NUTRIENT MANAGEMENT FOR YIELD AND QUALITY IMPROVEMENT IN KACHOLAM (*Kaempferia galanga* L.)

by

KAVITHA P. R.

(2009-11-137)

THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Nutrient management for yield and quality improvement in Kacholam (*Kaempferia galanga* L.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Kavitha

Vellanikkara

Date: 18-08-12

Kavitha P.R.

(2009-11-137)

Dr. Meera V. Menon
Associate Professor (Agronomy)
College of Horticulture
Kerala Agricultural University
Vellanikkara

Date : 18-08-12

CERTIFICATE

Certified that the thesis entitled **"Nutrient management for yield and quality improvement in Kacholam (*Kaempferia galanga* L.)"** is a record of research work done independently by **Mrs. Kavitha P. R (2009-11-137)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

Vellanikkara

Dr. Meera V. Menon
Chairperson
Advisory Committee

CERTIFICATE

We, the undersigned members of the advisory committee of **Mrs. Kavitha P. R (2009-11-137)** a candidate for the degree of **Master of Science in Agriculture**, with major field in Agronomy, agree that the thesis entitled **"Nutrient management for yield and quality improvement in Kacholam (*Kaempferia galanga* L)"** may be submitted by **Mrs. Kavitha P. R.**, in partial fulfilment of the requirement for the degree.

10-10-12

Dr. Meera V. Menon
(Major Advisor)
Associate Professor
Department of Agronomy
College of Horticulture
Vellanikkara.

Dr. C.T. Abraham
Professor and Head
Department of Agronomy
College of Horticulture
Vellanikkara.

Dr. P. S John
Professor
Department of Agronomy
College of Horticulture
Vellanikkara

10-10-12

Dr. M. Asha Shankar
Professor
Department of Plantation Crops and Spices
College of Horticulture
Vellanikkara

External Examiner

Dr. S Bhaskar
Professor of Agronomy
UAS GKVK Bangalore
[External Examiner]

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Kavitha

Kavitha P. R.

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Introduction

1. INTRODUCTION

Soil, climate, and management practices are the three basic factors which influence the yield of a crop. Management of essential nutrients in the soil by proper fertilizer use is important for increasing crop yield and quality. However, fertilizer management has become synonymous with management of the major nutrients, nitrogen, phosphorus and potassium. The secondary and micronutrients do not get the attention they deserve, even though they are essential and play key roles in the growth and productivity of crops.

Continuous mining of nutrients from soils, coupled with inadequate and imbalanced fertilizer use, led to secondary and micro nutrient deficiencies in soil. Deficiencies of at least six nutrients (N, P, K, S, Zn and B) are quite widespread in Indian soils (Tewatia, 2008). In Kerala too, there is widespread deficiency of sulphur. Of a number of alluvial and brown hydromorphic soil samples collected in Kerala 56 per cent and 83 per cent respectively, were sulphur deficient (Nair, 1995). Seventy per cent of soil samples collected from different parts of the four districts of Palakkad, Kollam, Thiruvananthapuram and Thrissur were low in sulphur (John *et al.*, 2005; Sheela *et al.*, 2006).

A relative or absolute deficiency of S, and its governing role in N utilization is related to a great degree to the declining productivity with increasing N levels in almost all crops in several states of India. Kerala, located in the humid tropical tract, is predisposed to have suboptimal contents of S and other nutrients in the soil. The losses due to leaching and erosion are remarkably serious in this high rainfall zone, where two third of the total annual rainfall of 3000 mm is received in South-West monsoon period alone. The laterite soils predominant in this area are generally deficient in K (Sarkar *et al.*, 1989) and Ca (Kanwar, 1976).

Crops respond differentially to different nutrient elements, and proper nutrient management for a plant species is important for increasing yield and quality. This is particularly relevant for medicinal plants, where quality component of yield is as important as quantitative yield.

Kaempferia galanga L., known as Kacholam, is one such important medicinal and aromatic plant of Kerala. There are 55 species reported in the genus *Kaempferia*, of which 10 are found in India, among which, *K.galanga* and *K.rotunda* are economically important. Lately, the consumption of the rhizome by the medicinal and perfumery industries has shot up, leading to high demand and price. Dried rhizomes are used in bulk quantities in ayurvedic medicine and in the cosmetic industry. The whole plant is refreshingly aromatic and is bestowed with several medicinal properties as being stimulant, expectorant, carminative and diurectic (Chopra *et al.*, 1956). It is used for curing inflammatory wounds, skin disorders, piles, oedema, fever, epilepsy, splenic disorders and asthma (Aiyer and Kolammal, 1964; Burkill, 1966). The constituents of the rhizome oil include para methoxy ethyl cinnamate, ethyl cinnamate, cineol, borneol, 3-carene, camphene, kaempferol, kaempferide and cinnamaldehyde.

In Kerala, kacholam has attained the status of a cash crop in homesteads. The climatic and soil conditions prevailing in Kerala are optimally suited to the cultivation of the crop. There is immense scope for its cultivation in the homestead as an intercrop in coconut gardens. Kacholam can also be successfully cultivated in various parts of South India and in the north-eastern states

Nutritional management practices which could increase the yield and quality of kacholam would greatly benefit the small farmers of Kerala. Though there is an approved *ad hoc* recommendation for organic manures, as well as for N, P and K for kacholam, there are reports that the K dose is inadequate (Gangadharan, 2003). The organic manure recommendation is quite high and rather unaffordable. There are also reports of the association of sulphur, calcium and magnesium with higher yield and quality in kacholam (Gangadharan and Menon, 2003 and 2006). Top dressing of sulphur and magnesium was advocated at the rhizome formation stage for increasing the productivity of the crop. However, no work has been done on the application of these elements.

An attempt was made to develop a more effective nutrient application schedule in kacholam incorporating the secondary elements Ca, Mg and S, and varying the organic manure and K rates for maximizing productivity in kacholam intercropped in coconut gardens.

The specific objectives of the study were:

1. To find out the effect of secondary nutrients, *viz.*, sulphur, calcium and magnesium, on yield and quality of kacholam.

2. To study the effect of varying organic manure levels in combination with fertilizers as well as that of different N:K ratios on the productivity of the crop.

Review of Literature

2. REVIEW OF LITERATURE

Medicinal and aromatic plants play an important role in the health care of people around the world. Until the advent of modern medicine, man depended on plants for treating human diseases. Zingiberaceae family constitutes a vital group of rhizomatous medicinal and aromatic plants characterised by the presence of volatile oils and oleoresins. Kacholam (*Kaempferia galanga L.)* also known as Sugandhavacha, Chandramulika or Sidhul, is a rhizomatous perennial plant of this family, the rhizomes of which yield an essential oil. The oil is utilized in the manufacture of perfumes and in curry flavouring. It is also employed in cosmetics, mouth washes, hair tonics and toiletries. The pungent, hot, sharp, bitter and aromatic rhizomes find an important place in indigenous medicine as stimulant, expectorant, diuretic and carminative, and are identified to have tremendous effect in curing bronchial and gastric diseases. The yield of kacholam has two components, the rhizomes and the oleoresin and essential oil. Management of major and secondary nutrients so as to optimize production of both quantitative and qualitative yields is the main objective in kacholam cultivation.

Review of literature is classified into three aspects, *viz.*, effect of nutrients on biometric characters, effect of nutrients on yield and quality, and interaction effect of nutrients in kacholam, and other oleoresin and essential oil yielding crops as well as rhizome and root crops.

1. Biometric characters

a. Relation of biometric characters with growth and yield

Latha *et al.* (1995) reported that in turmeric, increased vegetative growth generally resulted in increased production and storage of photosynthates in rhizomes, which accounted for higher yield. Nitrogen, phosphorus and potassium uptake was significantly higher with mother rhizome compared to finger rhizome because of better vegetative growth of the crop in the initial stages which resulted in higher uptake of nutrients.

Correlation and path analysis for yield and yield contributing characters in two types of micro propagated ginger plants showed that tiller number exhibited negative correlation and negative direct effect with the rhizome yield in the first generation. In the second generation of the aerial stem regenerated plants, tiller number, number of nodes per cormlet, circumference of cormlet, number of cormlet and plant height exhibited high positive correlation and maximum direct effect with rhizome yield (Lincy *et al.*, 2008).

b. Effect of organic manures on biometric characters

Maheswarappa *et al.* (2000) observed that the combination of organic manure with chemical fertilizer resulted in better growth of the crop as reflected in more number of leaves, tillers, higher leaf area duration and yield components in kacholam.

Hossain and Ishimine (2007) observed that vegetative growth parameters (number of leaves per plant, plant height, number of tillers per plant, leaf biomass) and yield of turmeric increased with the FYM application than control.

Sanwal *et al.* (2007) found that significantly higher rhizome yield was recorded with the application of FYM @ 18t/ha which was on a par with 10t/ha of poultry manure. Application of these organic sources resulted in 16-103 per cent higher rhizome yield over control and also improved the quality parameters in turmeric. Manhas and Gill (2010) also reported that application of FYM increased the growth, dry matter accumulation, yield and quality of turmeric. Similar observations were made by Maheswarappa *et al.* (2001) in kacholam

c. Effect of nutrient application on biometric characters

Top dressing of P and K at the initial stages of growth, that is, 1 ½ - 2 MAP would improve vegetative growth and yield in kacholam (Gangadharan, 2003).

Akamine *et al.* (2007) found that in turmeric, N applied alone or in combination with P and K resulted in a significantly higher plant height, and number of leaves and tillers. Similar results were observed by Haque *et al.* (2007), where plant height, number of leaves and finger number of turmeric increased with increase in N levels up to 150 kg/ha. The finger weight, finger size and turmeric yield were also increased. Banwasi and Singh (2010) observed that maximum fresh rhizome yield, plant height, number of tillers/clump, leaf length and leaf width were recorded with application of 150 kg P/ha in turmeric. Similar results were also reported by Sheshgiri and Uthaiah (1994) in turmeric.

Jayalakshmi (2003) found linear relationship between plant height and the level of nitrogen applied in medicinal coleus. The plant height recorded at 120, 150 and 180 days after planting (DAP) was the highest (49.5, 55.4 and 57.3 cm, respectively) when 50 kg N per hectare was applied compared to control (35.4, 39.8 and 41.8 cm, respectively). Number of laterals, number of leaves, number of tuberous roots per plant, tuber length and diameter, fresh and dry roots were found to be the highest with application of 50 kg N per hectare at all the growth stages. Jilani *et al.* (2010) observed, maximum number of leaves (18.70), leaf length (33.33 cm), weight of leaves (160.67 g), root length (23.77 cm), root diameter (4.43 cm), root weight (139.28 g) and yield (99.88 t/ha) were recorded when N was applied @ 200 kg per hectare in radish.

Jana and Kabir (1990) recorded maximum plant height (48.62 cm), number of leaves (9.14), weight of 10 bulbs (1.02 kg), diameter of bulb (6.13 cm) and yield (30.19 t/ha) in the treatment which received sulphur @ 30 kg ha^{-1} followed by that which received 40 kg ha^{-1} in onion. Similar results were observed by Poornima (2007), where the growth parameters such as plant height (45.32 cm) and total dry matter production (97.04 g/plant) was highest in treatment receiving K (100kg/ha) and S (30 kg/ha).

Lujiu *et al.* (2009) found that plant height, stem circumference, number of branches and tuber weight/plant increased with increasing rates of N (375 kg/ha) and K (450 kg/ha) in ginger. Plant growth was vigorous and robust when K was applied in ginger. Sugatto and Mafzuchah (1995) observed that the yield attributes like plant height, number of leaves and finger number responded significantly to K levels. K at the highest level (160 kg/ha) produced the greatest plant height, maximum number of leaves and finger number in ginger. In turmeric, similar result was observed by Haque *et al.* (2007), where the application of K (100 kg/ha) enhanced plant height, number of leaves and finger number/plant. An experiment was conducted on turmeric cv. Suguna with different levels of N (100, 150 and 200 kg/ha) and K (100, 150 and 200 kg/ha) along with uniform dose of P @ 60 kg/ha. The maximum plant height, leaf number and leaf dimension were obtained with highest level of both N and K (Medda and Hore, 2003). Kakar *et al.* (2002) reported that increasing nitrogen level up to 100 kg resulted in longer leaves (64.83), greater number of leaves per plant (17.90), maximum single bulb weight (42.60 g) and bulb yield per plant (7.08 kg) and total bulb yield (6746.03 kg/ha) of garlic. Ali *et al.* (2003) observed that maximum number of leaves, plant height, root length, root diameter, fresh and dry weight of shoot, fresh and dry weight of root and root yield, when 150 kg N per hectare was applied in carrot.

In *Alpinia galanga*, increasing levels of nitrogen application significantly increased plant height, number of tillers per clump and number of leaves per tiller up to 100 kg N/ha (Hussain *et al.*, 2005). Maheswarappa *et al.* (2000a) found that N content and dry matter in kacholam were significantly higher in plants treated with FYM (20 t/ha) and inorganic fertilizers (50:50:50 kg N,P,K ha^{-1}), compared with composted coirpith and inorganic fertilizers applied singly.

2. Yield and quality

a. Effect of nutrient sources on yield and quality

Vidyadharan and Swadija (2000) observed that in arrowroot (*Maranta arundinaceae*), rhizome yield increased with increasing levels of FYM, the highest yield (13.95 t/ha) being recorded at 20 t/ha. In kacholam, the essential oil and oleoresin contents were significantly higher in treatments with FYM (20 tha^{-1}) and NPK (50:50:50 $kgha^{-1}$), followed by FYM and vermicompost treatments (Maheswarappa *et al.*, 2000b). Trials conducted by Singh *et al.* (2006) revealed that in *Curcuma aromatica*, application of 22.5 t of FYM/ha provided higher oil yield (234.4 kg/ha). In *Curculigo orchioides*, application of FYM @ 40t/ha resulted in significant improvement in number, length and thickness of tuber and dry recovery (Kothari and Singh, 2003). Joy *et al.* (2002) found that in *Alpinia galanga L.*, the treatment receiving FYM (20 t/ha) recorded the highest number of clumps per plot (19.17), highest plant height (90.18cm), number of suckers per clump (57.10), number of leaves per sucker (10.23), fresh rhizome yield (45.14 t/ha) and oil yield (94.80 l/ha).

Maheshwari *et al.* (2000) reported that in Ashwagandha cultivar "JA 20", use of 2.5 tha^{-1} FYM along with 12.5 kg N and 25 kg P_2O_5, recorded 23.7 per cent higher root yield and was highly remunerative, fetching maximum net returns of Rs.29390/ha with a B:C ratio of 5. Harshavardhan *et al.* (2007) reported that in lemon balm (*Melissa officinalis* L.), application of 50 per cent inorganic fertilizers and 50 per cent enriched FYM (6 t ha^{-1}) resulted in increased oil yield of 47.27 kg ha^{-1}. Maheswarappa *et al.* (1999) observed that in arrowroot (*Maranta arundinaceae)* intercropped with coconut, the treatment combination of FYM along with inorganic fertilizers recorded the highest dry matter of 65.12 g per plant and 125.69 g per plant at 120 and 240 days after planting and at harvest (167.93 g per plant). The contents of chlorophyll a and b were significantly higher in the treatment of FYM + inorganic fertilizer alone (2.1 and 2.113 mg/g fresh leaf respectively). Gayathri and Anburani (2008) noticed that in kacholam, the number of rhizomes per plant (19), fresh weight of rhizome (76.66 g/ plant), dry weight of rhizomes (75.16 g/plant), yield of rhizome (1455.77 g/plant) and essential oil content (2.12%) were highest in the treatment combination of FYM at 30 t/ha along with the recommended dose of inorganic fertilizers at 50:50:50 kg NPK ha^{-1} and with the foliar application of vermiwash (1:5) dilution.

Veeraragavathatham *et al.* (1988) studied the effect of major nutrients on the growth and tuber yield of medicinal coleus and found that combination of 40 kg N, 60 kg P_2O_5 and 50 kg K_2O was optimum for maximum fresh (33.12 t/ha) and dry (3.98 t/ha) tuber yields. Further, they reported that tuber yield decreased when NPK levels were raised beyond 40:60:50 kg N, P_2O_5 and K_2O per hectare. Patne (2003) at

Bangalore in red sandy clay loam soil, also obtained higher dry tuberous root yield (3.45 t/ha), number of roots, girth of tuberous roots, length of tuberous roots and dry weight of tuberous roots per plant when 40:60:50 kg N, P_2O_5 and K_2O per hectare was applied along with 10 tonnes of FYM per hectare.

Attoe and Osodeke (2009) observed that in ginger, the optimum NPK treatment combination of 200:80:100 kg/ha resulted in increased growth and yield parameters (plant height, number of shoots, fresh weight of plant and rhizome yield).

b. Effect of nutrients on yield and quality

1. Nitrogen

Nitrogen is a vitally important plant nutrient and is the most frequently deficient of all nutrients. It is important for protein production. It plays a pivotal role in many critical functions (such as photosynthesis) in the plant and is a major component of amino acids, the critical element constituent component of proteins. These amino acids are then used in forming protoplasm, the site of cell division and plant growth. Nitrogen is necessary for enzymatic reactions in plants since all plant enzymes are proteins. It is a necessary component of several vitamins, e.g., biotin, thiamine, niacin and riboflavin (Brady, 1984). N is part of the nucleic acids (DNA and RNA). Nitrogen is an integral part of chlorophyll, which is the primary absorber of light energy needed for photosynthesis (Das, 1993).

At any given time, 95-99% of the potentially available nitrogen in the soil is in organic form, either in plant and animal residues, in the relatively stable soil organic matter or in living soil organisms, mainly microbes such as bacteria. Total nitrogen content in soils could vary from traces to 1-2% depending upon the C: N ratio of soil organic matter.

N is involved in chlorophyll formation, and it influences stomatal conductance and photosynthetic efficiency (Mazid, 1993). N is responsible for 26-41% increase in crop yield in turmeric (Maier *et al.*, 1996). Pandey (1992) stated that increasing rates of N significantly enhanced the yield and other yield attributing characters of turmeric. Singh *et al.* (1994) reported that application of 100 kg N/ha gave the maximum growth and yield of ginger under medium soil fertility conditions of Jabalpur. Thakur and Sharma (1997) reported significant increase in rhizome yield due to increased level of nitrogen up to 100 kg N/ha in ginger. Hussain *et al.* (2005) also noticed that application of 100 kg N/ha resulted in highest oil content and fresh rhizome yield.

Ganorkar *et al.* (2006) reported that the highest values for nutrient uptake and tuber yield in safed musli were observed with FYM application (20 t/ha) and nitrogen (75 kg N ha^{-1}), when applied alone or in combination. Sailaja *et al.* (2007) reported that the highest fresh and dry weight of roots (320.4 and 40 g/plant, respectively), number of roots per plant (15.1), root length (23.5 cm), highest fresh tuberous root yield (11.44 t/ha) and highest dry tuberous root yield (1.43 t/ha) were recorded with application of nitrogen at 40 kg per hectare. They also observed that the highest plant height, number of leaves per plant, leaf dry weight, leaf area, shoot dry weight and dry matter production were at 40 kg N per hectare. Veeraragavathatham *et al.* (1988) studied the effect of N on the yield of *C. forskohlii* with five N levels (0, 40, 80, 120 and 160 kg/ha). The effect of nitrogen was significant and the higher fresh (21.27 t/ha) and dry tuber yield (2.56 t/ha) were obtained from the treatment receiving 40 kg N per hectare.

Geetha and Nair (1990) studied the differential response of *C. parviflorus* to graded doses of nitrogen (0, 30, 60, 90 and 120 kg/ha). They reported that nitrogen at 60 kg per hectare produced maximum plant height, number of branches, number of leaves, leaf area index and dry matter yield. Further increase in the dose of nitrogen had no significant effect on growth and yield of the crop. Mastiholi (2008) reported that the yield contributing characters like number of tubers per plant (17.7), length (20.8 cm) and diameter of tubers (13.8 mm) at harvest were recorded maximum with application of 50 kg N per hectare were significantly superior over 100 and 150 kg N per hectare.

Muthuswamy and Muthukishnan (1984) observed a marked increase in fresh top weight and root diameter with 200 kg N per hectare in radish. Cabonce (1993) reported that radish plant supplied with 80 kg N per hectare produced longer, bigger and heavier roots over all other treatments. Ghanti *et al.* (1997) tried different nitrogen levels with various irrigation treatments. They found that N significantly influenced radish yield, leaf and root length, root girth and number of marketable roots per hectare. The highest radish yield (369.40 q/ha) was obtained with 100 kg N. Kakar *et al.* (2002) reported that increasing nitrogen level up to 100 kg resulted in longer leaves (64.83), greater number of leaves per plant (17.90), maximum single bulb weight (42.60 g) and bulb yield per plant (7.08 kg) and total bulb yield (6746.03 kg/ha) of garlic.

2. Phosphorus

The most essential function of P in plants is in energy storage and transfer. Adenosine di and tri phosphates (ADP and ATP) act as "energy currency" within plants (Tisdale *et al.*, 1993). Phosphorus is essential for the general health and vigour of all plants. Specific growth factors that have been associated with phosphorus are stimulated root development, increased stalk and stem strength, improved flower formation and seed production, more uniform and earlier crop maturity, increased nitrogen fixing capacity of legumes, improvements in crop quality, and increased resistance to plant diseases.

Phosphorus (P) is vital to plant growth and is found in every living plant cell. It is involved in several key plant functions, including energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next. The total P concentration in agricultural crops generally varies from 0.1 to 0.5 percent.

When P is limiting, the most striking effects are a reduction in leaf expansion and leaf surface area, as well as the number of leaves. Shoot growth is more affected than root growth, which leads to a decrease in the shoot-root dry weight ratio. Nonetheless, root growth is also reduced by P deficiency, leading to less root mass to reach water and nutrients (Tisdale *et al.*, 1993).

Application of farmyard manure increased the activity of phosphatase enzymes which enhanced P availability (Bopaiah and Shetty, 1991). Singh and Neopaney (1993) also reported that application of 80 kg P_2O_5/ha resulted in greater plant height, maximum number of leaves and higher yield in ginger. Banwasi and Singh (2010) found that application of phosphorus @100 kg/ha resulted in better vegetative growth as well as higher yield of turmeric.

Latha *et al.* (1995) observed that maximum yield of fresh rhizomes (156.3 q/ha) was recorded with the application of 150 kg P/ha, followed by 149.2 and 147.9 q/ha rhizomes in the treatments receiving 100 and 200 kg P/ha in turmeric. Veeraraghavathatham *et al.* (1988) studied response of coleus to P levels and reported higher tuber yield at 60 kg P_2O_5 per hectare over control. Ravi (2004) also recorded higher growth, yield attributes and tuber yield by applying 60 kg P_2O_5 per hectare along with VAM.

3. Potassium

Potassium, unlike N, P and most other nutrients, does not form co-ordinated compounds in the plants. Instead, it exists solely as the K^+ ion, either in solution or bonded to negative charges such as organic radicals like the acid radical $-R\text{-}COO^-$. As a result of its strictly ionic nature K+ has functions particularly related to the ionic strength of solutions within plant cells (Tisdale *et al.*, 1993).

Potassium is actively taken up from the soil solution by plant roots. The concentration of K^+ in vegetative tissue usually ranges from 1-4% on dry matter basis. Thus plant requirements for available K are quite high. Potassium apparently does not form an integral part of any plant component and its function is catalytic in nature. It is essential for the physiological functions of carbohydrate metabolism and synthesis of proteins, control and regulation of activities of various essential mineral elements, neutralization of physiologically important organic acids, activation of various enzymes, promotion of the growth of meristemic tissue and adjustment of stomatal movement and water relations (Tisdale *et al*, 1993). It is also involved in imparting resistance to drought, frost, pest, diseases and physiological disorders (Balram *et al.*, 1977; Singh and Tripathi, 1979).

Potassium favours plant growth, dry matter partitioning, production of tuberous roots, tuber yield and quality in cassava (John *et al.*, 2006). Rajagopalan *et al.* (1989) reported higher uptake of potassium compared to N and P in *Kaempferia galanga.* FYM+NPK combination resulted in better growth of the crop and ultimately higher fresh rhizome yield in kacholam (Maheswarappa *et al.*, 2000). In tapioca, potassium deficiency led to reduced tuber growth and production of poor quality tubers (Susan *et al.*, 2006). Nair and Aiyer (1986) found improvement in starch and quality parameters of starch with increasing rate of K application in cassava. Higher doses of K reduced the cyanogenic glucoside content in cassava (Ramanujan and Indira, 1987). Akamine *et al.* (2007) observed that in turmeric, K is the principal element involved in curcumin formation. Application of K alone resulted in the highest curcumin content in rhizomes. Bahadur *et al.* (2000) reported that an increased in the rate of potassium resulted in an increasing trend in growth, dry matter production and yield of turmeric, and highest yield (15.4 t/ha) was obtained with 120 kg ha^{-1} K_2O. Veeraragavathatham *et al.* (1988) found response of *C. forskohlii* to K levels at Coimbatore and recorded higher fresh (21.19 t/ha) and dry (2.53 t/ha) tuber yield with the application of 50 kg K_2O per hectare over 0 and 100 kg K_2O per hectare.

Salimath (1990) reported that dry matter production, bulb size and bulb yield increased with the increase in level of K from 0 to 150 kg/ha in onion. Kumar *et al.* (2001) observed that in onion, with an increase in potassium application significantly increased dry weight of top and bulbs, bulb diameter, 100 bulb weight and bulb yield up to 40 kg K_2O/ha. Hossain *et al.* (2004) reported that in carrot, plants receiving 250 kg K/ha produced maximum root fresh weight (180g) and minimum (160.95g) was obtained in control. Increased level of K produced longer and thicker roots giving higher individual fresh weight of roots. Sarkar *et al.* (1989) also reported that the fresh weight of root increased with increased K in potato.

4. Calcium

Calcium is seen as a constituent of calcium pectate, which strengthens the cell wall. It maintains the turgidity of cell wall and promotes normal root growth and development.

Singh and Dwivedi (1993) concluded that maximum tuber yields (414.8 and 418.75 q/ha) were recorded when sulphur was applied through gypsum @ 2.68q/ha in potato. Dabhi *et al.* (2004) recorded, the higher values of yield parameters (plant height, number of leaves/plant, bulb diameter and bulb weight) and highest bulb yield (246.50 q/ha) with application of 30 kg S/ha in the form of gypsum followed by 20 kg S/ha in garlic .

5. Magnesium

Magnesium is an important part of chlorophyll, a critical plant pigment important in photosynthesis. It is important in the production of ATP through its role as an enzyme cofactor. Magnesium deficiency can result in interveinal chlorosis (Tisdale *et al.*, 1993).

Application of $MgSO_4$ at the stage of formation of rhizome, favoured the development of quantitative components in rhizomes of kacholam (Gangadharan, 2003). Bose *et al.* (2008) observed that increasing rates of sulphur and magnesium improved the yield and quality of turmeric. Results showed that inclusion of S and Mg in the fertilization schedule improved the fresh rhizome yield 26t/ha with 44 kg S/ha and 22 kg Mg/ha when applied along with recommended NPK dose. Kleiber *et al.* (2011) noticed that, Mg nutrition was found to have a positive effect on yield and quality, producing significantly higher total yield (485 kg/m^2) and increased yield by 45% in comparison with the control combination in onion.

6. Sulphur

Sulphur is recognised as the fourth major nutrient in addition to N, P and K. Hedge and Babu (2007) reported that sulphur ranks thirteenth in terms of abundance in the earth's crust and thus has limitation in agriculture all over the world. For optimum plant growth and yield, all the essential nutrients are required in appropriate quantities. Sulphur is needed for synthesis of coenzyme A, which is involved in oxidation and synthesis of amino acids and oxidation of intermediaries of the citric acid cycle. Sulphur deficiency symptoms are more often observed in crops at early stages of crop growth, because sulphur can be easily leached from the surface soil. Sulphur deficient plants had poor utilization of nitrogen, phosphorus and potassium and a significant reduction of catalase activity at all the ages (Nasreen *et al.*, 2003).

Sulphur application is known to reduce plant content of iron by reducing leaf sap pH and increasing chlorophyll content (Singh, 1970; Pillai, 1972). Increasing levels of S up to 40 kg/ha significantly enhanced all the growth parameters (number of tillers per plant, plant height and dry matter accumulation), spikes per plant, grains per spike, grain and straw yields and net returns compared to the control and 20 kg S/ha in isabgol (Yadav *et al.*, 2003). Thippeswamy (1993) studied the response of onion to four levels of sulphur *viz.*, 0, 20, 40 and 80 kg ha^{-1} and recorded highest plant height (53.69 cm) and maximum number of leaves (14.50) at 20 kg S ha^{-1}. However, highest bulb length (20.29 cm) and bulb yield (43.75 t/ha) were noticed in the treatment which received 40 kg S ha^{-1} and lowest bulb yield (34.60 t/ha) was noticed in control.

In onion, largest increases in plant height, fresh and dry herbage yields, and essential oil, can be attributed to the nitrogen supplied as ammonium sulfate (Nasreen *et al.*, 2003). Application of 20 kg S/ha increased significantly increased the herb and oil yield and uptake of S and P in spearmint compared to control (Chattopadhyay *et al.*, 2000).

Sulphur has a direct effect on soil properties as it may reduce soil pH which improves the availability of micronutrients such as Fe, Zn, Mn and Cu as well as crop yield and its related characteristics (Tantawy *et al.*, 2009).

c. Effect of nutrient interactions on yield and quality

Interaction has been defined as mutual or reciprocal influence of one element upon another in relation to plant growth and its differential response to one element in combination with varying levels of the second element. Two or more growth factors are said to interact when their individual influence is modified by the presence of one or more of the others. When factors in combination result in a growth response that is greater than the sum of their individual effects, interaction is positive and when the combined effect is less, the interaction is negative. In the former case the factors are synergistic, whereas in the latter they are antagonistic. Additivity indicates the absence of interaction. The highest yields are obtained where nutrient and other growth factors are in a favourable state of balance. As one moves away from this state of balance, nutrient antagonisms are reflected in reduced yields (Olsen, 1972).

N and P are the two nutrients accounting for a major share of the current annual fertilizer consumption (IFA, 2003). Tisdale *et al.* (1993) reported that nitrogen promotes phosphorus uptake by increasing top and root growth, altering plant metabolism and increasing the solubility and availability of P. Hussain *et al.* (2005) observed that in *Alpinia galanga* L., interaction of N (150 kg/ha) and P (120 kg/ha) resulted in maximum fresh rhizome yield per plant. Ravi (2004) observed that *Coleus forskohlii* grown under sandy loam soil recorded higher growth parameters (plant height, number of laterals, number of leaves and plant spread) and yield attributes (length and diameter of tuberous roots, fresh and dry weight of tuberous roots per plant) and tuberous root yield with 50 kg N plus 60 kg P_2O_5 per hectare along with VAM.

In addition to nitrogen, potassium is the major plant nutrient absorbed and removed by crops in the largest amounts among all essential nutrients. Wilson and Ovid (1993) stated that N and K increased the quality of young ginger rhizome and produced maximum fresh yield of rhizome. Haque *et al.* (2007) found that highest plant height, number of leaves, finger number, highest finger weight and rhizome yield were obtained at a combined application of N (180kg/ha) and K (100kg/ha) in ginger. Combination of N (210 kg/ha) and K (150 kg/ha) provided four to six times greater shoot biomass and eight to nine times higher yield. This combination was the best for promoting both yield and curcumin content of turmeric ((Akamine *et al.*, 2007). Sanyal and Dhar (2008) reported that in turmeric, highest yield and curcumin content were noted with a combination of mulching + application of nitrogen and potassium at 120 and 160 kg/ha. Suja *et al.* (2006) observed that in arrowroot, combined effect of N and K levels significantly affected fresh rhizome yield. Application of N at 50 kg/ha and K at 75 kg/ha resulted in higher rhizome yield, total dry matter production and harvest index. Tuber yield was found to increase with increase in the rates of N (200 kg/ha) and K (200 kg/ha) under irrigated conditions in cassava (Nagar, 1985).

Nitrogen and sulphur are involved in protein synthesis and play an important role in the protection of plants against nutrient stress, pests and in the synthesis of vitamins and chlorophyll in the cell. The interaction of nutrients is of great importance because decline in S supply from the atmosphere has already caused substantial losses of N from agro-ecosystems to the environment (Luit *et al.*, 1999). Optimum use of fertilizers containing sulphur improves utilisation of nutrients, especially nitrogen. Favourable influence of sulphur on nitrogen metabolism and mutual interactions between those two elements were reported by Fismes *et al.* (2000).

Sulphur deficiency can reduce N use efficiency and N deficiency can also reduce S-use efficiency. Plants grown without N fertilizer showed no apparent S stress, whereas plants receiving N fertilizer, particularly at higher rate without S, showed symptoms suggesting severe physiological disorder in N nutrition (Kopriva and Rennenberg, 2004). Kumar *et al.* (2004) stated that biomass, leaf area and quercetin content, as well as dry weight of shoots, protein content in the leaves, sulfur content in the stem and photosynthetic rate at 30, 45 and 60 days after treatment were highest with the combined application of 100 kg N/ha, 30% S and neem cake containing 20% urea in Pluchea.

Kumar and Singh (1994) observed that under sulphur deficient conditions, phosphorus in plants is not properly utilized and hence an increase in total phosphorus occurs. There exists a synergistic relationship between P and S at low level of S application and antagonistic relationship at higher level of S application in wheat (Randhawa and Arora, 2000). Singh *et al.* (2001) found that there was a gradual increase in P uptake with increasing levels of S upto 80 kg/ha. Sulphur uptake by tubers increased at higher levels of P in potato.

Jaggi *et al.* (1995) reported an increase in potassium concentration in linseed due to sulphur application. Sulphur has been reported to increase K absorption and productivity of oilseed crops by Daliparthy (1994). Chandrasekharan (1983) carried out an experiment to study the effect of application of S and K on the yield and quality of radish and carrot. Significant increase in the yield of radish was obtained due to sulphur and potassium application. Singh *et al.* (1995) recorded increased tuber yield, % dry matter and soluble protein in tubers due to the application of 150 kg K_2O and 50 kg S/ha in potato. Mondal *et al.* (1996) noticed that the application of S @ 20 kg/ha along with NPK treatment (60 kg N+30 kg P_2O_5+60 kg K_2O/ha) increased the yield of potato by 8.5% over other treatments. Lalitha *et al.* (1997) reported that the higher starch and protein contents were recorded in potato, with the application of K @ 125 kg/ha and S @ 24 kg/ha. The combined application also resulted in significantly higher tuber yield and higher grade tubers of potato over control.

Kumar and Singh (1994) observed an increase in total potassium in sulphur deficient plants of onion because of improper utilization of potassium. Hariyappa (2003) observed that application of 125 kg K_2O ha^{-1} plus 30 kg S ha^{-1} recorded significantly higher yield (25.45 t/ha) and TSS (12.83%) in onion. The same treatment combination recorded highest uptake of nutrients *viz.*, N, P, K and S at harvest. Similar result was also observed by Poornima (2007), where the yield parameters such as bulb diameter, bulb length and bulb weight were significantly higher in treatment receiving K (100 kg/ha) and S (30 kg/ha). Nandi *et al.* (2002) recorded highest bulb yield of onion with the application of K @ 180 kg/ha and S @ 60 kg/ha and post harvest shelf life qualities like sprouting %, rotting % and weight loss % were recorded as the lowest in this combination

Upadhyay and Patra (2011) observed the interaction effect of calcium and magnesium when applied at the rate of Ca 200 + Mg 200 mg pot^{-1} resulted in the maximum plant height (60.5 cm), number of branches per plant (70), number of flowers per plant (362), width of flower (2.66 cm), fresh weight of flower per plant (26.94 g) and oil content (1.10%) in chamomile. This combination also resulted in the best quality of oil with respect to chemical constituents. Akhtar *et al.* (2009) also obtained the same result in *Mentha piperata*.

Karthikeyan *et al.* (2010) observed that number of tillers per plant in turmeric increased significantly with increased rates of application of potassium and magnesium. The treatment receiving 20 kg of K_2O/ha and 20 kg of $MgSO_4$ recorded highest rhizome yield and tiller count. Curcumin content was also high (4.28 %) with this treatment.

A significant variation in yield per plant as well as yield per hectare was noticed with sulphur and magnesium application in carrot. Maximum yield of 13.6 t/ha was obtained with the application of 44 kg S/ha and 22 kg Mg/ha. Increase in S and Mg rates caused a sharp decline in yield of carrot but improved the yield and quality of turmeric (Bose *et al*, 2008). Results showed that inclusion of S and Mg in the fertilization schedule improved the fresh rhizome yield. A yield of 26 t/ha was obtained with 44 kg S/ha and 22 kg Mg/ha along with recommended NPK dose.

Plate 1. General view of the experimental field

Plate 2. Foliage spread in Kacholam

Plate 3. Harvested rhizomes

Materials and Methods

3. MATERIALS AND METHODS

The present investigation on "Nutrient management for yield and quality improvement in kacholam (*Kaempferia galanga* L.)" was carried out in the Department of Agronomy, College of Horticulture, Vellanikkara during the year 2010-2011. The materials used and the methodology adopted for the study are described in this chapter.

3.1 General details

Location

The experiment was carried out in the Water Management Research Unit (a sub-centre of the Agronomic Research Station, Chalakkudy) located at Vellanikkara.

Experimental site

The area is located at $10^0 32'$ N latitude and $76^0 10'$E longitude and at an altitude of 22.25 m above mean sea level.

Weather and climate

The area has humid tropical climate with more than 80 per cent of the rainfall distributed through south-west and north-east monsoon showers. Weather data are given in Fig 1 and 2.

Soil characters

The soil of the experimental site is sandy clay loam in texture, belonging to the order Ultisol. The soil is acidic in reaction with pH of 5.3. The physico-chemical characteristics of the soil of the experimental field are presented in Table1.

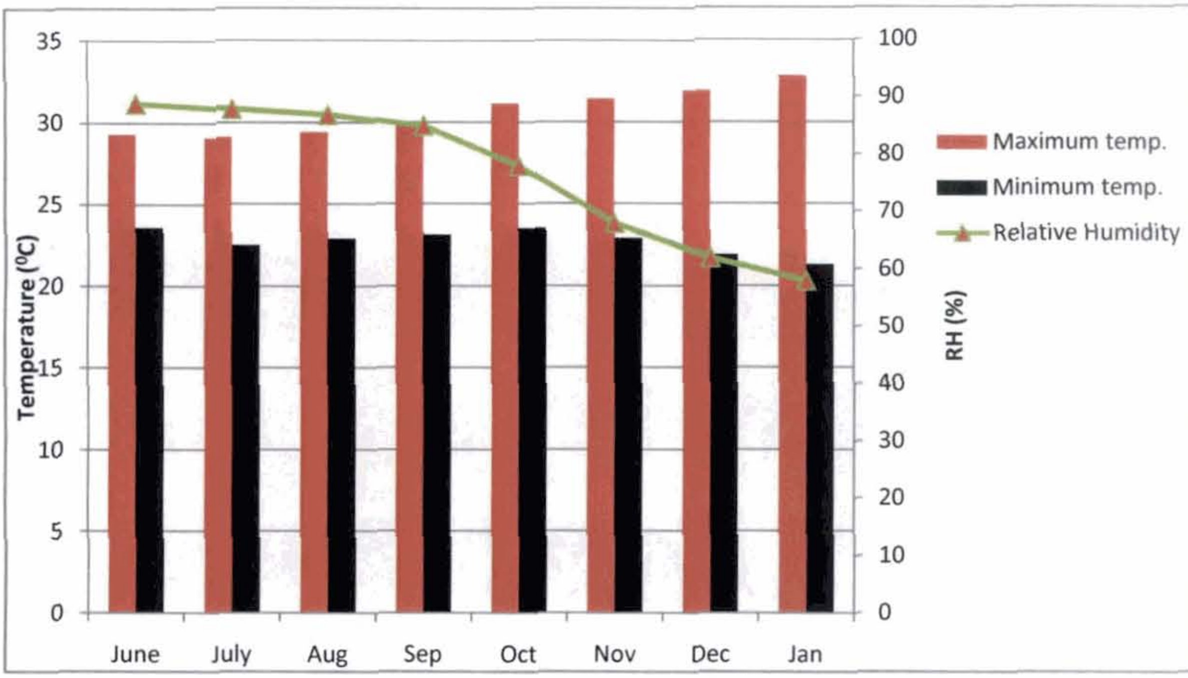

Fig.1. Temperature and relative humidity during the crop period at Vellanikkara,Thrissur

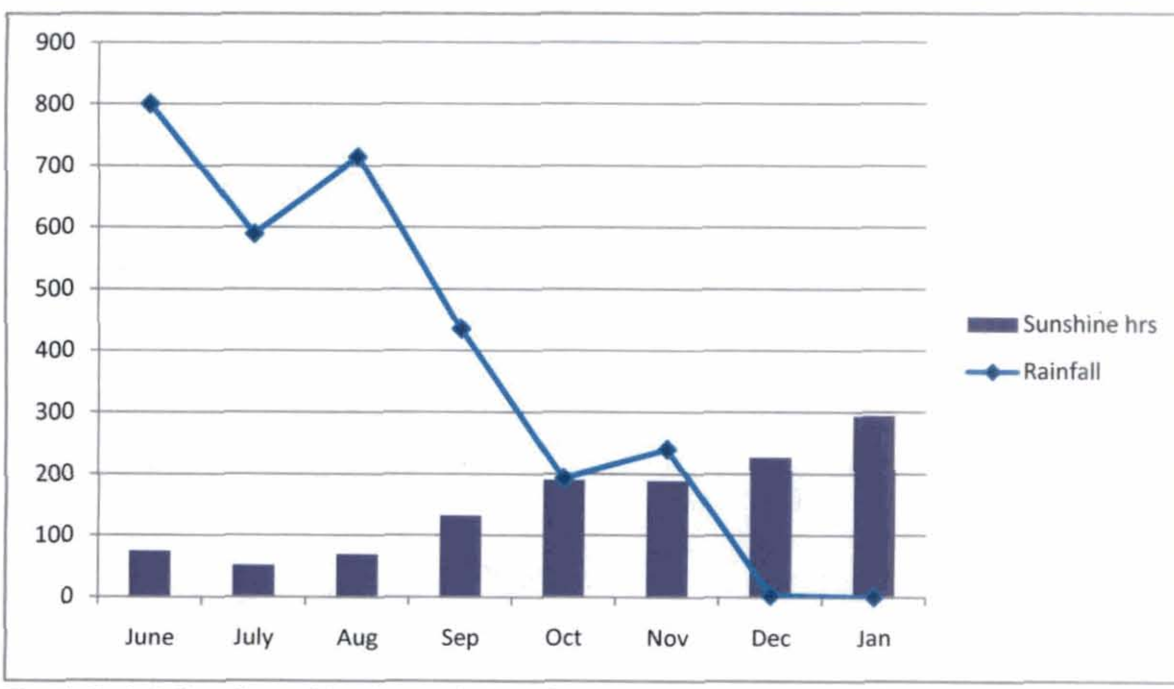

Fig. 2. Rainfall and sunshine hours during the crop period at Vellanikkara, Thrissur

Table 1. Physico-chemical properties of soil before the experiment

Particulars	**Value**
A. Particle size analysis	
Sand (%)	68.31
Silt (%)	18.14
Clay (%)	13.55
B. Chemical composition	
Organic carbon (%)	1.08
Available nitrogen (kg/ha)	756.00
Available phosphorus (kg/ha)	22.30
Available potassium (kg/ha)	356.00
Available sulphur (kg/ha)	21.03
Available calcium (kg/ha)	76.16
Available magnesium (kg/ha)	22.41
pH	5.3

3.2 Cropping history of the experimental site

The experimental site was a coconut garden, with 35 year old palms planted at a spacing of 7.5m x 7.5m. Kacholam was planted in the interspaces of coconut.

3.3 Details of experiment

The layout of the field experiment is given in Fig.3. The experiment was laid out in the interspaces of a coconut field in Randomised Block Design (RBD) with three replications. First two replications were iaid out as compact blocks. However, for the

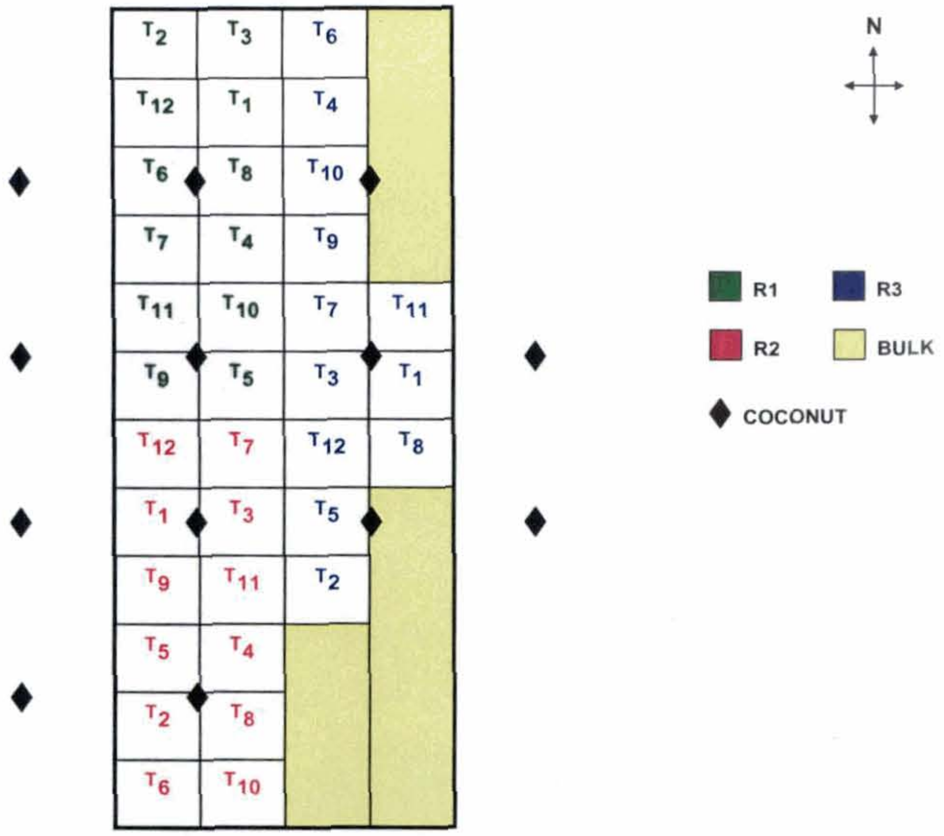

Fig. 3. Layout of the experiment

T1: 20t FYM /ha + POPR (50:50:50 kg NPK/ha)

T2: 10t FYM/ha + 50:50:50 kg NPK/ha

T3: POPR+ 20kg S as $(NH_4)_2SO_4$ (IMAP)

T4: POPR+ 20kg S as $(NH_4)_2$ SO_4(3MAP)

T5: 20t FYM+ 50:50:75 kg NPK/ha

T6: T5+ 20kg S as $(NH_4)_2SO_4$(1MAP)

T7: T5+ 20kg S as $(NH_4)_2SO_4$ (3MAP)

T8: POPR+ 20kg S as $CaSO_4$ (1MAP)

T9: POPR+ 20kg S as $MgSO_4$ (1MAP)

T10: 50:50:50kg NPK/ha

T11: FYM (20t/ha) alone

T12: Absolute control

third replication, a similar compact block was not available due to shade variation consequent to drying and death of palms. Hence the third replication was laid out as shown in the figure considering the availability of uniform shade to all the three replications. Considerable variation in soil fertility was not expected since the entire area of each replication was only 100 sq. meters. Planting was done on 3-06-2011. The variety used was Thodupuzha and the spacing adopted, 20 cm x 15 cm. Gross plot area was 8 m^2 and net plot area, 4.47 m^2. The experiment consisted of twelve treatments with different combinations of fertilizers. Treatments were applied one month and three months after planting. The first application was considered as basal application, applied after roots were established. Details are given in Table 2.

3.4 Field operations

The cultural operations were carried out as per the Package of Practices Recommendations (KAU, 2007)

Land preparation

The land was ploughed and leveled. Raised beds of 8.0 m length, 1.0 m width and 25 cm height were prepared using a bund former. Farmyard manure was applied at the time of bed formation as per treatment requirements.

Planting and fertilizer application

Planting was done during the month of May- June with the receipt of four to five pre-monsoon showers. Small pits were taken in the beds in rows at a spacing of 20 x15 cm. Rhizome bits were planted with a viable healthy bud facing upwards, at a depth of 4 to 5 cm and then covered with soil. Mulching was done immediately after planting with coconut leaves as per the farmers' practice. Weeding and earthing up were done twice, at 60 days and 90 days after planting. Fertilizers were applied in channels taken in between rows as per treatments. The crop was rainfed.

Harvesting

The crop was harvested during the second week of January, when yellowing and drying of leaves was observed in the field. Rhizome yield was recorded from each bed after removing the border row. Yields from the net plot areas were expressed in terms of tonnes per hectare.

Table 2. Treatments

Treatment	FYM/ha	NPK (kg/ha) applied 1 MAP*	NPK (kg/ha) applied 3 MAP
T1**	20 t	25:50:25	25:0:25
T2	10 t	25:50:25	25:0:25
T3	20 t	25:50:25+20 kg S as $(NH_4)_2SO_4$	25:0:25
T4	20 t	25:50:25	25:0:25+20 kg S as $(NH_4)_2SO_4$
T5	20 t	25:50:25	25:0:50
T6	20 t	25:50:25+20 kg S as $(NH_4)_2SO_4$	25:0:50
T7	20 t	25:50:25	25:0:50+20 kg S as $(NH_4)_2SO_4$
T8	20 t	25:50:25+20 kg S as $CaSO_4$	25:0:25
T9	20 t	25:50:25+20 kg S as $MgSO_4$	25:0:25
T10	–	25:50:25	25:0:25
T11	20 t	–	–
T12	–	Absolute control	–

* MAP – months after planting

**Package of practice recommendation

3.5 Field observations

Sampling technique

The border rows were avoided and six plants were selected from each plot and labeled for recording various morphological characters. Monthly observations for each morphological character were recorded from the same six plants and the mean values worked out.

Biometric observations

3.5.1 Number of shoots per plant

Total number of shoots produced per plant was recorded at monthly intervals from the six sample plants. The average was worked out for each plot.

3.5.2 Number of leaves per plant

Total number of leaves produced per plant was recorded at monthly intervals from the sample plants in each plot and the mean values were worked out.

3.5.3 Foliage spread

Spread of the plant was measured (using a scale) in two radial directions *viz.*, North-South and East-West and the means were recorded.

3.5.4 Fresh weight of rhizomes

Rhizomes were harvested from the net plot areas separately for each treatment and the yields were expressed on per hectare basis.

3.5.5 Dry weight of rhizomes and driage percentage

Rhizomes were chopped into small pieces and then dried to constant weight at 70^0C to 80^0C in a hot air oven. Dry rhizome yield per plot was calculated and expressed on per hectare basis. Driage was calculated from fresh and dry weight and expressed in percentage.

$$\text{Driage \%} = 100 - \frac{(\text{Fresh weight} - \text{Dry weight})}{\text{Fresh weight}}$$

3.6 Chemical analysis

3.6.1 Soil analysis

Initial and final status of nutrients in soil was estimated. Soil samples were collected and soil analysis was done for analyzing the status of major and secondary nutrients *viz.*, organic carbon, available N, P, K, S, Ca and Mg using the standard procedures as shown in Table 3.

Table 3. Methods used for chemical analysis of soil

Parameter	Method used	Reference
Soil texture	Robinson international pipette method	Piper (1942)
Soil pH	Soil - H_2O suspension in the ratio 1:2.5 read in pH meter	Jackson (1973)
Organic carbon (%)	Chromic acid wet digestion method	Walkley and Black (1934)
Available N	Alkaline permanganate method	Subbiah and Asija (1956)
Available P	Bray and Kurtz method	Bray and Kurtz (1945)
Available K	Neutral normal ammonium acetate extract using flame photometer	Jackson (1973)
Available S	$CaCl_2$ extract-turbidimetry method	Chesin and Yien (1951)
Exchangable Ca, Mg	EDTA titration	Page (1982)

3.6.2 Plant analysis

Major and secondary nutrients were estimated in leaves at 2 ½ MAP, 5 MAP and also from rhizomes at 5 MAP and at harvest. Destructive sampling was done to estimate the nutrient contents. For this, eight plants were kept aside at one end of the plot outside the net plot area and uprooted. At 5 MAP, nutrients were separately estimated inleaves and rhizomes, while at harvest, rhizomes alone were analysed. After uprooting, the plant parts were cleaned, dried in a hot air oven at 70-80^{0}C, powdered well and then analysed for major and secondary nutrients. The methods used for the analysis of different nutrients are given in Table 4.

Table 4. Methods used for chemical analysis of plant samples

Sl. No.	Nutrient	Digestion procedure	Method of estimation	Reference
1	N	H_2SO_4 digestion	Distillation and titration	Jackson (1973)
2	P	2:1 HNO_3:$HClO_4$ diacid digestion	Vanado-molybdate yellow colour method using spectrophotometer	Jackson (1973)
3	K	2:1 HNO_3:$HClO_4$ diacid digestion	Direct reading using flame photometer	Jackson (1973)
4	Ca and Mg	2:1 HNO_3:$HClO_4$ diacid digestion	Direct reading using atomic absorption spectrophotometer	Page (1982)
5	S	2:1 HNO_3:$HClO_4$ diacid digestion	Turbidimetric method using spectrophotometer	Williams and Steinberg (1959)

3.6.3 Chlorophyll content in leaf

Total chlorophyll content in the leaves was estimated at 2 ½ MAP and 5 MAP. The first fully opened leaves from top were selected as index leaves and were removed from the plants sampled for chemical analysis. For analysis, two grams of finely cut sample were taken in a beaker and 10 ml DMSO (dimethyl sulphoxide) solution was added. This was kept in a dark place overnight and the next day, made up to 25 ml in a volumetric flask after filtering. The chlorophyll content was read at two wavelengths, *i.e.*, 663 and 645 nm. Using the equations given below, chlorophyll a, chlorophyll b and total chlorophyll contents were estimated. Chlorophyll content of index leaves was estimated colorimetrically using spectrophotometer (Yoshida *et al.*, 1972).

Chlorophyll a = 12.7 X OD at 663nm-2.69 X OD at 645nm X V/1000 X W

Chlorophyll b = 22.9 X OD at 645nm-4.63 X OD at 663 nm X V/1000 X W

Total chlorophyll = (8.02 X A663) + (20.2 X A645) X V/1000 X W

3.6.4 Plant uptake of nutrients

Uptake of nutrients was estimated at 5 MAP and at harvest. Total uptake of nutrients was calculated as the product of the content of the nutrients and the plant dry weight and expressed in kilograms per hectare.

3.7 Quality attributes in kacholam

Qualitative components in kacholam estimated in the study were the oleoresin and essential oil.

3.7.1 Essential oil in rhizomes

Essential oil content of rhizomes was estimated by steam distillation adopting Clevenger trap method as per AOAC (1980) and expressed in percentage.

3.7.2 Oleoresin in rhizomes

The oleoresin content of rhizomes was estimated by Soxhlet extraction as per AOAC (1980) and expressed in percentage.

3.8 Statistical analysis

The data were subjected to analysis of variance using the statistical package MSTAT-C (Freed, 1986). Duncan's Multiple Range Test (DMRT) was used to compare means (Duncan, 1955; Gomez and Gomez, 1984).

Results

4. RESULTS

The results of the study on "Nutrient management for yield and quality improvement in kacholam (*Kaempferia galanga* L.)" conducted in the Department of Agronomy, College of Horticulture, Vellanikkara during the year, 2010-2011 are presented below.

4.1 Vegetative growth of kacholam

4.1.1 Number of leaves per plant

Data regarding the number of leaves per plant were observed at third, fourth, fifth, sixth and seventh month and are given in Table 5. In general, throughout the period of observation, there was an increase in number of leaves from the 3rd month to 6th month, and thereafter a decreasing trend was noticed. During third and fourth months after planting, highest number of leaves was observed in T_1 (POP). At 5 MAP (months after planting), treatments T_1 and T_4 recorded the highest number of leaves. Maximum number of leaves was observed at 6 MAP. At 6 MAP also the number of leaves was more in T_1, and was on par with T4. At 7 MAP, there was a decrease in number of leaves in all treatments and all the treatments from T_1 to T_9 were on par. During the entire period of observation, absolute control recorded significantly lower number of leaves.

4.1.2 Number of shoots per plant

The data pertaining to the number of shoots per plant are given in Table 6. In general the trend was similar to that of number of leaves. At 3 MAP, there was no significant difference in number of shoots between treatments. At 4 MAP, highest number of leaves was observed when S was applied as second top dressing at 3 MAP (T_4). At 5 MAP, treatments T_1 (POP), T_2 (POP less 10 t FYM) and T_7, where extra dose of K was top dressed along with S at 3 MAP showed the highest number of shoots, and were on par with T_8 and T_9 and T_4, in which S and Ca were applied as first and second top dressings. During 6 MAP, all the treatments from T_1 to T_{10}, except T_5, T_6 and T_7 showed highest number of leaves. At 7 MAP there was a decrease in number of shoots in all treatments. At this stage, treatments T_3, T_4, T_8 and T_9 which received S as first and second top dressing and T_7, where extra dose of K was top dressed along with sulphur, showed the highest number of shoots. In all months of observation the lowest number of shoots was observed in absolute control.

Table 5. Number of leaves/plant as influenced by nutrient management in Kacholam

Treatment No.	Treatment	Stage of growth				
		3MAP	4MAP	5MAP	6MAP	7MAP
1	POP	8^{a*}	11^{a}	14^{a}	17^{a}	12^{a}
2	POP less 10 t FYM	6^{ab}	8^{ab}	13^{ab}	15^{abc}	12^{a}
3	POP+ S- 1 MAP	7^{ab}	10^{ab}	12^{ab}	16^{ab}	12^{a}
4	POP+ S- 3 MAP	7^{ab}	10^{ab}	14^{a}	17^{a}	12^{a}
5	POP+ K- 3 MAP	7^{ab}	10^{ab}	11^{ab}	14^{abc}	12^{a}
6	POP+K+S-1 MAP	6^{ab}	9^{ab}	11^{ab}	14^{abc}	12^{a}
7	POP+K+S-3 MAP	5^{b}	9^{ab}	11^{ab}	14^{abc}	12^{a}
8	POP+ S + Ca	6^{ab}	10^{ab}	12^{ab}	14^{abc}	12^{a}
9	POP+ S + Mg	7^{ab}	10^{ab}	11^{ab}	14^{abc}	12^{a}
10	50:50:50 kg N, P,K	6^{ab}	9^{ab}	11^{ab}	13^{abc}	10^{ab}
11	FYM alone	7^{ab}	9^{ab}	11^{ab}	12^{bc}	9^{ab}
12	Absolute control	5^{b}	8^{b}	9^{b}	11^{c}	7^{b}

*In a column, means superscribed by common letters do not differ significantly at 5% level by Duncan's Multiple Range Test (DMRT)

Table 6. Number of shoots/plant as influenced by nutrient management in Kacholam

Treatment No.	Treatment	Stage of growth				
		3MAP	4MAP	5MAP	6MAP	7MAP
1	POP	2.67[a*]	3.33[ab]	3.67[a]	3.33[a]	2.33[ab]
2	POP less 10 t FYM	2.33[a]	2.67[bcd]	3.67[a]	3.33[a]	2.67[ab]
3	POP+ S-1 MAP	2.00[a]	3.00[abc]	3.00[ab]	3.33[a]	3.00[a]
4	POP+ S-3 MAP	2.00[a]	3.67[a]	3.33[a]	3.33[a]	3.00[a]
5	POP+ K-3 MAP	2.33[a]	2.67[bcd]	2.67[ab]	3.00[ab]	2.33[ab]
6	POP+K+S-1 MAP	2.33[a]	3.00[abc]	3.00[ab]	3.00[ab]	2.67[ab]
7	POP+K+S-3 MAP	2.00[a]	3.00[abc]	3.67[a]	3.00[ab]	3.00[a]
8	POP+ S + Ca	2.33[a]	2.33[cd]	3.33[a]	3.33[a]	3.00[a]
9	POP+ S + Mg	2.33[a]	3.00[abc]	3.33[a]	3.33[a]	3.00[a]
10	50:50:50 kg N,P,K	2.33[a]	2.33[cd]	2.67[ab]	3.33[a]	2.33[ab]
11	FYM alone	2.00[a]	2.00[d]	3.00[ab]	2.33[ab]	2.00[b]
12	Absolute control	2.00[a]	2.00[d]	2.00[b]	2.00[b]	2.00[b]

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.1.3 North-South foliage spread per plant

Data pertaining to the foliage spread (N-S) in different treatments of kacholam at different stages are presented in Table 7. Foliage spread (N-S) gradually increased and was maximum at 6 MAP and showed a decreasing trend from 7 MAP onwards, when the leaves started to dry. At 3 MAP, maximum foliage spread was observed when S and additional dose of K were top dressed 1 MAP (T_6). The least was recorded by T_{12} (absolute control), which was on par with T_{11}, in which only FYM was applied. At 4 MAP, maximum leaf spread were recorded in T_1 (POP) and that receiving S as second top dressing (T_4), which were on par with T_7, where extra dose of K and S were top dressed 3 MAP and in T_9, where S and Mg was applied as first top dressing. During 5 MAP also, T_1 and T_7 attained the maximum foliage spread. At 6 MAP, T_4 and T_7 recorded the maximum foliage spread and T_{12} recorded the least foliage spread at all stages of growth. Treatment T_7 recorded the highest foliage spread in all months except the initial month and the maximum foliage spread of 24.45 cm was recorded at 6 MAP. In 7 MAP, T_4 still showed the maximum foliage spread. The least was in absolute control.

Table 7. North South foliage spread per plant (cm) as influenced by nutrient management

Treatment No.	Treatment	Stage of growth				
		3MAP	4MAP	5MAP	6MAP	7MAP
1	POP	16.78^{ab*}	22.87^{a}	23.74^{a}	23.65^{ab}	18.52^{ab}
2	POP less 10 t FYM	15.69^{ab}	21.75^{ab}	21.18^{abc}	21.96^{ab}	19.78^{ab}
3	POP+ S-1 MAP	16.69^{ab}	22.32^{ab}	21.77^{ab}	23.32^{ab}	20.85^{ab}
4	POP+ S-3 MAP	17.12^{ab}	23.05^{a}	22.36^{ab}	24.24^{a}	23.07^{a}
5	POP+ K-3 MAP	14.66^{b}	21.86^{ab}	18.13^{cd}	22.56^{ab}	20.56^{ab}
6	POP+K+S-1 MAP	18.04^{a}	21.08^{ab}	19.95^{bcd}	21.68^{ab}	21.11^{ab}
7	POP+K+S-3 MAP	17.13^{ab}	24.18^{a}	23.57^{a}	24.45^{a}	20.34^{ab}
8	POP+ S + Ca	14.74^{b}	22.29^{ab}	19.27^{bcd}	22.42^{ab}	18.31^{ab}
9	POP+ S + Mg	17.02^{ab}	23.57^{a}	21.04^{abc}	23.51^{ab}	18.94^{ab}
10	50:50:50 kg N,P,K	16.75^{ab}	21.48^{ab}	19.65^{bcd}	22.29^{ab}	21.71^{ab}
11	FYM alone	14.77^{b}	21.13^{ab}	20.98^{abc}	20.76^{bc}	19.15^{ab}
12	Absolute control	14.19^{b}	19.28^{b}	17.62^{d}	18.52^{c}	17.76^{b}

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.1.4 East-West foliage spread per plant

Table 8. shows the foliage spread of kacholam in E-W direction. From the table it could be observed that among the treatments, T_7 in which S and K were top dressed at 3 MAP, resulted in more foliage spread up to 6 months after planting. At 3 MAP, there was no significant difference in foliage spread among treatments. In general there was an increase in the foliage spread up to 6 MAP. At 6 MAP, maximum foliage spread was observed in treatments T_9, T_7 and T_4 where S along with extra doses of Mg and K and S alone were top dressed at 1 MAP and 3 MAP, and thereafter it decreased. At 7 MAP, the highest foliage spread was recorded in T_3, where S was applied as first top dressing, which was on par with T_9, in which S was applied as $MgSO_4$ and T_2 (POP less 10 t FYM). At all stages, lowest values were recorded in the control plot.

Table 8. East-West foliage spread per plant (cm) as influenced by nutrient management

Treatment No.	Treatment	Stage of growth				
		3MAP	4MAP	5MAP	6MAP	7MAP
1	POP	18.24[a*]	24.45[a]	24.68[ab]	25.51[ab]	21.45[ab]
2	POP less 10 t FYM	16.30[a]	22.37[abc]	21.62[cd]	25.18[ab]	22.32[a]
3	POP+ S-1 MAP	17.52[a]	23.00[ab]	21.75[bcd]	25.60[ab]	23.61[a]
4	POP+ S-3 MAP	18.97[a]	23.76[ab]	23.42[abc]	26.21[a]	21.48[ab]
5	POP+ K-3 MAP	15.99[a]	21.95[abc]	19.92[de]	24.83[ab]	20.06[ab]
6	POP+K+S-1 MAP	19.58[a]	23.41[ab]	21.62[bcd]	25.12[ab]	21.66[ab]
7	POP+K+S-3 MAP	18.86[a]	24.18[a]	25.95[a]	26.44[a]	21.88[ab]
8	POP+ S + Ca	18.16[a]	23.44[ab]	22.26[bcd]	24.48[ab]	20.35[ab]
9	POP+ S + Mg	19.49[a]	24.63[a]	22.76[bcd]	27.25[a]	22.65[a]
10	50:50:50 kg N, P,K	16.91[a]	21.26[bc]	21.69[bcd]	24.80[ab]	21.78[ab]
11	FYM alone	16.80[a]	22.74[ab]	21.41[cd]	22.57[bc]	19.62[ab]
12	Absolute control	15.95[a]	20.05[c]	17.89[e]	20.21[c]	16.35[b]

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.1.5. Dry matter accumulation

Dry matter accumulation was recorded at 2 ½ MAP and 5 MAP. At 2 ½ MAP, dry matter was more in the treatment top dressed with S as $MgSO_4$ (T_9), which was on par with T_2 (POP less 10 t FYM), followed by T_3, where S was applied along with first top dressing (Table 9). It was observed that when S alone was applied as first top dressing, dry matter accumulation was more, but when an extra dose of K was top dressed along with S, dry matter accumulation decreased. At 5 MAP, all the treatments, from T_1 to T_9

were on par except in T_5, where an extra dose of K was top dressed at 3 MAP. T_{10}, in which only fertilizers were applied, and T_{11}, in which only FYM was applied, resulted in lower dry matter production. The least was in control (T_{12}).

Table 9. Dry matter accumulation as influenced by nutrient management

Treatment No.	Treatment	Dry matter (kg/ha)	
		2 ½ MAP	5 MAP
1	POP	850^{bcd*}	2622^{a}
2	POP less 10 t FYM	1083^{a}	2428^{a}
3	POP+ S-1 MAP	1017^{ab}	2389^{a}
4	POP+ S-3 MAP	833^{bcd}	2361^{a}
5	POP+ K-3 MAP	866^{bcd}	1917^{b}
6	POP+K+S-1 MAP	644^{ef}	2617^{a}
7	POP+K+S-3 MAP	761^{cde}	2500^{a}
8	POP+ S + Ca	944^{abc}	2417^{a}
9	POP+ S + Mg	1122^{a}	2322^{a}
10	50:50:50 kg N, P, K	749^{de}	1744^{bc}
11	FYM alone	566^{f}	1400^{cd}
12	Absolute control	516^{f}	1350^{d}

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.2 Rhizome yield and quality components

4.2.1 Fresh rhizome yield

Data on fresh and dry yields of kacholam at harvest are presented in Table 10. Harvest was done seven months after planting. Fresh and dry rhizome yields showed significant difference between the treatments. T_3, in which S was applied as first top dressing along with package of practice recommendation, and T_9, where Mg was also top dressed, recorded the highest rhizome yield (8.56 and 8.24 t/ha) and the yields obtained from these plots were about 47% more than control plot. There treatments were on par with T_4 and T_8, where S was given as second top dressing alone and along with Ca as first top dressing. But when an extra dose of K was top dressed along with S at 1 MAP and 3 MAP (T_6 and T_7 respectively), the yield was reduced (5.80 and 5.99 t/ha), while absolute control recorded the lowest yield. There was no significant difference between treatments with respect to driage per cent.

Table 10. Yield of rhizome as influenced by nutrient management in kacholam

Treatment No.	Treatment	Fresh yield (t/ha)	Dry yield (t/ha)	Driage (%)
1	POP	5.94[bc*]	2.08[bc]	35.09[a]
2	POP less 10 t FYM	6.28[b]	2.21[b]	35.20[a]
3	POP+ S-1 MAP	8.56[a]	2.84[a]	33.21[a]
4	POP+ S-3 MAP	8.19[a]	2.87[a]	35.06[a]
5	POP+ K-3 MAP	5.84[bc]	2.04[bc]	34.97[a]
6	POP+K+S-1 MAP	5.80[bc]	2.04[bc]	35.11[a]
7	POP+K+S-3 MAP	5.99[b]	2.09[bc]	34.89[a]
8	POP+ S + Ca	7.64[a]	2.68[a]	35.07[a]
9	POP+ S + Mg	8.24[a]	2.89[a]	35.09[a]
10	50:50:50 kg N,P,K	5.57[bcd]	2.04[bc]	36.69[a]
11	FYM alone	4.74[cd]	1.66[cd]	35.08[a]
12	Absolute control	4.43[d]	1.55[d]	35.09[a]

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.2.2 B:C ratios

Comparing B:C ratios between treatments, reducing organic manure to half did not show any decrease in yield as compared to POP recommendations, instead, increase in B:C ratio was observed. Highest B:C ratio was observed in treatment receiving S alone and S along with Mg and having high yields. High B:C ratio of 2.5 was observed in treatments T_3, T_4 and T_9, where yields were also high.

Table 11. B:C ratios as influenced by nutrient management

Treatment No	Treatments	Cost (Rs.)	Benefit (Rs.)	B:C ratio
1	POP	2,41,100	4,37,200	1.8
2	POP less 10 t FYM	2,21,100	4,64,500	2.1
3	POP+ S-1 MAP	2,41,100	5,96,820	2.5
4	POP+ S-3 MAP	2.41,100	6,03,120	2.5
5	POP+ K-3 MAP	2,41,592	4,28,820	1.8
6	POP+K+S-1 MAP	2,41,592	4,28,820	1.8
7	POP+K+S-3 MAP	2,41,592	4,39,320	1.8
8	POP+ S + Ca	2,42,300	5,63,220	2.3
9	POP+ S + Mg	2,42,900	6,07,320	2.5
10	50:50:50 kg N, P, K	2,01,100	4,28,820	2.1
11	FYM alone	2,37,100	3,49,020	1.5
12	Absolute control	1,97,100	3,25,920	1.5

4.2.3 Essential oil and oleoresin content

Data regarding oil and oleoresin are given in Table 12. Oleoresin content of rhizomes ranged from 2.07 to 3.07 per cent. There was significant difference among different treatments. Oleoresin contents were more in T_3 and T_4, which received S as first and second top dressing, and were on par with T_1 (POP), followed by T_{10}, where fertilizers alone were applied. When an extra dose of K was top dressed along with S, oleoresin content decreased. The lowest content was in absolute control. In essential oil content also, T_4 showed the highest value, followed by T_9, T_8, T_{10} and T_3. The lowest content of both oleoresin and essential oil were in T_{12} (control).

Table 12. Oleoresin and oil content in rhizomes as influenced by nutrient management

Treatment No.	Treatment	Oleoresin (%)	Essential oil (%)
1	POP	3.00[a*]	0.80[b]
2	POP less 10 t FYM	2.53[bc]	0.80[b]
3	POP+ S-1 MAP	3.07[a]	1.08[ab]
4	POP+ S-3 MAP	3.07[a]	1.49[a]
5	POP+ K-3 MAP	2.40[cd]	0.96[b]
6	POP+K+S-1 MAP	2.50[c]	0.96[b]
7	POP+K+S-3 MAP	2.43[cd]	0.93[b]
8	POP+ S + Ca	2.37[cd]	1.13[ab]
9	POP+ S + Mg	2.33[cd]	1.26[ab]
10	50:50:50 kg N, P, K	2.87[ab]	1.10[ab]
11	FYM alone	2.40[cd]	0.80[b]
12	Absolute control	2.07[d]	0.80[b]

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.3 Elemental composition in leaves and rhizomes

4.3.1 Content of major nutrients in leaves

Major nutrient contents of leaves at 2 ½ MAP and 5 MAP are given in Table 13. In general, N content was more in 5 MAP compared to 2 ½ MAP. At 2 ½ MAP, content of N in leaves ranged from 0.96 to 1.69 per cent, but at 5 month's stage, the content ranged from 1.10 to 1.94. Nitrogen content was found to be higher in T_5 (1.69%) at 2 ½ MAP, where extra dose of K was given as second top dressing. But the content decreased at 5 MAP. At 5 MAP, treatment receiving POP recommendation (T_1) recorded highest content of N, followed by T_3, where S was given as first top dressing. At both months the lowest values were in absolute control.

At 2 ½ MAP, highest P content was in T_1 (0.31%). Content of P in leaves ranged from 0.15 to 0.31 per cent. But at 5 MAP, P content was more in T_4 (0.28%), when S was applied as second top dressing. The least content was in absolute control.

At 2 ½ MAP, K content was more in T_5 (2.93%), where extra dose of K was given as second top dressing and this was on par with T_7 (2.92%), in which, extra dose of K along with S was given as second top dressing. Compared to 2 ½ MAP, K content increased at 5 MAP except in T_{11}, T_{12} and T_9. At 5 MAP, K content was significantly higher in T_5 and T_7 (3.15%). K contents were lowest in T_{12}.

4.3.2 Contents of secondary nutrients in leaves as influenced by nutrient management

Secondary nutrient contents of leaves at 2 ½ MAP and 5 MAP are given in Table 14. Treatments T_6 and T_7, in which a higher dose of K was top dressed along with S, at 1 MAP and 2 ½ MAP, showed higher S content as compared to other treatments at 2 ½ MAP. Content of S was less at 5 MAP compared to 2 ½ MAP. At 5 MAP, S content was more in T_3 (0.17 %) where S was applied as first top dressing and this was on par with T_6, where K was supplemented along with S. At both stages, the lowest contents were in T_{11} (FYM alone) and T_{12} (absolute control).

At 2 ½ MAP, Ca content was highest in T_8, wherein Ca was applied as first top dressing; the content was 57% more than in the control plot. At 5 MAP, Ca content was higher compared to 2 ½ MAP and was highest in T_8. The contents of Ca were least in T_{12}. Comparing Mg contents in the two periods of observation, the content was more at 5 MAP. At 2 ½ MAP, Mg content was highest in T_9, which received Mg as first top dressing. But at 5 MAP, content was more in T_5, where extra K was applied as second top dressing and the treatment where Ca was applied was significantly inferior. The content was lowest in absolute control

Table 13. Contents of major nutrients in leaves as influenced by nutrient management

Treatment No.	Treatment	N (%)		P (%)		K (%)	
		2 ½ MAP	5 MAP	2 ½ MAP	5 MAP	2 ½ MAP	5 MAP
1	POP	1.56[ab*]	1.94[a]	0.31[a]	0.24[abcd]	2.67[ab]	2.78[abc]
2	POP less 10 t FYM	1.60[ab]	1.75[bc]	0.24[b]	0.22[bcd]	2.42[ab]	2.68[bc]
3	POP+ S-1 MAP	1.26[cd]	1.88[ab]	0.26[b]	0.25[abcd]	2.68[ab]	2.76[bc]
4	POP+ S-3 MAP	1.48[abc]	1.69[bcd]	0.25[b]	0.28[a]	2.53[ab]	2.71[bc]
5	POP+ K-3 MAP	1.69[a]	1.58[cd]	0.25[b]	0.27[ab]	2.93[a]	3.15[a]
6	POP+K+S-1 MAP	1.44[abc]	1.64[cd]	0.23[b]	0.26[abc]	2.34[ab]	2.88[ab]
7	POP+K+S-3 MAP	1.39[bc]	1.75[bc]	0.24[b]	0.25[abcd]	2.92[a]	3.15[a]
8	POP+ S + Ca	1.60[ab]	1.62[cd]	0.25[b]	0.23[bcd]	2.52[ab]	2.99[ab]
9	POP+ S + Mg	1.38[bc]	1.52[d]	0.24[b]	0.22[cd]	2.74[ab]	2.42[ab]
10	50:50:50 kg N,P,K	1.08[d]	1.23[e]	0.21[b]	0.19[cd]	2.31[ab]	2.45[c]
11	FYM alone	1.08[d]	1.21[e]	0.17[c]	0.19[ab]	2.50[ab]	2.07[d]
12	Absolute control	0.96[e]	1.10[e]	0.15[c]	0.17[abcd]	2.20[b]	1.88[d]

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

Table 14. Contents of secondary nutrients in leaves as influenced by nutrient management

Treatment No.	Treatment	S (%)		Ca (%)		Mg (%)	
		2 ½ MAP	5 MAP	2 ½ MAP	5 MAP	2 ½ MAP	5 MAP
1	POP	0.17^{de*}	0.14^{cd}	0.29^{c}	0.58^{b}	0.11^{bc}	0.32^{c}
2	POP less 10 t FYM	0.16^{ef}	0.13^{d}	0.23^{e}	0.57^{b}	0.09^{c}	0.24^{f}
3	POP+ S-1 MAP	0.19^{bc}	0.17^{a}	0.31^{c}	0.57^{b}	0.10^{bc}	0.27^{de}
4	POP+ S-3 MAP	0.20^{ab}	0.15^{bc}	0.24^{e}	0.58^{b}	0.10^{bc}	0.34^{b}
5	POP+ K-3 MAP	0.18^{cde}	0.12^{de}	0.28^{d}	0.57^{b}	0.11^{bc}	0.36^{a}
6	POP+K+S-1 MAP	0.21^{a}	0.18^{ab}	0.24^{e}	0.59^{b}	0.10^{bc}	0.31^{c}
7	POP+K+S-3 MAP	0.22^{a}	0.15^{bc}	0.33^{b}	0.53^{bc}	0.11^{bc}	0.32^{c}
8	POP+ S + Ca	0.19^{bc}	0.14^{cd}	0.40^{a}	0.67^{a}	0.12^{b}	0.30^{c}
9	POP+ S + Mg	0.18^{bcd}	0.15^{bc}	0.27^{e}	0.56^{b}	0.18^{a}	0.32^{c}
10	50:50:50 kg N,P,K	0.15^{fg}	0.10^{ef}	0.20^{f}	0.55^{b}	0.10^{bc}	0.27^{d}
11	FYM alone	0.13^{g}	0.09^{f}	0.19^{g}	0.53^{b}	0.11^{bc}	0.25^{ef}
12	Absolute control	0.13^{g}	0.09^{f}	0.17^{g}	0.47^{c}	0.08^{d}	0.22^{g}

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.4. Nutrient contents in rhizomes of kacholam as influenced by nutrientmanagement

4.4.1. Contents of major nutrients in rhizomes

N contents in rhizomes at 5 MAP and at harvest are given in Table 15. At 5 MAP, T_5 (in which extra K was top dressed) showed the highest N content, and was on par with T_{10}, where only fertilizer was applied, followed by all other treatments except T_{11} (FYM alone). At harvest, the treatment receiving fertilizer alone (T_{10}) had the highest N content. Lowest values for N content were registered in absolute control and T_{11}, where only FYM alone was applied. At 5 MAP, P content in rhizomes was not significantly different among treatments. At harvest, P content was more in T_4 (0.24%), in which S was applied as second top dressing along with package of practice recommendation, and was on par with T_1 (0.23%). All other treatments except T_6 recorded values on par with one another. In most of the treatments, there was not much difference in P content between the two stages, that is, at 5 MAP and harvest. With regard to K content, there was no significant difference between treatments at 3 MAP. There was no difference in K content of rhizomes at 5 MAP and at harvest except in T_4 and T_5. At harvest, K content was more in T_7 (which was top dressed with a higher dose of K along with S at 3 MAP) but the content was the same as that at 5 MAP and was on par with all treatments from T_1 to T_6.

Table 15. Content of major nutrients in rhizomes as influenced by nutrient management

Treatment No.	Treatment	N (%)		P (%)		K (%)	
		5 MAP	Harvest	5 MAP	Harvest	5 MAP	Harvest
1	POP	1.17[ab*]	1.92[ab]	0.23[a]	0.23[a]	1.74[a]	1.74[ab]
2	POP less 10 t FYM	1.16[ab]	1.92[ab]	0.20[a]	0.21[ab]	1.65[a]	1.65[ab]
3	POP+ S-1 MAP	1.16[ab]	1.76[abc]	0.19[a]	0.21[ab]	1.67[a]	1.67[ab]
4	POP+ S-3 MAP	1.11[ab]	1.92[ab]	0.22[a]	0.24[a]	1.93[a]	1.81[ab]
5	POP+ K-3 MAP	1.35[a]	1.69[abc]	0.20[a]	0.21[ab]	1.84[a]	1.86[ab]
6	POP+K+S-1 MAP	1.05[ab]	1.71[abc]	0.13[a]	0.15[b]	1.76[a]	1.76[ab]
7	POP+K+S-3 MAP	1.11[ab]	1.81[ab]	0.15[a]	0.15[b]	2.11[a]	2.11[a]
8	POP+ S + Ca	1.11[ab]	1.62[abc]	0.20[a]	0.20[ab]	1.34[a]	1.34[b]
9	POP+ S + Mg	1.23[ab]	1.92[ab]	0.18[a]	0.18[ab]	1.44[a]	1.44[b]
10	50:50:50 kg N,P,K	1.28[a]	1.98[a]	0.18[a]	0.18[ab]	1.42[a]	1.42[b]
11	FYM alone	0.99[b]	1.56[bc]	0.16[a]	0.18[ab]	1.39[a]	1.39[b]
12	Absolute control	1.05[ab]	1.38[c]	0.16[a]	0.16[ab]	1.42[a]	1.42[b]

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.4.2 Contents of secondary nutrients in rhizomes as influenced by nutrient management

At 5 MAP, when rhizomes were in the initial stage of development, S content was less compared to rhizomes at harvest. At 5 MAP, the content was highest in T_7 (0.19%), where K and S were applied as second top dressing, followed by T_8 (0.13%), in which S and Ca were top dressed. At harvest, T_3, where S was top dressed at 1 MAP showed the highest S content (0.31%), and increase was 58% compared to S at 5 MAP. T_4, in which S was applied as second top dressing registered the second highest values for S content in rhizomes. T_3 was significantly superior to all other treatments, with respect to S content.

At 5 MAP, the highest Ca content was in T_8, the treatment receiving Ca and S as first top dressing, and was on par with T_5, where extra K was top dressed at 3 MAP. At harvest, Ca content was highest in this treatment (T_5), and T_8 was on par.

Magnesium content was generally less in rhizomes at harvest compared to rhizomes at 5 MAP. At 5 MAP, Mg content was more in the treatment receiving S top dressing at 3 MAP (T_4), and in T_1 (POP). At harvest, Mg showed highest value of 0.23% in T_5, where extra dose of K was top dressed and in T_3 where S was top dressed at 1 MAP. Mg content was least in absolute control.

Table 16. Contents of secondary nutrients in rhizomes as influenced by nutrient management

Treatment No.	Treatment	S (%)		Ca (%)		Mg (%)	
		5 MAP	Harvest	5 MAP	Harvest	5 MAP	Harvest
1	POP	0.10^{def*}	0.22^{d}	0.30^{def}	0.39^{de}	0.27^{a}	0.20^{c}
2	POP less 10 t FYM	0.10^{def}	0.22^{d}	0.27^{ef}	0.33^{e}	0.21^{d}	0.21^{bc}
3	POP+ S-1 MAP	0.13^{bc}	0.31^{a}	0.33^{de}	0.38^{de}	0.23^{c}	0.23^{a}
4	POP+ S-3 MAP	0.12^{bcd}	0.28^{b}	0.33^{de}	0.43^{cd}	0.27^{a}	0.20^{bc}
5	POP+ K-3 MAP	0.10^{def}	0.24^{d}	0.45^{ab}	0.59^{a}	0.24^{bc}	0.23^{a}
6	POP+K+S-1 MAP	0.11^{cde}	0.27^{c}	0.40^{bc}	0.50^{bc}	0.23^{c}	0.19^{cd}
7	POP+K+S-3 MAP	0.19^{a}	0.26^{c}	0.35^{cd}	0.42^{cd}	0.24^{bc}	0.19^{cd}
8	POP+ S + Ca	0.13^{b}	0.22^{d}	0.47^{a}	0.53^{ab}	0.25^{ab}	0.21^{bc}
9	POP+ S + Mg	0.12^{bcd}	0.19^{e}	0.32^{de}	0.38^{de}	0.24^{bc}	0.22^{ab}
10	50:50:50 kg N,P,K	0.10^{def}	0.17^{f}	0.32^{de}	0.42^{cd}	0.25^{ab}	0.21^{bc}
11	FYM alone	0.09^{g}	0.16^{fg}	0.29^{def}	0.41^{cde}	0.23^{c}	0.18^{de}
12	Absolute control	0.08^{fg}	0.15^{g}	0.25^{f}	0.33^{e}	0.23^{cd}	0.16^{e}

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.5. Uptake of nutrients

4.5.1 Uptake of different nutrients at 5 MAP in leaves as influenced by nutrient management

Uptake of different nutrients was also estimated at 5 MAP in leaves and the data are presented in Table 16. Highest nitrogen uptake of 28.48 kg/ha was noticed in T_1 (POP) and was followed by the treatment where S was top dressed 3 MAP (T_4), T_6 (where K and S were top dressed 1 MAP), and T_2 (POP less 10 t FYM). Treatments T_6 and T_4, in which S was top dressed with and without an extra dose of K, recorded the highest phosphorus uptakes of 3.87 and 3.41 kg/ha respectively. Highest uptake of K was noticed in T_6 (42.43 kg/ha). Highest Ca and Mg uptake were also observed in this treatment. In S uptake, there was no significant difference between treatments. Nutrient uptake was least in absolute control.

Table 17. Uptake of different nutrients at 5 MAP in leaves as influenced by nutrient management

Treatment No.	Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
1	POP	28.48[a*]	2.57[bc]	35.32[b]	1.68[a]	6.75[bcd]	3.01[b]
2	POP less 10 t FYM	22.86[b]	2.49[bc]	32.38[b]	1.54[a]	7.46[bc]	2.28[cd]
3	POP+ S-1 MAP	22.24[bc]	2.25[bc]	32.90[b]	2.07[a]	6.73[bcd]	3.18[b]
4	POP+ S-3 MAP	23.41[b]	3.41[a]	34.91[b]	1.96[a]	6.29[cd]	2.95[b]
5	POP+ K-3 MAP	21.24[bc]	2.81[b]	33.11[b]	1.26[a]	6.08[d]	3.14[b]
6	POP+K+S-1 MAP	24.03[b]	3.87[a]	42.43[a]	2.47[a]	8.77[a]	4.49[a]
7	POP+K+S-3 MAP	20.94[bc]	2.58[bc]	27.95[c]	1.27[a]	5.53[d]	3.02[b]
8	POP+ S + Ca	18.54[cd]	2.67[b]	35.04[b]	1.63[a]	7.89[ab]	3.42[b]
9	POP+ S + Mg	16.61[d]	2.62[bc]	26.43[cd]	1.69[a]	5.55[d]	2.79[bc]
10	50:50:50 kg N,P,K	8.75[ef]	1.38[de]	16.93[e]	0.66a	3.87[e]	1.95[d]
11	FYM alone	8.59[ef]	1.51[de]	12.51[f]	0.65[a]	3.17[ef]	2.13[d]
12	Absolute control	5.85[f]	1.17[e]	9.68[f]	0.41[a]	2.52[f]	1.91[d]

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.5.2 Uptake of different nutrients at 5 MAP in rhizomes as influenced by nutrient management

Data on uptake of different nutrients estimated in rhizomes at 5 MAP are presented in Table 18. Highest nitrogen uptake was noticed in T_5 (15.85 kg/ha), where extra dose of K was applied as second top dressing and T_1 (15.45 kg/ha). This was on par with T_9

(15.05 kg/ha) in which S was top dressed as $MgSO_4$. T_1 (POP) and T_3, the treatment where S was applied as first top dressing, recorded the highest phosphorus uptake of 3.04 and 2.92 kg/ha. In the case of K and S, there was no significant difference between treatments. Highest Ca and Mg uptakes were observed in T_7, where extra dose of K was applied along with S as second top dressing (Table 18). Nutrient uptake was least in absolute control.

Table 18. Uptake of different nutrients at 5 MAP in rhizomes as influenced by nutrient management

Treatment No.	Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
1	POP	15.45^{a*}	3.04^{a}	22.83^{a}	1.28^{a}	7.05^{abc}	2.96^{ab}
2	POP less 10 t FYM	13.02^{ab}	2.25^{abc}	18.61^{a}	1.15^{a}	3.45^{d}	2.34^{bc}
3	POP+ S-1 MAP	13.86^{ab}	2.92^{a}	20.11^{a}	1.50^{a}	6.45^{abc}	2.71^{abc}
4	POP+ S-3 MAP	12.84^{ab}	2.72^{ab}	17.89^{a}	1.34^{a}	5.92^{c}	3.12^{ab}
5	POP+ K-3 MAP	15.85^{a}	2.57^{abc}	26.66^{a}	0.89^{a}	6.04^{c}	2.88^{abc}
6	POP+K+S-1 MAP	10.57^{bc}	1.35^{c}	20.04^{a}	1.02^{a}	3.95^{d}	2.32^{bc}
7	POP+K+S-3 MAP	13.58^{ab}	2.21^{abc}	28.80^{a}	2.65^{a}	7.76^{a}	3.47^{a}
8	POP+ S + Ca	13.70^{ab}	2.45^{abc}	20.07^{a}	1.58^{a}	7.50^{ab}	3.15^{ab}
9	POP+ S + Mg	15.05^{a}	2.29^{abc}	17.96^{a}	1.39^{a}	6.19^{bc}	3.01^{ab}
10	50:50:50 kg N,P,K	13.52^{ab}	1.86^{abc}	15.88^{a}	0.76^{a}	3.45^{d}	2.60^{abc}
11	FYM alone	8.47^{c}	1.56^{bc}	11.19^{a}	0.73^{a}	3.12^{de}	2.19^{bc}
12	Absolute control	8.27^{c}	1.38^{c}	10.14^{a}	0.66^{a}	1.98^{e}	1.92^{c}

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.5.3 Uptake of different nutrients in rhizomes at harvest as influenced by nutrient management

Data on uptake of nutrients in rhizomes at harvest are given in Table 19. Highest nitrogen uptake was noticed in T_9 (in which S and Mg were applied as first top dressing) and was on par with the treatment that received S as second top dressing (T_4), while T_4 recorded the highest phosphorus uptake (6.64 kg/ha). Potassium uptake was also highest in this treatment. In case of Ca, highest uptake was in T8, in which S and Ca were applied as first top dressing, whereas T_9 (POP+S+Mg) showed the highest Mg uptake, and were on par with T_3 and T_4, where S was top dressed at 1 MAP and 3 MAP respectively. S uptake was more in T_4, which was on par with T_3, followed by T_6, which received an extra dose of K along with S as first top dressing. Nutrient uptake was least in absolute control.

4.6. Chlorophyll content in leaves

Chlorophyll content in leaves was estimated at 2 ½ MAP and 5 MAP and data are given in Tables (20 and 21). Total chlorophyll content was higher at 5 MAP compared to 2 ½ MAP. At 2 ½ MAP, T_1 (POP) showed maximum chlorophyll a and total chlorophyll content compared to other treatments. The ratio of chlorophyll a to b was highest in T_4 at 2 ½ MAP and in T_6 at 5 MAP. But chlorophyll b was higher in treatments T_7, T_6, T_2 and T_5, followed by all other treatments. At 5 MAP, there was no significant difference in chlorophyll a and b among treatments. Total chlorophyll content showed significant differences and was highest in T_1. The least content was in control.

Table 19. Uptake of different nutrients at harvest as influenced by nutrient management

Treatment No.	Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
1	POP	39.99^{c*}	4.79^{abcd}	36.06^{abcd}	4.58^{cd}	8.07^{f}	4.09^{c}
2	POP less 10 t FYM	42.27^{bc}	4.59^{abcd}	36.61^{abcd}	4.86^{bcd}	7.37^{f}	4.51^{bc}
3	POP+ S-1 MAP	49.41^{ab}	5.95^{ab}	47.22^{ab}	7.87^{a}	10.65^{bcd}	6.43^{a}
4	POP+ S-3 MAP	54.71^{a}	6.64^{a}	51.17^{a}	8.08^{a}	12.21^{ab}	5.86^{a}
5	POP+ K-3 MAP	34.78^{c}	4.35^{bcd}	38.49^{abcd}	4.85^{bcd}	12.24^{b}	4.63^{bc}
6	POP+K+S-1 MAP	38.88^{c}	2.75^{d}	34.94^{bcd}	6.24^{b}	10.08^{cde}	3.91^{cd}
7	POP+K+S-3 MAP	38.19^{c}	3.06^{d}	44.21^{ab}	5.46^{bc}	8.76^{def}	3.96^{cd}
8	POP+ S + Ca	43.18^{bc}	5.28^{abc}	36.48^{abcd}	5.89^{bc}	14.14^{a}	5.51^{ab}
9	POP+ S + Mg	55.25^{a}	5.34^{abc}	40.02^{abc}	5.61^{bc}	10.91^{abc}	6.36^{a}
10	50:50:50 kg N,P,K	40.31^{bc}	3.61^{cd}	28.94^{cd}	3.53^{e}	8.65^{ef}	4.23^{c}
11	FYM alone	25.79^{d}	3.48^{cd}	23.14^{d}	2.65^{e}	6.84^{fg}	2.92^{de}
12	Absolute control	21.40^{d}	2.64^{d}	21.93^{d}	2.27^{e}	5.13^{g}	2.52^{e}

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

Table 20. Chlorophyll content (mg g^{-1}) in leaves at 2 ½ MAP as influenced by nutrient management

Treatment No.	Treatment	Chlorophyll a	Chlorophyll b	Total	a/ b
1	POP	0.64^{a*}	0.09^{ab}	0.73^{a}	7.11
2	POP less 10 t FYM	0.55^{abc}	0.14^{a}	0.66^{abc}	3.92
3	POP+ S-1 MAP	0.57^{abc}	0.09^{ab}	0.68^{abc}	6.33
4	POP+ S-3 MAP	0.59^{ab}	0.06^{b}	0.66^{abc}	9.83
5	POP+ K-3 MAP	0.47^{c}	0.14^{a}	0.63^{abc}	3.35
6	POP+K+S-1 MAP	0.55^{abc}	0.13^{a}	0.67^{abc}	4.23
7	POP+K+S-3 MAP	0.51^{bc}	0.15^{a}	0.66^{abc}	3.40
8	POP+ S + Ca	0.54^{abc}	0.07^{b}	0.57^{cd}	7.71
9	POP+ S + Mg	0.53^{bc}	0.10^{ab}	0.58^{bcd}	5.30
10	50:50:50 kg N,P,K	0.49^{bc}	0.09^{ab}	0.57^{cd}	5.44
11	FYM alone	0.56^{abc}	0.09^{ab}	0.59^{bcd}	6.22
12	Absolute control	0.54^{abc}	0.09^{ab}	0.52^{d}	6.00

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

Table 21. Chlorophyll content (mg g^{-1}) in leaves at 5 MAP as influenced by nutrient management

Treatment No.	Treatment	Chlorophyll a	Chlorophyll b	Total	a/ b
1	POP	1.04^{a*}	0.37^{a}	1.41^{a}	2.81
2	POP less 10 t FYM	0.91^{a}	0.32^{a}	1.22^{abc}	2.84
3	POP+ S-1 MAP	0.88^{a}	0.34^{a}	1.18^{abc}	2.58
4	POP+ S-3 MAP	0.91^{a}	0.30^{a}	1.20^{abc}	3.03
5	POP+ K-3 MAP	0.83^{a}	0.28^{a}	1.25^{abc}	2.96
6	POP+K+S-1 MAP	0.88^{a}	0.28^{a}	1.15^{bc}	3.14
7	POP+K+S-3 MAP	0.96^{a}	0.34^{a}	1.27^{ab}	2.82
8	POP+ S + Ca	0.91^{a}	0.31^{a}	1.19^{abc}	2.93
9	POP+ S + Mg	0.87^{a}	0.29^{a}	1.16^{bc}	3.00
10	50:50:50 kg N,P,K	0.74^{a}	0.27^{a}	1.02^{c}	2.74
11	FYM alone	0.79^{a}	0.32^{a}	1.08^{bc}	2.46
12	Absolute control	0.76^{a}	0.35^{a}	0.78^{d}	2.17

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

4.7 Path analysis

To find out the level of contribution of major and secondary nutrients at various growth stages on the development of quantitative and qualitative yields, path co-efficient analysis was carried out. The four dependent characters in the study were fresh rhizome yield, dry rhizome yield, oleoresin content and essential oil content. The results are as follows.

Table 22a. Direct and indirect effect of nutrients and qualitative components on fresh rhizome yield

	N(L)	P(L)	K(L)	Ca(L)	Mg(L)	S(L)	DY	Oleoresin	Oil	rc
N(L)	**0.0208**	0.0014	-0.0183	0.0036	0.0088	0.0408	0.4366	-0.0023	0.0034	0.4868**
P(L)	0.0007	**0.0404**	-0.0113	-0.0012	0.0105	-0.0053	-0.1693	-0.0012	0.0000	-0.1574
K(L)	0.0088	0.0105	**-0.0434**	0.0080	0.0168	0.0363	0.2580	-0.0010	0.0038	0.2977**
Ca(L)	0.0040	-0.0025	-0.0184	**0.0188**	0.0075	0.0166	0.3375	-0.0013	0.0015	0.3719**
Mg(L)	0.0076	0.0176	-0.0303	0.0058	**0.0240**	0.0258	0.2885	-0.0011	0.0045	0.3322**
S(L)	0.0133	-0.0034	-0.0247	0.0049	0.0097	**0.0637**	0.6187	-0.0022	0.0066	0.6947**
N(R)	0.0040	-0.0073	-0.0073	-0.0003	0.0077	0.0070	0.1394	-0.0003	0.0014	0.1403
P(R)	0.0055	0.0005	-0.0042	0.0000	0.0037	0.0096	0.2418	-0.0013	0.0021	0.2604**
K(R)	0.0043	0.0118	-0.0077	-0.0026	0.0066	0.0189	0.0048	-0.0006	0.0015	0.0069
Ca(R)	0.0024	0.0100	-0.0285	0.0087	0.0126	0.0193	0.1900	-0.0004	0.0041	0.2080*
Mg(R)	-0.0010	0.0025	-0.0141	0.0035	0.0085	0.0105	0.2262	-0.0018	0.0018	0.2052*
S(R)	0.0071	0.0021	-0.0181	0.0016	0.0075	0.0333	0.2717	-0.0002	0.0035	0.3187**
N(H)	0.0035	0.0014	-0.0068	0.0017	0.0062	0.0240	0.1535	-0.0020	0.0036	0.1513
P(H)	0.0018	-0.0007	0.0014	-0.0024	0.0000	0.0027	0.1371	-0.0012	0.0020	0.1287
K(H)	0.0044	0.0116	-0.0082	-0.0024	0.0069	0.0197	0.0090	-0.0007	0.0018	0.0231
Ca(H)	0.0007	0.0166	-0.0289	0.0078	0.0134	0.0088	-0.0089	0.0004	0.0024	-0.0020
Mg(H)	0.0065	-0.0053	-0.0186	0.0069	0.0092	0.0290	0.4937	-0.0017	0.0049	0.5420**
S(H)	0.0114	0.0083	-0.0256	0.0053	0.0102	0.0496	0.3975	-0.0022	0.0042	0.4517**
DY	0.0098	-0.0074	-0.0121	0.0068	0.0075	0.0424	**0.9286**	-0.0022	0.0057	1.0000**
Oleoresin	0.0086	-0.0085	-0.0082	0.0043	0.0049	0.0251	0.3760	**-0.0055**	0.0021	0.4190**
Oil	0.0068	-0.0001	-0.0159	0.0027	0.0104	0.0407	0.5090	-0.0011	**0.0104**	0.5917**

L-in leaves at 5 MAP R-in rhizomes at 5 MAP H-in rhizomes at harvest

Table 22b. Direct and indirect effect of nutrients and qualitative components on fresh rhizome yield

	N (R)	P(R)	K (R)	Ca(R)	Mg (R)	S (R)	DY	Oleoresin	Oil	rc
N(L)	-0.0039	-0.0063	-0.4178	0.0022	-0.0002	0.0037	0.4366	-0.0023	0.0034	0.4868**
P (L)	0.0036	-0.0003	-0.5831	0.0047	0.0002	0.0006	-0.1693	-0.0012	0.0000	-0.1574
K(L)	-0.0034	-0.0023	-0.3533	0.0125	0.0013	0.0045	0.2580	-0.0010	0.0038	0.2977**
Ca(L)	0.0003	0.0000	0.2764	0.0088	0.0007	0.0009	0.3375	-0.0013	0.0015	0.3719**
Mg(L)	-0.0064	-0.0037	-0.5525	0.0099	0.0014	0.0034	0.2885	-0.0011	0.0045	0.3322**
S(L)	-0.0022	-0.0036	-0.5936	0.0057	0.0006	0.0057	0.6187	-0.0022	0.0066	0.6947**
N(R)	**-0.0201**	-0.0074	-0.3083	0.0051	0.0006	0.0008	0.1394	-0.0003	0.0014	0.1403
P(R)	-0.0062	**-0.0240**	-0.3895	0.0015	0.0019	-0.0008	0.2418	-0.0013	0.0021	0.2604**
K(R)	-0.0031	-0.0047	**-0.0137**	0.0039	0.0010	0.0041	0.0048	-0.0006	0.0015	0.0069
Ca(R)	-0.0054	-0.0019	-0.4114	**0.0190**	0.0009	0.0030	0.1900	-0.0004	0.0041	0.2080*
Mg(R)	-0.0032	-0.0119	-0.5040	0.0046	**0.0039**	0.0020	0.2262	-0.0018	0.0018	0.2052*
S(R)	-0.0015	0.0018	-0.7562	0.0053	0.0007	**0.0109**	0.2717	-0.0002	0.0035	0.3187**
N(H)	-0.0032	-0.0018	-0.8297	0.0022	0.0007	0.0009	0.1535	-0.0020	0.0036	0.1513
P(H)	-0.0024	-0.0203	-0.4281	0.0008	0.0019	-0.0021	0.1371	-0.0012	0.0020	0.1287
K(H)	-0.0033	-0.0047	-1.9980	0.0041	0.0009	0.0042	0.0090	-0.0007	0.0018	0.0231
Ca(H)	-0.0035	-0.0004	-0.2014	0.0169	0.0007	0.0012	-0.0089	0.0004	0.0024	-0.0020
Mg(H)	-0.0083	-0.0084	-0.1261	0.0074	0.0007	0.0015	0.4937	-0.0017	0.0049	0.5420**
S(H)	0.0017	-0.0011	-1.0003	0.0073	0.0006	0.0048	0.3975	-0.0022	0.0042	0.4517**
DY	-0.0030	-0.0063	-0.0103	0.0039	0.0009	0.0032	**0.9286**	-0.0022	0.0057	1.0000**
Oleoresin	-0.0010	-0.0058	-0.2186	-0.0015	0.0012	0.0005	0.3760	**-0.0055**	0.0021	0.4190**
Oil	-0.0028	-0.0049	-0.2921	0.0075	0.0007	0.0037	0.5090	-0.0011	**0.0104**	0.5917**

Table 22c. Direct and indirect effect of nutrients and qualitative components on fresh rhizome yield

	N(H)	P(H)	K(H)	Ca(H)	Mg(H)	S(H)	DY	Oleoresin	Oil	rc
N(L)	-0.0038	0.0012	0.4243	-0.0016	0.0039	-0.0097	0.4366	-0.0023	0.0034	0.4868**
P(L)	-0.0008	-0.0002	0.5751	-0.0177	-0.0017	-0.0036	-0.1693	-0.0012	0.0000	-0.1574
K(L)	-0.0035	-0.0004	0.3784	-0.0287	0.0054	-0.0104	0.2580	-0.0010	0.0038	0.2977**
Ca(L)	-0.0020	-0.0018	-0.2568	-0.0180	0.0047	-0.0049	0.3375	-0.0013	0.0015	0.3719**
Mg(L)	-0.0058	0.0000	0.5703	-0.0241	0.0049	-0.0075	0.2885	-0.0011	0.0045	0.3322**
S(L)	-0.0084	0.0006	0.6171	-0.0060	0.0058	-0.0137	0.6187	-0.0022	0.0066	0.6947**
N(R)	-0.0036	0.0017	0.3279	-0.0076	0.0052	0.0015	0.1394	-0.0003	0.0014	0.1403
P(R)	-0.0016	0.0118	0.3871	-0.0007	0.0044	-0.0008	0.2418	-0.0013	0.0021	0.2604**
K(R)	-0.0092	0.0030	1.9910	-0.0043	0.0008	-0.0088	0.0048	-0.0006	0.0015	0.0069
Ca(R)	-0.0026	0.0006	0.4270	-0.0385	0.0049	-0.0068	0.1900	-0.0004	0.0041	0.2080*
Mg(R)	-0.0040	0.0068	0.4833	-0.0079	0.0022	-0.0027	0.2262	-0.0018	0.0018	0.2052*
S(R)	-0.0019	-0.0026	0.7645	-0.0047	0.0017	-0.0078	0.2717	-0.0002	0.0035	0.3187**
N(H)	**-0.0223**	0.0012	0.8238	-0.0030	0.0040	-0.0065	0.1535	-0.0020	0.0036	0.1513
P(H)	-0.0019	**0.0139**	0.4223	-0.0019	0.0022	-0.0001	0.1371	-0.0012	0.0020	0.1287
K(H)	-0.0092	0.0029	**1.9967**	-0.0047	0.0010	-0.0089	0.0090	-0.0007	0.0018	0.0231
Ca(H)	-0.0015	-0.0007	0.2179	**-0.0432**	0.0048	-0.0053	-0.0089	0.0004	0.0024	-0.0020
Mg(H)	-0.0017	0.0024	0.1650	-0.0166	**0.0126**	-0.0059	0.4937	-0.0017	0.0049	0.5420**
S(H)	-0.0083	0.0001	1.0145	-0.0131	0.0042	**-0.0176**	0.3975	-0.0022	0.0042	0.4517**
DY	-0.0037	0.0021	0.0194	0.0004	0.0067	-0.0075	**0.9286**	-0.0022	0.0057	1.0000**
Oleoresin	-0.0082	0.0031	0.2503	0.0032	0.0039	-0.0069	0.3760	**-0.0055**	0.0021	0.4190**
Oil	-.00078	0.0027	0.3383	-0.0099	0.0060	-0.0071	0.5090	-0.0011	**0.0104**	0.5917**

Residual 0.0021

4.7.1 Correlation with fresh rhizome yield

Data on the direct and indirect effects of major and secondary nutrients in the leaves and rhizomes at 5 MAP, and in the rhizomes at harvest as well as oleoresin content, essential oil content and dry rhizome yield on fresh rhizome yield are presented in Tables 22a, 22b, 22c. The correlation with nutrient contents in leaves at 5 months after planting (MAP) are recorded in Table 22a , and in rhizomes at 5 MAP in Table 22b, and in rhizomes at harvest in Table 22c .

The direct contribution of nutrient contents in leaves and rhizomes at five month stage (Table 22a. and Table 22b.) revealed that the effects were not striking. But at harvest (Table 22c.), the K content showed significant positive effect on fresh rhizome yield (1.9967). Dry rhizome yield showed high positive and direct effect on fresh yield (0.9286). At this stage, direct effects of oleoresin and essential oil on fresh rhizome yield were not significant.

Comparing the values of correlation co-efficients, it was seen that the Ca, Mg and S contents in leaves and rhizomes at 5 MAP, and the N and K contents in leaves and P content in rhizomes at 5 MAP as well as the Mg and S contents in rhizomes at harvest showed high positive correlations with fresh rhizome yield. At 5 MAP, while in the leaves, nutrients did not exert indirect effect on each other, in the rhizomes, K contents were seem to have negative indirect effects on P, Ca, Mg and S contents. These were negated to some extent by indirect effect of dry rhizome yield. At harvest high indirect positive effects of K in rhizomes along with dry rhizome yield may have resulted in high positive correlation values for Mg and S in rhizomes.

4.7.2 Correlation with dry rhizome yield

The direct effect of nutrient contents of leaves at five months stage on dry rhizome yield was less (Table 23a.). However, K content of rhizomes at five months stage (Table 23b.) showed high positive effect (2.1544). This effect, however, was

Table 23a. Direct and indirect effect of nutrients and qualitative components on dry rhizome yield

	N (L)	P (L)	K (L)	Ca (L)	Mg (L)	S (L)	FY	Oleoresin	Oil	rc
N(L)	**-0.0220**	-0.0014	0.0181	-0.0036	-0.0085	-0.0393	0.5179	0.0036	-0.0034	0.4701**
P(L)	-0.0008	**-0.0402**	0.0112	0.0012	-0.0101	0.0051	-0.1675	-0.0018	0.0000	-0.1823
K(L)	-0.0093	-0.0105	**0.0428**	-0.0081	-0.0162	-0.0349	0.3167	0.0016	-0.0038	0.2778**
Ca(L)	-0.0042	0.0025	0.0182	**-0.0190**	-0.0072	-0.0160	0.3956	0.0020	-0.0015	0.3635**
Mg(L)	-0.0080	-0.0175	0.0299	-0.0059	**-0.0232**	-0.0248	0.3534	0.0018	-0.0045	0.3107**
S(L)	-0.0141	0.0033	0.0244	-0.0050	-0.0094	**-0.0613**	0.7390	0.0034	-0.0067	0.6663**
N(R)	-0.0042	0.0073	0.0072	0.0003	-0.0074	-0.0067	0.1492	0.0004	-0.0015	0.1501
P(R)	-0.0058	-0.0005	0.0042	0.0000	-0.0036	-0.0093	0.2560	0.0021	-0.0021	0.2604**
K(R)	-0.0046	-0.0117	0.0075	0.0026	-0.0064	-0.0181	0.0074	0.0010	-0.0015	0.0051
Ca(R)	-0.0026	-0.0100	0.0281	-0.0088	-0.0121	-0.0185	0.2212	-0.0007	-0.0041	0.2406*
Mg(R)	-0.0010	-0.0025	0.0139	-0.0035	-0.0082	-0.0101	0.2183	0.0028	-0.0019	0.0051
S(R)	-0.0075	-0.0021	0.0178	-0.0016	-0.0073	-0.0320	0.3391	0.0004	-0.0036	0.2046*
N(H)	-0.0037	-0.0014	0.0067	-0.0017	-0.0060	-0.0231	0.1610	0.0032	-0.0036	0.2436**
P(H)	-0.0019	0.0007	-0.0013	0.0025	0.0000	-0.0026	0.1370	0.0019	-0.0020	0.2926**
K(H)	-0.0047	-0.0116	0.0081	0.0024	-0.0066	-0.0189	0.0245	0.0011	-0.0018	0.1653
Ca(H)	-0.0008	-0.0165	0.0284	-0.0079	-0.0129	-0.0085	-0.0022	-0.0006	-0.0024	0.1477
Mg(H)	-0.0068	0.0053	0.0183	-0.0070	-0.0089	-0.0279	0.5766	0.0027	-0.0049	0.0097
S(H)	-0.0121	-0.0083	0.0253	-0.0053	-0.0098	-0.0477	0.4805	0.0034	-0.0042	-0.0096
FY	-0.0107	0.0063	0.0127	-0.0071	-0.0077	-0.0426	**1.0638**	0.0037	-0.0063	0.4049**
Oleoresin	-0.0091	0.0084	0.0081	-0.0043	-0.0048	-0.0241	0.4457	**0.0087**	-0.0021	0.5316**
Oil	-0.0072	0.0001	0.0157	-0.0027	-0.0100	-0.0392	0.3652	0.0018	**-0.0105**	0.4281**

L-in leaves at 5 MAP R-in rhizomes at 5 MAP H-in rhizomes at harvest

Table 23b. Direct and indirect effect of nutrients and qualitative components on dry rhizome yield

	N (R)	P(R)	K (R)	Ca(R)	Mg (R)	S(R)	FY	Oleoresin	Oil	rc
N(L)	0.0040	0.0066	0.4493	-0.0011	0.0001	-0.0043	0.5179	0.0036	-0.0034	0.4701**
P(L)	-0.0037	0.0003	0.6269	-0.0023	-0.0002	-0.0007	-0.1675	-0.0018	0.0000	-0.1823
K(L)	0.0035	0.0024	0.3799	-0.0061	-0.0009	-0.0052	0.3167	0.0016	-0.0038	0.2778**
Ca(L)	-0.0003	0.0000	-0.2972	-0.0043	-0.0005	-0.0011	0.3956	0.0020	-0.0015	0.3635**
Mg(L)	0.0066	0.0039	0.5941	-0.0048	-0.0009	-0.0039	0.3534	0.0018	-0.0045	0.3107**
S(L)	0.0023	0.0038	0.6382	-0.0028	-0.0004	-0.0066	0.7390	0.0034	-0.0067	0.6663**
N(R)	**0.0207**	0.0077	0.3315	-0.0025	-0.0004	-0.0010	0.1492	0.0004	-0.0015	0.1501
P(R)	0.0063	**0.0251**	0.4188	-0.0007	-0.0013	-0.0010	0.2560	0.0021	-0.0021	0.2604**
K(R)	0.0032	0.0049	**2.1544**	-0.0019	-0.0007	-0.0048	0.0074	0.0010	-0.0015	0.0051
Ca(R)	0.0055	0.0019	0.4423	**-0.0093**	-0.0006	-0.0035	0.2212	-0.0007	-0.0041	0.2406*
Mg(R)	0.0033	0.0124	0.5419	-0.0022	**-0.0027**	-0.0023	0.2183	0.0028	-0.0019	0.0051
S(R)	0.0016	-0.0019	0.8131	-0.0026	-0.0005	**-0.0126**	0.3391	0.0004	-0.0036	0.2046*
N(H)	0.0033	0.0018	0.8922	-0.0011	-0.0005	-0.0011	0.1610	0.0032	-0.0036	0.2436**
P(H)	0.0025	0.0212	0.4603	-0.0004	-0.0013	-0.0024	0.1370	0.0019	-0.0020	0.2926**
K(H)	0.0034	0.0049	2.1483	-0.0020	-0.0007	-0.0048	0.0245	0.0011	-0.0018	0.1653
Ca(H)	0.0036	0.0004	0.2165	-0.0083	-0.0005	-0.0014	-0.0022	-0.0006	-0.0024	0.1477
Mg(H)	0.0085	0.0088	0.1355	-0.0036	-0.0005	-0.0017	0.5766	0.0027	-0.0049	0.0097
S(H)	-0.0018	0.0011	1.0756	-0.0036	-0.0004	-0.0056	0.4805	0.0034	-0.0042	-0.0096
FY	0.0029	0.0060	0.0149	-0.0019	-0.0006	-0.0040	**0.0057**	0.0037	-0.0063	0.4049**
Oleoresin	0.0010	0.0061	0.2350	-0.0008	-0.0009	-0.0006	1.0638	**0.0087**	-0.0021	0.5316**
Oil	0.0029	0.0051	0.3141	-0.0037	-0.0005	-0.0043	0.3652	0.0018	**-0.0105**	0.4281**

Table 23c. Direct and indirect effect of nutrients and qualitative components on dry rhizome yield

	N(H)	P(H)	K(H)	Ca(H)	Mg(H)	S(H)	FY	Oleoresin	Oil	rc
N(L)	0.0035	-0.0014	-0.4567	0.0012	-0.0024	0.0099	0.5179	0.0036	-0.0034	0.4701**
P(L)	0.0007	0.0003	-0.6191	0.0136	0.0010	0.0037	-0.1675	-0.0018	0.0000	-0.1823
K(L)	0.0033	0.0005	-0.4074	0.0221	-0.0033	0.0106	0.3167	0.0016	-0.0038	0.2778**
Ca(L)	0.0019	0.0020	0.2764	0.0139	-0.0028	0.0050	0.3956	0.0020	-0.0015	0.3635**
Mg(L)	0.0054	0.0000	-0.6139	0.0186	-0.0030	0.0076	0.3534	0.0018	-0.0045	0.3107**
S(L)	0.0079	-0.0007	-0.6643	0.0046	-0.0035	0.0140	0.7390	0.0034	-0.0067	0.6663**
N(R)	0.0034	-0.0019	-0.3530	0.0058	-0.0032	-0.0016	0.1492	0.0004	-0.0015	0.1501
P(R)	0.0015	-0.0133	-0.4167	0.0006	-0.0027	0.0008	0.2560	0.0021	-0.0021	0.2604**
K(R)	0.0086	-0.0033	-2.1433	0.0033	-0.0005	0.0090	0.0074	0.0010	-0.0015	0.0051
Ca(R)	0.0024	-0.0007	-0.4596	0.0297	-0.0030	0.0070	0.2212	-0.0007	-0.0041	0.2406*
Mg(R)	0.0037	0.0077	-0.5202	0.0061	-0.0014	0.0028	0.2183	0.0028	-0.0019	0.0051
S(R)	0.0018	0.0029	-0.8230	0.0036	-0.0010	0.0080	0.3391	0.0004	-0.0036	0.2046*
N(H)	**0.0208**	-0.0013	-0.8868	0.0023	-0.0025	0.0067	0.1610	0.0032	-0.0036	0.2436**
P(H)	0.0018	**-0.0157**	-0.4546	-0.0015	-0.0014	0.0001	0.1370	0.0019	-0.0020	0.2926**
K(H)	0.0086	-0.0033	**-2.1494**	0.0036	-0.0006	0.0092	0.0245	0.0011	-0.0018	0.1653
Ca(H)	0.0014	0.0007	-0.2346	**0.0333**	-0.0030	0.0054	-0.0022	-0.0006	-0.0024	0.1477
Mg(H)	0.0066	-0.0028	-0.1776	0.0127	**-0.0077**	0.0060	0.5766	0.0027	-0.0049	0.0097
S(H)	0.0077	-0.0001	-1.0921	0.0101	-0.0026	**0.0180**	0.4805	0.0034	-0.0042	-0.0096
FY	0.0032	-0.0020	-0.0496	-0.0001	-0.0042	0.0081	**1.0638**	0.0037	-0.0063	0.4049**
Oleoresin	0.0077	-0.0035	-0.2695	-0.0024	-0.0024	0.0070	0.4457	**0.0087**	-0.0021	0.5316**
Oil	.00072	-0.0030	-0.3642	0.0077	-0.0036	0.0073	0.3652	0.0018	**-0.0105**	0.4281**

Residual 0.0024

diametrically opposite at harvest (-2.1494), becoming highly negative (Table 23c.). Fresh rhizome yield had high indirect positive effect on dry rhizome yield (1.0638).

Comparing correlation co-efficient values, high positive correlation was obtained between N, K, Ca, Mg and S contents in leaves at 5 MAP with dry rhizome yield. However in the rhizomes at the same stage, K content was seemed to exert significant high positive effects indirectly on P, Ca and S contents to give correlation co-efficient values of 0.2604, 0.2406.0.2046 respectively. N and P contents of rhizomes at harvest also showed high positive correlation co-efficient values with dry rhizome yield. Here high indirect negative effect of K content in rhizomes was observed. Fresh yield exerted positive indirect effect. High direct and indirect positive correlation of fresh rhizome yield probably resulted in high co-efficient values for oleoresin, essential oil and fresh rhizome yield with dry rhizome yield.

4.7.3 Correlation with oleoresin content

Nitrogen and Mg contents in the leaves at 5 MAP showed direct positive effect on oleoresin content (0.4476 and 0.113), while P and S showed high negative direct influences (Table 24a.). In the rhizomes at the same stage, K, Ca and P showed high negative effect while Mg had direct positive effect on oleoresin content (Table 24b.). At harvest, the effect was reversed, with K, Ca, S N and P showing high positive effects, while Mg had negative effect (Table 24c.). While fresh rhizome yield and essential oil had high negative effects on oleoresin content (-0.8391 and -0.1258), dry yield showed high positive effect (1.1561).

Contents of N, Ca, Mg and S in leaves at 5 MAP showed high positive correlation value with oleoresin content in rhizomes. This can partly be accounted for by direct and indirect positive effects of N in leaves. Phosphorus, K and S contents of leaves at 5 MAP were seen to produce negative effect indirectly on Mg content, while N exerted a positive influence. In the case of S in leaves also, positive indirect effect of N was observed. For all the elements at all the stages, fresh and dry rhizome yields showed

Table 24a. Direct and indirect effect of nutrients and yields on oleoresin

	N(L)	P(L)	K(L)	Ca(L)	Mg(L)	S(L)	FY	DY	Oil	rc
N(L)	**0.4476**	-0.0135	-0.0753	0.0016	0.0407	-0.1597	-0.4085	0.5435	-0.0411	0.4124**
P(L)	0.0160	**-0.3771**	-0.0465	-0.0005	0.484	0.0206	0.1321	-0.2107	-0.0004	-0.2098
K(L)	0.1890	-0.0984	**-0.1784**	0.0035	0.0778	-0.1419	-0.2498	0.3212	-0.0462	0.1882
Ca(L)	0.0855	0.0236	-0.0758	**0.0082**	0.0345	-0.0649	-0.3121	0.4202	-0.0181	0.2287*
Mg(L)	0.1636	-0.1639	-0.1247	0.0025	**0.1113**	-0.1009	-0.2787	0.3591	-0.0543	0.2053*
S(L)	0.2870	0.0312	-0.1061	0.0021	0.0451	**-0.2491**	-0.5829	0.7703	-0.0804	0.3938**
N(R)	0.0863	0.0680	-0.0299	-0.0001	0.0355	-0.0291	-0.1177	0.1735	-0.0176	0.0492
P(R)	0.1182	-0.0049	-0.0173	0.0000	0.0171	-0.0273	-0.2019	0.3010	-0.0258	0.2420*
K(R)	0.0934	-0.1097	-0.0315	-0.0011	0.0307	-0.0377	-0.0058	0.0059	-0.0183	0.1091
Ca(R)	0.0528	-0.0937	-0.1173	0.0038	0.0583	-0.0738	-0.1745	0.2365	-0.0498	-0.0815
Mg(R)	-0.0212	-0.0230	-0.0580	0.0015	0.0392	-0.0754	-0.1722	0.2816	-0.0223	0.3125**
S(R)	0.1524	-0.0199	-0.0742	0.0007	0.0348	-0.0413	-0.2674	0.3382	-0.0429	0.0444
N(H)	0.0762	-0.0132	-0.0279	0.0007	0.0288	-0.1302	-0.1270	0.1910	-0.0437	0.3694**
P(H)	0.0391	-0.0065	0.0055	-0.0011	0.0001	-0.0939	-0.1080	0.1707	-0.0244	0.2225*
K(H)	0.0951	-0.1086	-0.0338	-0.0010	0.0318	-0.0105	-0.0194	0.0112	-0.0213	0.1254
Ca(H)	0.0161	-0.1545	-0.1186	0.0034	0.0621	-0.0770	-0.0017	-0.0111	0.0289	-0.0729
Mg(H)	0.1392	0.0496	-0.0764	0.0030	0.0427	-0.0346	-0.4548	0.6146	-0.0593	0.3111**
S(H)	0.2464	-0.0778	-0.1054	0.0023	0.0472	-0.1135	-0.3790	0.4949	-0.0507	0.3905**
FY	0.2179	0.0594	-0.0531	0.0030	0.0370	-0.1730	**-0.8391**	1.1388	-0.0751	0.2018*
DY	0.2104	0.0687	-0.0496	0.0030	0.0346	-0.1659	-0.8266	**1.1561**	-0.0690	0.4049**
Oil	0.1464	0.0012	-0.0655	0.0012	0.0480	-0.1940	-0.5010	0.6337	**-0.1258**	1.0000**

L-in leaves at 5 MAP R-in rhizomes at 5 MAP H-in rhizomes at harvest

Table 24b. Direct and indirect effect of nutrients and yields on oleoresin

	N(R)	P(R)	K (R)	Ca (R)	Mg(R)	S (R)	FY	DY	Oil	rc
N(L)	-0.0189	-0.0343	-1.2752	-0.0918	-0.0183	-0.0085	-0.4085	0.5435	-0.0411	0.4124**
P(L)	0.0177	-0.0017	-1.7794	-0.1935	0.0236	-0.0013	0.1321	-0.2107	-0.0004	-0.2098
K(L)	-0.0164	-0.0126	-1.0782	-0.5119	0.1254	-0.0103	-0.2498	0.3212	-0.0462	0.1882
Ca(L)	0.0015	0.0002	0.8435	-0.3588	0.0718	-0.0021	-0.3121	0.4202	-0.0181	0.2287*
Mg(L)	-0.0313	-0.0200	-1.6862	-0.4075	0.1359	-0.0078	-0.2787	0.3591	-0.0543	0.2053*
S(L)	-0.0107	-0.0197	-1.8115	-0.2356	0.0639	-0.0130	-0.5829	0.7703	-0.0804	0.3938**
N(R)	**-0.0980**	-0.0399	-0.9409	-0.2080	0.0619	-0.0019	-0.1177	0.1735	-0.0176	0.0492
P(R)	-0.0300	**-0.1301**	-1.0887	-0.0601	0.1909	0.0019	-0.2019	0.3010	-0.0258	0.2420*
K(R)	-0.0151	-0.0253	**-1.0149**	-0.1599	0.0970	-0.0094	-0.0058	0.0059	-0.0183	-0.1091
Ca(R)	-0.0262	-0.0100	-1.2554	**-0.7787**	0.0926	-0.0069	-0.1745	0.2365	-0.0498	-0.0815
Mg(R)	-0.0157	-0.0644	-1.5381	-0.1869	**0.3858**	-0.0046	-0.1722	0.2816	-0.0223	0.3125**
S(R)	-0.0074	0.0099	-2.3079	-0.2173	0.0707	**-0.0249**	-0.2674	0.3382	-0.0429	0.0444
N(H)	-0.0158	-0.0095	-2.5322	-0.0895	0.0690	-0.0021	-0.1270	0.1910	-0.0437	0.3694**
P(H)	-0.0117	-0.1101	-1.3065	-0.0327	0.1886	0.0047	-0.1080	0.1707	-0.0244	0.2225*
K(H)	-0.0161	-0.0252	-6.0975	-0.1665	0.0934	-0.0095	-0.0194	0.0112	-0.0213	0.1254
Ca(H)	-0.0172	-0.0022	-0.6146	-0.6938	0.0707	-0.0027	-0.0017	-0.0111	0.0289	-0.0729
Mg(H)	-0.0405	-0.0454	-0.3847	-0.3042	0.0676	-0.0034	-0.4548	0.6146	-0.0593	0.3111**
S(H)	0.0085	-0.0057	-3.0529	-0.3010	0.0590	-0.0110	-0.3790	0.4949	-0.0507	0.3905**
FY	-0.0137	-0.0313	-0.0423	-0.1619	0.0792	-0.0079	**-0.8391**	1.1388	-0.0751	0.2018*
DY	-0.0147	-0.0339	-0.0313	-0.1593	0.0940	-0.0073	-0.8266	**1.1561**	-0.0690	0.4049**
Oil	-0.0137	-0.0267	-0.8914	-0.3085	0.0685	-0.0085	-0.5010	0.6337	**-0.1258**	1.0000**

Table 24c. Direct and indirect effect of nutrients and yields on oleoresin

	N(H)	P(H)	K(H)	Ca(H)	Mg(H)	S(H)	FY	DY	Oil	rc
N(L)	0.0529	0.0137	1.2897	0.0261	-0.0440	0.1858	-0.4085	0.5435	-0.0411	0.4124**
P(L)	0.0180	-0.0027	1.7481	0.2976	0.0187	0.0697	0.1321	-0.2107	-0.0004	-0.2098
K(L)	0.0487	-0.0049	1.1503	0.4829	-0.0607	0.1993	-0.2498	0.3212	-0.0462	0.1882
Ca(L)	0.0279	-0.0203	-0.7805	0.3026	-0.0522	0.0941	-0.3121	0.4202	-0.0181	0.2287*
Mg(L)	0.0803	0.0002	1.7334	0.4055	-0.0544	0.1430	-0.2787	0.3591	-0.0543	0.2053*
S(L)	0.1171	0.0066	1.8759	0.1009	-0.0646	0.2628	-0.5829	0.7703	-0.0804	0.3938**
N(R)	0.0500	0.0188	0.9969	0.1273	-0.0585	-0.0292	-0.1177	0.1735	-0.0176	0.0492
P(R)	0.0227	0.1324	1.1767	0.0125	-0.0495	0.0148	-0.2019	0.3010	-0.0258	0.2420*
K(R)	0.1286	0.0334	1.0521	0.0730	-0.0089	0.1685	-0.0058	0.0059	-0.0183	0.1091
Ca(R)	0.0357	0.0066	1.2979	0.6473	-0.0554	0.1305	-0.1745	0.2365	-0.0498	-0.0815
Mg(R)	0.0556	0.0765	1.4690	0.1331	-0.0248	0.0516	-0.1722	0.2816	-0.0223	0.3125**
S(R)	0.0267	-0.0294	2.3240	0.0783	-0.0193	0.1495	-0.2674	0.3382	-0.0429	0.0444
N(H)	**0.3106**	0.0133	2.5041	0.0503	-0.0450	0.1252	-0.1270	0.1910	-0.0437	0.3694**
P(H)	0.0264	**0.1565**	1.2836	-0.0319	-0.0249	0.0024	-0.1080	0.1707	-0.0244	0.2225*
K(H)	0.1282	0.0331	**1.2455**	0.0793	-0.0117	0.1715	-0.0194	0.0112	-0.0213	0.1254
Ca(H)	0.0215	-0.0069	0.6625	**0.7265**	-0.0542	0.1019	-0.0017	-0.0111	0.0289	-0.0729
Mg(H)	0.0987	0.0275	0.5015	0.2780	**-0.1417**	0.1124	-0.4548	0.6146	-0.0593	0.3111**
S(H)	0.1152	0.0011	3.0839	0.2194	-0.0472	**0.3375**	-0.3790	0.4949	-0.0507	0.3905**
FY	0.0470	0.0202	0.1400	-0.0015	-0.0768	0.1524	**-0.8391**	1.1388	-0.0751	0.2018*
DY	0.0513	0.0231	0.0590	-0.0070	-0.0753	0.1445	-0.8266	**1.1561**	-0.0690	0.4049**
Oil	0.1079	0.0303	1.0284	0.1671	-0.0668	0.1361	-0.5010	0.6337	**-0.1258**	1.0000**

Residual 0.3239

contradictory indirect effects which might have negated each other. Phosphorus and Mg in the rhizomes at 5 MAP recorded significantly high positive correlation values of 0.2420 and 0.3125 with oleoresin content. High negative direct effects of K as well as the negative direct effect of P may have been countered to some extent by positive indirect effect of Mg. With regard to Mg, again K in rhizomes along with Ca exerted high negative indirect effect. But the direct positive effect of Mg was also evident. Here again, fresh rhizome yield exerted negative effect while dry rhizome yield had positive influence. Contents of N, P, Mg and S of rhizomes at harvest also showed positive correlation with oleoresin content. This may be partially due to their own direct effect, and also due to high indirect positive effects of K, Ca, and S in rhizomes.

4.7.4 Correlation with essential oil

Table 25a, 25b, and 25c. depict the direct and indirect effect of nutrients on essential oil content of rhizomes. With respect to direct effects, at 5 MAP, leaf contents of K and Ca had high negative effects, while that of Mg and S were highly positive. In the rhizome at the same stage, K and N showed high negative effects (-0.8318 and-0.2656) while Ca had positive effect (0.6141). At harvest, effects of N, P, K and Mg were positive, while those of Ca and S were negative. Fresh rhizome yield had direct positive effects and dry yield and oleoresin content had direct negative effect on essential oil contents.

Correlation co-efficient values were significant and positive for N, Mg and S in the leaves at 5 MAP and in the rhizomes at harvest. Phosphorus and Ca in rhizomes at 5 MAP and at harvest were significantly and positively correlated with essential oil content, while K showed such an effect only at 5 MAP in the leaves. The data showed that indirect effects of nutrients in the leaves at 5 MAP were mainly in the form of negative effects of K and positive effects of Mg and S. In the rhizomes at the same stage, while K again showed indirect negative effect, here the positive indirect effects were mainly due to Ca. At harvest stage, K was the only nutrient to show high positive indirect effect, and this was evident on the nutrients N, P and S. Fresh rhizome yield, dry

Table 25a. Direct and indirect effect of nutrients and yields on essential oil

	N(L)	P(L)	K(L)	Ca(L)	Mg(L)	S(L)	FY	DY	Oleoresin	rc
N (L)	**0.0506**	-0.0028	-0.1105	-0.0506	0.1261	0.3212	0.6519	-0.5549	-0.0441	0.3270**
P(L)	0.0018	**-0.0793**	-0.0683	0.0166	0.1499	-0.0415	-0.2108	0.2151	-0.0224	-0.0033
K(L)	0.0213	-0.0207	**-0.2618**	-0.1124	0.2411	0.2854	0.3987	-0.3279	-0.0201	0.3673**
Ca(L)	0.0097	0.0050	-0.1111	**-0.2648**	0.1069	0.1305	0.4980	-0.4290	-0.0245	0.1443
Mg(L)	0.0185	-0.0345	-0.1830	-0.0820	**0.3449**	0.2030	0.4448	-0.3667	-0.0220	0.4314**
S(L)	0.0324	0.0066	-0.1491	-0.0690	0.1397	**0.5010**	0.9303	-0.7864	-0.0421	0.6391**
N(R)	0.0098	0.0143	-0.0439	0.0040	0.1101	0.5049	0.1878	-0.1771	-0.0053	0.1398
P(R)	0.0133	-0.0010	-0.0254	0.0005	0.0530	0.0759	0.3223	-0.3073	-0.0259	0.2052*
K(R)	0.0105	-0.0231	-0.0462	0.0365	0.0951	0.1484	0.0093	-0.0060	-0.0117	0.1458
Ca(R)	0.0060	-0.0197	-0.1721	-0.1220	0.1805	0.1516	0.2785	-0.2415	-0.0087	0.3962**
Mg(R)	-0.0024	-0.0048	-0.0851	-0.0493	0.1215	0.0830	0.2748	-0.2875	-0.0344	0.1777
S(R)	0.0172	-0.0042	-0.1089	-0.0222	0.1078	0.2618	0.4268	-0.3453	-0.0048	0.3407**
N (H)	0.0086	-0.0028	-0.0410	-0.0237	0.0062	0.1888	0.2026	-0.1950	-0.0395	0.3475**
P(H)	0.0044	-0.0014	0.0081	0.0344	0.0892	0.0211	0.1724	-0.1743	-0.0238	0.1937*
K(H)	0.0107	-0.0228	-0.0496	0.0340	0.0004	0.1548	0.0309	-0.0115	-0.0134	0.1694
Ca(H)	0.0018	-0.0325	-0.1740	-0.1103	0.0985	0.0696	-0.0027	-0.0113	0.0078	0.2300*
Mg(H)	0.0157	0.0104	-0.1121	-0.0976	0.1925	0.2283	0.7258	-0.6275	-0.0333	0.4714**
S(H)	0.0278	-0.0164	-0.1546	-0.0738	0.1324	0.3901	0.6049	-0.5053	-0.0418	0.4033**
FY	0.0246	0.0125	-0.0779	-0.0985	0.1146	0.3480	**1.3391**	-1.1626	-0.0448	1.0000**
DY	0.0238	0.0144	-0.0727	-0.0962	0.1072	0.3338	1.3191	**-1.1803**	-0.0433	0.5971**
Oleoresin	0.0209	0.0166	-0.0493	-0.0605	0.1461	0.1973	0.5611	-0.4779	**-0.1070**	0.2018*

L-in leaves at 5 MAP R-in rhizomes at 5 MAP H-in rhizomes at harvest

Table 25b. Direct and indirect effect of nutrients and yields on essential oil

	N (R)	P(R)	K(R)	Ca (R)	Mg (R)	S (R)	FY	DY	Oleoresin	rc
N (L)	-0.0512	-0.0155	-0.1735	0.0724	-0.0029	0.0074	0.6519	-0.5549	-0.0441	0.3270**
P(L)	0.0479	-0.0008	-0.2421	0.1526	0.0038	0.0012	-0.2108	0.2151	-0.0224	-0.0033
K(L)	-0.0445	-0.0057	-0.1467	0.4037	0.0202	0.0091	0.3987	-0.3279	-0.0201	0.3673**
Ca(L)	0.0040	0.0001	0.1147	0.2830	0.0116	0.0018	0.4980	-0.4290	-0.0245	0.1443
Mg(L)	-0.0848	-0.0090	-0.2294	0.3214	0.0219	0.0068	0.4448	-0.3667	-0.0220	0.4314**
S(L)	-0.0291	-0.0089	-0.2464	0.1858	0.0103	0.0114	0.9303	-0.7864	-0.0421	0.6391**
N(R)	**-0.2656**	-0.0180	-0.1280	0.1641	0.0100	0.0017	0.1878	-0.1771	-0.0053	0.1398
P(R)	-0.0814	**-0.0586**	-0.1617	0.0474	0.0307	-0.0017	0.3223	-0.3073	-0.0259	0.2052*
K(R)	-00409	-0.0014	**-0.8318**	0.1261	0.0156	0.0082	0.0093	-0.0060	-0.0117	0.1458
Ca(R)	-0.0710	-0.0045	-0.1708	**0.6141**	0.0149	0.0061	0.2785	-0.2415	-0.0087	0.3962**
Mg(R)	-0.0426	-0.0290	-0.2092	0.1474	**0.0621**	0.0040	0.2748	-0.2875	-0.0344	0.1777
S(R)	-0.0201	0.0044	-0.3140	0.1714	0.0114	**0.0218**	0.4268	-0.3453	-0.0048	0.3407**
N(H)	-0.0427	-0.0043	-0.3445	0.0706	0.0111	0.0019	0.2026	-0.1950	-0.0395	0.3475**
P(H)	-0.0318	-0.0496	0.1777	0.0258	0.0303	-0.0041	0.1724	-0.1743	-0.0238	0.1937*
K(H)	-0.0436	-0.0114	-0.8295	0.1313	0.0150	0.0084	0.0309	-0.0115	-0.0134	0.1694
Ca(H)	-0.0465	-0.0010	-0.0836	0.5472	0.0114	0.0024	-0.0027	-0.0113	0.0078	0.2300*
Mg(H)	-0.1097	-0.0204	-0.0523	0.2399	0.0109	0.0030	0.7258	-0.6275	-0.0333	0.4714**
S(H)	0.0230	-0.0026	-0.4153	0.2374	0.0095	0.0097	0.6049	-0.5053	-0.0418	0.4033**
FY	-0.0373	-0.0141	-0.0058	0.1277	0.0127	0.0070	**1.3391**	-1.1626	-0.0448	1.0000**
DY	-0.0339	-0.0152	-0.0043	0.1256	0.0151	0.0064	1.3191	**-1.1803**	-0.0433	0.5971**
Oleoresin	-0.0131	-0.0142	-0.0907	-0.0500	0.0200	0.0010	0.5611	-0.4779	**-0.1070**	0.2018*

Table 25c. Direct and indirect effect of nutrients and yields on essential oil

	N(H)	P(H)	K(H)	Ca(H)	Mg(H)	S(H)	FY	DY	Oleoresin	rc
N(L)	0.0389	0.0134	0.1449	-0.0086	0.0554	-0.1405	0.6519	-0.5549	-0.0441	0.3270**
P(L)	0.0080	-0.0026	0.1964	-0.0975	-0.0235	-0.0527	-0.2108	0.2151	-0.0224	-0.0033
K(L)	0.0358	-0.0048	0.1292	-0.1582	0.0763	-0.1508	0.3987	-0.3279	-0.0201	0.3673**
Ca(L)	0.0205	-0.0199	-0.0877	-0.0991	0.0657	-0.0712	0.4980	-0.4290	-0.0245	0.1443
Mg(L)	0.0590	0.0002	0.1947	-0.1328	0.0684	-0.1082	0.4448	-0.3667	-0.0220	0.4314**
S(L)	0.0861	0.0064	0.2108	-0.0331	0.0812	-0.1988	0.9303	-0.7864	-0.0421	0.6391**
N(R)	0.0367	0.0183	0.1120	-0.0417	0.0736	0.0221	0.1878	-0.1771	-0.0053	0.1398
P(R)	0.0167	-0.1294	0.1322	-0.0041	0.0622	-0.0112	0.3223	-0.3073	-0.0259	0.2052*
K(R)	0.0946	0.0327	1.6799	-0.0239	0.0112	-0.1275	0.0093	-0.0060	-0.0117	0.1458
Ca(R)	0.0263	0.0064	0.1458	-0.2121	0.0696	-0.0987	0.2785	-0.2415	-0.0087	0.3962**
Mg(R)	0.0409	0.0748	0.1650	-0.0436	0.0312	-0.0390	0.2748	-0.2875	-0.0344	0.1777
S(R)	0.0196	-0.0288	0.2611	-0.0257	0.0242	-0.1131	0.4268	-0.3453	-0.0048	0.3407**
N(H)	**0.2284**	0.0130	0.2813	-0.0165	0.0566	-0.0947	0.2026	-0.1950	-0.0395	0.3475**
P(H)	0.0194	**0.1529**	0.1442	-0.0104	0.0313	-0.0018	0.1724	-0.1743	-0.0238	0.1937*
K(H)	0.0942	0.0323	**0.6819**	-0.0260	0.0147	-0.1297	0.0309	-0.0115	-0.0134	0.1694
Ca(H)	0.0158	-0.0067	0.0799	**-0.2380**	0.0682	-0.0771	-0.0027	-0.0113	0.0078	0.2300*
Mg(H)	0.0726	0.0269	0.0563	-0.0911	**0.1782**	-0.0851	0.7258	-0.6275	-0.0333	0.4714**
S(H)	0.0847	0.0011	0.3465	-0.0719	0.0594	**-0.2253**	0.6049	-0.5053	-0.0418	0.4033**
FY	0.0346	0.0197	0.0157	0.0005	0.0966	-0.1153	**1.3391**	-1.1626	-0.0448	1.0000**
DY	0.0377	0.0226	0.0066	0.0023	0.0948	-0.1093	1.3191	**-1.1803**	-0.0433	0.5971**
Oleoresin	0.0844	0.0340	0.0855	0.0173	0.0554	-0.0997	0.5611	-0.4779	**-0.1070**	0.2018*

Residual 0.2754

rhizome yield and oleoresin content also showed significant positive correlation co-efficient values of 1.0000, 0.5971 and 0.2018 with essential oil content. Negative indirect influences by dry rhizome yield and oleoresin were overcome by positive influence of fresh rhizome yield.

Residual values of 0.0021 and 0.0024 were obtained when fresh rhizome yields and dry rhizome yields were taken as the dependant characters. In the case of oleoresin and essential oil, corresponding values were 0.3239 and 0.2754, indicating the involvement of other characters which are not considered in the analysis, on quantitative and qualitative yield components.

4.8 pH and nutrient content in the soil

4.8.1 pH

Before the experiment, pH of the soil was 5.3. Slight increases in values were noticed after the experiment. Highest value was observed in T_8, where S and Ca was given as first top dressing.

4.8.2 Organic carbon

Significant variations existed among the various treatments with regard to the organic carbon content (Table 26). Before the experiment, organic carbon content in the soil was 1.08 per cent. After the experiment, the highest value was recorded for T_1 (POP) and the least value was in absolute control (T_{12}), and T_{11}, where only FYM was applied and T_9, in which Mg was applied along with S as first top dressing. Under high quantity of OM @ 20 tonne ha^{-1} as in the experiment, the decomposition and mineralization may be higher particularly in the absence of chemical fertilizers. Under higher decomposition rate, the organic carbon content in the soil can be less.

4.8.3 Available nitrogen

Available nitrogen in the soil also showed significant variations among the various treatments. At the pre planting stage, content of available nitrogen was 756 kg per hectare. Crop cultivation resulted in decreased available N content after the experiment. After the experiment, the highest value was recorded in the treatment receiving Ca along with S as first top dressing (T_8), followed by T_3, where S was applied as first top dressing. The lowest value was recorded in absolute control (T_{12}).

4.8.4 Available phosphorus

The initial value of phosphorus recorded in the soil was 22.3 kg ha^{-1}. After the experiment available P contents were seen to increase, except in absolute control. The highest value was recorded in the treatment T_1 (POP), followed by T_8 (33.56 kg/ha) where Ca along with S was applied as first top dressing. Other treatments were on par except T_{11}, in which only FYM was applied, and T_{12} (absolute control), which recorded the lowest values.

4.8.5 Available potassium

Analysis of soil for available potassium also showed significant variations among the various treatments with contents increasing after the experiment. Before the experiment potassium content in the soil was 356 kg ha^{-1}. Afterwards the highest value of 417.21 kg/ha was recorded by the treatment T_6, where extra dose of K was applied along with S as first top dressing, and was on par with T_1(POP), followed by the treatment receiving S as first top dressing (T_3) and the least by T_{12}.

4.8.6 Available sulphur

Available sulphur in soil before the experiment was 21.03 kg ha^{-1}. After the experiment, sulphur content showed variation among the treatments. The highest value was recorded in T_5 (21.98 kg/ha), where an extra dose of K was applied as second top dressing, followed by T_9, in which S and Mg were top dressed 1MAP, and the lowest value was in absolute control (T_{12}).

4.8.7 Available calcium and magnesium

Before the experiment the contents of Ca and Mg in the soil were 76.16 and 22.41 kg/ha respectively. After the experiment calcium content was highest in the treatment where Ca and S were top dressed (T_8). Other treatments were on par except T_{11}, in which only FYM was applied and absolute control (T_{12}), In the case of Mg the highest value (29.12 kg/ha) was recorded in T_1 (POP), followed by the treatment in which both S and Ca were applied as first top dressing (T_8). In both the cases the lowest value was in T_{12}.

Table 26. pH and major nutrient contents in soil before and after the experiment

Before the experiment	Treatment	pH	Organic C (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
		5.3	1.08	756	22.3	356
After the experiment						
T_1	POP	5.4	1.170[a*]	616[bc]	36.30[a]	416.64[a]
T_2	POP less 10 t FYM	5.5	1.100[ab]	588[cd]	29.46[abc]	396.11[c]
T_3	POP+ S-1 MAP	5.5	1.103[ab]	658[ab]	26.03[abc]	408.81[b]
T_4	POP+ S-3 MAP	5.6	0.903[de]	518[ef]	23.95[abc]	348.32[fg]
T_5	POP+ K-3 MAP	5.5	0.980[cd]	574[cd]	25.07[abc]	352.81[fg]
T_6	POP+K+S-1 MAP	5.7	0.950[cde]	588[cd]	31.55[abc]	417.21[a]
T_7	POP+K+S-3 MAP	5.6	0.860[e]	616[bc]	29.43[abc]	346.09[g]
T_8	POP+ S + Ca	5.8	0.990[cd]	672[a]	33.56[ab]	361.76[de]
T_9	POP+ S + Mg	5.7	0.853[e]	560[de]	32.12[abc]	356.16[ef]
T_{10}	50:50:50 kg N,P,K	5.5	1.020[bc]	602[cd]	28.28[abc]	390.32[c]
T_{11}	FYM alone	5.4	0.860[e]	490[fg]	22.10[bc]	367.37[d]
T_{12}	Absolute control	5.4	0.860[e]	448[g]	19.83[c]	331.52[h]

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

Table 27. Secondary nutrient contents in soil before and after the experiment

Before the experiment	Treatment	S (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
		21.03	76.16	22.41
After the experiment				
T_1	POP	18.91[d]	82.88[ab]	29.12[a]
T_2	POP less 10 t FYM	15.12[g]	82.88[ab]	23.96[c]
T_3	POP+ S-1 MAP	16.25[f]	82.88[ab]	20.83[cd]
T_4	POP+ S-3 MAP	17.63[e]	89.60[ab]	21.78[cd]
T_5	POP+ K-3 MAP	21.98[a]	105.28[ab]	21.72[cd]
T_6	POP+K+S-1 MAP	20.17[c]	82.88[ab]	17.92[de]
T_7	POP+K+S-3 MAP	15.39[g]	82.88[ab]	20.83[cd]
T_8	POP+ S + Ca	16.28[f]	112.00[a]	28.44[ab]
T_9	POP+ S + Mg	21.07[b]	89.60[ab]	23.96[c]
T_{10}	50:50:50 kg N,P,K	19.83[c]	73.92[ab]	24.64[bc]
T_{11}	FYM alone	14.87[g]	67.20[b]	17.92[de]
T_{12}	Absolute control	14.70[g]	60.48[b]	15.68[e]

*In a column, means superscribed by common letters do not differ significantly at 5% level by DMRT

Discussion

5. DISCUSSION

Nutrient effects on vegetative growth and dry matter accumulation

Kacholam (*Kaempferia galanga* L.) is a medicinal plant with a distinct growth habit. The plant produces a limited number of overlapping persistent leaves and shoots which grow in a cluster. The leaves and shoots, which are the sites of photosynthesis were seen not to be influenced to a significant level by nutrient variations.

Observations on leaf number (Table 5) show that there was a progressive increase in number up to six months, and after which there was a decline, associated with senescence. Leaf number was lower in the treatment where manures and fertilizers were not provided and was not affected by nutrient supplementation to package of practice recommendations. Similar findings were reported by Maheswarappa *et al.* (2001) in kacholam, where combination of organic manure with chemical fertilizer resulted in better growth of the crop as reflected in more number of leaves. Similarly, shoot number remained at an almost fixed level, ranging from 2.33 to 3.33, indicating that these characters were not influenced by the combination of nutrients. Only the total avoidance of fertilizer and manure application (T_{12}) could bring about a significant decline in vegetative growth.

A difference in the trend of development was noticed in leaf expansion and in foliage spread (Table 7 and Table 8) measured in two opposite directions at five months after planting. A greater leaf expansion leads to more effective photosynthesis and subsequently improved rhizome production. In kacholam, rhizome development begins at the fourth month and is greatest at the fifth and sixth months. Foliage spread was seen to be significantly greater in some treatments, notably in T_1 (Fig.4 and Fig.5), *i.e.*, package of practice recommendations and where S, and S along with an additional dose of K were top dressed three months after planting (T_4 and T_7). In these three treatments all round foliage spread was found to be maximum, where S was applied as first top dressing and where S and Mg were

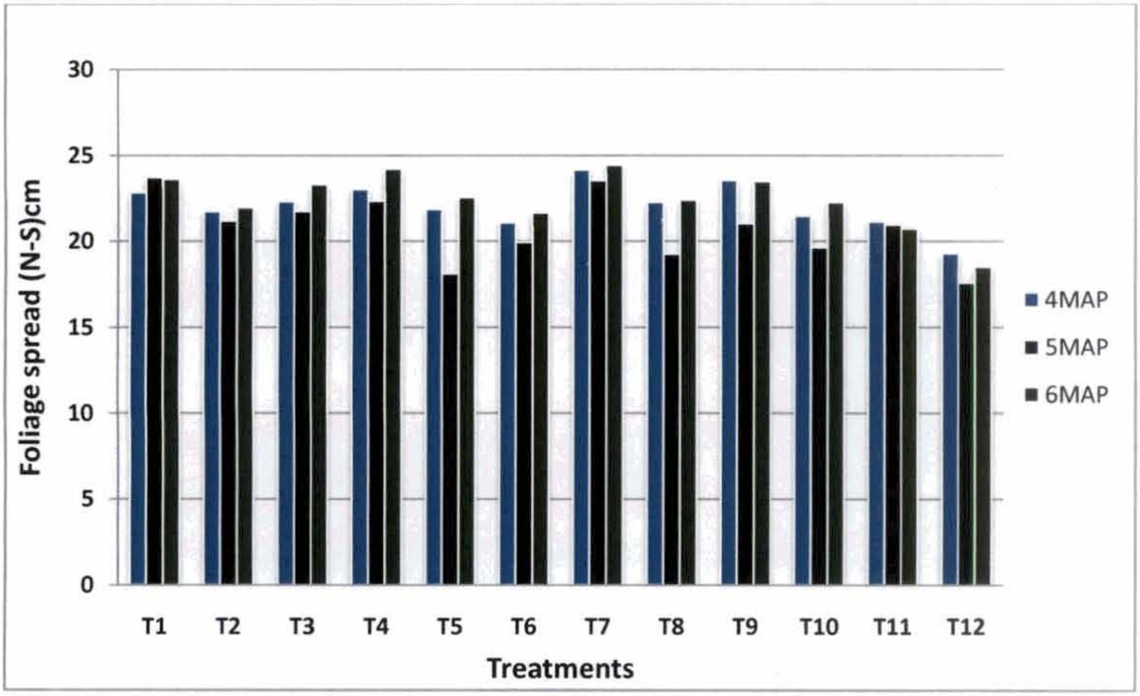

Fig.. 4. North – South foliage spread per plant as affected by nutrient management

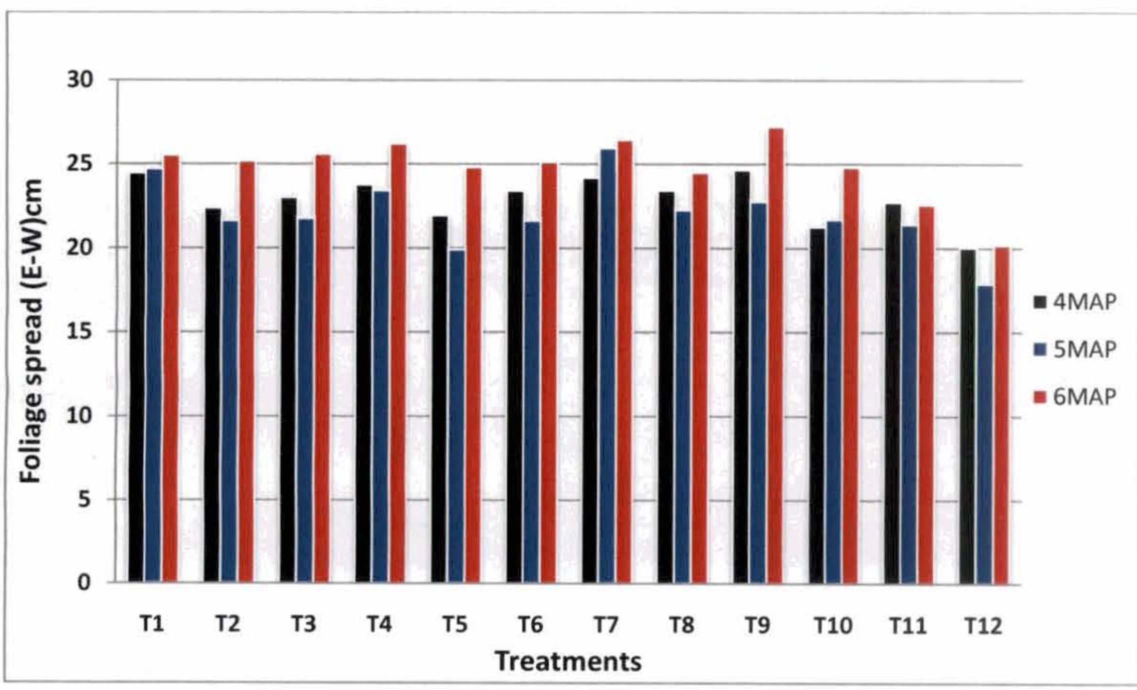

Fig. 5. East–West foliage spread per plant as affected by nutrient management

applied as second top dressing and also when FYM alone was applied (T_{11}), leaf expansion in the North- South direction alone was favourably influenced. The favourable influence of S, K and Mg on leaf expansion is indicated. A similar finding with regard to K application in kacholam was reported by Gangadharan (2003). Medda and Hore (2003) also observed that higher doses of N and K produced higher leaf dimensions in turmeric. However, the differences in leaf spread were not visible at 6 months stage and thereafter, except in absolute control, which was significantly inferior throughout.

Dry matter accumulation at 5 MAP (Table 9) was similar in all treatments except where additional K was top dressed and where fertilizers and manures were applied separately or were not applied at all, in which case DMA was less. The better performance of crops both vegetatively and in yield production due to the combined application of organic manures with chemical fertilizers have been reported in various medicinal plants like kacholam (Maheswarappa *et al.*, 2000), *Solanum nigrum* (Shivanna *et al.*, 2007), *Plantago ovata* (Lekhchand and Dadheesh, 2008) and *Phyllanthus amarus* (Kumar *et al.*, 2010).

Nutrient effects on yield and quality

Rhizome yield and yields of essential oil and oleoresin are equally important in kacholam. The qualitatively important components are synthesized from the primary photosynthates and stored in the rhizomes. Hence the development of both should proceed in a balanced manner.

Kacholam is harvested seven months after planting, by which time complete senescence and drying of the leaves would have occurred. Results show that significantly higher yields, both fresh and dry, were obtained when S was top dressed at one and three months after planting, and when along with S, Ca or Mg was also applied (Table 10 and Fig.6). This corresponded, to some extent, in treatments where leaf expansion was greater.

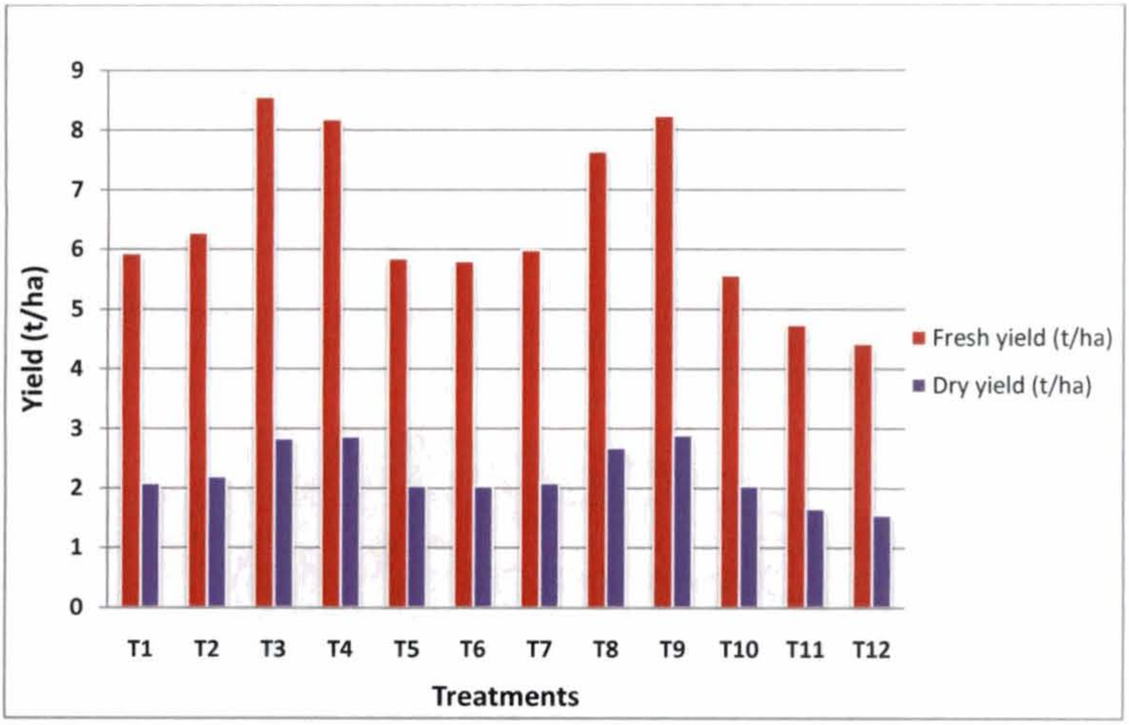

Fig. 6. Yield of rhizome as affected by nutrient management

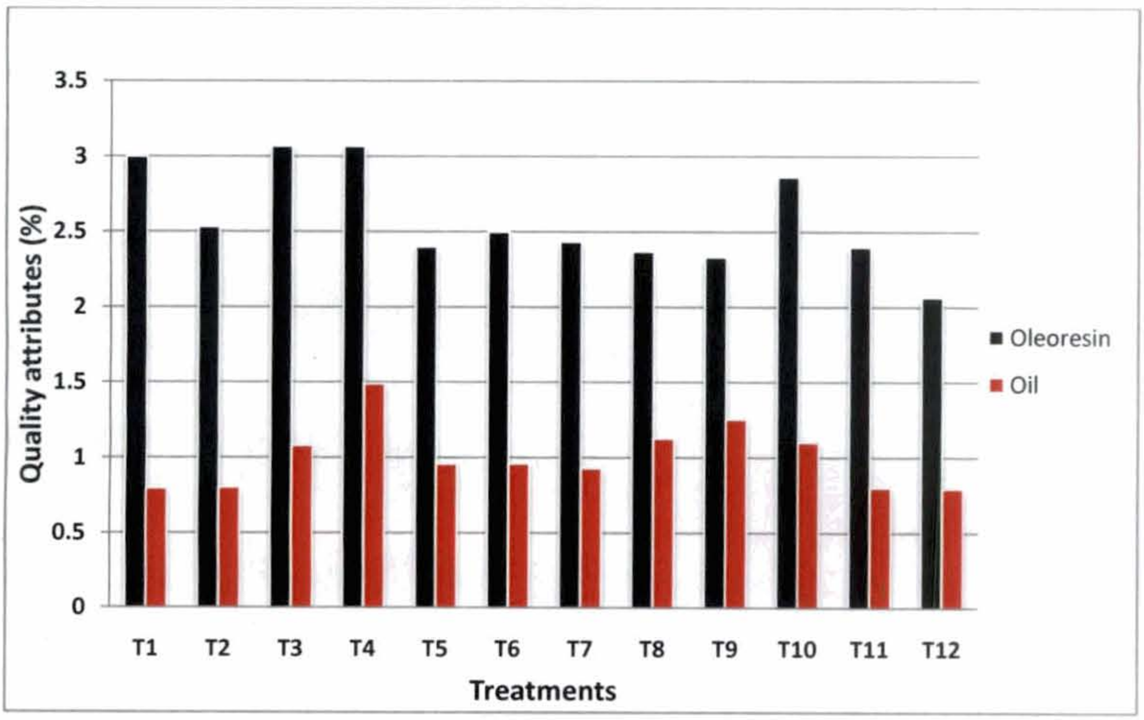

Fig. 7. Quality attributes in kacholam as affected by nutrient management

The dose of N seems to be adequate for growth and yield of kacholam. However, from the data on soil contents of available P (Table 26), it appears that the P dose is more than required, and a reduction can be considered.

The effect of S on increasing rhizome yields was strongly indicated (Table 10). Sulphur is reported to play a major role in increasing nitrogen use efficiency (Fismes *et al.*, 2000; Kopriva and Rennenberg, 2004). Sulphur is also observed to play a role in the proper utilization of phosphorus and potassium in plants (Kumar and Singh, 1994). Rhizome yields were also seen to be significantly higher when sulphur was applied in combination with calcium or magnesium. Gangadharan (2003) had speculated on the improvement in the development of quantitative components in kacholam by the application of $MgSO_4$ one month after planting. Similarly, Singh and Dwivedi (1993) reported maximum tuber yields in potato when sulphur was applied through gypsum. Increased potassium doses, even when combined with sulphur, produced less yields as compared to application of sulphur, or sulphur with calcium or magnesium along with recommended nutrient doses. The driage showed a different trend, with application of fertilizers alone, including a higher dose of K, recording the highest value of 36.69 %. However, the values were not significantly different (Table 10).

The data also showed that reduction of the organic manure dose to half did not reduce yield as compared to POPR, indicating the possibility of reducing the organic manure recommendation. Supplementing K, S, Ca and Mg with a reduced organic manure dose would therefore be effective in optimizing yields.

A perusal of the qualitative components in the rhizomes (Table 12 and Fig.7) revealed that accumulation of essential oil strongly followed the trend of rhizome yield. Treatments including sulphur application, either alone (T_3 or T_4) or with calcium or magnesium (T_8 and T_9) along with recommended package of practices resulted in higher essential oil yields. Oleoresin contents followed a slightly different pattern. Though treatments T_3 and T_4 exerted superiority here also, application of fertilizers alone with higher dose of K, and the treatment receiving recommended POP were on par. Ca and Mg application did not improve oleoresin contents.

Combined application of N and S has been reported to increase the quercitin content in Pluchea (Kumar *et al.*, 2004), while Lalitha *et al.* (1997) recorded higher starch and protein contents in potato when K and S were combined.

Data on uptake of nutrients revealed that integrated nutrient management resulted in higher uptake of all nutrients at five months stage (Table 17). The treatment receiving package of practices recommendations recorded highest uptake of N, which was in line with higher vegetative growth in terms of leaf number, shoot number and foliage spread. Top dressing with S also resulted in high N uptake, but K, Ca and Mg were seen to decrease N uptake. Reduction of farmyard manure to half the recommended dose (T_2) had a depressing effect on uptake of N, K, S and Mg and can be related to lower supply of these elements. S when top dressed alone at one month stage, increased N and S uptake, but K and Ca uptake were low. Second top dressing of K and S resulted in increased uptake of P, K and Mg indicating the need for these elements at later stages of growth.

Nutrient uptake figures in rhizomes at harvest (Table 19) indicated the beneficial effects of top dressing with S three months after planting (T_4). Highest values for uptake of N, P, K, S and Mg were obtained with this treatment. It also corresponded with highest rhizome yield, oleoresin and essential oil content. It was also seen that the treatments including top dressing with S, Ca and Mg (T_8 and T_9) also corresponded with increased uptake values of N, P, Ca and Mg (Table 12) and were reflected in increased essential oil contents.

Chlorophyll content in leaves at two and half and five month's stage was seen to be highest in T1, which was given nutrients as per package of practices recommendation, and was reflected in the high N uptake in this treatment (Table 20 and 21). Similar results were observed by Maheswarappa *et al.* (1999) in arrowroot. High chlorophyll a:chlorophyll b ratio in treatments T_3 and T_4, where S was top dressed indicated higher photosynthetic efficiency and gave further evidence of the role of this element in increasing yield and quality.

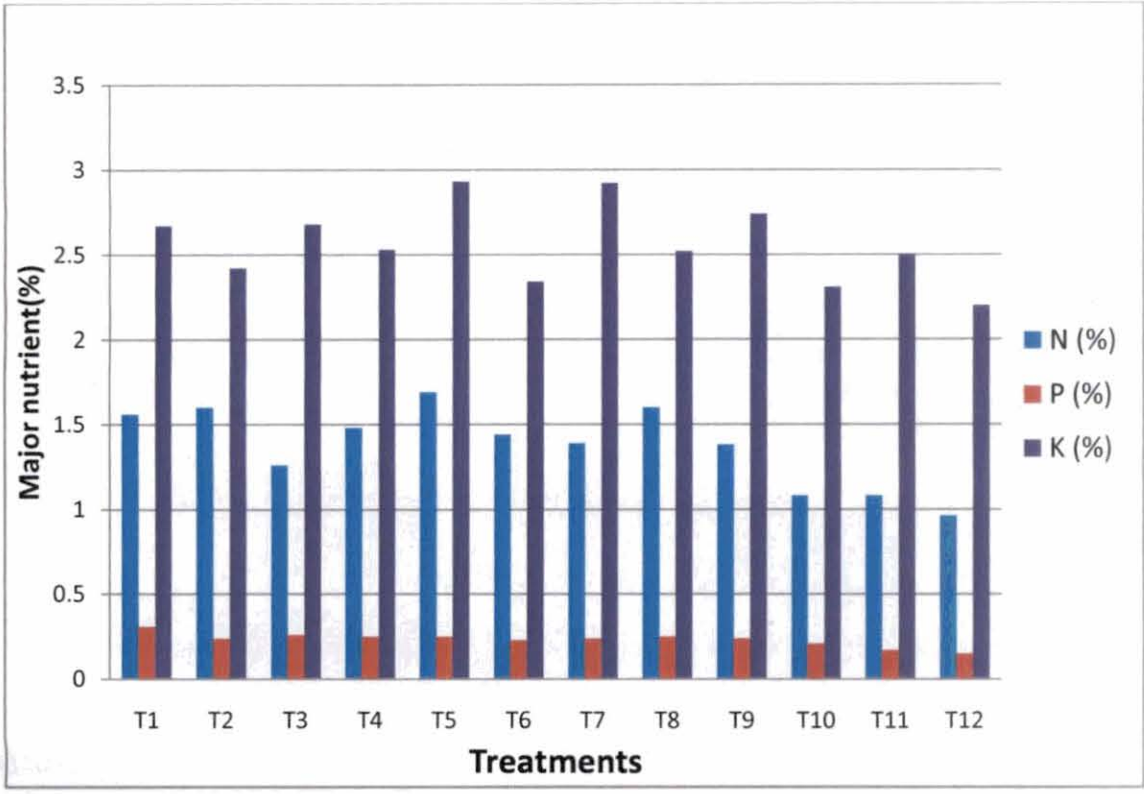

Fig. 8. Major nutrient in leaves at 2 ½ month as affected by nutrient management

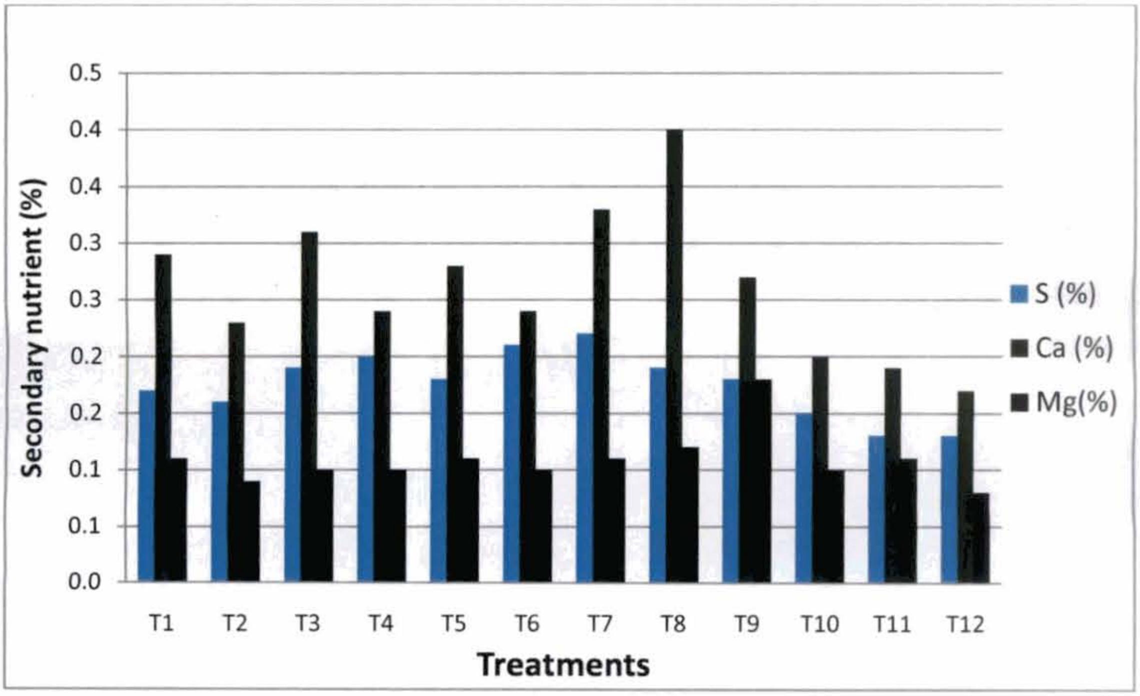

Fig. 9. Secondary nutrient in leaves at 2 ½ month as affected by nutrient management

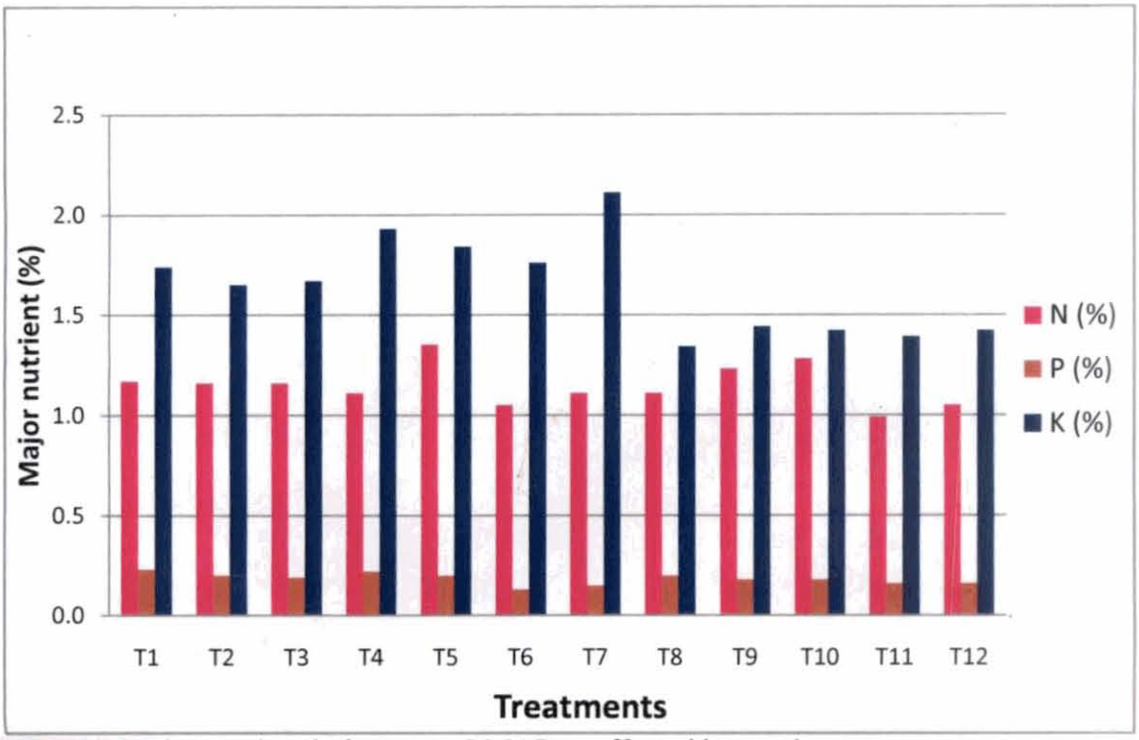

Fig. 10. Major nutrient in leaves at 5 MAP as affected by nutrient management

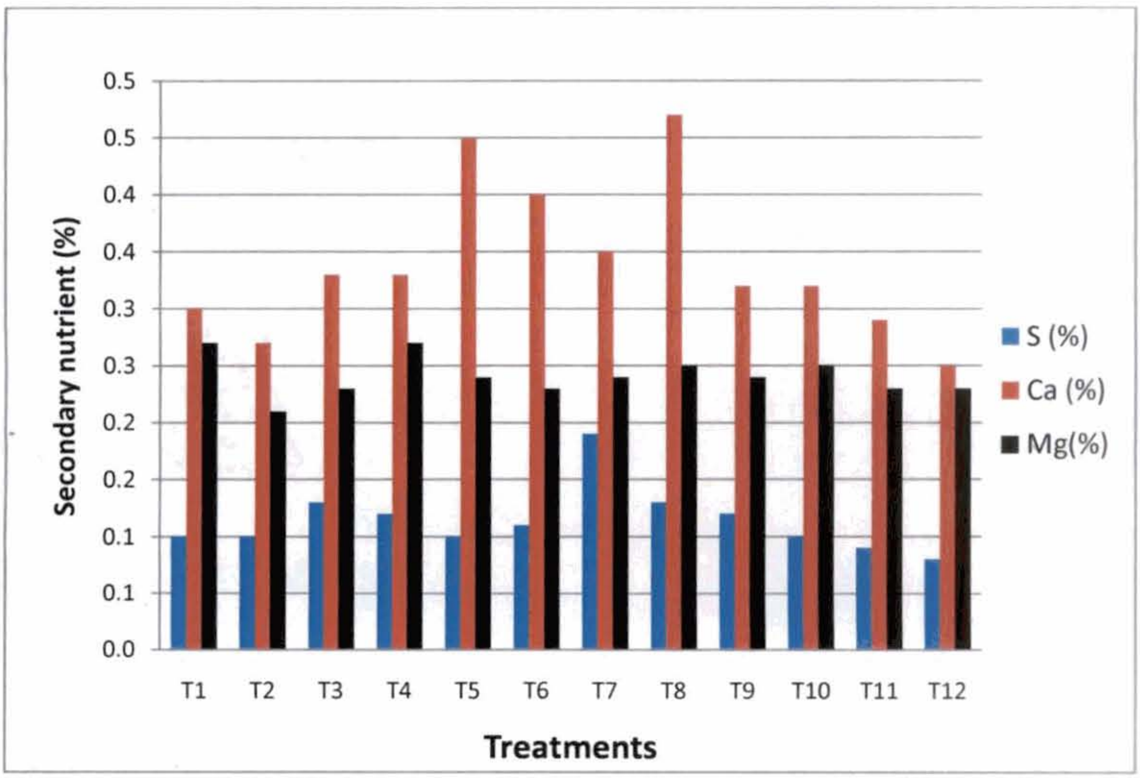

Fig. 11. Secondary nutrient in leaves at 5 MAP as affected by nutrient management

Elemental contents in leaves and rhizomes and effect on productivity

The nutrient contents in leaves and rhizomes showed varying trends (Table 13,14,15 and 16). In general, it could be observed that in absolute control and in treatments where either farmyard manure or fertilizers were avoided (T_{10} and T_{11}), contents were significantly lower (Fig.8,9,10,11,12,13,14 and15). Another observation was that P content did not vary with treatments, indicating that P is not a limiting factor. K contents were also not significantly different in treatments receiving both farmyard manure and fertilizers.

Path analysis

Path co-efficient analysis revealed that elemental contents of leaves and rhizomes at 5 MAP (months after planting) did not have any significant and high direct effects on fresh rhizome yield. However, K content of rhizomes at harvest stage was seen to have significant positive influence. Dry rhizome yield was also seen to be significantly and positively affected by K content of rhizomes at 5 month stage (Table 23b.). At harvest stage however, K was seen to exert high negative influence on dry rhizome yield (Table 23c.). Thus with regard to rhizome yield, it can be concluded that K application has a direct positive effect on fresh yield, but not on dry yield. Other nutrients did not seem to significantly influence rhizome yield. This indicates the role of K, and possibility of higher K doses significantly increasing yield. The assumption that higher K levels can increase yield is thus confirmed.

The qualitative components of kacholam are the oleoresin and essential oil. At 5 MAP, when rhizomes are developing, but qualitative development is expected to be just beginning, N and Mg in leaves were found to have positive impact, while P, K and S were seen to be inhibitory. In rhizomes at this stage, the inhibitory influence of K and Ca were very high (-1.0149 and -0.7787), while Mg again was found to have promoting effect. This effect was reversed at the harvesting stage of kacholam, when K, Ca and S were found to have high significant positive effects on oleoresin content, while Mg had depressing effect. At this stage, N continued to have

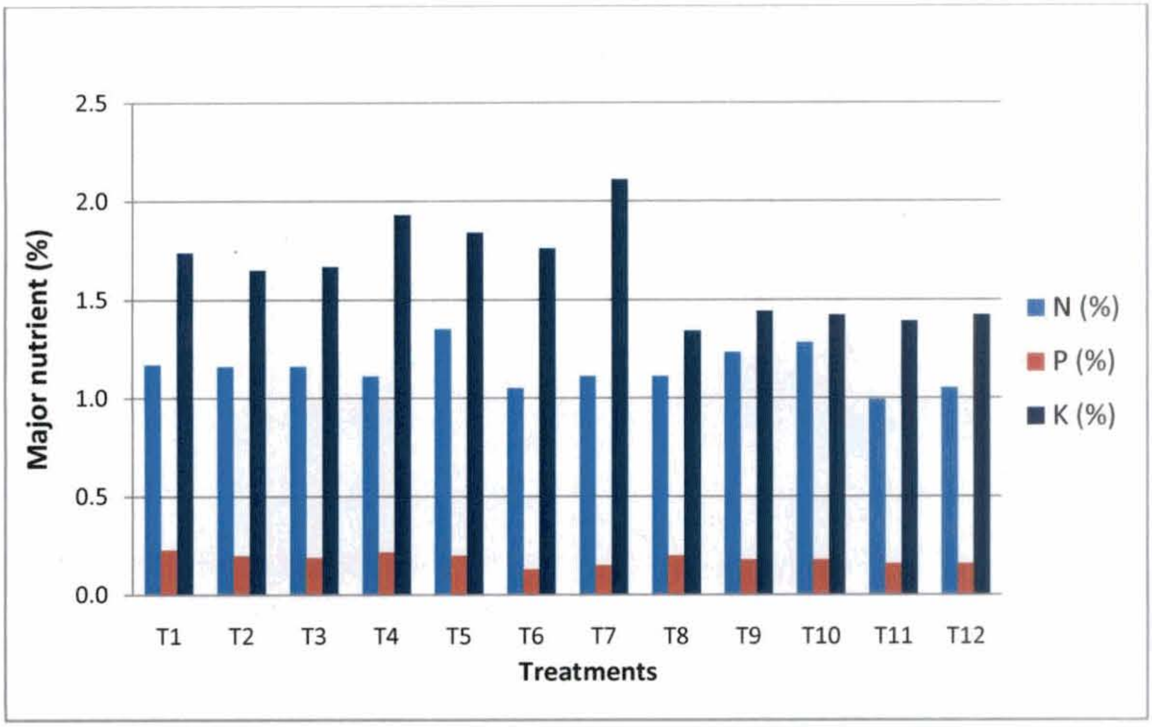

Fig. 12. Major nutrient in rhizomes at 5 MAP as affected by nutrient management

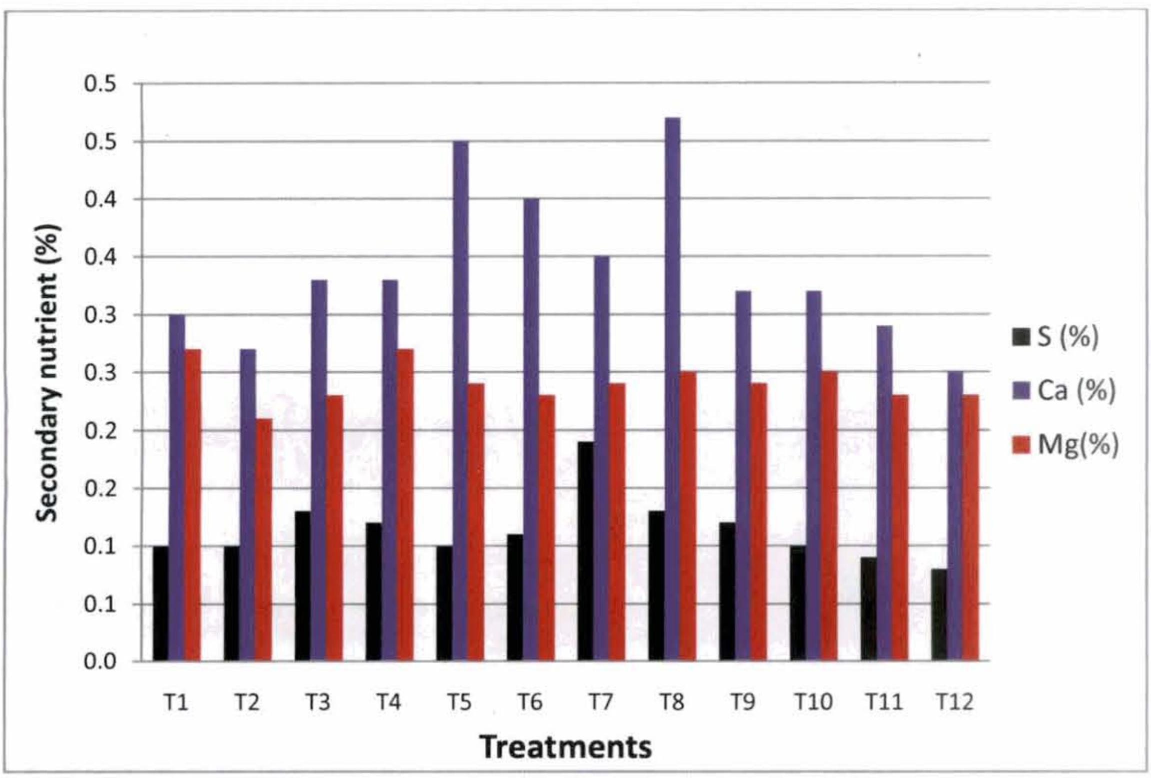

Fig. 13. Secondary nutrient in rhizomes at 5 MAP as affected by nutrient management

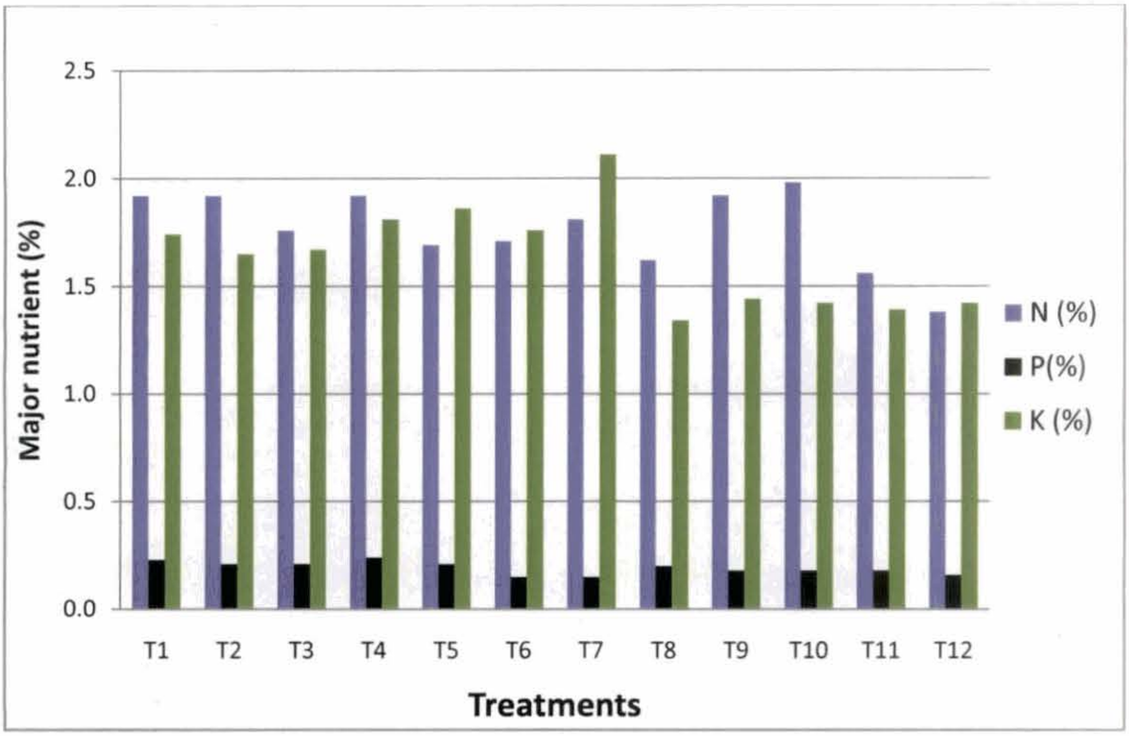

Fig. 14. Major nutrient in rhizomes at harvest as affected by nutrient management

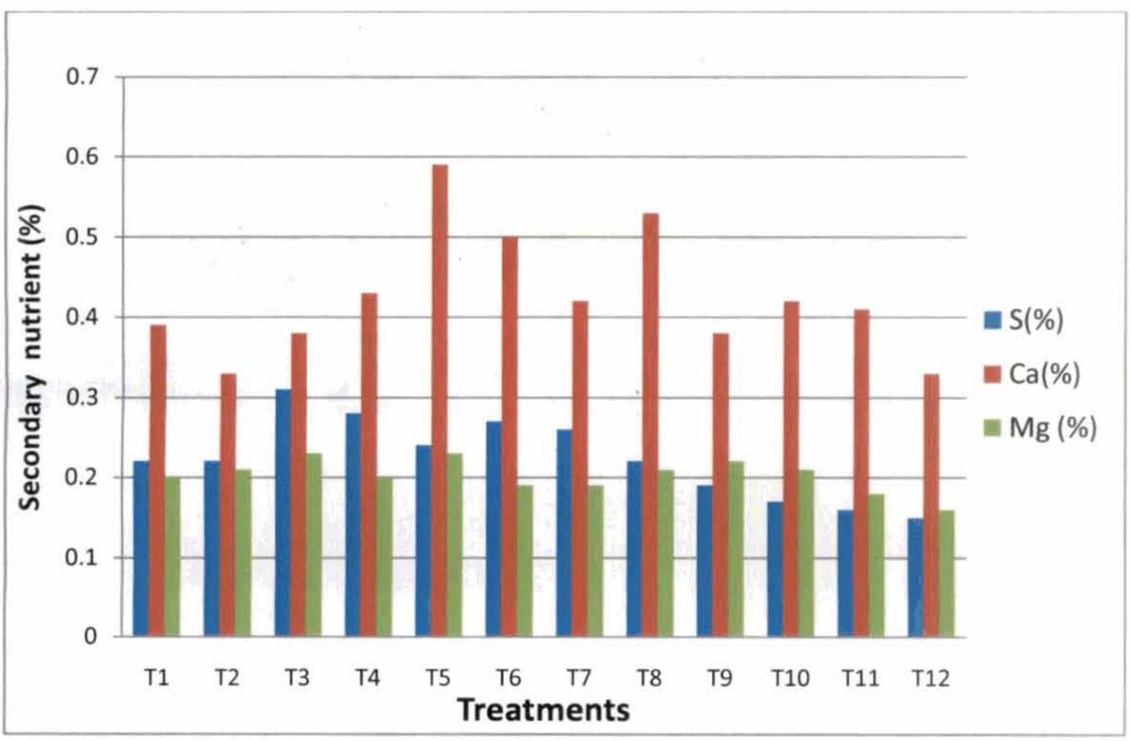

Fig. 15. Secondary nutrient in rhizomes at harvest as affected by nutrient management

positive effect, but to a lesser extent than that of K, Ca and S. The results clearly point to the role of N and Mg having definite roles in early development and photosynthate accumulation, and K, Ca and S being involved at later stages in oleoresin development (Table 24c.).

The data on essential oil content showed a different trend. At early stages, *i.e.* at 5 MAP, while just as in oleoresin development, K and Ca showed direct negative effects, Mg and S showed high positive influence. At this stage, in the rhizomes, N and K showed inhibitory effects while Ca had high promoting effect (Table 25b.). At harvest, K showed high positive effect (0.6819), along with N (0.2284) and Mg (0.1782), while, Ca and S were seen to be inhibitory (Table 25c.). The role of K in essential oil development again seems to be indicated, but Ca, Mg and S seem to be involved in a different manner from that in oleoresin formation. Mg appears to be involved significantly in essential oil development, while Ca and S seem to play lesser roles. Different pathways and involvement of different nutrients in development of the qualitative components, oleoresin and essential oil are indicated.

Higher rhizome yields in kacholam were obtained when S was applied in combination with calcium or magnesium (Table 22c.). Path coefficient analyses indicate that these elements play an important role in development of oleoresin and essential oil. The role of K in improving qualitative components is evident, and is probably due to interactive effects with other elements, particularly N. Similar results have been obtained in ginger (Haque *et al.*, 2007) and cassava (Suja *et al.*, 2006). Interactions of K and S leading to improved yields and quality have been reported in potato (Lalitha *et al.*, 1997) and onion (Nandi *et al.*, 2002).

From the above discussion, it is evident that a nutritional management system that includes the secondary nutrients at different phases of growth would maximize yield and quality of *Kaempferia galanga*. The nutrient application strategy should be based on the following:

1. N dose recommended as per package of practices was seen to be sufficient for vegetative growth and for development of quantitative and qualitative yields.

2. Reduction of the recommended dose of P can be considered.

3. Change in N:K ratio, or increasing the K dose, did not have positive effect on yield. However, K had significant effect on development of rhizomes as well as on oleoresin and essential oil contents. As the effect is evident in later stages, supplying an additional dose of K at a later stage, i.e., at 4 or 5 month stage is to be tried.

3. Sulphur and Ca, Mg all had significant positive effects on rhizome yield and on essential oil and oleoresin contents. Sulphur was seen to have a pronounced effect. Trials with varying doses of these elements for arriving at the optimum combination are called for.

4. Reduction of FYM to 50% of the recommended dose did not reduce rhizome yields or qualitative components as compared to POPR. Reduction in yield compared to other treatments can be offset if K, Ca, Mg and S are provided by way of fertilizers. A combination of half the recommended organic manure dose along with N, P, K, Ca, Mg and S would promote optimum yields.

Future thrust

Future line of work should be focused on the following :

- Reduction of the recommended dose of P is to be considered.

- Fixing the dose and schedule of application of S, Ca and Mg to maximize productivity.

- Supplementing Ca, Mg and S at reduced organic manure levels should be tested.

- Inclusion of N biofertilizers and P and K solubilizing microorganisms

- Investigating the role of micronutrients and micronutrient management for higher yield and quality.
- Studies on the application of lime to alter the pH and effect on availability of secondary and micronutrients.

Summary

6. SUMMARY

A field experiment was conducted during 2010-2011 in the coconut garden of the Water Management Research Unit, Vellanikkara to evaluate the effect of varying doses of K and secondary nutrients on yield and quality of kacholam. There were 12 treatments with 3 replications each. Treatments consisted of package of practices (POP) recommendation of 20 tonnes farmyard manure along with 50:50:50 kg N, P and K ha^{-1} and combinations with S, Ca, Mg and extra dose of K applied one month and three months after planting as first and second top dressing. Rhizome bits were planted at a spacing of 20 x 15 cm in the first week of June, 2011. Harvesting was done seven months after planting.

Leaf number was not affected by nutrient supplementation through package of practice recommendations. Leaf number was lower only in the treatment where manures and fertilizers were not provided.

Only the total avoidance of fertilizer and manure application could bring about a significant decline in vegetative growth.

Foliage spread was seen to be significantly greater in the treatments where package of practice recommendations was given and where S, and S along with an additional dose of K were top dressed three months after planting.

When S was applied as first top dressing, and where S and Mg were applied as second top dressing and also when FYM alone was applied, leaf expansion in the North- South direction alone was favourably influenced. The favourable influence of S, K and Mg on leaf expansion was indicated.

Higher yields, both fresh and dry, were obtained when S was top dressed one and three months after planting, and when along with sulphur, Ca or Mg was also applied.

The highest driage percentage of 36.69 % was recorded with application of fertilizers including a higher dose of K, alone.

Treatments including sulphur application, either alone or with calcium or magnesium along with recommended package of practices resulted in higher essential oil yields.

Treatments, where S was given as first and second top dressing showed highest oleoresin content. The application of fertilizers alone with higher dose of K, and the treatment receiving recommended POP were also on par. Ca and Mg application did not improve oleoresin contents.

Uptake of nutrients at five months stage revealed that the treatment receiving extra dose of K along with S showed highest uptake of all nutrients except N. Nitrogen uptake was highest in the treatment which received package of practices recommendation.

At harvest, highest values of N, P, K, S and Mg uptake were obtained in the treatment where S was given as second top dressing.

Chlorophyll content in leaves at two and half and five months stage was seen to be highest when package of practices recommendation was applied. High chlorophyll a : chlorophyll b ratio in treatments where S was top dressed indicated higher photosynthetic efficiency and gave further evidence of the role of this element in increasing yield and quality.

Comparing N:K ratios among different treatments, it was seen that N:K ratio of 1:1 was beneficial. Changing N:K ratio did not increase yield and other quality parameters.

Phosphorus content did not vary with treatments, thus indicating that P is not a limiting factor. P content in soil after the experiment was seen to increase, and so P application may be in excess.

Comparing benefit : cost (B:C) ratios between treatments, reducing organic manure to half did not cause any decrease in yield and resulted in increase in B:C ratio. Highest B:C ratios were observed in treatments receiving POP supplemented with S alone, and S along with Ca.

Path coefficient analyses indicated that K, S, Ca, and Mg play an important role in producing higher rhizome yields along with higher oleoresin and essential oil.

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Appendices

APPENDIX – 1

Weekely mean surface air temperature (0C), relative humidity (%), sunshine hours (hrs/day) and rainfall (mm/week), at COH, Vellanikkara from June 2011 to January 2012.

Month	Week No.	Surface air Temp.(^{0}C)		Relative Humidity (%)		Sunshine Hours (h/day)	Rainfall (mm/week)
		Max.	Min.	Morning	Evening		
June	23	29.60	24.00	95	86	1.9	211.50
	24	28.50	23.70	95	86	2.0	205.60
	25	30.40	23.40	96	76	3.9	122.00
	26	29.90	23.10	96	79	3.2	86.40
	27	30.40	23.20	94	94	4.0	19.10
July	28	29.00	23.30	94	94	2.3	16.20
	29	28.30	22.40	96	83	0.7	218.20
	30	28.50	22.90	96	83	1.1	132.80
	31	28.50	22.60	96	86	0.6	231.00
Aug	32	29.20	22.50	97	80	1.7	216.70
	33	30.20	22.90	96	74	3.0	20.80
	34	29.60	22.80	94	73	3.6	62.50
	35	28.80	23.30	95	85	0.9	286.90
	36	30.00	23.10	95	79	2.7	131.90
Sep	37	28.90	22.80	96	79	2.4	174.80

Month	Week No.	Surface air temp.(^0C)		Relative Humidity(%)		Sunshine Hours (h/day)	Rainfall (mm/week)
		Max.	Min.	Morning	Evening		
	38	30.20	23.40	94	71	4.6	34.20
	39	31.60	23.10	91	63	9.1	0.50
	40	32.30	23.30	91	58	9.5	0.00
Oct	41	32.40	23.40	92	62	6.2	5.90
	42	32.30	23.70	92	69	5.1	94.30
	43	31.70	23.30	89	71	5.0	87.40
	44	30.70	23.30	90	69	2.8	192.80
Nov	45	31.70	22.00	84	54	7.3	34.20
	46	32.40	22.00	80	48	9.3	0.00
	47	30.70	23.90	63	54	6.8	3.50
	48	31.50	23.80	87	64	3.8	11.90
Dec	49	32.10	22.80	82	51	8.5	0.00
	50	32.50	23.90	73	46	8.9	0.00
	51	31.00	23.50	62	44	6.1	0.00
	52	31.70	20.10	81	50	6.4	2.40
Jan	01	32.10	21.60	84	44	8.50	0.00
	02	33.30	22.60	81	44	9.50	0.00
	03	32.00	20.20	71	31	9.10	1.00
	04	32.60	20.80	67	34	9.90	1.00

NUTRIENT MANAGEMENT FOR YIELD AND QUALITY IMPROVEMENT IN KACHOLAM (*Kaempferia galanga* L.)

by

KAVITHA P. R.

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ABSTRACT OF THE THESIS

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ABSTRACT

Kacholam *(Kaempferia galanga L.)* is an important medicinal and aromatic plant of the Zingiberaceae family. In India, kacholam is cultivated throughout the plains for the rhizomes. The economic produce of kacholam is the chopped and dried rhizomes of 6-7 months maturity. Dried rhizomes are used in bulk quantities in ayurvedic medicine and in the cosmetic industry. It is used for curing inflammatory wounds, skin disorders, piles, oedema, fever, epilepsy, splenic disorders and asthma. The constituents of the rhizome oil include para methoxy ethyl cinnamate (60.24 % of the oil), ethyl cinnamate (20.66%), cineol, borneol, 3-carene, camphene, kaempferol, kaempferide and cinnamaldehyde. There is immense scope for cultivation of kacholam in Kerala, as the climatic and soil conditions are optimally suited to its growth and development. Kacholam can be grown as an intercrop in coconut gardens and it has attained the status of a cash crop of homesteads.

Though there is an approved *ad hoc* recommendation of organic manures as well as N, P and K for kacholam, there are reports that the K dose is inadequate. Also, considering the low availability and high cost, the present organic manure recommendation of 20 tonnes ha^{-1} is rather unaffordable. There are also reports about the inadequacy in the availability of secondary nutrients *viz.*, S, Ca and Mg, which may affect yield and quality of kacholam. A field experiment was conducted during 2011-2012 in the coconut garden of Water Management Research Unit, Vellanikkara to evaluate the effect of varying doses of K and secondary nutrients on yield and quality of kacholam. There were 12 treatments with 3 replications each. Treatments consisted of package of practices (POP) recommendation of 20 tonnes farmyard manure along with 50:50:50 kg N, P and K ha^{-1} and combinations with S, Ca, Mg and extra dose of K applied as first and second top dressing. Rhizomes were planted at a spacing of 20 x 15 cm and planting was done on 3/ 06/ 2011. Harvesting was done seven months after planting.

Observations included biometric observations taken at monthly intervals, nutrient contents at 2 ½ and 5 months after planting, and at harvest. Nutrient uptakes was also worked out. Essential oil and oleoresin in rhizomes were also analysed. The soil pH and chemical parameters were analysed before and after the experiment.

There were significant differences among treatments with respect to yield, essential oil, oleoresin, nutrient contents and nutrient uptake. With respect to yield, the treatment receiving S applied either at first top dressing or at second top dressing and that with S, Ca and Mg recorded highest yields as compared to other treatments. Essential oil content also showed the same trend as that of yield. But in case of oleoresin, the content was more only in the treatments receiving S as first and second top dressing. This treatment resulted in highest uptake of all nutrients except Ca at harvest. Application of the secondary nutrients thus had a direct positive effect on yield and quality.

Changing the N:K ratio of present NPK recommendation resulted in reduction of yield and other quality parameters. The yield and quality parameters with the reduced organic manure dose were found similar to the present POP. Increased phosphorus content of soil observed after experimentation indicated the possibility of reducing the recommended phosphorus dose. Supplementing S, Ca and Mg with a reduced organic manure dose is also to be tested.