values especially during the later stages of growth.

Application of moderate levels of K increased Mg uptake. But higher K levels caused a reduction in Mg uptake during the early stages. Similar results were obtained by Wicke (1968). During the later stages, higher K application rates did not affect Mg uptake. Thus K did not generally affect Mg uptake.

Increasing the level of Mg application significantly increased its uptake throughout the growth period. In the absence of Mg or at Mg_1 increasing the K level from K_0 to K_1 significantly increased Mg uptake but further increase in K did not affect the uptake of Mg. When Mg levels were raised further, increase in K levels significantly reduced Mg uptake especially at the early stages. Thus high levels of K showed antagonistic effect on Mg uptake only at higher levels of Mg. In the presence of low Mg, higher K did not hinder uptake.

Increasing the Mg levels at a constant K level caused significant increase in Mg uptake at all stages and application of Mg at the highest level gave significantly higher Mg uptake values irrespective of the level of K applied.

It was seen that as Mg addition increased an increase in exchangeable Mg occurred in both soils. An increase in Mg uptake due to increased exchangeable Mg was also reported by Mc Intosh *et al.* (1973), Ananthanarayana and Rao (1979) and Harrison and Bergman (1981).

Thus it is seen that as we apply the needed K to soils that are marginal with respect to Mg, a deficiency of Mg is induced. But addition of Mg along with K overcomes this induced deficiency.

3.6 Sulphur (Table 38)

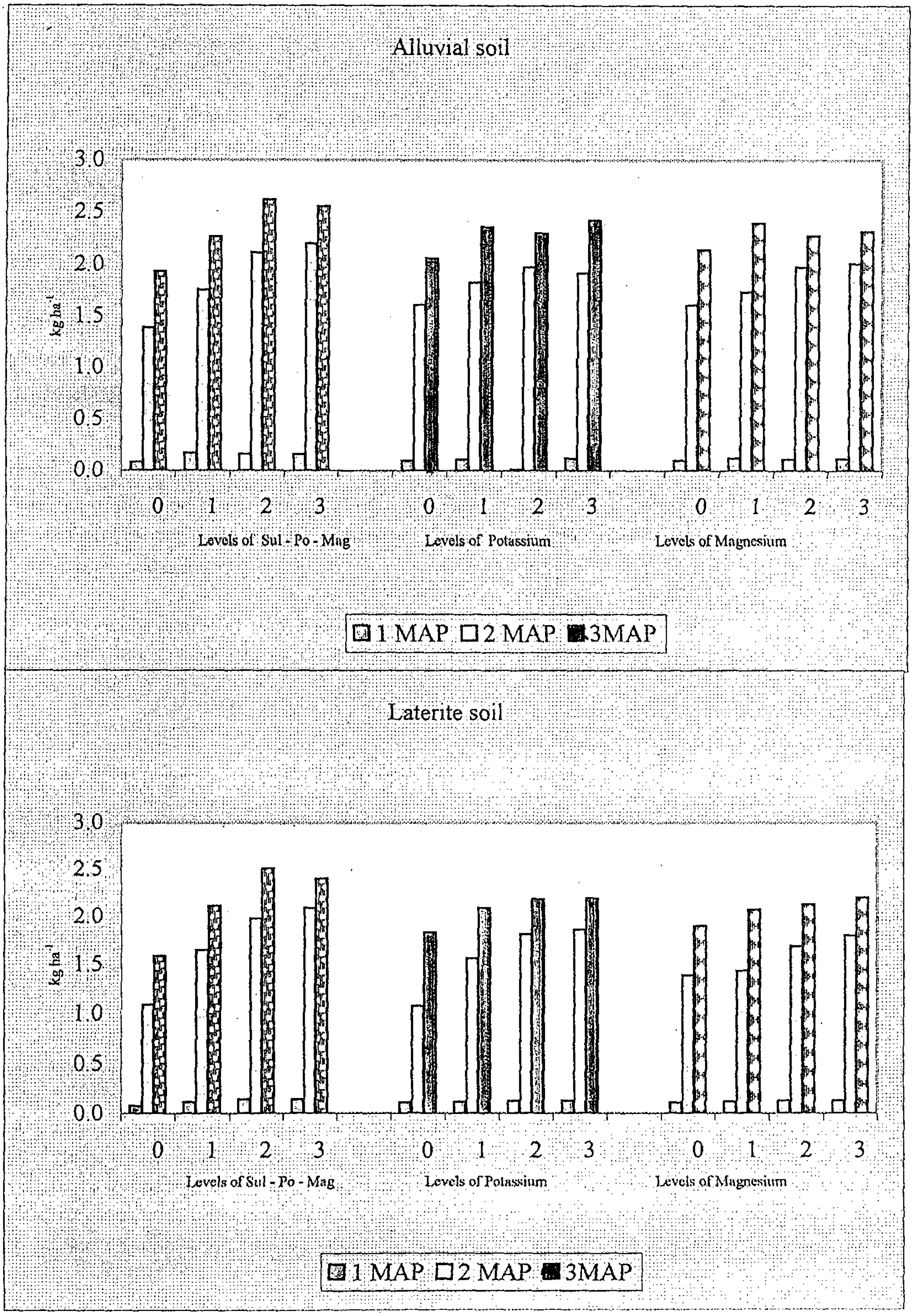
In alluvial soil, increasing the level of application of Sul-Po-Mag did not bring about a significant increase in S uptake though SPM_2 and SPM_3 gave increased uptake values. Increasing the K levels at different Mg levels generally increased the uptake of S significantly upto K_1 level and thereafter no significant increase was noticed (Fig. 15). Thus increasing K above moderate levels either as Sul-Po-Mag or as muriate of potash did not increase S uptake, but at low levels of K, increased addition of K increased the uptake of S. Mg addition as $MgSO_4$ resulted in significantly higher S uptake values when compared to no Mg but on incremental addition of Mg, though uptake values were high, no significant increase was obtained. An increased S uptake by Mg application was also reported by Ananthanarayana and Rao (1979). The increased S uptake can also be due to the presence of S in $MgSO_4$ (Singh and Singh, 1992 and Turker and Dikshit, 1994).

The NPK treatment receiving no Mg gave S uptake values significantly less than the Sul-Po-Mag and the K + Mg treatments.

Table 38. Sulphur uptake by bhindi at different stages (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	0.063^{H}	1.123^{I}	1.68^{G}	0.074^{G}	0.820^{H}	1.330^{K}
$NPSPM_1$	0.168^{A}	1.760^{EF}	2.265^{ABCDEF}	0.117^{CDEF}	1.650^{DE}	2.110^{DEF}
$NPSPM_2$	0.159^{A}	2.115^{AB}	2.620^{A}	0.143^{A}	1.980^{ABC}	2.510^{A}
$NPSPM_3$	0.159^{A}	2.200^{A}	2.560^{AB}	0.144^{A}	2.090^{A}	2.400^{AB}
NPK	0.121^{BCDE}	1.800^{CDEF}	2.215^{ABCDEF}	0.109^{F}	1.860^{ABCD}	1.990^{FGH}
NPK_0Mg_0	0.079^{GH}	1.395^{H}	1.930^{EFG}	0.075^{G}	1.095^{GH}	1.585^{J}
NPK_1Mg_0	0.105^{EF}	1.585^{FGH}	2.245^{ABCDEF}	0.113^{DEF}	1.310^{FG}	1.895^{HI}
NPK_2Mg_0	0.109^{DE}	1.795^{CDEF}	1.855^{FG}	0.125^{ABCDEF}	1.55^{DEF}	2.065^{EF}
NPK_3Mg_0	0.106^{DEF}	1.670^{EFG}	2.520^{ABC}	0.126^{ABCDEF}	1.595^{DEF}	2.045^{EFG}
NPK_0Mg_1	0.114^{BCDE}	1.470^{GH}	2.055^{DEFG}	0.110^{F}	0.835^{A}	1.825^{I}
NPK_1Mg_1	0.116^{BCDE}	1.715^{EF}	2.475^{ABCD}	0.116^{CDEF}	1.470^{EF}	2.070^{EF}
NPK_2Mg_1	0.133^{B}	1.890^{BCDE}	2.620^{A}	0.135^{ABC}	1.700^{CDE}	2.215^{CD}
NPK_3Mg_1	0.125^{B}	1.920^{BCDE}	2.465^{ABCDE}	0.136^{AB}	1.750^{BCDE}	2.170^{CDE}
NPK_0Mg_2	0.105^{EF}	1.750^{EF}	2.105^{CDEF}	0.113^{EF}	1.095^{GH}	1.920^{GHI}
NPK_1Mg_2	0.110^{DE}	2.000^{ABCD}	2.290^{ABCDEF}	0.129^{ABCDE}	1.620^{DEF}	2.150^{CDE}
NPK_2Mg_2	0.113^{CDE}	2.095^{AB}	2.375^{ABCDE}	0.137^{AB}	1.985^{ABC}	2.210^{CD}
NPK_3Mg_2	0.114^{BCDE}	2.09^{AB}	2.335^{ABCDE}	0.126^{ABCDEF}	2.055^{AB}	2.250^{C}
NPK_0Mg_3	0.089^{FG}	1.815^{CDEF}	2.160^{BCDEF}	0.123^{BCDEF}	1.305^{FG}	2.000^{FGH}
NPK_1Mg_3	0.114^{BCDE}	2.035^{ABC}	2.410^{ABCD}	0.132^{ABCD}	1.830^{ABCD}	2.265^{B}
NPK_2Mg_3	0.127^{B}	2.140^{A}	2.365^{ABCDE}	0.133^{ABC}	2.020^{ABC}	2.240^{CD}
NPK_3Mg_3	0.130^{BC}	2.035^{ABC}	2.355^{ABCDE}	0.140^{AB}	2.060^{AB}	2.310^{B}
Levels of K						
K_0	0.097	1.61	2.06	0.110	1.08	1.83
K_1	0.112	1.83	2.36	0.124	1.56	2.09
K_2	0.121	1.98	2.30	0.126	1.81	2.18
K_3	0.119	1.92	2.42	0.132	1.86	2.19
CD (5%)	0.007	0.09	0.16	0.007	0.119	0.052
Levels of Mg						
Mg_0	0.100	1.61	2.14	0.105	1.39	1.90
Mg_1	0.120	1.74	2.40	0.122	1.44	2.07
Mg_2	0.111	1.98	2.28	0.132	1.69	2.13
Mg_3	0.115	2.01	2.32	0.132	1.80	2.20
CD (5%)	0.007	0.09	0.16	0.007	0.119	0.052
CD-K x Mg (5%)	0.014	0.18	0.32	0.014	0.239	0.105

m.a.p. – Months after planting



MAP – Months after planting

Fig. 15 Uptake of Sulphur by bhindi at different levels of fertilizers

Increasing the K levels without Mg application increased the S uptake values only upto K_1. A similar trend was seen at Mg_1, Mg_2 and Mg_3 also. Thus in the presence of a particular level of Mg, increasing the K levels did not bring about a significant variation in S uptake. It can hence be inferred that though K application increases S uptake, its increased application does not affect the uptake of S by the plant. But as the level of Mg increased an increase in S uptake was noticed at all levels of K.

In laterite soil also increasing the Sul-Po-Mag level caused a significant increase in S uptake upto SPM_2 and thereafter no significant increase was noticed (Fig. 15). The NPK treatment gave significantly lower uptake than SPM_2 and SPM_3. Increasing the level of K application caused an increase in the S uptake values, which was significant upto K_2 level. Thus in laterite soil, S uptake increased when K was raised for K_0 to K_2 but in alluvial soil uptake increased only upto K_1.

In the absence of Mg, as the K levels were increased S uptake also increased significantly upto K_1 and higher application of K did not cause any significant increase. Similarly in the presence of higher Mg levels (Mg_1, Mg_2 or Mg_3) increasing the K application rate from K_1 to K_3 at a constant rate of Mg did not bring about significant variation in the S uptake values. Thus increasing the rate of K application does not affect S uptake.

But increasing the Mg levels at a constant K level significantly increased the S uptake by the plant. The interaction between K and Mg was also found to be significant. Hence increasing K and Mg simultaneously (K_0 Mg_0 to K_3 Mg_3) was found to significantly increase the S uptake. This may be because of the presence of S and due to the synergetic effect of Mg on S uptake.

4. *Effect of treatments on soil available nutrients*

The effect of application of different treatments on the availability of the different nutrients in soil is presented and discussed below:

4.1 Nitrogen (Table 39)

In alluvial soil, the application of Sul-Po-Mag at increasing rates significantly increased the availability of N throughout the growth of the bhindi crop. But when K was applied as muriate of potash, the addition of incremental levels of K significantly increased N availability only upto K_2 and a further increase in K to K_3 resulted in a decrease which was significant at the early stages of growth. Increasing the Mg levels as $MgSO_4$ also showed a similar trend with the N availability increasing significantly upto Mg_2 and thereafter showing no significant effect. Thus though moderate levels of K and Mg as muriate of potash and $MgSO_4$ caused significant increase in the N availability, higher levels of K decreased availability.

Increasing K levels in the absence of Mg increased N availability only upto K_2 level and thereafter showed a significant decrease. The same trend was obtained at higher levels of Mg also with varying levels of K. It is also observed that irrespective of the K level, as Mg is increased, a significant increase in N availability occurred till Mg_3. Thus Mg had a synergetic effect on N availability in alluvial soil. But in the presence of high levels of

Table 39. Effect of treatments on soil available nitrogen at different stages of bhindi crop (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	367.01^{G}	325.10^{J}	334.61^{F}	328.32^{I}	316.74^{H}	324.15^{I}
$NPSPM_1$	513.81^{BCDE}	504.40^{DEFG}	495.00^{BCD}	510.67^{BCDE}	474.09^{FG}	477.22^{BCDEF}
$NPSPM_2$	531.57^{ABC}	523.21^{ABCD}	509.63^{ABC}	524.26^{ABC}	489.77^{BCDEF}	494.00^{ABCD}
$NPSPM_3$	546.20^{A}	542.02^{A}	528..44^{A}	524.26^{ABC}	505.45^{ABC}	497.09^{ABC}
NPK	507.54^{CDE}	501.27^{EFG}	485.59^{CDE}	504.40^{CDEF}	479.31^{DEF}	462.59^{FG}
NPK_0Mg_0	460.50^{F}	470.95^{I}	467.82^{E}	429.64^{H}	452.14^{G}	418.60^{A}
NPK_1Mg_0	489.77^{E}	475.13^{HI}	476.18^{DE}	484.54^{FG}	478.27^{EF}	464.68^{EFG}
NPK_2Mg_0	516.94^{BCDE}	496.04^{FG}	495.00^{BCD}	490.82^{EFG}	483.49^{CDEF}	475.13^{CDEFG}
NPK_3Mg_0	501.27^{E}	465.73^{I}	468.86^{E}	473.04^{G}	474.09^{FG}	450.40^{G}
NPK_0Mg_1	493.95^{E}	490.82^{GH}	490.82^{BCDE}	488.73^{FG}	473.04^{FG}	463.63^{EFG}
NPK_1Mg_1	500.22^{DE}	510.67^{BCDEFG}	509.63^{ABC}	487.68^{FG}	478.27^{EF}	469.91^{DEFG}
NPK_2Mg_1	524.26^{ABCD}	516.94^{BCDEF}	512.76^{AB}	520.08^{ABCD}	475.13^{FG}	482.45^{ABCDEF}
NPK_3Mg_1	514.85^{BCDE}	509.63^{BCDEFG}	515.90^{AB}	520.08^{ABCD}	505.45^{ABC}	475.13^{CDEFG}
NPK_0Mg_2	509.63^{CDE}	507.54^{CDEFG}	492.91^{BCDE}	500.20^{DEF}	493.95^{ABCDEF}	489.77^{ABCDE}
NPK_1Mg_2	524.26^{ABCD}	518.00^{BCDE}	506.49^{ABC}	516.94^{ABCD}	502.31^{ABCDE}	505.45^{A}
NPK_2Mg_2	549.34^{A}	529.48^{AB}	516.94^{AB}	524.26^{ABC}	516.94^{A}	506.49^{A}
NPK_3Mg_2	524.26^{ABCD}	513.81^{BCDEF}	500.22^{BCD}	524.26^{ABC}	507.54^{ABC}	486.64^{ABCDEF}
NPK_0Mg_3	515.90^{BCDE}	499.18^{EFG}	476.18^{DE}	504.40^{CDEF}	485.59^{BCDEF}	482.45^{ABCDEF}
NPK_1Mg_3	532.62^{ABC}	523.21^{ABCD}	506.49^{ABC}	518.00^{ABCD}	491.86^{ABCDEF}	489.77^{ABCDE}
NPK_2Mg_3	538.89^{AB}	518.00^{BCDE}	503.36^{ABC}	528.44^{AB}	511.72^{AB}	501.27^{AB}
NPK_3Mg_3	530.53^{ABC}	526.35^{ABC}	503.36^{ABC}	535.75^{A}	504.40^{ABCD}	499.18^{ABC}
Levels of K						
K_0	495.00	492.12	481.93	480.74	476.18	463.61
K_1	511.72	506.92	499.69	501.79	487.68	482.45
K_2	532.35	515.12	507.02	515.90	496.82	491.34
K_3	517.73	503.92	497.09	513.28	497.87	477.84
CD (5%)	12.27	8.84	11.37	9.16	11.2	11.33
Levels of Mg						
Mg_0	492.12	476.96	476.97	469.51	472.00	452.20
Mg_1	508.32	507.02	507.28	504.14	482.97	472.78
Mg_2	526.87	517.18	504.14	516.42	505.19	497.09
Mg_3	529.49	516.67	497.32	521.65	498.39	493.17
CD (5%)	12.27	8.84	11.37	9.16	11.2	11.33
CD-K x Mg (5%)	24.54	17.68	22.74	18.32	22.4	22.66

m.a.p.– Months after planting

muriate of potash (K_3), it was noticed that the magnitude of increase was diminished.

Thus K and Mg interacted in a significant manner in affecting the N availability of the alluvial soil. Similar results were obtained by Menon and Marykutty (1993).

In laterite soil, increasing the Sul-Po-Mag levels did not bring about a significant increase in N availability though there was an increasing trend. The NPK treatment gave available N values on par with SPM_1 and SPM_2 but significantly less than SPM_3.

Increasing the rate of K application increased the available N significantly upto K_2 and thereafter a non-significant decrease was observed. Incremental additions of Mg also significantly increased the N availability upto Mg_2 and thereafter produced a non-significant decrease. Increasing the K levels without the application of Mg caused a significant increase in available N only from K_0 to K_1 and thereafter failed to produce any significant increase. At Mg_1, increasing K levels produced significant increase in N availability only from K_2 and at higher Mg levels no significant increase was observed in the N availability. Thus in the presence of high Mg the synergetic effect of K on N availability was reduced.

In the absence of K, increasing Mg did not significantly increase the soil available N during early stages but caused a significant increase in N availability during the later stages. When Mg was increased in the presence of K (K_1 or K_2), a significant increase in N availability occurred from Mg_2 onwards. At the highest level of K, the very low levels of available N obtained of at Mg_0 was significantly raised when Mg was added at Mg_1 but further increasing the Mg levels did not increase availability. Thus the negative effect of high K levels on N availability was overcome by the addition of Mg.

4.2 Phosphorus (Table 40)

In alluvial soil, increasing the rate of Sul-Po-Mag application significantly increased the P availability during the initial stages. After one month of planting, all Sul-Po-Mag treatments gave significantly high available P values. The NPK treatment recorded significantly low available P than the higher levels of Sul-Po-Mag and was on par with the lower Sul-Po-Mag treatment (SPM_1).

Increasing the level of K application significantly increased the P availability upto K_3 especially during the initial stages of growth. Addition of incremental levels of Mg also showed a similar trend especially after one month after planting. In the absence of Mg, increasing K levels significantly increased available P. Addition of Mg at lowest level (Mg_1) significantly increased the availability of P of soil when compared to no Mg application. But further increase in Mg did not cause significant effects. Thus it is seen that in alluvial soil, the treatments receiving Mg at Mg_1 gave significantly high P levels when compared to treatments without Mg addition. Thus Mg has a synergistic effect on P availability in alluvial soil. The increase in P availability due to increased Mg is because of the greater solubilization of P by Mg (Jacob, 1958).

In laterite soil also increasing the level of Sul-Po-Mag significantly increased the available P of soil. The available P of laterite soil was higher when compared to alluvial soil. Increasing the levels of K significantly in-

Table 40. Effect of treatments on soil available phosphorus at different stages of bhindi crop (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	14.07^{IJ}	15.56^{D}	10.77^{E}	28.70^{J}	29.15^{J}	30.20^{J}
$NPSPM_1$	16.88^{DEFGH}	21.05^{ABC}	23.08^{ABC}	75.05^{BCD}	87.45^{CD}	90.05^{BCD}
$NPSPM_2$	17.75^{CDEFG}	21.90^{AB}	25.45^{AB}	88.35^{AB}	94.70^{ABC}	95.55^{ABC}
$NPSPM_3$	19.95^{ABC}	23.20^{AB}	26.70^{AB}	93.50^{A}	103.60^{A}	91.35^{ABC}
NPK	17.40^{DEFGH}	18.50^{BCD}	20.28^{ABCD}	61.05^{DEFG}	70.50^{E}	75.93^{FG}
NPK_0Mg_0	14.92^{HIJ}	16.03^{CD}	15.65^{DE}	52.40^{FGH}	45.90^{J}	50.50^{I}
NPK_1Mg_0	15.14^{HIJ}	16.03^{CD}	16.73^{CDE}	40.04^{HI}	47.35^{I}	48.30^{I}
NPK_2Mg_0	18.33^{CDEF}	18.78^{BCD}	19.85^{BCD}	59.00^{EFG}	69.45^{FG}	69.30^{GH}
NPK_3Mg_0	21.98^{A}	21.64^{AB}	21.30^{ABCD}	68.85^{DE}	80.10^{DE}	80.95^{DEF}
NPK_0Mg_1	19.25^{BCD}	22.95^{AB}	20.63^{ABCD}	50.10^{FGH}	59.60^{H}	59.10^{H}
NPK_1Mg_1	15.99^{FGHI}	23.45^{AB}	23.16^{ABC}	49.54^{GH}	61.80^{GH}	63.75^{H}
NPK_2Mg_1	17.40^{DEFGH}	23.25^{AB}	21.35^{ABCD}	51.39^{FGH}	61.10^{GH}	69.05^{GH}
NPK_3Mg_1	21.23^{AB}	22.85^{AB}	25.78^{AB}	64.13^{DEF}	72.15^{EF}	77.00^{EFG}
NPK_0Mg_2	18.33^{CDEF}	19.49^{ABCD}	19.99^{ABCD}	71.88^{CDE}	75.60^{EF}	80.80^{DEF}
NPK_1Mg_2	15.31^{GHIJ}	20.05^{ABCD}	21.94^{ABCD}	83.35^{ABC}	84.50^{D}	87.20^{CDE}
NPK_2Mg_2	14.87^{HIJ}	21.40^{AB}	21.95^{ABCD}	89.00^{AB}	96.65^{AB}	97.80^{ABC}
NPK_3Mg_2	16.13^{EFGHI}	20.20^{ABCD}	20.88^{ABCD}	90.30^{A}	99.30^{AB}	102.05^{A}
NPK_0Mg_3	17.37^{DEFGHI}	22.15^{AB}	23.31^{ABC}	88.05^{ABC}	99.25^{AB}	92.55^{ABC}
NPK_1Mg_3	18.65^{CDE}	22.10^{AB}	26.91^{A}	89.00^{AB}	101.45^{AB}	96.30^{ABC}
NPK_2Mg_3	17.68^{CDEFG}	23.60^{AB}	23.71^{AB}	85.01^{ABC}	94.20^{ABC}	100.10^{AB}
NPK_3Mg_3	18.09^{CDEF}	24.75^{A}	24.01^{AB}	89.30^{AB}	98.15^{AB}	99.08^{AB}
Levels of K						
K_0	16.22	20.16	19.89	64.84	70.09	70.74
K_1	16.27	20.41	22.18	65.48	73.77	73.89
K_2	17.08	21.76	21.71	71.10	80.35	84.06
K_3	19.36	22.36	22.99	78.15	87.43	89.76
CD (5%)	1.10	2.47	2.94	6.45	4.05	4.71
Levels of Mg						
Mg_0	17.59	18.12	18.38	54.07	60.70	62.26
Mg_1	18.47	23.13	22.73	53.79	63.66	67.23
Mg_2	14.91	20.29	21.19	83.63	89.01	91.96
Mg_3	17.95	23.15	24.48	87.08	98.26	97.00
CD (5%)	1.10	2.47	2.94	6.45	4.05	4.71
CD-K x Mg (5%)	2.20	4.94	5.89	12.90	8.1	9.42

m.a.p. – Months after planting

creased available P both in the presence and absence of Mg but the Mg applied pots gave higher P in soil than the zero Mg treatments. Increasing the Mg levels also significantly increased available P. The application of fertilizers in general increased the available P of soil.

4.3 Potassium (Table 41)

Increasing the level of Sul-Po-Mag to SPM_3 significantly increased the available K of soil during the early stages though at three months after planting no significance was noticed. Incremental addition of K as muriate of potash also caused the available K of soil to increase upto K_3 level but significant increase occurred only upto K_2.

Incremental addition of Mg caused a significant decrease in available K especially when Mg was increased to Mg_2 and higher. Similar observations were made by Grimme *et al.* (1977). The decrease in K availability by incremental addition of Mg is because of the high solution concentration of Mg, which suppresses the K activity in soil. But lower levels of Mg (Mg_1) did not significantly reduce the K level of soil. Thus low rates of application of Mg did not bring about a significant reduction in the availability of K and hence Mg can be applied to crops at reasonable levels (Mg_1) to produce beneficial effects. The NPK treatment receiving fertilizer dose as recommended by the package of practices, Kerala Agricultural University, gave available K of soil on par with SPM_2 at all stages and significantly less than SPM_3.

Increasing the K levels without Mg addition significantly increased soil K especially during the initial stages though the magnitude of difference decreased as growth progressed. Application of a constant level of Mg with increasing levels of K did not affect the increase in soil K but at higher Mg levels it was seen that the availability of K decreased. Thus though available K increased as K levels increased in the presence of increased Mg, the values showed a decrease. Hence the available K values for K_0 to K_3 at Mg_1 were higher than the available K values at Mg_3.

Increasing the Mg levels without K application did not bring about significant reduction in available K values. But in the presence of K as Mg was applied at incremental doses the available K of soil was found to decrease progressively, the decrease being significant generally upto Mg_2. Higher Mg levels did not bring about a significant reduction in available K values. This may be because of an increase in K fixation caused by an increase in exchangeable Mg. (Ningappa and Vasuki 1989 and Talele *et al.*, 1993). But at higher levels of K a significant reduction was not observed with increasing Mg levels. Thus increasing Mg significantly reduced K availability only at low levels of K. At high K levels, added Mg did not show any marked effect on the available K of soil.

In laterite soil, increase in Sul-Po-Mag levels significantly increased the available K but it was seen that SPM_2 and SPM_3 were on par. The NPK treatment gave available K significantly less than SPM_3 and on par with SPM_2.

With incremental levels of K application, the available K also increased but significant increase occurred only upto K_2. Increasing the rate of application of Mg resulted in a decrease in available K, which was significant at Mg_3 only. Significant interaction occurred between K and Mg at all stages. A progres-

Table 41. Effect of treatment on soil available potassium at different stages of bhindi crop (kg ha^{-1})

Treatment	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	138.88^{FGH}	144.48^{DE}	134.40^{EFG}	169.12^{EFG}	163.52^{F}	141.12^{H}
$NPSPM_1$	169.12^{BCD}	157.92^{CD}	152.32^{BCDEFG}	196.00^{CDEF}	227.36^{BCD}	200.48^{ABCDEF}
$NPSPM_2$	175.84^{ABC}	172.48^{ABC}	$156.80^{ABCDEFG}$	231.84^{A}	238.56^{ABC}	222.88^{ABC}
$NPSPM_3$	191.52^{A}	187.04^{A}	176.96^{AB}	245.28^{A}	266.56^{A}	244.16^{A}
NPK	173.60^{ABC}	161.28^{BCD}	142.24^{DEFG}	221.76^{ABC}	219.52^{BCD}	206.08^{ABCD}
NPK_0Mg_0	142.24^{FGH}	145.60^{DE}	134.40^{EFG}	172.48^{EFG}	169.12^{F}	165.76^{DEFGH}
NPK_1Mg_0	163.52^{CDE}	174.72^{ABC}	163.52^{ABCD}	194.88^{CDEF}	217.28^{BCDE}	191.52^{BCDEFG}
NPK_2Mg_0	174.72^{ABC}	176.96^{ABC}	170.24^{ABC}	224.00^{ABC}	232.96^{ABCD}	220.64^{ABC}
NPK_3Mg_0	189.28^{A}	188.16^{A}	172.48^{ABC}	234.08^{A}	246.40^{AB}	235.20^{AB}
NPK_0Mg_1	126.56^{H}	131.04^{E}	132.16^{FG}	164.64^{FG}	179.20^{EF}	159.04^{EFGH}
NPK_1Mg_1	154.56^{DEF}	180.32^{ABC}	160.16^{ABCDE}	192.64^{CDEF}	221.76^{BCDE}	199.36^{BCDEFG}
NPK_2Mg_1	188.16^{A}	184.80^{AB}	178.08^{A}	228.48^{AB}	234.08^{ABCD}	218.40^{ABC}
NPK_3Mg_1	183.68^{AB}	189.28^{A}	180.32^{A}	238.56^{A}	255.36^{AB}	239.68^{A}
NPK_0Mg_2	133.28^{GH}	142.24^{DE}	131.04^{G}	155.68^{G}	154.56^{F}	156.80^{FGH}
NPK_1Mg_2	147.84^{EFG}	144.48^{DE}	145.60^{CDEFG}	185.92^{DEF}	200.48^{CDEF}	207.20^{ABCD}
NPK_2Mg_2	175.84^{ABC}	172.48^{ABC}	171.36^{ABC}	219.52^{ABC}	229.60^{ABCD}	215.04^{ABC}
NPK_3Mg_2	187.04^{AB}	184.80^{AB}	171.36^{ABC}	231.84^{A}	249.76^{AB}	234.08^{AB}
NPK_0Mg_3	124.32^{H}	132.16^{E}	133.28^{EFG}	153.44^{G}	166.88^{F}	152.32^{GH}
NPK_1Mg_3	150.08^{DEFG}	145.60^{DE}	146.72^{CDEFG}	179.20^{EF}	198.20^{DEF}	180.32^{CDEFGH}
NPK_2Mg_3	173.60^{ABC}	171.36^{ABC}	157.92^{ABCDEF}	198.24^{BCDE}	224.00^{BCD}	201.60^{ABCDE}
NPK_3Mg_3	180.32^{ABC}	179.20^{ABC}	169.12^{ABC}	213.92^{ABCD}	226.24^{BCD}	212.80^{ABC}
Levels of K						
K_0	131.60	137.76	132.72	161.56	167.44	158.48
K_1	154.00	161.28	154.11	188.16	209.44	194.60
K_2	178.08	176.40	169.40	217.56	230.16	213.92
K_3	185.08	185.36	173.32	229.60	244.44	230.44
CD (5%)	8.83	10.63	12.54	13.98	17.49	19.90
Levels of Mg						
Mg_0	167.44	171.36	160.16	206.36	216.44	203.28
Mg_1	163.24	171.36	162.68	206.08	222.60	204.12
Mg_2	161.00	161.00	154.84	198.24	208.60	203.28
Mg_3	157.08	157.08	151.76	186.20	203.84	186.76
CD (5%)	8.83	10.63	12.54	13.98	17.49	19.90
CD-K x Mg (5%)	17.66	21.26	25.08	27.96	34.99	39.80

m.a.p. – Months after planting

sive increase in soil K occurred as K levels increased in the absence of Mg and also with different Mg levels. But at higher Mg levels (Mg_2 and Mg_3) it was seen that the values were less than that at lower Mg levels.

In the absence of K, incremental additions of Mg decreased progressively the available K but there was no significant difference. Increasing Mg rates in the presence of K at different levels also did not significantly affect available K. Thus the available K in soil was not significantly affected by the levels of Mg in laterite soil.

4.4 Calcium (Table 42)

In alluvial soil, varying the Sul-Po-Mag levels did not bring about a significant effect on exchangeable calcium of soil. Increasing the Mg levels did not show significant effect on calcium content. No particular trend was seen with incremental additions of Mg. Thus high Mg did not show any depressing effect on the soil calcium content in alluvial soil. But increasing the K levels significantly increased the soil calcium during one month after planting and thereafter no significant effect was noticed.

In laterite soil, exchangeable calcium was generally on par for the three Sul-Po-Mag treatments and the NPK treatments. Increasing the K levels did not significantly affect the soil calcium levels but incremental additions of Mg caused a reduction in soil calcium especially at the highest level (Mg_3) contrary to the effect on alluvial soil. This decrease in exchangeable calcium with incremental additions of Mg is because of the high solution concentrations of Mg, which suppresses the calcium activity in soil (Grimme *et al.*, 1977). Thus in laterite soil, exchangeable calcium was significantly higher for the treatment receiving no/low Mg. In the presence of different levels of Mg, as K increased, no significant effect was observed in soil calcium. Thus in the laterite soil, levels of K did not affect exchangeable calcium whereas in alluvial soil, increasing K levels increased exchangeable Ca.

4.5 Magnesium (Table 43)

In alluvial soil, exchangeable Mg showed an increasing trend with incremental additions of Sul-Po-Mag during one month after planting but later the different levels of SPM did not cause significant effect on soil Mg. Thus it is seen that applying Sul-Po-Mag above SPM_2 is not generally beneficial.

Increasing the level of application of K significantly decreased exchangeable Mg only at the highest level (K_3). Thus antagonistic effect was shown by relatively high levels of K on the exchangeable Mg of soil. A decrease in exchangeable Mg by increased application of K was also reported by Turner and Barkus (1983), Rajdhar (1989), Yang (1992) and Sindu (1997). This antagonistic effect of increasing K on soil Mg was exhibited at all levels of Mg.

It was also seen that increasing the Mg levels significantly increased the soil exchangeable Mg. The increase in exchangeable Mg by the addition of increased levels of Mg was because of the saturation of the exchange complex with Mg ions (Alston, 1972). An increase in soil Mg with Mg addition was also reported by Ananthanarayana and Rao (1979). But in the presence of high levels of K, addition of higher Mg levels did not bring about significant increase in exchangeable Mg in alluvial soil.

Table 42. Effect of treatments on soil exchangeable calcium at different stages of bhindi crop (c mol (+) kg^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	5.00^{BCDE}	5.75^{A}	4.55^{BC}	5.05^{B}	4.80^{BCD}	3.65^{E}
$NPSPM_1$	4.50^{DE}	3.60^{A}	4.85^{ABC}	5.45^{ABC}	5.30^{BC}	6.05^{A}
$NPSPM_2$	4.65^{CDE}	4.85^{A}	5.30^{AB}	5.40^{ABC}	6.30^{A}	5.70^{ABC}
$NPSPM_3$	4.55^{DE}	4.90^{A}	5.60^{A}	4.80^{3}	4.80^{BCD}	5.25^{ABCD}
NPK	6.00^{AB}	5.90^{A}	4.25^{C}	5.45^{ABC}	4.75^{BCD}	4.75^{ABCD}
NPK_0Mg_0	4.80^{CDE}	5.80^{A}	5.10^{ABC}	6.75^{A}	4.45^{CD}	4.70^{ABCDE}
NPK_1Mg_0	4.20^{E}	5.90^{A}	4.80^{ABC}	6.50^{A}	5.50^{AB}	5.15^{ABCDE}
NPK_2Mg_0	4.90^{BCDE}	5.95^{A}	5.05^{ABC}	6.35^{AB}	4.60^{BCD}	5.75^{ABCDE}
NPK_3Mg_0	6.50^{A}	4.80^{A}	4.60^{ABC}	6.10^{ABC}	5.20^{BCD}	4.95^{ABCDE}
NPK_0Mg_1	4.75^{CDE}	6.00^{A}	4.55^{BC}	5.60^{ABC}	5.50^{ABC}	4.60^{BCDE}
NPK_1Mg_1	5.10^{BCDE}	5.25^{A}	4.60^{ABC}	6.00^{ABC}	4.80^{BCD}	5.10^{ABCDE}
NPK_2Mg_1	5.35^{BCD}	5.70^{A}	4.80^{ABC}	6.35^{AB}	4.80^{BCD}	5.90^{AB}
NPK_3Mg_1	5.70^{ABC}	6.15^{A}	5.15^{ABC}	5.50^{ABC}	4.85^{BCD}	5.80^{ABC}
NPK_0Mg_2	4.10^{E}	5.90^{A}	5.25^{ABC}	5.20^{BC}	4.15^{D}	3.80^{E}
NPK_1Mg_2	4.80^{CDE}	5.75^{A}	5.10^{ABC}	5.50^{ABC}	4.55^{BCD}	4.15^{DE}
NPK_2Mg_2	5.45^{ABCD}	5.85^{A}	5.50^{AB}	6.00^{ABC}	4.55^{BCD}	4.00^{DE}
NPK_3Mg_2	6.50^{A}	5.55^{A}	5.25^{AB}	5.65^{ABC}	4.60^{BCD}	5.15^{ABCDE}
NPK_0Mg_3	4.60^{CDE}	5.05^{A}	4.80^{ABC}	5.55^{ABC}	5.30^{BC}	4.25^{DE}
NPK_1Mg_3	5.55^{ABCD}	5.15^{A}	4.60^{ABC}	5.50^{ABC}	5.25^{BC}	4.40^{CDE}
NPK_2Mg_3	5.45^{ABCD}	4.95^{A}	5.25^{ABC}	5.45^{ABC}	5.00^{BCD}	4.60^{BCDE}
NPK_3Mg_3	5.75^{ABCD}	4.90^{A}	5.05^{ABC}	5.45^{ABC}	5.00^{BC}	4.60^{BCDE}
Levels of K						
K_0	4.55	5.70	4.90	5.75	4.85	4.35
K_1	4.90	5.50	4.75	5.90	5.05	4.60
K_2	5.30	5.60	5.15	6.05	4.75	4.75
K_3	6.05	5.35	5.00	5.65	4.90	5.10
CD (5%)	0.50	0.55	0.45	0.65	0.45	0.55
Levels of Mg						
Mg_0	5.10	5.60	4.85	6.40	4.95	4.90
Mg_1	5.20	5.75	4.75	5.85	5.00	5.35
Mg_2	5.20	5.75	5.25	5.65	4.45	4.25
Mg_3	5.25	5.00	4.90	5.50	5.15	4.45
CD (5%)	0.50	0.55	0.44	0.65	0.47	0.57
CD-K x Mg (5%)	1.00	1.10	0.87	1.30	0.95	1.15

m.a.p. – Months after planting

Table 43. Effect of treatment on soil exchangeable magnesium at different stages of bhindi crop (c mol (+) kg^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	2.82^{H}	2.92^{FGH}	2.78^{FG}	1.48^{E}	1.42^{E}	1.36^{BC}
NPSPM$_1$	3.29^{CDE}	3.49^{ABC}	3.22^{ABCD}	1.81^{ABCD}	1.61^{BCDE}	1.50^{ABC}
NPSPM$_2$	3.52^{ABCD}	3.62^{AB}	3.40^{AB}	1.98^{A}	1.77^{ABC}	1.55^{ABC}
NPSPM$_3$	3.73^{A}	3.60^{AB}	3.30^{ABC}	2.00^{A}	1.91^{A}	1.72^{A}
NPK	2.91^{FGH}	3.14^{DEFG}	2.90^{EFG}	1.53^{DE}	1.54^{CDE}	1.42^{ABC}
NPK$_0$Mg$_0$	2.87^{GH}	3.02^{EFGH}	2.82^{FG}	1.52^{DE}	1.55^{CDE}	1.39^{BC}
NPK$_1$Mg$_0$	3.00^{EFGH}	2.97^{EFGH}	2.83^{EFG}	1.59^{BCDE}	1.52^{CDE}	1.43^{ABC}
NPK$_2$Mg$_0$	2.97^{EFGH}	2.87^{GH}	2.69^{G}	1.57^{BCD}	1.65^{ABCDE}	1.40^{BC}
NPK$_3$Mg$_0$	2.87^{H}	2.77^{H}	2.65^{G}	1.54^{CDE}	1.45^{DE}	1.33^{C}
NPK$_0$Mg$_1$	3.29^{CDE}	3.46^{ABC}	3.28^{ABC}	1.93^{AB}	1.80^{ABC}	1.56^{ABC}
NPK$_1$Mg$_1$	3.20^{EDFG}	3.26^{CDE}	3.18^{BCD}	1.82^{ABCD}	1.84^{AB}	1.65^{AB}
NPK$_2$Mg$_1$	3.22^{DEF}	3.33^{BCD}	3.20^{BCD}	2.08^{ABCD}	1.75^{ABC}	1.52^{ABC}
NPK$_3$Mg$_1$	2.94^{FGH}	3.12^{DEFG}	3.01^{DEF}	1.74^{ABCDE}	1.67^{ABCDE}	1.53^{ABC}
NPK$_0$Mg$_2$	3.39^{BCE}	3.58^{AB}	3.37^{ABC}	1.90^{ABC}	1.70^{ABCD}	1.58^{ABC}
NPK$_1$Mg$_2$	3.45^{ABCD}	3.37^{BCD}	3.29^{ABC}	1.79^{ABCD}	1.73^{ABCD}	1.56^{ABC}
NPK$_2$Mg$_2$	3.31^{CD}	3.46^{ABC}	3.34^{ABC}	1.64^{ABCDE}	1.74^{ABC}	1.52^{ABC}
NPK$_3$Mg$_2$	3.00^{EFGH}	3.21^{CDEF}	3.13^{CDE}	1.66^{ABCDE}	1.70^{ABCDE}	1.49^{ABC}
NPK$_0$Mg$_3$	3.58^{ABC}	3.70^{A}	3.47^{A}	1.82^{ABCDE}	1.90^{A}	1.62^{ABC}
NPK$_1$Mg$_3$	3.67^{AB}	3.57^{AB}	3.33^{ABC}	1.70^{ABCDE}	1.72^{ABCDE}	1.35^{BC}
NPK$_2$Mg$_3$	3.48^{ABCD}	3.50^{AB}	3.29^{ABC}	1.99^{A}	1.74^{ABC}	1.43^{ABC}
NPK$_3$Mg$_3$	3.28^{CDE}	3.42^{ABC}	3.38^{ABC}	1.72^{ABCDE}	1.74^{ABC}	1.53^{ABC}
Levels of K						
K$_0$	3.28	3.44	3.23	1.80	1,74	1.54
K$_1$	3.33	3.29	3.17	1.72	1.70	1.50
K$_2$	3.25	3.29	3.13	1.77	1.72	1.47
K$_3$	3.02	3.13	3.04	1.67	1.64	1.47
CD (5%)	0.15	0.12	0.12	0.16	0.12	0.13
Levels of Mg						
Mg$_0$	2.92	2.91	2.76	1.56	1.54	1.39
Mg$_1$	3.17	3.29	3.17	1.84	1.77	1.57
Mg$_2$	3.29	3.41	3.28	1.75	1.72	1.54
Mg$_3$	3.51	3.55	3.37	1.81	1.77	1.48
CD (5%)	0.15	0.12	0.12	0.16	0.12	0.13
CD-K x Mg (5%)	3.0	0.24	0.24	0.32	0.24	0.27

m.a.p.– Months after planting

Table 44. Effect of treatments on soil available sulphur at different stages of bhindi crop (kg ha^{-1})

Treatments	Alluvial			Laterite		
	1 m.a.p.	2 m.a.p.	3 m.a.p.	1 m.a.p.	2 m.a.p.	3 m.a.p.
$N_0P_0K_0Mg_0$	50.75^{G}	42.95^{F}	44.00^{F}	52.50^{EF}	46.00^{G}	51.15^{CD}
$NPSPM_1$	63.03^{BCDEFG}	59.80^{ABCDEF}	62.50^{ABC}	70.50^{BCD}	64.30^{BCD}	67.95^{A}
$NPSPM_2$	71.00^{ABCDE}	65.15^{ABCDE}	66.75^{AB}	78.30^{AB}	75.00^{AB}	68.45^{A}
$NPSPM_3$	80.00^{A}	75.50^{A}	70.00^{A}	82.87^{A}	76.90^{A}	63.25^{AB}
NPK	48.45^{G}	42.95^{F}	45.70^{EF}	53.55^{EF}	48.00^{FG}	50.75^{CD}
NPK_0Mg_0	54.90^{EFG}	50.75^{CDEF}	55.35^{BCDEF}	52.35^{EF}	50.75^{EFG}	52.10^{CD}
NPK_1Mg_0	53.55^{FG}	47.05^{EF}	48.45^{DEF}	53.55^{EF}	48.45^{FG}	49.90^{CD}
NPK_2Mg_0	55.35^{DEFG}	49.75^{DEF}	54.90^{BCDEF}	51.15^{EF}	49.30^{FG}	46.30^{D}
NPK_3Mg_0	51.15^{G}	45.30^{F}	58.05^{ABCDE}	50.75^{F}	45.75^{G}	49.90^{CD}
NPK_0Mg_1	61.60^{BCDEFG}	50.75^{CDEF}	60.55^{ABCDE}	62.50^{CDE}	60.05^{CDE}	57.00^{BC}
NPK_1Mg_1	59.80^{CDEFG}	55.35^{BCDEF}	59.15^{ABCDE}	63.03^{CDE}	60.50^{CDE}	66.12^{A}
NPK_2Mg_1	57.65^{CDEFG}	50.75^{CDEF}	51.15^{CDEF}	62.50^{CDE}	56.95^{DEF}	62.50^{AB}
NPK_3Mg_1	61.60^{BCDEFG}	57.00^{ABCDEF}	53.55^{BCDEF}	60.80^{DEF}	57.45^{DEF}	63.45^{AB}
NPK_0Mg_2	69.25^{ABCDEF}	67.20^{ABCD}	64.00^{ABC}	69.25^{BCD}	65.15^{ABCD}	61.60^{AB}
NPK_1Mg_2	$65.15^{ABCDEFG}$	59.40^{ABCDEF}	62.50^{ABC}	72.95^{ABC}	66.05^{ABCD}	67.70^{A}
NPK_2Mg_2	62.50^{BCDEFG}	61.60^{ABCDEF}	61.60^{ABCD}	71.00^{ABCD}	69.75^{ABC}	63.80^{AB}
NPK_3Mg_2	55.35^{EFG}	52.40^{BCDEF}	58.05^{ABCDE}	66.15^{CD}	61.60^{CD}	67.10^{A}
NPK_0Mg_3	76.90^{ABC}	71.00^{A}	64.00^{ABC}	70.05^{BCD}	67.00^{ABCD}	61.60^{AB}
NPK_1Mg_3	73.40^{ABC}	70.10^{AB}	64.00^{ABC}	73.40^{ABC}	67.12^{ABCD}	68.90^{A}
NPK_2Mg_3	74.45^{ABC}	71.00^{A}	65.15^{AB}	72.95^{ABC}	66.05^{ABCD}	66.60^{A}
NPK_3Mg_3	72.15^{ABCD}	68.90^{ABC}	66.75^{AB}	71.00^{ABCD}	66.90^{ABCD}	67.95^{A}
Levels of K						
K_0	65.67	59.94	61.11	63.64	60.84	58.08
K_1	62.98	58.00	58.41	66.03	60.66	63.16
K_2	62.55	58.15	58.31	64.56	60.51	59.81
K_3	60.09	55.90	59.06	62.16	57.93	62.10
CD (5%)	7.12	8.39	6.23	5.06	4.92	3.45
Levels of Mg						
Mg_0	53.74	48.21	54.16	52.08	48.68	49.55
Mg_1	60.25	53.49	56.09	62.36	58.74	62.28
Mg_2	63.06	60.01	61.56	69.84	65.75	65.05
Mg_3	74.23	70.28	65.09	72.10	66.77	66.26
CD (5%)	7.12	8.39	6.23	5.06	4.92	3.45
CD-K x Mg (5%)	14.24	16.78	12.46	10.12	9.84	6.90

m.a.p. – Months after planting

Table 45. Correlation coefficeints showing relationship among various plant characteristics and nutrient uptake of bhindi

Characteristics	N 1map	N 2map	N 3map	P 1map	P 2map	P 3map	K 1map	K 2map	K 3map	Ca 1map	Ca 2map	Ca 3map	Mg 1map	Mg 2map	Mg 3map	S 1map	S 2map	S 3map
Alluvial soil																		
DMP 1map	0.803 **	0.522 *	0.387	0.786 **	0.623 **	0.581 **	0.311	0.416	0.128	0.506 *	0.606 **	0.371	-0.016	-0.058	0.069	0.514 *	0.078	0.387
DMP 2map	0.775 **	0.527 *	0.472 *	0.676 **	0.548 **	0.636 **	0.338	0.471 *	0.246	0.494 *	0.526 *	0.312	-0.098	0.030	0.160	0.561 **	0.191	0.413
DMP 3map	0.782 **	0.477 *	0.451 *	0.703 **	0.533 *	0.603 **	0.400	0.533 *	0.317	0.523 *	0.404	0.258	-0.074	0.084	0.258	0.618 **	0.319	0.527 *
Yield	0.780 **	0.488 *	0.456 *	0.739 **	0.572 **	0.640 **	0.458 *	0.572 **	0.396	0.530 *	0.427 *	0.221	-0.019	0.166	0.271	0.708 **	0.348	0.531 *
Crude protein	-0.032	0.700 **	-0.274	0.050	0.070	0.368	-0.780 **	-0.027	-0.121	0.219	0.185	0.222	-0.200	-0.215	-0.362	-0.119	-0.152	-0.187
Crude fibre	-0.162	-0.220	-0.770 **	-0.359	-0.455 *	-0.332	-0.459 *	-0.455 *	-0.459 *	-0.255	-0.084	0.280	-0.158	-0.297	-0.508 *	-0.513 *	-0.608 **	-0.406
Ascorbic acid	0.511 *	0.890 **	0.276	0.628 **	0.458 *	0.257	0.451 *	0.458 *	0.374	0.366	0.240	0.001	0.214	0.289	0.561 **	0.623 **	0.494 *	0.616 **
Laterite soil																		
DMP 1map	0.923 **	0.725 **	0.774 **	0.622 **	0.411	0.460 *	0.400	0.040	0.020	0.289	0.375	0.348	0.278	-0.059	0.064	0.170	0.016	0.110
DMP 2map	0.696 **	0.874 **	0.814 **	0.568 **	0.616 **	0.619 **	0.228	-0.153	-0.028	0.121	0.514 *	0.345	0.088	-0.298	-0.101	-0.036	-0.170	-0.046
DMP 3map	0.657 **	0.870 **	0.827 **	0.612 **	0.592 **	0.596 **	0.386	-0.089	0.006	0.137	0.552 **	0.381	0.166	-0.170	0.010	0.053	-0.074	0.059
Yield	0.132	0.226	0.172	0.239	0.326	0.383	0.097	0.264	0.076	0.222	0.383	0.292	0.128	0.269	0.404	0.354	0.352	0.489 *
Crude protein	0.170	0.282	0.319	0.193	0.392	0.417	0.057	0.179	-0.058	0.055	0.373	0.230	0.007	0.229	0.193	0.139	0.266	0.278
Crude fibre	0.276	-0.199	-0.293	-0.588 **	-0.152	-0.228	-0.347	-0.342	-0.185	-0.351	-0.271	-0.392	-0.388	-0.421	-0.700	-0.651 **	-0.519 *	-0.695 **
Ascorbic acid	0.540 *	-0.049	-0.126	0.324	0.119	0.190	0.380	0.397	0.428	0.501 *	0.227	0.285	0.348	0.374	0.539 **	-0.610 **	0.549 **	0.657 **

* Significant at 5 % level ** Significant at 1 % level DMP - Dry Matter Production map - months after planting

In laterite soil also incremental additions of Sul-Po-Mag did not significantly increase soil Mg. The NPK treatment receiving no Mg gave significantly low exchangeable Mg values which was on par with absolute control.

As the level of Mg application increased significant increase in exchangeable Mg occurred. Increasing the Mg levels in the presence of different levels of K also significantly increased the exchangeable Mg of laterite soil.

Though increasing the K levels decreased the exchangeable Mg no significance was observed. In the absence of Mg, increasing K levels increased exchangeable Mg but there was no significant difference. Similar results were obtained by Adams and Hendersen (1962) who reported that in Mg deficient soils, the availability of Mg to crops is greater at higher levels of K and in Mg sufficient soils the availability of Mg is less at higher K levels. The exchangeable Mg of soil decreased as growth of the crop progressed. This is because of the uptake of Mg by the plant.

4.6 Sulphur (Table 44)

Increasing Sul-Po-Mag levels resulted in increased levels of S in soil, which was significant at one month after planting. The Sul-Po-Mag and the K + Mg treatments gave available S of soil significantly more than the NPK treatment. This is because of the presence of S in both Sul-Po-Mag and Mg SO_4.

As the level of K increased, the available S in soil did not show significant variation but increasing the Mg levels significantly increased the available S especially at higher levels of Mg. This can either be due to a synergistic effect of added Mg on S availability or due to the presence of S in $MgSO_4$.

In laterite soil, the Sul-Po-Mag treatment gave significantly higher available S when compared to the treatments receiving no Mg but it was on par with the K + Mg treatments. Increasing the level of Sul-Po-Mag did not significantly increase the available S of soil.

Application of K decreased the available S when compared to K_0 but incremental addition of K did not bring about any significant effect. But the addition of Mg significantly increased S in soil at higher levels of application (Mg_2 and Mg_3). The increase in S by incremental addition of Mg also occurred in the presence of different levels of K. Thus no interaction occurred between K and Mg on the available S content of laterite soil.

Summary

SUMMARY

The present investigation entitled 'Dynamics of potassium, magnesium and sulphur in plant and soil with special reference to the application of langbeinite' was undertaken to examine the dynamics of K, Mg and S in soil as influenced by the application of langbeinite (Sul-Po-Mag) and to assess the suitability of langbeinite as a potassium-cum-magnesium fertilizer in the acid-laterite soil of Kerala using tapioca and bhindi as test crops.

The first part of the study comprised of a field experiment conducted at the Instructional Farm, College of Horticulture, Vellanikkara to find out the suitability of Sul-Po-Mag as K-cum-Mg fertilizer for tapioca in Kerala. The treatments included the application of K_2O as Sul-Po-Mag or muriate of potash alone at different levels of substitution.

Observations were made on plant characteristics, nutrient uptake and soil nutrient level at harvest stage. It was seen that the Sul-Po-Mag treatments gave drymatter production and yield on par with muriate of potash. N and P uptake was significantly higher for the treatments receiving Sul-Po-Mag during the initial stages only but during the later stages, the Sul-Po-Mag and muriate of potash treatments were on par. Muriate of potash treated plants generally did not show significant difference in K and Ca uptake from the Sul-Po-Mag treatments at different stages of growth. Mg and S uptake values for the muriate of potash treatment remained low throughout the growth period when compared to Sul-Po-Mag treatment and this was significant during the initial stages. Application of gypsum significantly increased the S uptake values.

The different treatments did not influence the available N content of soil. The available P was significantly low for the plots receiving Sul-Po-Mag, muriate of potash and Mg than those receiving gypsum or gypsum + Mg along with muriate of potash. Application of higher levels of Mg or gypsum along with muriate of potash gave increased available K content of soil at harvest but the treatments with 100 per cent muriate of potash or Sul-Po-Mag gave significantly low available K values. The treatments receiving gypsum recorded high values for exchangeable calcium. Magnesium availability increased with increasing levels of Mg addition but application of gypsum decreased the available Mg in soil. Available S increased with increasing S application as Sul-Po-Mag or gypsum. The plots receiving muriate of potash and muriate of potash + Mg gave significantly low available S values than those receiving Sul-Po-Mag or gypsum. Thus Sul-Po-Mag can be substituted for tapioca in the acid-laterite soils of Kerala.

The second part of the study comprised of an incubation experiment programmed with the intention of delineating the pattern of release of K, Mg and S during the course of incubation under submerged conditions after the application of Sul-Po-Mag, muriate of potash, $MgSO_4$ and a combination of muriate of potash and $MgSO_4$ at three different levels of these fertilizers. Application of K fertilizers (Sul-Po-Mag or muriate of potash) resulted in a significant increase in the available K of both the alluvial and laterite soil. In alluvial soil, the available K first increased till 15 days after incubation and then decreased to a stable value towards the end of incubation. Muriate of potash application gave lower available K during the later stages but Sul-Po-Mag maintained K availability throughout incubation. In laterite soil also the available K increased during the later stages, the decrease being more for muriate of potash than for Sul-Po-Mag. In both soils, available K decreased with incremental additions of $MgSO_4$ especially during the initial stages.

Alluvial soil gave comparatively very low amount of K in leachate than the laterite soil. Leachate K was more for the treatments receiving $MgSO_4$ +MOP and muriate of potash while Sul-Po-Mag gave lower leachate K in both soils. Increasing the K levels increased leachate K in both soils.

Application of Mg fertilizers significantly increased exchangeable Mg in both soils throughout the period of incubation. Thus Sul-Po-Mag and $MgSO_4$ application increased the exchangeable Mg when compared to muriate of potash. As the incubation period advanced, exchangeable Mg for the Sul-Po-Mag treatments showed higher values when compared to $MgSO_4$ indicating the gradual release of Mg from Sul-Po-Mag in alluvial soil. In laterite soil, the pattern of release was almost similar for Sul-Po-Mag and $MgSO_4$ though Sul-Po-Mag gave slightly higher values for exchangeable Mg at the end of incubation. The presence of K in Sul-Po-Mag did not affect significantly the exchangeable Mg values of both soils.

Leachate Mg showed a decrease during the initial stages and then showed an increase in both soils. The increase was in a more stable manner in laterite soil but fluctuated in alluvial. In laterite soil, a steep decline in leachate Mg was noticed for the treatments receiving $MgSO_4$ and muriate of potash alone and in combination, but for the treatments receiving Sul-Po-Mag, the decline was gradual. In alluvial soil, a steep decline was noticed for all treatments. Thus Mg release occurred over a prolonged period for Sul-Po-Mag than $MgSO_4$. Increasing the level of Mg fertilizer increased leachate Mg. Leachate Mg was lower for Sul-Po-Mag than for the $MgSO_4$ treatments.

The alluvial and laterite soils did not vary much in their available S contents. Application of Sul-Po-Mag or $MgSO_4$ resulted in an increase in available S throughout the incubation period in both soils. The available S initially decreased during the first eight days and then showed an increase in both soils, the magnitude of which was more in alluvial soil than in laterite soil. The treatments with muriate of potash recorded comparatively lower values for available S when compared to the treatments receiving Sul-Po-Mag or $MgSO_4$. The leachate S showed an initial decrease in both soils and then increased after 30 days after incubation. At the end of incubation both soils showed a decrease in leachate S. Thus release of S was in a fluctuating pattern especially for alluvial soil. The leachate S for muriate of potash treatment was less than $MgSO_4$ or Sul-Po-Mag.

No significant difference was observed among the fertilizer treatments in available N during incubation in both soils. Both alluvial and laterite soils showed the same pattern of changes during incubation. Available N remained stable till 30 days after incubation and then showed an increase. N in leachate was higher during the initial stages and then gradually decreased till the end of incubation.

The available P was found to increase progressively during the initial stages of incubation and then showed a decrease. The trend of changes was similar in both soils but in laterite soil, the peak value was attained later than alluvial soil. Application of different K and Mg fertilizers did not result in much deviation from the original pattern of P release and sorption in both the soils but it was seen that the treatments receiving K and Mg as KCl and $MgSO_4$ gave comparatively lower values than Sul-Po-Mag after the initial stages of incubation. The P contained in leachate in alluvial soil was only in traces when compared to the laterite soil.

Exchangeable Ca was slightly higher in alluvial soil when compared to laterite soil but the two soils showed almost similar pattern of release. The leachate Ca remained almost stable in laterite soil but showed a gradual increase in alluvial soil.

The third part of the study comprised of a pot culture experiment undertaken to examine the interaction of K and Mg in soil plant system using bhindi as the test crop, with different levels of muriate of potash, $MgSO_4$ and Sul-Po-Mag.

In alluvial soil, the Sul-Po-Mag applied plants gave relatively higher drymatter production when compared to the treatments receiving muriate of potash at all stages but a decrease in drymatter production was observed as the level of application increased. Similarly application of Mg as $MgSO_4$ at the lowest level (10 kg ha^{-1}) caused a significant increase in drymatter production but higher levels of application did not cause any significant increase. In laterite soil, the Sul-Po-Mag treatments did not significantly increase the drymatter production, but Mg addition as $MgSO_4$ (upto 20 kg Mg per ha) increased the drymatter production.

Fruit yield was significantly higher for the Sul-Po-Mag treatments in alluvial soil when compared to the treatments receiving muriate of potash and $MgSO_4$. The NPK treatment receiving the normal fertilizer dose recommended by the Kerala Agricultural University gave significantly lower yield when compared to the Sul-Po-Mag treatments. But addition of $MgSO_4$ at moderate levels (Mg_1) along with muriate of potash significantly increased the yield of bhindi fruit in alluvial soil. Yields were generally lower in laterite soil than in alluvial soil. The $SPM_2$was found to give fruit yield significantly higher than SPM_1 and SPM_3 which was on par with the NPK treatment. Addition of $MgSO_4$ also increased yield upto Mg_2. Higher levels of Mg significantly decreased yield.

In alluvial soil, Sul-Po-Mag treatment registered higher nutrient uptake values than the muriate of potash and the muriate of potash + $MgSO_4$ treatments especially during the later stages of growth. When Mg and K were supplied as Sul-Po-Mag, N uptake was significantly higher than when a corresponding level of Mg and K were applied as $MgSO_4$ and KCl respectively in alluvial soil. . Thus in alluvial soil, the application of K as K_2SO_4 increased N uptake when compared to KCl. In laterite soil, Sul-Po-Mag treatments gave significantly lower N uptake values especially at higher levels of application when compared to the muriate of potash + $MgSO_4$ treatments. But N uptake by the treatment receiving NPK was on par with SPM_1 and SPM_2. Increasing the level of K application increased the K uptake by the crop in both soils.

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P uptake was significantly higher for the Sul-Po-Mag treatments when compared to the other treatments in both alluvial and laterite soils but with incremental addition of Sul-Po-Mag, the P uptake decreased significantly. Application of increasing levels of K resulted in increased P uptake values upto K_2 level (30 kg ha^{-1}) in both soils.

Increasing the level of Sul-Po-Mag application increased the uptake of K in both soils. K uptake by the Sul-Po-Mag treatments was in general higher than the muriate of potash treatments in both soils. Increasing the Mg levels increased K uptake in alluvial soil but did not give significant effect in laterite soil.

Application of Increased levels of Sul-Po-Mag did not produce a significant effect on the uptake of Ca by bhindi though a decreasing trend was noticed. Addition of $MgSO_4$ at increased levels decreased the Ca uptake significantly in both soils.

Application of increasing levels of Sul-Po-Mag or $MgSO_4$ increased Mg uptake in both alluvial and laterite soils. Increasing the level of K application as muriate of potash decreased Mg uptake significantly at two months after planting. But in the presence of Mg (10 kg ha^{-1}), the different K levels did not influence significantly the Mg uptake by the plant. In laterite soil, Sul-Po-Mag gave comparatively lower Mg uptake values when compared to muriate of potash treatments receiving Mg at moderate to high levels (20 to 30 kg ha^{-1}).

Increasing Sul-Po-Mag levels did not significantly increase S uptake in both soils. Application of Mg at moderate levels increased S uptake in both alluvial and laterite soils.

Soil available N was increased significantly by the application of Sul-Po-Mag at increasing rates in alluvial soil, but in laterite soil there was no significant increase. It was observed that irrespective of the K level as Mg increased, a significant increase in N availability occurred in both soils.

Increasing the level of Sul-Po-Mag application significantly increased P availability upto K_3. Application of K and Mg also significantly increased P availability in both soils.

Incremental addition of Mg in the presence of K caused a significant decrease in available K especially at higher Mg levels in both soils but increasing the Mg levels without K application did not bring about a significant reduction in available K values.

Varying the Sul-Po-Mag levels did not bring about a significant effect on exchangeable Ca of both soils. Increasing Mg levels did not show significant effect on Ca content in alluvial soil but caused a reduction in exchangeable Ca in laterite soil.

Exchangeable Mg showed an increasing trend with incremental additions of Sul-Po-Mag only during the initial stages of growth in both soils. Increasing the K level to K_3 significantly decreased exchangeable Mg. Thus antagonistic effect was shown by relatively high levels of K on the exchangeable Mg of soil. Increasing the levels of Sul-Po-Mag and $MgSO_4$ significantly increased available S in both alluvial and laterite soils.

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Appendices

APPENDIX 1. Weather parameters during 1994-95

Months	Temperature (°C)		Mean relative humidity (%)	Total sunshine (h)	Total rainfall (mm)	Number of rainy days
1994 April	34.9	24.4	73.5	240	165.2	10
1994 May	33.6	24.7	74.5	248.	124.2	7
1994 June	28.9	22.9	90	63.9	955.1	27
1994 July	28.6	22.4	91	44.5	1002.1	29
1994 August	30	22.8	85	92.5	509.2	20
1994 September	31.8	23.2	78	217.7	240.5	8
1994 October	32.3	22.7	80	207.4	358.2	20
1994 November	31.8	23.3	68	242.5	125.3	5
1994 December	32.2	22.2	58	328.3	-	-
1995 January	32.9	22.4	59	298.4	-	-
1995 February	35.4	23.4	60	279.5	0.5	1
1995 March	37.6	23.8	60	289.5	2.8	1
1995 April	36.6	24.9	71	271.7	118.7	5
1995 May	33.5	23.9	78	201.9	370.5	13
1995 June	31.6	23.1	86	109.6	500.4	19
1995 July	29.9	23.2	89	65.6	884.7	26
1995 August	30.6	23.7	86	115.5	448.7	22
1995 September	30.1	23.5	82	184.4	282.5	13
1995 October	33.2	23.2	78	257.7	110.4	8

APPENDIX 2. Experiment I – Lay out

N

R_1

T_1	T_{13}
T_4	T_9
T_{12}	T_3
T_{10}	T_6
T_5	T_2
T_7	T_{14}
T_{11}	T_8

R_2

T_{11}	T_5
T_1	T_{12}
T_{14}	T_6
T_3	T_2
T_4	T_8
T_9	T_{10}
T_{13}	T_7

R_3

T_5	T_{10}
T_1	T_6
T_9	T_7
T_{13}	T_{11}
T_4	T_8
T_3	T_2
T_{12}	T_{14}

DYNAMICS OF POTASSIUM, MAGNESIUM AND SULPHUR IN PLANT AND SOIL WITH SPECIAL REFERENCE TO THE APPLICATION OF LANGBEINITE

By

B. RANI

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA
2000

ABSTRACT

An investigation entitled 'Dynamics of potassium, magnesium and sulphur in plant and soil with special reference to the application of langbeinite' was undertaken to examine the dynamics of K, Mg and S in soil as influenced by langbeinite (Sul-Po-Mag), a K-cum-Mg fertilizer in the acid laterite soil of Kerala using tapioca and bhindi as test crops.

The first part of the study comprised of a field experiment to assess the suitability of Sul-Po-Mag as a K-cum-Mg fertilizer for tapioca in Kerala. It was seen that Sul-Po-Mag application produced drymatter and yield on par with the muriate of potash treatments and hence Sul-Po-Mag can be substituted for muriate of potash for tapioca in the acid-laterite soils of Kerala. Mg application increased the available Mg of soil but gypsum application caused a reduction in available Mg.

The incubation study was programmed with the intention of delineating the pattern of release of K, Mg and S during the course of incubation under submerged conditions, after the addition of Sul-Po-Mag, muriate of potash, $MgSO_4$ and a combination of muriate of potash and $MgSO_4$ at three different levels of these fertilizers to two soils namely alluvial and laterite. Application of either Sul-Po-Mag or muriate of potash resulted in a significant increase in the available K of both soils. The available K decreased with incremental additions of $MgSO_4$ especially during the initial stages. Muriate of potash application gave lower available K during the later stages but Sul-Po-Mag maintained availability throughout the incubation period. The alluvial soil gave very low amount of K in leachate when compared to the laterite soil. The leachate K was less for the Sul-Po-Mag treatment when compared to the treatment receiving muriate of potash + $MgSO_4$. Application of Sul-Po-Mag or $MgSO_4$ increased the exchangeable Mg when compared to muriate of potash as the incubation period advanced, the exchangeable Mg for the Sul-Po-Mag treatments showed higher values when compared to $MgSO_4$ indicating the gradual release of Mg from Sul-Po-Mag in alluvial soil. In laterite soil, the pattern of release was almost similar for Sul-Po-Mag and $MgSO_4$ though Sul-Po-Mag gave slightly higher values for exchangeable Mg at the end of incubation. The presence of K in Sul-Po-Mag did not affect significantly the exchangeable Mg values of both soils. The leachate Mg showed a decrease during the initial stages of both soils but leachate Mg was lower for Sul-Po-Mag than the muriate of potash treatments.

Application of Sul-Po-Mag or $MgSO_4$ resulted in an increase in available S throughout the incubation period in both soils. Available S initially decreased and then showed an increase, the magnitude of which was higher for alluvial than the laterite soil. The leachate S showed an initial decrease in both soils and then increased after 30 days after incubation but at the end of incubation, a decrease was again noticed.

The third part of the study consisted of a pot culture experiment undertaken to examine the interaction of K and Mg in soil-plant system using bhindi as the test crop with different levels of muriate of potash, $MgSO_4$ and Sul-Po-Mag.

In alluvial soil, application of Sul-Po-Mag gave relatively high drymatter production when compared to the other treatments but a decrease was observed as the level of application increased. Similarly application of $MgSO_4$ at the lowest level caused a significant increase in drymatter production but higher levels did not cause any significant effect. In laterite soil, the Sul-Po-Mag treatments did not significantly increase drymatter production but addition of increased levels of $MgSO_4$ (upto Mg_2) caused a significant increase.

Fruit yield was significantly higher for the Sul-Po-Mag treatments in alluvial soil when compared to the treatments receiving muriate of potash, $MgSO_4$ and the treatments receiving NPK at the rate recommended by the Kerala Agricultural University but in laterite soil the yield recorded by the Sul-Po-Mag treatments were on par with the NPK treatment. In laterite soil SPM_2 was found to give fruit yields significantly higher than SPM_1 and SPM_3. Addition of Mg (as $MgSO_4$) increased yield upto Mg_2 but higher Mg levels significantly reduced yields.

Sul-Po-Mag treatments registered higher nutrient uptake values than the muriate of potash and the muriate of potash + $MgSO_4$ treatments. Increasing the Mg levels increased K uptake in alluvial soil but did not give significant effect in laterite soil. Increasing the Sul-Po-Mag or $MgSO_4$ levels increased Mg uptake in both soils. But increasing the levels of muriate of potash significantly decreased Mg uptake. In the presence of Mg (10 kg ha^{-1}) the different K levels did not significantly influence the Mg uptake values when compared to the muriate of potash treatments receiving Mg at moderate to high levels (20-30 kg ha^{-1}). Application of Mg at moderate levels increased S uptake in both the soils.

Incremental addition of Mg in the presence of K caused a significant decrease in available K especially at higher Mg levels in both soils, but increasing the Mg levels without K addition did not bring about a significant reduction in available K values. Exchangeable Mg showed a increasing trend with incremental additions of Sul-Po-Mag during the initial stages of crop growth. Increasing the level of application of K significantly decreased exchangeable Mg. Thus antagonistic effect was shown by relatively high levels of K on the exchangeable Mg of soil. Increasing the levels of Sul-Po-Mag and $MgSO_4$ increased soil available S in both laterite and alluvial soils.