NUTRIENT STATUS OF THE SOIL AND PLANT AS INFLUENCED BY SPACING AND CONTINUED MANURING IN COCONUT *(Cocos nucifera L.)*

By

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1998

DECLARATION

I hereby declare that this thesis entitled "Nutrient status of the soil and plant as influenced by spacing and continued manuring in coconut (Cocos nucifera L.)" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled "Nutrient status of the soil and plant as influenced by spacing and continued manuring in coconut (Cocos nucifera L.)" is a record of research work done independently by Mr. M. S. Pratheep (94-11-11) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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INTRODUCTION

1. INTRODUCTION

Among the world's different species of palms, coconut palm (*Cocos nucifera* L.) is the most versatile, providing edible and industrial oil, protein rich milk and invigourating water. It is a valuable source of food, fuel, fibre and timber. So the tree is popularly adored as "*Kalpa Vriksha*". Coconut palm is grown under highly heterogeneous conditions of soil ranging from littoral sand to clay, in situations from poorly drained low lying marshes to well drained uplands and hill tops and in acid to highly calcareous soils.

Coconut is grown in an area of about 1.80 million hectares in India with an annual production of 13968 million nuts. The share of India in the global coconut production is 24.1 per cent and in an area of 14.7 per cent. The area and production trends in the country shows that the area increased from 0.59 million hectares in 1949-50 to 1.80 million hectares in 1995-96 and the production during the same period increased from 3448 million to 13968 million nuts.

In India the productivity of coconut per hectare is comparable with yields of other countries, but the per palm productivity is low. Among the various factors responsible for this low production, management practices like improper spacing and inadequate nutrition are important.

Kerala, the land of coconuts as the name means, accounts for the lions share with 50.91 per cent of area and 36.91 per cent of total production in the country. Coconut is one of the most important cash cum food crops of Kerala. About 98 per cent of coconut are grown by small holders distributed throughout the state. It has been estimated that in Kerala there are about 2.5 million holdings and 170 million coconut palms with a palm density of 229 palms per hectare. Coconut being the crop occupying the largest area (45 per cent) in net cropped area and supporting the vast majority of the farming community, the rural prosperity of the state is closely linked with the fortunes of this crop.

Coconut is characterised by a long pre-bearing period and the influence of management practices applied in the early years lasts during the entire productive life. Fertilizer is one of the most influential factors in coconut production, but due to higher fertilizer costs, it is not widely used. In order to make this technique cost effective, fertilizer doses must be chosen carefully applying only what is strictly necessary. Response to fertilizer application is manifested after a time lag in coconut. So the fertilizer experiments in coconut will last for a longer duration.

The spacing adopted in different countries and within the country are varied. In Kerala under square system of planting a spacing ranging from 7.5 to 9 m is generally recommended. With the advancement of more effective agricultural technique it is well accepted that maximum yields can be obtained only if the palms are planted at optimum density. One of the reasons for increasing palm density by cultivators was that the valuation of lands were earlier done on the basis of number of trees and not on yield or area (Menon and Pandalai, 1958).

The productivity of coconut trees is low in Kerala. To ensure uninterrupted high yields, the palms need to be fertilized regularly and adequately and should be planted at optimum distances. The requirement for different fertilizer and their optimal quantities vary with the available nutrients in the soils, the variety of palm and its age and productive capacity as well as the climatic and soil conditions in which they grow.

Continuous application of manures and fertilizers in coconut palms planted at varying densities is likely to bring about changes in soil properties and nutrient status of both soil and plant parts which may influence the crop production in long run.

To achieve maximum crop production more and more fertilizers are often being used by many farmers without ascertaining the rationality of the practices in sustainable agricultural production. Further, there are apprehensions regarding the effects of continuous application of chemical fertilizers. In these circumstances a study to assess the impact of continuous fertilizer application and planting density on the growth and yield of coconut as well as the nutrient composition of soil and plant, is of great practical importance for sustainable coconut cultivation.

The long term "spacing cum manurial experiment" conducted exclusively with chemical fertilizers over a period of 30 years at Coconut Research Station, Balaramapuram, Kerala offered itself an excellent site for conducting such studies. So the present investigation entitled. "Nutrient status of the soil and plant as influenced by spacing and continued manuring in coconut" was taken up with the following objectives :

- To study the effect of spacing and inorganic fertilizer on the growth, yield, yield attributing characters and oil content of coconut ;
- to study the nutrient status of soil in coconut basin under different spacing and fertilizer levels and
- to study the nutrient concentration in leaf due to spacing and fertilizer levels.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Attempts have been made to assess the crop removal of nutrients and the optimum cultural practices in coconut started in the first decade of this century (Child, 1964). There were only few systematic cultural and manurial trials conducted in the first half of this century. Many reasons were put forth for the less number of field experiments in coconut such as the demand of large area for experimentation, little availability of well planted and uniform existing fields to impose treatments and the requirement of long years of efficient supervision.. However a quite large number of experiments on the coconut culture has been taken up in the later part of this century. Available literature on the studies of manurial levels and planting density in coconut has been reviewed in this chapter. The review has been classified mainly under the following headings.

* Effect of fertilization on vegetative growth characters.
* Effect of fertilization on yield and yield components.
* Effect of fertilization on soil and foliar nutrient status.
* Effect of spacing on growth components .
* Effect of spacing on yield and yield components.

2.1 Effect of fertilization on vegetative growth characters

2.1.1 Height and girth

Cultivation and manuring and better soil conditions favour the production of taller stems (Patel, 1938). Mathew and Ramadasan (1964) reported that phosphoric acid has been found to increase the girth of collar in coconut seedlings. Studies in Jamaica showed that application of N increased trunk growth (Anon., 1970 a). Fremond and Ouvrier (1971) have recorded that absence of K application for initial seven years of planting had produced smaller trees (height as well as girth). Muhammed *et al.* (1974) found that height and girth of palms (1.70 m and 68.00 cm respectively) were less in unmanured plots as compared to manured plots (2.21 m and 72.0 cm respectively).

Nelliat *et al.* (1976) observed that application of NPK fertilizers in combination with Ca + Mg to nursery improved height of plants and girth at the collar but the seedling growth was adversely affected by application of Ca + Mg in the absence of NPK. At Davao in an inland upland area coconut palms fertilized with KCl either with N or P produced taller and stouter palms (Prudente and Mendoza, 1976).

Cecil and Pillai (1978) observed that on root wilt affected coconut palms the main effect of P was not found favourable on girth at collar. N application in coconut increased girth and height during the pre-bearing period but P and K had no effect in this (Anon., 1979). Manciot *et al.* (1979 a) showed that application of ammonium nitrate to coconuts on quaternary sandy soil very significantly increased girth and on the coastal sands in the North East which are poor in P, phosphate application increased girth by 30 per cent.

Oguis *et al.* (1979) found that KCl and NaCl significantly increased the girth of the seedlings. Also observed that application of 110 g NH_4Cl

significantly depressed the height of seedlings whereas treatment with 50 g ammonium sulphate significantly increased height of the seedlings and noticed that leaf content of P and S are positively correlated with girth, height and fresh weight of seedlings.

Young coconut palms need N, P, K and Mg fertilizers for optimum development (Manciot *et al.*, 1980). Louis *et al.* (1981) reported that rate of growth of stem in the manured palms was significantly higher by 38 and 83 per cent for single and double dose treatments over control, while the height of trunk was also significantly higher by 19 per cent and 24.7 per cent in palms that received single and double doses respectively than in palms that received no fertilizers. Chattopadhyay and Hasan (1986) pointed out that plant height increased significantly with N nutrition and was maximum at 1000 g N per palm annually and girth was positively influenced by K nutrition.

Bonneau *et al.* (1993) observed that in coconut palms higher urea rates improved the girth by around 20 per cent, P application increased the girth by 10 to 15 per cent and K application increased the girth by 4 to 5 per cent during the first two years of application over control in peat soil. Secretaria *et al.* (1994) indicated that the application of first and second levels of inorganic fertilizer produced 13 and 19 per cent increase in girth over control while the combination of Sagana 100 and KCl produced 17 per cent increase. Palm fertilized with inorganic and goat manures produced the biggest girth, tallest palms and largest number of leaf lets (Secretaria and Maravilla, 1997).

2.1.2 Leaf production

There will be 30 to 40 opened leaves in adult healthy trees (Menon and Pandalai, 1958). According to Patel (1938) the number of leaves in a group of trees vary from 22 to 35 per tree. He has further reported that manuring and cultivation had beneficial effects on the production of leaves and on fertile soil the rate of production is more. He has also stated that trees having greater rate of production of leaves in general gave better yield than others. Davis (1954) has recorded that the average length of leaves was between 4.5 to 6.0 m which varies according to fertility. He has also stated that on an average there would be 200 to 250 leaf lets in a leaf on an average coconut palm.

A higher rate of leaf production and total number of leaves per palm with increased N application in oil palm was observed by Rosenquist (1962) ; Corley and Mok (1972) and Tan (1973). Mathew and Ramadasan (1964) found that application of phosphoric acid has increased the number of leaves and rate of leaf production in seedlings of coconut. According to Fremond and Ouvrier (1971) absence of K application for initial seven years of planting produces trees with less number of leaves, less length for limb of fronds, less weight of leaf lets and the total number of leaves produced since planting was also less. Uexkull (1971) based on the results of experiment in Philippines has also reported that potash application caused increased number of fronds.

In a replanting experiment of Cadang-Cadang devastated area Bigomia *et al.* (1973) showed that the application of NK and NPK produced more leaves in five years from replanting. Tan (1973) found that in islands of

Malaysia out of three levels of N fertilizer tried, the level 0.36 kg Nitro - 26 (26 per cent nitrogen) per palm gave the highest number of leaves. Influence of P on leaf production has been reported in oil palm by Tan (1973) and in coconut by Manciot *et al.* (1979 a). Muhammed *et al.* (1974) found that manuring increased the number of functioning leaves (20.67 leaves) over no manuring (18.22 leaves).

Breure and Rosenquist (1976) noted a reduction in frond production with 1.5 kg urea application per palm per year in volcanic soils of Papua New Guinea. Cecil and Pillai (1978) reported that on root wilt diseased coconut palms the effect of P was not found on production of leaves and functioning of leaves. N application in coconut increased leaf production during the pre-bearing period, but P and K had no influence on this. Also application of kieserite showed a significant effect of Mg on the number of leaves produced and percentage of palms in flower (Anon., 1979). Manciot *et al.* (1979 a) observed that application of NH_4NO_3 to coconut in West Africa significantly increased the number of leaves and leaf lets while $(NH_4)_2SO_4$ increased the number of leaves by only 4 per cent.

The number of leaves produced per palm per year affected by manuring in the first two years after application and thereafter there was no significant difference. Though not significant, the number of leaves produced per annum showed an upward trend with increase in manuring levels (Louis, 1981).

Nelliat and Gopalasundaram (1984) found that N improves the rate of leaf production and production of bunches in coconut. Mathew (1986) revealed that palms fertilized at higher rates in the form of urea, single super phosphate and MOP produced maximum leaves and set coconuts earlier. The effect of N and K was beneficial than that of P in leaf production and best growth of palms was obtained with 1000 g N + 1250 g K_2O per palm but different P levels showed similar effects (Chattopadhyay and Hasan, 1986).

Sudhakara and Nambiar (1991) reported that the leaf production was not increased due to the application of fertilizer in plantations of eight different locations studied. Bonneau *et al.* (1993) observed that coconut tree supplied with urea develop a growth habit typical of well nourished trees with numerous long dark green leaves and well loaded crowns. Also noticed that high urea rates increases the number of leaves emitted by 44 per cent in third year and also have produced 36 per cent more leaves, P application increased the number of leaves emitted by 5 per cent and higher level of K application increased the number of leaves produced by 5 to 9 per cent over control in peat soil.

Total number of leaves produced for the whole year was significantly increased by both organic and inorganic fertilization applied separately (Magat *et al.*, 1994). Mathewkutty *et al.* (1994) reported that number of green leaves in the palm crown is an index of its Mg nutrition while Mg starved palms will have fewer leaves. Secretaria *et al.* (1994) observed that double doses of inorganic fertilizers and combined inorganic and organic fertilizer produced significantly higher leaf count over the control, the double dose of fertilizer 3 kg each $(NH4)_2SO_4$ + KCl manifested the highest number of leaves produced followed by the combined organic fertilizer and KCl. Secretaria and Maravlla

(1997) reported that the number of leaves produced and total living fronds were significantly affected by inorganic fertilization.

2.2 Effect of fertilization on yield and yield components

2.2.1 Nutrients and yield of nuts

2.2.1.1 Major nutrients

The response of NPK fertilizers on yield of coconut has been reported by many workers from very early times. Romney and Smith (1956) stressed the relationship between yield potential and fertilizer responsiveness in coconut. John and Jacob (1959) observed that the application of balanced NPK fertilizer combined with green manure gave 35 per cent increase in yield of nuts and by reviewing the results of fertilizer demonstration in the West Coast found that where normal dose fails, response will be obtained by increasing the level of phosphorus and potash. Potassium is a primary factor deciding the coconut yield and the levels of K must be increased to optimise the yield per palm (Prevot and Ollagnier, 1963 ; Fremond and Villemain, 1964 ; Smith, 1969 and Wahid *et al.*, 1974). After 10 years of fertilizer application of K at 0.5, 1.0 and 1.5 kg KCl per palm per year the yield differences were 43 per cent, 60 per cent and 82 per cent over control on marine sands of Ivory Coast (Fremond and Villemain, 1964).

Ramanandan (1964) found that phosphoric acid application does not appear to influence yield and increase in yield was little. Fremond (1966) recommended that nitrogen fertilization is subsequently halted with no apparent effect on nitrogen nutrition and yields, provided a legume is established right from planting. Velasco *et al.* (1966) have shown that the addition of ammonium phosphate brought about a more intense green colour of the leaves and marked increase in nut production two years after initial fertilization. Phosphate fertilization is subsequently halted with no apparent effect on phosphate nutrition and yields (Brunin, 1968).

Application of NPK fertilizer at 1.59 kg per palm per year increased annual production to 200 per cent over unfertilized area in Sri Lanka. Also on the leached inland soils significant responses to P (1.8 kg rock phosphate per palm per year) and K (2.7 kg KCl per palm per year) were attained in the first two years of bunch production. Also on the coastal alluvial soils there was no response to P or Mg but 2.7 kg KCl per palm per year had a significant effect at the 4^{th} to 5^{th} year of yield (Anon., 1970 b).

As soon as bearing starts the number of nuts on the trees well supplied with K will be much greater than the deficient trees (Fremond and Ouvrier, 1971). Muliyar and Nelliat (1971) reported that in a NPK fertilizer experiment, N showed significant effect in the third year after the commencement of fertilizer application and then onwards and the mean increase in the yield for the 10 year period was 8.1 nuts (16.9 per cent) per palm per year, while P failed to show any significant effect for the first 9 years but then for the next 3 years significant effects were seen. K also showed significant impact on yield for the first time in the 5^{th} year and onwards and the higher level of K gave higher yield than lower level, but in N and P the difference in yield between the higher and lower doses however was not significant.

Müliyar and Nelliat (1971) reported 17 per cent increased yield of nuts due to N, 6 per cent due to P and 9 per cent due to K over 10 years period. Mendoza and Prudente (1972 a) noticed that an annual application of ammonium sulphate and KCl significantly increased nut and copra yield of bearing palms of coconut. Application of KCl corrected the chlorine deficiency of coconuts resulting in substantial increase in nut and copra yield (Mendoza and Prudente, 1972 b ; Magat *et al.*, 1975 a; Magat, 1979 and Magat *et al.*, 1981). A minimum increase of about 1500 nuts per acre per annum could be obtained from neglected lands within 3 to 5 years by the annual application of the fertilizers containing NPK (De Silva, 1973). Loganathan (1973) obtained significant response to P and K in nut yield of coconut in Sri Lanka.

In Solomon Islands palms grown on leached weathered clay loam soils and coral sands showed growth and yield responses to KCl application (Friend, 1975). In the Davao the effect of increasing rates of KCl on bearing palms revealed a quadratic response of palms to KCl application in terms of nuts per tree (Magat *et al.*, 1975 b). They further reported accelerated growth and development and yield of palms with the application of $(NH_4)_2\ SO_4$ + KCl fertilizer combination. Similar findings were also reported by Prudente and Mendoza, (1976) and Margate *et al.*, (1978). Markose and Nelliat (1975) showed from fertilizer experiments at Kasaragod that annual application of 500 g N + 320 g P_2O_5 + 1200 g K_2O per palm per year will ensure a sustained yield of around 60 nuts per palm per year under rainfed condition and application of this annual dose in two splits will also help to obtain an increase in yield of about 8 per cent. Reports also have shown that nitrogen and phosphate had little effect on growth and yield but muriate of potash has increased yield to a greater extent (Breure and Rosenquist, 1977).

For bearing palms nitrogen is responsible for high nut production and chlorine for copra yield (Prudente and Mendoza, 1976 ; Margate *et al.*, 1979 and Magat and Margate, 1989). Potty (1978) recommended that palms belonging to high yield groups require a fertilizer schedule that emphasises more on phosphorus and potash and palms belonging to low yield groups require a schedule that gives more weight to nitrogen and potash.

Magat (1979) observed that palms treated with two kg KCl per palm per year produced the highest yield of 128 nuts as against 87 by the control, an increase of about 47 per cent and slightly decreasing with further addition of KCl. Highest dose of P (450 g P_2O_5 per palm) induced a depressive effect on yield of nuts and it was inferred that application of P_2O_5 beyond 225 g per palm per year may not be advisable under typical red sandy loam soil conditions (Anon., 1980 b). Nitrogen increased the number of nuts and copra yield per palm while K was observed to improve both nut number and size, the later being more pronounced (Anon., 1980 b). Louis *et al.* (1981) suggested that manuring increased both yield per palm and yield per hectare and the effect being more pronounced in the closest spacing of 6.1 m x 6.1 m than in the other two spacing of 9.1 m x 9.1 m and 7.1 m x7.1 m.

In a low yielding and nutritionally deficient inland coconuts grown under the dark brown clay loam soil, application of $(NH_4)_2SO_4$ + KCl + $CaMgCO_3$ and $(NH_4)_2SO_4$ + NaCl gave a higher yield of 32 and 34 nuts per palm per year respectively than the unfertilized palms from the third year (Magat *et al.*, 1981). In Brazil and Columbia, (Ollagnier and Ochs, 1981) on ultisols, a clear response of coconut to phosphate application in terms of yield has been reported. Application of double the recommended dose of fertilizers to coconut palms grown under neglect in the first year followed by the normal dose in later years resulted in the yield of such palms to 58 nuts from the fifth year compared to 27 nuts in the control plots (Nelliat *et al.*, 1982).

In an experiment of replanting old coconut palms in the Ivory Coast N increased considerably the number of nuts per tree and thereby the quantity of copra per tree (Pomier and de Taffin, 1982). Results of studies in countries like Ivory Coast, Dahomey, Puerto Rico and India have indicated that response to N fertilization in coconut was best only when sufficient potash was available in the soil and major portion of absorbed potash (63 per cent) was utilized in the production of nuts (Thampan, 1981).

In a multi-storey cropping pattern with three intercrop combinations, coconut yield was significantly increased when both coconut and intercrops were fertilized (Margate and Magat, 1983). Nelliat and Gopalasundaram (1984) suggested that application of 340 g P_2O_5 per palm per year to WCT enhanced the yield by 2.6 nuts per palm per year and application of 680 g K_2O per palm per year gave an increased yield of 4.4 nuts per palm per year and improved the copra weight per nut by 5.2 per cent. Ollagnier and Wahyuni (1984) reported that both in the Ivory Coast and Indonesia the application of N in the form of urea has no significant effect on yield in terms of nuts, but in the P deficient soils where coconut is grown the correction of this deficiency by application of rock phosphate increased yield by 10 to 15 per cent.

On red sandy loam soil the response to applied P was obtained for two consecutive years and higher level of P at 1000 and 1500 g P_2O_5 per palm per year gave more nut yield, however the response was not consistent and significant in succeeding years (Khan *et al.* 1985 and Anon., 1982). Khan *et al.* (1986) found that large yield responses were obtained due to annual application of NPK fertilizers over 18 years period on red sandy loam soil to coconut.

Significant increase in nut yields were observed from ammonium sulphate, super phosphate and muriate of potash applications (Anon., 1987 and Anilkumar and Wahid, 1989). Clarson *et al.* (1988) revealed from an NPK fertilizer experiment that there was a significant linear response to N, P and K application and found that the optimum dose of N, P and K to coconut to get maximum rate of return ranged from 0.9 to 2.0, 0.12 to 0.30 and 1.4 to 1.8 kg per palm per annum respectively.

Nallathambi *et al.* (1988) showed from the mean cumulative yield of nuts per palm for three years a marked increase significantly due to application of 100 kg Farmyard manure + 2.4 kg Urea + 1.4 kg MOP per palm over control. Anilkumar and Wahid (1989) found that the yield response was highest for KCl application from 2.1 nuts to 33.6 nuts per palm per year at the highest dose of 747 g per palm per year.

Magat and Padrones (1989) obtained the highest average nut production of 47.1 nut per tree per year with the application of 2.5 kg KCl per palm per year which was an increase of 17 nuts over the unfertilized palms. Mongia *et al.* (1989) reported that long term use of K fertilizer significantly increased the yield of coconut palm.

Jeganathan (1990) found that nut yield significantly increased as a result of K application. Ballad (1991) obtained the highest nut yield in palms fertilized with 2 kg ammonium sulphate in combination with 2 kg KCl and also observed a strong relationship between nut yield and quantity of N present in the leaves of palms. At the inland soils of Davao, Magat *et al.* (1991) observed that nut production of palms applied with NaCl, KCl and NH_4Cl was clearly higher than those of control palms.

Adverse effect of ammonium sulphate on yield of coconut was reported by Nair *et al.* (1991). Bopaiah (1993) revealed that an yield increase of 156 per cent over control was obtained by the use of 500 g N, 320 g P and 1200 g K per palm per year, also 50 per cent reduction in the NPK dose did not affect the yield of coconut which indicated that there was good response to fertilizer application at low levels also. Joseph *et al.* (1993) found that in laterite soils K application is necessary to coconut trees for maintaining stability in nut yield and in the soils with low to medium availability of K, its requirement for coconut can be met by applying 500 g K_2O every year and a boosting effect can be obtained by combining with 500 g NaO (935 g NaCl).

Joseph *et al.* (1994) indicated that in laterite soils coconut palms receiving good management under rainfed cultivation need not require high quantities of K applications every year and further revealed that complete stopping of K application is not at all desirable if we aim at high yield targets. Magat *et al.* (1994) reported that both the higher and the lower level of inorganic fertilizer application significantly improved the nut production over the control. Combined application of organic fertilizer and KCl gave an appreciable improvement of 58 per cent increase in nut per palm over the control (Secretaria *et al.*, 1994).

Joseph *et al.* (1994) suggested that in laterite soils for low and medium yield potential groups once we stop K application after ensuring considerable buildup of available K content in the basins of coconut palms by regular application of potassic fertilizers, the yield is not likely to go below the pre-treatment mean even after 15 years of skipping of K application. However the productivity of high yield groups are seen affected after a few years. Zakra *et al.* (1996) showed that despite a very drastic reduction in K and Mg fertilizer application rates, and even a total suspension of fertilizer application for 6 years, adult palms have maintained good nutrition and yield levels.

2.2.1.2 Secondary nutrients

De Silva (1965) recommended that addition of $MgSO_4$ was more effective than dolomite in increasing the yield in coconut. Only after K deficiency has been corrected that Mg manuring was found to have a positive effect on production (Brunin, 1970 and Coomans, 1977). At Ivory Coast KCl application resulted in a general fall of Mg level in coconut and by ensuring the balance between the K and Mg ions, Mg manuring enabled to increase yield particularly when the palms have been manured late (Ch Brunin, 1970).

De Silva (1973) found that an increase in yield of about 1000 nuts per acre annually has resulted over and above what could be obtained from the N, P and K fertilizers, consequent on the additional application of Mg fertilizers.

Application of Mg, Mn and S have improved growth, but have not increased yield in coconut (Breure and Rosenquist, 1977). Mathew (1977) has shown that the palms which received Mg gave significantly higher yield than those which received no Mg and the increase in yield was from 49 to 62 nuts per palm per year. Manciot *et al.* (1979 b) reported that in the Ivory Coast application of Ca in the form of $CaCO_3$ for 4 consecutive years in coconut had no significant influence on yield, but the application of Mg fertilizer Kieserite corrected the Mg deficiency and significantly increased yield and growth. When K shortage has been made up Mg deficiency induced by heavy K fertilization have reduced yield by 40 per cent in coastal sandy soils.

The yield components were negatively correlated with leaf Mg content (Anon., 1980 a). Kamalakshiamma and Pillai (1980) observed from a fertilizer trail conducted at CPCRI, Kasaragod on sandy loam soils with 3 combinations of NPK and 3 levels of Mg and 2 levels of Ca that the effect of Mg was highly significant in cumulative yield and in the production of nuts per palm per year. In the experiment conducted to find out the requirement of micro nutrient in coconut nutrition Clarson *et al.* (1986) found that application of Mg at the rate of 15 kg ha^{-1} had significant by higher response on yield.

Magat *et al.* (1988) noticed that leaf content of Mg proved to be negatively correlated with nuts per tree. As coconuts are regularly manured with high levels of K , an induced deficiency of Mg is to be expected while there was a definite negative interaction of K on Mg absorption (Prabhakumari, 1992).

2.2.1.3 Micro nutrients

Brunin and Coomans (1973) reported that boron application to coconut palm raised the foliar boron levels but had no marked effect on yield. Kamaladevi *et al.* (1975) observed that continuous application of NPK fertilizers without supplementing with micro nutrients to coconut might have feuded to lower the available Zn and Cu in the soil, which when amended resulted in the increased nutrient content and also nut yield. Application of Mg, Mn and S have not increased the yield of coconut (Breure and Rosenquist, 1977).

Manciot *et al.* (1979 a) found that NaCl dressing in coconut have stimulated increase in nut production. Eschbach and Manciot (1981) found that application of Cu to young palms in the form of Nutramine or to adult coconuts at 50 g per tree per year as $CuSO_4$ never affected either growth or yield, but on adult coconut palms application of $FeSO_4$ 400 g per tree increased the number of nuts per tree and application of Mn increased both growth and number of nuts per tree while $ZnSO_4$ application at the rate of 50 g per tree per year did not have any effect on yield of nuts.

Application of borax at the rate of 5 kg ha^{-1} was found to have response on coconut yield which recorded significantly higher yield (Clarson *et al.*, 1986). Magat *et al.* (1988) showed that in the Tugbok Clay loam soils application of NaCl significantly improved nut production of bearing palms. Along with recommended dose of NPK 200 g of $ZnSO_4$ per palm per year has significantly increased the nut yield to 122.9 nuts per palm per annuam which was 69.5 per cent higher than the control and also the application of $CuSO_4$

increased the Cu content of leaves but the increase in yield is not much pronounced (Vijayaraghavan *et al.*, 1988). Magat *et al.* (1991) reported that application of 3.8 kg NaCl per tree per year produced 126 nuts per palm per year and also noticed that even at low rate of 1 kg NaCl per tree, palms yielded better.

2.2.2 Nutrients and copra yield

2.2.2.1 Major nutrients

Copra yield was estimated as 32 per cent of the husked nut weight (Pieris, 1935). The effect of potash on the outturn of copra has been pointed out by many workers. The major effect of potash in coconut is its capacity to produce better copra outturn and induce earliness in bearing (Salgado, 1947 and 1952 and Fremond, 1964). Murray and Smith (1952) reported that application of 340 g N per palm per year increased the yield of nuts by 16.9 per cent but reduced the copra per nut by 9.0 per cent. John and Jacob (1959) found that the application of balanced NPK fertilizer combined with green manure gave 44 per cent increase in copra yield. On Jamaican soil copra weight per nut was influenced only by P (Smith, 1969).

In the sandy coastal region of the Ivory Coast, application of potash brought a very appreciable improvement in copra yield which raised on an average from 600 kg of copra ha^{-1} to 1800 kg ha^{-1}. Muliyar and Nellait (1971) observed that application of P increased copra outturn per nut both at lower level (340 g P_2O_5 per palm) and at higher level (680 g P_2O_5 per palm) of annual application.

The NPK fertilizer experiment conducted in sandy loam soil of the west coast of India confirmed that nitrogen had relatively little effect on the copra out turn per palm. But in case of P some beneficial effect both at lower and higher levels while K has very high beneficial effect which tended to increase with passage of time (Muliyar and Nelliat, 1971). Mendoza and Prudente (1972 b) indicated that at the Davao the annual application of fertilizers $(NH_4)_2SO_4$ and KCl significantly increased nut and copra yield of bearing palms. In the Philippines several studies have shown the beneficial effect of fertilization in increasing copra yields as high as 3 tonnes ha^{-1} per year (Mendoza and Prudente, 1972 b ; Magat *et al.*, 1975 a ; Prudente and Mendoza, 1976 ; Magat, 1978 and Magat *et al.*, 1981).

N and P increased the production of nuts but had no effect on copra out turn (De Silva, 1973). Magat *et al.* (1975 a) observed that increasing rates of KCl on bearing palms with blanket application of N showed a liner response in copra weight per nut and copra per tree ; a 45 per cent increase of copra weight per nut and 68 per cent increase of copra yield per tree over the control palms was obtained with the highest level of KCl of 3.33 kg per palm per year and the increase was in positive relationship with leaf Cl content and in negative relationship with leaf K content.

In a study in Davao on palms fertilized from transplanting time, KCl fertilizer applied either with N or NP significantly increased nut and copra production over those trees without Kcl. Also N and Cl levels in the leaves are highly correlated with nut and copra production (Prudente and Mendoza, 1976). Thye *et al.* (1976) found from a NPK trial on Malayan red dwarf palms on marine coastal alluvial clay that 30 per cent increase in copra yield by the addition of 0.47 kg N per palm per year. Magat (1978) concluded that KCl fertilization at 2 kg per palm per year in combination with 1.5 kg ammonium sulphate produced the highest nut yield and gave optimum yield of copra, and also found that increased KCl rate up to 8.0 kg increased copra per nut or copra per palm.

Copra out turn was influenced both by MOP and sulphate of ammonia, while MOP linearly increased copra per palm and copra weight per nut and sulphate of ammonia linearly decreased only copra weight per nut. Copra weight was related positively to leaf K and Cl and negatively to Mg (Loganathan and Balakrishnamurti, 1979). Similar findings were reported by Salgado (1950) in Sri Lnaka and Muliyar and Nelliat (1971) in India.

Manciot *et al.* (1979 a) reported that the nitrogenous fertilizer had significant decreasing effect on the copra per tree. On coconut hybrid without the application of K the mean copra yield for six years was 980 kg ha^{-1} per year and the application of 1.5 kg KCl per palm per year the copra yield raised to 2100 kg ha^{-1} per year (Manciot *et al.*, 1979 b). Margate *et al.* (1979) indicated that increase in copra weight per nut was observed with application of KCl and increase in KCl rates correspondingly increased copra weight per nut and the highest KCl rate of 8 kg produced the highest copra yield over all other treatments.

MOP up to 1.8 kg per palm per year linearly increased copra per palm and copra per nut while sulphate of ammonia up to 4.4 kg per palm per year decreased copra per nut. The optimum rates of fertilizer were 1.1 kg sulphate of ammonia 0.83 kg Saphos phosphate and 1.8 kg muriate of potash per palm per year giving an yield of 12 kg copra per palm per year (Anon., 1980 a). At North Sumatra Rosenquist (1980) noticed that application of MOP has very significantly increased the fresh copra weight per nut in coconut. Ollaginear *et al.* (1983) reported that N and K increased the copra weight per nut and copra yield per palm. N adversely affected the copra content of nuts in coconut (Nelliat and Gopalasundram, 1984).

In South East Ivory Coast without phosphatic fertilizers copra production was 12.7 kg per tree per year with an yield of about 1700 kg per hectare, while spreading phosphate fertilizer at the rate of 1 and 2 kg per tree per year improved considerably 16.1 and 16.3 kg copra per tree per year which corresponds to approximately 2200 kg copra per hectare. Thus by using the rate of 1 kg per tree per year production increased by about 30 per cent in comparison to control (Youan, 1985). Magat and Padrones (1989) showed that during the second year the copra per nut of palms applied with 2.5 kg KCl increased from 264 g per nut in unfertilized plots to 292 g per nut under application of 2.5 g KCl . While doubling the level of KCl to 5.0 kg per palm did not produce a commensurate increase in copra yield.

Jeganathan (1990) reported a significant response in terms of copra production by increasing K applications. Ballad (1991) reported that significantly higher copra weight per nut was realized from palms applied with inorganic sources of N (2 kg each ammonium sulphate + KCl per palm per year) than organic sources and control plots, and also observed that the meat of the nuts in the former case was thicker than the later two cases.

In a multistorey cropping system the weight of copra per nut was lower in unfertilised palms and higher in fertilized coconut palms regardless of whether the intercrop was fertilized or not (Margate *et al.*, 1993). Nunez, (1993) found that copra per nut was higher in fertilized plots than in the control, consequently annual copra yield per hectare was significantly higher in fertilized palms. The copra yield per nut or that per tree was greatly improved with both higher and lower level of inorganic fertilization and the increase in copra yield per palm over the control ranged from 134 to 300 per cent (Margate *et al.*, 1994).

Secretaria *et al.* (1994) showed that 3 kg of each ammonium sulphate + KCl per palm per year gave 10 per cent and 87 per cent heavier copra per nut and copra per palm respectively over the unfertilized palms, but when organic fertilizer was combined with 1.5 kg KCl per tree appreciable improvement of 74 per cent copra per palm over the unfertilized palms was observed.

2.2.2.2 Secondary and micro nutrients

Magnesium tends to concentrate in kernal of the nuts and its deficient supply results in low copra yield (Ouvrier and Ochs, 1979). Ouvrier (1987) observed that in PB - 111 coconut hybrid Mg fertilizer kieserite application increased meat content slightly. While leaf Mg proved to be negatively correlated with copra per tree (Magat *et al.*, 1988).

Eschbach and Manciot (1981) found that in the absence of any visible symptoms of boron deficiency no relation between boron levels and growth or copra yield could be observed, but on adult coconut trees application of 400 g per tree of Iron sulphate increased the yield of copra per tree and application of Mn to coconut palms did not have influence on copra per nut. Leaf Cl and Ca levels are positively and significantly correlated with copra weight per nut (Magat *et al.*, 1981). Application of NaCl significantly increased copra weight per nut and copra yield per tree of bearing palms in the Tugbok clay loam soils (Magat *et al.*, 1988).

Vijayaraghavan *et al.* (1988) found that there was marginal increase in the contents of kernal and copra weight due to the application of Cu + Zn to coconuts. Magat and Padrones (1989) found that boron was significantly and negatively correlated with copra yield due to antagonistic relationship between K and B and Cl^- and B. The optimum dose of NaCl per tree per year was 3.8 kg which produced 22.6 g more copra per nut and a total yield of 25.9 kg copra per tree which was 112 per cent increase over control palms and also noticed that NaCl at low rates of 1 kg per tree produced about 18 kg copra per tree (Magat *et al.*, 1991). Mathewkutty *et al.* (1994) indicated that the significance of Mg is not confined to the number of nuts obtained from palms and its inadequate availability reduces copra content of nuts drastically.

2.2.3 Female flower production

Female flower production and the setting percentage are generally enhanced by fertilizer application . Beirnaert (1935) found that female flower production was decreased by nitrogen application due to high photosynthetic activity. Salgado (1947) noticed that female flower production increased by 15 per cent from N application and NP interaction had a positive effect. The

K_2O application of 0.68 kg per tree increased setting percentage by 35 per cent over no application of K. Based on the observation on number of palms at Kasaragod and Nileshwar, Menon and Pandalai (1958) have stated that on an average, good yielding palms produced 151, medium yielders 120 and poor yielders 41 female flowers per annum. They also found that poor yielders responded well to manuring, with 33.3 per cent increase, while good yielders produced only 6.5 per cent more flowers.

Marar and Pandalai (1959) observed that in the palms of uncultivated and unmanured plots abortion of inflorescence occurs to a large extent. Fremond (1964) reported the results from young coconuts that the application of NaCl could increase sufficiently the number of inflorescences, bunches and nuts per tree. Potash is mainly involved in inducing the production of more female flowers (Fremond, 1964 and Uexkull, 1971). Beneficial effect of N was seen in the increased production of bunches ranging from 11.7 per cent to 12.8 per cent and female flowers between 20 per cent to 40 per cent (Anon., 1967). Smith (1969) reported that with increasing leaf N the number of female flowers produced per infloresence increased and at low level the loss of female flowers limited the yield, moreover K application improves flower setting. Other reports from Jamaica also support the role of N in increasing female flower production (Anon., 1970 a).

De Silva (1973) observed that N and P increased the production of female flowers, and that application of a complete fertilizer mixture increased the rate of flowering to 82 per cent in virgin jungle clearing and to 42 per cent in the secondary jungle clearing. Child (1964) has indicated that NaCl dressings can significantly increase the number of inflorescences, number of female flowers per tree (19 per cent increase) and number of nuts (13 per cent). Annual single application of fertilizers resulted in high production of female flowers (Markose and Nelliat, 1975). At the Ivory Coast sandy soils which are extremely low in fertility, application of KCl, kieserite and urea on hybrid coconut resulted in a significant effect on vegetative development and precocity of flowering (Coomans, 1977).

Cecil and Pillai (1978) indicated that in root wilt diseased coconut palms the main effect of P was not found favourable on flowering and yield of nuts. Application of K fertilizer to coconut significantly increased the number of inflorescence (Manciot *et al.*, 1979 (b)).

Louis *et al.* (1981) reported that fertilizer application induced remarkable increase in the production of spathe, female flowers and advanced the flowering phase and also increased fruit setting considerably. Nelliat and Gopalasundaram (1984) observed that N improved production of female flowers and yield of nuts in coconut. On red sandy loam soil higher level of P at 1000 and 1500 g per palm per year significantly increased female flower production (Khan *et al.*, 1985).

Nallathambi *et al.* (1988) indicated that application of fertilizers produced significantly higher number of female flowers per palm over control. The increase in the female flower production by the application of 100 kg farmyard manure + 2.5 kg urea + 1.4 kg MOP per palm was 34 per cent over control. Sudhakara and Nambiar (1991) observed that female flower production increased following fertilizer application and the increase being more or less restricted to the lower level of fertilizer dose.

Nunez (1993) found that palms receiving higher levels of fertilizers (Ammonium sulphate + MOP) had significantly more button in their inflorescence and higher annual bunch production per tree than control. Application of 100 per cent K (1200 g K_2O) produced highest number of female flowers and nut yield per palm in laterite soils at CPCRI, Kasaragod (Anon., 1994). Joseph *et al.* (1994) suggested that decline in female flower production and nut yield in plots receiving no K was due to shortage of available K in the basins of the palm.

2.2.4 Weight and volume of nuts

Smith (1969) stated that neither N nor K influenced nut size though P did influence. In a fertilizer experiment Muliyar and Nelliat (1971) showed that potash had beneficial effect on both yield and all the nut characters which tend to increase with the passage of time. They also found that N adversely affected all the nut characters viz. weight and volume of whole nuts and weight and volume of husked nut while K improved these characters and P had negligible effect.

Uexkull (1971) found that nut size and weight decreased rapidly in the absence of K. Uexkull (1972) estimated that the increased copra out turn due to K fertilizer could be apportioned as 70 per cent to the increase in nut size. Weight of husk decreased with an increase in N level (Nelliat, 1973).

Nallathambi *et al.* (1988) showed that the palms which received farmyard manure with chemical fertilizers recorded the highest weight of whole nut and dehusked nut. Due to the application of Zn and Cu there was marginal increase in the contents of kernal and copra weight but did not have any deleterious effect on whole nut weight and dehusked nut weight (Vijayaraghavan *et al.*, 1988). Husk and shell were more heavier in fertilized trees and a more profound influence of fertilizer ammonium sulphate + KCl on nut size when compared to that of control was observed (Nunez, 1993).

2.2.5 Oil Content

When oil percentage of copra from N, P, K and Ca applied plots was 64.30 per cent, it was only 56.77 per cent in plots with only green manure (Menon and Pandalai, 1958). Smith (1968) found that there was no difference in oil percentage (72.50 per cent) in copra with fertilized and unfertilized plots in the same variety. Similarly Muliyar and Nelliat (1971) did not find much difference in oil content due to N, P or K treatments.

Romney (1972) reporting the results of four fertilizer experiments, did not observe any significant difference in oil content of copra due to application of fertilizers except that there was effect for P in one year which later disappeared.

2.3 Effect of fertilization on soil and foliar nutrient status

Sampson (1923) gave a detailed table of analysis of various parts of the coconut and the removal of different macro nutrient elements by the palm. He suggested that a mature ripe coconut removes 6.85 g N, 0.99 g P_2O_5 and 4.90 g K_2O from the soil.

One of the early suggestions for a scientific approach in the mineral nutrition of coconut palm was that of Nathanael (1958) in which he suggested three approaches viz. assessment of the mineral requirement of the palm with the aid of fertilizer experiments and by successive approximation, analysis of soil for its nutrient supplying capacity and analysis of coconut water and leaves for understanding the level of nutrition of the palm in relation to its productivity as well as the available nutrient status of the soil. Nathanael (1959) further elaborated the conceptual basis to assess the nutrient requirement of the coconut palm by the equation $F = R - S + L$, where F is the quantity of fertilizer nutrient, R is the quantity of nutrient required by the crop for unrestricted growth, S is the quantity of nutrient supplied by the soil and L is that portion of the nutrient not utilised by the crop plant.

2.3.1 Nitrogen

2.3.1.(a) Soil nutrient status

Nethsinghe (1962) found that six months after application of fertilizers, there was little difference in available nitrogen and potassium contents of soil between fertilized and unfertilized plots. The continued application of fertilizers had little effect on soil organic carbon and available N, but there was considerable build up of available P and K in the soil (Nelliat *et al.*, 1982).

Ramanandan and Pillai (1974) observed that there was no significant difference in soil nitrogen content between manured and cultivated plots and control during both rainy and summer seasons. Annual application of NPK fertilizers over 18 years to coconut on red sandy loam soil resulted in a minimal increase in mineralizable nitrogen (Khan *et al.*, 1986). Secretaria *et al.* (1994) reported that application of organic and mixed organic + inorganic fertilizer to coconut palm resulted in higher soil nitrogen levels. Khan *et al.* (1996) obtained the available nitrogen status of plots receiving inorganic fertilizer on par with control plots and indicated that in the humid tropics it was difficult to create nitrogen gradients by simple inorganic fertilization.

2.3.1. (b) Foliar nutrient status

Fremond and Conclaves (1967) reported that in coconut groves nitrogen uptake continued while the soil was damp but decreased rapidly during dry season.

The N content of leaves of the cultivated and manured palms were significantly higher than those of uncultivated and unmanured palms (Ramanandan and Pillai, 1974). Wahid *et al.* (1975) noticed that discontinuation of fertilizer application decreased the leaf N below the critical level and that of K was in the critical range which indicated the necessity for annual replenishment of these two nutrients. Two years and three months after initial application of either $(NH_4)_2 SO_4$ + KCl combination or $NH_4 Cl$ to palms, leaf analysis clearly indicated that considerable increase in leaf N and Cl (Magat, 1978). Loganathan and Balakrishnamurti (1979) noted a positive influence of leaf N level of coconut by the application of sulphate of ammonia in a lateritic gravelly soil in Sri Lanka and at North Sumatra by Rosenquist (1980).

From the leaf analysis for N values in Lakshadweep it was found that N content in 41 per cent palms were more than the critical value of 1.8 per cent. It was less than 1.5 per cent in 16 per cent palms and ranged between 1.5 and 1.8 per cent in the remaining 43 per cent palms which indicated that about 50 per cent of palms might respond to N fertilization (Singh and Velayutham, 1979). Margate *et al.* (1979) stated that application of KCl to coconut palms improved the leaf N content over that in control plots. Oguis *et al.* (1979) observed that application of ammonium chloride significantly produced higher leaf N level in addition to Cl among the three sources of chloride fertilizers applied.

Magat *et al.* (1981) reported that the application of NH_4Cl to low yielding and nutritionally deficient inland coconuts significantly increased leaf N levels. There was an increase in foliar N levels following N application (Anon., 1987 and Anilkumar and Wahid, 1989). Magat and Padrones (1989) suggested that combined application of KCl and $(NH_4)_2$ SO_4 consistently increased leaf N level in coconut.

Magat *et al.* (1994) opined that leaf N content was greatly improved with the application of inorganic fertilizer compared with control but noted that the levels were still below the critical level even with higher dose. Secretaria *et al.* (1994) observed that 3 kg each of ammonium sulphate + KCl and combined organic fertilizer + KCl application attributed to highly significant increase in leaf N on the third year . Secretaria and Maravilla (1997) reported that leaf N, Cl and S were significantly improved by inorganic fertilization with ammonium sulphate.

2.3.2 Phosphorus

2.3.2 (a) Soil nutrient status

The phosphorus requirement of coconut palm is comparatively very little and specific instances of phosphorus deficiency are rarely met with. Various workers (Eden *et al.*, 1963 ; Pillai and Davis, 1963 and Child, 1964) opined that P needs of the palms are less. Mollegaard (1971) reported that application of C. I. R. P. significantly increased the available P status of soil in Malaysia. Ramanandan and Pillai (1974) observed that available P content of the soil was higher in palms cultivated without manuring than those cultivated with regular manuring. Khan *et al.* (1983) revealed that the discontinuation of P fertilizer application has resulted in the reduction of soil available P from an initial status of 84 ppm to 59 ppm whereas application of P_2O_5 increased the available P level to 133 ppm and to 266 ppm by the annual application of 160 g and 320 g P_2O_5 respectively per palm.

The annual application of phosphatic fertilizer to coconut resulted in the build up of soil P (Khan *et al.*, 1983 and Wahid, 1984). The rate of 1 kg per tree per year of phosphate fertilizer considerably increased total and assimilable P contents, both in the surface horizon and between 20-40 cm (Youan, 1984). Youan (1985) reported that mean soil P content in the control plots had to be considered as low since there was a real deficiency according to coconut production from these plots. The total P contents were 65 ppm in the surface horizon and 81 ppm between 20 and 40 cm.

In red sandy loam soil annual application of NPK fertilizers to coconut over a period of 18 years resulted in a marked increase in available P;

Similarly application of organic and mixed organic + inorganic fertilizer provided higher level of soil P (Khan *et al.*, 1986). Application of superphosphate increased the available P content of the soil 25 fold at the highest level of 198 g P per palm per year of application and depth wise analysis revealed that P accumulated even at a depth of 75 to 100 cm (Anilkumar and Wahid, 1989).

Khan *et al.* (1996) found that the soil P status was much influenced by the fertilizer treatments and higher P content was recorded at the surface 0 to 25 cm which gradually decreased with depth. Joseph and Wahid (1997) noticed a substantial build up of P reserves in the rhizosphere soil upto a depth of 75 cm due to regular application of super phosphate

2.3.2 (b) Foliar nutrient status

Phosphorus content of the leaves were always found to be higher in the younger leaves compared to older leaves though contents varied as a function of time and season maintaining the same gradient in the crown. During summer the leaf P content in the manured and cultivated palms were significantly less than the unmanured and uncultivated palms and in rainy season it did not show any significant difference (Ramanandan and Pillai, 1974). Wahid *et al.* (1975) observed that when the fertilizer application to coconut palm was discontinued the foliar levels of N and K were lowered and neither the soil P nor the leaf P level fell below the original or the foliar critical level which indicated that skipping of certain years without the application of P fertilizers might not adversely affect the nutrition when sufficient build up of P had been obtained.

Kamaladevi *et al.* (1976) did not observe any increase in leaf P content due to graded dose of fertilizer application. However, Kamaladevi and Velayutham (1977) found that on the fifth day after fertilizer application the increase in P concentration was 14 to 25 per cent in unopened leaf and 29 to 47 per cent in the fourteenth and outer leaves. Application of super phosphate to coconut increased the leaf P level (Loganathan and Balakrishnamurti, 1979). Rosenquist (1980) noted an increase in leaf P level at North Sumatra due to the application of rock phosphate. Manciot *et al.* (1979 a) reported that application of phosphatic fertilizer to coconut accompanied by a significant increase in leaf P level and also the application of nitrogenous fertilizers raised the leaf P level while a negative trend was noted with potassic or magnesium fertilization.

Khan *et al.* (1983) observed that the discontinuation of P fertilizer application for six years had no significant effect on foliar P levels indicating the efficiency of accumulated residual P reserves in soil in catering the P need of the palm and also noted that even after continuous fertilizer application for 28 years the foliar P level did not reach the critical level of 0.120 per cent as reported by Manriot *et al.* (1979 a). So he suggested that the foliar critical levels of P cannot be relied upon as a guide for fertilizer application or yield enhancement.

Plant P levels were not influenced even when soil available P levels drained to 59 ppm at 0 to 30 cm depth and 10 ppm at 30 to 60 cm depth and also when the soil available P values increased considerably (Khan *et al.*, 1983). Khan *et al.* (1985) reported that P uptake by coconut is little nearly one tenth of the total uptake of K as well as Cl. In the leaves of unfertilized coconuts with P, mean P content of 0.114 per cent of dry matter which is below the critical threshold of 0.120 per cent of dry matter and the application of 1 kg per palm per year of bi and tri calcic phosphate over several years enabled mean content of 0.131 per cent of dry matter to be reached (Youan, 1985).

Khan *et al.* (1986) reported that in the annual application of NPK fertilizer over 18 years to coconut palm on red sandy loam soil, P fertilizer did not increase the P content of leaves. Also Anilkumar and Wahid (1989) noted that super phosphate dressing over the years did not improve P uptake by coconut palms. At Philippines Ballad (1991) observed that coconut palm did not show any effect on leaf P content due to N fertilizer application.

2.3.3 Potassium

2.3.3 (a) Soil nutrient status

Next to N, potash is the most important nutrient element for coconut. Production as well as nut characters are highly influenced by the availability of these two nutrients. Since K is removed in large quantities by coconut, it is worthy to study the potash build up as well as its depletion in soil consequent to the application of the same in varying quantities or nil application and its impact on production. Mollegaard (1971) reported that application of MOP increased the available K status of soil and decreased by the application of sulphate of ammonia and C. I. R. P. in Malaysia. Soil K content was higher in palms which received regular manuring and cultivation than those received only cultivation and of control (Ramanandan and Pillai, 1974). Ollagnier and Olivin (1984) noticed that K content of soil decreased year after year in the absence of fertilization in acid sands of Cameroon. Khan *et al.* (1986) reported that annual application of NPK fertilizer over 18 years period to coconut palms on red sandy loam soils resulted in a marked increase in available K.

Anilkumar and Wahid (1989) observed that application of superphosphate over years significantly reduced the exchangeable potassium content of the soil and also found that higher rates of ammonium sulphate application led to a reduction in exchangeable K. Application of MOP increased the available K and organic carbon content of the soil and the accumulation of K was noticed in lower layers upto 75 to 100 cm (Anilkumar and Wahid, 1989 and Joseph *et al.*, 1994). The build up of available K decreased in proportion with the quantity of K applied and which steadily declined on the basins of the trees which received no potash application and also concluded that for sustaining the productivity of coconut at a high level, the requirement of available K in the basins of the palm should be about 200 kg per hectare and an annual application of 250 to 500 g K_2O per coconut palm is sufficient under rainfed cultivation on laterite soils to maintain the available potash status above the critical level if the palms are grown under good management and the available potash status of the soil is medium to high (Joseph *et al.*, 1994).

Margate *et al.* (1994) reported that in an experiment treatments which received inorganic fertilizer application the K content of the soil was significantly lower. While the treatments involving KCl fertilizer application provided for a significantly higher dose of K both in the top and sub soil (Secretaria *et al.*, 1994). Khan *et al.* (1996) observed in a red sandy loam soil that the available soil K values were very high in the fertilizer treatments compared to cultural treatments were the values below the critical level of 59 to 78 ppm as suggested by Biddappa *et al.* (1993). Joseph and Wahid (1997) noticed that application of MOP resulted in a large increase of K reserve in the soil to a depth of 100 cm with relatively less accumulation in the 0 to 50 cm root zone.

2.3.3 (b) Foliar nutrient status

Coconut is a heavy consumer of potash. Though function wise its importance is next to nitrogen, uptake-wise it ranks first. It is because of this reason we generally apply K at the rate of two times that of nitrogen and four times that of phosphorus. The leaf potassium content during the rainy season was more than that of summer (Ziller and Prevot, 1962 and Ramanandan and Pillai, 1974). Ramanandan and Pillai (1974) observed that the K content of the leaves of the cultivated and manured palms were significantly higher both in rainy as well as summer season compared to those of uncultivated and unmanured palms.

Prudente and Mendoza (1976) showed that addition of KCl did not increase the level of leaf K, while Breure and Rosenquist (1977) noticed that application of MOP has resulted in a decrease of frond K level in coconut.

Also on clay loom soil in the philippines MOP significantly increased leaf Cl but had no effect on leaf K (Margate *et al.*, 1978). But trials in India showed that supply of MOP increased leaf K and Cl content in coconut (Anon., 1980 b). The same trend was reported from Sri Lanka by Loganathan and Balakrishnamurti (1979) and at North Sumatra by Rosenquist (1980). Further the increasing rate of KCl application improved the leaf K content in coconut (Margate *et al.* 1979).

Analysis of the 14th frond of coconut in Lakshadweep showed that the available value of K content ranges between 0.45 and 0.78 per cent of which 44 per cent of the palms contained less than 0.50 per cent K, 38 per cent between 0.5 and 0.8 per cent and only 18 per cent had values above critical level indicated that 44 per cent palms were severly deficient in K (Singh and Velayutham, 1979). Due to even spreading of KCl mean K content and N content in coconut leaves remain above the critical level (Youan, 1985).

Khan *et al.* (1986) reported that annual application of NPK fertilizer to coconut palm over a period of 18 years in red sandy loam soil, K fertilizer raised the leaf K content to sufficiency levels which had antagonistic effect on leaf Mg and leaf Na. Increasing rate of KCl application resulted in increase in foliar K concentration of coconut leaves (Anon., 1987 and Anilkumar and Wahid, 1989). Leaf K level of 14th frond of coconut was consistently increased by the continued application of KCl and $(NH_4)_2SO_4$ (Magat and Padrones, 1989).

Margate *et al.* (1994) suggested that the leaf K content depressed due to inorganic fertilizer application in coconut. Secretaria *et al.* (1994) stated that double dose of inorganic fertilizer and combined inorganic + organic fertilizer application attributed to highly significant increase in leaf K. The plant K content of the palms receiving fertilizer was much higher whereas the palms receiving cultural treatment only was under severe deficiency (Khan *et al.*, 1996). Rodrigues *et al.* (1997) observed that in the absence of potassium fertilization, K content gradually fell to very low levels.

2.3.4 Calcium

2.3.4 (a) Soil nutrient status

Calcium plays a dual role in the nutrition of coconut. Apart from the role of a nutrient it acts as a soil ameliorant, especially under acidic conditions. Ramanandan and Pillai (1974) reported that there was a slight increase in the soil Ca content in the surface soil due to cultivation and manuring both during rainy and summer season. Anilkumar and Wahid (1989) found that Ca content of leaf and soil steadily increased with increasing levels of superphosphate application.

Application of organic and mixed organic + inorganic fertilizer applications to coconut palm resulted in an increase in soil calcium status (Secretaria *et al.*, 1994). Khan *et al.* (1996) observed no difference in soil exchangeable Ca in the fertilizer and cultural treatments as compared to that of control. Joseph and Wahid (1997) pointed out that as a result of regular application of superphosphate Ca reserve of the soil was improved to a depth of 50 cm, but the application of ammonium sulphate decreased total calcium content of the coconut root zone.

2.3.4 (b) Foliar nutrient status

Ramanandan and Pillai (1974) reported that the Ca content of leaves did not show any significant difference between the manured and cultivated as well as unmanured and uncultivated plots. Breure and Rosenquist (1976) found that application of MOP to coconut has resulted in an increase in the 14^{th} frond Ca level. But on clay loam soil in the Philippines MOP had no effect on Ca content of coconut leaves (Margate *et al.*, 1978). There are similar reports that plant Ca values were not influenced by leaf K levels (Wahid *et al.*, 1974 ; Khan *et al.*, 1986 and Khan *et al.*, 1996). At Sri Lanka application of Saphos *phosphate* increased leaf Ca while the application of MOP decreased Ca content of coconut leaves (Loganathan and Balakrishnamurti, 1979). Manciot *et al.* (1979 b) found in the Ivory coast that application of Ca in the form of $CaCo_3$ to coconut for four consecutive years never modified the Ca level in the leaves while an appreciable increase was observed by nitrogenous or phosphatic fertilizers but K manuring tends to depress the level in the 14^{th} frond.

MOP application had decreased the leaf Ca content in coconut (Anon., 1980 a). Ouvrier (1990) observed that Ca content of the leaf of coconut palm slightly increases in line with age. Ballad (1991) noted that the N fertilizer application did not show any effect on leaf Ca content in the 14^{th} frond. However, it is reported that leaf Ca level was increased due to the application of inorganic fertilizers at the highest dose (Margate *et al.*, 1994).

2.3.5 Magnesium

2.3.5 (a) Soil nutrient status

Ramanandan and Pillai (1974) reported that Mg content was lesser in plot which received regular cultivation and manuring due to higher absorption of Mg by the palms than that of control. Manciot *et al.* (1979 a) stated that N may interfere with Mg nutrition. In acid sandy soils of Cameroon soil Mg content decreased from one year to the next in the absence of fertilization (Ollagnier and Olivin, 1984).

Mathewkutty *et al.* (1994) recorded that Mg level declined drastically as depth increased and would only be 50 to 60 per cent at a depth of 40 to 60 cm and would be less than that still below. Tennakoon (1995) mentioned that animal or green manure of organic sources when applied either as manure, soil ameliorant or mulch provide the coconut palm with sufficient quantities of Mg in addition to other nutrients such as N, P and K. Coconut palms with out NaCl revealed serious Mg deficiency symptoms, but the Mg deficiency was probably correlated by the antagonism between cations, the increase in Na content depressed K contents there by promoting higher Mg contents by a knock on effect (Bonneau *et al.*, 1997).

2.3.5 (b) Foliar nutrient status

Magnesium has been considered as an element essential for healthy growth of coconuts particularly its role in formation of chlorophyll and building up of plant food reserves. Increasing rate of KCl application resulted in depressing of foliar Mg levels (Fremond *et al.*, 1966 ; Coomans, 1977 and

Anilkumar and Wahid, 1989). Leaf K level has an antagonistic relationship with leaf Mg where Mg level was not depressed by K (Wahid *et al.*, 1974 ; Khan *et al.*, 1986 and Khan *et al.*, 1996).

Margate *et al.* (1978) observed that on a clay loam soil in the Philippines MOP had no effect on Mg content of coconut leaf. But at Sri Lanka application of MOP had decreased Mg content (Loganathan and Balakrishnamurti, 1979). Similar findings are also reported due to application of MOP which decreased leaf Mg content in coconut (Anon., 1980 b).

Manciot *et al.* (1979 b) found that the application of Mg fertilizer Kieserite corrects the Mg deficiency and increases the leaf Mg level in the 14th frond of coconut when K shortage has been made up, also in sandy coastal soils N and K fertilizer application often depress Mg level and on the other hand P increases leaf Mg level. Margate *et al.* (1979) reported that Mg content of coconut leaves was not significantly reduced even at higher levels of KCl of 4 and 8 kg per tree due to adequate supply of Mg and K in the soil.

Rosenquist (1980) found that Kieserite application to coconut increased the leaf Mg level at North Sumatra. Khan *et al.* (1986) revealed that in the annual application of NPK fertilizer to coconut on red sandy loam soils leaf K level increased due to K fertilization which had antagonistic effect on leaf Mg and leaf Na level, so suggested that palms receiving K might have supplied with additional Mg fertilizer. Fairly high exchangeable Mg levels in the soil can be expected to raise the Mg concentration in the leaves (Jeganathan, 1990).

Ouvrier (1990) found that Mg content of coconut leaves slightly increased with age of the palm. Ballad (1991) noticed that application of N fertilizer to coconut did not show any effect on Mg content of the 14^{th} frond. The extreme variability in yield obtained between palms in the same garden appears to be the result of inadequate leaf content of Mg in the palms (Mathewkutty, 1994). Coconut palms require Mg content of 0.175 to 0.190 per cent in the index leaf to produce 100 nuts per palm per year (Mathewkutty *et* al., 1994).

2.3.6 Micro nutrients

In recent years much emphasis is being given to the micro nutrient application for the maintenance of yield and good quality of produce in coconut. The micro nutrient elements required for the growth and productivity of the palm are iron, copper, manganese, zinc, boron, molybdenum and probably cobalt. The evolution of high yielding and fertilizer responsive varieties and increased use of inorganic major nutrients have been reported to aggravate the micro nutrient problems of plants (Kamaladevi *et al.*, 1975). To overcome the problems due to micro nutrient deficiency, in addition to supply of mirco nutrients certain cultural practices are also advisable (Velayutham and Singh, 1978).

2.3.6 (a) Iron

Critical value for iron in the soil is 15 ppm (Randhawa, 1967). Takkar and Randhawa (1978) and Singh and Velayutham (1980) reported that organic carbon in the soil showed a significant positive correlation with total iron and available iron and significant negative correlation with $CaCO_3$. The soil analysis at Lakshadweep showed that almost all the soils were found to be deficient in available iron content which is quite obvious in view of high soil pH, $CaCO_3$ and Na content, also its concentration in coconut leaves indicated that marginal cases of iron deficiency are prevalent in the islands. High quantity of total and sodium acetate extractable iron were observed in surface layer with a general decrease in sub soil (Singh and Velayutham, 1980).

Eschbach and Manciot (1981) reported that on young coconuts the application of 5 to 10 g $FeSO_4$ in the husk turned out to be better than a soil dressing and the leaf iron level increased compared to the control. The effect of long term NPK fertilizer application on the availability of Fe, Cu, Zn and Mg was not found to be significant (Anilkumar and Wahid, 1989). Khan *et al.* (1996) observed that in plots receiving fertilizer the soil available Fe was more. Joseph and Wahid (1997) found that total Fe content of the coconut root zone was unaffected due to the application of ammonium sulphate.

2.3.6 (b) Copper

Kee *et al.* (1974) found that in matured palms application of 2.5 kg $CuSO_4$ per palm showed a good response after three months of application and leaf Cu status was considerably enhanced at 2 to 5 ppm compared to 1.4 to 2.1 ppm in untreated normal palms. Copper content was found to be comparatively higher in surface soil than sub soil in Lakshadweep and also the available copper content of the soil was adequate in most of the samples above the critical limits and its concentration in coconut leaves was below the optimum concentration (Singh and Velayutham, 1980). Eschbach and Manciot (1981) observed that application of ammonium sulpahte significantly increased Cu level in rank 14 leaves from 5.1 to 6.4 ppm.

Vijayaraghavan *et al.* (1988) noticed that the Cu content in coconut leaf was increased due to $CuSO_4$ application. Six months after $CuSO_4$ application in copper deficient coconuts the Cu content fell down from 3 to 1 ppm with a more substantial drop for the coconut treated with $CuSO_4$ than for the control which clearly showed that it is not possible to make valuable judgements about copper nutrition based on leaf contents if the coconuts are deficient (Ochs *et al.*, 1993). Joseph and Wahid (1997) suggested that total copper content of the coconut root zone was increased due to ammonium sulphate application.

2.3. 6 (c) Manganese

Critical value of Mn in the soil is 5 ppm (Toth , 1951). Devi *et al.* (1975) suggested that available Mn in the soil was increased due to regular application of ammoniacal fertilizers for 8 years. In calcareous soil Mn availability increases with organic matter content but decreases with $CaCO_3$ content (Khan and Ryan, 1978).

Rosenquist (1980) reported that application of sulphate of ammonia, rock phosphate, MOP and Kieserite increased the leaf Mn levels in coconut at North Sumatra. Singh and Velayutham (1980) suggested that in Lakshdweep coconut growing soil is not having sufficient total and exchangeable Mn for healthy growth of palms and its concentration in the coconut leaves is also less than the critical limit and a higher concentration of total and available Mn was invariably observed in surface layer with general decrease in sub soil. Also a significant positive correlation was found between total Mn and Organic carbon and EDTA + ammonium carbonate extractable Mn.

Eschbach and Manciot (1981) observed that injection of Mn into the stem of coconut had increased the 14^{th} frond leaf Mn level. In red soil with increasing rate of application of ammonium sulphate, decreased available Mn in soil markedly at various depths from 0 to 100 cm (Anilkumar and Wahid , 1989). Joseph and Wahid (1997) found that application of ammonium sulphate decreased the total Mn content of coconut root zone.

2.3.6 (d) Zinc

Katyal and Ponnamperuma (1974) stated that the critical limit for soil Zn is 1.5 ppm. Misra *et al.* (1975) and Takkar and Randhawa (1978) reported significant positive correlation between organic matter and available Zn. In Lakshadweep the soils were found to be sufficient in available Zn in coconut grown areas and the Zn content of the coconut leaves was also more than the critical limits and a positive correlation was found between organic carbon and total zinc and organic carbon and EDTA + ammonium carbonate extractable Zn (Singh and Velayutham, 1980).

Eschbach and Mancoit (1981) observed that application of $ZnSO_4$ given to nursery plants in the form of Nutramin and to adult trees as 50 g per palm per year of $ZnSO_4$ lead to increase in leaf Zn levels. Joseph and Wahid (1997) reported that application of ammonium sulphate decreased total Zn content of the coconut root zone.

2.4 Effect of spacing on growth components

Fertility and depth of soil are important factors determining optimum spacing. According to Jones (1940) spacing should be so adjusted as to provide enough volume of soil for exploitation of nutrients by roots. Patel (1938) and John (1952) reported that in Indian condition higher number of palms per acre is recommended for fertile soils. However, in Sri Lanka and Philippines few number of palms are recommended. Nevertheless, close spacing of coconut is advocated in Sri Lanka for areas subjected to drought (Ganarajah, 1954).

Reviewing the works of various authors Thampan (1975) stated that the general recommendations for pure stand of tall variety of coconut are 7.5 to 9.0 m on square or triangle in India, 26 to 28 feet square in Sri Lanka, 29 to 30 feet spacing in West Malaysia, 26 to 28 feet in East Malaysia, 27 feet triangle in Jamaica and 28 feet in Indonesia. Manthriratna (1976) reported from a spacing trial on coconut that spacing had no significant influence on total leaf production, had a significant effect on the length of leaves and the girth of the trunk and had no significant effect on the period taken for the emergence of the first inflorescence (initial flowering).

Louis *et al.* (1981) observed that spacings did not show any significant difference in the rate of increase in girth or height of palms of coconut, however closest spacing had forced vertical growth in palms after 3 to 4 years of their establishment compared to those in the wider spacings. Also found that the number of leaves produced per year were not affected by spacing, even though not significantly differed number of leaves produced per annum showed an upward trend with increase in spacing. The palms under wider spacings (9.1 m x 9.1 m) irrespective of manuring levels flowered earlier by seven months than those with closer spacings.

Mohammed *et al.* (1982) showed that there was a greater tendency for lateral root expansion particularly in the form of primary roots in lower density systems and the development of more feeder roots in the higher density systems. Tan Yap Pau and Chan (1985) found that in MAWA hybrids the length of 4th frond increased with increasing palm density but the differences between treatments were small, the number of pinnae of 14th frond to be similar in all four densities. They further recorded that @ 185 palms per hectare maximum overlap between fronds at 8 years from field planting was about one fourth of the rachis length.

Foale (1993) indicated that planting at a higher density was resulted in intense competition between the young palms as they approach maximum leaf area resulting in an extended period of rapid stem elongation, to the detriment of yield.

In Sri Lanka Fernando and Bandaranayake (1996) recommended that the range of plant population density for commercial tall variety varies from 123 to 210 palms per hectare and different systems of planting are adopted to obtain the relevant densities. They also revealed that spacing had no significant influence on total leaf production or time taken for initial flowering but had a significant effect on the length of fronds and the girth of the trunk.

2.5. Effect of spacing on yield and yield components

Coconut palms are generally planted at spacings determined from past experience. As a result, several plant to plant spacings are followed in different coconut growing countries. However experimental findings on the optimum spacing to get maximum return, from unit area are meagre. Recommendations made on spacings in coconut in various countries are based on empirical considerations. Sampson (1923), Copeland (1931) and Patel (1938) have discussed this aspect of coconut cultivation and recommended different spacings under diverse soil and climatic conditions.

Menon and Pandalai (1958) have cited the different spacings adopted in different countries. In India it varies from 6 m to 9 m, whereas in Sri Lanka the range is wider with 2.75 m to 14 m, though the common spacing being 8 to 8.7 m. Smith (1968) found that fields with higher palm density tend to have lower oil per cent. Thomson (1968) obtained higher yields of coconut in Cook Islands by thinning of existing stand. In the spacing experiment conducted in Jamaica Whitehead and Smith (1968) obtained maximum yield of 4815 nuts per acre at 22' x 22' spacing which was the lowest spacing tried, per palm yield of 95.1 nuts per year was obtained at the widest spacing of 35' x 35'. He also found that the number of set nuts increased from closest to the widest spacing and a large part of the increased nut count per palm at the wider spacing was due to greater number of set nuts per bunch rather than to an increase in the number of bunches. He further noticed that nut size decreased with increased plant density. The same trend has been reported from a spacing cum manurial trail conducted at Veppankulam in India (Thampan, 1975).

Romney (1972) opined that in the development of more effective agricultural methods, planting density appears to be an important point to be cosidered in precocity and high yields per acre. At high densities though flower production per infloresence was high, setting was less (Smith, 1972). Further it was also observed that maximum yields could be obtained only if the palms are planted with in an optimal density range.

The maximum yield of nuts per acre was obtained with a palm density of 145 to 160 palms per acre in an experiment at Jamaica (Anon., 1974). According to Child (1964) the consensus of opinion among experienced planters in Sri Lanka was that planting density should not exceed 160 ha^{-1} in the worst soil and 140 in the best. Coomans (1974) found that in Ivory Coast the number of nuts per tree, copra yield per tree and copra content per nut decreased with increasing density and in the prevailing condition he recommended an optimum density of 150 trees per hectare. Muhammed *et al.* (1974) recommended a spacing of 9.1 m x 9.1 m based on the results of a spacing cum manurial experiment at Veppankulam where there was 70 per cent increase in yield in plots with lowest density over plots with highest density in the eighth year of planting. While a stand of 250 palms per hectare (based on return per rupee invested) has been arrived as the best from the spacing trails at RARS, Pilicode, and a spacing of 7.5 m x 7.5 m (178 palms per hectare) demonstrated its superiority at CRS Balaramapuram (Anon., 1976).

Kannan *et al.* (1977) found that the annual yields per tree are not influenced by plant densities, age or position of trees, while the nut yield per tree in the plant density of 100 trees per acre was 31.63 and 36.73 for the whole bearing period and for steady bearing period respectively, they were 34.22 and 35.22 for plant density of 80 trees and 34.62 and 37.17 for plant density of 60 trees per acre. They also observed that maximum number of nuts per acre was obtained from the closer spacing palms due to large population (100 trees per acre) and though the copra out turn per nut in wider spaced palms was slightly higher than the closer spaced palms the yield per acre was higher in the later due to larger number of plants per unit area. Manthriratne and Abeywardena (1979) showed that significant differences existed in the mean yield per palm for change in both, between and within row and the number of nuts per palm decreased with increasing density. The change in spacing varied nut production with 83 nuts per palm at a density of 128 palms per hectare, 68 nuts at a density of 175 palms per hectare and 54 nuts at a density of 239 palms per hectare. They also recommended a spacing of 9.14 m x 4.57 m and 7.62 m x 4.58 m to get higher yields per unit area.

Louis *et al.* (1981) indicated that there was no significant differences in the per palm yield due to the spacings. However the per palm yield was 85.7 per cent higher in the spacing 7.1 m x 7.1 m than in the spacing 6.1 m x 6.1 m. But the per hectare yield was highest in the closest spacing of 6.1 m x 6.1 m.

Tan Yap Pau and Chan (1985) found that the number of nuts produced per palm per year increased with increasing area, but the rate of increase was lower with increasing densities. It was also clearly demonstrated the adverse effect of high density on nut production per palm in which the nut yield per palm per year in the fifth year of production of 136 palms per hectare was 88 per cent higher than that of first year of production and that of 211 palms per hectare was 62 per cent only. However, the nut production per hectare was highest in 211 palms per hectare eventhough the nut per palm was the lowest and per hectare yield was lowest in 136 palms per hectare even though the nuts per palm was highest in this. Also observed that the density of the coconut palms not affected the oil content of copra.

Bopaiah (1989) noticed that coconut yield was markedly higher in areas where the palm density was 300 per hectare as against the areas with plant density of 800 palms per hectare.

De Taffin *et al.* (1992) observed that the variation in the number of nuts per tree was inversely related to density. They also revealed that copra per nut was not affected by the density of coconut palms, but significant differences were observed between densities for copra per hectare. Though the spacing of 8 m x 8 m distance appears to be ideal, considering land scarcity and fuel needs of the Lakshadweep island, about 300 palms per hectare would satisfy the fuel and coconut need of the islanders and any density higher than this would be uneconomical (Bopaiah, 1993). Fernando and Bandaranayake (1996) reported that the nuts per palm decreased with increasing density but the yield per hectare maximised at a density of 171 palms per hectare and decreased beyond 171. In another study at a density of 179 palms per hectare copra per hectare maximised to 2260 kg and decreased beyond 179 and they recommended that a planting density ranging from 171 to 179 palms per hectare is optimum for planting coconut in dry intermediate zone.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

An investigation was conducted during 1995-96 to estimate the changes in the nutrient status of both soil and plant tissues as influenced by different planting density and continuous application of different levels of inorganic fertilizers in coconut. Samples for the investigation were collected from an ongoing spacing cum manurial experiment on West Coast Tall (WCT) palms systematically laid out and maintained for over 30 years in the Coconut Research Station, Balaramaupram of the Kerala Agricultural University.

Experimental site

The Coconut Research Station is located at Kattachalkuzhy, 3.2 km South of Balaramapuram lie at 8^0 29' N latitude and 76^0 57' E longitude and at 64 metre above mean sea level (MSL) on the Balaramapuram - Vizhinjam road in Neyyattinkara taluk of Thiruvananthapuram district in Kerala State.

Climate

The experimental area has a humid tropical climate. The mean annual rainfall ranges from 1200 to 1500 mm. The average maximum and minimum temperatures are 30.7^0C and 23.4^0C respectively.

Soil

The soil is red loam and an acidic alfisol. The taxonomic name of the soil is Fine Loamy Kaolinitic Isohyperthermic Kandic Haplustalfs (Bindukumari, 1993).

The experiment

The study was conducted deriving materials from the 30 year old coconut palms of the spacing cum manurial experiment located in the B block of the experimental station. This experiment was initiated in June 1964 using relatively homogenous WCT coconut seedlings. One year old seedlings were planted in 0.9 m^3 pits.

The experiment was designed to determine the optimum spacing at different levels of fertilizer application. The treatment consisted of three spacings and three levels of N, P and K. There was no organic matter addition in the treatments.

Design : 3 x 3 Factorial experiment in RBD

Number of replication : 3

Variety : West Coast Tall (WCT)

Treatments :

(1) spacing

Symbols	Spacings (m)	No. of palms $plot^{-1}$	Net plot size (m)	Plant density (No. of palms ha^{-1})
S_1	5.0 x 5.0	5 x 5	25.0 x 25.0	400
S_2	7.5 x 7.5	3 x 3	22.5 x 22.5	178
S_3	10.0 x 10.0	2 x 2	20.0 x 20.0	100

(2) Fertilizer level

Symbols	Nitrogen	Phosphorus	Potassium
	g palm^{-1} year^{-1}		
M_0	0	0	0
M_1	340	225	450
M_2	680	450	900

Source of nutrients :

Nitrogen : Urea (46 % N)

Phosphorus : Rock phosphate (20 % P_2O_5)

Potassium : Muriate of potash (60 % K_2O)

Border rows : Common border rows for the plot

Number of trees under experiment : 342

Number of trees under border : 259

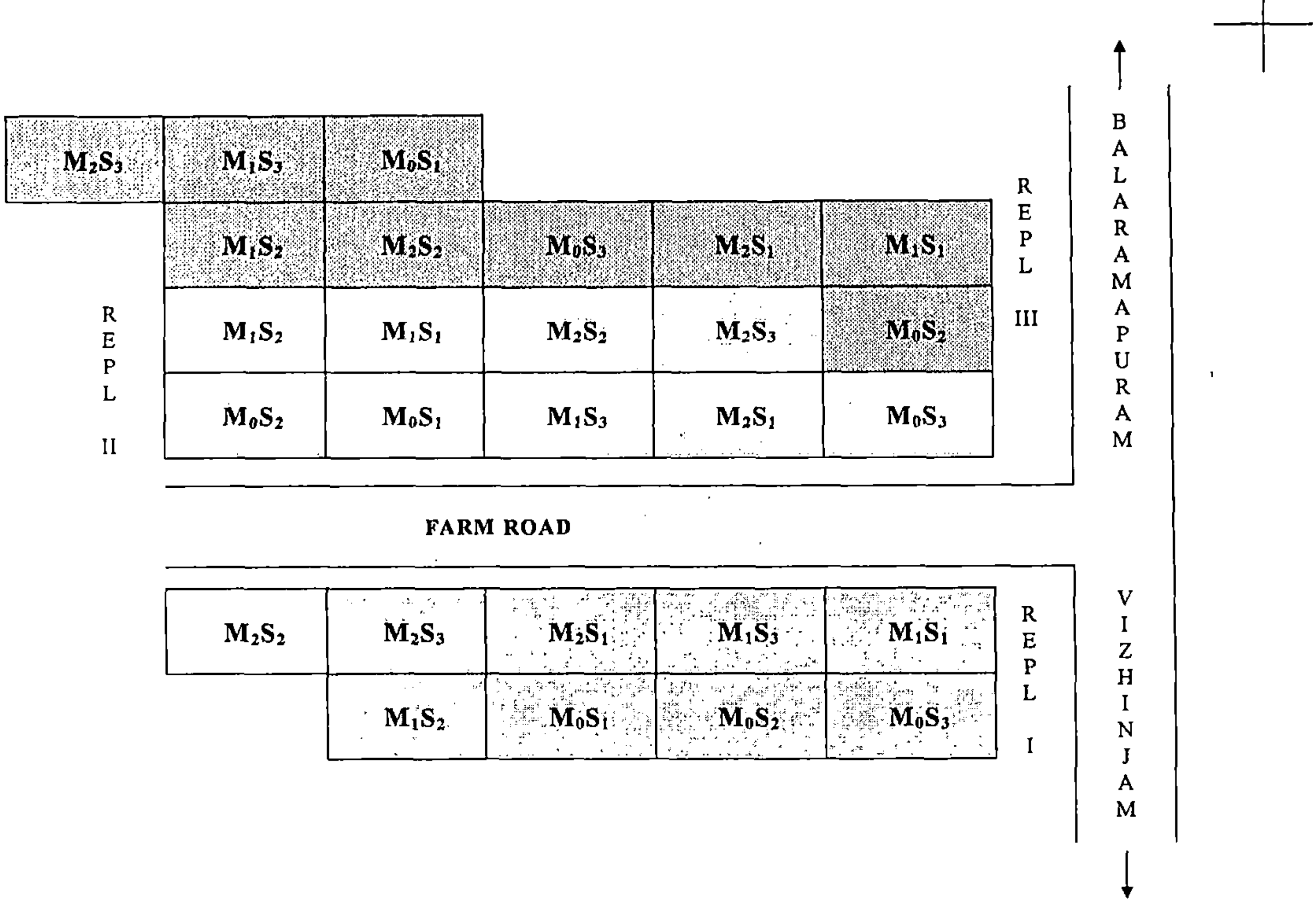
Harvest interval : 60 days

Treatment combinations

S_1M_0	S_2M_0	S_3M_0
S_1M_1	S_2M_1	S_3M_1
S_1M_2	S_2M_2	S_3M_2

The fertilizers were applied annually in one dose in trenches of 45.0 cm width and 22.5 cm depth around the trunk at a distance of 1.4 m. During the first year 1/3 of the full dose and during the second year 2/3 of the full dose were given. From third year onwards full dose was applied

Fig. 1 Lay-out of field experiment



annually in September. The trenches were covered after incorporating the fertilizers using the soil of the basin.

Observations

The investigation was conducted for a period of one year commencing from June 1995 to June 1996 to study the nutrient status of the soil and plant as influenced by spacing and continued manuring in relation to yield of nuts, copra and oil. Harvesting of nuts from the selected palms started during June 1995 and subsequent harvests were conducted at an interval of 60 days. Thus during the period of one year six harvests were conducted. Nut characteristics of the entire six harvests in the year was studied. Four palms were selected from each plots for taking the observations.

3.1 Vegetative growth characters

Studies on the following vegetative growth characters of the palms were recorded.

3.1.1 Height of palms

Height of all the randomly selected palms were measured from the base of the crown to the ground level and the mean height expressed in metres.

3.1.2 Girth of palms

The girth of trunk of randomly selected palms were measured just below the crown (ie., just below the oldest leaf) and at 1.50 m above the ground level separately and expressed in cm.

3.1.3 Number of leaves produced in a year

Total number of leaves produced in a year was recorded in June 1996 from the tagging made in the last opened leaf during the previous year June 1995 and counting the number of new leaves produced above the tagged leaf.

3.2 Yield and yield components

Studies on the following yield components of the selected palms were recorded. To study the nut characteristic a single medium sized nut from each of the four selected palms from each plot was selected during every harvest in a year (Vijayalakshmi *et al.*, 1962 ; Silva and George, 1970 and Balingasa and Carpio, 1983). Nut, kernel, shell and copra characters were recorded as follows.

3.2.1 Number of nuts per palm per year

This was obtained by adding the total number of nuts harvested in each harvest for one year.

3.2.2 Yield of nuts

Yield of individual palms were recorded from six bimonthly harvests from June 1995 to April 1996. Also the nut yields for the individual years from 1994 to 1997 were collected for the study.

3.2.3 Production of female flowers

Number of female flowers in each harvested bunch were added with number of nuts in that particular bunch which gave the number of female flowers in that spadix. Then the total number of female flowers in total number of bunches harvested in a harvest was counted.

3.2.4 Number of bunches per year

The number of bunches harvested in each harvest added together to obtain number of bunches per year.

3.2.5 Setting per centage (per cent fruit set)

This was estimated as follows :

$$X = \frac{a}{b} \times 100$$

Where, X = Setting per centage

a = Total number of nuts produced

b = Total number of female flowers produced

3.2.6 Number of nuts per bunch

Number of nuts per bunch in each harvest was added together and mean number of nuts per bunch was obtained as follows :

$$X = \frac{a}{b}$$

Where, X = mean number of nuts per bunch

a = total number of nuts produced in a year

b = total number of bunches produced during the year

3.2.7 Weight of unhusked nut

Weight of all the nuts with husk were found out by using a pan balance on the same day of harvest and expressed in grams.

3.2.8 Volume of unhusked nut

The nut with husk were individually imersed using a strong needle in a 45 cm tall plastic trough filled with water and fitted with a spout near the top and the displaced water flowing out through the spout was measured using a measuring cylinder to determine the volume in cc.

3.2.9 Weight of husked nut

The nuts were husked, cleaned and weighed and expressed in grams.

3.2.10 Volume of husked nut

The volume of husked and cleaned nuts were determined by immersing the nut using a strong needle in a 45 cm tall plastic trough filled with water and fitted with a spout near the top and the displaced water flowing out through the spout was measured using a measuring cylinder to determine the volume in cc.

3.2.11 Ratio of weight of husked nut to unhusked nut

This was estimated as follows :

$$X = \frac{a}{b}$$

Where, X = Ratio of weight of husked nut to unhusked nut a = Weight of husked nut

b = weight of unhusked nut

3.2.12 Weight of husk

Weight of husk was obtained by deducting weight of husked nut from weight of unhusked nut and expressed in grams.

3.2.13 Husk / nut ratio

The difference in weight of unhusked nut and husked nut divided by weight of unhusked nut gave the husk / nut ratio.

3.2.14 Weight of split nut

The husked nut was split into two halves and weighed after completely draining the nut water and weight was recorded in grams.

3.2.15 Weight of shell

Weight of shell was noted after removing the kernel from the shell and weight recorded in grams.

3.2.16 Thickness of shell

Shell thickness was measured by using screw gauge at three different places on the circumference of the opened nut and the mean shell thickness expressed in cm.

3.2.17 Weight of kernel

Weight of kernel was obtained by deducting the weight of shell from the corresponding split nut weight and expressed in grams.

3.2.18 Thickness of kernel (meat)

Meat thickness was measured by using screw gauge at three different places on the circumference of the opened nut and the mean meat thickness expressed in cm.

3.2.19 Weight of copra per nut

Copra was prepared by sun drying of the kernel for 4 to 5 days depending upon the sunlight, after which the level of moisture was expected to be between 6 to7 per cent (Ramachandra, 1987). At this stage weight of copra was found out and expressed in grams.

3.2.20 Ratio of weight of copra to husked nut

This was calculated as follows :

$$X = \frac{a}{b}$$

Where, X = ratio of weight of copra to husked nut

a = weight of copra

b = weight of husked nut

3.2.21 Per cent oil in copra

The copra from each nut was sampled to about 50 g, oven dried at 60^0C for 16 hours and sub sampled to 10 g (Horney, 1972) and the oil content of copra was estimated by ether extraction method (Anon, 1971).

Chemical analysis

3.3 Soil nutrient status

3.3.1 Collection of soil samples

Soil samples were collected to study the treatment effects on the soil nutrient status. From each plot composite soil samples from the basins of the four selected experimental palms were separately collected from four depths viz., 0 to 25 cm, 25 to 50 cm, 50 to 75 cm and 75 to 100 cm using a 5 cm diameter soil auger at a lateral distance of 160 cm away from the bole of the palm during September 1995. The samples collected from the basins of the four palms in a plot for a particular depth were pooled to form a single sample. The samples were air dried, cleaned and processed by passing through a 2 mm mesh sieve and approximately 250 g sample was finally taken adopting quartering technique.

3.3.2 Analytical methods

The 108 soil samples (9 treatments x 3 replications x 4 depths) collected were powdered with a wooden mallet and seived through 2 mm mesh seive and subjected to the following analytical estimations. Available N, P, K, Ca. Mg, Fe, Cu, Mn and Zn were estimated by standard procedures as indicated in table 1.

3.4 Leaf nutrient status

3.4.1 Collection of leaf sample

Leaf samples were collected in the last week of August 1995. The four selected trees from each plot from the basin of which soil samples were collected were selected for taking leaf samples.

Leaf samples from the 14^{th} frond as suggested in the sampling procedure of I.R.H.O. (Prevot and Bachy, 1962 ; Fremond *et al.*, 1966 and Uexkull and Cohen, 1978) starting from the first fully opened one (Chapman, 1964) were collected. The 14^{th} leaf was particularly selected since it had attained the full physiological maturity, but had not entered the phase of senescence. Five middle leaf lets from either side of the central rachis were separated and from each leaf let the central 10 cm portion was taken after discarding the midrib and marginal 2 mm of the laminae (Fremond *et al.*, 1966).

The samples were cleaned with moist cotton to remove dust and then cut into small pieces, dried in an oven at 75^0C, powdered in an ultra centrifugal mill with 1 mm sieve and stored in polythene bottles.

3.4.2 Leaf analysis

The leaf samples were digested using a 9 : 3 : 1 HNO_3 : $HClO_4$: H_2SO_4 acid mixture for estimation of all the nutrients mentioned below except for N.

Table 1 Details of methods followed in soil chemical analysis

Soil characteristics	Soil solution ratio	Extraction time	Extractant used	Method of estimation	Instrument used	Reference
Available N	-	-	Alkaline permanganate	Distillation and Titration	-	Subbiah and Asija (1956)
Available P	1 : 10	5 minutes	Bray - I	Molybdenum blue	Klett Summersion Photoelectric Colorimeter	Jackson (1973)
Available K	1 : 10	30 minutes	N-Ammonium acetate (pH = 7)	Direct reading	Flame Photometer	Jackson (1973)
Available Ca	1 : 10	30 minutes	N-Ammonium acetate (pH = 7)	Direct reading	Atomic Absorption Spectrophotometer	Jackson (1973)
Available Mg	1 : 10	30 minutes	N-Ammonium acetate (pH = 7)	Direct reading	Atomic Absorption Spectrophotometer	Jackson (1973)
Available Fe	1 : 2	2 hours	DTPA	Direct reading	Atomic Absorption Spectrophotometer	Lindsay and Norvel (1978)
Available Cu	1 : 2	2 hours	DTPA	Direct reading	Atomic Absorption Spectrophotometer	Lindsay and Norvel (1978)
Available Mn	1 : 2	2 hours	DTPA	Direct reading	Atomic Absorption Spectrophotometer	Lindsay and Norvel (1978)
Available Zn	1 : 2	2 hours	DTPA	Direct reading	Atomic Absorption Spectrophotometer	Lindsay and Norvel (1978)

3.4.2 (a) Nitrogen

Nitrogen was estimated by the modified Kjeldhal method as described by Jackson (1973).

3.4.2 (b) Phosphorus

Phosphorus in the digest was estimated colorimatrically by the vanado molybdate yellow colour method using a Spectronic 2000 (Jackson, 1973).

3.4.2 (c) Potassium

Potassium content was determined in the acid extract using an EEL Flamephotometer (Jackson, 1973).

3.4.2 (d) Calcium

Calcium content was determined in the triple acid extract by using a Perkin Elmer Atomic Absorption Spectrophotometer (Issac and Kerber, 1971 and Cooksey and Barnett, 1979).

3.4.2 (e) Magnesium

Magnesium content was determined in the triple acid extract by using a Perkin Elmer Atomic Absorption Spectrophotometer (Issac and Kerber, 1971 and Cooksey and Barnett, 1979).

3.4.2 (f) Iron

Iron content was determined in the acid extract using a Perkin Elmer Atomic Absorption Spectrophotometer (Issac and Kerber, 1971 and Cooksey and Barnett, 1979).

3.4.2 (g) Copper

Copper content was determined in the acid extract using a Perkin Elmer Atomic Absorption Spectrophotometer (Issac and Kerber, 1971 and Cooksey and Barnett, 1979).

3.4.2 (h) Manganese

Manganese content was determined in the acid extract using a Perkin Elmer Atomic Absorption Spectrophotometer (Issac and Kerber, 1971 and Cooksey and Barnett, 1979).

3.4.2 (i) Zinc

Zinc content was determined in the acid extract using a Perkin Elmer Atomic Absorption Spectrophotometer (Issac and Kerber, 1971 and Cooksey and Barnett, 1979).

3.4.2 (j) Sodium

Sodium content was determined in the acid extract using a Perkin Elmer Atomic Absorption Spectrophotometer (Issac and Kerber, 1971 and Cooksey and Barnett, 1979).

Statistical analysis

The data obtained under various observations were statistically analysed and the results were interpreted.

RESULTS

4. RESULTS

The results of the investigation conducted to study the effect of spacing and continued manuring in the nutrient status of both soil and plant tissues, growth characters, yield and yield components are presented below.

4.1. Effect of spacing and manuring on growth characters

4.1.1 Height of palms

Mean height of palms due to the influence of spacing, manuring and their interaction are given in table 2.

Both spacing and manuring had a significant effect on height. Height of palms did not differ significantly between wider spacing of S_2 and S_3. The height of S_2 and S_3 were significantly low compared to S_1 which was planted at closer spacing of 5.0 m. The maximum height was recorded in palms planted at S_1 spacing (12.80 m) and the lowest in case of S_3 (10.85 m).

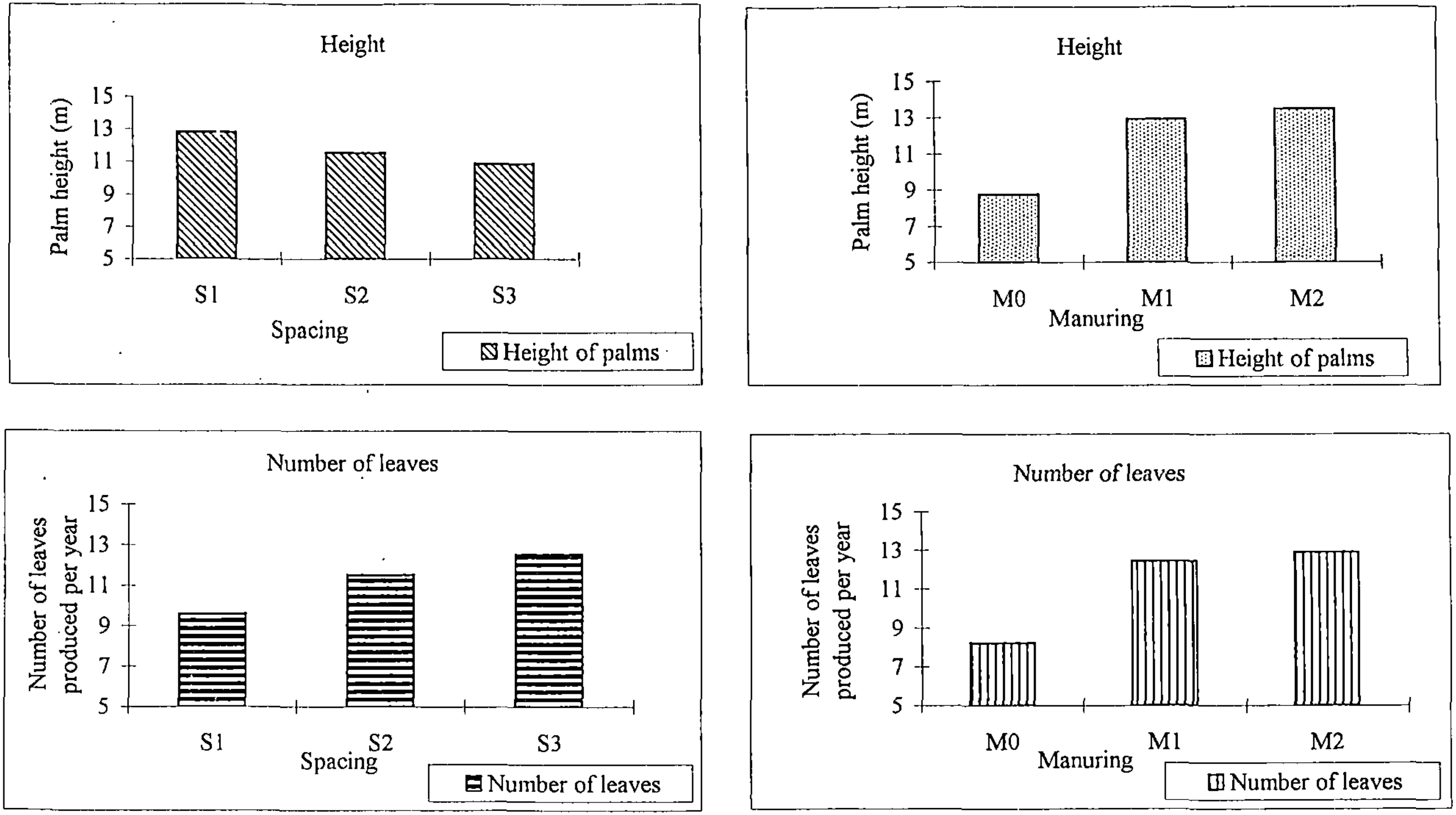
Manuring enhanced the plant height to a greater extent. The palms in plots receiving fertilizers were taller than palms in unmanured plots. The highest palm height was recorded in palms applied with M_2 level of fertilizer (13.47 m) which did not differ significantly with M_1 level of fertilizer. In the absence of manuring palm height was observed to be the lowest (8.77 m).

There was no interaction between spacing and manuring on palm height.

Table 2 Effect of spacing and manuring on palm height, girth and number of leaves produced in a year

Effect	Height of palms (m)	Girth of palms (below the crown) (cm)	Girth of palms (1.5 m above ground level) (cm)	Number of leaves produced per year
Spacing				
S_1	12.80	69.67	76.17	9.58
S_2	11.52	71.67	80.11	11.49
S_3	10.85	70.00	78.11	12.50
Manuring				
M_0	8.77	66.94	67.83	8.21
M_1	12.93	73.78	83.44	12.45
M_2	13.47	71.61	83.11	12.90
C D	1.059	2.645	4.092	0.258
$S_1 M_0$	9.76	67.00	65.67	6.60
$S_1 M_1$	13.83	69.83	78.83	11.01
$S_1 M_2$	14.80	72.17	84.00	11.12
$S_2 M_0$	9.43	68.50	73.67	8.46
$S_2 M_1$	12.33	76.67	84.17	12.68
$S_2 M_2$	12.79	71.83	82.50	13.32
$S_3 M_0$	7.11	65.33	64.17	9.58
$S_3 M_1$	12.63	74.83	87.33	13.66
$S_3 M_2$	12.81	70.83	82.83	14.27
C D	N.S.	N. S.	N. S.	N. S.
$SE_M \pm$	0.612	1.528	2.364	0.149

Fig. 2 Effect of spacing and manuring on height of palms and number of leaves produced in a year



4.1.2 Girth of palms

The results on the effect of treatments on girth of palms below the crown and at 1.50 m above ground level as presented in table 2.

Manuring alone had a significant effect on the girth in both cases. Below the crown manuring increased the plant girth up to the highest level of M_2. The same result was observed in plant girth at 1.50 m above the ground level and both the plant girth was not significantly different at M_1 and M_2 doses of NPK. The unamnured plots recorded the lowest plant girth of 66.94 cm and 67.83 cm at below the crown and at 1.50 m above ground level respectively.

In both girths at below the crown and at 1.50 m above ground level, spacing and spacing × manuring interaction did not have any significant effect.

4.1.3 Number of leaves produced in a year

The data on number of leaves produced in a year are presented in table 2. The data revealed that spacing as well as manuring had highly significant effect on leaf production. More number of leaves were produced in wider spacings of S_2 and S_3. The highest number of leaves (12.50) were produced in the widest spacing (S_3) which is significantly superior to S_2 and the closest spacing (S_1) which produced the lowest number of leaves (9.58).

Manuring also considerably increased the production of leaves progressively with fertilizer levels and the highest leaf production (12.90) was at M_2 level of NPK application which is significantly superior to the lower levels of M_1 and M_0. The lowest number of leaves (8.21) were produced by the

Fig. 3 Effect of spacing and manuring on girth of palms (below the crown and 1.5 m above ground level)

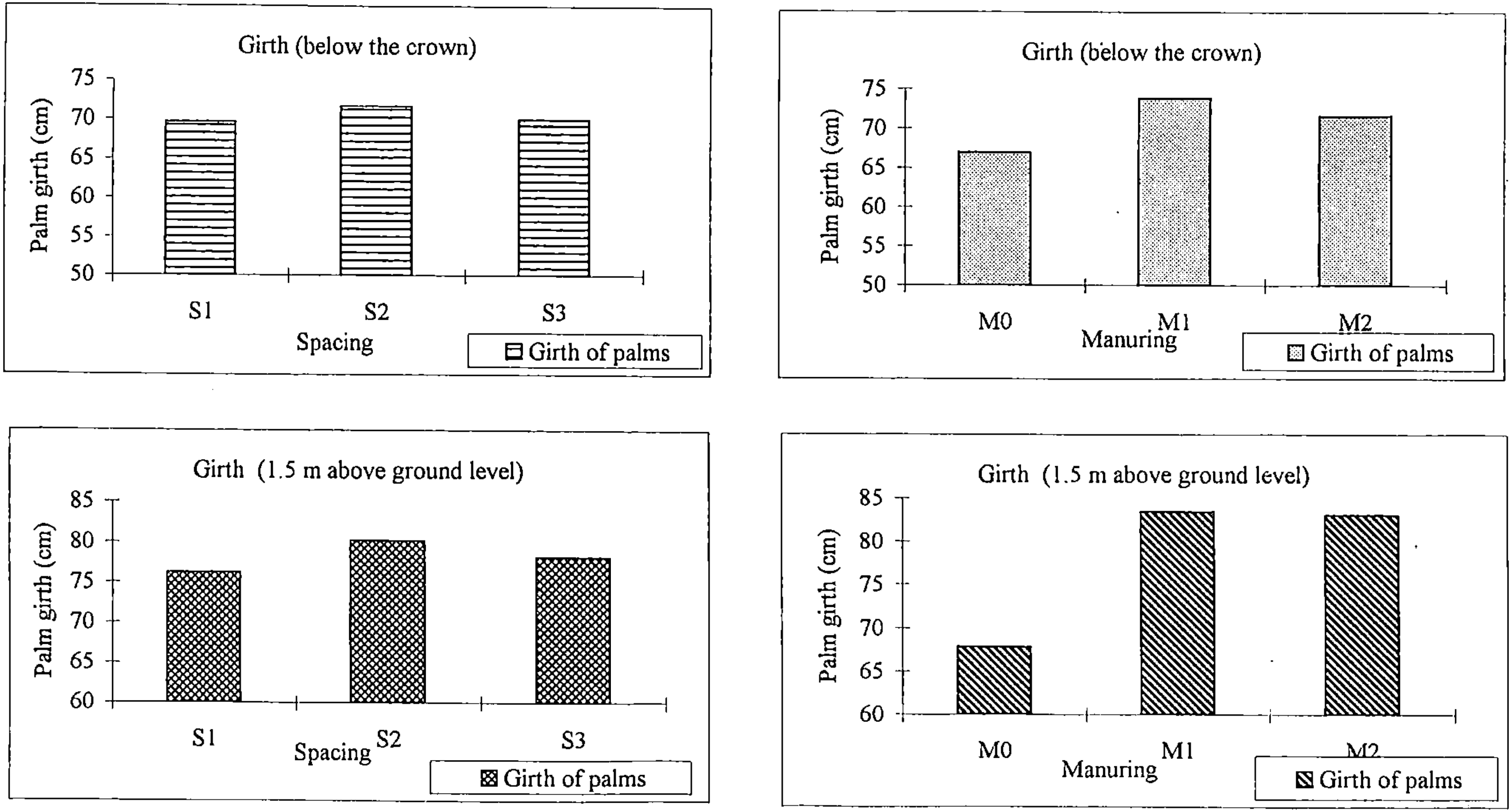


Plate 1. Crown of coconut palms planted at 5.0 x 5.0 m (S_1) spacing

Plate 2. Crown of coconut palms planted at 7.5 x 7.5 m (S_2) spacing

Plate 3. Crown of coconut palms planted at 10.0 x 10.0 m (S_3) spacing

Plate 4. Coconut palms planted at 5.0 x 5.0 cm (S_1) spacing and applied with no fertilizers (M_0)

unmanured palms(M_0).

The combined effect of spacing and manuring on leaf production was not significant.

4.2 Effect of spacing and manuring on yield and yield components

4.2.1 Yield of nuts per palm

The per palm yield of nuts for four consecutive years from 1994 to 1997 as influenced by spacing, manuring and their interaction are presented in table 3.

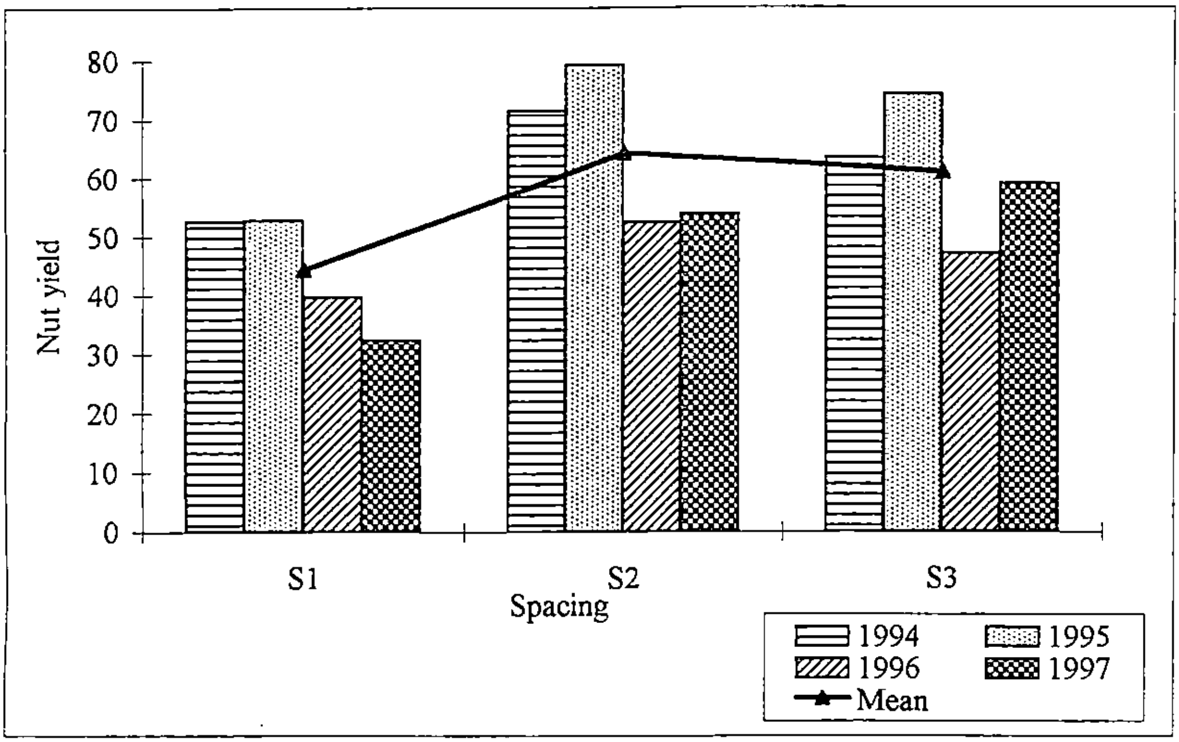
Yield varied significantly with spacing and manuring. Wider spacings gave more yield than closer spacing. During the years 1994 and 1996 the yield of nuts per palm did not differ significantly when they were planted at S_1 and S_3 spacings but differed significantly during 1995 and 1997. In all the four years from 1994 to 1997, the yield did not differ significantly when the palms were planted at S_3 and S_2 spacings but significantly higher than those planted at S_1 spacing. Also in all the four years the lowest per palm yield was recorded in palms planted at S_1 spacing (5.0 m) and the highest yield in S_2 spacing (7.5 m) except in the year 1997 in which the highest yield was observed in palms planted at a spacing of 10.0 m.(S_3).

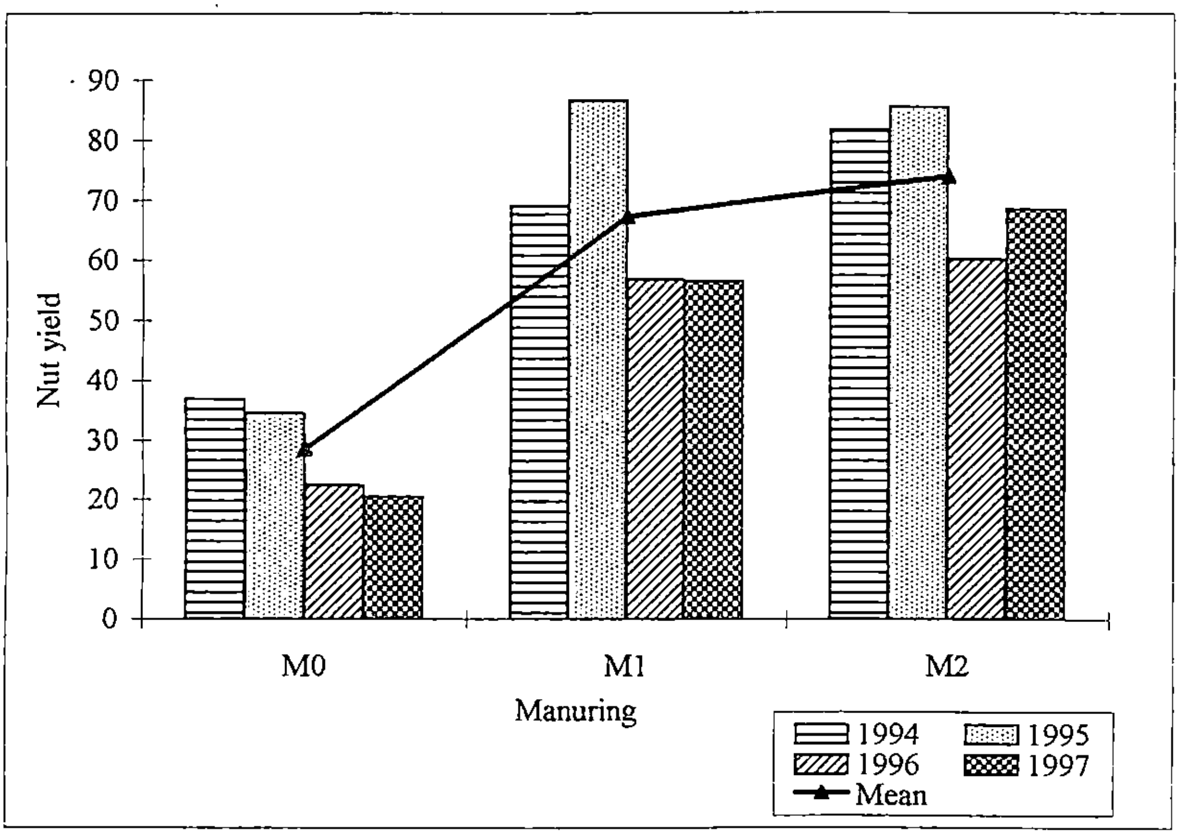
Manuring significantly influenced the yield of nuts per palm. The highest per palm yield was obtained in palms fertilized at M_2 level in all the four years except in 1995 where the highest yield per palm was observed at M_1 level. Yield of palm did not differ significantly when they were fertilized at M_1 and M_2 doses during the years 1995, 1996 and 1997 where as a significant

Table 3. Effect of spacing and manuring on yield of nuts per palm for the years 1994 to 1997

Effect	1994	1995	1996	1997	Mean
Spacing					
S_1	52.73	52.88	39.73	32.42	44.44
S_2	71.38	79.21	52.46	53.88	64.23
S_3	63.36	74.19	47.14	59.00	60.92
Manuring					
M_0	36.91	34.50	22.49	20.55	28.61
M_1	69.00	86.50	56.76	56.37	67.16
M_2	81.57	85.28	60.08	68.37	73.83
C D	12.365	12.305	9.926	14.452	12.26
$S_1 M_0$	24.27	22.45	14.59	11.91	18.31
$S_1 M_1$	63.44	63.09	44.87	35.71	51.78
$S_1 M_2$	70.49	73.09	59.75	49.64	63.24
$S_2 M_0$	56.96	55.89	32.63	32.00	44.37
$S_2 M_1$	74.15	92.48	57.33	66.67	72.66
$S_2 M_2$	83.04	89.26	67.40	62.96	75.67
$S_3 M_0$	29.50	25.17	20.25	17.75	23.17
$S_3 M_1$	69.42	103.92	68.08	66.75	77.04
$S_3 M_2$	91.17	93.50	53.08	92.50	82.56
C D	N.S.	21.313	N. S.	N. S.	21.313
$SE_M \pm$	7.144	7.109	5.734	8.349	7.084

Fig. 4 Effect of spacing and manuring on yield of nuts per palm for the years 1994 to 1997





difference was observed during 1994. However the yield of palms at M_1 and M_2 levels were significantly higher compared to unmanured palms (M_0) which recorded the lowest yield in all the four years.

Spacing × Manuring interaction effect on per palm yield was significant only during the year 1995. In the absence of manuring (M_0), S_1 and S_3 spacings were on par and significantly low compared to S_2 spacing. At M_1 level of manuring, per palm yield did not differ significantly at S_2 and S_3 spacings but significantly superior to the closest spacing (S_1) of 5.0 m. At M_2 level, per palm yield did not differ significantly among the 3 spacings.

Yield of nuts per palm did not differ significantly at M_2 and M_1 manuring levels under all the three spacings but was found to be significantly superior to the unmanured palms (M_0).

4.2.2 Yield of nuts per hectare

The yield of nuts per hectare for four consecutive years from 1994 to 1997 are presented in table 4.

It was noticed that there was a significant effect of spacing in yield of nuts per unit area in all the four years. An inverse relationship between spacing and nut yield was observed. The highest number of nuts per hectare was produced by the closest spacing of 5.0 m (S_1) which was significantly superior to S_2 and S_3 spacings. The lowest nut yield per hectare was observed in the wider spacing of 10.0 m (S_3) and was found to be significantly lesser to S_2 spacing.

Manuring had increased the production of nuts per hectare significantly in all the four years. The highest level of manuring (M_2) produced the highest nuts per hectare and did not differ significantly with M_1 level of manuring during 1994 and 1995 and significantly superior to M_1 during 1996 and 1997. M_1 level of manuring was also found to be significantly superior to the unmanured palms (M_0) in all the four years which produced the lowest per hectare yield.

There was significant interaction between spacing and manuring on per hectare nut yield in all the four years. When manuring was not done (M_0), the palms at S_3 spacing (10.0 m) produced the lowest nut yield per hectare and the highest nut yield was produced by S_2 spacing during 1994 and 1997 and by S_1 spacing during 1995 and 1996. In the absence of manuring in all the four years nut yield per unit area by palms planted at S_1 and S_2 spacings were on par and significantly superior to 10.0 m spacing (S_3). By manuring palms at M_1 level the highest nut yield was observed in closer spacing of 5.0 m (S_1) which was significantly superior to S_2 and S_3 spacings except in 1997 where S_1 and S_2 were on par. The spacing S_2 also found to be significantly superior to the widest spacing of 10.0 m (S_3) except in 1996 in which S_2 and S_3 were on par. The lowest nut yield was recorded in all the four years by the palms planted at a wider spacing of 10.0 m (S_3).

At the highest dose of fertilizer (M_2), S_1 spacing produced the highest number of nuts which was significantly superior to S_2 and S_3 spacings. The lowest number was produced by the wider spacing of 10.0 m (S_3).

When palms were planted at the closer spacing of 5.0 m (S_1) manuring

Table 4 Effect of spacing and manuring on average yield of nuts per hectare for the years 1994 to 1997

Effect	1994	1995	1996	1997	Mean
Spacing					
S_1	21093.34	21152.00	15893.33	12967.11	17776.45
S_2	12706.11	12770.33	9337.22	9590.00	11100.92
S_3	6336.11	7419.45	4713.89	5900.00	6092.36
Manuring					
M_0	7598.67	5819.67	4555.89	4077.89	5513.03
M_1	15172.00	17363.56	11653.44	10941.44	13782.61
M_2	17364.89	18158.56	17735.11	13437.78	16674.09
C D	2357.569	2525.870	2001.479	2108.140	2248.260
$S_1 M_0$	9706.67	8981.33	5834.67	4762.67	7321.34
$S_1 M_1$	25376.00	25237.34	17946.67	14282.67	20710.67
$S_1 M_2$	28197.34	29237.34	23898.67	19856.00	25297.34
$S_2 M_0$	10139.33	5961.00	5808.00	5696.00	6901.08
$S_2 M_1$	13198.33	16461.67	10205.33	11866.67	1293.00
$S_2 M_2$	14780.67	15888.33	11998.33	11207.33	13468.67
$S_3 M_0$	2950.00	2516.67	2025.00	1775.00	2316.67
$S_3 M_1$	6941.67	10391.67	6808.33	6675.00	7704.17
$S_3 M_2$	9116.67	9350.00	5308.33	9250.00	8256.25
C D	4083.429	4374.935	3466.664	3651.406	3894.110
$SE_M \pm$	1361.991	1459.220	1156.274	1217.893	1298.840

significantly increased the number of nuts per unit area and the highest nut yield was produced by heavier dose of manuring (M_2) which was significantly superior to M_1 and M_0 level of manuring during 1995 and 1997 and was on par with M_1 level during 1994 and 1995. The unmanured palms produced the lowest number of nuts in all the three spacings during all the four years. At S_2 and S_3 spacings the nut yield at M_1 and M_2 level of manuring were on par and found to be significantly superior to unmanured plots (M_0) during all the years except in 1994, where M_1 and M_0 were on par.

4.2.3 Production of female flowers

Female flower production per palm per year due to the effect of treatments presented in table 5 showed that increase in spacing significantly increased the production of female flowers. The spacing S_2 produced maximum number of female flowers (190.89) which was on par with S_3 spacing. Both S_2 and S_3 spacings produced significantly more number of female flowers compared to S_1 spacing which recorded the lowest production (141.39).

Similar to spacing, manuring also significantly increased the production of female flowers up to M_1 level. When level of manuring was increased further to M_2 level female flower production decreased, though the differences were not significant. But both M_1 and M_2 level of manuring produced significantly higher female flowers than the unmanured palms (M_0).

There was interaction between spacing and manuring on female flower production. In the absence of manuring S_2 spacing (7.5 m) resulted in the production of more female flowers than the wider (S_3) and narrow (S_1) spacings which were statistically not significant. When manuring was given at M_1 level the wider spacings S_2 and S_3 produced higher female flowers which were not significant but significantly higher compared to those planted at a closer spacing of 5.0 m (S_1). When fertilizer was further increased to M_2 level there was no significant difference between S_2 and S_3 spacings however S_3 spacing produced higher number of female flowers.

At the closer spacing of 5.0 m (S_1) female flower production was maximum at M_1 level manuring, but it was on par with M_2 level and both were significantly superior to the unmanured palms (M_0). When spacing was further increased to 7.5 m (S_2) and 10.0 m (S_3) results similar to that of 5.0 m spacing (S_1) was observed.

4.2.4 Number of bunches per year

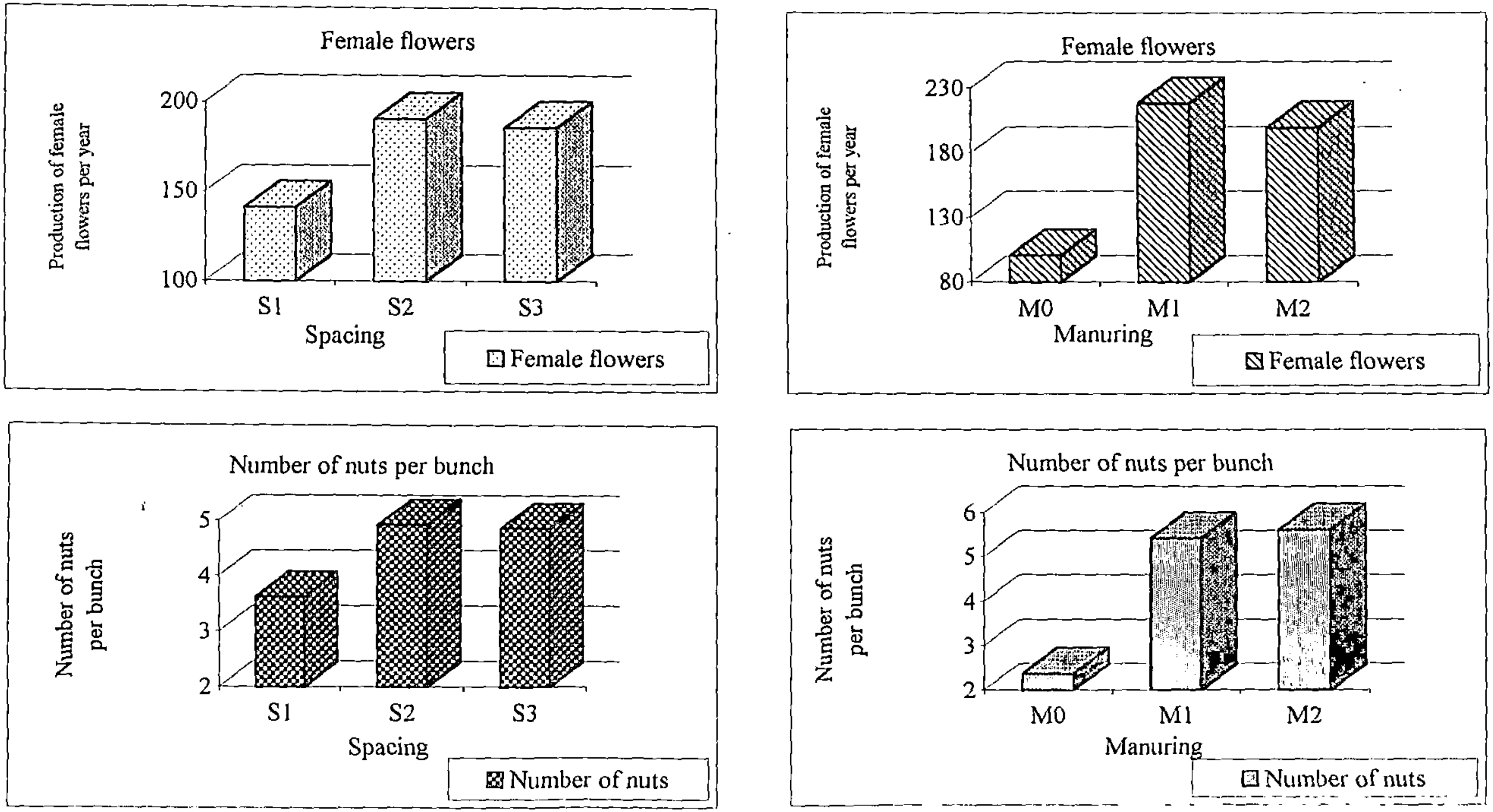
The results given in table 5 revealed that spacing did not have any significant effect on the number of bunches produced per palm per year. However, manuring had significant influence in this. Incremental dose of NPK fertilization increased the production of bunches in coconut palm up to the highest level of M_2. But the treatment M_2 was found to be on par with M_1 level of manuring and both were significantly superior to M_0. The lowest bunch production (9.36) was observed in palms which were not fertilized.

No interaction effect of spacing and manuring was observed on the production of bunches by the coconut palm.

Table 5 Effect of spacing and manuring on production of female flowers, number of bunches, setting percentage and nuts per bunch

Effect	Production of female flowers per year	Number of bunches per year	Setting percentage	Number of nuts per bunch
Spacing				
S_1	141.39	10.50	36.19	3.62
S_2	190.89	10.58	41.17	4.93
S_3	186.14	9.64	38.45	4.87
Manuring				
M_0	100.81	9.36	32.88	2.37
M_1	218.00	10.58	39.22	5.42
M_2	199.61	10.78	43.70	5.62
C D	23.908	0.927	6.589	0.965
$S_1 M_0$	80.33	8.50	28.16	1.74
$S_1 M_1$	181.75	11.17	34.78	4.05
$S_1 M_2$	162.08	11.83	45.62	5.06
$S_2 M_0$	143.83	10.17	38.62	3.21
$S_2 M_1$	227.83	10.83	40.32	5.22
$S_2 M_2$	201.00	10.75	44.56	6.35
$S_3 M_0$	78.25	9.42	31.86	2.16
$S_3 M_1$	244.42	9.75	42.56	6.99
$S_3 M_2$	235.75	9.75	40.92	5.46
C D	41.411	N. S.	N. S.	N. S.
$SE_M \pm$	13.812	0.536	3.806	0.558

Fig. 5 Effect of spacing and manuring on production of female flowers per year and number of nuts per bunch



4.2.5 Setting percentage

The data on per cent fruit set are given in table 5.

Spacing did not have any significant influence on fruit set. However manuring significantly increased the fruit set. The highest fruit set (43.70) was recorded in palms fertilized with M_2 level of NPK and the lowest in the unfertilized plots. (M_0). But fruit set did not have significant difference between M_1 and M_2 level of manuring and M_2 was significantly superior to the palms of unfertilized plots, similarly no significant difference was observed between palms of M_0 and M_1 fertilization.

Spacing and manuring interaction did not influence the fruit set.

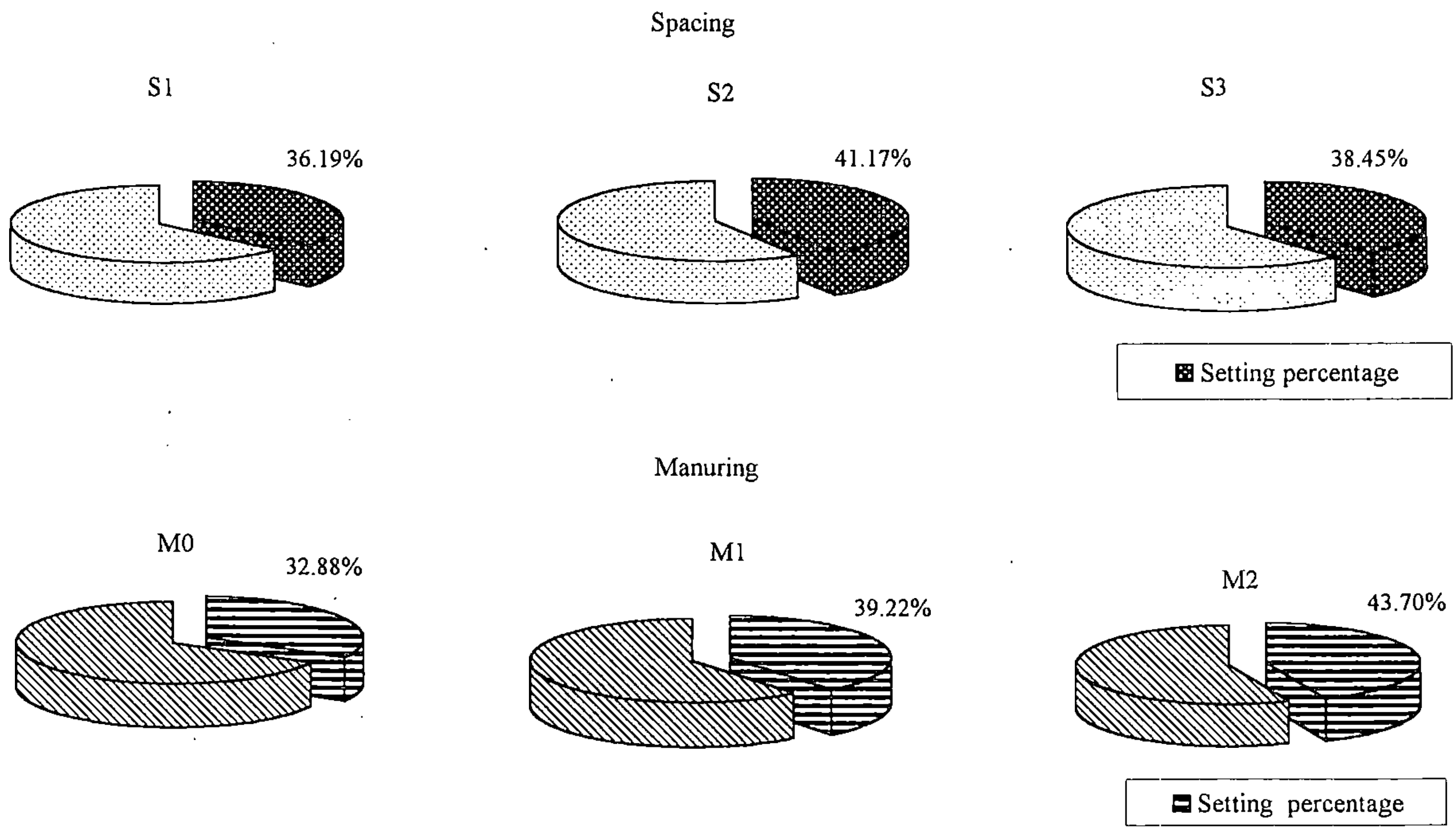
4.2.6 Number of nuts per bunch

The data pertaining to the influence of spacing and manuring on number of nuts per bunch are given table 5.

The results revealed that spacing significantly increased the mean number of nuts per bunch. Eventhough the highest number (4.93) of nuts was obtained from S_2 spacing it was on par with S_3 spacing. Both these S_2 and S_3 spacings were significantly superior to the closer spacing of 5.0 m (S_1). The S_1 spacing recorded the lowest number of nuts per bunch (3.62).

Similarly manuring gave significant increase in the number of nuts per bunch compared to non manured plots. The mean number of nuts per bunch did not differ significantly at M_1 and M_2 level of manuring but M_2 recorded the highest number of nuts per bunch (5.62) and both were significantly superior to the unmanured palms (M_0). The lowest nuts per bunch (2.37) was recorded by the

Fig. 6 Effect of spacing and manuring on setting percentage



unmanured palm (M_0).

Spacing × Manuring interaction was not significant on number of nuts produced per bunch.

4.2.7 Weight of unhusked nut

The results on the effect of spacing and manuring on the weight of unhusked nuts presented in table 6 revealed that spacing alone had significantly increased the weight. Weight of unhusked nut did not differ significantly at wider spacing of S_2 and S_3 but the highest weight (1314.13 g) was recorded by S_2 spacings and both these wider sapcings were significantly superior to the closer spacing of 5.0 m (S1). The lowest weight (1153.96 g) was observed in the closer spacing of S_1.

Both manuring and interaction effect were not significant on weight of unhusked nut.

4.2.8 Volume of unhusked nut

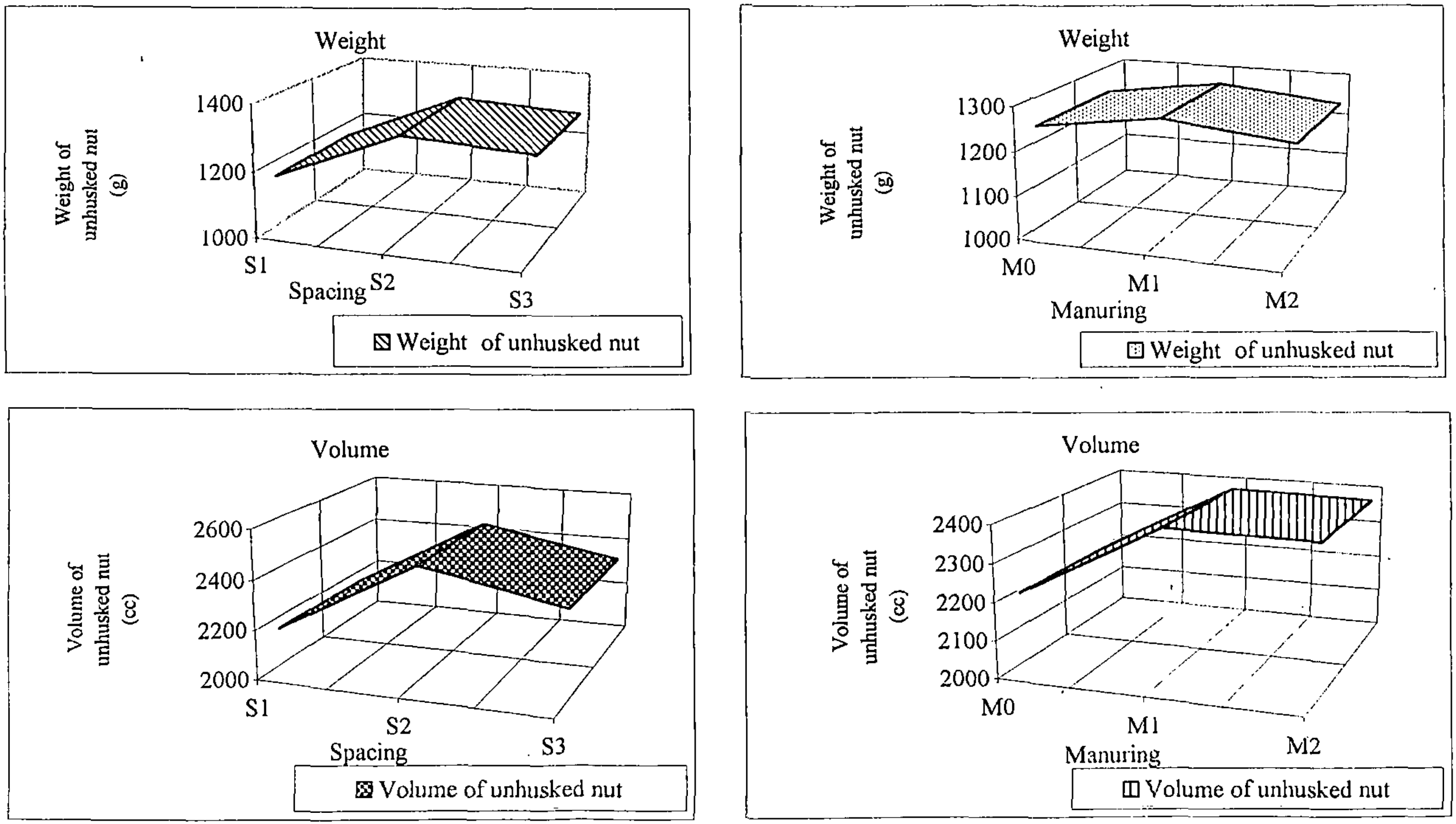
The data on the volume of unhusked nut are presented in table 6.

It was observed from the data that spacing had significant influence on the volume of unhusked nuts. The highest volume (2464.93 cc) was for S_2 spacing (7.5 m) and it was not significantly different from the widest spacing of 10.0 m (S_3). Both these wider spacings were significantly superior to the closer spacings of 5.0 m (S_1) which recorded the lowest unhusked nut volume (2151.92 cc).

Table 6 Effect of spacing and manuring on weight and volume of unhusked and husked nut

Effect	Weight of unhusked nut (g)	Volume of unhusked nut (cc)	Weight of husked nut (g)	Volume of husked nut (cc)
Spacing				
S_1	1153.96	2151.92	479.16	525.87
S_2	1314.13	2464.93	505.60	525.90
S_3	1295.47	2358.02	485.78	530.57
Manuring				
M_0	1237.59	2191.65	467.66	518.72
M_1	1277.79	2394.09	522.84	555.85
M_2	1248.18	2389.16	480.03	536.77
C D	102.017	202.731	N. S.	N. S.
$S_1 M_0$	1187.78	2095.50	499.87	513.40
$S_1 M_1$	1190.43	2239.77	522.47	549.83
$S_1 M_2$	1083.70	2120.50	415.13	514.37
$S_2 M_0$	1249.90	2288.73	471.40	522.03
$S_2 M_1$	1309.77	2489.83	519.33	564.07
$S_2 M_2$	1382.73	2616.23	526.07	578.60
$S_3 M_0$	1275.13	2190.70	431.70	520.73
$S_3 M_1$	1333.17	2452.67	526.73	553.63
$S_3 M_2$	1278.10	2430.70	498.90	517.33
C D	N.S.	N. S.	N. S.	N. S.
$SE_M \pm$	58.936	117.120	32.329	21.429

Fig. 7 Effect of spacing and manuring on weight and volume of unhusked nut



The effect of manuring and interaction did not have any significant influence on the volume of unhusked nuts.

4.2.9 Weight of husked nut

The data on weight of husked nut presented in table 6 revealed that spacing, manuring and their interaction had no significant influence on this. However the highest husked nut weight (505.60 g) was observed in palms planted at S_2 spacings (7.5 m) and the lowest (479.16 g) in palms planted at closer spacing of 5.0 m (S_1). In the absence of manuring (M_0) palms recorded the lowest husked nut weight (467.66 g) and the highest weight (522.84 g) was recorded in M_1 level of manuring.

4.2.10 Volume of husked nut

The data on the effect of spacing and manuring on the volume of husked nut are presented in table 6. It was observed that the results are similar to that of the weight of husked nut described above.

4.2.11 Ratio of weight of husked to unhusked nut

The data on the ratio of weight of husked nut to unhusked nut are given in table 7.

The effect of spacing alone was significant. The results revealed that the ratio was lower (0.3740) at wider spacing of 10.0 m (S_3) than 7.5 m (S_2) and 5.0 m (S_1). But S_3 spacing was found to be on par with S_2 spacing and significantly lower than the closer spacing of 5.0 m (S_1). The highest ratio (0.4150) was recorded for the closer spacing of 5.0 m (S_1).

The ratio did not differ significantly when the palms were given different doses of manuring. Spacing × manuring interaction effect was also not significant on the ratio of weight of husked to unhusked nut.

4.2.12. Weight of husk

The result on the effect of treatments on weight of husk are given in Table 7.

The results showed that spacing alone had significant effect on the weight of husk. The highest husk weight (809.69 g) was recorded in palms planted at wider spacing of 10.0 m (S_3) and it was found to be on par with palms planted at 7.5 m spacing (S_2) but significantly superior to palms planted at closer spacing of 5.0 m (S_1).

Manuring and spacing × manuring interaction did not have any significant effect on weight of husk.

4.2.13. Ratio of weight of husk to unhusked nut

Ratio of weight of husk to unhusked nut presented in Table 7 showed that spacing had significant effect on this. The lowest ratio (0.5850) was observed in palms planted at the closer spacing of 5.0 m (S_1). The highest ratio (0.6260) was observed in palms planted at wider spacing of 10.0 m (S_3). The ratio did not differ significantly when they were planted at S_3 and S_2 spacings but significantly superior to palms planted at closer spacing of 5.0 m (S_1).

There was no interaction between spacing and manuring on ratio of husk to unhusked nut. Different doses of NPK fertilizers also did not have any effect on

Table 7 Effect of spacing and manuring on ratio of weight of husked nut to unhusked nut, weight of husk, ratio of weight of husk to unhusked nut and weight of split nut

Effect	Ratio of weight of husked nut to unhusked nut	Weight of husk (g)	Ratio of weight of husk to unhusked nut	Weight of split nut (g)
Spacing				
S_1	0.4150	674.80	0.5850	394.79
S_2	0.3850	808.53	0.6150	421.30
S_3	0.3740	809.69	0.6260	388.39
Manuring				
M_0	0.3790	769.93	0.6210	391.68
M_1	0.4100	754.94	0.5900	413.36
M_2	0.3860	768.15	0.6140	399.43
C D	0.0312	75.396	0.0312	N. S.
$S_1 M_0$	0.4208	687.87	0.5792	403.13
$S_1 M_1$	0.4395	667.97	0.5605	414.59
$S_1 M_2$	0.3847	668.57	0.6153	366.64
$S_2 M_0$	0.3771	778.50	0.6229	414.96
$S_2 M_1$	0.3954	790.43	0.6046	417.11
$S_2 M_2$	0.3817	856.67	0.6183	431.82
$S_3 M_0$	0.3380	843.43	0.6620	356.95
$S_3 M_1$	0.3943	806.43	0.6057	408.40
$S_3 M_2$	0.3903	779.20	0.6097	399.84
C D	N.S.	N. S.	N. S.	N. S.
$SE_M \pm$	0.0180	43.557	0.0180	23.881

this ratio.

4.2.14. Weight of split nut

The results presented in Table 7 revealed that spacing, manuring and their interaction did not have any significant influence on the weight of split nut. However the highest weight (421.30 g) was observed in palms planted at wider spacing of 7.5 m (S_2) and the lowest weight (388.39 g) in the widest spacing of 10.0 m (S_3). Also in the absence of manuring (M_0) palms recorded the lowest split nut weight (391.68 g) and the highest (413.36 g) at M_1 level of manuring.

4.2.15. Weight of shell

The results presented in table 8 revealed that there was no effect of spacing, manuring and their interaction on the weight of shell.

4.2.16. Thickness of shell

The results on the thickness of shell are presented in table 8. It was observed from the data that spacing and manuring had no significant effect on shell thickness.

Also there was no interaction between spacing and manuring on this character.

4.2.17. Weight of kernel

The data on the effect on spacing and manuring on the weight of kernel given in Table 8 revealed that treatments had no effect on this.

4.2.18. Thickness of kernel

The results on thickness of kernel are presented in Table. 8. The data shows that neither spacing, manuring nor their interaction had effect on kernel thickness.

4.2.19. Weight of copra per nut

The data on weight of copra per nut are given in Table 9.

It was observed that spacing, manuring and their interaction did not have any significant effect on this.

4.2.20. Ratio of weight of copra to husked nut

The results presented in table 9 indicated that neither manuring nor spacing had significant effect on the ratio of weight of copra to husked nut. Also there was no interaction between spacing and manuring on the ratio.

4.2.21. Oil content of copra

The per cent oil content of copra due to the effect of spacing and manuring are presented in Table 9. The results revealed that the oil content did not differ significantly when the palms were planted at wider spacing of 10.0 m (S_3) and 7.5 m (S_2) but significantly lower compared to the closer spacing of 5.0 m (S_1). The highest oil content was recorded in S_1 spacing and the lowest in the wider spacing of 10.0 m (S_3).

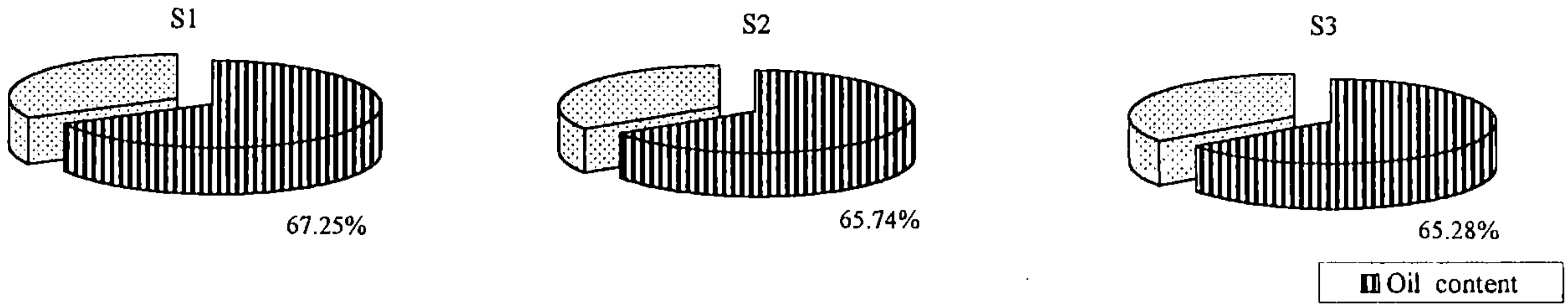
Manuring also had a significant effect on oil content of copra. The lowest oil content was recorded in the unmanured palms and highest in palms receiving

Table 9 Effect of spacing and manuring on weight of copra, ratio of weight of copra to husked nut and oil content

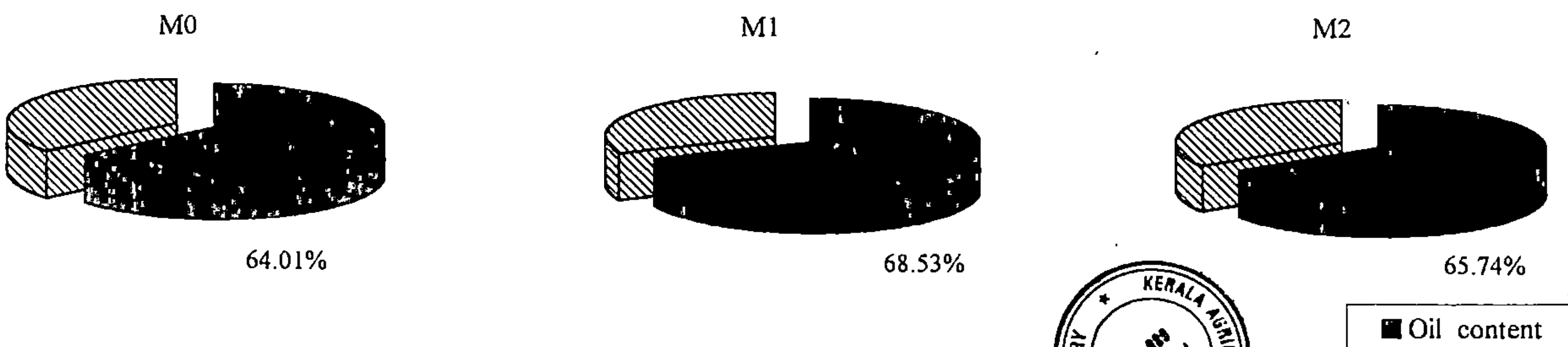
Effect	Weight of copra per nut (g)	Ratio of weight of copra to husked nut	Oil content of copra (%)
Spacing			
S_1	151.67	0.3190	67.25
S_2	165.77	0.3290	65.74
S_3	156.66	0.3240	65.28
Manuring			
M_0	151.91	0.3260	64.01
M_1	161.96	0.3110	68.53
M_2	160.22	0.3360	65.74
C D	N. S	N. S	1.198
$S_1 M_0$	152.59	0.3051	65.90
$S_1 M_1$	155.52	0.2986	68.28
$S_1 M_2$	146.92	0.3542	67.57
$S_2 M_0$	157.53	0.3352	63.52
$S_2 M_1$	167.35	0.3236	67.98
$S_2 M_2$	172.42	0.3284	65.72
$S_3 M_0$	145.61	0.3380	62.60
$S_3 M_1$	163.02	0.3110	69.32
$S_3 M_2$	161.34	0.3240	63.93
C D	N.S.	N. S.	2.075
$SE_M \pm$	8.540	0.0134	0.692

Fig. 8 Effect of spacing and manuring on oil content of copra

Spacing



Manuring



M_1 level of NPK fertilizers. The oil percentage in M_1 level manured palms were significantly superior to the other two levels of manuring namely M_0 and M_2.

Spacing and manuring had a significant interaction effect on oil content. In the absence of manuring (M_0) wider spacing of 10.0 m (S_3) recorded the lowest oil content and it was found to be on par with the spacing of 7.5 m (S_2). The closer spacing of 5.0 m (S_1) recorded the highest oil content and was significantly superior to spacing S_2 and S_3. When fertilizer was given at M_1 level, oil content in all the three spacings were found to be on par. When the highest dose of NPK (M_2) was applied, S_3 spacing recorded the lowest oil content and was on par with S_2 spacing. At this level of manuring the highest oil content was noticed in S_1 spacing and was found to be on par with S_2 spacing but significantly superior to S_3 spacing.

At all the three spacings, the unmanured palms (M_0) recorded the lowest oil content and the palms receiving M_1 level of manuring recorded the highest oil content. However, at the closer spacing of 5.0 m (S_1) oil content at M_0 and M_2 doses of manuring and M_1 and M_2 doses were on par. At the wider spacing of S_2 (7.5 m) M_1 manuring level recorded significantly superior oil content than the other two levels of NPK M_0 and M_2. At S_3 spacing also M_1 manuring level recorded significantly higher oil content and M_0 and M_2 levels of manuring were found to be on par.

4.3 Effect of spacing and manuring on soil nutrient status

4.3.1 Nitrogen

The results given in table 10 showed that spacing had significant effect on the available nitrogen status of soil. The lowest soil nitrogen was recorded in S_2 spacing and the highest nitrogen in closer spacing of 5.0 m (S_1). The nitrogen content in S_1 spacing was significantly superior to the wider spacings of 7.5 m (S_2) and 10.0 m (S_3).

Manuring also had highly significant effect on the available nitrogen status of soil. There was a significant gradual increase in nitrogen status from unmanured plots to the plots receiving the highest dose of fertilizers. The highest nitrogen content was noticed in plots receiving M_2 dose of manuring and was significantly superior compared to the plots receiving the lower level of manuring (M_1) and no manuring (M_0).

Different depths of sampling also had a significant influence on available nitrogen content of soil. The nitrogen content decreases from surface soil to subsurface soil upto 1.0 m depth. Soil taken from 75 to 100 cm depth recorded the lowest soil nitrogen status. The highest nitrogen was recorded in the surface soil of 0 to 25 cm depth and was significantly superior to the soils taken from higher depths upto 1.0 m.

Mean available nitrogen status of soil due to the interaction effect of spacing and manuring are given in table 10.

It could be seen from the data that spacing and manuring interaction had highly significant effect on soil available nitrogen status. When manuring was not given to palms, available nitrogen content of soil did not differ significantly at S_2 and S_3 spacings. However the highest nitrogen content was observed in the closest spacing of 5.0 m (S_1) and was significantly superior compared to the wider spacing of 7.5 m (S_2) but on par with 10.0 m spacing

(S_3). By providing manuring at M_1 dose there was a gradual increase in soil nitrogen content as the spacing become closer. The lowest nitrogen content was recorded in the widest spacing of 10.0 m (S_3) and the highest nitrogen content in closer spacing of 5.0 m (S_1). The 5.0 m spacing was significantly superior to the wider spacings S_2 and S_3. At M_2 level of manuring the highest nitrogen content was recorded in closer spacing of 5.0 m (S_1) and was on par with the widest spacing of 10.0 m (S_3), but both were significantly superior to the spacing of 7.5 m (S_2).

At all the three spacings the mean available nitrogen content of the soil increased as the dose of manuring increases. The lowest nitrogen content was recorded in the unmanured plots (M_0) and the highest in plots receiving M_2 dose of manuring which was significantly superior to the lower levels of manuring M_1 and M_0.

The interaction effect of spacing and depth on the mean available nitrogen status of soil are shown in table 11. The results revealed that at 0 to 25 cm depth (D_1) the lowest soil nitrogen content was noticed in the wider spacing of 7.5 m (S_2) and the highest nitrogen content in closer spacing of 5.0 m (S_1). The nitrogen content at S_1 spacing was found to be on par with the widest spacing of 10.0 m (S_3) and both were significantly superior compared to 7.5 m spacing (S_2). At 25 to 50 cm depth (D_2) also S_1 spacing (5.0 m) recorded the highest soil available nitrogen content and was found to be on par with the spacing 7.5 m (S_2) but significantly superior compared to the widest spacing of 10.0 m (S_3) which noticed the lowest value. At 50 to 75 cm depth (D_3) S_1 spacing recorded the highest available soil nitrogen content and was significantly superior to the wider spacings of S_2 and S_3. The spacing S_2 (7.5m) recorded the lowest nitrogen content at this depth. At 75 to 100 cm depth (D_4) soil available nitrogen content did not differ significantly between S_1 and S_2 spacings but both were significantly higher compared to the widest spacing S_3.

In all the three spacings, there was gradual decrease in available soil nitrogen content as the depth increases from D_1 to D_4. The lowest value was observed in 75 to 100 cm depth (D_4) and the highest value in surface layer of 0 to 25 depth (D_1). At the closer spacing of 5.0 m (S_1) and the wider spacing of 10.0 m (S_3) the decrease in nitrogen content with depth was significant among all the levels of depth. But at S_3 spacing (7.5 m) there was no significant difference in nitrogen content between depths D_3 and D_4, D_1 and D_2.

There was interaction between manuring and depth on available nitrogen status of soil. The data presented in table 11 showed that at all the four depths, soil nitrogen status increases significantly from unmnaured plots (M_0) to the plots receiving the highest dose of fertilizer (M_2). So there was a gradual increase in nitrogen status of soil as the dose of manuring increases.

Similarly at all the three levels of manuring the soil nitrogen status decreased with increase in depth of soil. The lowest nitrogen content was recorded in 75 to 100 cm depth (D_4) and the highest in 0 to 25 cm depth (D_1) and D_1 depth was found to be significantly superior to all other three higher depths.

4.3.2 Phosphorus

The results are presented in table 10. It was observed from the results that available phosphorus content of soil was lowest in the widest spacing of 10 m (S_3) and the highest value was observed in the closer spacing of 5.0 m (S_1). But soil phosphorus content did not differ significantly when the palms were planted at S_2 and S_1 spacings but both were significantly higher compared to those planted at the wider spacing of 10.0 m (S_3).

Manuring also had significant influence on available phosphorus content of soil. There was significant increase in phosphorus content as the dose of manuring increases from M_0 to M_2 level with M_2 recorded the highest value.

Soil phosphorus content was significantly influenced by the depth of sampling. It was noticed that there was an inverse relationship between depth and phosphorus content of soil. The lowest value was noticed in 75 to 100 cm depth (D_4) and the highest value in the surface layer of 0 to 25 cm depth (D_1). The phosphorus content of soil at D_1 depth was significantly superior compared to the other three higher depths.

The spacing and manuring interaction effect on available phosphorus content of soil presented in table 10 revealed that in the absence of manuring available soil phosphorus did not differ significantly among the closer (S_1) and wider spacings (S_2 and S_3). However, the lowest value was observed in closer spacing of 5.0 m (S_1) and the highest value in the wider spacing of 10.0 m (S_3). At M_1 level of manuring the lowest soil phosphorus content was recorded in S_3 spacing and the highest value in S_1 spacing which was significantly superior compared to the wider spacings S_2 and S_3. By applying manures at the highest dose of M_2 the closer spacing of 5.0 m (S_1) recorded the lowest soil phosphorus content and the wider spacing of 7.5 m (S_2) recorded the highest value. The phosphorus content at S_2 spacing was significantly superior to S_3 and S_1 spacings.

At all the three spacings soil phosphorus content increases with increase in dose of manuring. The lowest phosphorus content was noticed in the unmanured plots (M_0) and the highest value in plots receiving M_2 level of manuring. The phosphorus content at M_2 level of manuring was significantly high and superior to M_1 and M_0 doses of manuring.

The results presented in table 11 showed that spacing and depth interaction had a highly significant effect on the available phosphorus content of soil. At all the three spacings, the available phosphorus decreases with increase in depth of sampling. The highest phosphorus content was observed in the surface soil of 0 to 25 cm depth (D_1) which was significantly superior compared to all other depths and the lowest content was observed in 75 to 100 cm depth (D_4).

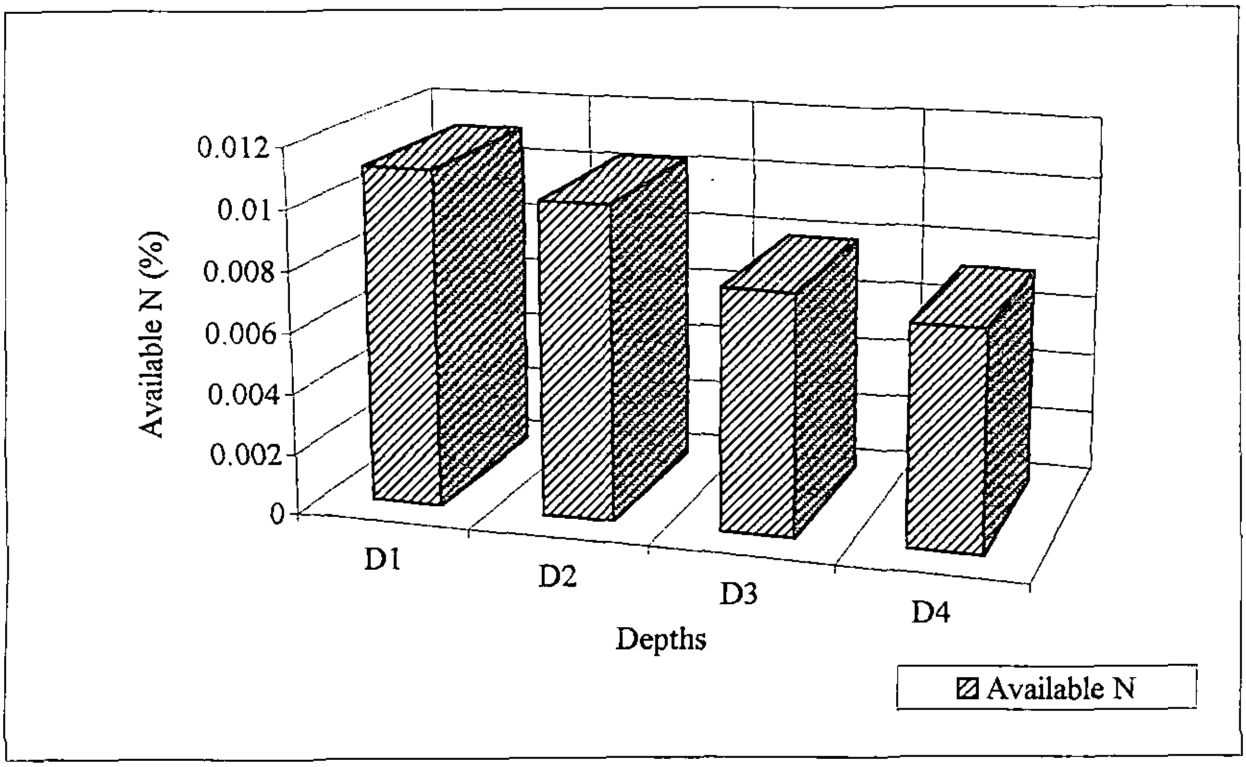
In the top 0 to 25 cm layer of soil (D_1), S_2 spacing noticed significantly higher value for available phosphorus content of soil and the lowest value in the closer spacing of 5.0 m (S_1). In all other three depths (D_2, D_3 and D_4), the highest available soil phosphorus was observed in the closest spacing of 5.0 m (S_1) and it was significantly superior in D_2 and D_3 depths and on par with S_3 in D_4 depth. The lowest soil phosphorus was observed in S_2 spacing in D_3 and D_4 depths and S_3 spacing in D_2 depth.

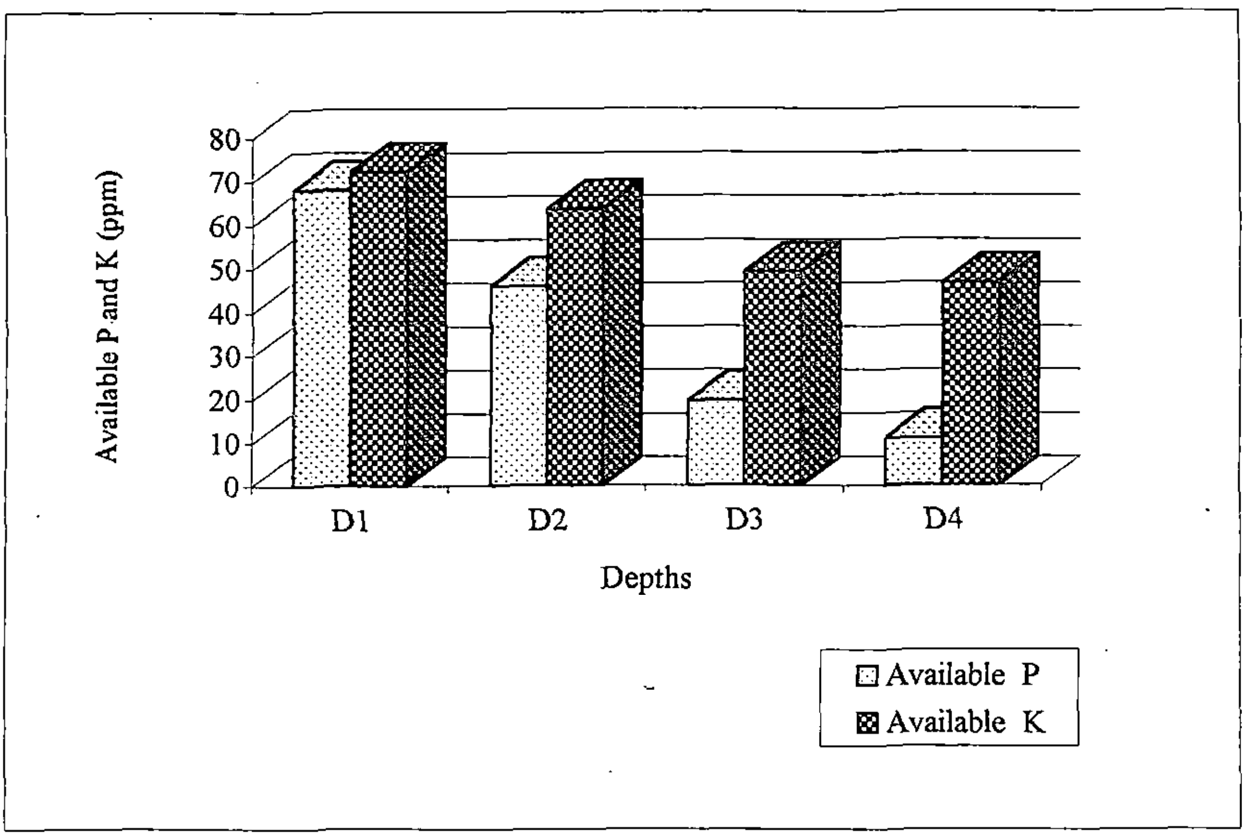
It could be seen from the data presented in table 11 that manuring and depth interaction had a highly significant influence on the available phosphorus

Table 10 Effect of spacing and manuring on the available macro and secondary nutrient status of soil at different depths

Effect	Available N (%)	Available P (ppm)	Available K (ppm)	Available Ca (ppm)	Available Mg (ppm)
Spacing					
S_1	0.00934	36.815	63.924	40.292	31.350
S_2	0.00892	36.630	55.285	38.042	30.712
S_3	0.00908	34.944	54.708	38.541	33.547
Manuring					
M_0	0.00664	4.981	40.042	55.536	42.853
M_1	0.00937	29.593	61.444	29.271	28.974
M_2	0.01133	73815	72.431	32.068	23.782
C D	0.000120	0.6483	1.5605	0.7397	0.7128
Depths					
D_1	0.01108	68.074	72.269	48.172	33.468
D_2	0.01030	46.000	63.657	41.637	29.682
D_3	0.00788	19.630	49.296	34.183	30.805
D_4	0.00719	10.815	46.667	31.841	33.526
C D	0.000138	0.7486	1.8019	0.8542	0.8231
$S_1 M_0$	0.00680	4.555	38.750	57.563	43.153
$S_1 M_1$	0.00958	34.778	68.750	30.238	28.933
$S_1 M_2$	0.01163	71.111	84.271	33.075	21.966
$S_2 M_0$	0.00646	5.056	38.958	54.088	40.097
$S_2 M_1$	0.00937	27.722	59.271	28.275	28.805
$S_2 M_2$	0.01093	77.111	67.625	31.763	23.235
$S_3 M_0$	0.00666	5.333	42.417	54.958	45.310
$S_3 M_1$	0.00915	26.278	56.313	29.300	29.186
$S_3 M_2$	0.01143	73.222	65.696	31.367	26.144
C D	0.000207	1.1229	2.7029	N. S.	1.2347

Fig. 9 Effect of spacing and manuring on available nitrogen, phosphorus and potassium status of soil at different depths





content of soil. Similar to spacing, a gradual decrease in phosphorus content was noticed with increase in depth at all the three levels of manuring with the highest phosphorus content in the surface 0 to 25 cm layer (D_1) of soil which was significantly superior to other depths. The lowest phosphorus content was noticed in 75 to 100 cm depth (D_4). In the unmanured plots soil P content did not differ significantly at D_4, D_3 and D_2 depths but differ significantly in M_1 and M_2 levels of manuring. In all the four depths the available phosphorus content of soil increases as the dose of NPK increases. The lowest value was noticed in the unmanured plots (M_0) and the highest value in plots receiving the highest dose of manuring (M_2). The M_2 manured plots were significantly superior to M_1 manured plots and unmanured ones in all the four depths.

4.3.3 Potassium

Mean available soil potassium content due to the influence of spacing, manuring and depth are presented in table 10. The results revealed that spacing had a significant effect on the soil potassium content. The soil potassium content decreases as the spacing becomes wider. The highest value was noticed in closer spacing of 5.0 m (S_1) and the lowest in the wider spacing of 10.0 m (S_3) which was seen on par with the spacing 7.5 m (S_2) and both S_2 and S_3 were significantly low compared to the closer spacing S_1.

Manuring had significant effect on available potassium content of soil. The potassium content increases with increase in dose of NPK application. The lowest soil potassium was observed in plots where manuring was not done (M_0) and the highest value in plots receiving the highest dose of manuring

(M_2). The M_2 manured plots were significantly superior to plots receiving M_0 and M_1 level of manuring.

Depth of sampling had significant effect on available potassium content of soil. An inverse relation between depth of soil and potassium content was noticed. The lowest value was noticed in soils taken from 75 to 100 cm depth (D_4) and the highest value in soils from surface layer of 0 to 25 m depth (D_1). The potassium content of surface layer was significantly high compared to the sub surface layers.

The results of spacing and manuring interaction on available soil potassium content are given in table 10. The data revealed that in the absence of manuring the wider spacing of 10.0 m (S_3) recorded the highest value for soil potassium content and the closer spacing of 5.0 m (S_1) recorded the lowest value and it was found on par with the spacing of 7.5 m (S_2). Both S_2 and S_1 spacing were significantly lower than the wider spacing of 10.0 m (S_3). When manuring was applied at M_1 and M_2 levels, the highest potassium content was recorded in the closer spacing of 5.0 m (S_1) and the lowest value in the wider *spacing of 10.0 m (S_3). The soil potassium content at* S_1 spacing was found to be significantly superior to other two spacings of 7.5 m and 10.0 m at both M_1 and M_2 levels of manuring. However, at M_2 level of manuring the soil potassium content at wider spacings of S_3 and S_2 did not differ significantly but significantly low compared to the closer spacing S_1.

Higher soil potassium content was observed in the plots receiving higher doses of NPK than the unmanured plots in all the three spacings. The highest value was recorded in plots receiving M_2 level of manuring and it was significantly superior to M_1 and M_0 level manured plots. Thus a direct relationship was observed between levels of manuring and available soil potassium content.

It could be seen from the results presented in table 11 that at D_1 and D_2 depths, the highest available soil potassium was observed in the closest spacing of 5.0 m (S_1) and was significantly superior to the wider spacings of 7.5 and 10.0 m. The lowest value was observed in the widest spacing of 10.0 m (S_3). At D_3 depth, the lowest soil potassium was recorded in S_2 spacing and the highest value for S_1 spacing and this was found to be on par with the widest spacing of 10.0 m (S_3) but both were significantly superior to the spacing of 7.5 m (S_2). At 75 to 100 cm depth (D_4), the lowest soil potassium was recorded in S_1 spacing and the highest value is 10.0 m spacing (S_3). The S_3 spacing was significantly superior to S_2 and S_1 spacings.

At the closer spacing of 5.0 m (S_1) the soil potassium content decreases with increase in depth. The lowest value was noticed in 75 to 100 cm depth (D_4) and the highest value for 0 to 25 cm depth (D_1). However, D_1 and D_2 depths did not differ significantly but both were significantly superior to D_3 and D_4 depths. At 7.5 m spacing (S_2) the lowest soil potassium was observed in D_3 depth and was significantly low compared to other depths. The highest value was recorded for 0 to 25 cm depth (D_1). At 10.0 m spacing (S_3) the highest soil potassium content was observed for 0 to 25 cm depth (D_1) and was significantly high compared to other depths. The soil potassium content did not differ significantly at all the three depths D_2, D_3 and D_4 with the lowest value for D_2 depth (25 to 50 cm).

The available soil potassium content due to the effect of manuring and

Table 11 Interaction effect of spacing and manuring on the available macro and secondary nutrient status of soil at different depths

Effect	Available N (%)	Available P (ppm)	Available K (ppm)	Available Ca (ppm)	Available Mg (ppm)
$S_1 D_1$	0.01142	62.963	80.139	49.883	32.368
$S_1 D_2$	0.01050	48.074	79.583	44.083	28.263
$S_1 D_3$	0.00817	24.222	54.722	34.867	30.327
$S_1 D_4$	0.00727	12.000	41.250	32.333	34.443
$S_2 D_1$	0.01042	76.074	72.361	47.400	32.336
$S_2 D_2$	0.01034	45.852	61.000	39.067	29.027
$S_2 D_3$	0.00757	15.926	40.972	33.783	30.290
$S_2 D_4$	0.00734	8.667	46.806	31.917	31.197
$S_3 D_1$	0.01140	65.185	64.306	47.233	35.694
$S_3 D_2$	0.01006	44.074	50.389	41.760	31.757
$S_3 D_3$	0.00791	18.741	52.194	33.900	31.799
$S_3 D_4$	0.00696	11.778	51.944	31.272	34.97
$M_0 D_1$	0.00769	9.111	50.278	58.550	35.918
$M_0 D_2$	0.00683	4.222	45.306	55.360	40.807
$M_0 D_3$	0.00636	3.333	35.139	56.200	45.861
$M_0 D_4$	0.00568	3.259	29.444	52.033	48.827
$M_1 D_1$	0.01158	53.630	75.417	40.633	32.020
$M_1 D_2$	0.01060	34.000	64.528	33.713	25.890
$M_1 D_3$	0.00816	20.222	54.168	21.950	26.128
$M_1 D_4$	0.00313	10.518	51.667	20.783	31.860
$M_2 D_1$	0.01398	141.481	91.111	45.333	32.460
$M_2 D_2$	0.01347	99.778	81.139	35.833	22.350
$M_2 D_3$	0.00913	35.333	58.583	24.400	20.427
$M_2 D_4$	0.00876	18.667	58.889	22.706	19.890
C D	0.000240	1.2967	3.1210	1.4795	1.4257

depth was given in table 11. The results showed that at all the four depths, the soil potassium content increased significantly with increase in doses of NPK. The highest value was recorded in M_2 manured plots and the lowest value in the unmanured plots (M_0).

In the absence of manuring (M_0) and in plots receiving M_1 and M_2 level of manuring the highest available soil potassium content was recorded in 0 to 25 cm depth (D_1) of soil and it was significantly superior to other higher depths. The lowest value was recorded at D_4 depth in M_0 and M_1 level of manuring and in D_3 depth at plots manured with the highest dose of NPK (M_2). Both in M_1 and M_2, the soil potassium content did not differ significantly at D_3 and D_4 depths.

4.3.4 Calcium

The influence of spacing, manuring and depth on soil available calcium content is presented in table 10. The results showed that spacing had significant effect on soil calcium content. The highest Ca content was noticed for the closer spacing of 5.0 m (S_1). The lowest value was noticed for 7.5 m (S_2) spacing and it was on par with the widest spacing of 10.0 m (S_3). Both S_2 and S_3 spacings were significantly low compared to the closer spacing at 5.0 m (S_1).

Manuring also had significant effect on available soil calcium content. The lowest calcium content was observed in plots receiving M_1 level of NPK and the highest value in the unmanured plots (M_0). The calcium content at M_0 level of manuring was significantly superior to M_1 and M_2 levels of manuring.

Calcium content of soil had significantly influenced by depth of sampling. Calcium content decreases as the depth of sampling increases. The lowest calcium was observed in soils obtained from 75 to 100 cm depth (D_4) and the highest value in the surface layer of 0 to 25 cm depth (D_1). The D_1 depth was significantly superior to other higher depths.

The spacing and manuring interaction effect on available soil calcium content presented in table 10 revealed that the interaction had no significant effect on soil calcium content.

From the data presented in table 11, it was seen that in all the four depths the highest available soil calcium content was observed in plots of closer spacing of 5.0 m (S_1). At 0 to 25 cm depth (D_1) the lowest value was noticed in plots of the widest spacing of 10.0 m (S_3) and was seen on par with 7.5 m spacing (S_2). S_2 spacing was recorded as the lowest value for soil calcium content at 25 to 50 cm depth (D_2) and was significantly low compared to the closer spacing of 5.0 m (S_1) and wider spacing of 10.0 m (S_3). At 50 to 75 cm depth and at 75 to 100 cm depth soil available calcium content at all the three spacings did not differ significantly.

In all the three spacings, the available soil calcium content decreases with increase in depth of sampling. The highest value was noticed in surface layer of 0 to 25 cm depth (D_1) and was significantly superior to higher depths. The lowest value was recorded for 75 to 100 cm depth (D_4) of sampling in all the three spacings.

Effect of manuring and depth interaction presented in table 11 showed that the lowest calcium content was recorded at M_1 level of manuring and the highest calcium content was recorded in the unmanured plots (M_0) at all the four depths from D_1 to D_4. A significant difference was observed among all the 3 fertilizer levels for calcium content at all the four depths of sampling.

When fertilization was not done to palm, the lowest available soil calcium content was noticed at 75 to 100 cm depth (D_4) which was significantly low compared the lower depths. Nevertheless the calcium content of soil did not differ significantly at D_2 and D_3 depths. The surface 0 to 25 cm depth (D_1) noticed the highest calcium content and it was significantly higher than calcium contents of deeper layers.

4.3.5 Magnesium

The influence of spacing and manuring on available magnesium content of soil given in table 10 revealed that spacing had significant effect on this. The lowest magnesium content was observed in the wider spacing of 7.5 m (S_2) and it did not differ significantly with the closer spacing of 5.0 m (S_1). The highest magnesium content at 10.0 m spacing (S_3) was found to be significantly higher than the lower levels of spacings.

Manuring significantly decreased the available magnesium content of soil upto the highest dose (M_2) of fertilizer application. The minimum magnesium content was recorded in the higher dose (M_2) of fertilizer application and the maximum content in the unmanured plots (M_0). The magnesium content of control plots were significantly higher than the manured plots.

Depthwise study revealed that the magnesium content significantly affected by the depth of sampling. Magnesium content at the surface layer (D_1) and the deepest layer (D_4) did not differ significantly but significantly higher over the intermediate depths D_2 and D_3. The lowest value was recorded in 25 to 50 cm depth (D_2).

The interaction effect of spacing and manuring presented in table 10 revealed that in the absence of manuring (M_0) and at M_1 level of fertilizer application the lowest magnesium content was noticed in the wider spacing of S_2 (7.5 m) and the maximum content in the widest spacing of 10.0 m (S_3). However magnesium content of S_3 spacing was significantly higher than the lesser spacings at M_0 level of manuring and no significant differences were observed among the three spacings at M_1 level of fertilizer application . At the highest dose of M_2, magnesium content significantly increased with decrease in palm density and the highest value was observed in plots of least palm density (S_3).

In the wider as well as closer spacings significant difference was observed among the three levels of fertilizer application. The lowest magnesium content was recorded in plots receiving the highest dose of fertilizer (M_2) and the maximum value was recorded in the unmanured plots (M_0) at all the three spacings.

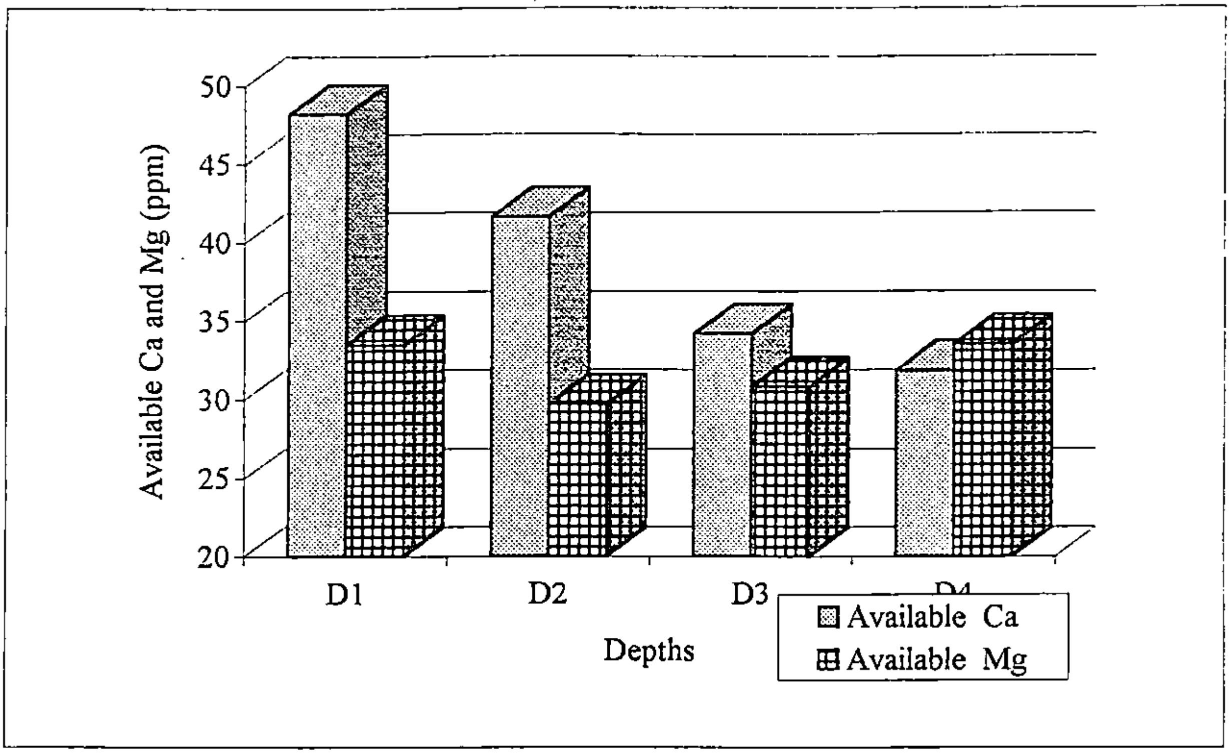
The results given in table 11 revealed that available magnesium content at all the four depths was highest in the widest spacing of 10.0 m (S_3) and it was significantly higher in D_1, D_2 and D_3 depths, however on par with the closer spacing of 5.0 m (S_1) at D_4 depth. The lowest magnesium content was recorded in S_1 spacing at 25 to 50 cm depth (D_2) and in S_2 spacings (7.5 m) at the other three depths (D_1, D_3 and D_4). S_1 and S_2 spacings did not differ significantly in magnesium content at D_1 to D_3 depth and S_2 was significantly low at D_4 depth.

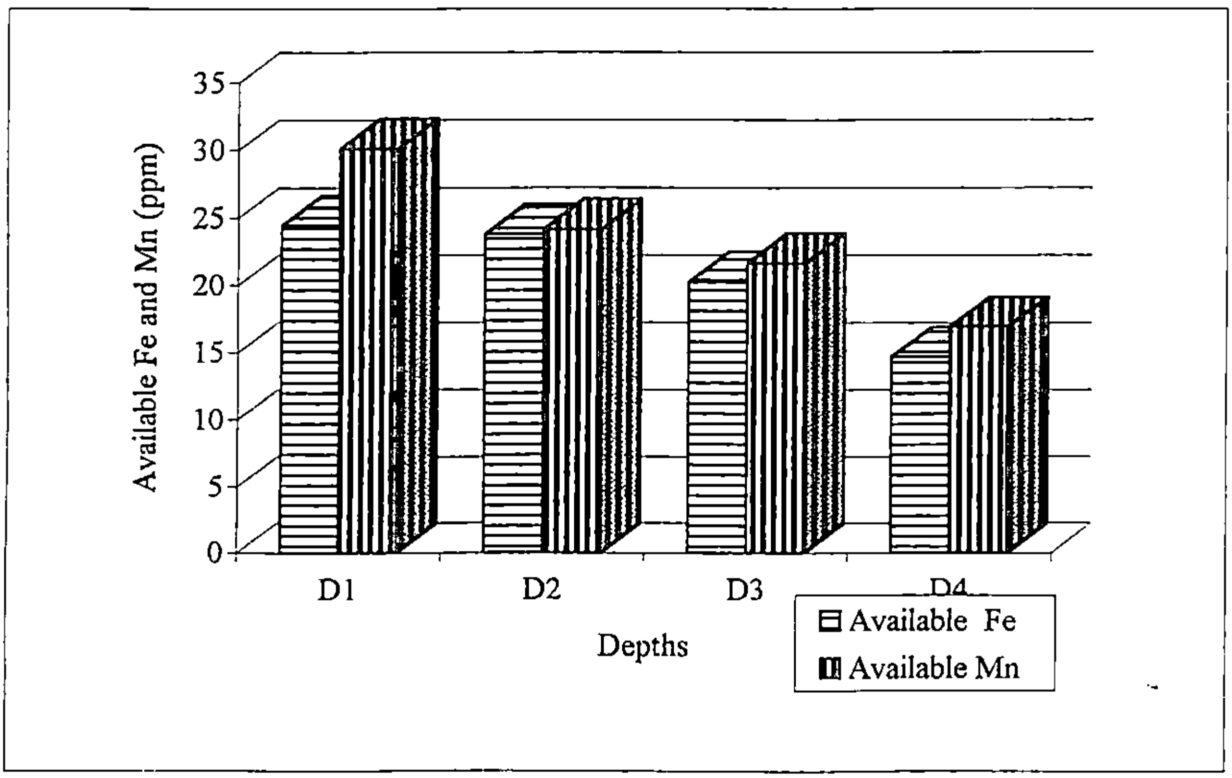
At the closer spacing of 5.0 m (S_1) D_2 depth recorded the lowest soil magnesium content and D_4 depth recorded the maximum content which was significantly higher than the other depths. At wider spacings of 7.5 m and 10.0 m D_2 depth recorded the lowest soil magnesium content and D_1 depth recorded the highest magnesium content. However magnesium content did not differ significantly between D_2 and D_3, D_3 and D_4 and between D_4 and D_1 depths at 7.5 spacing (S_2) and between D_2 and D_3, D_4 and D_1 depths at the widest spacing of 10.0 m (S_3).

The manuring and depth interaction results given in table 11 showed that at all the 4 depths from D_1 to D_4 highest magnesium content was noticed in the unmanured plots (M_0) which was significantly higher than the manured plots. The lowest magnesium content was observed in M_2 dose of fertilizer in D_2, D_3 and D_4 depths and M_1 dose of fertilizer in the surface 0 to 25 m depth (D_1) however it was on par with M_2 dose of fertilizer.

In the unmanured plots magnesium content significantly increases with depth with the maximum value at D_4 depth. In M_1 and M_2 dose of fertilizer application D_1 depth recorded the maximum magnesium content and D_2 depth recorded the lowest magnesium content at M_1 and D_4 depth recorded the lowest magnesium at M_2 level of fertilizer application .

Fig. 10 Effect of spacing and manuring on available calcium, magnesium, iron and manganese status of soil at different depths





4.3.6 Iron

Mean available iron content of soil due to the influence of spacing and manuring are given in table 12. It could be seen from the results that iron content decreased as the spacing became wider. The highest iron content was recorded in the closer spacing of 5.0 m and it was on par with the wider spacing of 7.5 m. The 10 m spacing (S_3) recorded the significantly lowest value.

Mean iron content of soil significantly increases with increase in level of manuring. The lowest iron content was observed in control plots (M_0) and the highest value in plots receiving the highest dose of fertilizers (M_2).

Iron content of soil significantly varies with the depth of sampling. The lowest iron content was recorded in the deeper layer of 75 to 100 cm and it was significantly lower than the lower depths. The highest iron content was observed in the surface soil of 0 to 25 cm (D_1) and it was on par with D_2 depth.

Spacing and manuring combination effect on available iron content of soil presented in table 12 revealed that in all the 3 doses of fertilizer application S_3 spacing recorded the lowest iron content, and it was on par with S_1 spacing in the control plot, S_2 and S_1 spacing in the highest dose of fertilizer application and significantly low in M_1 level of fertilizer application . The highest value of iron was recorded in S_2 spacing in the control plot which was on par with S_1 spacing. Nevertheless S_1 spacing recorded the highest iron content in both the manured plots (M_1 and M_2) and in M_1 plot. S_1 was on par with S_2 spacing.

At all the three spacings the soil iron content significantly increases as the dose of fertilizer increases. The lowest iron content was observed in the control plot (M_0) and the highest iron content in plots receiving M_2 dose of fertilizer.

The result presented in table 13 revealed that at the surface layer of 0 to 25 cm depth (D_1) S_1 spacing recorded the significantly lowest soil iron content and S_2 spacing recorded the highest iron content. At D_2 and D_3 depth S_3 (10.0 m) spacing recorded the lowest iron content and S_1 spacing recorded significantly the highest iron content in D_2 depth and S_2 spacing (7.5 m) recorded significantly the highest iron content in D_3 depth. At D_4 depth S_2 (7.5 m) spacing recorded the lowest iron content and S_1 spacing recorded the highest iron content which was significantly higher than other spacing. Soil iron content did not differ significantly between the wider spacings of S_2 and S_3 at D_1, D_2 and D_4 depths.

At the closer spacing of 5.0 m (S_1) D_4 depths recorded the lowest iron content and D_2 depth recorded the highest iron content which was significantly higher than the other depths. At wider spacings of S_2 and S_3, the iron content increases with decrease in depth with the highest value in the surface 0 to 25 cm depth (D_1) which was significantly higher than other depths. At S_2 spacing in D_3 and D_2 depth the iron content was on par but significant differences existed in S_3 spacing.

Mean iron content of soil due to the combined effect of manuring and depth presented in table 13 revealed that at all the four depths significant differences were observed among the three doses of fertilizer with lowest soil

Table 12 Effect of spacing and manuring on the available micronutrient status of soil at different depths

Effect	Available Fe (ppm)	Available Cu (ppm)	Available Mn (ppm)	Available Zn (ppm)
Spacing				
S_1	21.373	0.376	23.559	5.939
S_2	21.275	0.331	23.610	5.793
S_3	19.683	0.299	22.427	5.901
Manuring				
M_0	16.433	0.297	28.136	5.834
M_1	21.317	0.398	18.845	6.102
M_2	24.581	0.311	22.615	5.698
C D	0.6605	0.0147	0.8907	0.1111
Depths				
D_1	24.415	0.423	30.106	5.496
D_2	23.767	0.371	24.117	6.279
D_3	20.252	0.310	21.648	6.320
D_4	14.673	0.238	16.924	5.417
C D	0.7627	0.0170	1.0285	0.1283
$S_1 M_0$	16.475	0.321	29.908	5.928
$S_1 M_1$	22.595	0.440	17.668	6.233
$S_1 M_2$	25.048	0.367	23.103	5.658
$S_2 M_0$	17.366	0.294	26.435	5.757
$S_2 M_1$	21.833	0.415	21.268	7.953
$S_2 M_2$	24.627	0.285	23.128	5.670
$S_3 M_0$	15.458	0.278	28.065	5.818
$S_3 M_1$	19.523	0.339	17.600	6.120
$S_3 M_2$	24.068	0.280	21.615	5.765
C D	1.1441	0.0254	1.5427	N. S.

iron content in the control plots (M_0) and the highest iron content in plots receiving the highest dose fertilizer (M_2).

Similarly at all the three doses of fertilizer application , D_4 depth recorded the lowest iron content and the iron content increases with decrease in depth of sampling. The surface 0 to 25 cm depth recorded the highest soil iron content and it was on par with D_2 depth and both were significantly superior over D_3 and D_4 depths in all the three doses of fertilizer application .

4.3.7 Copper

The effect of spacing and manuring on available copper content of soil are given in table 12. The data showed that soil copper content significantly increases as the spacing become closer. The lowest copper content was observed in S_3 (10.0 m) spacing and the maximum content in S_1 spacing (5.0 m).

Manuring also showed significant effect of soil copper content. The lowest copper content was observed in the control plots (M_0) and it was on par with M_2 level of manuring and both were significantly lower than M_1 which recorded the highest soil copper content.

A significant decrease in soil copper content was observed as the depth of sampling increases with the highest value in 0 to 25 cm depth (D_1) and the minimum value in 75 to 100 cm (D_4) depth.

The data presented in table 12 revealed that spacing and manuring combination had significant effect on soil copper content. The highest value was observed in S_1 spacing (5.0 m) in all the 3 levels of manuring. A decline in copper content was observed with increase in spacing with the wider spacing of 10.0 m (S_3) having the lowest copper content. The copper content at S_3 spacing was significantly low in M_1 level of manuring and on par with S_2 spacing in M_0 and M_2 level of manuring and the copper content at both S_2 and S_3 spacing were significantly lower than S_1 spacing except in M_1 level of manuring.

At the closest spacing (5.0 m) and at the wider spacing of 10.0 m (S_3) the control plot recorded the lowest soil copper content and it was significantly low in the closer spacing of S_1 (5.0 m) and on par with M_2 level of manuring at the wider spacing of 10.0 m (S_3). M_2 dose of manuring recorded the lowest copper content at S_2 spacing (7.5) and it was found on par with the control plot. At all the 3 spacings the M_1 dose of fertilizer application recorded significantly the highest soil copper content.

4.3.8 Manganese

The results on the effect of spacing and manuring on available manganese content of soil are given in table 12.

The data revealed that spacing had significant effect on available manganese content of soil . The lowest manganese content was observed in the widest spacing of 10.0 m (S_3). Manganese content did not differ significantly between 7.5 m spacing and 5.0 m spacing but both were significantly high compared to those planted at the widest spacing of 10.0 m (S_3).

Manuring had significant effect on soil manganese content. The highest value for available manganese content was recorded in the unmanured palms

(M_0) and it was significantly superior to both the manured palms M_1 and M_2. The lowest manganese content was recorded in the palms applied with M_1 level of manuring.

Depth also significantly influence the available manganese content of soil. There was significant decrease in the manganese content of soil as depth of sampling increases. The lowest manganese content was observed in the highest depth of 75 to 100 cm (D_4) and the highest manganese content was in the surface soil of 0 to 25 cm depth which was significantly higher than the other higher depths.

Table 12 shows the interaction effect of spacing and manuring on the available manganese content of soil. In the absence of manuring the wider spacing of 7.5 m (S_2) observed that lowest manganese content and the manganese content significantly increased as the spacing become wider to 10.0 m (S_3). But the highest manganese content was observed in the closer spacing of 5.0 m (S_1) and it was significantly high over the other two wider spacing of S_2 and S_3. When fertilizers were applied at M_1 and M_2 doses, S_3 spacing recorded the lowest soil manganese value and it was found on par with S_1 spacing in M_1 level of manuring and no significant difference was observed among all the three spacings in M_2 level of manuring. S_2 spacing recorded the highest manganese content in both M_1 and M_2 manuring levels and significantly superior to S_1 and S_3 spacings only in M_1 level of manuring.

By planting the palms in all the three spacings the available soil manganese content significantly increases from M_1 to M_2 level of manuring. The lowest value for manganese was observed in M_1 level of manuring in all

Table 13 Interaction effect of spacing and manuring on the available micronutrient status of soil at different depths

Effect	Available Fe (ppm)	Available Cu (ppm)	Available Mn (ppm)	Available Zn (ppm)
$S_1 D_1$	22.767	0.461	30.757	5.403
$S_1 D_2$	25.790	0.438	24.963	6.290
$S_1 D_3$	20.693	0.351	21.040	6.523
$S_1 D_4$	16.240	0.255	17.477	5.540
$S_2 D_1$	25.742	0.435	30.693	5.413
$S_2 D_2$	23.380	0.350	24.030	6.310
$S_2 D_3$	22.313	0.306	22.300	6.343
$S_2 D_4$	13.664	0.233	17.417	5.107
$S_3 D_1$	24.737	0.372	28.867	5.670
$S_3 D_2$	22.130	0.323	23.357	6.237
$S_3 D_3$	17.750	0.273	21.603	6.093
$S_3 D_4$	14.113	0.227	15.880	5.603
$M_0 D_1$	20.083	0.389	35.220	5.713
$M_0 D_2$	19.450	0.300	29.490	6.003
$M_0 D_3$	14.840	0.273	25.260	5.907
$M_0 D_4$	11.358	0.228	22.573	5.713
$M_1 D_1$	24.583	0.537	24.733	5.660
$M_1 D_2$	24.057	0.447	17.913	6.497
$M_1 D_3$	21.933	0.346	17.893	6.650
$M_1 D_4$	14.693	0.262	14.840	5.600
$M_2 D_1$	28.579	0.342	30.363	5.113
$M_2 D_2$	27.793	0.365	24.947	6.337
$M_2 D_3$	23.983	0.311	21.790	6.403
$M_2 D_4$	17.967	0.225	13.360	4.937
C D	1.3210	0.0294	1.7814	0.2222

the three spacings and the highest value was recorded in the unmanured plots (M_0) and it was significantly superior to the plots receiving M_1 and M_2 level of manuring in all the three spacings.

The data presented in table 13 clearly indicated that there was no interaction between spacing and depth on available manganese content of soil.

The table 13 shows the results of the interaction effect of manuring and depth on available manganese content of soil. It could be observed that at all the 4 depths of sampling M_0 level of manuring (control plot) recorded the highest soil manganese content and it was significantly higher than the other manurial levels. At D_1, D_2 and D_3 depths M_1 manurial level recorded the minimum soil manganese content and at D_4 depth M_2 manurial level recorded the lowest manganese content and it was on par with M_1 level of manuring.

Both in the control plot as well as in plot applied with different doses of fertilizers the higher depth of 75 to 100 cm (D_4) observed the lowest manganese content and the surface depth of 0 to 25 cm (D_1) observed the highest manganese and it was significantly higher over the higher depths. At M_1 manurial level no significant difference in manganese content was observed between D_3 and D_2 depths.

4.3.9 Zinc

It could be seen from the results presented in table 12 that spacing had significant effect on available zinc content of soil. There was a decline in zinc content from spacing S_1 to S_2 and further increase in spacing to S_3 the zinc content increases. The highest value was observed in S_1 spacing of 5.0 m and the lowest value in 7.5 m spacing (S_2). There was no significant difference in soil zinc content between the wider spacings of 7.5 m and 10.0 m and also between 10.0 m and 5.0 m.

Manuring had significantly influenced the soil zinc content. At the highest dose of manuring (M_2) the lowest zinc content was recorded. In plots manured with M_1 level of manuring the highest soil zinc content was recorded. The zinc content at M_1 level of manuring was significantly superior to the higher (M_2) and lower doses (M_0) of manuring.

There was a gradual increase in zinc content from surface layer of 0 to 25 cm to 50 to 75 cm and beyond this depth a sudden decline was observed. The lowest zinc content was recorded in the deeper level of 75 to 100 cm and the highest value in 50 to 75 cm depth. Zinc content did not differ significantly at D_4 and D_1, D_2 and D_3 depths. D_3 depth was significantly superior to the lower depth of D_1 and the higher depth of D_4.

There was no interaction between spacing and manuring on available zinc content of soil which could be very clear from the data presented in table 12.

The interaction effect of spacing and depth on available zinc content of soil are given in table 13.

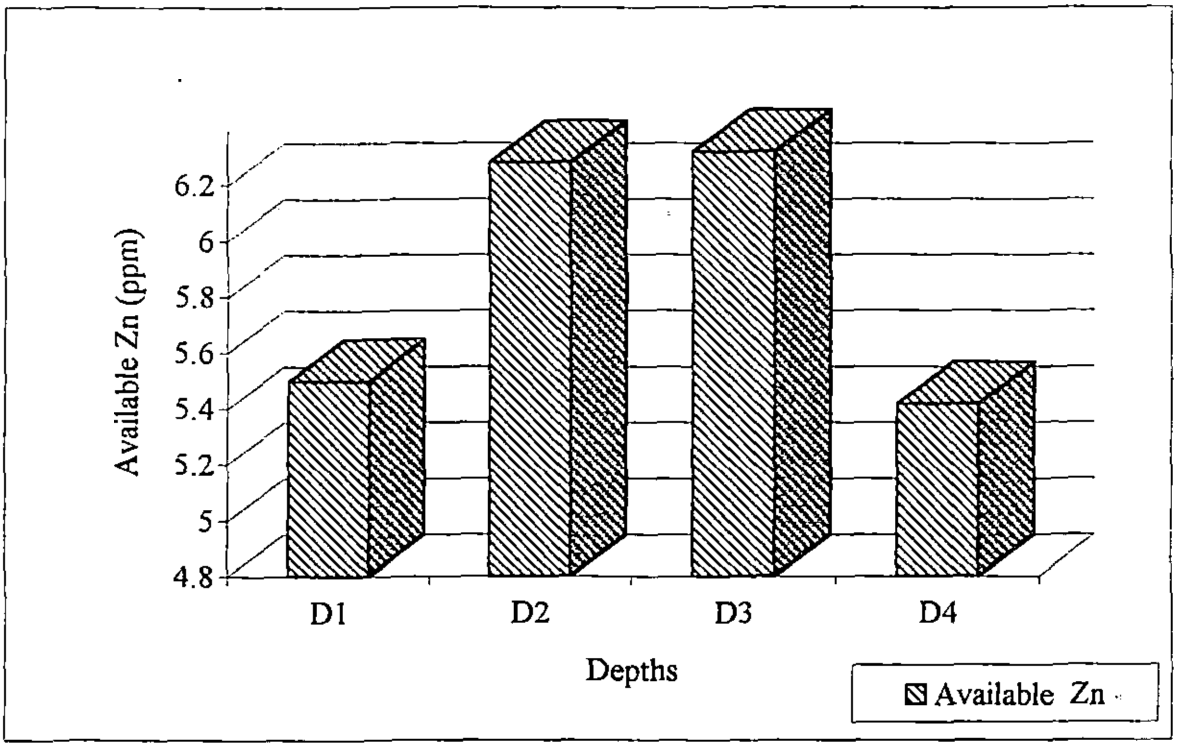
It could be observed from the table that at the surface layer of 0 to 25 cm depth (D_1) the zinc content increases as spacing becomes wider. The highest zinc content was observed in the widest spacing of 10.0 m (S_3) and it was significantly superior to the lower spacings S_1 and S_2. The lowest zinc content was observed in the closer spacing of 5.0 m (S_1) and it was found on par with the wider spacing of 7.5 m (S_2). At D2 depth (25 to 50 cm) there was no significant difference among the three spacings on available zinc content of soil, however the highest and the lowest value for zinc are recorded in 7.5 m and 10.0 m spacings respectively. At 50 to 75 cm depth (D_3) the lowest zinc content was observed in the wider spacing of 10.0 m (S3) and the highest in the closer spacing of 5.0 m (S_1) which did not differ significantly with S_2 (7.5 m). Both S_1 and S_2 spacings were significantly superior to the wider spacing S_3. At he higher depth of 75 to 100 cm (D_4) the wider spacing of 7.5m (S_2) recorded the lowest available zinc content of soil and 10.0 m spacing recorded the highest value. The closer spacing of 5.0 m (S_1) and the wider spacing of 10.0 m (S_3) did not differ significantly on available zinc content of soil, but both were significantly superior compared to S_2 spacing.

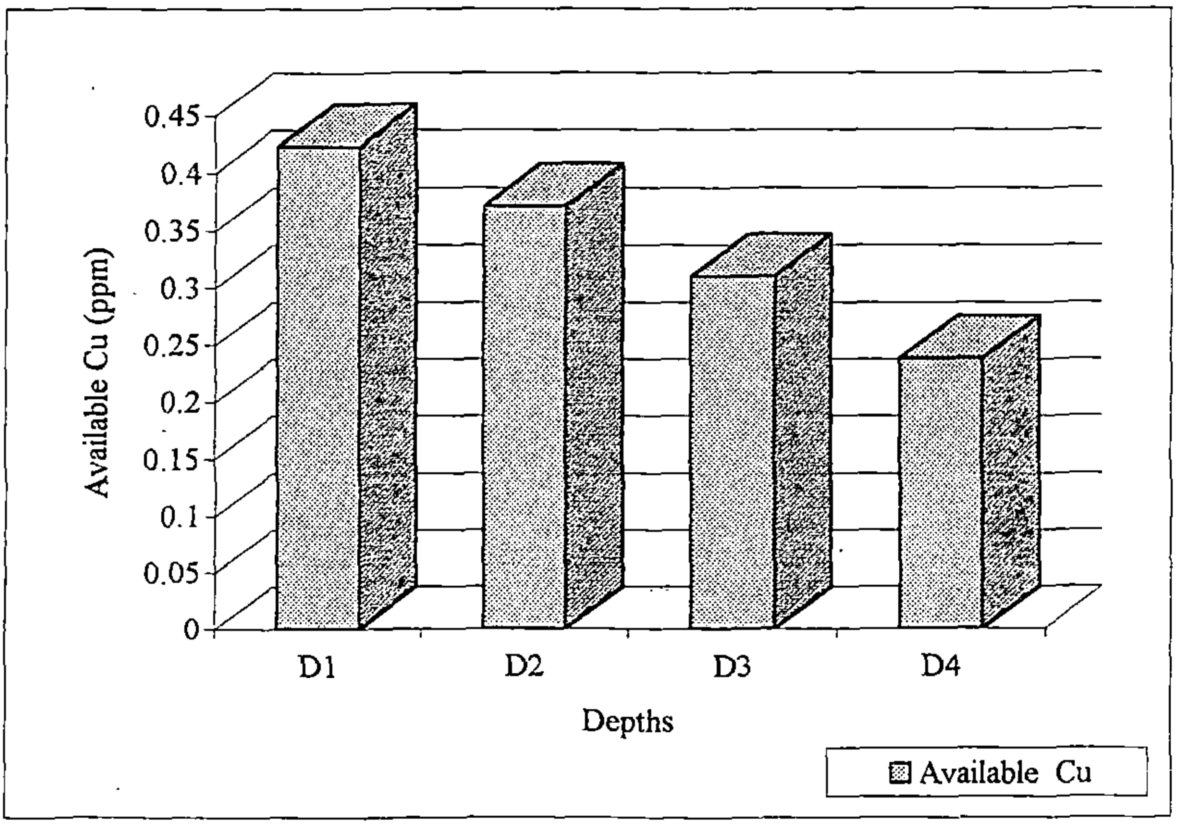
When the palms were given the closer spacing of 5.0 m (S_1) the lowest available zinc content of soil was noticed in the surface level of 0 to 25 cm depth and it was found on par with the depth of 75 to 100 cm. The highest zinc content of soil was noticed in soil taken from 50 to 75 cm depth (D_3) and it was significantly superior to the higher (D_4) and lower depths (D_1 and D_2). At the wider spacing of S_2 and S_3 the lowest soil zinc was observed in the higher depth of 75 to 100 cm (D_4) and it was significantly low compared to other depths in S_2 spacing and on par with the surface layer of 0 to 25 cm depth in the wider spacing of S_3. The highest soil zinc content was observed in 50 to 75 cm depth (D_2) in the wider spacing of S_3. Zinc content of soil at D2 and D3 depths were on par and significantly superior to the higher (D_4) and lower (D_1) depths both in the wider spacings of S_2 and S_3.

The manuring and depth interaction effect on the available zinc content of soil are presented in table 13. The results revealed that at 0 to 25 cm depth there was no significant difference between the unmanured plot and the plot receiving M_1 level of manuring on available zinc content of soil of which the unmanured plot recorded the highest value for zinc. Both these M_0 and M_1 were significantly superior to the plot receiving the highest dose of manuring (M_2) which recorded the lowest value for zinc. The same result as that of 0 to 25 cm depth was observed for zinc in the deepest layer of 75 to 100 cm (D_4) depth. At D_2 and D_3 depth the unmanured plot recorded the lowest soil zinc content and it was significantly low compared to plots receiving M_1 and M_2 level of manuring. The highest value was recorded for M_1 level of manuring in both D_2 and D_3 depths and the zinc content both at M_1 and M_2 level of manuring were on par at D_2 depth and M_1 is significantly superior over M_2 at D_3 depth.

In the absence of manuring D_1 depth recorded the lowest available zinc content of soil and there was no significant difference among D_1, D_3 and D_4 depths. The highest value was recorded for D_2 depth and it was found on par with D_3 depth and significantly superior over D_1 and D_4 depths. In both M_1 and M_2 level of manuring D_4 depth recorded the lowest available soil zinc content and it was found on par with D_1 depth. The highest zinc content was observed in D_3 depth and it was on par with D_2 depth and both were significantly superior to D_1 and D_4 depth in both M_1 and M_2 manuring levels.

Fig. 11 Effect of spacing and manuring on available zinc and copper status of soil at different depths





4.4. Effect of spacing and manuring on leaf nutrient status

4.4.1 Nitrogen

The data on the nitrogen content of 14^{th} leaf of coconut given in table 14 clearly show the significant effect of spacing on this. Leaf nitrogen content increased with increase in spacing upto the wider spacing of 10.0 m (S_3). The highest leaf nitrogen content (1.920 %) at S_3 level of spacing was found on par with S_2 spacing and both were significantly superior to the closer spacing S_1 (5.0 m), which recorded the lowest leaf nitrogen (1.823 %).

Increase in the dose of NPK fertilizer increased leaf nitrogen content significantly upto M_2 level . The highest leaf nitrogen content was recorded in palms fertilized at M_2 level (2.027 %) and the lowest in unfertilized palms (1.675 %).

When the palms were not fertilized S_2 level of spacing resulted in a higher leaf nitrogen content (1.750 %) and it was not significantly different with S_3 spacing. But both S_2 and S_3 spacings were superior over S_1. However when the fertilizer was applied at M_1 level the wider spacing of 10.0 m (S_3) recorded the highest leaf nitrogen and was found to be on par with the closer spacing of 5.0 m (S_1) which in turn was found to be on par with 7.5 m spacing (S_2). At M_2 level of NPK application leaf nitrogen content increased with increase in spacing upto 10.0 m (S_3) and it was found to be on par with S_2 level of spacing. Also the leaf nitrogen content at M_2 was not significantly different at S_1 and S_2 levels of spacings.

At the closest spacing (S_1) of 5.0 m leaf nitrogen content increased with increase in manuring and the highest value of 1.974 at M_2 level of manuring was on par with M_1 level and both were significantly superior to the unmanured palms (M_0). Similarly at S_2 and S_3 spacings manuring significantly increased the leaf nitrogen content and the highest value was recorded in M_2 level and the lowest value in M_0 level of NPK fertilizer application.

4.4.2 Phosphorus

Per cent phosphorus content in the leaf of coconut (Table 14) increased as the palm density decreased. Mean phosphorus content increased from 0.119 % to 0.151 % as spacing increased from 5.0 m (S_1) to 10.0 m (S_3). The highest phosphorus content at 10.0 m (S_3) was significantly different with S_2 and S_3 was significantly superior to the closer spacing of 5.0 m (S_1).

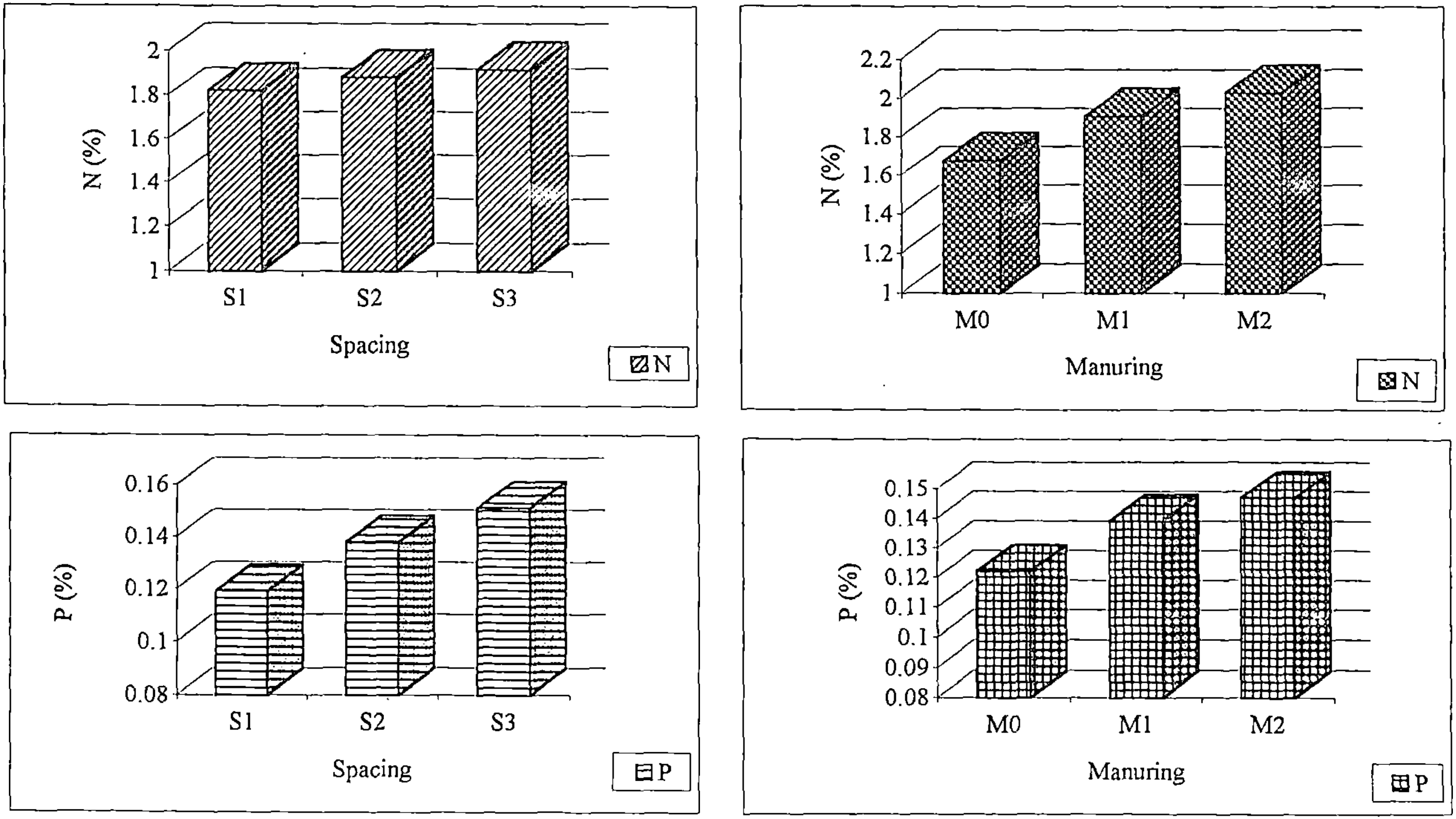
Application of fertilizer increased the per cent phosphorus content in the 14th leaf of coconut upto M_2 level of application. The highest value (0.147 %) at M_2 level of manuring was significantly superior to M_1 level and the phosphorus content at M_1 level was also significantly superior to the unmanured palms (M_0) and the latter recorded the lowest value (0.122 %).

Spacing manuring interaction also showed a significant effect on soil available phosphorus content. In the absence of manuring (M_0) different levels of spacing influenced the phosphorus content of the leaf significantly, the highest spacing (S_3) recorded the maximum phosphorus content and the closest spacing (S_1) with minimum leaf phosphorus content. When the manuring was increased to M_1 level, similar results as that of M_0 level was observed with maximum leaf phosphorus content in the wider spacing of 10.0 m (S_3) and minimum in the closest spacing (S_1). The leaf phosphorus content at S_3

Table 14 Effect of spacing and manuring on the macro and secondary nutrient content of 14th leaf of coconut

Effect	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Spacing					
S_1	1.823	0.119	1.325	0.160	0.247
S_2	1.884	0.138	0.930	0.170	0.259
S_3	1.92	0.151	0.856	0.152	0.256
Manuring					
M_0	1.675	0.122	0.543	0.142	0.266
M_1	1.907	0.139	1.159	0.162	0.253
M_2	2.027	0.147	1.335	0.177	0.243
C D	0.0429	0.0035	0.0775	0.0091	0.0089
$S_1 M_0$	1.591	0.106	0.554	0.138	0.262
$S_1 M_1$	1.904	0.121	1.482	0.165	0.244
$S_1 M_2$	1.974	0.129	1.718	0.176	0.236
$S_2 M_0$	1.750	0.126	0.514	0.150	0.273
$S_2 M_1$	1.857	0.134	1.064	0.174	0.260
$S_2 M_2$	2.044	0.155	1.211	0.187	0.243
$S_3 M_0$	1.685	0.135	0.560	0.139	0.263
$S_3 M_1$	1.960	0.163	0.931	0.148	0.254
$S_3 M_2$	2.063	0.156	1.076	0.170	0.251
C D	0.0743	0.0061	0.1342	N. S.	N . S.
$SE_M \pm$	0.0248	0.0020	0.0448	0.0053	0.0051

Fig. 12 Effect of spacing and manuring on nitrogen and phosphorus content of 14th leaf of coconut



spacing was significantly superior to S_2 and S_1 spacing both at M_1 and M_0 level of manuring. However at M_2 level of manuring also S_3 spacing recorded the highest leaf phosphorus content and it was not significantly superior to S_2 spacing but leaf phosphorus content in both S_2 and S_3 spacings were significantly superior to the closest spacing of 5.0 m (S_1).

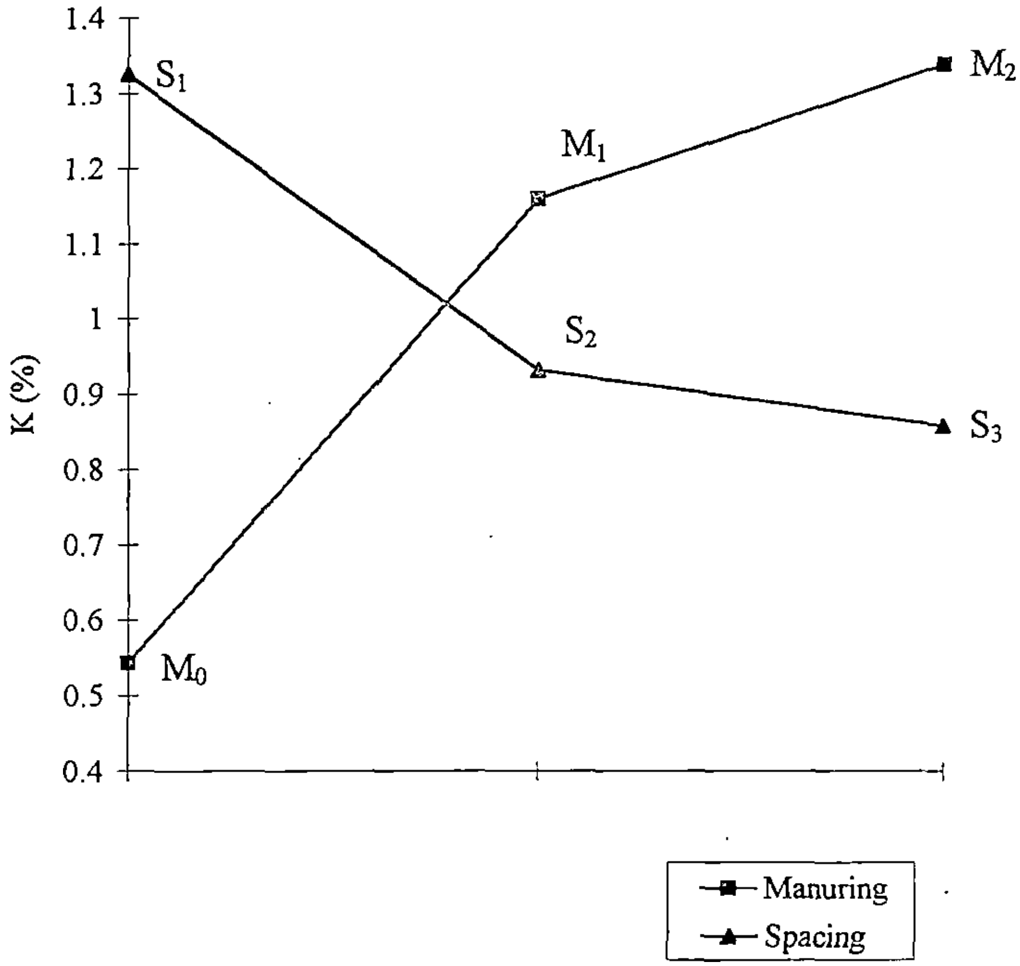
Increase in the level of manuring from M_0 to M_2 level significantly increased the leaf phosphorus content both at S_1 and S_2 level of spacings. In both these spacings M_2 level of manuring recorded the highest value and M_0 with the lowest value. But at S_3 spacing highest leaf phosphorus content was observed in M_1 dose of NPK application and is significantly superior to M_2 level and the phosphorus content at M_2 level was significantly superior to the lowest value recorded in the unmanured palms (M_0).

4.4.3 Potassium

Potassium content of coconut leaf due to the influence of spacing and manuring are presented in table 14. The results showed that there was significant decrease in potassium content from the closest spacing of 5.0 m (S_1) to the wider spacing of 10.0 m (S_3). The lowest value for Potassium was noticed in the wider spacing of 10.0 m (S_3) and it was on par with 7.5 m spacing (S_2) and both were significantly lower compared to leaf potassium content of palms planted at the closer spacing of 5.0 m (S_1).

Leaf potassium content increased significantly when the dose of NPK fertilizer was increased from M_0 to M_2 level. The highest value was observed in palms fertilized at M_2 level and the lowest in M_0 level. Leaf potassium at

Fig. 13 Effect of spacing and manuring on potassium content of 14th leaf of coconut



M_2 level of manuring was significantly superior to the lower levels of M_1 and M_0.

In the unmanured coconut palms (M_0) the highest leaf potassium content was observed in S_3 spacing and the lowest in 7.5 m spacing (S_2). At all 3 levels of spacings the leaf potassium content was not significantly different in M_0 level of manuring. When manuring was given at M_1 level the leaf Potassium content significantly decreased with increase in spacings. The lowest Potassium content was recorded in S_3 spacing and it was on par with 7.5 m spacing (S_2). The highest value for potassium content was recorded in S_1 spacing which was significantly superior to the other two wider spacing of 7.5 m and 10.0 m. At the highest dose of manuring (M_2) leaf potassium content also significantly decreased with increase in spacing with the lowest value at 10.0 m wider spacing and the highest value at 5.0 m closer spacing (S_1).

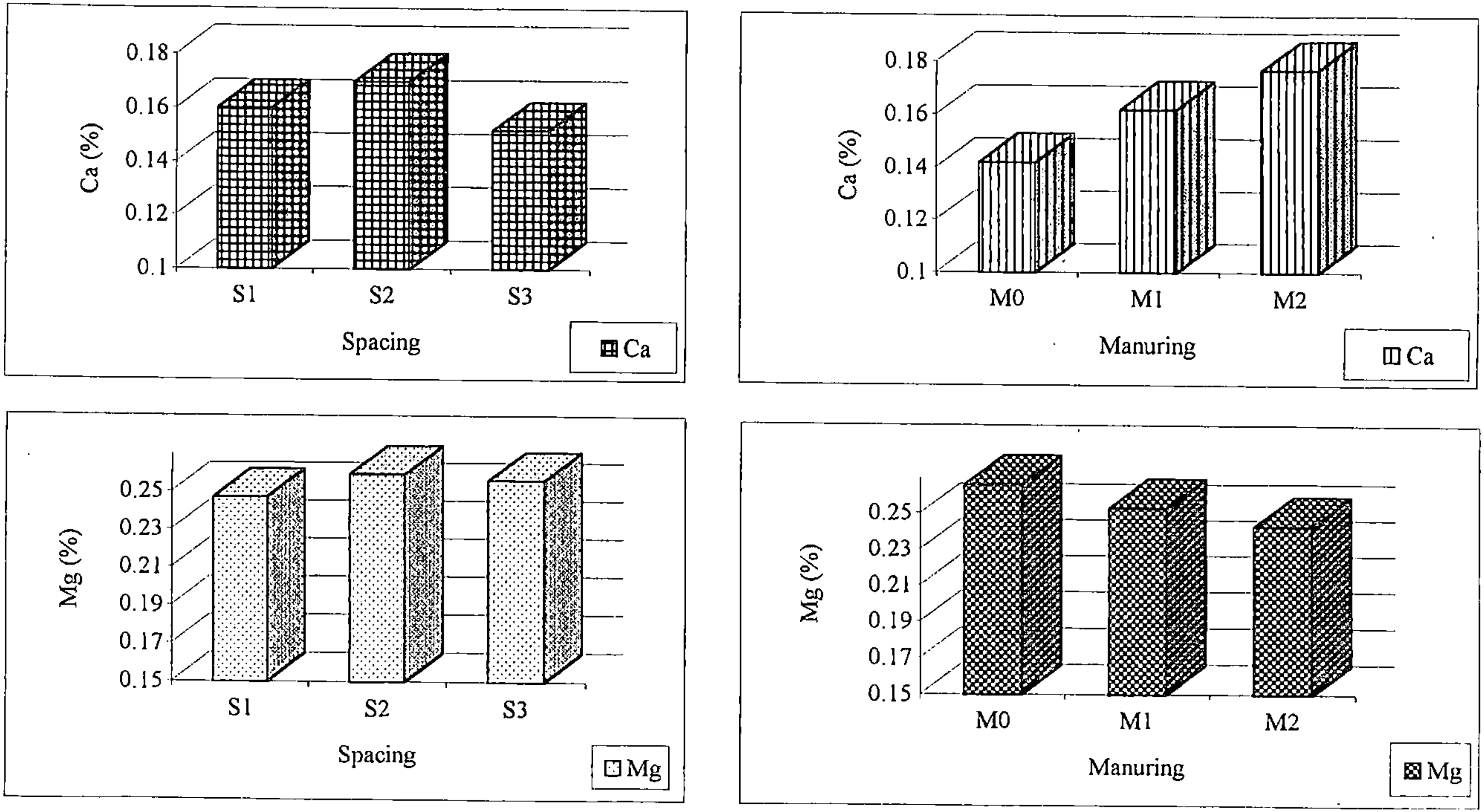
The leaf potassium content of coconut leaf significantly increased with increase in manuring in all the three spacings with the highest value for M_2 level of manuring and the lowest value for the unmanured palms (M_0).

4.4.4 Calcium

The data on leaf calcium content of coconut palm presented in table 14 revealed that calcium content did not differ significantly when the palms were planted at closer spacing of 5.0 m (S_1) and wider spacing of 10.0 m (S_3) but significantly low compared to those planted with a spacing of 7.5 m (S_2). However the highest value was recorded in S_2 spacing and the lowest in S_3 spacing.

Leaf calcium content differ significantly at all the three doses of NPK fertilizer application and the increase in level of fertilization enhanced the leaf

Fig.14 Effect of spacing and manuring on calcium and magnesium content of 14th leaf of coconut



calcium content with the lowest value for unmanured palms (M_0) and the highest value in M_2 level of manuring.

There was no interaction between spacing and manuring on leaf calcium content of 14^{th} leaf of coconut.

4.4.5 Magnesium

The data presented in table 14 showed that leaf magnesium content was highest when the palms were planted at wider spacing of 7.5 m (S_2) and it was found on par with the widest spacing of 10.0 m (S_3) . The lowest value was observed for the closest spacing of 5.0 m (S_1).

Manuring had significant influence on leaf magnesium content. The increase in level of manuring from M_0 to M_2 level was found to be significantly influenced the leaf magnesium content. The highest leaf magnesium was recorded in the absence of manuring (M_0) and was found to be significantly different with the two higher levels of M_1 and M_2. The lowest leaf magnesium content was noticed in palms receiving highest dose of manuring (M_2) and was significantly lower than the other two levels of M_0 and M_1.

The interaction effect of spacing and manuring was not significantly influenced the leaf magnesium content.

4.4.6 Iron

The data given in table 15 showed that the leaf iron content was not significantly influenced by the different spacing levels. However there was slight decrease in the content of iron in the leaf when the palms were planted from closer spacing of 5.0 m (S_1) to wider spacing of 10.0 m (S_3).

The effect of different levels of NPK fertilizer application in increasing the leaf iron content was significant and there was an increase in leaf iron content when the palms were given the highest level (M_2) of fertilizer application . The highest leaf iron content of 169.28 ppm was recorded in palms manured with M_2 dose of fertilizers and it was significantly superior to the lower doses of NPK application . The lowest value (154.18 ppm) was recorded in case of unmanured palms (M_0).

The interaction effect of spacing and manuring did not significantly influence the leaf iron content in coconut.

4.4.7 Copper

The data on leaf copper content of coconut palms given in table 15 revealed that the spacing did not have any significant effect on this. However the copper content increases slightly when the palms were planted from 5.0 m to 10.0 m spacing.

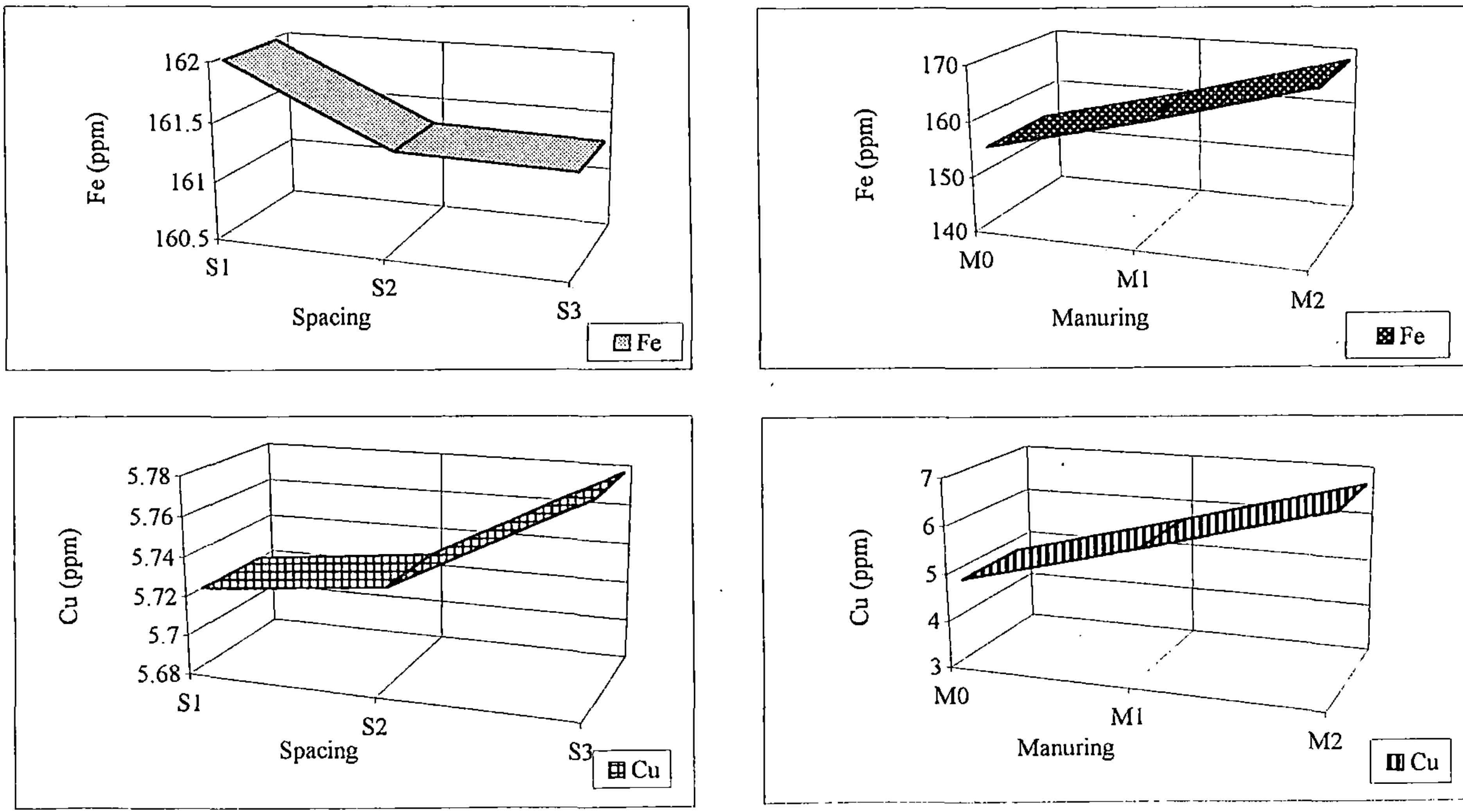
Unlike spacing manuring had a significant effect on the copper content of 14th leaf of coconut. The leaf copper content showed a significant difference in all the three levels of manuring. The highest value was recorded for M_2 level of fertilizer application which was significantly superior to the lower levels of manuring. The lowest value recorded was 4.73 ppm in the palms which were not fertilized (M_0)

The spacing and manuring interaction effect was not significant in influencing the plant copper content in coconut.

Table 15 Effect of spacing and manuring on the micro nutrient content of 14th leaf of coconut

Effect	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	Na (%)
Spacing					
S_1	161.98	5.72	365.81	25.39	0.184
S_2	161.34	5.73	369.93	26.16	0.227
S_3	161.31	5.78	367.39	26.95	0.225
Manuring					
M_0	154.18	4.73	338.37	30.61	0.222
M_1	161.18	5.72	359.44	24.79	0.212
M_2	169.28	6.77	405.32	23.08	0.202
C D	4.794	0.378	9.554	1.320	0.0080
$S_1 M_0$	151.57	4.62	331.87	29.85	0.209
$S_1 M_1$	161.77	5.78	358.30	23.59	0.179
$S_1 M_2$	172.60	6.77	407.28	22.68	0.165
$S_2 M_0$	156.20	4.81	342.60	30.74	0.268
$S_2 M_1$	161.10	5.58	362.97	24.73	0.221
$S_2 M_2$	166.73	6.81	404.23	23.01	0.194
$S_3 M_0$	154.77	4.77	340.63	31.24	0.190
$S_3 M_1$	160.67	5.82	357.07	26.06	0.237
$S_3 M_2$	168.50	6.74	404.47	23.55	0.248
C D	N.S.	N. S.	N. S.	N. S.	0.0138
$SE_M \pm$	2.770	0.218	5.519	0.762	0.0046

Fig.15 Effect of spacing and manuring on iron and copper content of 14th leaf of coconut



4.4.8 Manganese

Manganese content of 14th leaf of coconut (Table 15) showed that there was no significant effect of spacing on this.

Manuring had a significant influence on the manganese content of leaf. There was a gradual increase in leaf manganese from the unmanured palms to the palms receiving the highest level of manuring. The highest leaf manganese was noticed in M_2 level of NPK application which was significantly superior to the lower two levels of fertilizer application. The lowest leaf manganese was noticed in the palms of unmanured plots (M_0).

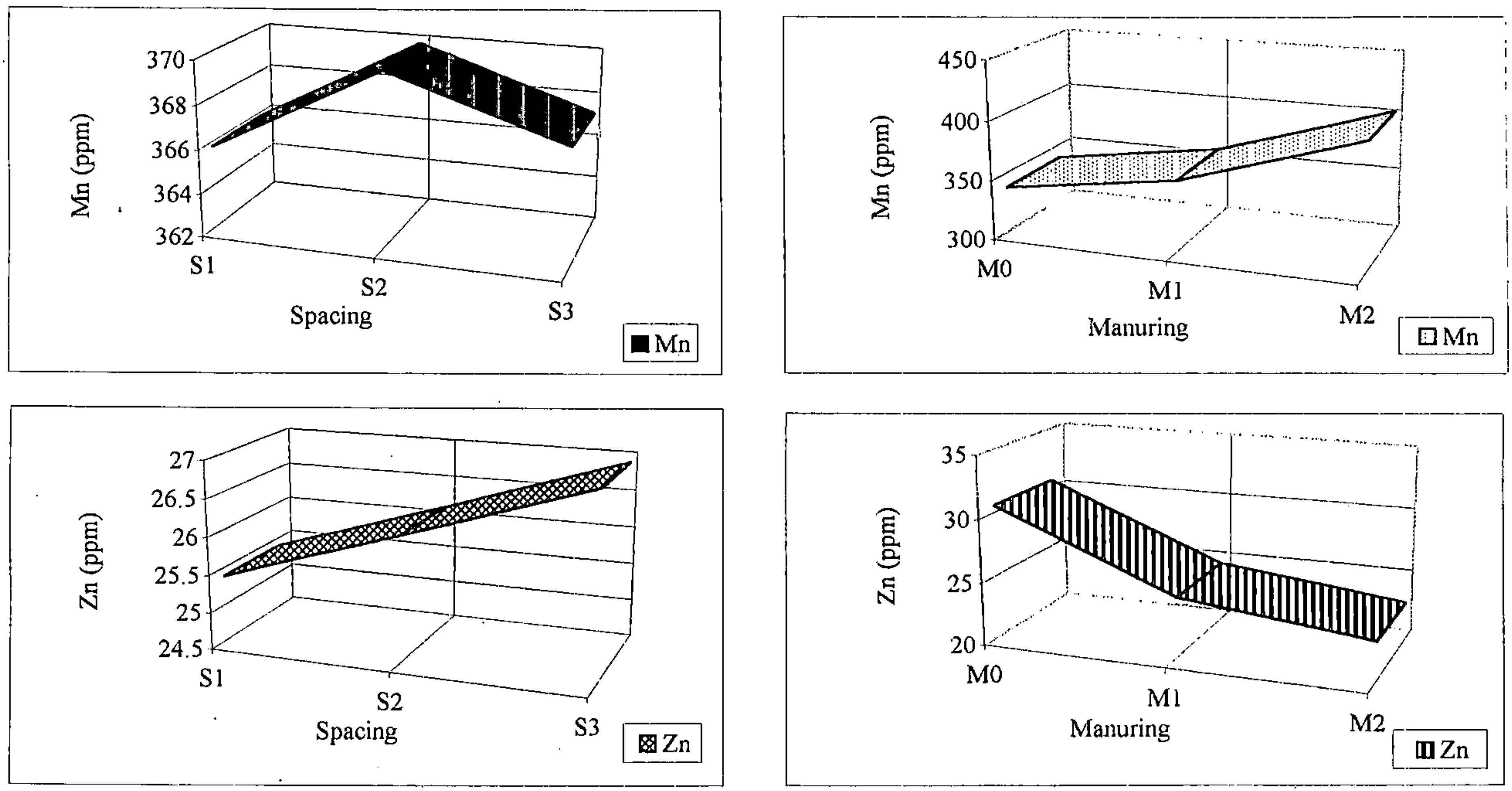
There was no interaction effect of spacing and manuring on leaf manganese content of coconut.

4.4.9 Zinc

Coconut leaf zinc content is given in table 15. The data revealed that spacing did not significantly influence the leaf zinc content. A gradual increase in leaf zinc content was noticed with increase in spacing.

Manuring showed a significant effect on the leaf zinc content of coconut. An inverse relationship between manuring and leaf zinc content was observed. The lowest zinc content was noticed in palms applied with the highest dose (M_2) of NPK and the highest leaf zinc was observed in palms of the unmanured plots. The zinc content in unmanured palms was found to be significantly superior to the two higher levels of manuring.

Fig. 16 Effect of spacing and manuring on manganese and zinc content of 14th leaf of coconut



The interaction effect of spacing and manuring was not significant on leaf zinc content of coconut.

4.4.10 Sodium

The data on leaf sodium content in 14th leaf of coconut are presented in table 15.

The results revealed that there was significant effect for spacing and manuring on leaf sodium content. The leaf sodium content of palms at wider spacing of 7.5 m (S_2) and 10.0 m (S_3) did not differ significantly, but significant effect was observed when the palms were planted at closer spacing of 5.0 m (S_1). The highest leaf sodium content (0.225 %) was noticed in S_3 spacing and the lowest in S_1 spacing.

Manuring had a significant inverse relationship with leaf sodium content. The lowest sodium content was recorded in palms received the heavier dose (M_2) of fertilizer and the highest in unmanured palms which was significantly superior to the palms fertilized with M_1 and M_2 levels of fertilizer

. In the absence of manuring to coconut palms, S_2 (7.5 m x 7.5 m) spacing recorded the highest leaf sodium content and the lowest in the widest spacing of 10.0 m (S_3). But at M_1 and M_2 level of NPK application the leaf sodium content increased as the spacing became wider and the widest spacing of 10.0 m (S_3) recorded the highest leaf sodium which was significantly superior compared to the other two spacings of 7.5 m and 5.0 m.

When the spacing was given at 5.0 m and 7.5 m distance the lowest leaf sodium content was noticed in palms receiving the highest dose (M_2) of manuring and the highest leaf sodium content in the unmanured palms (M_0) which was significantly superior to the palms receiving M_1 and M_2 doses of manuring. But when the spacing was increased to S_3 levels (10.0 m) the highest leaf sodium content was noticed in palms received the highest dose of NPK and it was on par with palms receiving M_1 dose of fertilizer. The lowest leaf sodium content was noticed in the unmanured palms (M_0) which was significantly low compared to palms receiving M_1 and M_2 doses of manuring.

DISCUSSION

5. DISCUSSION

Investigations were conducted to study the effect of spacing and continued manuring on growth characters, yield and yield attributes and the nutrient status of soil and plant during 1995-96 from an existing field experiment at Coconut Research Station, Balaramapuram. The results of this study are discussed below.

5.1 Effect of spacing and manuring on growth characters

5.1.1 Height and girth of palms

The results presented in table 2 revealed that there was significant increase in height when the palms were planted with narrower spacings of 5.0 m x 5.0 m. The closest spacing of 5.0 m x 5.0 m had forced vertical growth in palms, probably to compete for more sunlight from their early years of growth as shown by the slightly higher height of trunk in these palms compared to those in the other two wider spacings. Under closer planting there is a tendency for the palms to grow tall and lanky in their struggle to get sunlight (Menon and Pandalai, 1958). The comparatively increased height of these palms under lower spacings in this experiment can be due to such competition between the seedlings due to the over crowing as reported by Menon and Pandalai (1958). Similar increase in vertical growth of palms three to four years after their establishment planted at close spacing compared to those in wider spacing were reported by Louis *et al.* (1981). Also Pamin and Harris (1988) observed 7 to 8 years after planting increasing palm density increased height. Planting at a higher density resulted in intense competition among the young palms, resulting in an extended period of rapid stem elongation (Foale, 1993).

Manuring had shown significant effect on the rate of increase in height. Fertilizer application significantly increased the height of palms with progressive increase in height under manuring compared to control. Higher growth manifested in terms of height by fertilizer levels. However no significant differences were observed between the higher and lower doses of NPK for height. The height of the trunk in the manured palms were higher by 47.43 per cent and 53.59 per cent for single and double doses of NPK treatments respectively over control.

Nitrogen promotes the development of vegetative parts of the plant especially the leaves and shoots (Menon and Pandalai, 1958). Phosphorus is essential for the root development of palm. The complete effect of nitrogen in plant metabolism is achieved in the presence of phosphorus and potassium. It is a well established fact that the major nutrients N, P and K are having a positive beneficial effect in increasing the height of plants. Increase in the height of coconuts by application of fertilizer containing NPK were reported by many workers (Muhammed *et al.*, 1974 ; Nelliat *et al.*, 1976 ; Prudente and Mendoza, 1976 ; Louis *et al.*, 1981 ; Chattopadhyay and Hasan,1986 and Secretaria and Marivalla, 1997). The results of this experiment are in agreement with these findings.

Spacings did not show any significant difference in the rate of increase in the girth, while it showed significant difference in the rate of increase in height. Only manuring significantly increased the girth of palm and highest girth was for 340 : 225 : 450 g N, P_2O_5 and K_2O per palm per year . The rate of growth of the stem was also higher by 5.17 per cent and 2.55 per cent in palms which received single and double doses respectively than in palms that received no fertilizers. Girth is another vegetative character which is positively affected by N, P ad K. An adequate supply of nitrogen is associated with vigorous vegetative growth (Tisdale *et al.*, 1985). Under conditions of nitrogen deficiency the stems are thin and upright, phosphorus deficiency produces certain effects that of similar to the effects of nitrogen deficiency (Black, 1973). Potassium jointly performs in association with phosphorus and nitrogen (Menon and Pandalai, 1958) in plant growth. The girth of collar in coconut seedlings was increased by phosphoric acid (Ramanandan, 1964) and in the absence of K application palms produced lesser girth (Fremond and Ouvrier, 1971). The findings of this trial corroborates the results of Muhammed *et al.* (1974) ; Nelliat *et al.* (1976) ; Prudente and Mendoza (1976) ; Manciot *et al.* (1979 (a)) ; Oguis *et al.* (1979) ; Chattopdhyay and Hasan (1986) ; Bonneau *et al.* (1993) and Secretaria *et al.* (1994).

5.1.2 Number of leaves produced in a year

Both spacing and manuring had shown significant effect on the number of leaves produced per year (Table 2). Leaf production per annum significantly showed an upward trend with increase in spacing and manuring levels. Closer spacing significantly decreased the leaf number. Under over crowding the plants have a tendency to grow tall and the energy received is utilised for this purpose at the expense of the production of leaves and fruit. In studies conducted in Tamil Nadu it was observed that number of leaves produced per annum showed an upward trend with increase in spacing (Louis *et al.*, 1981). The findings in this experiment is in agreement with the reports of Tan Yap Pau and Chan (1985) that there was a reduction of frond production when palms were planted at higher density.

There was a progressive and significant increase in leaf production with fertilizer levels upto the highest level. Manuring, also increased the longivity and retention of leaves on the crown. Green colouration of leaves and more dense crown were observed on palms applied with NPK fertilizers. Nitrogen is an integral part of chlorophyll which is the primary absorber of light energy needed for photosynthesis. An adequate supply of nitrogen is associated with leaf production and a dark green colour (Tisdale *et al.*, 1985). Characteristic discolouration often occurs on the leaves where phosphorus is in short supply, leaf area is found to increase with potassium nutrition (Steineck and Haeder, 1980). The number leaves in a group of trees vary from 22 to 35 per tree (Patel, 1938). Muhammed *et al.* (1974) found that manuring increased the number of functioning leaves over no manuring. Also the possible effect of NPK on leaf production has been reported by many workers (Manciot *et al.*, 1979 (a) ; Louis, 1981 ; Nelliat and Gopalasundaram, 1984 ; Mathew, 1986 ; Chattopadhyay and Hasan, 1986 ; Bonneau *et al.*, 1993 and Secretaria *et al.*, 1994 and Secretaria and Maravilla, 1997).

5.2 Effect of spacing and manuring on yield and yield components

5.2.1 Yield of nuts per palm

The results given in table 3 showed that both spacing and manuring significantly influenced the per palm yield. The highest yield was obtained under wider spacings compared to the lowest spacing of 5.0 m x 5.0 m. There was no significant differences in the per palm yield of nut between wider spacing of 7.5 m x 7.5 m and 10.0 m x 10.0 m. The yield was 37.08 per cent higher in the spacing of 10.0 m x 10.0 m and 44.52 per cent higher in the spacing of 7.5 m x 7.5 m than in the closest spacing of 5.0 m x 5.0 m.

Annual yield of nuts in a coconut palm is the resultant effect of a number of yield factors or attributes. The main yield attributes in coconut are the number of inflorescence produced, number of female flowers per inflorescence and setting percentage which indicate the number of female flowers developed out of the number produced by the palm in a year.

A steady and significant increase in nut yield per palm is observed from the control plots to manured ones. The interaction between spacing and manuring was significant during 1995 in which fertilizer dose of 340 : 225 : 450 g N, P_2O_5 and K_2O per palm per year at 10.0 m x 10.0 m spacing recorded the highest per palm yield. The increase in yield due to wider spacing can be due to the efficient utilization of resources for production of nuts whereas in the case of closer spacing considerable energy might have lost in the production of a tall trunk as suggested by Menon and Pandalai (1958). The higher yield per palm under fertilizer application was significant upto M_1 dose is due to the beneficial effect of macronutrient application. The increase in yield is due to the combined effect of yield attributing characters. Results from the experiments conducted at RARS, Pilicode with different plant densities indicated similar trends. Muhammed *et al.* (1974) have recommended a spacing of 9.1 x 9.1 m where there was 70 per cent increase in per palm yield in plots with lowest density over plots with highest density. Significant difference existed in the mean yield per palm for change in both between and within row spacing and the number of nuts per palm decreased with increasing density (Manthriratna and Abeywardena, 1979). Similar results are reported by Louis *et al.* (1981), Tan Yap Pau and Chan (1985), Bopaiah (1989), De Taffin *et al.* (1992) and Fernando and Bandaranayake (1996). Similarly fertilizer application increases per palm yield as reported by Louis *et al.* (1981), Magat *et al.* (1981), Nelliat and Gopalasundaram (1984), Nallathambi *et al.* (1988), Magat and Padrones (1989) and Secretaria *et al.* (1994).

5.2.2. Yield of nuts per hectare

The results (Table 4) indicated that the per hectare yield was higher when the palm density was high, the lower per palm yield being compensated by the number of palms. The increase in yield per hectare under higher plant density is due to the significantly higher number of palms under such planting. Here eventhough the per palm yield at closer spacing was low total production per hectare out yielded due to total number of yielding palms in unit area. The results of the experiment indicated that for yield maximisation under good fertilizer management closer spacing can be useful. However it would be rational to assess the yield performance of palms per unit area under different spacing only after evaluating the total production from planting to total yielding period. Romney (1972) is of the view that in the development of more effective agricultural methods, planting density appears to be an important elements in higher yields per unit area. Maximum number of nuts per hectare was obtained from the closer spacing of palms due to large population (Kannan *et al.*, 1977). The findings of this experiment is in conformity with the findings of Louis *et al.* (1981), Tan Yap Pau and Chan (1985), Nair *et al.* (1988) and Fernando and Bandaranayake (1996). Fertilizer application increased the yield of nuts per hectare. This is in agreement with the findings of Muliyar and Nelliat (1971), Mendoza and Prudente (1972 b), Loganathan (1973), Magat *et al.* (1981), Jeganathan (1990) and Bopaiah (1993).

5.2.3. Production of female flowers

The results presented in Table 5 revealed that high plant density gave a less number of female flowers per year. The treatment with spacing 7.5 m x 7.5 m and 10.0 m x 10.0 m were on par which indicate that the optimum spacing for higher production of female flowers is 7.5 m x 7.5 m. The lower rate of production of female flowers at closer spacing may be due to the competition between palms for an advantageous position to trap adequate sunlight at the expense of yield attributing characters. Pamin *et al.* (1985) recorded that as the planting density increased, the number of female flowers decreased. Similar findings were also reported by Breure *et al.* (1990).

Fertilizer application significantly increased female flower production over control. Nitrogen fecilitates early flowering. The specific function of this nutrient is the production of more female flowers (Thampan, 1981). Reports of Salgado (1947) and Nelliat (1973) also have indicated that nitrogen exercises much influence on the formation of female flowers. It can therefore be assumed that the production of female flowers is directly related to the quantity and duration of availability of nitrogen and inversely to the deficiency of this nutrient. The maximum number of female flowers obtained in this experiment is 218.00 for 340 : 225 : 450 g N, P_2O_5 and K_2O per palm per year compared to 199.61 for double the dose of this fertilizer.

Phosphorus is also essential for the proper growth and development of palms and it increased the yield by increasing the female flower production. The response to phosphorus is often observed only after a number of years of continuous application . Potassium has also been reported to increase the production of female flowers (Nelliat, 1973). All these findings are corroborative to the findings of this experiment.

5.2.4 Number of bunches per year

Only fertilizer application had a significant influence on the number of bunches produced per year and there was no significant difference between the lower (M_1) and higher (M_2) doses. Nitrogen is of extreme importance in plants because it is a constituent of protein, nucleic acids and many other important substances. The deficiency of nitrogen invariably results in decline in fruit production. However abundant nitrogen often causes reduction in fruit (Bidwell, 1979). Phosphorus is essential to promote flowering and fruit setting (Menon and Pandalai, 1958). The positive effect of fertilizer application in increasing the bunch production has been reported by Kee (1970), Manciot *et al.* (1979 b) and Nunez (1993).

5.2.5 Setting percentage

Spacing had no significant effect on setting percentage. However manuring increased the setting percentage. Significant positive influence of fertilizer application in enhancing the setting percentage over control is similar to the findings of Salgado (1947), Smith (1969) and Louis *et al.* (1981).

5.2.6 Number of nuts per bunch

Both spacing and manuring had significantly increased the number of nuts per bunch. The increase in number of nuts per bunch is the manifestation of the higher female flower production and better setting percentage due to spacing and manuring as mentioned earlier. Similar results were also reported from spacing cum manurial trial conducted at Veppamkulam in Tamil Nadu (Thampan, 1975) and at Ivory Coast by Coomans (1974).

5.2.7 Weight and volume of unhusked nut

Though wider spacing and fertilizer application increased the weight of unhusked nut, it was significant only in the case of spacing where wider spacing gave higher weight of unhusked nut. The increase in weight of unhusked nut might be due to better utilization of plant nutrient resources for nut production by the palms since they have lesser wastage of energy for competition to harness solar energy. Only spacing was significant in the case of volume of unhusked nut. Both the wider spacings had unhusked nuts with higher volume. Whitehead and Smith (1968) reported that nut size decreased with increased plant density. The same trend has been reported from spacing cum manurial trial (Thampan, 1975). These findings are in agreement with the results of this investigation.

5.2.8 Ratio of weight of husked to unhusked nut, weight of husk and ratio of weight of husk to unhusked nut

The results (Table 7) revealed that only spacing had significant influence in the weight of husk and the ratios entitled above. The higher plant density had significantly high ratio of weight of husked nuts to unhusked nut compared to lower plant densities. It may be seen that per palm yield were lower at higher plant densities than at lower plant densities.

In the case of weight of husk, wider spacings produced nuts with higher husk weight. The higher ratio of weight of husked nut to unhusked nut at high density planting might have been attributed by a low husk weight in closer spacing of S_1 compared to wider spacings.

In the case of ratio of weight of husk to unhusked nut, the results are in the negative line, ie, the lower is recorded at higher plant density. This again is a manifestation of low husk weight at closer spacing.

5.2.9 Oil content of copra

The results presented (Table 9) indicates that both spacing and manuring as well as their interaction were statistically significant. The lower oil content at wider spaced palms might be due to their higher nut production per palm compared to that of closer spacing . Smith (1968) held the view that oil percentage tends to be lower in sites were higher yields of nuts are obtained. The present finding is in conformity to the above report. However, the general observations were that oil percentage was not affected by manuring (Smith, 1968 ; Muliyar and Nelliat, 1971 and Romney, 1972). Similar trends have also been reported in oil palm by Corley (1973).

5.3 Effect of spacing and manuring on soil nutrient status

5.3.1 Nitrogen

The results showed that spacing and manuring significantly affected the available nitrogen status of soil (Table 10). The lowest nitrogen content was noticed in 7.5 m x 7.5 m spacing followed by 10.0 m x 10.0 m spacing which showed that there was efficient utilization of the applied nitrogen for vegetative growth as well as for the production of nuts. Nitrogen improves the rate of leaf production, production of bunches, female flowers and yield of nuts (Nelliat and Gopalasundaram, 1984). The nut production per palm in wider spacings were high compared to the closer spacing of 5.0 m x 5.0 m. The closer spacing of 5.0 m (S_1) recorded the highest soil nitrogen status due to lesser utilisation of the plant nutrient from the soil, resulted in low nut production by the palms.

Application of fertilizers increased the nitrogen status of the soil. Nitrogen content increased in M_1 and M_2 level of manuring over that in unmanured plot. M_2 level of manuring had the highest N content. This indicated that at the highest dose of 680 g of N per palm per year the soil available nitrogen status is in medium range (250 to 500 kg N ha^{-1}). So at a dose of nitrogen lesser than this the soil become low in nitrogen status which might cause nitrogen stress in palms affecting its growth and yield. The increase in nitrogen content of soil due to the continuous application of NPK fertilizers as noticed in this experiment was reported by Khan *et al.* (1986) and Secretaria *et al.* (1994). The available nitrogen content of the soil decreased as the depth increased. This might be due to the fact that the fertilizers are applied in the surface layer. This is in conformity with the findings of Khan *et al.* (1996).

5.3.2 Phosphorus

The results given in Table 10 revealed that the available phosphorus content of soil decreased as the spacing became wider. The lowest value was observed in 10.0 m x 10.0 m spacing. Similar to nitrogen, application of NPK fertilizers especially rock phosphate increased the available phosphorus content of soil upto the highest level of application of 680 : 450 : 900 g N, P_2O_5 and K_2O per palm per year (M_2). The phosphorus content of soil increased from 4.981 ppm in the unmanured plots to 73.815 ppm in plots receiving M_2 level of manuring. The increase in phosphorus content due to fertilizer application was reported by Mollegaard (1971), Khan *et al.* (1983), Wahid (1984), Youan

(1984), Khan *et al.* (1996) and Anilkumar and Wahid (1989).

Depth wise analysis of the soil revealed that phosphorus is accumulated even at the deeper layer of 75 to 100 cm while the concentration decreases as the depth of sampling increases. At the surface layer of 0 to 25 cm the P content was 68.074 ppm which decreased to 10.815 ppm at the depth of 75 to 100 cm. This results were in agreement with the findings of Anilkumar and Wahid (1989), Khan *et al.* (1996) and Joseph and Wahid (1997). Since the fertilizers are applied on the surface layer the potassium concentration is high upto top 50 cm layer of soil. Soil build up of phosphorus fertilizers to coconut has been reported by several workers (Wahid, 1984 and Khan *et al.*, 1983). The results of the present study however revealed that prolonged application of rock phosphate can enhance the movement of phosphorus into deeper soil layers. Nevertheless the very low levels in the deeper layers was on account of the low mobility of phosphorus and suggests that placement of the nutrient will be more beneficial.

5.3.3 Potassium

Table 10 shows the available potassium content of soil. It could be seen from the table that the soil potassium content decreased as the spacing become wider. The highest soil potassium was recorded in the closest spacing of 5.0 m (S_1). The nut production per palm was better in the wider spacings which showed the higher utilisation of the available nutrients.

Fertilizer application increases the nutrient status of soil which shows the higher potassium content in the plots applied with the higher dose of fertilizers. The increase was from 40.042 ppm in the unfertilized plots to 61.444 ppm in plots applied with 340 : 225 : 450 g N, P_2O_5 and K_20 per palm per year and again to 72.431 ppm in plots applied with double the dose. Potassium predominates in the mineral export of coconut. Responses to potassium fertilizer are the most frequent. Production as well as nut characters were highly influenced by the availability of potassium as well as nitrogen. The increase in potassium content of soil due to fertilizer application was reported by Mollegaard (1971), Ramanandan and Pillai (1974), Khan *et al.* (1986), Anilkumar and Wahid (1989), Secretaria *et al.* (1994) and Khan *et al.* (1996). All these findings are in corroborative to the findings of this experiment.

The available potassium values were very high in the fertilizer treatments which varied from 72.269 ppm in the surface layer of 0 to 25 cm depth compared to 46.667 ppm in the deeper layer of 75 to 100 cm depth. Application of MOP resulted in a large increase in potassium reserve in soil to a depth of 100 cm (Joseph and Wahid, 1997 ; Anilkumar and Wahid, 1989 and Joseph *et al.*, 1994). Coconut being a heavy consumer of potassium, it is likely that the major portion of the nutrients absorbed by the palm is derived from the middle layers. This would explain the greater depletion of potassium from the middle layers of the soil. The higher content in the surface layer might be due to the surface application of fertilizers. The decrease in potassium content with increase in depth is in agreement with the findings of Khan *et al.* (1996).

5.3.4 Calcium and magnesium

Spacing as well as manuring had significant effect on available calcium and magnesium content of soil. Both calcium and magnesium content decreased from that in closer spacing of 5.0 m x 5.0 m to 7.5 m x 7.5 m ; but further increase in spacing to 10.0 m x 10.0 m noticed an increase in content of these nutrients. This might be due to the higher utilization of calcium by the palms planted at 7.5 m x 7.5 m spacing in which higher production of nuts were observed compared to that in closer spacing of 5.0 m (S_1).

Manuring influenced the available calcium content of soil . The highest calcium content of 55.536 ppm was noticed in the unmanured plots followed by the plots receiving 680 : 450 : 900 g N, P_2O_5 and K_2O per palm per year (M_2) and the lowest value of 29.271 ppm was in plots receiving half of this dose (M_1). The application of ammonium sulphate decreased calcium content of the root zone in coconut (Joseph and Wahid , 1997). This might be the reason for the decrease in calcium content with fertilizer application . Also there might be dilution of calcium content of soil due to plant absorption since no replenishment to the exhausted nutrient is done by calcium fertilizers. Calcium content was higher in the upper layer and gradual decrease was noticed as depth increases. This was in conformity with the findings of Ramanandan and Pillai (1974) and Joseph and Wahid (1997).

Magnesium content showed a gradual decrease from control plot to the plots receiving M_2 level of manuring. This might be due to the reason that applied ammonium sulphate might have resulted in decrease in content of this nutrient (Mollegaard, 1971), and also due to the higher absorption of magnesium by palms than that of control. Ramanandan and Pillai (1974) have reported similar results.

Depth wise analysis of magnesium content shows a decreasing trend upto 50 cm and thereafter a slight increase was noticed up to 100 cm depth. Similar results were also reported by Mathewkutty *et al.* (1994). Magnesium, one of the secondary nutrients required for the coconut palm and bulk of its active root is confined to within 60 cm depth (Anilkumar and Wahid, 1989) it might be that the major portion of the available magnesium is absorbed from this layer. This would explain the greater depletion of magnesium from the upper layers of soil than from the lower layers.

5.3.5 Micronutrients

The effect of spacing and long term NPK fertilizer application on the available iron, copper, manganese and zinc content of soil was found to be significant. All these micronutrients in soil decreases as the spacing become wider and the highest value was recorded in the closer spacing of 5.0 m (S_1). The efficient utilization of palms in the wider spacing for their vegetative growth and nut production could be the reason for this. Higher per palm production of nuts from the palms of wider spacing would further support this result.

Manuring increases the available iron content of the soil upto the highest level (M_2). The increase was from 16.433 ppm in control plots to 24.581 ppm in M_2 manured plots. This is in agreement with the findings of Khan *et al.* (1996). Iron content in both control as well as manured plots were higher than the critical value of 15 ppm suggested by Randhawa (1967). The iron content of soil decreases with increase in depth of sampling upto the deepest layer of 75 to 100 cm. Similar observation was also reported by Singh and Velayutham (1980).

Copper content of soil increases gradually with fertilizer application, with 0.297 ppm in control plots to 0.398 ppm in M_1 level manured plots and further decreased to 0.311 ppm in M_2 level manured plots. The zinc content of soil also showed a similar trend. The zinc content of soil in all the treatments were above the critical level of 1.5 ppm as suggested by Katyal and Ponnamperuma (1974). The decrease in zinc content at M_2 level of manuring than the M_1 level may be due to ammonium sulphate as reported by Joseph and Wahid (1997). In the depth wise analysis, copper content of soil decreased with increase in depth. Similar findings of higher copper content in surface soil than in subsurface layer was reported in Lakshadweep by Singh and Velayutham (1980).

Manganese content of soil decreased from control to plots receiving M_1 level of manuring and further increased when manuring was given at M_2 level. The manganese content of the soil was much higher than the critical value of 5 ppm (Toth, 1951) in all the treatments. The decrease in manganese content due to increasing rate of ammonium sulphate application was reported by Anilkumar and Wahid (1989). The available manganese content decreases from surface soil to the subsurface soil upto 100 cm depth. Similar findings were reported by Singh and Velayutham (1980).

5.6 Effect of spacing and manuring on leaf nutrient status

5.6.1 Nitrogen

The results shown in table 14 revealed that spacing and manuring had significant effect on leaf nitrogen content. Nitrogen content increased from 1.823 per cent in the closer spacing of 5.0 m x 5.0 m to 1.884 per cent in the wider spacing of 7.5 m x7.5 m and further to 1.902 per cent in the wider spacing of 10.0 m x 10.0 m.

The fertilizer application had significantly increased leaf nitrogen level from 1.675 per cent in the unfertilized palms to 2.027 per cent in palms receiving the highest dose (M_2) of fertilizers. Nitrogen is indispensable as a constituent of amino acids, proteins and nucleic acids. A shortage in nitrogen affects the physiological activities and resulting in a drop in yield. With the application of 680 g of N per palm per year the leaf nitrogen level (2.027 per cent) was higher than the critical level of 1.80 to 2.00 per cent suggested by IRHO (Fremond *et al.* 1966), however in the unfertilized palms it was less (1.675 per cent) than the critical level. Below this value the nitrogen nutrition is not assured which leads to anomalies manifested by deficiency symptoms. In the first stage there is slight and continuous yellowing of all the foliage, the tree no longer has the green colour characteristics of good nutrient balance. The nitrogen content of the leaves of the cultivated and manured palms were significantly higher than those of uncultivated and unmanured palms as observed by Ramanandan and Pillai (1974). A positive influence of leaf nitrogen level of coconut by the application of fertilizer was reported at Sri Lanka by Loganathan and Balakrishnamurti (1979) and at North Sumatra by

Rosenquist (1980). Also the results of many workers (Magat, 1979 ; Oguis *et al.*, 1979 ; Magat *et al.*, 1981 ; Anilkumar and Wahid, 1989 ; Magat *et al.*, 1994 and Secretaria and Maravilla, 1997) support the findings of this experiment.

5.6.2 Phosphorus

Spacing as well as manuring significantly influenced the phosphorus content of the 14th leaf of coconut (Table 14). Phosphorus content of leaves increased as the palm density decreased with the highest phosphorus content in the widest spacing of 10.0 m (S_3). Palms in the plots fertilized with 680 : 450 : 900 g N, P_2O_5 and K_2O per palm per year registered a higher level of phosphorus (0.147 per cent) than the unfertilized palms (0.122 per cent). These values both in the fertilized and control palms are above the critical level of 0.12 per cent proposed by IRHO indicating that the palms in this experiment do not suffer due to the deficiency of this nutrient. Nevertheless in view of appreciably high level of phosphorus, it appears that application of phosphorus at M_1 level (225 g per palm per year) would suffice. When fertilizer application to coconut palms was discontinued Khan *et al.* (1983) and Wahid *et al.* (1975) observed that leaf phosphorus level did not fall below the critical level which indicated that skipping of phosphorus fertilizers in certain years might not adversely affect the nutrition when sufficient build up of phosphorus had been attained. Phosphorus uptake is small, 1 / 10 of the uptake of potassium (Khan *et al.*, 1985) however phosphorus is important because it enters into the regeneration of ATP and in the constitution of the phosphoro proteins. It is usually abundant in the young organs. Phosphorus deficiency is rare in coconut, the deficiency results in slowing down of the growth and shortening of the fronds. But Kamaladevi *et al.* (1976) , Khan *et al.* (1986) , Anilkumar and Wahid (1989) and Ballad (1991) did not observe any increase in leaf phosphorus content due to graded dose of fertilizer application. However Rosenquist (1980) noted an increase in leaf phosphorus content at North Sumatra due to the application of rock phosphate. The increase in leaf phosphorus content due to fertilizer application was also reported by Manciot *et al.* (1979 a) and Youan (1985) which are in conformity with these findings.

5.6.3 Potassium

Potassium content of the 14^{th} leaf of coconut was significantly influenced by spacing and manuring (Table 14). The results indicated that there was a significant decrease in potassium content from the closest spacing of 5.0 m (S_1) to the widest spacing of 10.0 m (S_3).

Manuring increased the leaf potassium content from 0.543 per cent in the unmanured plots (M_0) to 1.159 per cent and 1.335 per cent in the plots receiving 340 : 225 : 450 g N, P_2O_5 and K_2O per palm per year and it's double dose respectively. The leaf potassium content in the unmanured plots were much below the critical level of 0.80 to 1.00 per cent suggested by IRHO whereas in the manured plots with both M_1 and M_2 level of manuring it was above the critical level . Coconut is a heavy consumer of potash. Potassium is reported to have considerable physiological importance. It is involved in plant metabolism, in accelerating the movements of the stomata, in activating the enzymes in the transport of metabolites and in cell division. The causes for the deficiency are linked mainly to the soils, which rarely possess largest quantities of potassium required by the coconut.

At all the three levels of spacing, potassium level was influenced by manuring. At a planting density of 400 palms per hectare (5.0 m x 5.0 m spacing) with fertilization the potassium level increased from 0.554 per cent in the unmanured plots (M_0) to 1.482 per cent in M_1 plots and 1.718 per cent in M_2 plots. At the lower plant density of 178 (S_2) and 100 (S_3) palms per hectare, the rate of leaf potassium increase was less while yield per palm were higher than in S_1 plots. This is probably due to dilution effect as the growth rates and yield were higher in S_2 and S_3 plots than in S_1. It also indicate that the potassium dosage of 900g per palm per year at M_2 level was not significant when the palms gave higher yields. This shows the high requirement of potash by coconut palms. Application of MOP increased the leaf potassium content (Anon, 1980 b; Loganathan and Balakrishnamurti, 1979 and Rosenquist, 1980). The findings of Anilmumar and Wahid (1989), Magat and Padrones (1989), Secretaria *et al.* (1994), Khan *et al.* (1996) and Rodrigues *et al.* (1997) are in corroborative to the findings of this investigations in which the leaf potassium content increases with fertilizer application.

5.6.4 Calcium

The results (Table 14) showed that spacing and manuring had significant effect on leaf calcium content. The highest calcium content of 0.170 per cent was recorded in 7.5 m x 7.5 m spacing and further increase or decrease in plant density decreased the leaf calcium content.

Manuring significantly increased the leaf calcium content upto highest dose of 680 : 450 : 900 g N, P_2O_5 and K_2O per palm per year (M_2). The increase was from 0.142 per cent in unmanured palms to 0.177 per cent in the palms receiving M_2 level of manuring. In all the treatments the leaf calcium content was much below the critical value (0.50 per cent) of IRHO. Non-application of calcium fertilizers in this experiment could be one of the reason for this low calcium content. Also it was reported that MOP application decreased the leaf calcium content in coconut (Loganathan and Balakrihsnamurti, 1979 ; Manciot *et al.*, 1979 (b) and Anon. (1980 b). The gradual increase in calcium content from the unmanured palms to the palms receiving M_2 level of manuring might be due to the application of nitrogenous and phosphoric fertilizers. This is in agreement with the reports of (Loganathan and Balakrihsnamurti, 1979 ; Manciot *et al.*, 1979 (b) and Magat *et al.*, 1994). However calcium content did not seem to play a major role in nut production (Fremond, 1964 ; Indirakutty and Pandalai, 1968 ; Barrant, 1977 and Mohanachandran, 1990).

5.6.5 Magnesium

Table 14 revealed that spacing and manuring had significant effect on leaf magnesium content. The higher leaf magnesium content was recorded in the wider spacings of 7.5 m x 7.5 m (S_2) and 10.0 m x 10.0 m (S_3). Magnesium is an important nutrient in coconut nutrition. It enters in to the physiology of the plant as a constituent of chlorophyll. The deficiency of this element may cause yellowing of leaf lets. Further absorption may lead to regreening of the foliage, an increase in the leaf levels and significant action on growth and production when the potassium shortage has been made up (Manciot *et al.*, 1979 b).

A significant inverse relationship between the leaf magnesium content and the levels of manuring was observed. The content of leaves decreased from 0.266 per cent in the unfertilized plot to 0.253 and 0.243 per cent in the plots receiving M_1 and M_2 level of manuring respectively. In all the treatments the levels of magnesium are higher than the critical level suggested by IRHO. It was in 1955 that IRHO proved that there was a general relationship between potassium and magnesium, and the application of high KCl rates could induce a severe magnesium deficiency. Several studies on potassium had shown antagonism between potassium and magnesium (Wahid *et al.*, 1974 ; Khan *et al.*, 1986 and Khan *et al.*, 1996), and the application of potassic fertilizer may lead to decrease in leaf magnesium content (Fremond *et al.*, 1966 ; Coomans, 1977 ; Loganathan and Balkrishnamurti, 1979 ; Anon., 1980 b and Anilkumar and Wahid, 1989). The findings of this experiment is in agreement with the above reports.

5.6.6 Micronutrients

Manuring alone had significant effect on iron, copper, manganese and zinc content of leaf whereas both spacing and manuring had significant effect on leaf sodium content. Iron, copper and manganese content of leaves increased with increase in the dose of manuring from the control plots to the plots receiving M_2 level of manuring, whereas zinc and sodium content decreased with increase in the level of manuring. Micronutrients are important for the maintenance of yield and produce good quality produce. The use of HYV and continued application of NPK fertilizers have aggravated the micronutrient problems (Kamaladevi *et al.*, 1975). Application of ammonium sulphate increased the leaf copper level in 14^{th} leaf of coconut (Eschbach and Manciot, 1981). Also application of ammonium sulphate, rock phosphate and MOP increased the leaf manganese content of coconut at North Sumatra. These findings were in conformity with the results of this investigation.

Application of ammonium sulphate decreased total zinc content of the coconut root zone (Joseph and Wahid, 1997) which might have resulted in the low uptake of zinc by the palms. This might be the reason for decreasing zinc content with increasing dose of manuring. Sodium content of leaf did not have much correlation with yield of coconut (Ollagnier and Ochs, 1971 ; Pushpangadan, 1985 and Mohanachandran, 1990). Moreover sodium seemed to be important only when potassium became limiting.

SUMMARY AND CONCULSION

6. SUMMARY AND CONCLUSION

A study on nutrient status of soil and plant as influenced by spacing and continued manuring was conducted utilizing the on going experiment in West Coast Tall coconut palms initiated in 1964 at the Coconut Research Station, Balaramapuram of Kerala Agricultural University. The treatments of the field experiment consisted of three spacings (5.0 m x 5.0 m, 7.5 m x 7.5 m and 10.0 m x 10.0 m on square system) and three levels of NPK fertilizers i.e., control (no fertilizers), the lower level (340 g N + 225 g P_2O_5 + 450 g K_2O per palm per year) and the higher level (680 g N + 450 g P_2O_5 + 900 g K_2O per palm per year). The brief summary of the results are furnished below.

Planting coconut palms at closer spacing as well as application of fertilizers increased the height of palm. Though the girth of palms below the crown and at 1.5 m above the ground level were not influenced by spacing, palms at wider spacings produced larger trunks and application of fertilizer increased the girth, however no significant difference was observed between the higher and lower doses of NPK.

Spacing as well as manuring had significant effect on production of leaves. Wider the spacing, greater was the leaf production. Manuring progressively produced more number of leaves than the unmanured plots. Nevertheless, the spacing and manuring did not show any significant interaction on growth characters viz. height of palm, girth and leaf production.

The per palm yields were practically very low when palms were not fertilized. When fertilizers were applied at the lower level, the per palm yields were much higher than the control however, further increase of NPK did not give significant yield increase. Yield per palm increased significantly by wider planting however, both the wider spacings were on par.

Higher palm density gave the highest yield per hectare and also higher dose of manuring progressively increased the yield upto the highest dose of NPK. Spacing and manuring interaction had significantly influenced the per hectare yield with 680 : 450: 900 g N, P_2O_5 and K_2O per palm per year at the closer spacing of 5.0 m x 5.0 m gave the highest yield.

Female flower production was higher in 7.5 m x 7.5 m spacing and further increase or decrease in spacing decreased the production. Manuring increased the female flower production upto 340 : 225 : 450 g N, P_2O_5 and K_2O per palm per year. This lower dose of fertilizer at 10.0m x 10.0 m spacing produced the highest number of females flowers. Spacing did not have any significant effect on the production of bunches however a decline in production was noticed as spacing became wider. But incremental dose of NPK upto the highest level increased the production of bunches.

Fruit setting was not influenced by palm density, but fertilization significantly increased fruit setting upto the highest dose over unmanured palms. Number of nuts per bunch was higher in the wider spacing of 7.5 m x 7.5 m and manuring progressively increased the production of nuts per bunch. But there was no significant difference between the higher and lower doses.

The weight and volume of unhusked nut was lower at 5.0 m x 5.0 m spacing than higher spacings, eventhough the yields were also low at the lower spacing. Manuring did not have significant effect on weight and volume of unhusked nut nevertheless at the highest dose of 680 : 450 : 900 g N, P_2O_5 and K_2O per palm per year, it was found to be lesser than that at the lower dose. Palm density and doses of NPK did not influence the weight and volume of husked nut. A lower ratio for weight of husked nut to unhusked nut was observed at the widest spacing of 10.0 m x 10.0 m, while manuring had no significant effect on this ratio.

A progressive increase in the weight of husk was observed due to increase in spacing, but manuring had no effect on this. An increase in ratio of weight of husk to unhusked nut was noticed with increase in spacing with no significant difference between the wider spacings. The spacing and manuring interaction did not change the ratios or the husk weight significantly.

Palm density and manuring level did not affect the split nut weight however 7.5 m x 7.5 m spacing gave split nut with maximum weight and also at lower level of NPK, the weight of split nut was more. Shell weight and thickness was not influenced by spacing and fertilizer levels. Nevertheless 7.5 m x 7.5 m spacing and the palms in plots applied with 340 g N + 225 g P_2O_5 + 450 g K_2O produced the nuts with maximum weight and thickness of shell. Similar to shell, maximum thickness and weight of kernel was recorded in the plant density of 178 palms per hectare and in plots receiving the lower dose of fertilizers.

Copra out turn per nut was more at densities of 178 and 100 palms per hectare and also in manured palms where yield of nuts were also higher and hence copra out turn per hectare was also high at these densities. The oil content of copra was negatively correlated with per palm yield. Maximum oil content was observed in palms planted at the closer spacing of 5.0 m x 5.0 m and decrease at wider spacings. Fertilizer dose of 340 : 225 : 450 g N, P_2O_5 and K_2O gave the maximum oil content. Oil content was significantly influenced by spacing and manuring interaction with the lower dose of NPK and widest spacing of 10.0 m x 10.0 m produced copra with highest oil percentage.

Available N, P and K content of soil decreases as spacing becomes wider. In case of P and K a gradual decrease was noticed with increase in spacing from 5.0 m x 5.0 m to 10.0 m x 10.0 m but not in case of N where the least content was observed in 7.5 m x 7.5 m spacing. The least content at wider spacings shows the better uptake by the plant from the soil.

All the three major nutrients (N, P and K) in the soil increased from the control plots to the plots receiving the highest dose of fertilizers. A heavy build up of N, P and K was recorded in the surface 0 to 25 cm layer of soil and was found to be maximum in plots receiving the highest level of fertilization. A gradual decrease in N, P and K content was recorded with increase in depth of sampling.

Available Ca and Mg content of soil decreased from the closest spacing of 5.0 m x 5.0 m to the wider spacing of 7.5 m x 7.5 m and further increase was noticed as the spacing become wider to 10.0 m x 10.0 m. Lower level of both of these nutrient are noticed in the spacing 7.5 m x 7.5m.

Both Ca and Mg content of soil decreases with increase in fertilization. In Mg a gradual decrease was noticed from the unmanured plots to plots receiving the higher dose of 680 g N + 450 g P_2O_5 + 900 g K_2O per palm per year. But Ca content decreased from control plots to the plots receiving lower dose of fertilizer and further a slight increase was noticed when fertilizer was given at the highest dose which was much lower than the Ca content of control plots. In depth wise analysis the Ca content decreases with increase in depth whereas the Mg content decreases up to 50 cm depth and slightly increases with further increase in depth.

Available micronutrient (Fe, Cu, Mn and Zn) content of soil decreases with increase in spacing, and with wider spacing the lower values were recorded. Fe, Cu and Zn content of soil increases from the unmanured plots to the plots receiving the lower and higher level of manuring. However in case of Mn the concentration in soil decreases from the control plots to the fertilizer applied plots.

Available Fe, Cu and Mn content of soil decreases with increase in depth of sampling with the lowest value in 75 to 100 cm depth. Nevertheless in case of zinc a gradual increase in soil content was recorded from the surface layer to the deeper layer of 50 to 75 cm.

N and P content of the 14^{th} leaf of coconut increases as spacing becomes wider while K content decreases from closer spacing of 5.0 m x 5.0 m to the wider spacings. All the three major nutrients (N, P and K) increases with increase in the dose of manuring and the highest value was observed in palms receiving 680 g N + 450 g P_2O_5 + 900 g K_2O per palm per year.

Ca and Mg content of leaf increased from the closest spacing of 5.0 m x 5.0 m to the wider spacing of 7.5 m x 7.5 m and thereafter a marginal decrease was observed in the widest spacing of 10.0 m x 10.0 m. Ca content progressively increases with increase in dose of manuring while a reverse relationship was observed between leaf Mg content and dose of fertilizer.

The micronutrient Cu, Mn, Zn and Na content of leaf is higher in the wider spacings than the closest spacing of 5.0 m x 5.0 m. However the Fe content of leaf decreased as spacing became wider. By applying fertilizers Fe, Cu and Mn content of leaf increases gradually up to the highest dose of 680 : 450 : 900 g N, P_2O_5 and K_2O per palm per year, whereas Zn and Na content showed a negative trend with higher dose of fertilizers.

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* Originals not seen

NUTRIENT STATUS OF THE SOIL AND PLANT AS INFLUENCED BY SPACING AND CONTINUED MANURING IN COCONUT *(Cocos nucifera L.)*

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ABSTRACT OF THE THESIS
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ABSTRACT

A study was conducted during 1995-96 at Coconut Research Station, Balaramapuram of Kerala Agricultural University to asses the nutrient status of the soil and plant in West Coast Tall coconuts planted at three different spacings and manured with three levels of macro nutrients. The treatments were three spacings (5 m x 5 m, 7.5 m x 7.5 m and 10 m x 10 m) and three fertilizer levels (control i.e., zero NPK, the lower level i.e., 340 g N + 225 g P_2O_5 + 450 g K_2O per palm per year and the higher level i.e., 680 g N + 450 g P_2O_5 + 900 g K_2O per palm per year). The basic experiment was started in 1964 and being continued. The data collected during the study (1995-96) was statistically analysed and the results are presented here under.

Closer spacing increased height of palms. The spacings of 7.5 m x 7.5 m was statistically superior since it gave the highest nut yield per palm per year. Manuring increased height of palms, girth and leaf production. At the highest level of NPK closer spacing of 5 m x 5 m could give the highest yield per unit area. Female flower production was higher under 7.5 m x 7.5 m spacing. Fertilizer application also increased flower production. Fruit setting was not influenced by palm density and fertilizer application significantly increased fruit setting.

Number of nuts per bunch was higher at the spacing of 7.5 m x 7.5 m and progressively increased with manuring. The weight and volume of unhusked nut was the lowest at the closest spacing and in unfertilized palms.

There was increase in weight of husk with increase in spacing. Similarly there was an increase in the ratio of weight of husk to unhusked nut with increasing spacing. Maximum thickness and weight of kernal was recorded at the spacing of 7.5 m x 7.5 m. Copra out turn was more at the spacing of 7.5 m x 7.5 m. In manured palms there was a higher copra out turn per hectare contributed by the higher yield. The oil content of copra was negatively correlated with per palm yield.

Available NPK of soil decrease with wider spacing. The soil nutrient status increased with application of macronutrients and the accumulation of fertilizer was more in the upper layer of 0 to 25 cm. There was decline in NPK status with increase in depth. The Ca and Mg content of soil decreased with increase in spacing up to 7.5 m x 7.5 m. Both Ca and Mg content of soil decreased with increase in macro nutrient application. Ca content of soil decreased with increase in depth. However, the decrease of Mg content was seen only up to 50 cm depth. Available micro nutrients (Fe, Cu, Mn and Zn) decreased with increase in spacing and application of fertilizers. Available Fe, Cu and Mn content of soil decreased with increase in depth.

N and P content of leaf of coconut increased with wider spacing. However K content decreased with spacing. All the three macro nutrients increased with increase in fertilizer application. Ca and Mg content of leaf also increased with increase in spacing and fertilizer application. By fertilizer application Fe, Mn and Cu content of leaf increased whereas Zn and Na decreased.