FORMS, AVAILABILITY AND TRANSFORMATION OF POTASSIUM IN LATERITE SOIL AS INFLUENCED BY CROP UPTAKE

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I hereby declare that the thesis entitled '**Forms, availability and transformation of potassium in laterite soil as influenced by crop uptake**' 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 or other similar title, of any other University or Society.

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Sri. C.S. Gopi
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CERTIFICATE

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Dedicated to
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Introduction

INTRODUCTION

The soil is no longer considered as an inert matter for the anchoral support of the plant, studied for its chemistry and nutrient content, but an ecologically dynamic system to study. So there is compelling relevance and imperative need to monitor the soil health in terms of physical, chemical and biological properties. In the present context of integrated nutrient management, the concept is for optimisation of the effects of all available sources of plant nutrients to improve soil fertility availing nature's gifts. The soil fertility is not static but dynamic and a deep understanding of the dynamics is needed for the best soil management.

Soil-water-plant system is the gift of nature to mankind of which soil is a treasure of nutrients for plant growth. The fertility of the soil is the capacity of the soil to supply essential nutrients to normal plants in adequate amounts and balanced proportion which is maintained by the use of fertilizers in an indispensable condition for profitable landuse and sustained agricultural production (Gupta, 1991).

The original source of nutrients in the soil are the rocks and minerals from which it forms. It is a fact that no more than two per cent of the total quantity of most nutrients in a soil is readily available for crop uptake. This is of great importance in the study of soil and plant nutrition.

Among the major nutrients, potassium is required by plants in larger amounts since it has to perform a variety of functions in them. It has the most important role of enzyme activation in plants. Other functions include osmoregulation, maintaining energy balances, inducing disease resistance, translocation of assimilates etc.

Potassium is released into the soil solution by weathering of minerals especially feldspars. The mineral K, exchangeable K, non-exchangeable K and solution K which are the four forms of potassium are in dynamic equilibrium with each other. Water soluble and exchangeable K in the soil are the immediate source of this nutrient to plant while non-exchangeable K contributes significantly to plant uptake over a longer period.

Equilibrium reactions occurring between solution and exchangeable phases of soil K profoundly affect K supply to plants. The rate and direction of these reactions predict whether applied K will be leached into lower soil horizons, absorbed by plants, converted into unavailable forms or released into available forms. It is also of importance that potassium is a nutrient which undergoes changes in soils as a result of its interaction with plants and other nutrients. The uptake of potassium by a crop is influenced by many factors such as nature of the soil, nutrient content, crop species etc.

The present study is to get information regarding the forms, availability and transformation of potassium in laterite soil, under the influence of varying levels of other major nutrients and an annual crop like banana.

The objectives of the study include

i) to investigate the fate of applied and native potassium in a soil of low fertility status, as influenced by other major nutrients, organic matter and uptake by an annual crop banana

ii) to explore the interactive influence of potassium with other added and native elements present in the soil in the presence of a crop

iii) to determine the effect of added potassium on fixation and availability at different growth stages of an annual crop like banana grown under gradients of N, P, K and organic matter.

Review of Literature

REVIEW OF LITERATURE

Potassium is a major nutrient which is present in relatively large quantities in most soils averaging about 1.9 per cent. It is absorbed by the plants in larger amounts than any other nutrient except nitrogen. Potassium-soil mineral relationships are of greater significance because of the fact that only a small fraction of the total K is available to the plants.

The total K content varies with soils. The laterite soils, which cover more than 60 per cent of the total area of Kerala are high in acidity and low in plant nutrients and organic matter. Praseedom (1970) found that in Kerala soils, the total K_2O content varied from 0.04 to 0.54 per cent. Different forms of potassium present in laterite soils of Kerala and Tamil Nadu were estimated by Nambiar (1972). According to him the total content of these soils ranged from 0.04 to 0.27 per cent. Hassan (1980) reported that in upland laterite soils the total K content varied between 0.03 and 0.44 per cent, while the available potassium ranged from 6 to 38 ppm. Jacob and Venugopal (1987) reported that the total reserve of K_2O of laterite soils of Kerala ranged from 0.2 to 1.8 per cent.

A precise knowledge of the occurrence, distribution, forms, availability, transformations and interaction pattern of potassium is considered most essential to understand and interpret the behaviour of native and added potassium in soil. An attempt is made here to review some of the earlier works carried out in these aspects which are of relevance to the present study.

1 Occurrence of potassium in soil

The potassium in soils originates from the slow weathering of K bearing minerals. Micas and potash feldspars accounted for the major portion of potassium in soil (Syers, 1995). Orthoclase (K, Na) $AlSi_3O_8$ and microcline ($KAlSi_3O_8$) are the main potash feldspars. Micas include biotite, $(H_2K(Mg,Fe^{2+})_3(Al,Fe^{3+})\ SiO_4)_3$ and muscovite $(H_2KAl_3(SiO_4)_3)$.

Dubey *et al.* (1988) reported that feldspar K was greater than mica K in the non-clay component.

Pal and Durge (1993) opined that the potassium bearing minerals in alluval soils of India (Entisols and Inceptisols) are micas which are fine grained and concentrated, mainly in the clay fractions.

The condition with which K minerals weather depend on their properties and the envrionment. K is also found in secondary clay minerals in the soil which include illites, vermiculites, chlorites and unstratified minerals (Tisdale *et al.*, 1995).

2 Forms and availability of potassium in soils

A lot of works have been conducted on the forms of potassium and their relationships with soil physico-chemical properties.

Soil K exists in four forms - the mineral K, the exchangeable, nonexchangeable and solution K.

Nambiar (1972) observed that the values of water soluble K, available K and nitric acid soluble K ranged from 0.028 to 0.248, 0.166 to 0.969 and 0.440 to 2.041 (mol(p^+) kg^{-1} respectively in laterite soils of Kerala and Tamil Nadu.

Dhillon *et al.* (1985) reported that exchangeable K represented 0.34 per cent of total K content of soils of north western India. The increasing order of availability of the four forms of K were mineral, nonexchangeable, exchangeable and solution K (Martin and Sparks, 1985, Tisdale *et al.*, 1995).

Singh and Singh (1986) obtained significant positive correlation of organic carbon with total K and water soluble K.

Tarafdar and Mukhopadhyay (1986) reported that the different forms of K such as water soluble, exchangeable, labile, nonexchangeable and total K were positively correlated with each other except the interlayer K which did not significantly correlate with total K in the alluvial soils of West Bengal.

In some Alfisols of Himachal Pradesh, the average content of exchangeable, nonexchangeable and total K were 0.004, 0.027 and 1.8 per cent respectively (Shankayan and Bhardwaj, 1987).

Studies conducted by Ravikumar *et al.* (1987) on the forms of potassium in soils of Haryana revealed that the water soluble, exchangeable, HNO_3 soluble and HCl soluble were 6 to 70 ppm, 28 to 528 ppm, 220 to 1170 ppm and 1480 to 3960 ppm respectively.

Rao and Sekhon (1988) classified laterite soils as low to medium with respect to K status, alluvial soils as medium to high and black cotton soils as high.

Singh *et al.*(1989) reported that in the soils of Chotanagpur region of Bihar, nearly 7 per cent of the total K was present as HCl soluble, 4 per cent as nonexchangeable and 0.5 per cent as in available form. Most soils had medium content of available K, water soluble K and exchangeable K contributing 8 and 92 per cent respectively towards K availability.

Water soluble K was significantly and positively correlated with exchangeable and available forms of K in Vellayani series (Devi *et al.*, 1990).

Mercykutty *et al.* (1990) reported that water soluble, exchangeable and available K were significantly correlated with fixed K in rubber growing soils of South India. They observed a positive correlation between clay content and total K and also a positive correlation of organic carbon with water soluble, exchangeable, fixed and available K.

Rao and Sekhon (1991) reported that water soluble and exchangeable K were positively correlated. Nonexchangeable K constituted 4.4, 3.0 and 5.1 per cent of total K in Entisols, Inceptisols and Alfisols which are the major soil orders of Assam. Exchangeable K varied from 29.2 to 54.1, 30.7 to 50.0 and 35.6 to 72.1 ppm in these soil orders respectively which accounted for 0.35, 0.47 and 0.47 per cent total K, water soluble K ranged from 7.9 to 15.1, 7.9 to 11 and 4.5 to 8.1 ppm in the soil orders respectively (Boruah and Nath, 1992).

Sutar *et al.* (1992) studied the forms of K in laterite soils of Maharashtra. The values of water soluble, exchangeable, nonexchangeable and total K ranged from 6 to 30, 13 to 23, 76.4 to 374.4 and 2975 to 3250 ppm, respectively. Available K measured as water soluble and exchangeable K was higher in lateritic soils (Basumatary and Bordoloi, 1992).

Das *et al.* (1993) conducted studies in the Balisahi soil series of Orissa and reported that water soluble and exchangeable K which are easily available to the crops constituted 0.61 to 3.0 per cent and 1.0 to 1.6 per cent of total K.

Studies on the forms of K in relation to landform and soil properties of Basaltic terrain revealed that water soluble K was not related to other forms of K. Water soluble K was maximum at the surface which constituted about 1.8 to 17.4 per cent of available K. Exchangeable K accounted for 80 to 98.2 per cent of available K (Das *et al.*, 1993).

Dixit *et al.* (1993) observed that the content of exchangeable K ranged from 15.15 to 221.12 mg kg^{-1} in some soil series of Western Uttar Pradesh. Singh and Tripathi (1993) reported that water soluble K showed signfiicant distribution pattern in some representative soils of Himachal Pradesh. Water soluble K accounted for 0.05 per cent of total K while available K and exchangeable K constituted 0.64 per cent and 0.59 per cent of total K, respectively. Water soluble K was positively correlated with mica and K feldspar in some profiles of Rajasthan (Mishra *et al.*, 1993).

Rao *et al.* (1993) studied the nonexchangeable K reserves and classified kaolinite dominated soils as low in nonexchangeable reserve, smectitic as medium and illitic as high respectively.

Lateritic and non-lateritic soils of the humid region were comparatively low in available potassium. K supplying capacity ranged from 98.4 to 310.6 and 136 to 294.7 ppm K for lateritic and medium black soils respectively (Patil *et al.*, 1993).

The variation in the distribution of K depends on the mineral present, particle size and degree of weathering. Water soluble, exchangeable and nonexchangeable and lattice forms of K constituted 0.02 per cent, 2.6 per cent, 8.4 per cent and 86.5 per cent of total K respectively. Major fraction was mineral K. All forms were inter correlated indicating the presence of dynamic equilibrium among them (Venkatesh and Satyanarayana, 1994a). In another study, they also found that total soil K was high in the clay fraction. All the forms of K in soils were significantly and positively correlated with K content in silt and clay (Venkatesh and Satyanarayana, 1994b).

3 Factors affecting potassium availability in soils

Since K is one of the exchangeable cations, its level and availability are governed by complimentary ions on the exchange sites and soil properties such as pH, texture, type of clay minerals, content of $CaCO_3$ and organic matter content.

3.1 Effect of complimentary ions

The major phenomenon of K uptake is the replacement of K^+ ions from the exchange complex to soil solution from where plants can easily assimilate it. The K^+ ions present in the soil exchange complex thus have to be primarily replaced by other cations to bring them into solution for their uptake by plants (Gupta *et al.*, 1978).

The difference between cations in case of displacement is due to the lyotropic series for exchangeable cations; i.e., the strength of adsorption is Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+} (Tisdale *et al.*, 1995).

3.2 Effect of other major nutrients on potassium

Chattopadhyay and Mallik (1977) in their study on uptake of nutrients by Musa Cavendish banana at flowering stage revealed that K uptake was more at low N and P and double K_2O doses.

Mathew and Aravindakshan (1981) studied the nutritional uptake of rainfed banana and their study revealed that N uptake was highest at highest N level given by them. Phosphorus and to a lesser extent K uptake was enhanced by N nutrition.

Singh and Verma (1988) noticed that increasing N rates increased N and K uptake while P uptake was increased upto a particular level of nitrogen only.

In the study on the effect of irrigation, N and P levels on N, P and K content and uptake of hybrid sorghum, increased rates of nitrogen increased both content and uptake of N, P and K (Panwar *et al.*, 1988).

Munda and Patel (1989) found greater effect of P fertilizer on plant N, P and K uptake than K fertilizer. Potassium uptake was highest at the higher rate of P application in groundnut.

Nilokova *et al.* (1989) could find unfavourable effect of N and P fertilization on the soil K forms. Potassium applications did not conform to N, P additions. The extent of reduction in the soil K balance was dependent on the level of N fertilizer application.

Increasing rates of each nutrient, N, P and K increased the yields and uptake of N, P and K in rice and wheat (Singh *et al.*, 1989).

Mello and Kaminski (1990) reported that while applying Ca and Mg as correctors of soil acidity, K accumulation and dry matter yield were not affected. But both increased with increase in rate of K applied.

3.3 Effect of potassium on other major nutrients

Muthuswamy *et al.* (1974) reported that potassium application was correlated with the uptake of N, P and K by rice.

Turner and Barkus (1983) observed that increased K supply increased plant uptake of P while it reduced that of N, Ca, Mg and Cu.

In the study on the response of cultivar Giant Cavendish to increasing rates of K Garita and Jaramillo (1984) reported that leaf K and leaf K/Mg ratio increased while leaf K/N ratio decreased as rate of K increased.

Barber (1986) confirmed the antagonism between K and Ca as well as K and Mg.

Available K and exchangeable Ca increased with K applications (Alvarenga and Loper, 1988) in cerrado vegetation in red latosol.

Rajdhar (1989) studied the effect of K on the nutrient content in wheat. Increasing K concentration increased N, P and K contents but decreased Ca and Mg contents.

Oshima *et al.* (1990) reported that in sorghum and rye grass, the Ca uptake was competetively inhibited by excess soil K. Sheela and Aravindakshan (1990) noted that K rate had no effect on N uptake whereas P and K uptake increased. Increasing K fertilization significantly increased the uptake of N, K and Ca (Hegde and Srinivas, 1991).

Taharieva and Romheld (1991) reported antagonistic interactions between K and Ca, Mg and K and K and N on low calcareous soils.

Antagonism was observed between K and Mg while conducting a study by Yang, 1992 on relationship between K and Mg and effect of N and K in different types of soil.

Menon and Marykutty (1993) in their study on ashgourd observed increase in content of N, K and exchangeable Ca with application of K while available P and Mg content remained unaffected.

Sindu (1997) reported that in banana with increased level of K decreased N content while P showed an increasing trend. Calcium and Mg were found to show a decreasing trend with increasing K.

3.4 Effect of micronutrients

Studies on the effect of micronutrients on K availability is very limited. K deficiency is accompanied by Fe toxicity. High levels of Fe depressed K absorption (Mengel and Kirkby, 1982). Application of graded dose of K had no effect on Mn uptake in soybean. K deficiency was reported to choke Fe translocation in plants (Tisdale *et al.*, 1995).

Studies on the influence of long term fertilization on the factors of the soil K regime revealed that the K saturation of soils increased the mobility of K^+ ions and reduced K fixation. A high concentration of Ca^{2+} ions in relation to K^+ ions enhanced this effect (Hudcova, 1984)..

3.5 Effect of soil pH

Exchangeable and available K reserves of Punjab alluvial soils were found to increase with an increase in pH (Kansal and Sekhon, 1975). Kansal and Sekhon (1976) found significant correlation with HNO_3 soluble K and pH.

Bolan and Ramulu (1981) reported a positive correlation between water soluble and exchangeable K and pH, EC, exchangeable Ca and Mg and organic carbon, While Prakash and Singh (1985) found that total K had no significant relationship with organic carbon and pH.

The lattice K had significant and positive correlation with pH organic carbon, CEC, $CaCO_3$, exchangeable Ca, exchangeable Mg, silt and clay (Singh *et al.*, 1985, Dixit *et al.*, 1993).

Dutta and Joshi (1990) found that the K potential was negatively correlated with pH and positively with CEC.

According to Rao and Sekhon (1991), soil pH had no effect on the available K status of acid tropical soils

Studies on the K distribution in some orchard soils of Himachal Pradesh revealed marked effect of organic carbon and electrical conductivity on K availability (Tripathi *et al.*, 1992).

Basumatary and Bordoloi (1992) observed that water soluble, exchangeable and nonexchangeable K were positively and total K and lattice K were negatively correlated with pH.

Singh and Kumar (1993) conducted studies on the K and Zn relationship in wheat. They reported that heavy doses of K may influence the availability of Zn to plants and vice versa. The effect of K and Zn concentration in antagonistic and Zn decreased significantly with K addition.

3.6 Effect of organic matter

The organic matter of the soils held a positive correlation with the availability of K (Verma and Verma, 1968). According to Juo and Grimme (1980) vegetation cycling and soil organic matter were mainly responsible for the relatively higher levels of water soluble and exchangeable K in the surface layer.

Diez (1986) studied the effect of organic matter on potassium dynamics on soil. He observed that manure increased levels of available K in soils.

Mehta *et al.* (1987) conducted a study on the exchange equilibria of K in soils. They could observe that addition of FYM enhanced the preference for K over Na and NH_4.

Sud *et al.* (1990) studied the effect of FYM and N on potato production and P and K availability in the soils of Shimla. FYM increased soil organic carbon, available N, P and K contents. Applied N decreased soil K content and increased NO_3-N content. FYM increased the use-efficiency of applied N by 22.4 per cent.

Management of organic matter in tropical soils rich in kaolinite was important to maintain the available K status for sustainable farming (Rao and Sekhon, 1991).

Studies conducted by Kuzelewski and Labetowicz (1992) on the effect of mineral fertilizer and FYM application on soil chemical properties showed that soil available P and K content increased with P, K and FYM application. FYM also increased soil available Mg content.

Patiram and Singh (1993) reported that addition of manure raised the soil pH, organic carbon, available P, CEC, exchangeable Ca^{2+}, Mg^{2+} and K^+. Patiram (1994) confirmed his earlier work in his study on effect of organic matter and N application in K quantity-intensity relationship in acid inceptisol. He observed that organic matter addition increased the exchangeable cations like K^+, Ca^{2+} and Mg^{2+} in the soil.

3.7 Effect of soil texture, type of clay mineral and parent material

Brar and Sekhon (1985) and Dhillon *et al.* (1985) reported that the content of available K was influenced by fineness of texture in soils of North India. Higher contents of exchangeable and nonexchangeable K were observed in fine textured soils compared to coarse textured soils (Sharma and Mishra, 1986). Coarser textured soils had higher levels of water soluble K. Singh *et al.* (1989) reported that total and water soluble K was positively correlated with sand and negatively correlated with clay. Studies on the K availability in textural classes of tropical soils revealed the influence of texture on K equilibrium activity ratios in both swell-shrink and red and lateritic soils (Rao *et al.* 1991).

The study of Mishra and Singh (1992) on the K release in Indian soils, revealed that the illitic soils having lower amounts of NH_4OAC-K showed faster release than somectitic soils having higher NH_4OAC-K. The kaolinitic soils showed still lower K release.

4 Transformation of potassium in soils

The content of water soluble and exchangeable K showed a marked rise with potash application in soils with slow and moderate K releasing capacity while non-exchangeable and total K increased conspicuously in those having high releasing power (Prasad and Rajamannar, 1987). Potassium fixation in laterite soils of Karnataka varied in the range of 2.35 to 27.0 per cent and the reason for low fixation was attributed to the presence of 1:1 type clay mineral (Ningappa and Vasuki, 1989).

Prakash and Singh (1989) found that the exchangeable K in texturally different soils increased with increasing levels of K and decreased with passage of time. Similarly the amounts of K fixed increased with levels and passage of time.

Deshmukh *et al.* (1991) conducted a study on the transformation of applied K in relation to its availability in entisols. Applied K transformed into nonexchangeable K, followed by exchangeable and water soluble forms.

According to Ano *et al.* (1992) soils in general fixed more K under dry conditions and the sub soils fixed more K than surface soils. Fixation was significantly correlated with soil clay content, CEC and exchangeable K but not with organic matter and pH.

Sharma *et al.* (1993) could find that surface layers of soil were rich in water soluble and exchangeable K. Significant positive correlation was obtained between water soluble and exchangeable K, exchangeable and non-exchangeable K, nonexchangeable and total K indicating the dynamic equilibrium existing between them.

Talele *et al.* (1993) working on the effect of added K and incubation on transformation of available K and nonexchangeable K in different soils of Maharashtra reported that nonexchangeable K decreased with increase in the level of K added to soil and it increased with time of incubation. Fixation of K in different soils had positive and significant relationships with pH, $CaCO_3$, clay and silt contents, but it was negatively correlated with sand and organic carbon content of soils.

Singh and Jha (1994) studied the transformation of K applied to sugarcane in Calciorthent. Applied K transformed into water soluble, exchangeable, non-exchangeable and lattice K. Jessymol and Mariam (1993) studied the transformation of added K in laterite soil for three months. At the end of the incubation period, there was a remarkable increase in all the fractions of K viz., water soluble, ammonium acetate extractable and nitric acid soluble.

5 Fate of applied and native K as influenced by crop uptake

Potassium reserves and their availability to plants largely depended on mineralogy and degree of weathering which in turn determined the dynamic equilibrium between nonexchangeable, exchangeable and water soluble forms (Ranganathan and Satyanarayana, 1980).

According to Ramanathan and Krishnamoorthy (1982), continuous exhaustive cropping had to be adopted with a reasonable degree of success to understand the release characteristics of reserve K and its subsequent mobility to meet the requirement of plants. K releasing power refers to the total availability of K in the soil, while the K supplying power denotes the actual uptake of K by plants.

Studies by Bhadoria *et al.* (1986) on the soil K in alluvial soils of Madhya Pradesh, through correlation with dry matter production, relative yield, percentage of K concentration and total K uptake by wheat crop showed significant relationships with plant growth indices.

Yadav and Swami (1988) in their study on the effect of K fertilization on dry matter yield and composition and uptake of nutrients in maize and change in soil K could find that K increased dry matter yield and concentration and uptake of nutrients except P. Also exchangeable K decreased with cropping. The contribution of soil reserve K towards K nutrition of plants was considerable.

Study on the dynamics of added K in a red soil under banana plantation revealed the increased contents of easily and potentially available forms of K in the soil with increased application rates (Bhargava *et al.*, 1992).

Materials and Methods

MATERIALS AND METHODS

Potassium is one of the major nutrients required for the plants in larger amounts, which undergoes rapid changes in soil as a result of its interaction with plants. The present study was aimed at to investigate the fate of applied and native potassium in laterite soils as influenced by varying levels of other major nutrients, organic matter and uptake by an annual crop, banana.

1 Experimental details

1.1 Location

The experiment was laid out at Banana Research Station, Kannara of Kerala Agricultural University, in a deep well drained laterite soil which enjoyed a humid tropical climate.

1.2 Design and Layout

Design : Second order rotatable design.

As a 5^4 factorial experiment would be quite unhandy and that too in a replicated banana trial it would be obviously impracticable. To avoid this difficulty, treatments were so chosen that only a few combinations need be tested. For the very purpose, the treatments confirming to a second order rotatable design were so chosen that the treatment combinations were reduced to seventeen. In addition to this, an absolute control combination was also included for favour of comparison between fertilized and unfertilized set up. So as to suit the principles of experimentation two replications were laid out. Thus altogether there were only 36 plots so that management was quite handy and results quite trustworthy.

No. of replications	: 2
Crop/variety	: Banana - Nendran
Pit size	: 50 x 50 x 50 cm
Spacing	: 2 x 2 m
Plot size	: 4 x 4 m
No. of plants per plots	: 4

1.3 Treatment details

There were eighteen treatments including one absolute control. The details were as follows.

1) Level of FYM = 5 viz, 5.0, 7.97, 12.5, 17.13, 20.0 kg/plant
2) Level of N = 5 viz, 100.0, 138.27, 200.0, 261.73, 300.0 g N/plant
3) Level of P = 5 viz, 50.0, 78.7, 125.0, 171.3, 200.0 g P_2O_5/plant
4) Level of K = 5 viz, 100.0, 176.54, 300.0, 423.46, 500.0 g K_2O/plant

1.3.1 Treatment combinations

The treatment combinations were as follows.

Treatment	FYM (kg/p)	N (g/p)	P_2O_5 (g/p)	K_2O (g/p)
T_1	5.00	200.00	125.0	176.54
T_2	5.00	200.00	125.0	423.46
T_3	7.97	100.00	125.0	300.00
T_4	7.97	300.00	125.0	300.00
T_5	12.50	138.27	50.0	300.00
T_6	12.50	138.27	200.0	300.00
T_7	12.50	200.00	78.7	100.00
T_8	12.50	200.00	78.7	500.00
T_9	12.50	200.00	125.0	300.00
T_{10}	12.50	200.00	171.3	100.00
T_{11}	12.50	200.00	171.3	500.00
T_{12}	12.50	261.73	50.0	300.00
T_{13}	12.50	261.73	200.0	300.00
T_{14}	17.13	100.00	125.0	300.00
T_{15}	17.13	300.00	125.0	300.00
T_{16}	20.00	200.00	125.0	176.54
T_{17}	20.00	200.00	125.0	423.46
T_{18}	0.00	0.00	0.0	0.00

1.3.2 Planting of suckers

Almost uniform sword suckers were selected for planting. The wet weight of the suckers ranged from 3 to 5.5 kg. Within this range, uniform suckers were planted in each plot. The planting was done on 19th August 1996.

1.3.3 Application of treatments

FYM was applied as single dose at the time of planting suckers. N, P_2O_5 and K_2O were applied in two equal splits at two months and four months after planting. Other cultivation practices were carried out as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 1993).

The farmyard manure application was done on dry weight basis after finding out the moisture percentage. The fertilizers were applied based on content. Both FYM and fertilizers were applied within the basin of 60 cm radius formed around each plant.

2 Collection and preparation of samples

2.1 Soil

Soil samples were collected at a depth of 0 to 30 cm. The samples were taken using soil auger from four different directions around the plant at varying radii within the basin of 60 cm radius. The samples collected from the basins of four plants in a plot were pooled to make a composite sample. The fresh samples were packed in polythene bags, labelled and transported to the laboratory. In the laboratory, the samples were dried in shade, clods were broken using a wooden mallet and sieved through 2 mm sieve. The soil samples were then stored in air tight containers for further analysis. The samples were designated as follows.

Notation	Stage of sampling	Field characteristics
P_1	Before planting	Field ploughed, weeds removed, levelled and samples collected
P_2	Two months after planting (2 MAP)	Suckers planted, FYM as per treatments applied, basins formed, samples collected
P_3	Four months after planting (4 MAP)	first half dose of N, P_2O_5 and K_2O applied, samples collected
P_4	Six months after planting (6 MAP)	second half dose of N, P_2O_5 and K_2O applied, samples collected
P_5	At harvest	Uprooted the crop

2.2 Plant

2.2.1 Leaf

Leaf samples were collected from index leaf ie. the third leaf considering the fully opened leaf from the apex as No.1(Bhargava and Reddy, 1991). From the middle portion of the index leaf, on either side of the petiole,a portion of the lamina was collected without damaging the whole leaf. The leaf samples were collected at different growth stages and the samples were assigned the following notations.

Notation	Stage of sampling
S_1	Four months after planting (4 MAP)
S_2	Six months after planting (6 MAP)
S_3	At harvest

The samples were first dried under shade and then in a hot air oven at 70°C. The dried samples were cut into tiny bits and stored in paper covers for chemical analysis.

2.2.2 Biomass

After harvest, the plants were uprooted and separated into rhizome, pseudostem, leaves and bunch. Samples were collected from each portion. Rhizome samples were collected from the base of the corm. Pseudostem samples were taken from the middle one-third portion. Samples of unripe fruits were collected from the middle finger in the top row of the second hand (D-finger) (Gottreich *et al.*, 1964). The samples were well dried under shade and then in a hot air oven at 60-70°C. The samples were then ground in a mechanical grinder. The powdered samples were stored in separate polythene containers for chemical analysis.

3 Biometric observations

Biometric observations were recorded monthly up to flowering stage. Observations were taken from the four plants in a plot and the mean value was calculated. After harvest the yield and yield attributes and biomass yield were recorded.

3.1 Plant characters

3.1.1 Height of the pseudostem

The height of the pseudostem from the base to the axil of the youngest leaf was measured.

3.1.2 Girth of the pseudostem

The girth of the pseudostem at a height of 20 cm from the ground level was measured.

3.1.3 Total number of functional leaves

Functional leaves were counted and recorded monthly.

3.1.4 Leaf area

Length and breadth of leaf were measured and leaf area was calculated using the formula

$$LA = 0.825 \times L \times B$$

where LA - leaf area, L - length, B - breadth, 0.825-constant (Robinson and Nel, 1985).

3.2 Bunch characters

3.2.1 Weight of bunch

The matured bunches were harvested and the weight of the bunches including the exposed peduncle was recorded.

3.2.2 Number of hands and fingers per bunch

The total number of hands and fingers per bunch was recorded.

3.3 Biomass yield

The biomass yield of the plant at harvest was recorded.

4 Chemical analysis of samples

4.1 Soil samples

Mechanical analysis of the initial soil samples was done by hydrometer method (Piper, 1942). The soil samples were analysed for pH, EC, organic carbon, total and available/exchangeable N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn.

Soil reaction in a 1:2.5 soil-water suspension was determined using a pH meter. Electrical conductivity (EC) of the supernatent liquid of soil-water suspension used for the determination of pH was read with the help of a conductivity meter (Jackson, 1958).

The organic carbon content was determined by Walkley and Black method as described by Jackson (1958). Total nitrogen was determined by nodified microkjeldahl digestion - distillation method (Hesse, 1971).

For the total elemental analysis of P, K, Ca, Mg, S, Fe, Mn, Cu and Zn the samples were extracted with a diacid mixture (HNO_3 and $HClO_4$ in 2:1 ratio). Total P was determined colorimetrically by ascorbic acid blue colour method. For total K, the extract was diluted and read in EEL flame photometer. Total content of Ca, Mg, Fe, Mn, Cu and Zn were determined in atomic absorption spectrophotometer. Total S was estimated by turbidimetry (Hesse, 1971).

Available nitrogen content was estimated by alkaline permanganate method (Subbiah and Asija, 1956). Available P was extracted using the Bray No.1

extract (0.03 N NH_4F in 0.025 N Hcl) and the P content in the extract was estimated colorimetrically (Watanabe and Olsen, 1965).

Neutral 1N NH_4OAC was used for the extraction of exchangeable cations. Exchangeable K was determined by flame photometry (Jackson, 1958). Cations such as Ca, Mg, Fe, Mn, Cu and Zn exchanged by neutral normal NH_4OAC were determined by atomic absorption spectrophotometry.

Available S was found out by the turbidimetric method (Hesse, 1971). Water soluble K in a water extract (1:5 soil and water shaken for five minutes) was estimated by flame photometry.

4.2 Farmyard manure

Samples were collected from the farmyard manure used for the experiment, dried and analysed for total content of N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn as in the case of soil samples.

4.3 Plant samples

Leaf and other plant parts were analysed for total N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn. Total N was determined by microkjeldahl method (Jackson, 1958). For the determination of P, K, Ca, Mg, S, Fe, Mn, Cu and Zn, the samples were extracted with a diacid mixture (HNO_3 and $HClO_4$ in 2:1 ratio). P content was determined colorimetrically by the vanado-molybdophosphoric acid yellow colour method in HNO_3 system (Jackson, 1958). For K determination, the extract was diluted and read in a flame photometer. Other cations Ca, Mg, Fe, Mn, Cu and Zn were estimated using atomic absorption spectrophotometer.

5 Statistical Analysis

The results of various parameters obtained from the experiment were analysed statistically for test of significance using the standard procedures using Mstat C Package, College of Horticulture, Vellanikkara. The correlations were worked out (Snedecor and Cochran, 1967). The methods as described by Singh and Chaudhary (1977) was followed for path analysis.

Results and Discussion

RESULTS AND DISCUSSION

The present study is to get an information regarding the forms, availability and transformation of potassium in a laterite soil under the influence of varying levels of other major nutrients and organic matter and uptake by an annual crop, banana. In order to achieve the objectives given under chapter 1, a field experiment was laid out at Banana Research Station, Kannara, Kerala Agricultural University. Soil and plant samples were taken at different stages of growth of the plant and analysed. Biometric observations were recorded. The results and discussion of the study are narrated in this chapter.

The physico-chemical characteristics of the experimental site are given in Appendix-I. The experimental site was found homogeneous with respect to different nutrients evidenced from the non-significance of the data of initial samples (Tables 1 to 11).

1 Soil analysis

The effect of treatments on the pH, EC and organic carbon content in the soil at different sampling periods are depicted in Table 1.

1.1 pH

The soil was acidic in nature with a mean value of 4.85. The pH was found to decrease at P_2 (2 MAP) then an increase at P_3 (4 MAP) and a slight decrease at P_4 (6 MAP) and then became almost stabilised at harvest. The pH decreased at P_2 (2 MAP) to range from 4.5 to 5.1. The treatments T_{14} and T_{15} were observed with lowest pH values. The decrease was noticed in all the treatments except the control treatment. The pH again raised at P_3 (4 MAP) to range from 5.10 to 5.30. At P_4 (6 MAP) the pH values varied from 4.7 (T_1) to 5.2 (T_3, T_7 and T_{18}). At harvest (P_5) the pH showed an increase over P_4 (6 MAP).

The decrease in pH at P_2 (2 MAP) was due to the acidity produced by the decomposition of FYM which might have released many organic acids. The increase in pH at P_3 (4 MAP) could be attributed to the added fertilizers urea and superphosphate at P_2 (2 MAP). The hydroxyl ions released during the hydrolysis of urea might have contributed to the increase in pH (Biswas and Mukherjee, 1987). The decrease in pH at P_4 (6 MAP) may be due to the H^+ ions released from the plant roots for exchange of nutrient ions from the soil solution (Mengel and Kirkby, 1982). At harvest (P_5) the uptake of nutrients is minimum and so exchange of H^+ ions by roots into the soil solution will be minimum and the reason for the increase in pH at P_5 (at harvest) may be the decreased root activity.

1.2 Electrical conductivity (dS m^{-1})

The EC of the soil showed an increasing trend up to P_4 (6 MAP) and thereafter a decline was observed. The EC at P_1 (initial) was found with a mean of 0.050. At all periods of sampling T_{18} (control) registered the lowest value and all the other treatments remained significantly superior to it. At P_2 (2 MAP), the values ranged from 0.058 (T_{18} - control) to 0.127 (T_{17}) with a mean value of 0.099. At P_3 (4 MAP), T_8 recorded the highest EC (0.855). The EC showed a decrease at P_4 (6 MAP) over P_3 (4 MAP) with a mean value of 0.302. The treatment T_{18} (control) recorded the lowest value at P_5 (at harvest) though the treatments did not differ significantly.

Table 1. Effect of treatments on the pH, EC and organic carbon content of the soil at different sampling periods

Treatments	pH					EC ($dS\ m^{-1}$)					Organic carbon (%)				
	P_1	P_2	P_3	P_4	P_5	P_1	P_2	P_3	P_4	P_5	P_1	P_2	P_3	P_4	P_5
T_1	4.8	4.7	5.1	4.7	5.1	0.056	0.078	0.183	0.159	0.144	0.464	0.484	0.479	0.478	0.553
T_2	4.8	4.8	5.3	4.9	5.1	0.053	0.072	0.285	0.198	0.140	0.460	0.492	0.507	0.488	0.651
T_3	4.8	4.6	5.1	5.2	5.2	0.049	0.089	0.222	0.182	0.109	0.479	0.502	0.507	0.495	0.590
T_4	4.9	4.6	5.3	4.8	5.4	0.050	0.113	0.193	0.217	0.080	0.465	0.543	0.533	0.527	0.623
T_5	4.9	4.6	5.1	5.1	5.4	0.053	0.089	0.298	0.195	0.098	0.458	0.605	0.593	0.484	0.548
T_6	4.8	4.7	5.2	5.0	5.2	0.048	0.106	0.655	0.374	0.093	0.462	0.547	0.519	0.529	0.507
T_7	4.9	4.7	5.2	5.2	5.3	0.048	0.119	0.272	0.199	0.092	0.470	0.621	0.616	0.587	0.621
T_8	4.8	4.5	5.1	5.0	5.3	0.048	0.120	0.855	0.332	0.109	0.475	0.562	0.555	0.512	0.633
T_9	4.9	4.7	5.3	4.9	5.1	0.050	0.119	0.386	0.234	0.104	0.485	0.614	0.583	0.544	0.645
T_{10}	4.8	4.7	5.1	5.0	5.5	0.054	0.082	0.830	0.242	0.080	0.522	0.607	0.576	0.600	0.606
T_{11}	4.8	4.6	5.3	5.1	5.3	0.048	0.106	0.447	0.316	0.113	0.478	0.562	0.534	0.604	0.628
T_{12}	4.9	4.6	5.3	4.9	5.3	0.053	0.119	0.800	0.321	0.128	0.570	0.585	0.593	0.569	0.604
T_{13}	4.9	4.5	5.1	4.9	5.2	0.051	0.062	0.609	0.529	0.144	0.525	0.539	0.528	0.508	0.593
T_{14}	4.9	4.5	5.1	5.0	5.2	0.048	0.083	0.533	0.485	0.158	0.400	0.657	0.546	0.490	0.500
T_{15}	4.8	4.5	5.3	5.0	5.1	0.048	0.115	0.840	0.345	0.085	0.525	0.610	0.593	0.526	0.598
T_{16}	4.8	4.6	5.1	4.8	5.4	0.048	0.124	0.784	0.697	0.098	0.465	0.686	0.583	0.536	0.625
T_{17}	4.9	4.6	5.3	5.2	5.4	0.048	0.127	0.794	0.352	0.082	0.500	0.676	0.659	0.576	0.725
T_{18}	4.9	5.1	5.1	5.2	5.1	0.048	0.058	0.081	0.064	0.044	0.525	0.471	0.430	0.397	0.448
Mean	4.85	4.64	5.18	4.99	5.26	0.050	0.099	0.503	0.302	0.106	0.485	0.575	0.552	0.525	0.594
CD(0.05)	NS	NS	0.0944**	0.149**	0.163**	NS	0.0061**	0.22**	NS	NS	NS	0.116*	0.084**	0.099**	0.150*

The EC of the soil at P_2 (2 MAP) showed an increase over P_1 (initial). It may be due to the soluble nutrients released from the FYM (Russell, 1973). The increase in EC at P_3 (4 MAP) can be attributed to the effect of added fertilizers. At P_4 (6 MAP) the EC showed a decrease compared to P_3 (4 MAP) due to vigorous uptake of the nutrients by the crop. At harvest (P_5) the EC decreased over P_4 (6 MAP) indicating further decrease in ionic content in the soil. The EC at P_5 (at harvest) was found to be more than that in the initial samples because of the residual effect of added nutrients.

1.3 Organic carbon (per cent)

The organic carbon content showed an increase at P_2 (2 MAP) and a decline afterwards. At harvest, the content got almost stabilised. Initially (P_1) the content varied from 0.458 to 0.525 with a mean value of 0.485. The treatment T_{18} (control) showed a steady decline in organic carbon content over the growth periods. It remained inferior to all other treatments at all periods of sampling. At P_2 (2 MAP), the content ranged from 0.471 to 0.686 (T_{16}). At P_3 (4 MAP), the organic carbon content manifested a decrease over P_2 (2 MAP). The treatment T_{11} recorded the maximum content (0.604) at P_4 (6 MAP). At harvest (P_5) the organic carbon content slightly increased and the treatment T_{17} (0.725) registered the highest content because it received the highest dose of FYM. The increase in organic carbon at P_2 (2 MAP) might be due to the application of FYM (Sutar *et al.*, 1992). The faster decomposition of organic matter in the soil may be the reason for the decreased content at P_3 (4 MAP) and P_4 (6 MAP). At P_5 (at harvest) the soil regained the carbon content which may be the result of the addition of root debris into the soil which sluffed off regularly for the initation of new roots.

1.4 Nitrogen

The changes in the total and available contents of N in soil as influenced by the treatments are presented in Table 2.

1.4.1 Total nitrogen (per cent)

The mean total N content in soil showed an increasing trend upto P_4 (6 MAP) while it stabilised at P_5 (at harvest). The mean value was 0.064 for the initial samples. With the addition of FYM at P_2 (2 MAP) the total content ranged from 0.044 (T_{18} control) to 0.095 (T_{16}) with a mean value of 0.069. The control was found on par with T_1, T_2, T_3 and T_4. The total N content was observed to increase at P_3 (4 MAP) and P_4 (6 MAP) due to addition of nutrients whereas the control treatment (T_{18}) showed a decline over the different periods of sampling. T_{15} was found superior at P_3 (4 MAP) and P_4 (6 MAP). At P_5 (at harvest, the content varied from 0.054 (T_{18} control) to 0.068 (T_9 and T_{10}) with a mean value of 0.063.

1.4.2 Available N (ppm)

A perusal of the data at different sampling periods showed an increasing trend upto P_4 (6 MAP) in the case of available N also. The available N content at P_1 (before planting) ranged from 70 to 130 with a mean value of 89. It accounted for 14 per cent of the total nitrogen content. The treatments did not differ significantly at P_2 (2 MAP) also. At P_3 (4 MAP), the available N content ranged from 69 (T_{18}) to 160 (T_{15}) with a mean value of 111. The variation was significant between treatments and a similar trend was observed during P_4 (6 MAP) also. This difference was due to the difference in the quantity of nutrient applied and also due

Table 2. Effect of treatments on the content of nitrogen in the soil at different sampling periods

Treatment	P_1		P_2		P_3		P_4		P_5	
	Total (%)	Available (ppm)	Total (%)	Available (ppm)	Total (%)	Available (ppm)	Total (%)	Available (ppm)	Total (%)	Available (ppm)
T_1	0.063	110	0.049	90	0.083	120	0.100	135	0.060	80
T_2	0.056	110	0.045	100	0.080	125	0.101	160	0.056	60
T_3	0.061	100	0.050	80	0.078	70	0.095	80	0.060	60
T_4	0.061	100	0.050	80	0.095	88	0.126	90	0.063	60
T_5	0.067	90	0.071	95	0.091	90	0.101	110	0.065	70
T_6	0.060	130	0.065	130	0.084	154	0.095	161	0.056	80
T_7	0.063	100	0.068	110	0.081	80	0.099	100	0.063	60
T_8	0.067	80	0.070	85	0.095	105	0.112	117	0.063	80
T_9	0.065	80	0.075	90	0.100	90	0.116	80	0.068	70
T_{10}	0.060	80	0.080	90	0.103	145	0.120	130	0.068	60
T_{11}	0.067	80	0.080	110	0.110	140	0.125	160	0.062	70
T_{12}	0.075	70	0.085	80	0.120	90	0.138	120	0.065	90
T_{13}	0.070	90	0.080	90	0.118	125	0.135	180	0.062	90
T_{14}	0.060	70	0.080	130	0.090	95	0.103	110	0.061	70
T_{15}	0.064	80	0.080	120	0.125	160	0.140	175	0.065	70
T_{16}	0.061	80	0.095	110	0.120	156	0.126	150	0.060	60
T_{17}	0.061	80	0.088	100	0.150	100	0.121	180	0.060	60
T_{18}	0.063	70	0.044	80	0.043	69	0.040	70	0.054	80
Mean	0.064	89	0.069	98	0.098	111	0.111	128	0.063	71
CD(0.05)	NS	NS	0.0007**	NS	0.006*	5.37**	0.021*	6.77**	0.0063**	13.65**

to the differential uptake from various treatments. At P_5 (at harvest) the available N content ranged from 60 to 90 with a mean value of 71.

The decrease in total and available N content at P_2 in treatments T_1, T_2 (5.0 kg FYM/plant), T_3 and T_4 (7.97 kg FYM/plant) may be due to the absorption of N by the plant or leaching loss from the soil. In other treatments receiving FYM more than 7.97 kg/plant, the total and available N contents were found to increase. Here the leaching loss and plant uptake might have been compensated by the higher rate of mineralised N from the higher quantity applied. This is in confirmity with the findings of Sud *et al.* (1990).

The decrease in the contents of total and available N at P_5 (at harvest) is due to the exhaustion of the nutrient by the crop.

1.5 Phosphorus

The data on the effect of treatments on the total and available contents of P at different sampling periods are tabulated in Table 3.

1.5.1 Total P (per cent)

The total P at P_1 (initial samples) varied between 0.103 and 0.122 with a mean value of 0.114. The content showed an increasing trend over other periods of sampling except at P_5 (at harvest) where a drop was observed. The control treatment (T_{18}) showed a steady decline throughout the course of sampling. At P_2 (2 MAP), the highest content was noticed in T_{17} which received the highest level of FYM (20 kg FYM/plant). All the other treatments remained significantly superior to T_{18} (control) at P_3 and P_4. The content of P at P_5 ranged from 0.087 (T_5) to 0.131 (T_6)

Table 3. Effect of treatments on the content of phosphorus in the soil at different sampling periods

Treatment	P_1		P_2		P_3		P_4		P_5	
	Total (%)	Available (ppm)	Total (%)	Available (ppm)	Total (%)	Available (ppm)	Total (%)	Available (ppm)	Total (%)	Available (ppm)
T_1	0.105	23	0.106	26	0.109	48	0.119	28	0.097	15.6
T_2	0.115	20	0.116	26	0.128	51	0.136	27	0.107	14.0
T_3	0.108	25	0.110	29	0.113	54	0.116	37	0.090	13.1
T_4	0.103	26	0.106	33	0.115	69	0.118	42	0.093	14.6
T_5	0.105	29	0.108	35	0.111	41	0.110	26	0.087	22.0
T_6	0.114	28	0.119	34	0.129	63	0.159	38	0.131	16.6
T_7	0.109	29	0.112	30	0.115	57	0.139	27	0.094	14.1
T_8	0.112	26	0.115	36	0.124	46	0.120	26	0.097	13.7
T_9	0.115	29	0.118	31	0.122	55	0.126	31	0.117	14.5
T_{10}	0.115	28	0.118	33	0.120	77	0.124	46	0.115	15.3
T_{11}	0.109	26	0.113	32	0.119	75	0.122	41	0.091	17.0
T_{12}	0.115	26	0.116	34	0.116	40	0.117	36	0.088	16.7
T_{13}	0.112	34	0.117	42	0.120	85	0.130	53	0.114	15.1
T_{14}	0.113	31	0.118	36	0.123	58	0.128	31	0.109	14.5
T_{15}	0.115	25	0.119	32	0.122	65	0.124	49	0.095	13.9
T_{16}	0.106	26	0.110	39	0.113	69	0.116	33	0.095	14.7
T_{17}	0.122	26	0.127	32	0.131	54	0.136	23	0.116	13.2
T_{18}	0.114	28	0.108	16	0.088	12	0.080	70	0.089	2.4
Mean	0.114	26.9	0.114	32.9	0.118	56.6	0.123	34.5	0.102	14.5
CD(0.05)	NS	NS	0.006**	NS	0.067*	8.99**	0.039*	7.94**	NS	6.98*

with a mean value of 0.102. The mean total P content of the treatments at harvest was found to be 10.5 per cent less than that at P_1.

1.5.2 Available P (ppm)

The available P content of the soil initially (P_1) ranged from 20 to 34 with a mean value of 26.9. The treatments remained statistically non-significant at P_2 though there was marginal increase in the content of available P. At P_3 (4 MAP), there was a sharp increase in available P content which ranged between 12 and 85. The lowest content was noticed in T_{18} (control) while all the other treatments remained significantly superior. There was slight decline in available P at P_4 (6 MAP). The treatment T_{13} receiving the highest level of P remained superior to all other treatments at P_3 and P_4. The control treatment (T_{18}) showed a definite decreasing trend in available P content with the age of the crop. The values at P_5 (at harvest) ranged from 2.4 to 22.0. During this stage, the available P content showed a decrease of 46.0 per cent than the initial stage (P_1).

The contents of total and available P increased at P_2 (2 MAP) due to the application of FYM (Yaduvanshi, 1988). But the available P content at P_2 remained non-significant among the various treatments indicating that the organic P from FYM has not contributed significantly to the available P fraction of the soil. At P_3 (4 MAP), the total and available P content increased due to the application of inorganic fertilizer. The increase in the ratio of available to total P was found to be in proportional to the quantity of fertilizer added. At 6 MAP, the values of total and available P showed a marked decrease indicating exhaustive removal of the nutrient by the crop during this period. At P_5 (at harvest), the contents of both total and available P of the soil was all time low and got stabilised indicating that the crop had absorbed this nutrient from the soil.

1.6 Potassium

The effect of treatments on the total, exchangeable and water soluble forms of K at different periods of sampling are depicted in Table 4.

1.6.1 Total K (per cent)

A perusal of the data showed that the total K content increased up to P_3 (4 MAP) and thereafter it decreased. Initially the total K content varied from 0.110 to 0.150 with a mean value of 0.119. At P_2 (2 MAP), the lowest content was recorded by T_{18} (control) while all the other treatments were significantly superior to it. At P_3 (4 MAP), the content of total K increased due to the application of fertilizers. At P_4 (6 MAP), the values of total K started a decline and the contents stabilised with a mean value of 0.160 at P_5 (at harvest). The mean content was 34 per cent more than the initial value. During the different periods of sampling the absolute control was significantly inferior to all the other treatments. The content of K in T_{18} (control) remained the same all throughout the experimental period.

1.6.2 Exchangeable K (ppm)

At P_1 (initial), the exchangeable K varied from 323 to 391 with a mean value of 359.3. This accounted for 30 per cent of total K content. At P_2 (2 MAP), the content showed a decrease and then a sharp increase at P_3 (4 MAP) and thereafter a linear decrease. At all periods, the control recorded the lowest value. At P_2 (2 MAP), the maximum content was recorded in T_2 (322) whereas at P_3 (4 MAP), T_8 (867) registered the maximum content. The treatment T_{17} (517) was found superior at P_4 (6 MAP). At P_5 (at harvest), the content ranged from 127 to 317

Table 4. Effect of treatments on the content of potassium in the soil at different sampling periods

Treatment	P_1			P_2			P_3			P_4			P_5		
	Total (%)	Exch. (ppm)	WS (ppm)	Total (%)	Exch. (ppm)	WS (ppm)	Total (%)	Exch. (ppm)	WS (ppm)	Total (%)	Exch. (ppm)	WS (ppm)	Total (%)	Exch. (ppm)	WS (ppm)
T_1	0.150	367	71	0.160	207	64	0.245	551	67	0.181	247	35	0.174	245	25
T_2	0.130	378	75	0.147	322	69	0.316	751	80	0.184	376	45	0.167	235	40
T_3	0.140	368	70	0.180	269	63	0.237	531	96	0.185	339	61	0.179	299	48
T_4	0.110	347	69	0.138	289	75	0.209	399	63	0.179	282	55	0.148	255	29
T_5	0.110	362	70	0.161	277	50	0.203	457	78	0.155	271	55	0.142	293	47
T_6	0.130	391	69	0.168	262	68	0.192	402	75	0.167	355	52	0.183	222	33
T_7	0.110	387	70	0.149	250	75	0.244	289	43	0.198	139	45	0.152	171	35
T_8	0.110	331	70	0.149	289	63	0.216	867	78	0.246	320	51	0.182	286	42
T_9	0.140	323	65	0.169	262	56	0.197	694	61	0.193	455	36	0.150	255	32
T_{10}	0.110	362	67	0.149	209	69	0.193	269	44	0.189	176	64	0.160	152	40
T_{11}	0.130	330	66	0.166	202	63	0.195	706	63	0.163	429	65	0.144	240	45
T_{12}	0.110	371	69	0.135	255	88	0.233	499	62	0.157	405	47	0.160	279	49
T_{13}	0.110	345	73	0.142	238	50	0.178	350	63	0.176	413	50	0.120	317	40
T_{14}	0.110	362	65	0.153	287	56	0.233	540	64	0.170	338	46	0.164	286	43
T_{15}	0.110	363	63	0.136	304	56	0.193	860	63	0.185	388	63	0.150	295	45
T_{16}	0.110	366	73	0.133	245	44	0.231	308	46	0.205	182	36	0.172	242	31
T_{17}	0.110	350	69	0.144	267	50	0.257	707	68	0.243	517	43	0.216	253	32
T_{18}	0.110	365	67	0.109	201	50	0.107	218	52	0.110	110	34	0.107	127	29
Mean	0.119	359.3	68.9	0.151	257.5	61.6	0.215	522	64.8	0.180	319.0	49.1	0.160	247.3	38.1
CD(0.05)	NS	NS	NS	0.006**	12.5**	NS	0.636**	55.45**	9.53**	0.0211**	30.92**	14.72**	0.017**	28.41**	9.0**

Exch. - Exchangeable; WS - Water soluble with a mean of 247.3. The exchangeable K content at P_5 (at harvest) constituted about 15.4 per cent of the total K content.

1.6.3 Water soluble K (ppm)

The water soluble K content in the soils at the experimental site ranged from 63 to 75 with a mean value of 68.9. The treatments did not differ significantly at P_2 (2 MAP). The water soluble fraction of K showed an increase at P_3 (4 MAP) over P_2 with the treatment T_3 recording the highest content (96). A decrease was observed in water soluble K at P_4 (6 MAP). At harvest, the content was observed to decline drastically over all other periods. The values varied from 25 to 49 with a mean of 38.1 which constituted 2.4 per cent of total K.

The increase in total K at P_2 (2 MAP) could be attributed to the application of FYM (Patiram and Singh, 1993; Patiram, 1994). The decrease in available and water soluble fractions at this period might be due to the shift in equilibrium of K due to the addition of FYM. At P_3 (4 MAP), all the forms of K - total, available and water soluble were found to be increased over P_2 (2 MAP). This was due to the addition of inorganic fertilizer (KCl). Similar reports were made by Brunet and Treto (1988). At P_4 (6 MAP), the crop was in the active vegetative phase which coincided with the time of maximum absorption of nutrients. As a result, the total, available and water soluble K contents decreased at this period (Yadav and Swami, 1988). At harvest, the samples showed a decrease in all forms of K compared to P_4 (6 MAP). When compared to the initial status, the total K content of the soil was found be to more at the end of the crop. This indicated that K from the added fertilizer might have entered into the total pool (Prasad, 1993).

1.7 Calcium

The data on the total and exchangeable content of Ca in the soil at different sampling periods as influenced by the various treatments are presented in Table 5.

1.7.1 Total Ca (ppm)

The initial (P_1) total Ca content varied between 715 and 913 and the mean values remained 816.4. The total content of Ca showed an increase up to P_3 (4 MAP) and then decreased. Control treatment remained statistically inferior to all other treatments at all periods of sampling. At P_2 (2 MAP), the treatment T_{14} receiving 17.13 kg FYM/plant was found superior while at P_3 (4 MAP) the treatment T_{13} receiving the highest P dose (200 g P_2O_5/plant) was found superior. At harvest, the total content of Ca ranged from 270 (control) to 765 (T_{10} receiving 171.3 g P_2O_5/plant). The mean value at this stage was 540.3 which was noticed to be 33.8 per cent less than the initial value. The control treatment showed a significant decrease over the entire growth period.

1.7.2 Exchangeable Ca (ppm)

The exchangeable Ca content at P_1 (initial) constituted about 18.4 per cent of total Ca. The values ranged from 140 to 162 ppm with a mean of 150.2. The content of available Ca showed an increasing trend up to P_4 (6 MAP) while at harvest (P_5) it got stabilised. At P_2 (2 MAP), the content of available Ca ranged from 153 to 231 with T_{13} recording the lowest content and T_7 the highest. The treatments did not show significant difference at P_3 (4 MAP). At P_4 (6 MAP), the lowest content was registered in the control (T_{18}) while all the other

Table 5. Effect of treatments on the content of calcium (ppm) in the soil at different sampling periods

Treatment	P_1		P_2		P_3		P_4		P_5	
	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable
T_1	786	148	813	159	934	225	842	261	485	134
T_2	759	141	960	166	1029	241	958	281	530	146
T_3	715	140	1012	181	1085	271	985	291	555	109
T_4	773	157	911	184	1059	287	932	313	503	159
T_5	768	141	813	193	917	231	616	252	500	173
T_6	843	159	963	182	1055	256	999	280	562	177
T_7	813	153	925	231	958	281	874	340	555	208
T_8	885	148	948	206	983	251	861	341	571	128
T_9	786	162	913	187	1057	268	955	352	668	127
T_{10}	814	156	903	186	1083	243	1004	284	765	130
T_{11}	885	157	920	170	1035	263	936	296	490	142
T_{12}	896	140	992	161	1012	221	997	234	510	162
T_{13}	913	146	1012	153	1088	297	994	326	585	138
T_{14}	900	151	1056	170	1075	266	975	298	550	152
T_{15}	784	160	984	179	1015	263	989	284	530	192
T_{16}	758	147	919	185	987	265	859	286	547	197
T_{17}	813	151	981	188	1010	291	967	337	550	202
T_{18}	805	148	600	175	433	147	339	125	270	97
Mean	816.4	150.2	926.9	180.9	989.7	253.7	894	287.8	540.3	154.0
CD	NS	NS	45.1**	26.21**	116.94**	NS	107.83**	35.56**	59.68**	27.94**

treatments were significantly superior to it. The treatment T_9 (125 g P_2O_5/plant) recorded the highest content (352) followed by T_8, T_7, T_{17} and T_{13}. At P_5 (at harvest) the available Ca content exhibited a decline with the values ranging from 97 (T_{18}) to 208 (T_7). The available Ca content at this stage contributed to about 28.5 per cent of the total Ca content.

The results obtained in this study revealed that addition of FYM increased both total and available Ca contents at P_2 (2 MAP) (Patiram, 1994). During the next period (P_3 - 4 MAP), the increase in content of total and available Ca was due to the application of phosphatic fertilizer and also from the mineralisation of FYM. Due to the increased demand of the crop for the nutrient at P_4 (6 MAP), the equilibrium was found to be shifted towards the available fraction which resulted in a decrease in total content. At harvest, the total as well as available Ca content of soil decreased indicating the increased removal of the nutrient by the crop. The gradual decline in total and available Ca content in the control treatment (T_{18}) illustrated the utilization of the nutrient by the crop.

1.8 Magnesium

The effect of treatments on the total and exchangeable contents of Mg in the soil at different sampling periods are provided in Table 6.

1.8.1 Total Mg (ppm)

The general trend of change in total Mg content was that of an increase in nature up to P_3 (4 MAP). It showed a decline thereafter. The total content in the initial samples ranged between 1010 and 1250 with a mean value of 1128.9. After the addition of FYM, there was a slight increase in Mg content. At P_2, the treatment T_{17}

Table 6. Effect of treatments on the content of magnesium (ppm) in the soil at different sampling periods

Treatment	P_1		P_2		P_3		P_4		P_5	
	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable
T_1	1080	32.4	1088	83.6	1090	87.1	1030	56.7	985	77.1
T_2	1230	33.3	1238	63.4	1243	58.2	1175	63.8	1138	47.9
T_3	1030	34.9	1035	58.7	1040	56.3	1010	75.4	951	68.6
T_4	1060	35.1	1080	85.3	1095	58.3	987	43.8	931	34.0
T_5	1010	32.8	1025	72.6	1031	49.7	1042	81.3	1016	47.6
T_6	1050	34.9	1062	78.3	1120	52.5	1095	89.8	1037	41.8
T_7	1010	37.2	1057	85.8	1080	53.7	1039	28.3	1010	31.5
T_8	1250	34.1	1261	65.0	1248	57.0	1218	57.4	1153	47.5
T_9	1230	35.3	1241	76.4	1283	67.9	1267	29.2	1237	40.0
T_{10}	1060	34.3	1081	90.1	1090	63.9	1028	64.3	1023	36.1
T_{11}	1190	35.6	1207	89.8	1220	48.1	1186	67.8	1160	31.2
T_{12}	1180	35.4	1194	92.2	1197	60.9	1083	62.3	1059	39.2
T_{13}	1110	35.7	1137	78.9	1155	55.5	1096	49.5	931	44.1
T_{14}	1250	33.6	1275	79.7	1320	68.7	1265	31.1	1068	48.9
T_{15}	1150	33.0	1164	96.0	1175	66.7	1137	45.6	1054	62.5
T_{16}	1100	35.0	1150	84.7	1175	60.9	1158	44.9	1069	59.5
T_{17}	1250	32.0	1286	89.1	1301	40.9	1272	48.8	1213	41.4
T_{18}	1080	34.9	837	78.8	752	26.3	657	21.2	590	20.3
Mean	1128.9	34.4	1134.3	80.4	1145.3	56.8	1096.9	53.4	1034.7	45.5
CD(0.05)	NS	NS	86.68**	NS	72.98**	16.29**	188.75**	2.25**	142.74**	19.7**

(receiving 20 kg FYM/plant) registered the highest content (1286) while the treatment T_{18} (control) showed a gradual decline over the entire period of plant growth. At P_3 (4 MAP) the content exhibited an increase with T_{14} (1320) registering the highest value and T_{18} (control) recorded the lowest (752). At P_4 (6 MAP), the content showed an decrease with T_{17} (1272) recording the maximum content. All the other treatments remained significantly superior to the absolute control (T_{18}) which recorded the lowest content (657). At harvest (P_5) the content of Mg was lower than that at P_4 in all the treatments.

1.8.2 Exchangeable Mg (ppm)

At P_1 (initial) the content of exchangeable Mg ranged from 32 to 37.2 with a mean value of 34.4. At P_2 (2 MAP), the values ranged from 58.7 (T_3) to 96.0 (T_{15}). The values showed a range of 26.3 (T_{18}) to 87.1 (T_1) at P_3 (4 MAP). The treatment (T_{17}) was found on par with T_{18} (control). At P_4 (6 MAP) the values ranged from 21.2 to 89.8. The lowest content was registered by the control treatment while all the other treatments were significantly superior to it. At harvest (P_5) the exchangeable Mg content ranged from 20.3 (T_{18}) to 77.1 (T_1) with a mean value of 45.5 which was 32.3 per cent more than that of initial (P_1) values.

The increase in both total and available Mg content at P_2 (2 MAP) and P_3 (4 MAP) was due to the addition of the nutrient through FYM (Kuzelewski and Labetowicz, 1992) and through the impurities of the fertilizers added. At vegetative phase, the crop is in its peak stage of growth where the maximum absorption is taking place and this can be attributed to the decline in the content at P_4 (6 MAP). At harvest (P_5), the content of total Mg declined and a shift in equilibrium of the nutrient towards availability could be seen. The control treatment got depleted of the nutrient over the growth phases necessitating FYM or fertilizer addition to regain the soil health.

At harvest (P_5) the content of Mg declined over the entire period indicating that the nutrient is depleted by the crop.

1.9 Sulphur

The total and available S content in soil at different periods of plant growth as influenced by treatments are presented in Table 7.

1.9.1 Total S (ppm)

The total S content was noticed to increase up to P_4 (6 MAP). The total S content of the initial samples varied from 272 to 545 with a mean value of 412.47. The content of total S drastically increased with the addition of FYM and fertilizers. At P_2 (2 MAP) the content ranged from 393 to 1696 with a mean value of 1123.9. The highest content was observed in the treatment receiving 20 kg FYM/plant (T_{16}) and the lowest content was noticed in the control (T_{18}). At P_3 (4 MAP) the highest content was registered by T_8 (1875) which was on par with T_3 and T_{13} and the lowest was recorded by T_{18} (345). A sharp increase was noticed at P_4 (6 MAP) over P_3 (4 MAP) with T_8 recording the highest content (3381). At harvest (P_5) the content varied between 269 (T_{18}) and 2790 (T_7). During the entire period of plant growth the control treatment T_{18} recorded the lowest values and it exhibited a steady decline with time.

Table 7. Effect of treatments on the content of sulphur (ppm) in the soil at different sampling periods

Treatment	P_1		P_2		P_3		P_4		P_5	
	Total	Available	Total	Available	Total	Available	Total	Available	Total	Available
T_1	477	3.5	924	7.1	1711	8.6	2805	11.2	1860	4.5
T_2	341	4.0	970	6.9	1689	8.7	2474	12.0	1360	4.1
T_3	409	3.0	1122	6.8	1808	9.7	2499	9.0	2109	4.1
T_4	477	4.5	1592	7.1	1737	9.7	2252	10.2	2310	3.1
T_5	341	3.5	1656	7.1	1663	8.0	2647	8.1	2384	5.5
T_6	409	4.5	958	6.1	1776	8.5	2844	9.5	2061	4.4
T_7	409	4.5	809	7.1	1766	9.6	2834	12.0	2094	4.7
T_8	409	4.5	965	4.7	1875	6.1	3381	8.3	2790	3.5
T_9	272	4.5	951	7.1	1656	9.4	2963	10.2	2455	4.4
T_{10}	272	5.0	821	4.6	1655	8.4	1809	9.1	1650	6.2
T_{11}	545	4.0	1102	4.9	1551	5.8	1834	6.3	1718	3.9
T_{12}	477	4.5	1054	5.4	1692	5.8	2402	7.1	2100	9.5
T_{13}	545	5.0	1677	6.9	1839	9.2	1958	11.9	1014	4.1
T_{14}	341	4.5	959	6.6	1654	7.6	3328	11.7	2207	6.3
T_{15}	272	4.5	1369	4.8	1748	7.7	3315	14.8	2641	4.7
T_{16}	545	4.5	1696	5.9	1703	7.1	2891	23.8	2611	5.2
T_{17}	477	4.5	1212	8.3	1655	5.6	2773	8.9	2117	3.1
T_{18}	409	4.5	393	4.0	345	3.8	272	2.8	269	2.8
Mean	412.5	4.31	1123.9	6.19	1640.2	7.74	2432.3	10.38	1986	4.67
CD(0.05)	NS	NS	110.33**	1.66**	97**	2.08**	225.62**	2.8**	230.1**	0.78**

1.9.2 Available S (ppm)

The available S content at P_1 (initial) values ranged from 3.0 to 5.0 with a mean of 4.31 which accounted for 1.04 per cent of total content. At P_2 (2 MAP), with the addition of FYM, the available S showed an increase. At P_3 (4 MAP) an increase in content was observed over P_2 (2 MAP), due to the application of phosphatic fertilizer. The content ranged from 3.8 (T_{18}) to 9.7 (T_3 and T_4). At P_4 (6 MAP) again an increase in content was observed. The highest content was registered by T_{16} (23.8) and the lowest was recorded by T_{18} (control). At P_5 the available S content decreased due to crop uptake. The mean available S content at harvest (P_5), was 4.67 which is accounted to 0.24 per cent of the total S content. The control treatment (T_{18}) remained inferior to all other treatments at all sampling periods. The available S in the control treatment showed a steady decline indicating the removal by the crop.

The results revealed that increase in total S content at P_2 (2 MAP), P_3 (4 MAP) and P_4 (6 MAP) was due to the application of FYM and fertilizer. The sulphur content of FYM was 0.32 per cent (Appendix-II) and that of super phosphate was 12.0 per cent. At harvest (P_5), though there was decrease in total S over P_4 (6 MAP), a net gain was noticed compared to P_1, indicating addition of this nutrient through the fertilizers and FYM and the nutrient was utilized only to a limited extent. The gradual decrease of the S content in the control treatment explains the crop removal of the nutrient. The low content of available S in the soil at all stages of crop growth might be due to the leaching loss of sulphate ions and also can be due to the adsorption of SO_4^{2-} ions by the Fe and Al oxides (Brady, 1988).

1.10 Micronutrients

1.10.1 Total and NH_4OAC exchangeable Fe (ppm)

The total and exchangeable Fe content in the soil at different sampling periods are provided in Table 8.

The total Fe content in the initial soil samples (P_1) varied from 1738 to 1981 with a mean value of 1885. Only a meagre quantity of total Fe was in the exchangeable form. It ranged from 0.8 to 1.2 which constituted about 0.05 per cent of the total Fe content. At P_2 (2 MAP),the total Fe content showed a slight increase (1945.9) whereas exchangeable Fe showed a decrease (0.313). This decrease might be due to chelation of the nutrient with organic matter (Tisdale *et al.*, 1995). Treatments did not differ significantly either in total or exchangeable contents at any of the sampling period. During P_3 (4 MAP), P_4 (6 MAP) and P_5 (at harvest), there were a declining trend in total content with a mean of 1847, 1639.4 and 1099.8 respectively. The low value of total Fe obtained in T_{18} (control) at all sampling periods indicated that there was addition of Fe from added FYM and fertilizers in the other treatment plots. It was observed that there was an increase in exchangeable Fe content at P_3 (4 MAP) over P_2 (2 MAP). It might be due to the Fe present in the added fertilizers as impurities. From 6 MAP (P_4) onwards the total Fe showed a general decrease and being present in the exchangeable form indicating that the element is absorbed by the crop.

1.10.2 Total and NH_4OAC exchangeable Mn (ppm)

The effect of treatments on the total and exchangeable Mn in the soil at different sampling periods are presented in Table 9. Initially the total content of Mn varied from 827 to 1020 ppm with a mean value of 896.5 and that of exchangeable

Table 8. Effect of treatments on the content of iron (ppm) in the soil at different sampling periods

Treatment	P_1		P_2		P_3		P_4		P_5	
	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable
T_1	1943	1.2	1976	0.43	1860	0.89	1640	0.89	1233	0.89
T_2	1900	0.9	1969	0.20	1885	0.83	1630	0.73	1205	0.83
T_3	1886	1.6	1953	0.18	1880	0.76	1670	0.79	1103	0.91
T_4	1738	0.8	1929	0.29	1705	0.69	1665	0.72	1074	0.88
T_5	1952	1.2	1977	0.25	1840	0.59	1600	0.76	1098	0.85
T_6	1932	0.9	1941	0.36	1860	0.72	1690	0.73	1140	0.97
T_7	1921	1.1	1956	0.26	1720	0.75	1620	0.89	1099	0.87
T_8	1883	1.2	1949	0.24	1865	0.88	1625	0.81	1070	0.98
T_9	1878	1.1	1933	0.19	1850	0.99	1630	0.77	1040	0.96
T_{10}	1869	1.3	1933	0.17	1865	0.67	1620	0.81	1110	0.96
T_{11}	1936	1.0	1943	0.43	1855	0.88	1600	0.83	1090	0.83
T_{12}	1981	1.1	1951	0.22	1860	0.92	1630	0.85	1095	0.81
T_{13}	1866	0.9	1963	0.45	1855	0.98	1665	0.84	1009	0.90
T_{14}	1921	1.2	1928	0.33	1895	0.99	1625	0.82	1071	0.93
T_{15}	1793	1.2	1952	0.28	1870	0.76	1665	0.92	1010	0.84
T_{16}	1793	0.9	1966	0.35	1865	0.84	1640	0.91	1080	0.87
T_{17}	1867	1.2	1961	0.22	1870	0.81	1655	0.94	1168	0.94
T_{18}	1868	1.2	1847	0.84	1670	0.29	1345	0.29	1060	0.18
Mean	1885	1.1	1945.9	0.316	1847	0.79	1639.4	0.79	1099.8	0.85
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 9. Effect of treatments on the content of manganese (ppm) in the soil at different sampling periods

Treatment	P_1		P_2		P_3		P_4		P_5	
	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable
T_1	867	14	896	6	785	8	764	8	737	10
T_2	956	13	1070	8	945	8	895	8	754	14
T_3	852	14	989	8	870	6	858	9	848	12
T_4	859	20	915	8	904	8	886	10	644	17
T_5	1020	24	1069	7	985	7	911	10	840	15
T_6	832	15	971	7	897	9	846	9	825	7
T_7	858	15	1033	8	1013	10	892	10	854	12
T_8	870	14	1060	8	913	8	832	10	680	13
T_9	926	13	931	7	926	9	793	11	655	12
T_{10}	1008	13	1013	9	945	10	876	8	703	7
T_{11}	924	16	1022	8	977	9	784	9	647	5
T_{12}	985	16	1086	7	909	9	849	10	691	11
T_{13}	854	17	876	7	960	11	954	8	569	10
T_{14}	856	13	1065	6	864	12	815	9	801	14
T_{15}	898	16	978	7	856	10	872	8	782	12
T_{16}	829	14	854	8	830	10	909	8	755	12
T_{17}	916	14	1024	8	913	11	827	10	855	15
T_{18}	827	15	820	10	806	14	775	7	605	5
Mean	896.5	15.4	981.8	7.6	905.3	9.4	852	9.0	739	11.3
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	0.43**	NS	0.006*

Mn ranged from 13 to 24 ppm with a mean of 15.4. At P_2 (2 MAP) though the treatments were not significantly different, there was a marginal increase in total Mn content and a slight decrease in the exchangeable content. The increase in total content was due to the application of FYM while the decrease in exchangeable content was due to the chelating effect of organic matter (Bear, 1976). At P_3 (4 MAP) and P_4 (6 MAP), the contents of Mn showed a general trend of decrease because of the intake by the plants at this active growth period. At P_5 (at harvest) the total content decreased to a mean value of 739 and the exchangeable content remained with a mean value of 11.3.

1.10.3 Total and NH_4OAC exchangeable Cu (ppm)

The total and exchangeable contents of Cu in the soil of different sampling periods are provided in Table 10. The total Cu content of the initial samples (P_1) varied between 24.4 and 33.1 with a mean value of 28.8 and the exchangeable content ranged from 0.135 to 0.425 with a mean value of 0.235. The exchangeable, Cu content showed an increase at P_2 (2 MAP) because of the addition of FYM. At P_3 (4 MAP), the total content showed a marginal increase whereas the exchangeable content showed a decrease. The decrease may be due to the chelation by organic matter (Russell, 1973), microbial assimilation or by crop uptake. At P_4 (6 MAP), the total content showed a decrease over P_3 (4 MAP) which was not significant among treatments. This decrease was reflected as increase in the exchangeable Cu content indicating the shift in equilibrium of the nutrient. At harvest (P_5), the total as well as exchangeable content of Cu declined in all the treatments due to crop removal. The continued gradual decrease in total and exchangeable Cu content in T_{18} (control) explicitly illustrated the uptake of this nutrient by the crop and the need for a time gap before next cropping. Crop removal lowered the level of trace elements in the soil (Brady, 1988).

Table 10. Effect of treatments on the content of copper (ppm) in the soil at different sampling periods

Treatment	P_1		P_2		P_3		P_4		P_5	
	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable
T_1	28.6	0.195	29.0	0.650	33.0	0.365	28.9	0.328	24.9	0.05
T_2	33.6	0.265	36.6	0.285	38.7	0.163	28.5	0.320	24.4	0.10
T_3	24.4	0.135	26.7	0.400	28.5	0.302	25.5	0.322	21.9	0.15
T_4	28.1	0.235	29.7	0.300	30.5	0.217	29.5	0.377	23.5	0.10
T_5	25.6	0.180	28.0	0.300	28.9	0.263	30.4	0.388	25.9	0.30
T_6	28.1	0.220	25.6	0.200	35.5	0.290	30.2	0.355	30.1	0.05
T_7	25.6	0.195	28.0	0.600	30.4	0.360	31.6	0.407	26.4	0.08
T_8	24.4	0.160	26.1	0.320	30.4	0.300	28.3	0.440	22.1	0.05
T_9	33.1	0.330	28.5	0.500	28.8	0.413	26.8	0.415	24.9	0.15
T_{10}	32.5	0.425	24.4	0.315	32.3	0.368	31.4	0.377	29.7	0.15
T_{11}	26.9	0.320	28.9	0.315	34.0	0.430	28.0	0.338	21.9	0.45
T_{12}	28.1	0.215	26.9	0.400	32.0	0.259	28.3	0.335	23.7	0.12
T_{13}	33.1	0.200	31.9	0.300	34.5	0.108	27.7	0.335	24.7	0.15
T_{14}	24.4	0.235	28.4	0.280	28.0	0.337	25.3	0.530	23.9	0.20
T_{15}	32.3	0.195	24.7	0.215	31.4	0.327	30.7	0.428	25.0	0.10
T_{16}	28.6	0.200	26.1	0.300	30.9	0.395	28.5	0.332	25.0	0.35
T_{17}	28.6	0.265	28.4	0.480	34.9	0.313	31.3	0.337	25.8	0.35
T_{18}	33.1	0.255	28.4	0.330	27.0	0.278	26.9	0.350	20.9	0.05
Mean	28.8	0.235	28.1	0.360	31.54	0.300	28.8	0.370	24.7	0.16
CD(0.05)	NS	NS	NS	0.149**	NS	0.067**	NS	NS	NS	NS

Table 11. Effect of treatments on the content of zinc (ppm) in the soil at different sampling periods

Treatment	P_1		P_2		P_3		P_4		P_5	
	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable	Total	Exchangeable
T_1	56.3	0.375	62.9	0.300	57.7	0.245	55.1	0.306	51.2	0.230
T_2	61.9	0.325	71.5	0.275	60.0	0.197	59.1	0.225	39.6	0.165
T_3	58.1	0.225	63.5	0.480	58.8	0.178	57.1	0.400	54.3	0.195
T_4	55.6	0.375	65.3	0.325	59.8	0.188	61.4	0.475	54.7	0.125
T_5	62.5	0.275	76.0	0.273	62.5	0.233	58.0	0.405	48.4	0.185
T_6	56.3	0.350	62.5	0.380	53.2	0.202	67.9	0.350	51.5	0.220
T_7	62.5	0.300	72.0	0.465	64.7	0.257	79.0	0.385	63.3	0.135
T_8	62.5	0.350	85.9	0.725	50.7	0.150	59.1	0.450	57.4	0.135
T_9	58.5	0.350	65.9	0.435	52.1	0.182	49.9	0.485	45.8	0.275
T_{10}	68.8	0.325	77.5	0.435	53.6	0.105	49.5	0.455	48.6	0.248
T_{11}	56.3	0.375	64.0	0.365	56.6	0.110	66.2	0.400	58.7	0.240
T_{12}	61.7	0.275	71.9	0.270	56.3	0.235	57.2	0.225	54.3	0.195
T_{13}	50.3	0.350	61.5	0.265	54.1	0.200	57.4	0.195	40.9	0.155
T_{14}	56.3	0.375	60.0	0.265	57.5	0.155	56.5	0.343	48.0	0.270
T_{15}	55.3	0.390	63.4	0.390	55.7	0.165	54.0	0.383	49.5	0.174
T_{16}	58.5	0.275	65.4	0.380	57.9	0.350	61.5	0.415	51.1	0.246
T_{17}	56.3	0.275	61.5	0.350	53.5	0.237	59.5	0.450	34.3	0.195
T_{18}	56.3	0.375	32.9	0.220	50.7	0.180	42.5	0.135	28.8	0.098
Mean	55.3	0.330	67.0	0.369	57.0	0.199	58.4	0.372	55.6	0.193
CD(0.05)	NS	NS	5.56*	NS	13.1**	NS	NS	NS	11.1*	NS

1.10.4 Total and exchangeable Zn (ppm)

The content of total and exchangeable Zn in the soil at different sampling periods are given in Table 11. At P_1 (initial), the content of total Zn varied from 50.3 to 68.8 with a mean value of 55.36. At P_2 (4 MAP), the total content showed an increase ranging from 32.9 (T_{18}) to 85.9 (T_8). All the other treatments were significantly superior to T_{18} (control). The increased content may be due to the application of FYM. The exchangeable content of Zn at P_1 (initial) showed a mean value of 0.330. The exchangeable content of Zn at P_2 (2 MAP) remained non significant among treatments with a mean of 0.369. The marginal increase in the exchangeable content could be due to the added FYM. At P_3 (4 MAP), the total and exchangeable content of Zn showed a decrease over P_2 (2 MAP). At P_4 (6 MAP), the total content of Zn showed a decrease while exchangeable Zn increased compared to P_2. This might be due to the shift in equilibrium towards available fraction which might have got decreased due to crop removal. The continuous decrease of Zn both total and exchangeable indicates the need for studying the role of this nutrient for banana crop.

2. Biometric observations

2.1 Height of pseudostem (cm)

The data on the height of the pseudostem are depicted in Table 12. The height of the plants did not show significant difference between treatments during the initial four months of growth. The lowest value was recorded by T_{18} (control). At 2 MAP, T_{16} (166.6) was found with highest value followed by T_{17} (162.1). At 3 MAP and 4 MAP, T_{13} registered highest measurement. At 5 MAP, the height of the plants differed significantly to vary between 201.0 to 336.9. The treatment T_8 was found superior while T_{18} recorded the least value. All the treatments were

Table 12. Effect of treatments on the height (cm) of pseudostem of banana at different stages of growth

Treatment	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP	7 MAP
T_1	142.6	187.6	238.1	296.5	357.1	377.4
T_2	126.4	183.4	206.8	276.5	339.8	387.0
T_3	140.9	168.5	230.6	296.5	350.5	379.9
T_4	138.5	170.8	197.5	277.5	331.0	361.1
T_5	112.4	160.3	245.0	308.5	366.5	427.1
T_6	133.9	174.0	219.3	335.0	389.6	415.7
T_7	138.3	174.0	233.2	301.9	363.5	389.5
T_8	156.9	190.6	228.2	336.9	395.0	464.6
T_9	109.6	169.4	217.7	263.2	305.1	344.6
T_{10}	145.1	192.8	229.1	279.4	326.7	382.0
T_{11}	125.7	177.4	236.3	303.1	356.0	437.9
T_{12}	150.1	192.2	228.6	308.8	325.2	407.7
T_{13}	158.3	203.9	249.2	296.7	354.3	402.9
T_{14}	153.4	168.2	206.2	300.4	394.3	408.2
T_{15}	148.1	183.0	214.4	280.8	376.0	392.2
T_{16}	166.6	196.5	229.4	290.9	356.3	379.3
T_{17}	162.1	199.4	223.8	300.3	367.3	392.7
T_{18}	139.9	152.4	160.4	201.0	253.0	282.2
Mean	141.6	180.2	221.9	291.9	350.4	390.7
CD(0.05)	NS	NS	NS	57.29*	59.3*	65.19*

MAP - Months after planting

significantly superior to T_{18}. Treatments except T_2, T_4, T_9 and T_{10} were on par with T_8. At 6 MAP, the height ranged between 253.0 to 395.0. The treatment T_8 recorded the highest value and T_{18} which registered the lowest value was on par with T_9. At 7 MAP, the maximum height was recorded by T_8 (464.4) itself. T_{18} (282.2) registered the lowest height.

The results revealed that in the early growth stages, plant height remained more or less unaffected by the treatments. After 2 months, the plants getting maximum FYM dose recorded the highest value. In general, plant height was found to increase with increasing K levels. The plants getting more of nitrogen also showed an increasing trend.

The effect of treatments varied significantly at 5th, 6th and 7th months. This could be explained on the basis of differential requirement of K.

The considerable increase in height of pseudostem noticed from fifth month after planting may be due to the increased hormonal activity at the flower initiation stage which occurred at this stage (Sheela, 1995). George (1994) attributed the non-significance for K treatments at the early growth stages to the initial high K content in soil and the lack of competition between plants for sunlight at the early stages.

Increased plant height as a result of enhancing the levels of K application has also been reported by many workers (Jambulingam *et al.*, 1975; Sheela, 1982; Mustaffa, 1987; Khoreiby and Salem, 1991 and George, 1994).

In the present study, the control plants recorded lowest plant height. This is in accordance with the findings of Freiberg and Steward (1960) and Lahav (1972).

2.2 Girth of the pseudostem (cm)

Girth of the pseudostem also followed a similar pattern as that of the height (Table 13). Girth of the pseudostem was found non-significant during the early stages of growth. At 2 MAP maximum girth was recorded by T_{18} (control). But after 3 months, girth showed an increase while the control (T_{18}) recorded the least value (24.4). Maximum girth was observed for T_{10} (34.0) followed by T_{16} (32.6). At 4 MAP, the highest value was recorded by T_5 (43.1) whereas T_{18} (28.1) recorded the lowest. The treatment T_5 was followed by T_8, T_{10} and T_{17}. At 5 MAP, the highest value was recorded by T_{11} (53.0) and T_{18} (32.9) recorded the lowest girth. The treatments differed significantly. Treatments except T_9 and T_{16} were found on par with T_{11}. All the treatments were significantly superior to T_{18}. 6 MAP, T_8 (59.7) was found with maximum girth while the minimum was recorded for T_{18} (37.8). Treatments except T_9 were on par with T_8. All the other treatments were superior to T_{18}, though the treatments did not differ statistically. At 7 MAP, T_8 (67.6) showed the maximum girth while the control (44.3) had the minimum.

Results showed that the treatments did not show any significant influence on the girth of plants during the first 3 months. After four months, the girth was found to increase with increase in the level of K application. The girth was minimum for control plants in all the growth stages studied.

Table 13. Effect of treatments on the girth (cm) of pseudostem of banana at different stages of growth

Treatment	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP	7 MAP
T_1	20.9	27.5	38.3	46.7	53.4	56.2
T_2	22.0	29.2	37.9	49.3	55.8	63.4
T_3	20.5	27.8	37.9	49.3	56.9	61.3
T_4	21.8	27.3	37.6	46.3	54.4	62.1
T_5	20.9	28.4	43.1	49.9	55.4	61.6
T_6	21.6	30.2	38.8	49.5	55.1	63.7
T_7	21.0	28.5	39.7	48.5	55.1	59.7
T_8	23.6	31.3	42.3	49.5	59.7	67.6
T_9	20.9	27.2	36.8	44.9	50.7	58.3
T_{10}	23.6	34.0	42.7	48.4	58.9	65.1
T_{11}	22.4	29.6	39.3	53.0	55.5	65.9
T_{12}	23.8	29.9	39.4	47.6	58.3	59.7
T_{13}	25.0	30.4	35.7	49.3	55.0	64.1
T_{14}	20.3	25.8	38.3	45.8	55.4	60.1
T_{15}	21.1	28.5	38.3	47.2	55.4	62.2
T_{16}	25.4	32.6	38.1	44.8	55.2	58.1
T_{17}	21.0	29.8	40.6	50.4	57.8	62.3
T_{18}	22.1	24.4	28.1	32.9	37.8	44.3
Mean	22.1	29.0	38.5	47.4	51.7	60.9
CD(0.05)	NS	NS	NS	7.89*	6.9**	NS

MAP - Months after planting

Positive effect of K on girth of pseudostem has been reported by Turner and Bull (1970), Lahav (1972), Jambulingam *et al.* (1975), Fabregar (1986), Mustaffa (1987), Hegde and Srinivas (1991), George (1994) and Sheela (1995).

The number of functional leaves produced was more in plants receiving higher levels of K which may be a reason for girth of pseudostem registering higher values at increased K levels and the minimum value at zero K.

2.3 Number of functional leaves

The effect of treatments on the number of functional leaves at different stages of growth are given in Table 14. The number of functional leaves showed a range of 6.3 to 7.3 at 2 MAP. Treatments did not differ significantly. The treatment T_{18} recorded the minimum number of functional leaves. Though the number of functional leaves increased after 3 months of age, there was no significant difference among treatments. The treatment T_{17} (9.3) registered the maximum number of functional leaves whereas T_{18} (6.8) recorded the minimum. Treatments remained non-significant at 4 months of age also. The treatment T_{11} recorded the highest value while T_{18} had the lower values. Significant difference between treatments was observed after 5 months of age. The treatment T_8 (13.9) recorded the maximum number of functional leaves. All the other treatments except T_{18} (9.0) were on par with it. At 6 MAP, the treatments T_{17} and T_2 (14.5) were found superior with maximum number of functional leaves. The treatments T_8 and T_{11} were on par with them. The treatment T_{18} (10.1) recorded the minimum number of functional leaves. All the other treatments were significantly superior to this. At 7 MAP, T_8 (15.8) had the highest number of functional leaves. T_{18} recorded the least value (11.2).

Table 14. Effect of treatments on the number of functional leaves of banana at different stages of growth

Treatment	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP	7 MAP
T_1	6.5	7.9	9.6	11.1	12.6	13.9
T_2	6.5	8.3	10.2	12.6	14.5	15.4
T_3	6.8	8.5	8.6	12.4	13.3	13.9
T_4	6.5	7.5	9.4	10.8	12.0	13.5
T_5	6.8	8.3	10.3	11.8	13.0	13.0
T_6	6.9	8.3	9.8	12.5	14.0	13.8
T_7	7.0	7.8	9.5	11.5	12.3	13.8
T_8	6.9	8.1	10.0	13.9	14.4	15.8
T_9	6.4	7.1	9.8	11.4	13.6	13.3
T_{10}	7.0	8.1	9.3	12.3	12.4	13.8
T_{11}	6.4	8.3	10.8	12.0	14.3	14.8
T_{12}	6.6	7.5	10.0	12.1	13.5	13.4
T_{13}	6.9	8.6	9.8	11.8	13.4	13.5
T_{14}	6.8	7.9	9.8	13.0	13.6	13.6
T_{15}	7.3	8.6	10.1	12.0	13.3	13.0
T_{16}	6.5	8.0	10.1	11.5	12.1	13.0
T_{17}	6.8	9.3	10.0	11.1	14.5	14.9
T_{18}	6.3	6.8	8.4	9.0	10.1	11.2
Mean	6.7	8.1	9.8	11.8	13.2	13.8
CD(0.05)	NS	NS	NS	10.34**	0.88**	1.54**

MAP - Months after planting

The results revealed that the number of functional leaves showed an increasing trend over the periods of growth. Treatments differed significantly only after 5 months of age. Increased K levels showed increased number of functional leaves. Anil (1994) had obtained similar results. The influence of mineral nutrition on the rate of leaf production was reported by Murray (1960). Sindu (1997) also reported the similar results. The leaf production rate was about 6 to 7 leaves per month in early vegetative growth phase (Pradeep *et al.*, 1992).

2.4 Leaf area (m^2)

Area of the index leaf of plants did not differ significantly during the early 3 months (Table 15). At 2 MAP, T_{13} had the highest leaf area whereas T_3 had the lowest measure. At 3 MAP and 4 MAP, T_8 had the highest measure of leaf area while T_{18} was noted with lowest value. At 5 months of age leaf area showed significant difference among different treatments. T_{11} (0.589) was found superior with highest leaf area. Treatments except T_1, T_7 and T_{10} were found on par with T_{11}. The treatment T_{18} (0.425) recorded the lowest leaf area which was on par with T_1, T_3, T_4, T_7, T_9, T_{10} and T_{13}. Though the treatments did not differ significantly at 6 MAP, T_{11} (0.788) recorded the highest measure followed by T_{17} and T_8. The treatment T_{18} recorded the minimum leaf area (0.600). After 7 months, T_8 (0.866) was found with maximum measure of leaf area followed by T_{11} and T_2. Lowest leaf area was observed in T_{18} (0.693).

In the present study, significant variation in leaf area was observed only after 5 months of age. Among the treatments, control plants registered minimum values whereas plants getting maximum K treatments registered maximum values.

Table 15. Effect of treatments on the area (m^2) of index leaf of banana at different stages of growth

Treatment	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP	7 MAP
T_1	0.176	0.280	0.447	0.489	0.546	0.761
T_2	0.160	0.255	0.445	0.539	0.676	0.861
T_3	0.159	0.243	0.437	0.510	0.598	0.743
T_4	0.186	0.259	0.401	0.502	0.612	0.727
T_5	0.173	0.262	0.452	0.564	0.695	0.813
T_6	0.174	0.280	0.496	0.584	0.686	0.835
T_7	0.163	0.257	0.473	0.489	0.677	0.724
T_8	0.199	0.355	0.531	0.581	0.702	0.866
T_9	0.177	0.229	0.454	0.501	0.601	0.801
T_{10}	0.196	0.306	0.475	0.458	0.624	0.635
T_{11}	0.192	0.265	0.497	0.589	0.788	0.863
T_{12}	0.211	0.267	0.477	0.532	0.613	0.844
T_{13}	0.212	0.298	0.481	0.504	0.655	0.836
T_{14}	0.178	0.223	0.367	0.513	0.603	0.822
T_{15}	0.175	0.254	0.483	0.536	0.578	0.806
T_{16}	0.206	0.282	0.407	0.523	0.616	0.775
T_{17}	0.206	0.280	0.528	0.581	0.725	0.836
T_{18}	0.179	0.204	0.284	0.425	0.600	0.693
Mean	0.185	0.267	0.452	0.523	0.644	0.791
CD(0.05)	NS	NS	NS	0.094*	NS	NS

MAP - Months after planting

Similar observations were made by Murray (1960), Lahav (1972), Mustaffa (1987), Khoreiby and Salem (1991), Anil (1994), George (1994) and Sindu (1997).

3 Yield (kg) and yield attributes of banana

The data on the yield and yield attributes are presented in Table 16. The yield data are illustrated in Fig.1.

The highest fresh weight of rhizome was recorded by T_8 (43.01) followed by T_{13} (41.04) and T_{10} (37.96) which were on par. The control treatment (T_{18}) obtained the least value of 28.75. The fresh weight of pseudostem did not show any significant difference among the treatments eventhough the treatment plots recorded higher values than control. There was a significant difference in the fresh weight of the leaves. The treatment T_{15} showed the highest value of 5.85 and the lowest value was exhibited by T_{18} (2.80).

Bunch weight of the treatment plots showed a significant difference over control. The control (T_{18}) got the lowest bunch weight of 3.75 whereas the highest yield was recorded by T_2 (9.52). The increase in the yield was 154 per cent over the control. T_2 was on par with T_3, T_5, T_6, T_8, T_9, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16} and T_{17}. Again T_5 and T_6 were on par with T_1, T_4, T_7 and T_{10}. Among the treated plots, T_4 recorded the least value of 8.21 which was also found to be 119 per cent more than the control. This clearly indicated that the banana plants require application of nutrients. The treatments receiving 300 g K_2O/plant and above, recorded higher bunch weights which were on par. The treatments T_1, T_7 and T_{10} recorded slight lesser bunch weights which may be due to the lesser quantity of applied K_2O. But T_{16}, eventhough received lesser quantity of K_2O exhibited better yield. The K

Table 16 . Yield (kg) and yield attributes

Treatments	Rhizome		Pseudostem		Leaves		Biomass yield		Bunch			
	FW	DW	FW	DW	FW	DW	FW	DW	FW	DW	No.of hands	No.of fingers
T_1	34.86	1.71	25.09	1.13	3.38	1.49	71.57	7.30	8.23	2.97	5	47.6
T_2	35.93	1.68	27.31	1.28	4.00	1.90	77.29	8.39	9.52	2.89	5	52.6
T_3	31.99	1.77	24.08	1.08	4.61	2.03	70.61	7.44	9.00	2.56	6	52.2
T_4	33.60	1.69	23.74	1.07	5.73	2.53	71.84	7.95	8.21	2.66	5	47.9
T_5	34.19	1.81	24.91	1.10	4.42	1.90	72.79	7.38	8.67	2.57	5	52.0
T_6	36.90	1.84	24.80	1.12	4.03	1.78	75.53	7.67	8.67	2.93	5	49.3
T_7	33.31	1.67	23.01	1.04	3.40	1.49	68.55	6.94	8.24	2.79	5	44.8
T_8	43.01	2.15	28.58	1.29	4.23	1.86	85.91	8.23	9.47	2.93	6	50.2
T_9	31.34	1.56	25.46	1.15	3.93	1.73	70.05	7.13	8.87	2.74	5	45.8
T_{10}	37.96	1.91	24.23	1.20	3.88	1.71	74.68	7.75	8.32	2.93	5	49.1
T_{11}	36.28	1.81	25.26	1.14	4.63	2.04	76.14	8.84	9.28	2.89	5	50.4
T_{12}	30.24	1.52	24.06	1.08	4.63	2.04	67.33	7.73	8.74	2.69	5	47.8
T_{13}	41.04	2.04	27.72	1.25	5.28	2.32	84.27	8.54	9.34	2.93	5	52.8
T_{14}	29.29	1.46	23.64	1.06	5.25	2.31	67.80	7.59	8.80	2.76	6	49.0
T_{15}	37.76	1.89	23.31	1.05	5.85	2.57	77.74	8.67	9.16	2.86	5	51.8
T_{16}	34.01	1.70	22.27	1.09	4.25	1.87	68.13	7.15	8.87	2.49	5	47.3
T_{17}	34.41	1.50	24.23	1.09	4.60	2.02	74.26	7.44	9.04	2.83	5	48.4
T_{18}	28.75	1.44	13.50	0.67	2.80	1.23	48.14	4.52	3.75	1.18	4	29.5
Mean	34.72	1.73	24.18	1.12	4.38	1.93	72.37	7.59	8.57	2.70	5.10	48.25
CD(0.05)	19.13*	NS	NS	0.22**	1.543**	NS	3.582*	2.12*	1.13**	0.006**	NS	7.58**

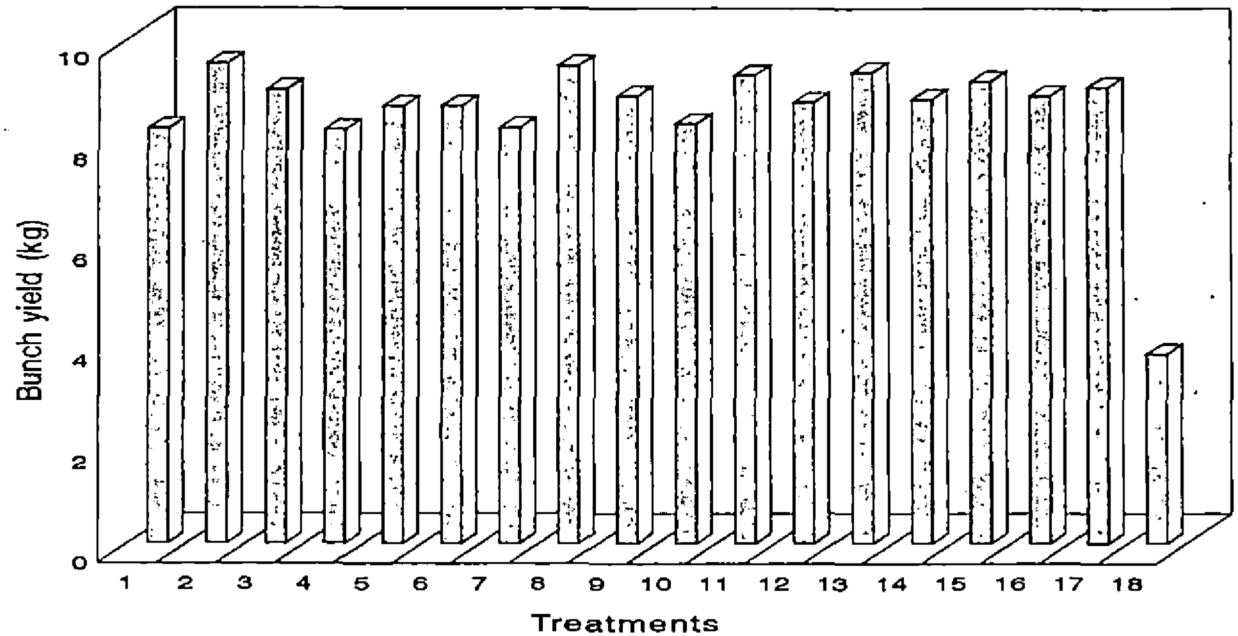

Fig.1. Effect of treatments on the bunch yield of banana

content of FYM was 0.6 per cent (Appendix-II). The plant might have absorbed the required amount of K from the FYM and attributed a higher yield. The treatment T_{14} also gave a better yield (8.80) eventhough the applied N was less. Here the required N was taken from FYM. Hence in economic point of view 200:125:300 g $N:P_2O_5:K_2O$/plant is sufficient for getting the maximum yield. If 17 to 20 kg, FYM/plant is given the quantity of fertilizers to be applied can be reduced.

In the case of biomass yield, the control plot showed the lowest value. The treatment plots exhibited significantly higher yields. Highest yield was recorded by T_8 (85.91) followed by T_{13} (84.27) which was on par with it.

The number of hands did not show any significant difference among the treatments. The highest number of fingers was recorded by T_2 (52.6) and the lowest value by T_{18} (29.5). The treatment plots were highly significant over control.

4 Plant analysis

4.1 Major nutrients

The effect of treatments on the content of major nutrients (N, P and K) in the index leaf at different growth stages is given in Table 17.

4.1.1 Nitrogen (per cent)

It was found that the nitrogen content of the index leaf at S_1 (4 MAP) varied from 0.88 (T_8) to 1.75 (T_4). The control treatment (T_{18}) was observed with a nitrogen content higher than T_6 and T_8. The possible reason could be the dilution of the nutrient in T_6 and T_8 due to increased leaf area and the higher number of leaves present in them compared to T_{18}. During S_2 (6 MAP) the treatments differed

Table 17. Effect of treatments on the content of N, P and K (per cent) in the index leaf of banana at different growth stages

Treatment	S_1			S_2			S_3		
	N	P	K	N	P	K	N	P	K
T_1	1.40	0.198	3.18	1.72	0.175	3.01	1.26	0.140	1.82
T_2	1.35	0.193	3.65	2.58	0.167	4.07	1.51	0.141	2.40
T_3	1.24	0.186	3.26	1.88	0.159	3.09	1.51	0.155	2.08
T_4	1.75	0.175	3.55	2.12	0.172	3.09	1.64	0.132	1.62
T_5	1.41	0.173	3.40	1.74	0.158	2.73	1.76	0.131	2.07
T_6	0.96	0.186	3.67	2.25	0.182	3.12	1.51	0.167	2.27
T_7	1.36	0.182	3.13	1.97	0.163	2.59	2.06	0.141	2.81
T_8	0.88	0.186	3.46	1.78	0.159	4.43	1.69	0.161	2.64
T_9	1.39	0.195	3.30	2.20	0.168	2.33	1.76	0.176	1.78
T_{10}	1.31	0.190	3.51	1.88	0.166	2.52	2.01	0.183	1.81
T_{11}	1.39	0.180	3.58	1.75	0.160	4.74	1.73	0.183	2.71
T_{12}	1.13	0.170	3.18	2.50	0.156	2.64	2.02	0.132	1.99
T_{13}	1.58	0.188	3.33	2.53	0.170	2.72	2.26	0.161	1.86
T_{14}	1.23	0.182	3.63	2.30	0.109	3.86	2.02	0.100	2.28
T_{15}	1.40	0.194	3.38	1.78	0.182	2.44	2.07	0.157	2.35
T_{16}	1.39	0.188	3.45	1.77	0.173	2.25	1.76	0.164	2.24
T_{17}	1.23	0.172	3.72	2.52	0.161	3.98	1.76	0.160	2.79
T_{18}	1.14	0.229	3.38	1.51	0.171	3.19	1.01	0.050	0.60
Mean	1.31	0.187	3.43	2.04	0.164	3.16	1.74	0.146	2.11
CD(0.05)	0.149**	0.006**	0.275**	0.094**	0.012**	0.133**	0.24**	0.608**	0.094**

significantly with T_{13} possessing the highest content of N (2.53). The absolute control registered the lowest value at this stage. This period coincided with the peak requirement of the nutrient and hence the increase in content over S_1. Similar observations were made by Sheela and Aravindakshan (1990). The treatment T_{18} (control) also showed a higher content than S_1 which indicated the increased uptake by the crop at this period. At harvest (S_3) the leaf N content decreased. The decrease in content could be attributed to the translocation of the nutrient for the production of bunch. Similar findings were reported by Ram and Prasad (1989) and Anil (1994). The N content in the index leaf showed an increase at its vegetative phase and then declined at harvest.

4.1.2 Phosphorus (per cent)

The leaf P content decreased with the age of the crop. At S_1, the content varied from 0.170 (T_{12}) to 0.229 (T_{18}). The increased content in T_{18} (control) might be due to the lesser number of leaves and thereby concentration of the nutrient. The treatments T_5 and T_{12} exhibited decreased contents since they received lower P doses. At S_2 (6 MAP) the content of P exhibited a decreasing trend due to the increased utilization of the nutrient for root development. The treatments receiving lower P doses showed decreased content. At harvest (S_3), the control treatment (T_{18}) registered the lowest value (0.05) while T_{10} and T_{11} (0.183) recorded the highest. It is clearly evident from the data that increase in P rate exhibited increased uptake.

4.1.3 Potassium (per cent)

The content of K in the index leaf showed a gradual decline with the age of the crop. At S_1 (4 MAP) the content varied from 3.13 (T_7) to 3.72 (T_{17}).The content of K in the control treatment (T_{18}) was on par with other treatments. At S_2

(6 MAP) the higher K content was observed in treatments getting higher K doses. The treatment T_4 registered the highest content (4.74) followed by T_8 (4.43). The decrease in K content in all the treatments could be attributed to the translocation of the nutrient to other parts since the crop was at its peak period of growth. At harvest (S_3) there was marked decrease in the content of K. The treatment T_{11} registered the highest content (2.71) while the lowest content (0.60) was registered by T_{18}. The decreased content of leaf K at harvest explains the utilization of the nutrient for the production of bunches. The results showed that at all stages of growth, the content of K in the leaves was higher than any other nutrient. This confirms with the findings of Ram and Prasad (1989); Kulasekharan (1993) and Natesh *et al.* (1993).

4.2 Secondary nutrients

The content of secondary nutrients (Ca, Mg and S) in the index leaf of banana at different stages of growth are provided in Table 18.

4.2.1 Calcium (ppm)

The Ca content in the leaf was found to show a decline at S_2 (6 MAP). Four months after planting (S_1), the Ca content in the leaf ranged from 4180 to 5970. The treatment T_{18} (control) registered the lowest content while the treatment T_9 receiving 125 g P_2O_5/plant was found superior. At the three stages of sampling, the control treatment (T_{18}) recorded the lowest content. The decrease in Ca content in all the treatments at S_2 (6 MAP) could possibly due to the translocation of this nutrient to meet the increased demand during flower initiation stage (reproductive phase). At harvest (S_3), there was increased content of Ca over S_2 (6 MAP). This may be due to the accumulation of unutilized Ca from the fertilizers. The treatment T_6 receiving highest P dose (200 g P_2O_5/plant) was found superior while T_9, T_{13}, T_{15}

Table 18. Effect of treatments on the content of Ca, Mg and S in the index leaf of banana at different growth stages

Treatment	S_1			S_2			S_3		
	Ca (ppm)	Mg (ppm)	S (%)	Ca (ppm)	Mg (ppm)	S (%)	Ca (ppm)	Mg (ppm)	S (%)
T_1	5480	2180	0.811	4050	2880	0.523	6870	2268	1.38
T_2	4620	2520	0.713	3880	2960	0.683	5900	1405	1.40
T_3	5790	2640	0.856	3600	2820	0.661	6880	2315	1.27
T_4	5400	2480	0.696	4060	2500	0.537	9450	2002	1.01
T_5	4470	2700	0.652	3610	2910	0.540	8090	2075	1.22
T_6	5580	2590	0.727	3670	2840	0.576	9940	2889	1.39
T_7	5320	2740	0.760	3890	2970	0.670	7630	1772	1.31
T_8	5660	2180	0.753	3800	2700	0.603	7390	1776	1.27
T_9	5970	2480	0.886	4090	2860	0.811	9650	2216	1.63
T_{10}	5070	2890	0.755	3680	2840	0.743	6790	1742	1.78
T_{11}	5090	2560	0.872	3610	2870	0.608	6450	1629	1.39
T_{12}	5250	2800	0.811	4080	2890	0.611	9190	2075	0.88
T_{13}	5560	2730	0.786	3730	2830	0.556	9650	1599	1.26
T_{14}	5570	2250	0.789	4180	2620	0.486	9560	2067	1.33
T_{15}	5580	2660	0.830	4460	2840	0.678	9760	2275	1.39
T_{16}	5230	2650	0.604	3500	2880	0.449	8970	1980	1.40
T_{17}	5720	2330	0.472	3600	2870	0.448	8410	1569	1.69
T_{18}	4180	2150	0.608	3480	2260	0.485	2440	1362	0.55
Mean	5307	2529	0.743	3831	2796	0.593	7946	1945	1.30
CD(0.05)	93**	944**	NS	69**	NS	0.334**	319**	93.19**	0.34**

were on par. Iqbal and Yogaratnam (1995) reported that K applications increased leaf K:Mg, K:Ca and K:(Mg+Ca) ratios.

4.2.2 Magnesium (ppm)

The nutrients content was noticed to be increasing from S_1 (4 MAP) to S_2 (6 MAP). At harvest (S_3), the content was found decreased. At S_1 (4 MAP), the content ranged from 2150 to 2890. The control (T_{18}) registered the lowest content (2150) while T_1 and T_8 (2180) were on par with it. At S_2 (6 MAP), there was an increase over S_1 (4 MAP), due to the fact that, Mg an important constituent of chlorophyll might have accumulated in the leaf to meet the increased photosynthetic need at the beginning of reproductive phase. The treatments remained non-significant at this stage. At S_3 (harvest), the content decreased to vary from 1362 (T_{18}) to 2889 (T_6). The absolute control remained inferior to all other treatments at all stages.

4.2.3 Sulphur (per cent)

During the different stages of plant growth the sulphur content was found to follow an increasing, decreasing and then an increasing pattern. At S_1 (4 MAP) the treatments did not differ significantly among themselves. At S_2 (6 MAP) the nutrient got distributed among different plant parts and hence the decrease. At harvest (S_3) the maximum content was obtained for T_{10} (1.78) and the lowest content was obtained T_{18} (control) (0.554). The content of S increased at S_3 in the treatment plants because the accumulated nutrient might not have been utilized by the crop.

4.3 Micronutrients

The details on the content of micronutrients in the index leaf at different stages of growth are presented in Table 19.

4.3.1 Iron (ppm)

In general, the Fe content was found to increase at S_2 (6 MAP) over S_1 (4 MAP) and thereafter it showed a decrease at harvest (S_3). The Fe content at S_1 varied between 103 and 387. The control treatment (T_{18}) had nutrient content higher than a few treatments viz. T_{11}, T_{12}, T_{13} and T_{14}. This may be due to the decreased leaf area of the control plant. The increased demand for photosynthesis at S_2 (6 MAP) resulted in increased content of Fe in the leaf at this stage. There was an increase in Fe content of T_{18} (control) also at S_2 indicating the need for the metal ion to act as electron acceptors. At harvest (P_5) the content decreased due to the distribution of the nutrient to other plant parts.

4.3.2 Manganese (ppm)

The Mn content in the index leaf at S_1 (4 MAP) ranged from 118 to 350 whereas it varied from 214 to 343 at S_2 (6 MAP). This decreasing trend could possibly due to the allocation of the nutrient to the needed sites. The increased content in T_{18} (control) could be due to the lesser number of leaves which might have facilitated the concentration of the nutrient in the leaves. At S_3 (at harvest) there was increased content in the leaves which could be attributed to the fact that, the need for the nutrient at other plant parts is less at this stage and hence the accumulation of Mn in the leaf.

Table 19. Effect of treatments on the content Fe, Mn, Cu and Zn (ppm) in the index leaf of banana at different growth stages

Treatments	S_1				S_2				S_3			
	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn
T_1	247	280	22.6	23.2	445	278	26.1	28.5	338	397	12.5	29.9
T_2	355	306	17.3	24.5	539	302	37.1	18.9	358	407	12.5	47.4
T_3	216	222	15.2	20.2	485	216	26.0	40.7	370	406	20.4	35.1
T_4	334	350	26.0	17.4	638	311	48.7	19.4	511	579	12.5	56.5
T_5	387	256	22.2	18.2	569	248	28.2	40.3	479	499	12.5	36.6
T_6	277	341	20.2	17.1	459	214	22.5	27.2	340	457	12.5	29.8
T_7	217	269	18.8	28.2	579	235	49.2	19.9	336	606	12.8	31.4
T_8	206	237	17.2	26.0	504	280	26.3	39.5	454	477	12.5	48.8
T_9	231	268	18.7	23.9	540	268	29.2	33.1	408	880	21.4	39.9
T_{10}	209	307	25.0	22.5	420	217	28.9	44.7	439	645	12.5	30.0
T_{11}	182	245	18.4	20.0	587	263	28.1	43.4	432	635	12.5	33.8
T_{12}	103	245	16.1	23.0	470	343	42.9	40.6	430	488	12.5	59.5
T_{13}	170	203	33.6	20.0	446	239	36.9	29.3	396	688	12.5	40.9
T_{14}	158	233	12.8	24.4	379	225	32.5	40.9	229	540	12.5	43.4
T_{15}	201	320	16.6	23.8	536	290	42.1	20.0	487	802	12.5	51.4
T_{16}	319	320	20.7	21.1	521	280	47.8	21.2	510	781	12.5	52.5
T_{17}	275	331	36.7	29.2	559	307	33.7	34.3	418	573	12.5	35.9
T_{18}	196	118	11.4	16.0	308	281	23.2	34.0	203	343	9.4	28.5
Mean	237.9	269.5	20.53	22.20	499.1	266.5	33.93	31.9	396.5	566.8	13.28	40.6
CD(0.05)	121.41*	42.76**	3.21**	2.19**	8.39**	22.56**	8.26**	3.88**	227.4**	84.85**	2.06**	5.11**

S_1 - 4 MAP; S_2 - 6 MAP; S_3 - at harvest

4.3.3 Copper (ppm)

The Cu content in the leaf exhibited an increase at S_2 (6 MAP) over S_1 (4 MAP) and then a decline. The increased content at S_2 (6 MAP) indicates the increased demand for the nutrient at the peak vegetative period and the flower bud initiation stage.

4.3.4 Zinc (ppm)

The content of Zn in the index leaf, at S_3 showed an increase over the other stages of growth of plants. At S_1 (4 MAP) the content ranged from 16.0 (T_{18}) to 29.2 (T_{17}) with a mean value of 22.2. At S_2 (6 MAP) the content increased to range from 18.9 (T_2) to 44.7 (T_{10}) with a mean value of 31.9. At S_3 (harvest) the content varied from 28.5 (T_{18}) to 59.5 (T_{12}) with a mean value of 40.6. The increase in content of this element at different stages of growth may be due to less utilization than absorbed by the plants.

5 Uptake of nutrients

5.1 Nitrogen (g/plant)

The uptake of nitrogen by different parts of banana plant and the total uptake are presented in Table 20.

Among the different plant parts the leaves exhibited the maximum uptake followed by bunch rhizome and pseudostem. The uptake by rhizome exhibited a mean value of 14.5 with T_5 registering the highest content (27.44) and T_{14} the lowest (3.68). The N uptake by pseudostem varied from 2.09 to 26.78 with a mean value of 11.46. The leaves showed the highest N uptake of 12.42 (T_{18} control) to

Table 20. Effect of treatments on the content and uptake of nitrogen in different parts of banana

Treatments	Rhizome		Pseudostem		Leaves		Bunch		Total	
	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)
T_1	0.630	10.77	1.512	17.09	1.26	18.77	0.460	13.60	0.83	60.24
T_2	1.008	16.93	0.252	3.09	1.57	28.69	0.760	21.97	0.90	70.68
T_3	1.260	22.30	1.080	11.66	1.51	30.65	1.150	29.53	1.27	94.14
T_4	0.756	12.78	0.756	8.09	1.64	41.49	0.530	19.43	1.03	81.79
T_5	1.516	27.44	1.134	12.47	1.76	33.44	0.884	22.53	1.29	95.88
T_6	0.756	13.91	0.504	5.64	1.51	26.88	0.960	28.01	0.97	74.44
T_7	1.331	22.23	0.202	2.09	2.06	30.69	0.830	22.68	1.12	77.69
T_8	1.260	27.09	1.134	14.63	1.69	31.43	0.810	23.83	1.18	96.98
T_9	1.260	19.66	1.008	11.59	1.76	30.45	1.140	37.65	1.38	99.35
T_{10}	0.504	9.63	0.882	10.58	2.01	34.37	0.880	25.97	1.04	80.55
T_{11}	0.630	11.40	1.008	11.49	1.73	35.29	0.120	33.69	1.16	91.87
T_{12}	0.504	7.67	1.890	20.41	2.02	41.21	0.690	18.44	1.19	87.73
T_{13}	0.277	5.65	2.142	26.78	2.26	52.43	0.820	23.98	1.27	108.84
T_{14}	0.252	3.68	1.260	13.36	2.02	46.66	0.780	21.54	1.12	85.24
T_{15}	0.882	16.67	1.008	10.58	2.07	53.19	0.130	42.62	1.42	123.06
T_{16}	0.882	14.99	1.260	13.73	1.76	32.91	0.980	24.34	1.20	85.97
T_{17}	0.756	11.34	0.110	9.61	1.76	35.55	0.110	31.34	1.18	87.84
T_{18}	0.504	7.26	0.504	3.68	1.01	12.42	0.480	5.38	0.63	28.45
Mean	0.832	14.50	0.980	11.46	1.74	34.25	0.695	24.81	1.12	85.04
CD(0.05)	0.499**	11.26**	NS	10.06**	0.24**	12.95**	0.086**	19.28**	NS	23.33**

53.19 (T_{15}) with a mean value of 34.25. The N uptake in bunch was noticed with a mean value of 24.81 ranging from 5.38 (T_{18}) to 42.62 (T_{15}). The total uptake of N by the plant ranged from 28.45 g/plant (control) to 123.06 (T_{15}) g/plant.

The results revealed that increased levels of N resulted in increased uptake of the nutrient. This is in confirmity with the results obtained by Mathew and Aravindakshan (1981); Buragohain and Shanmughavelu (1990); Kulasekharan (1993).

5.2 Phosphorus (g/plant)

The uptake pattern of P in differnt parts of banana and the total uptake by the plant are provided in Table 21.

The uptake of P was noticed to be highest in the rhizome followed by leaves, bunch and pseudostem. In the rhizome the uptake varied from 2.59 to 11.22 with a mean value of 7.69. The P uptake in pseudostem was observed to range from 0.275 (T_{18}) to 1.09 (T_{10}) with a mean of 0.080. The leaves exhibited an uptake of 0.615 (T_{18}) to 4.035 (T_{15}) and the mean value was 2.90. The uptake of P by the fruits ranged from 0.963 (T_{18}) to 3.543 (T_2) with a mean value of 2.36. Thus the total uptake of P by the plant ranged from 4.44 g/plant (T_{18}) to 18.45 (T_{13}) g/plant.

5.3 Potassium (g/plant)

The pattern of uptake of potassium in different parts of the crop and the total uptake by the crop are given in Table 22. The percentage of distribution of K in different parts of banana is given in Fig.2.

Table 21. Effect of treatments on the content and uptake of phosphorus in different parts of banana

Treatments	Rhizome		Pseudostem		Leaves		Bunch		Total	
	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)
T_1	0.430	7.35	0.074	0.836	0.140	2.086	0.098	2.512	0.180	12.78
T_2	0.460	7.73	0.067	0.861	0.141	2.679	0.084	3.543	0.190	14.81
T_3	0.510	9.03	0.058	0.626	0.155	3.147.	0.105	3.029	0.210	15.83
T_4	0.420	7.10	0.080	0.856	0.132	3.361	0.079	2.012	0.170	13.33
T_5	0.580	10.05	0.086	0.946	0.131	2.489	0.089	2.374	0.220	17.86
T_6	0.440	8.10	0.078	0.874	0.167	3.008	0.033	2.733	0.200	14.72
T_7	0.540	9.07	0.078	0.811	0.141	2.101	0.109	2.813	0.190	14.79
T_8	0.410	8.82	0.073	0.942	0.161	2.995	0.034	2.501	0.210	15.26
T_9	0.400	6.74	0.070	0.805	0.176	3.045	0.078	2.145	0.190	12.74
T_{10}	0.540	10.31	0.091	1.092	0.183	3.129	0.087	2.555	0.170	17.09
T_{11}	0.320	5.79	0.078	0.889	0.183	3.733	0.084	2.398	0.240	11.77
T_{12}	0.340	5.17	0.088	0.953	0.132	2.693	0.075	2.018	0.220	12.39
T_{13}	0.550	11.22	0.077	0.963	0.161	3.735	0.087	2.535	0.220	18.45
T_{14}	0.540	7.88	0.085	0.901	0.126	2.927	0.120	3.318	0.190	15.02
T_{15}	0.350	6.62	0.087	0.914	0.157	4.035	0.098	3.108	0.170	12.88
T_{16}	0.410	6.97	0.086	0.937	0.164	3.067	0.089	2.203	0.180	13.78
T_{17}	0.580	7.95	0.071	0.774	0.160	3.333	0.088	2.502	0.190	14.56
T_{18}	0.180	2.59	0.041	0.275	0.050	0.615	0.082	0.963	0.050	4.44
Mean	0.440	7.69	0.080	0.800	0.138	2.900	0.084	2.360	0.170	14.07
CD(0.05)	NS	0.573**	0.013**	0.071**	0.608**	0.147**	0.067*	0.101**	NS	3.75**

Table 22. Effect of treatments on the content and uptake of potassium in different parts of banana

Treatments	Rhizome		Pseudostem		Leaves		Bunch		Total	
	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)
T_1	3.32	56.77	2.92	32.29	1.82	27.12	1.26	32.32	2.03	148.50
T_2	2.80	47.04	3.47	42.68	2.40	40.80	1.60	47.64	2.29	178.10
T_3	2.70	47.79	2.35	25.38	3.08	62.52	1.36	39.18	2.35	174.87
T_4	2.96	50.02	2.72	29.10	1.62	40.97	1.47	37.64	1.95	154.73
T_5	2.82	51.04	2.96	32.56	2.07	39.33	2.26	60.09	2.48	183.02
T_6	1.99	36.62	3.39	37.97	2.27	40.41	1.16	35.38	1.96	150.38
T_7	2.39	39.91	3.01	31.30	1.81	26.97	2.16	55.40	1.91	153.58
T_8	2.46	52.89	3.34	43.19	2.64	49.10	1.35	29.41	2.43	199.97
T_9	2.63	41.03	3.63	41.74	1.78	30.79	1.75	48.03	2.02	161.59
T_{10}	1.90	36.29	4.63	55.56	1.81	30.95	2.12	58.04	2.21	180.84
T_{11}	3.02	54.66	2.39	37.25	2.71	55.28	1.14	42.51	2.19	189.70
T_{12}	2.53	38.46	3.26	35.21	1.99	40.51	1.99	53.58	2.01	167.76
T_{13}	3.04	62.02	3.03	31.63	1.86	43.15	0.98	28.80	2.25	165.60
T_{14}	2.55	37.23	3.13	32.22	2.28	52.67	1.17	32.23	1.98	154.35
T_{15}	2.13	51.59	3.21	33.71	2.35	50.39	1.67	42.63	2.06	178.45
T_{16}	2.54	43.18	3.19	34.77	2.24	41.89	2.12	52.80	2.37	172.64
T_{17}	2.52	37.80	4.05	44.15	2.79	46.16	1.52	53.23	2.44	181.34
T_{18}	2.01	28.94	4.83	13.47	0.60	7.38	1.45	17.07	1.48	66.86
Mean	2.57	45.18	3.31	34.67	2.12	40.36	1.57	42.09	2.13	164.74
CD(0.05)	0.633**	NS	0.743**	12.38**	0.094**	17.31**	0.006**	15.96**	NS	25.45**

The uptake of K in the rhizome remained non-significant among the treatments with a mean value of 45.18. The uptake of K was found to be highest in rhizome followed by fruits, leaves and pseudostem. The uptake of K in the pseudostem ranged from 13.47 to 55.56 with a mean value of 34.67. The uptake of the nutrient by the leaves varied from 7.38 to 62.52 and the mean value remained 40.36. The uptake of K by the fruits ranged from 17.07 (T_{18}) to 60.09 (T_5) with a mean value of 42.09. The total uptake of the nutrient by the plant ranged from 66.86 (control T_{18}) to 199.97 (T_8). All the other treatments were significantly superior to T_{18}.

The results revealed that increasing levels of K showed increased uptake of K. Among the three major nutrients studied the uptake of K was found to be the highest. Similar reports were given by Sheela and Aravindakshan, (1990).

5.4 Calcium (g/plant)

The uptake of Ca in different parts of the plant and the total uptake of the nutrient are presented in Table 23.

The uptake was noticed to be highest in leaves followed by rhizome, fruits and pseudostem. The uptake by the rhizome did not differ significantly among the various treatments. The uptake by the rhizome varied from 2.05 (T_2) to 4.88 (T_7) with a mean value of 3.24. The uptake by the pseudostem ranged from 1.01 to 3.48 with a mean value of (T_{18}) 2.3. The leaf uptake of Ca varied from 5.46 to 25.08 (T_{15}) with a mean value of 15.92. The uptake of Ca by the fruits ranged from 0.97 (T_{18}) to 2.64 (T_{10}) with a mean of 1.45. The total uptake of the nutrient varied from 9.79 (T_{18}) to 33.27 (T_{15}).

Table 23. Effect of treatments on the content and uptake of calcium in different parts of banana

Treatments	Rhizome		Pseudostem		Leaves		Bunch		Total	
	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)
T_1	0.206	3.52	0.269	3.04	0.687	10.24	0.054	1.38	0.250	18.16
T_2	0.122	2.05	0.171	2.09	0.590	11.21	0.059	1.75	0.220	17.10
T_3	0.148	2.62	0.183	1.98	0.688	13.97	0.046	1.31	0.270	19.89
T_4	0.201	3.39	0.187	2.00	0.945	23.91	0.069	1.78	0.390	30.64
T_5	0.191	3.46	0.150	1.65	0.809	15.37	0.028	1.67	0.300	22.15
T_6	0.199	3.66	0.262	2.94	0.994	17.69	0.083	2.51	0.350	26.80
T_7	0.292	4.88	0.314	3.23	0.764	11.37	0.061	1.56	0.300	21.04
T_8	0.170	3.66	0.167	2.15	0.739	13.75	0.057	1.67	0.260	21.23
T_9	0.191	2.98	0.202	2.32	0.965	16.62	0.050	1.37	0.330	23.37
T_{10}	0.159	3.04	0.228	2.74	0.679	11.66	0.090	2.64	0.260	20.03
T_{11}	0.166	3.00	0.153	1.75	0.645	13.11	0.064	1.82	0.260	19.68
T_{12}	0.182	2.77	0.211	2.29	0.919	18.75	0.051	1.38	0.290	25.20
T_{13}	0.142	2.89	0.274	3.48	0.965	22.39	0.084	2.46	0.430	31.17
T_{14}	0.194	2.83	0.189	2.00	0.956	22.08	0.073	2.02	0.380	28.94
T_{15}	0.202	3.82	0.200	2.60	0.976	25.08	0.056	1.77	0.440	33.27
T_{16}	0.301	5.12	0.187	2.04	0.897	16.77	0.066	1.64	0.350	25.57
T_{17}	0.150	2.25	0.194	2.11	0.841	16.99	0.059	1.69	0.310	23.05
T_{18}	0.163	2.35	0.151	1.01	0.444	5.46	0.082	0.97	0.220	9.79
Mean	0.181	3.24	0.205	2.30	0.806	15.92	0.063	1.45	0.310	23.17
CD(0.05)	0.073**	NS	NS	1.02**	NS	11.24**	0.0319**	0.133**	0.006**	4.54**

Table 24 . Effect of treatments on the content and uptake of magnesium in different parts of banana

Treatments	Rhizome		Pseudostem		Leaves		Bunch		Total	
	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)	Content (%)	Uptake (g)
T_1	0.419	7.17	0.259	2.93	0.297	4.45	0.090	2.39	0.230	16.94
T_2	0.318	5.33	0.111	1.37	0.141	2.67	0.080	2.90	0.160	12.27
T_3	0.250	4.33	0.079	0.86	0.232	4.69	0.092	2.67	0.170	12.65
T_4	0.185	3.15	0.200	1.79	0.200	5.05	0.150	3.94	0.180	13.93
T_5	0.206	4.23	0.144	1.58	0.208	3.94	0.076	2.01	0.160	11.76
T_6	0.203	3.74	0.208	2.33	0.289	5.14	0.140	4.35	0.200	15.57
T_7	0.353	5.89	0.244	2.54	0.172	2.60	0.050	6.49	0.250	17.53
T_8	0.266	5.72	0.118	1.52	0.178	3.30	0.095	2.78	0.160	13.33
T_9	0.347	5.42	0.101	1.16	0.232	4.01	0.186	5.11	0.220	15.69
T_{10}	0.163	3.11	0.159	1.96	0.174	2.98	0.116	3.41	0.190	11.46
T_{11}	0.272	4.91	0.249	3.09	0.163	3.23	0.121	3.44	0.150	14.67
T_{12}	0.267	4.06	0.361	3.94	0.208	4.23	0.083	2.24	0.190	14.48
T_{13}	0.231	3.99	0.203	2.54	0.159	3.71	0.105	3.08	0.160	13.32
T_{14}	0.167	3.62	0.102	1.08	0.307	7.08	0.093	2.58	0.190	14.37
T_{15}	0.353	3.66	0.271	2.84	0.228	4.85	0.069	2.20	0.200	13.55
T_{16}	0.458	7.61	0.083	0.89	0.198	3.70	0.102	2.55	0.210	14.75
T_{17}	0.366	5.49	0.149	1.62	0.157	3.17	0.093	2.63	0.170	12.96
T_{18}	0.094	1.35	0.085	0.56	0.136	1.67	0.077	0.91	0.099	4.47
Mean	0.273	4.59	0.174	1.92	0.204	3.92	0.101	3.09	0.180	13.54
CD(0.05)	NS	0.65**	0.11**	0.76**	0.0096**	2.36**	0.0043**	3.09	NS	2.78**

5.5 Magnesium (g/plant)

The total uptake of Mg by the plant as well as the uptake by different plant parts are presented in Table 24.

The uptake was found to be highest in rhizome followed by leaves, fruits and pseudostem. In the rhizome, the uptake ranged from 1.35 (T_{18}) to 7.61 (T_{16}) with a mean of 4.59. In the pseudostem the uptake was found to vary from 0.56 (T_{18}) to 3.94 (T_{12}) with a mean value of 1.92. The uptake of Mg by leaves varied from 1.67 (T_{18}) to 7.08 (T_{14}) and the mean value was 3.92. Fruits exhibited an uptake ranging from 0.91 (T_{18}) to 6.49 (T_7). The total uptake of Mg by the plant was noticed with contents ranging from 4.47 (T_{18} control) to 17.55 (T_{15}).

6 Distribution of nutrients in different parts of banana (per cent)

The per cent distribution of N, P, K, Ca and Mg in different parts of banana are given in Tables 20 to 24.

6.1 Nitrogen

The content of nitrogen was found to be highest in leaves followed by pseudostem, rhizome and bunch. The content in the rhizome varied from 0.252 (T_{14}) to 1.516 (T_5) with a mean of 0.832 whereas in pseudostem it varied from 0.110 (T_{17}) to 2.142 (T_{13}) with a mean value of 0.980. The leaves showed a N content ranging from 1.010 (T_{18}) to 2.070 (T_{15}). The N content in bunch varied from 0.110 (T_{17}) to 1.150 (T_3). The total content in the plant varied from 0.630 (T_{18}) to 1.380 (T_9) with a mean value of 1.12.

6.2 Phosphorus

The P content in the plant showed its highest content in rhizome (0.440) followed by leaves (0.138). The content of P in the rhizome though did not different significantly among treatments, it showed accumulation in this plant part. The content in the pseudostem varied from 0.041 (T_{18}) to 0.091 (T_{10}). The leaves exhibited a P content ranging from 0.050 (T_{18}) to 0.183 (T_{10} and T_{11}). The bunch showed a content varying from 0.033 (T_6) to 0.120 (T_{14}). The total content of P in the plant varied from 0.050 (T_{18}) to 0.240 (T_{11}).

6.3 Potassium

The content of K in banana plant was highest in pseudostem followed by rhizome, leaves and bunch. The content ranged from 1.90 (T_{10}) to 3.02 (T_{11}). The pseudostem the K content varied from 2.39 (T_{11}) to 4.83 (T_{18}). Leaves exhibited a content varying from 0.60 (T_{18}) to 3.08 (T_3). The content K in bunch was highest in T_5 (2.26) and the lowest in T_{13} (0.98). The total content of K in the plant varied from 1.48 (T_{18}) to 2.48 (T_5).

6.4 Calcium

The distribution of Ca followed the order of leaves, pseudostem, rhizome and bunch in banana. The content of Ca in rhizome varied from 0.122 (T_2) to 0.301 (T_{16}) whereas in pseudostem it ranged from 0.150 (T_5) to 0.274 (T_{13}). The content of Ca in the leaves was highest in T_{15} (0.976) and the lowest in T_{18} (0.444). The bunch showed a content varying from 0.046 (T_3) to 0.084 (T_{13}). The total content of Ca was highest in T_{15} (0.440) and the lowest in T_2 and T_{18} (0.220) with a mean value of 0.310.

6.5 Magnesium

The Mg content in the plant was found highest in rhizome (0.273) followed by leaves, pseudostem and bunch. The content of Mg in the rhizome varied from 0.094 (T_{18}) to 0.458 (T_{16}) and that in pseudostem ranged from 0.079 (T_3) to 0.361 (T_{12}). Leaves showed a content ranging from 0.136 (T_{18}) to 0.307 (T_{15}) with a mean of 0.204. The bunch had a content varying from 0.077 (T_{18}) to 0.150 (T_4). The total Mg content in the banana plant varied from 0.099 (T_{18}) to 0.250 (T_7) with a mean value of 0.180.

7 Fate of potassium as influenced by a crop like banana in a laterite soil

A perusal of the data on the potassium content in the soil revealed that the initial content of total, exchangeable and water soluble K on an average were 0.12 per cent, 359.30 ppm and 68.9 ppm respectively. The application of FYM resulted in an increase in the total K content at P_2 (2 MAP) while the exchangeable content showed a decrease due to absorption by the plant. The removal of the nutrient by the crop was found to be at its peak during P_3 (4 MAP) and P_4 (6 MAP) periods. The exhaustion of the nutrient from P_4 (4 MAP) to P_5 (at harvest) is noticeable from the decreased content in the total K. At the end of the crop the total K increased to 0.16 per cent over P_1 (0.12 per cent) indicating fixation of the added K to a tune of 33.33 per cent.

Correlation studies were conducted between different forms of K at different stages and yield. A highly significant positive correlation was obtained between yield and total K at P_2 (2 MAP) (r = 0.592**) and P_3 (4 MAP) (r = 0.4486*). The available K showed a positive correlation (r = 0.5454**) at P_4 (6 MAP) followed by P_3 (4 MAP) (r = 0.5186**). Water soluble K at different stages also had significant correlations with yield. The r values at P_3 (4 MAP), P_4 (6 MAP) and P_5 (at harvest) were 0.4387*, 0.4195* and 0.4398* respectively.

In order to get an information on the movement of K in the soil-plant system and also to find out the influence of potassium in association with other elements, path coefficient analysis was carried out.

The content of various forms of K in the soil at different stages are given in Table 4. From the Fig.3 it is clear that the total K at P_4 (6 MAP) had the highest direct effect on yield followed by P_2 (2 MAP) and P_3 (4 MAP). The content at P_1

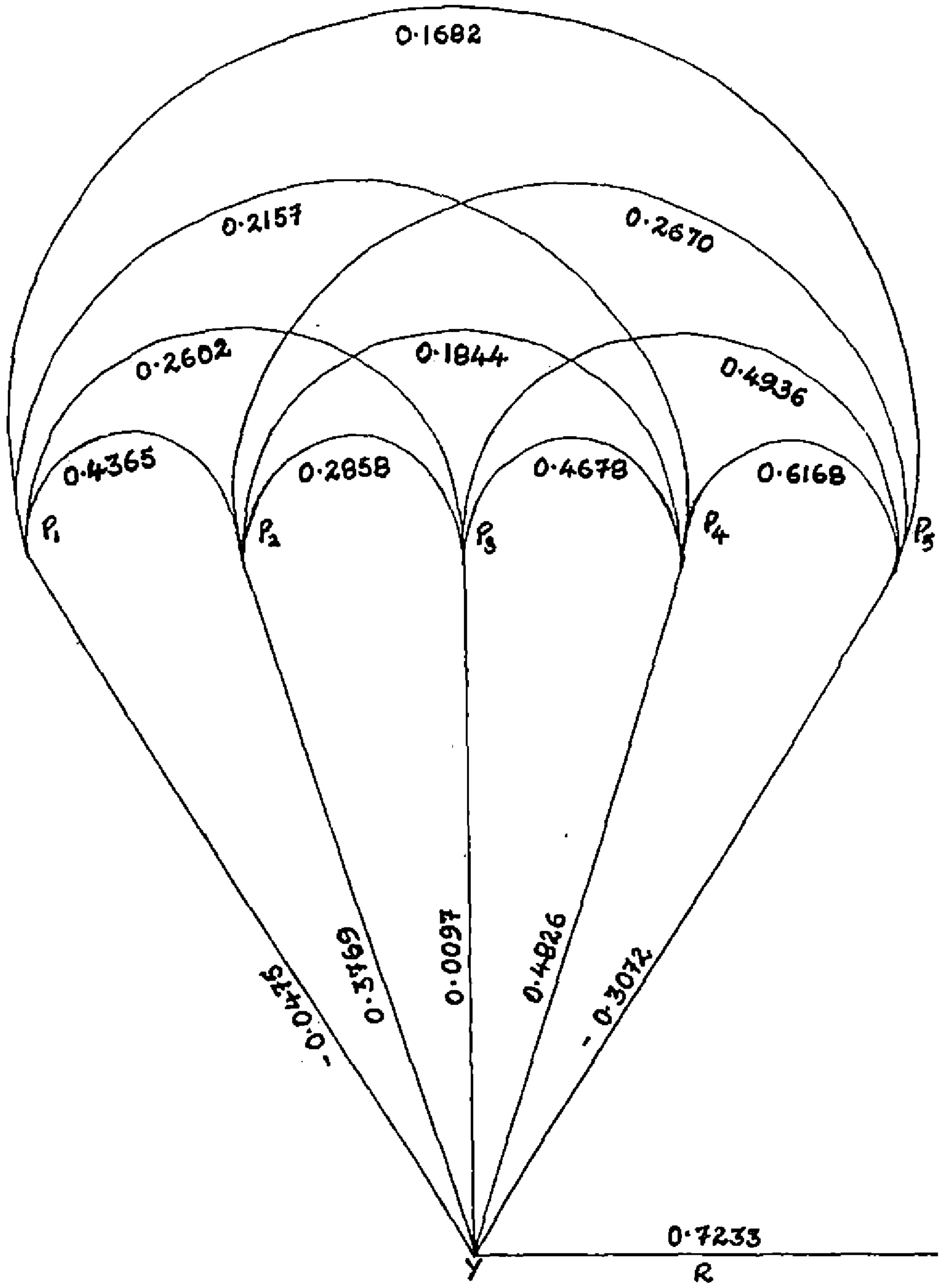

Fig.3. Path diagram - Direct and indirect effects of total K (per cent) in the soil at different periods on the yield of banana

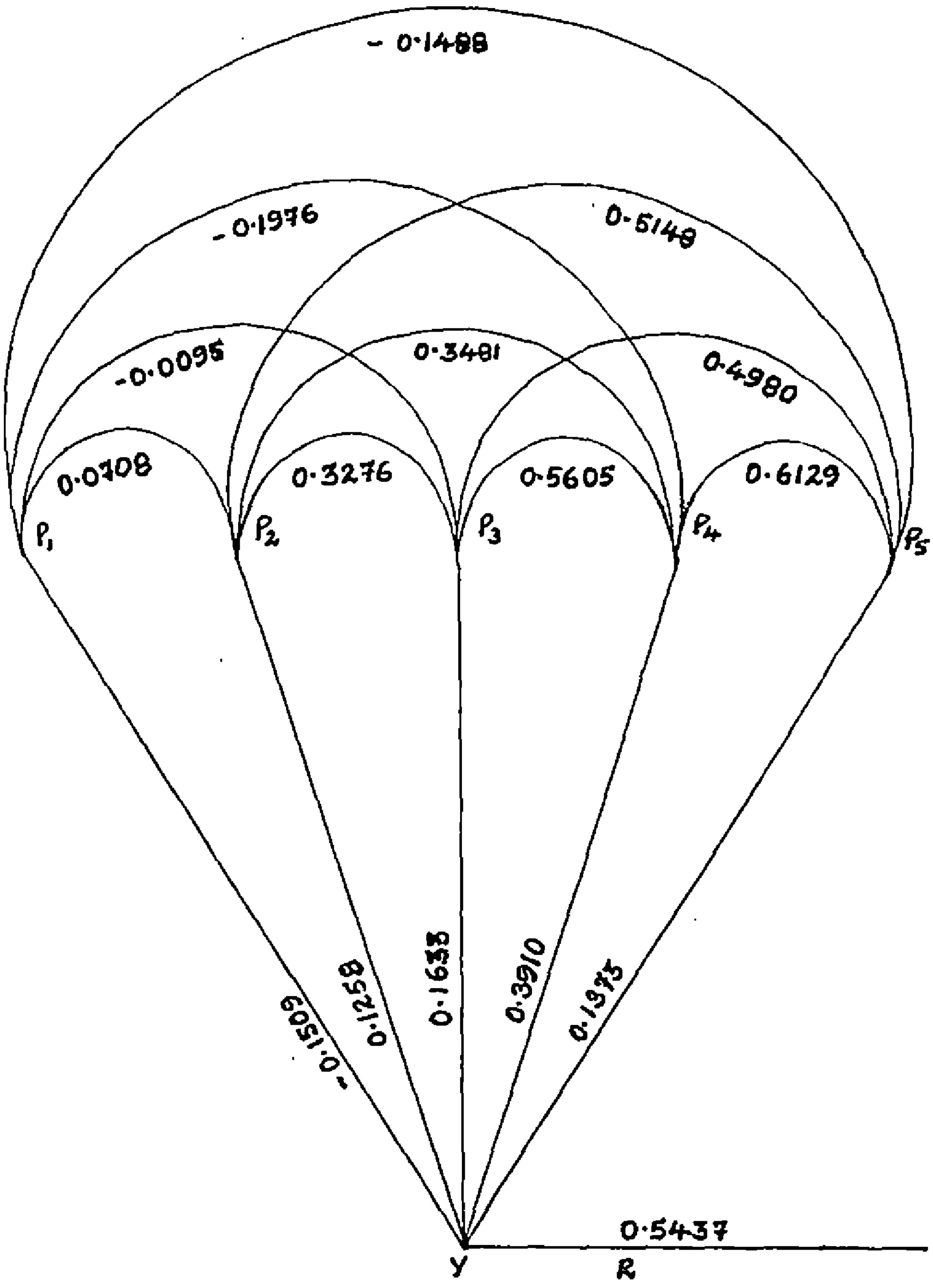

Fig.4.Path diagram - Direct and indirect effects of exchangeable K (ppm) in the soil at different periods on the yield of banana

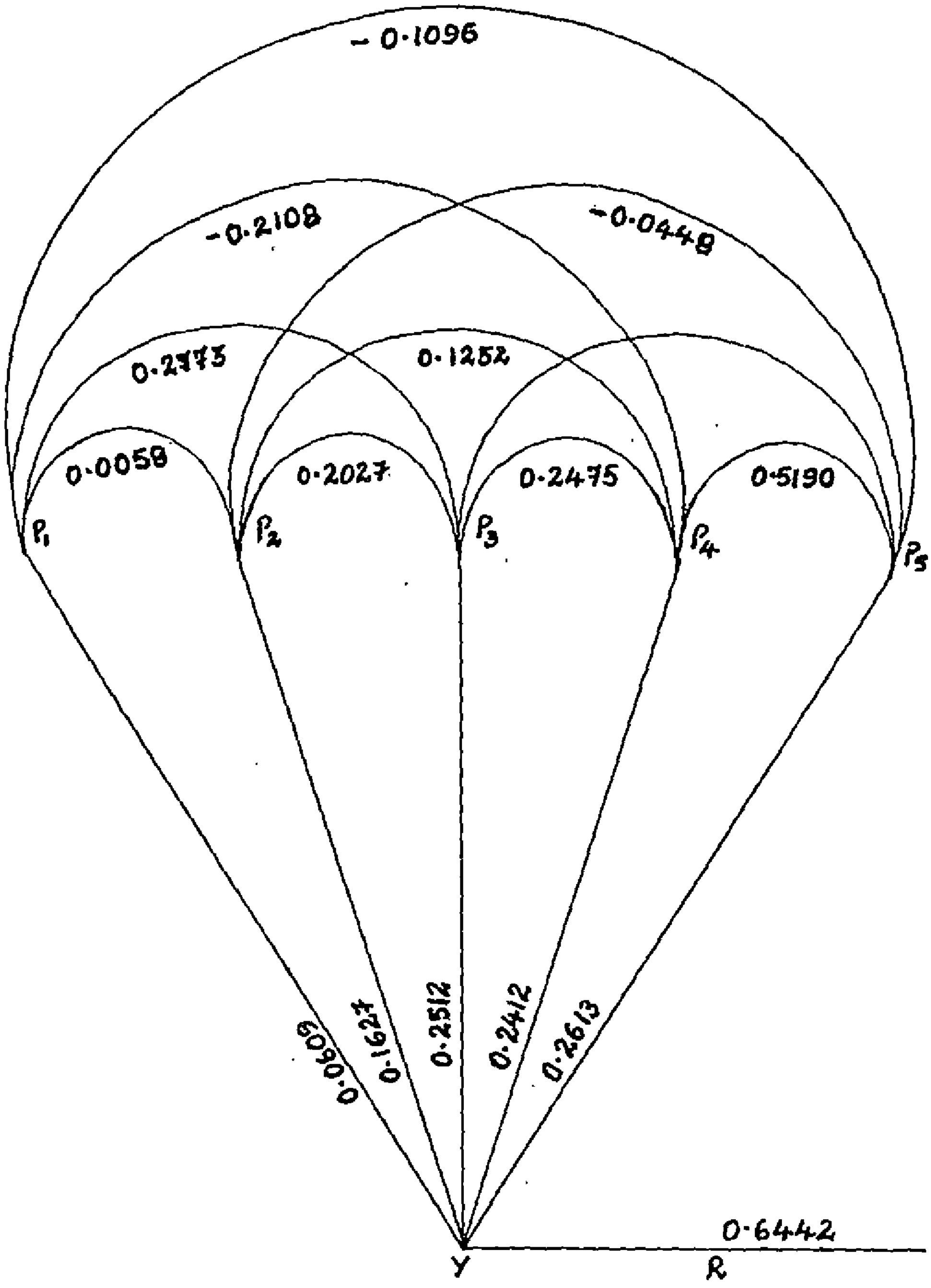

Fig.5. Path diagram - Direct and indirect effects of water soluble K (ppm) in the soil at different periods on the yield of banana

(initial) and P_5 (at harvest) showed a negative effect on yield. Maximum indirect effect on yield was observed at P_4 (6 MAP) through P_3 (4 MAP).

To understand the direct and indirect effects of exchangeable K on yield at different stages path analysis was done. The direct effect of exchangeable K at P_4 (6 MAP) was found to be the maximum as in the case of total K followed by that at P_3 (4 MAP) (Fig.4). The indirect effect was highest at P_4 (6 MAP) through P_3 (4 MAP). This explains that the requirement of the nutrient K for the crop is high during the early and late vegetative periods. Fertilizers should be applied from 2 MAP and continued up to 6 MAP. The effect of fertilizer will be carried over to the remaining period. Thus the study gives a good idea about the role of K during different periods of growth of banana.

The water soluble K at different periods of growth was studied to get an idea of its effect on the yield of banana. From the path diagram (Fig.5) it is clear that this form of K in the soil showed a direct effect of comparable magnitude at different periods.

7.1 Interaction effect of K with other nutrients

7.1.1 Total nutrients

Correlation between yield and different nutrients at different stages was worked out to rank the role of nutrient K among the other nutrients and their relationship with yield of banana. Total K showed a highly significant correlation at P_2 (2 MAP) ($r = 0.592^{**}$) while the other two major nutrients remained non-significant with yield. During P_3 (4 MAP) and P_4 (6 MAP) the correlations were highly significant and the magnitude of correlation was in the order of P, N and K respectively with yield.

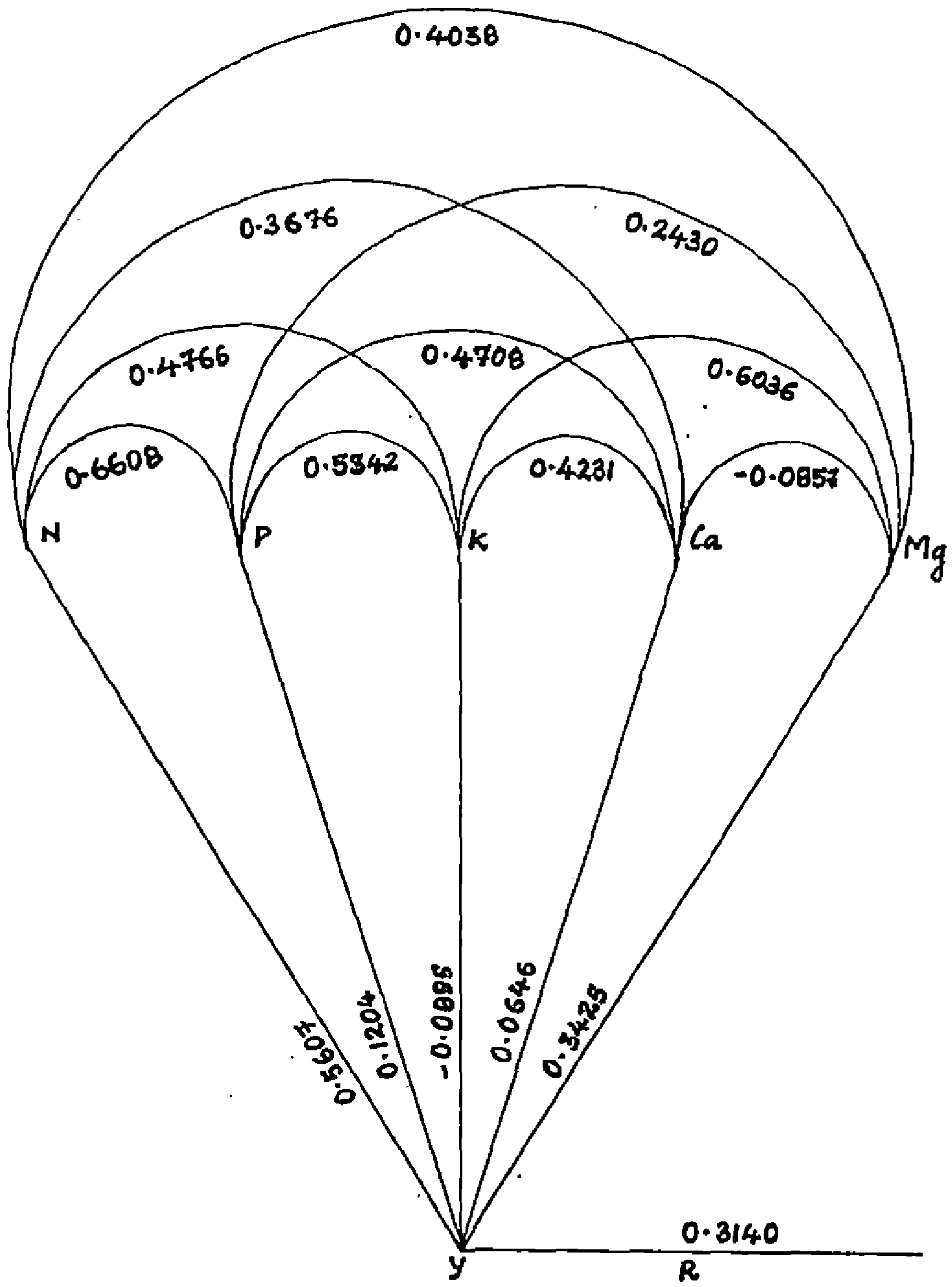

Fig.6.Path diagram - Direct and indirect effects of total N, P, K, Ca and Mg in the soil at P_2 (2 MAP) on the yield of banana

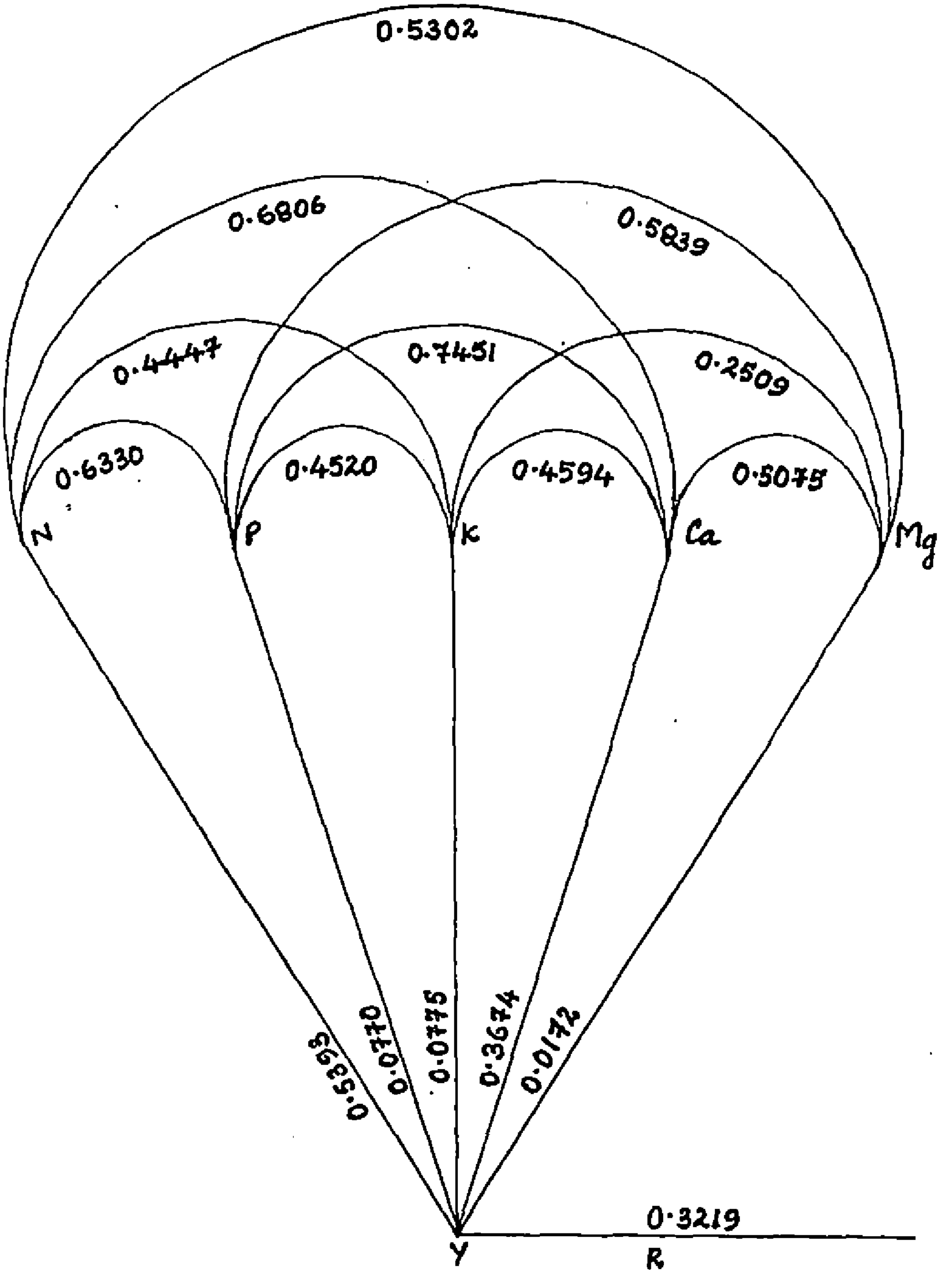

Fig.7.Path diagram - Direct and indirect effects of total N, P, K, Ca and Mg in the soil at P_3 (4 MAP) on the yield of banana

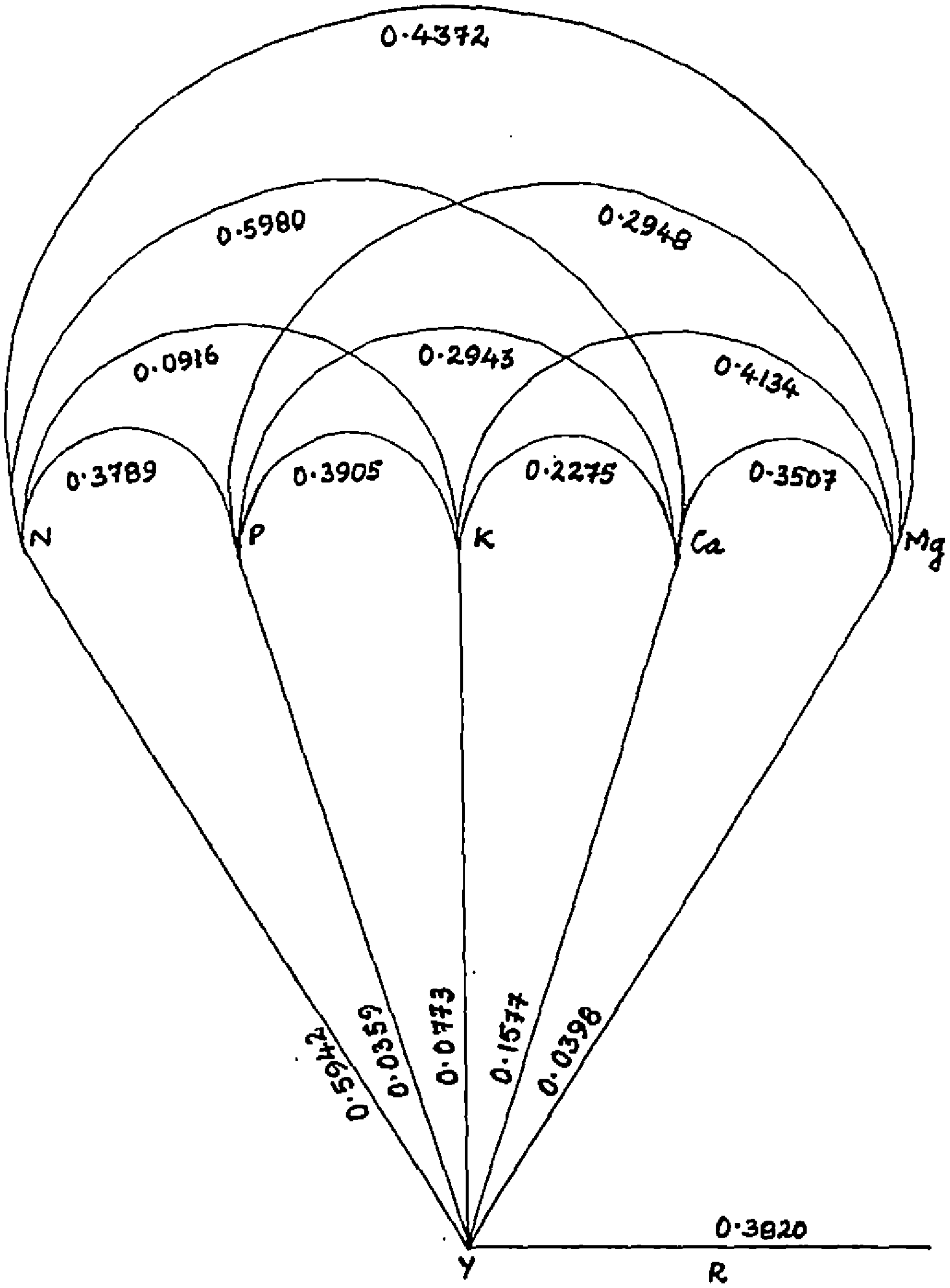

Fig.8.Path diagram - Direct and indirect effects of total N, P, K, Ca and Mg in the soil at P_4 (6 MAP) on the yield of banana

To get a clear idea of the interaction of K with other nutrients and the yield of banana, path analysis was done (Fig.6). The results indicated that total K had no direct effect on yield at P_2 (2 MAP) whereas total N showed a significant direct effect at this stage. The content of P in the soil showed a significant indirect effect on yield through N.

From the Fig.(7), at P_3 (4 MAP) also, the direct effect of K on yield remained non-significant. The indirect effect of K through N was positive though not significant. The content of N in the soil had direct significant effect on yield and the indirect effect of P through N was also significant.

At P_4 (6 MAP) (Fig.8) the total K had no direct significant effect on yield. The direct effect was significant for total N on yield. The indirect effect of K through N was the highest at this stage.

7.1.2 Available Nutrients

Available nutrients N, P and K were correlated with yield. Significant positive correlation was obtained for the nutrients. Exchangeable K ranked first at all stages of growth.

To understand the effect of exchangeable nutrients particularly K on yield, path analysis was carried out which gave the following results.

The direct and indirect effects of different nutrients on yield are depicted in Fig.9, 10 and 11. From the path diagram (9), it is clear that among the direct effects of available nutrients on yield, the effect of available K was maximum

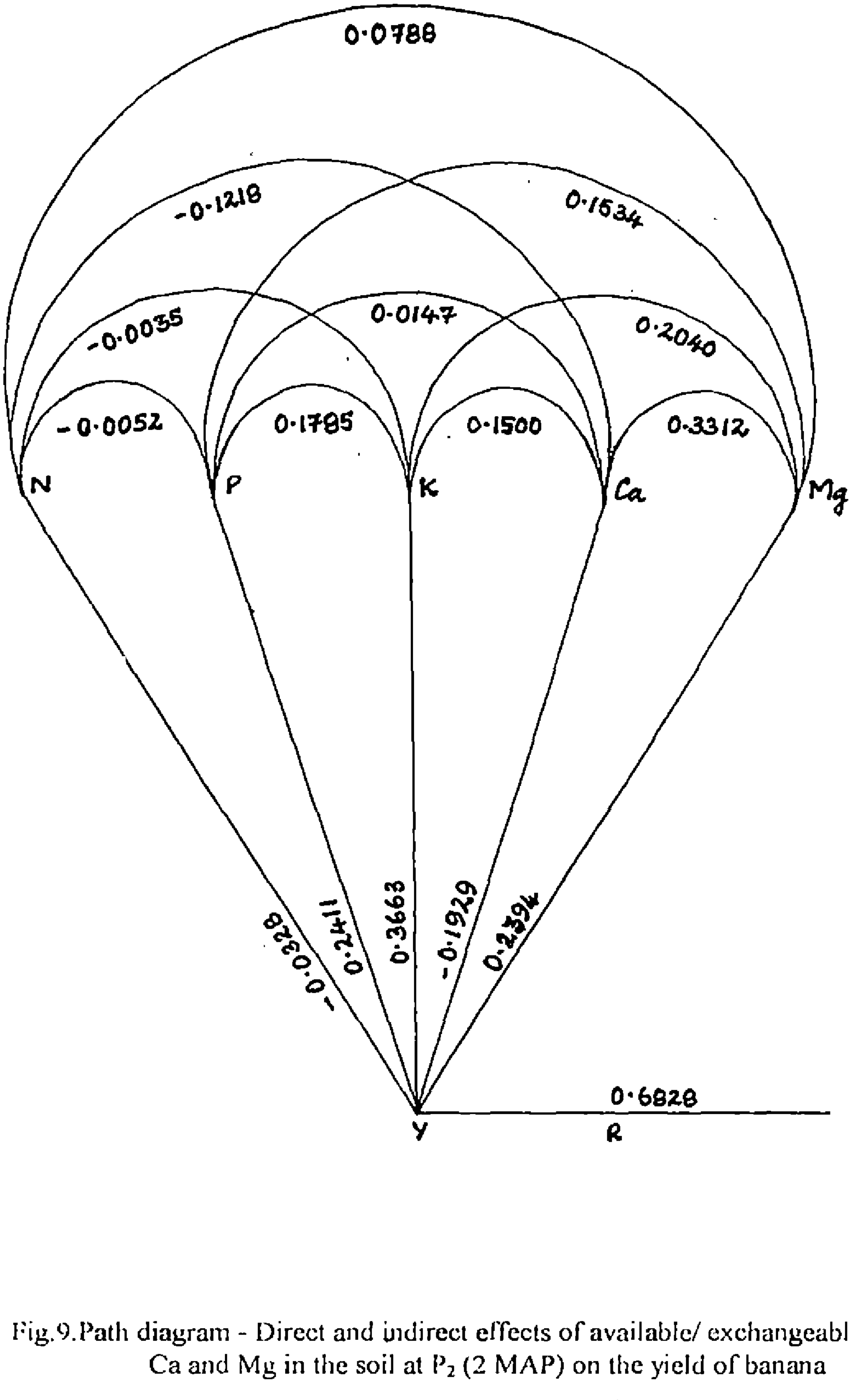

Fig.9.Path diagram - Direct and indirect effects of available/ exchangeable N, P, K, Ca and Mg in the soil at P_2 (2 MAP) on the yield of banana

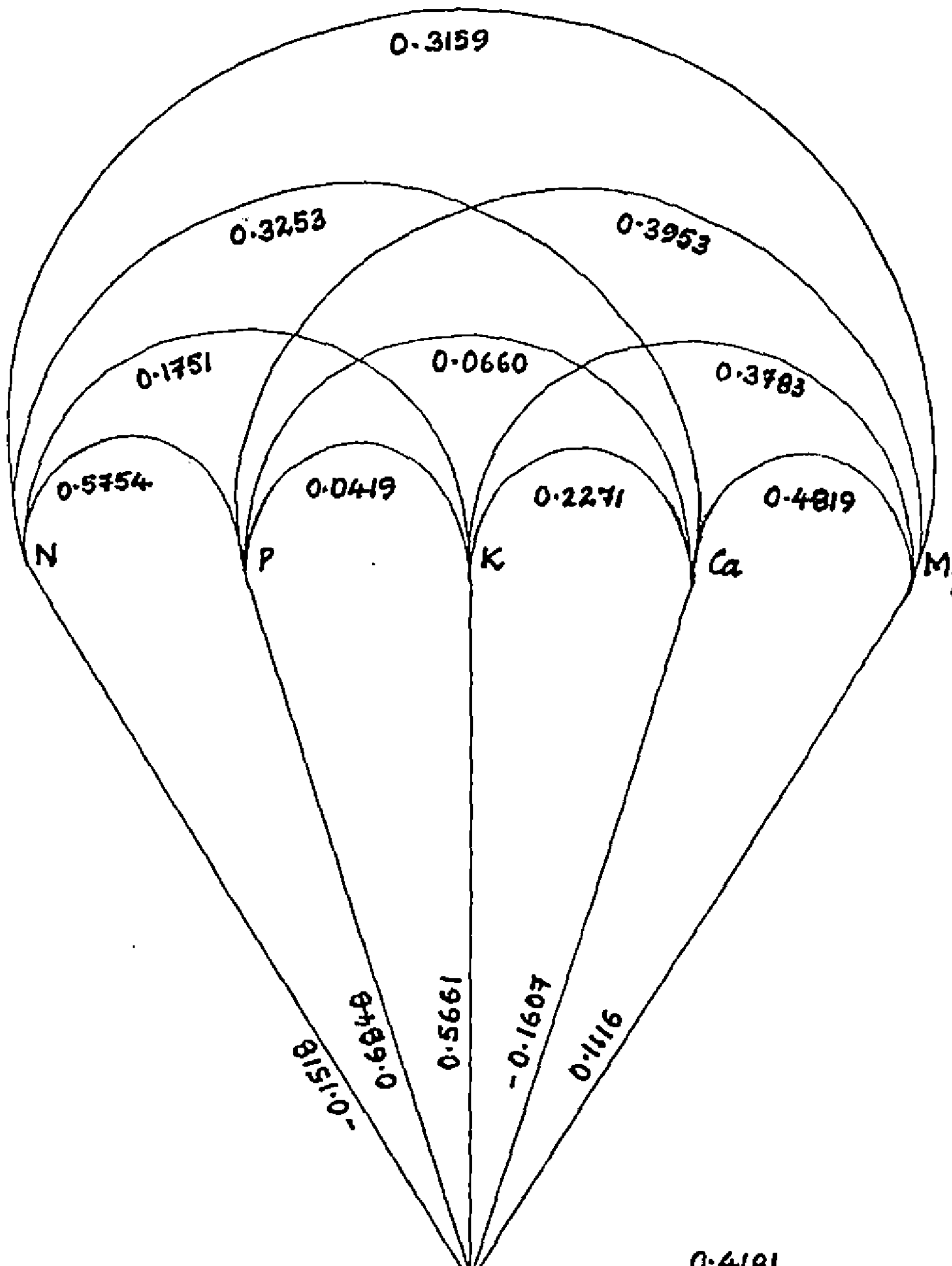

Fig.10. Path diagram - Direct and indirect effects of available/ exchangeable N, P, K, Ca and Mg in the soil at P_3 (4 MAP) on the yield of banana

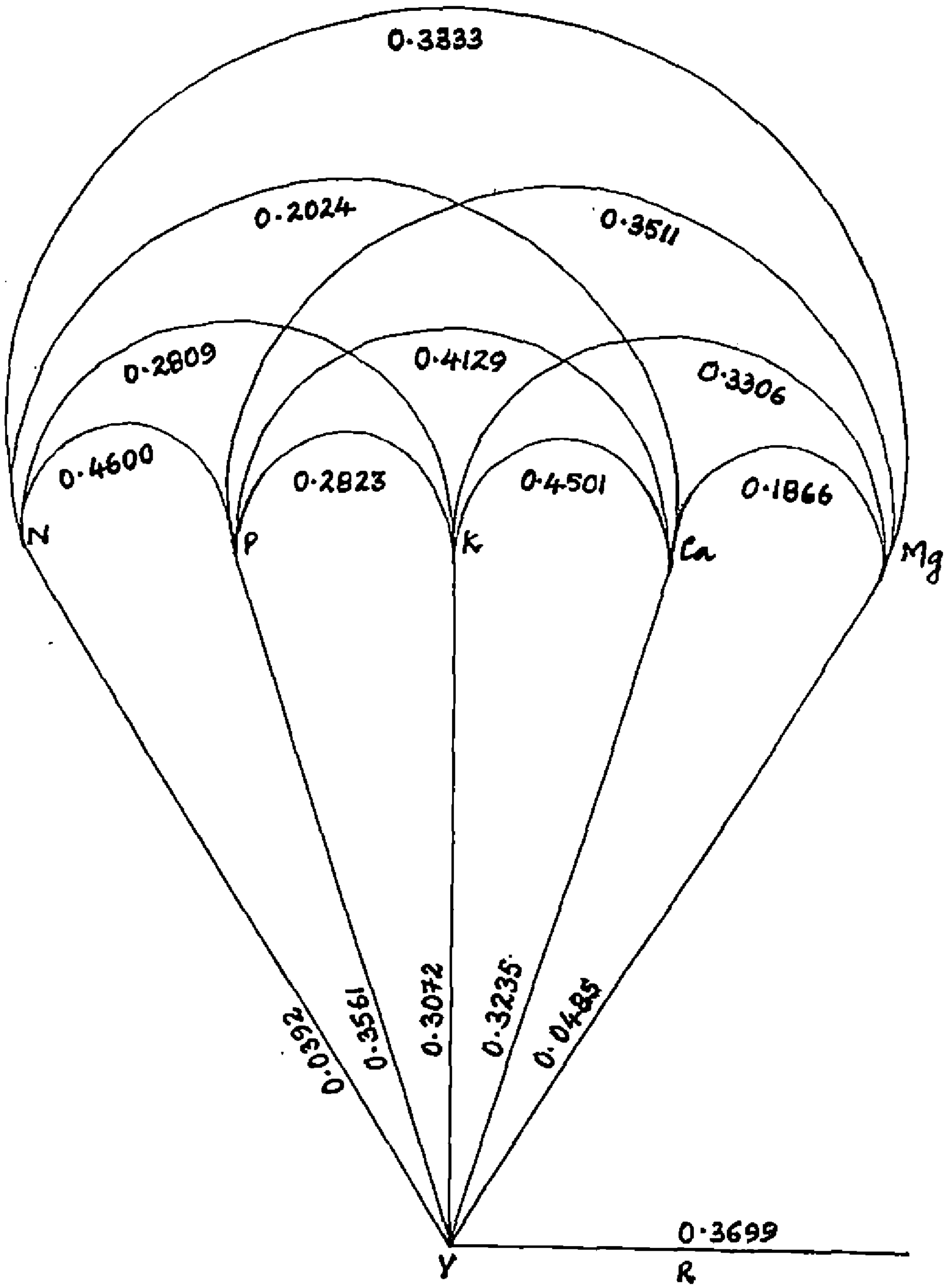

Fig. 11. Path diagram - Direct and indirect effects of available/ exchangeable N, P, K, Ca and Mg in the soil at P_4 (6 MAP) on the yield of banana

followed by P and Mg at P_2 (2 MAP). The indirect effects of various nutrients were not significant at this stage.

At P_3 (4 MAP) the direct effect of exchangeable K on yield was next to P (Fig.10).

At P_4 (6 MAP) (Fig.11) the direct effect of K was found to be next to P and Ca. The indirect effects of other nutrients through K were not significant.

7.2 Distribution of K in the plant

The total uptake and distribution of K in different parts of the plants are provided in Table 22. The Fig.2 depicts the apportioning of the nutrient in rhizome, pseudostem, leaves and bunch. On an average, the uptake of K was found to be highest in the rhizome followed by fruits leaves and pseudostem.

The total uptake of K in the plant ranged from 66.86 (T_{18}) to 199.97 (T_8) g/plant. Percentage distribution of K in rhizome was highest in T_1 and lowest in T_{10}. With regard to percentage distribution of K in pseudostem, the highest percentage was observed in T_{10} and the lowest in T_{11}. In the case of leaves the highest accumulation of K was observed in T_3 and the lowest in T_{18}. In the bunch the K distribution was found to be highest in T_7 and the lowest in T_{13}.

There was signfiicant positive correlation between the uptake of K and yield (r = 0.5420**). The uptake had positive correlation with biometric characters like leaf area (r = 0.5120**), height of the pseudostem (r = 0.5910**) and the girth of the pseudostem (r = 0.7430**).

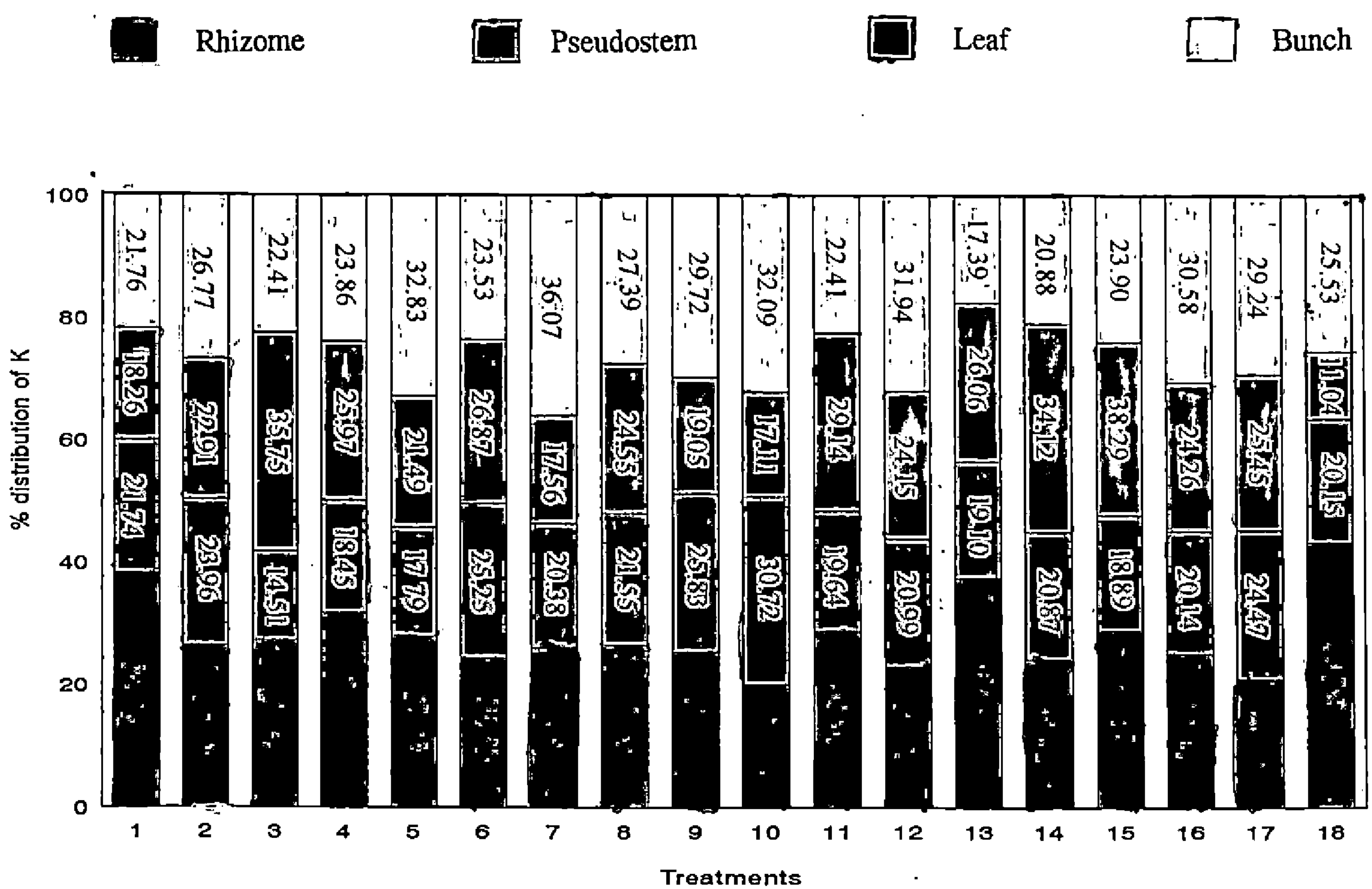

Fig.2. Effect of treatments on the per cent distribution of K in different parts of banana

In the index leaf, N and K showed a negative correlation at S_1 (4 MAP) (r = 0.3120*). Potassium and Mg showed an antagonism (r = -0.3070) at this period. At S_2 (6 MAP) there was antagonistic relation between K and Ca (r = -0.4560*) and K and Mg (r = -0.2470). The nutrient content of K in the index leaf at S_2 (6 MAP) showed a positive relation with yield (r = 0.4810*).

Thus the study indicated that the different forms of K in the soil are in a dynamic equilibrium to meet the requirement of the crop. In the crop, the nutrient is apportioned as per the metabolic necessities of the plant. From the study, it is evident that though the soil contained an available K of 359 ppm which is high in rating, had to be fertilized with K from 2 months onwards for better yield. It is also seen that the added K got fixed to an extent of 33.33 per cent. Correlation studies and path analysis could explain the influence of the nutrient at various stages of banana crop. Path analyais test revealed the aforesaid fact of fertilization of the soil with K from 2 MAP to 6 MAP which coincides with time of peak requirement of the nutrient for the crop. The direct and indirect effects of K on yield also could be established.

Table 25. Correlation matrix for the total content of K in the soil at different periods and yield of banana

	P_1	P_2	P_3	P_4	P_5	Yield
P_1	1.0000					
P_2	0.4365*	1.0000				
P_3	0.2602	0.2858	1.0000			
P_4	0.2157	0.1844	0.4678*	1.0000		
P_5	0.1682	0.2670	0.4936**	0.6168**	1.0000	
Yield	0.1720	0.5920**	0.4486*	0.3569*	0.0879	1.0000

Table 26. Correlation matrix for the content of available K in the soil at different periods and yield of banana

	P_1	P_3	P_4	P_2	P_5	Yield
P_1	1.0000					
P_3	-0.0095	1.0000				
P_4	0.1976	0.5605**	1.0000			
P_2	-0.0708	0.5276**	0.3481*	1.0000		
P_5	-0.1488	0.4980**	0.6129**	0.5148**	1.0000	
Yield	-0.1045	0.5186**	0.5806**	0.4294*	0.5454**	1.0000

* Significant at 5% level

**Significant at 1% level

Table 27. Correlation matix for the content water soluble K in the soil at different periods and yield of banana

	P_1	P_2	P_3	P_4	P_5	Yield
P_1	1.0000					
P_2	0.0058	1.0000				
P_3	0.2773	0.2027	1.0000			
P_4	-0.2108	0.2152	0.2475	1.0000		
P_5	-0.1096	-0.0448	0.3238*	0.5190**	1.0000	
Yield	0.0577	0.2291	0.4387*	0.4195*	0.4398*	1.0000

Table 28. Correlation matrix for the total content of N, P, K, Ca and Mg in the soil at P_2 (2 MAP) and yield of banana

	N	P	K	Ca	Mg	Yield
N	1.0000					
P	0.6608**	1.0000				
K	0.4766*	0.5342**	1.0000			
Ca	0.3676*	0.4708*	0.4231*	1.0000		
Mg	0.4038*	0.2430	0.0036	-0.0857	1.0000	
Yield	0.7597**	0.5568**	0.2707	0.2602	0.5924**	1.0000

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

Table 29. Correlation matrix for the total content of N, P, K, Ca and Mg in the soil at P_3 (4 MAP) and yield of banana

	Yield	N	P	K	Ca	Mg
Yield	1.0000					
N	0.7771**	1.0000				
P	0.6330**	0.7249**	1.0000			
K	0.4522*	0.4447*	0.4520*	1.0000		
Ca	0.7213**	0.6806**	0.7457**	0.4594*	1.0000	
Mg	0.4486*	0.5302**	0.5839**	0.0509	0.5075**	1.0000

Table 30. Correlation matrix for the total content of N, P, K, Ca and Mg in the soil at P_4 (6 MAP) and yield of banana

	Yield	N	P	K	Ca	Mg
Yield	1.0000					
N	0.7729**	1.0000				
P	0.3494*	0.3789*	1.0000			
K	0.5542**	0.6916**	0.3905*	1.0000		
Ca	0.5551**	0.5980**	0.2943	0.2275	1.0000	
Mg	0.3974*	0.4372*	0.2948	0.4134*	0.3507*	1.0000

* Significant at 5% level

**Significant at 1% level

Table 31. Correlation matrix for the content of available/exchangeable N, P, K, Ca and Mg at P_2 (2 MAP) in the soil and yield of banana

	Yield	N	Mg	P	K	Ca
Yield	1.0000					
N	0.0070	1.0000				
Mg	0.2847	0.0788	1.0000			
P	0.3405*	-0.0052	0.1534	1.0000		
K	0.4294*	-0.0035	0.2040	0.1785	1.0000	
Ca	-0.0512	-0.1218	0.3312*	0.0147	0.1500	1.0000

Table 32. Correlation matrix for the content of available/exchangeable N, P, K, Ca and Mg at P_3 (4 MAP) in the soil and yield of banana

	Yield	K	Mg	N	P	Ca
Yield	1.0000					
K	0.5186**	1.0000				
Mg	0.4763*	0.3783*	1.0000			
N	0.3265*	0.1751	0.3159*	1.0000		
P	0.5131**	-0.0419	0.3953*	0.5754**	1.0000	
Ca	0.4310*	0.2271	0.4819*	0.3253*	0.6660**	1.0000

* Significant at 5% level

**Significant at 1% level

Table 33. Correlation matrix for the content of available/exchangeable N, P, K, Ca and Mg at P_4 (6 MAP) in the soil and yield of banana

	Yield	K	Mg	N	P	Ca
Yield	1.0000					
K	0.5806**	1.0000				
Mg	0.3485*	0.3306*	1.0000			
N	0.3710*	0.2809	0.3333*	1.0000		
P	0.6115**	0.2823	0.3511*	0.4600*	1.0000	
Ca	0.6360**	0.4507*	0.1866	0.2024	0.4129*	1.0000

Table 34. Correlation matrix for the content of N, P, K, Ca and Mg in the index leaf at S_1 (4 MAP) at yield of banana

	N	P	K	Ca	Mg	Yield
N	1.0000					
P	-0.1020	1.0000				
K	-0.3120*	-0.0340	1.0000			
Ca	-0.1900	-0.4250*	0.0420	1.0000		
Mg	0.3290*	-0.0820	-0.3070*	-0.0690	1.0000	
Yield	0.0610	0.3480*	0.0360	0.4710*	0.2970	1.0000

* Significant at 5% level

**Significant at 1% level

Table 35. Correlation matrix for the content of N, P, K, Ca and Mg in the index leaf at S_2 (6 MAP) and yield of banana

	N	P	K	Ca	Mg	Yield
N	1.0000					
P	-0.0930	1.0000				
K	-0.0440	-0.1310	1.0000			
Ca	-0.0460	0.3840*	-0.4560	1.0000		
Mg	0.1900	-0.1000	-0.2470	-0.1390	1.0000	
Yield	0.3850*	-0.2260	0.4810	0.1760	0.2790	1.0000

Table 36. Correlation matrix for the content of N, P, K, Ca and Mg in the index leaf at S_3 (at harvest) and yield of banana

	N	P	K	Ca	Mg	Yield
N	1.0000					
P	0.2780	1.0000				
K	0.0300	0.5620**	0.3930*	1.0000		
Mg	-0.0390	0.5230**	0.5340**	0.8370**	1.0000	
Yield	0.2580	0.7100**	0.6540**	0.5310**	0.4930**	1.0000

* Significant at 5% level

**Significant at 1% level

Table 37. Correlation matrix for the uptake of N, P, K, Ca and Mg by the crop and yield of banana

	N	P	K	Ca	Mg	Yield
N	1.0000					
P	0.4500*	1.0000				
K	0.7450**	0.6460**	1.0000			
Ca	0.6160**	0.3160*	0.6450**	1.0000		
Mg	0.3800*	0.2770	0.5800**	0.4690*	1.0000	
Yield	0.7330**	0.5420**	0.7810**	0.5490**	0.3850*	1.0000

* Significant at 5% level

**Significant at 1% level

Summary

SUMMARY

The study was conducted to investigate the forms, availability and transformation of potassium in a soil of low fertility status, as influenced by varying levels of other major nutrients and organic matter and uptake by an annual crop like banana. The study was also intended to explore the interactive influence of potassium with other elements present in the soil in the presence of a crop. The important findings of the study are summarised below.

1. The soil reaction of the experimental site was acidic in nature (pH = 4.85). The addition of FYM decreased the pH while addition of urea and super phosphate increased it. The organic acids released from the mineralisation of FYM increased soil acidity. At 6 MAP (peak period of nutrient absorption) the pH of the soil decreased due to the H^+ ions released from the plant roots for exchange of nutrient ions from the soil solution. At harvest the exchange decreased and pH raised.

2. The EC of the soil solution increased with the addition of fertilizers. The soluble ions released from the fertilizers resulted the increase in EC. The EC of the soil samples at harvest was found more than that of the initial samples indicating the residual effect of added nutrients.

3. The organic carbon content of the soil showed an increase at P_2 (2 MAP) due to the addition of FYM and a decline afterwards. At harvest, the organic carbon content got almost stabilised due to the root debris added to the soil.

4. At P_2 (2 MAP) the treatments receiving 5.0 and 7.97 kg FYM/plant showed a decrease in total N while the other treatments showed an increase in total N. A proper N balance in the soil can be maintained in banana plantations by adding FYM atleast 7.97 kg/plant.

5. The P released from the mineralisation of FYM could not contribute significantly to the available P fraction of the soil which was evident from the available P content of the soil at P_2 (2 MAP).

6. The different forms of K viz. total, exchangeable and water soluble were in a dynamic equilibrium and they were found to adjust themselves to meet the requirements of the crop. At the end of the crop the mean total content of K (0.16%) was found more than the initial samples indicating fixation of added K to the tune of 33.33 per cent.

7. The Ca content of the soil at P_3 (4 MAP) increased over P_2 (2 MAP) due to the addition of phosphatic fertilizer containing Ca.

8. The low content of available S in the soil at all stages of growth might be due to plant uptake, leaching loss of sulphate ions and adsorption of sulphate ions by the Fe and Al oxides and hydroxides.

9. Addition of FYM resulted in chelation of micronutrients resulting in the decreased content of the nutrients in the soil.

10. The height and girth of the pseudostem during early growth stages remained unaffected by the treatments. Increased plant height was observed as a result of enhancing the levels of K. Also increased K levels resulted in increased

number of functional leaves. Leaf area showed significant difference among the treatments only at five months after planting. These biometric characters viz. height and girth of the pseudostem, number of functional leaves and leaf area were positively correlated with yield.

11. With regard to bunch yield, the control treatment (T_{18}) recorded the lowest yield (3.75 kg) while the maximum yield (9.52 kg) which was observed in T_2 was about 154 per cent more than the control. From the economic point of view, 300 g K_2O/plant is sufficient for getting the maximum yield. The present recommended dose of 190:115:300 g N:P_2O_5 :K_2O/plant can be reduced provided 17 to 20 kg FYM/plant is given.

12. Among the major nutrients N, P and K, the concentration of K was found highest in the index leaf at all stages of growth. The content of nutrients in the index leaf increased from 4 MAP to 6 MAP while at harvest it declined. At S_1 (4 MAP) N and K and K and Mg showed antagonistic effects. The correlation coefficients were -0.3120 and -0.3010 between N and K and K and Mg respectively. At S_2 (6 MAP) the antagonistic effects were between K and Ca and K and Mg giving r values of -0.4560* and -0.2470 respectively.

13. Application of increased levels of N resulted in the increased uptake of N. The uptake of P was found to be highest in the rhizome indicating the need of the nutrient for root development. Increasing levels of K increased K uptake and among the major nutrients the uptake of K was found to be the highest.

14. Correlation studies revealed the highly significant positive correlation between yield and diferent forms of K at different stages. Total K showed a positive correlation with yield at P_2 (2 MAP) (r = 0.5920**) and at P_3 (4MAP) (r =

0.4486*). The available K showed a positive correlation at P_4 (6 MAP) (r = 0.5454**) followed by P_3 (4 MAP) (r = 0.5186**) water soluble K at different stages also had significant positive correlations with yield.

15. Path coefficient analysis revealed that the total K content at P_4 (6 MAP) had direct effect on yield followed by that at P_2 (2 MAP) and P_3 (4 MAP). The direct effect of exchangeable K at P_4 (6 MAP) was found to be maximum. The indirect effect of total and exchangeable K on yield was maximum at P_4 (6 MAP) through P_3 (4 MAP). This explains that the requirement of the nutrient K for banana crop is during its early and late vegetative periods. So K fertilizer should be applied from 2 MAP and continued up to 6 MAP.

16. The direct effect of total K on yield was not significant when the interaction of nutrients was considered. Total N showed significant direct effect on yield at different stages. The indirect effect of K through N was found significant at P_4 (6 MAP).

17. The direct effect of available K was maximum at P_2 (2 MAP) among the nutrients analysed. The indirect effects of various nutrients through K were not significant at different stages.

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* Originals not seen

Appendices

Appendix-I

Physico-chemical characteristics of the soils of the experimental site

Structure	:	Medium subangular blocky
Texture	:	Sandy clay
Coarse sand (%)	:	17.04
Fine sand (%)	:	9.27
Silt (%)	:	34.07
Clay (%)	:	41.91
Bulk density	:	1.44
Particle density	:	2.64
pH	:	4.85
EC (dS m^{-1})	:	0.050
CEC (cmol (+) kg^{-1})	:	3.64
Organic carbon (%)	:	0.485
Total nitrogen (%)	:	0.064
Available N (ppm)	:	89
Total phosphorus (%)	:	0.114
Available P (ppm)	:	26.9
Total K (%)	:	0.119
Available K (ppm)	:	359.3
Total Ca (ppm)	:	816.4
Exchangeable Ca (ppm)	:	150.2
Total Mg (ppm)	:	1128.9
Exchangeable Mg (ppm)	:	34.4
Total S(%)	:	412.5
Available S (ppm)	:	4.31
Total Fe (ppm)	:	1885
NH_4OAC Exchangeable Fe (ppm)	:	1.11
Total Mn (ppm)	:	896.5
NH_4OAC Exchangeable Mn (ppm)	:	15.4
Total Cu (ppm)	:	28.8
NH_4OAC Exchangeable Cu (ppm)	:	0.235
Total Zn (ppm)	:	55.3
NH_4OAC Exchangeable Zn (ppm)	:	0.330

Appendix-II

Content of nutrients (total and water soluble) in the farmyard manure used in the experiment

Nutrients	Total				Water soluble (ppm)			
	1	2	3	Mean	1	2	3	Mean
Nitrogen (%)	0.70	0.80	0.60	0.70	1500	2000	1800	1700
Phosphorus (%)	0.11	0.12	0.12	0.12	19.20	9.40	11.30	13.30
Potassium (%)	0.80	0.60	0.40	0.60	7.50	6.30	5.70	6.50
Calcium (%)	0.36	0.76	0.56	0.563	10.90	11.00	8.80	10.20
Magnesium (%)	0.23	0.096	0.32	0.22	3.90	2.75	2.65	3.10
Sulphur (%)	0.32	0.34	0.30	0.32	11.70	12.00	13.00	12.20
Iron (ppm)	2371	2200	2500	2357	8.75	6.80	7.75	7.80
Manganese (ppm)	17.4	16.3	16.7	16.8	1.00	1.00	1.00	1.00
Zinc (ppm)	10.0	8.5	12.1	10.2	0.81	0.63	0.74	0.73
Copper (ppm)	5.0	7.0	6.0	6.0	0.20	0.40	0.30	0.30

FORMS, AVAILABILITY AND TRANSFORMATION OF POTASSIUM IN LATERITE SOIL AS INFLUENCED BY CROP UPTAKE

By

NICY THOMAS

ABSTRACT OF THE THESIS

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ABSTRACT

An investigation was taken up to study the fate of applied and native potassium in a laterite soil as influenced by other major nutrients and organic matter and uptake by an annual crop, banana. The experiment was laid out at Banana Research Station, Kannara, Kerala Agricultural University during the period 1996-1997.

The result of the study revealed the necessity of fertilization of the field/soil for better yield. The maximum content and uptake of nutrients N, P and K occurred during the early and late vegetative stages of banana. Hence fertilizers should be applied for the crop from 2 months after planting onwards and continued up to six months after planting. Correlation studies revealed the significant relationship of total K in the soil with yield at different stages. Also poistive correlation between the exchangeable K content in the soil and yield was established. Path coefficient analysis revealed that the direct effect of total K content in the soil on yield was highest at P_4 (6 MAP). The indirect effect was maximum at P_4 (6 MAP) through P_3 (4 MAP). The exchangeable K also was found to have positive direct effect on yield. The indirect effects were not significant. Water soluble K at different stages showed a direct effect of comparable magnitude on yield.