ABSORPTION AND TRANSLOCATION OF ^{32}P BY ROOT (WILT) AFFECTED COCONUT PALMS

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(2014-11-126)

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KERALA, INDIA

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THESIS

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Kerala Agricultural University, Thrissur

Department of Soil Science and Agricultural Chemistry

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR - 680 656

KERALA, INDIA

2016

DECLARATION

I hereby declare that the thesis entitled “Absorption and translocation of ^{32}p by root (wilt) affected coconut palms” is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title, of any other university or society.

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Date: 29.07.2016 (2014-11-126)

CERTIFICATE

Certified that the thesis entitled **"Absorption and translocation of ^{32}p by root (wilt) affected coconut palms"** is a record of research work done independently by **Miss. Beena S. George** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

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(1 Corinthians 15:10)

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Introduction

1. INTRODUCTION

Coconut (*Cocos nucifera Linn*.) is one of the most important tropical palms of India. For the past 3000 years it is the main traditional plantation crop especially along the coasts of India. It is closely related to the social, cultural and economic life of a vast multitude of small and marginal coconut growers. It is commonly known as 'Kalpavriksha' the "tree of heaven", because the tree provides all the necessities of life. Each and every part of the tree is used for some or other purpose.

Globally India ranks first in both production and productivity and third in area under cultivation. It is grown in an area of 1.98 million hectares. The annual production is 20439. 60 million nuts and productivity is 10345 nuts/ha. In India, Kerala ranks first in area (0.65 million hectares) and production (4896.61 million nuts) followed by Tamil Nadu, Karnataka and Andra Pradesh. The coconut productivity of Kerala is 7535 nuts/ha (CDB, 2016).

The production of coconut is affected by a number of factors, among which pest and disease plays a significant role. Some of them are lethal and others are debilitative in nature leading to severe economic loss. Root (wilt) is one of the major diseases affecting coconut production both in India and Kerala. The annual crop loss by the disease in Kerala was reported to be about 968 million nuts. The total monetary loss calculated was about 3000 million in terms of loss of husk, copra, leaf number and quality, according to 1984 price index for coconut (Anon, 1985).

Over the past few decades, lot of research works have been done on different aspects of the root (wilt) disease. Etiology of the disease has been examined from several angles such as, virological, bacteriological, fungal, nematological and nutritional aspects. Though the disease first appeared in Kerala in 1882 (Butler, 1908), the etiology of the disease remain elusive for nearly a century. The systematic investigation since 1980 proved the phytoplasmal etiology of the disease. There is no effective control measures for the disease and improving the general health of the diseased palm through better crop management focusing nutritional aspect is the only suggested measures for sustaining the productivity of disease affected palms. The response of diseased palms to the application of nutrients is very less compared to healthy palms. Many researchers found out nutrition imbalance in association with root (wilt) and it remains so even if integrated nutrient management practices are applied to diseased palms. This results call for detailed investigation of the geochemical difference between disease affected and disease free tract for identification of the soil chemical factors associated with the incidence of the disease. The study reported here mainly examines the nutritional aspects of soil and leaf of coconut palms in relation to root (wilt) disease.

Considering the economic importance of root (wilt) disease to Kerala state in general and to the coconut cultivation in particular, it is important to identify a suitable control measure for the disease and/increase the effectiveness of the existing measures recommended for the management of the disease. Keeping in view the fact that coconut is not a crop of a few farmers but that of every landholder in Kerala, the attention that is to be given to remedy for the disease requires very special consideration.

The present study was proposed to find out the nutritional imbalance if any in root (wilt) affected palms. The disease can be tackled by the identification and correction of this nutritional imbalance. Also a thorough understanding about the absorption and translocation pattern of root (wilt) affected palms is needed in order to find out any hindrance in absorption and translocation, so that suitable technologies can be developed in future to overcome this malady. If it proves to be successful, the widespread disease can be controlled, managed, and the efficiency of existing recommendation for the disease control can be enhanced, which could have a dramatic impact on economy of Kerala.

The present study was under taken with the following objectives

1. To identify nutritional imbalance if any in root (wilt) affected palms in comparison to healthy palms.

2. To unravel the absorption and translocation pattern of nutrients in root (wilt) affected palms compared to healthy palms.

Review of literature

2. REVIEW OF LITERATURE

Literature relevant to root (wilt) disease- origin, distribution, production loss, soil and crop nutrition, physiological imbalance, method of radioisotope application, absorption, translocation and root activity pattern is reviewed in this chapter.

2.1 Root (wilt) disease - origin, distribution and production loss

Coconut root (wilt) disease was first reported from Erattupetta region of Menachil taluk in Kottayam district of Kerala state in 1882 (Butler, 1908; Pillai, 1911; Menon and Pandalai, 1958). The disease was also noticed around 1907 from Kalloopara and Kaviyoor region of Tiruvalla Taluk and later from Kayamkulam areas of Karthikappally Taluk. Several studies were also performed to find out the disease spread and disease intensity (Menon and Nair, 1952; Verghese, 1959; PiIlai *et aI.*, 1973; George *et al.*, 1979).

A detailed survey carried out by the CPCRI (Central Plantation Crop Research Institute), Kasargod in association with the Department of Agriculture, Kerala and other agencies showed that out of the fourteen districts of Kerala the disease was prevalent contiguously in eight southern districts (4,10,000 ha). The disease intensity was highest in Kottayam district (75.6 %) followed by Alappuzha (70.7 %), both in bearing and non-bearing palms. The disease incidence was reported to be 2.6 per cent in Thrissur and 1.5 per cent in Thiruvananthapuram (Anon, 1985). The incidence was also reported from Malappuram, Palakkad, Kozhikode, Kasargod, Kannur, and neighbouring areas of Tamil Nadu such as Coimbatore, Shenkotta, Cumbam, Kulasekharam and Pollachi.

The survey also pointed out that the disease leads to an annual loss of 968 million nuts in Kerala. Husk loss per nut was 25.8 per cent, copra loss per nut was 9.08 per cent and oil loss per nut was 11.3 per cent. Sixty per cent of the foliage was damaged by the disease. Mathew *et al.* (1993) reported that the disease resulted 45 per cent yield decline in West Coast Tall and 60 per cent in DxT hybrids. Disease also caused delayed bearing in seedlings.

3.2 Soil and crop nutrition in root (wilt) affected palms

Many workers investigated the association of root (wilt) disease with various soil conditions and nutritional factors including major and minor nutrient element.

The coconut root (wilt) disease has been reported from all soil types in Kerala under different ecological conditions varying from Western Ghats to the coastal plains (Pillai *et al*., 1973). During 1939 investigations about nutritional factors and soil conditions were initiated. Menon and Nair (1949) and Menon *et al*., 1950 reported that nutritional deficiencies might be associated with the incidence of root (wilt) disease. They reported the deficiency of major nutrients particularly K and a lower level of exchangeable cations, low pH and cation exchange capacity in soils of disease affected areas. The incidence of disease is mainly due to soil sickness characterised by low pH, insufficient activity and imbalance of nutrients along with deficiencies of nutrients particularly those of K, Ca and Mg (Menon *et al*., 1950, 1952; Pandalai *et al*., 1958a, 1958b; Menon, 1961; Verghese, 1961; Lal, 1964, 1968). A study conducted by Sankarasubramoney *et al.* 1954, 1955, 1956 and Pandalai *et al.* 1958a, 1958b, 1959a, 1959b representing healthy and diseased pockets of the major soil groups of erstwhile Travancore Cochin state showed lower level of available K, exchangeable Ca and Mg, total Ca and Fe, total exchangeable cations, CEC, percentage base saturation and pH in disease affected soils.

Menon *et al.* (1950) reported that the root (wilt) disease shows the same symptoms irrespective of locality and soil types. Compared with healthy areas, soil around diseased trees showed a very low level of fertility. Periodic water logging and the possibility of deficiencies of trace elements may be some contributory factors in many diseased areas. Pillai and Pushpadas (1965) reported that coconut growing in peat soil (Kari tract) having high acidity, pH in the range of 3-4, had less incidence of the disease. Verghese (1966) indicated faulty nutrient status in soils with disease incidence particularly K/Mg, K/Ca and N/K.

Menon and Nair (1952) first conducted fertilizer field trial at Kayamkulam and found that N and K were the most limiting factor in root (wilt) affected areas. John and Jacob (1959) observed that application of NPK fertilizer along with insecticides and fungicides markedly increased the yield of root (wilt) affected areas of West Coast Tall. Nair and Radha (1959) and Lal (1964) observed the enhancement in yield and decrease in foliar yellowing as a result of application of farm yard manure, NPK, lime, magnesium, micronutrients and Bordeaux mixture. Several fertilizer field studies with different levels of primary and secondary nutrients have shown that Ca and Mg application leads to a general improvement in coconut yield but it neither prevent fresh incidence and nor control the disease (Chettiar *et al*., 1959; John *et al*., 1959).

Sahasranaman *et al.* (1964) reported that higher dose of NPK fertilizer application than optimum dosage aggravated the disease and decreased the yield of diseased palms, while lower doses helped to maintain economic yield. Davis and Pillai (1966) conducted a fertilizer field trial with 128 combinations of Mg, B, Cu, Mn, Fe, Mo and Zn to examine the effect of micronutrients on coconut root (wilt) disease. Yield was taken as improvement criteria. He tabulated the pre treatment and post treatment yield of severely affected, mildly affected and healthy palms. It was observed that no treatment combination prevented fresh incidence of disease, but Mg improved yield in all categories, Cu increased yield both in healthy and severely diseased palms, Fe increased yields only in healthy palms, Mn improved yield in all categories, especially in mildly affected palms and Mo increased yield in diseased palms. He also reported that the amounts of B, Cu, Mn and Zn in foliage of diseased palms were significantly higher than leaf tissues of healthy palms.

Cecil (1969) reported that continued application of three doses of N (higher dose-1.362 kg N), P (higher dose-0.908 kg P_2O_5) and K (higher dose-2.724 kg K_2O) in factorial combination was not effective in preventing the fresh incidence of disease on young healthy palms and also curing the disease. The experiment with three doses of NPK and two doses of Ca and Mg on root (wilt) affected palms revealed that NPK @ 350-500-600g and MgO @ 500 g per palm per year could be the economic doses for root (wilt) management (Anon, 1981).

The major nutrient status of coconut foliage in relation to the disease was first examined by Menon and Nair (1952). Subsequent trials conducted by Sankarasubramoney *et al*., 1952; Verghese *et al*., 1959; Pillai, 1959; Pandalai, 1959 revealed that primary nutrients were accumulated in the foliage of diseased palms and accumulation increased with the enhancement of the disease. Verghese *et al.*, 1959 reported that foliage of diseased palms contain more N, P, K and silica in the range of 5 to 13, 0 to 13, 5 to 39 and 59 to 134 per cent respectively. Cecil (1969) observed that the accumulation of the nutrients was only apparent, probably due to the low dry matter production in foliage as a result of disease incidence.

Varkey *et al.* (1969) determined various fractions of N and P at three different stages of the disease from foliage of healthy and diseased palms and reported an abnormal N and P metabolism in foliage of root (wilt) affected palms. The arginine content (non-protein N) and organic P were significantly higher in diseased palms especially in the middle stages of the disease but water-soluble and protein-N fractions were decreased. Total carbohydrate in the middle and advanced stages was sharply decreased.

Cecil (1975) studied the mineral composition of coconut leaves in relation to root (wilt) disease and he concluded that Ca and Mg content of healthy palms were significantly higher than that of apparently and diseased palms. Major nutrient content did not differ. He concluded that the root (wilt) affected palms are in the state of unbalanced nutrition with wider ratios of N/Mg, P/Mg, K/Mg and Ca/Mg representing a lower level of Mg compared to other nutrients.

PilIai *et al.* (1975) carried out nutritional survey throughout Kerala and estimated major and micro nutrient status of soils from healthy and diseased areas. He ruled out the involvement of major nutrients in the incidence of root (wilt) based on an elaborate study on soil and tissue samples from both healthy and diseased tract of major coconut growing area. He observed that soils of diseased area have lower level of Zn and Mn, while B, Mn, Fe, Mo, Zn were comparatively higher in foliage of healthy palms. Varkey *et al*. (1979) reported that basal application of $MgSO_4$ and foliar spraying of 2 per cent $MgSO_4$ and 1 per cent $FeSO_4$ reduced foliar yellowing in root (wilt) affected coconut palms by 26 per cent and healthy palms by 87 per cent. Yield was increased by 106 per cent in diseased palms and 95 per cent in healthy palms. Cecil (1981) studied the effect of Mg for the management of diseased palms and concluded that Mg addition leads to reduction in pre bearing age by 9 months and the response of Mg was more for diseased palms.

Pillai et al. (1980) reported that disease spread was faster in light sandy loam, clayey soil and alluvial soil than in the laterites. The disease intensity was more in low lying water logged areas.

A comparative study on the performance of WCT (Cecil, 1981) and CODxWCT (Amma *et al.*, 1982) under rain fed conditions and regular fertilisation with N, P, K Ca and Mg since field planting showed that the hybrid was superior to WCT with respect to disease resistance and nut yield.

Wahid *et al*. (1983) determined the non nutrient elemental composition of soil, leaf and root samples of diseased and healthy coconut palms from certain selected locations using energy dispersive X-ray fluorescence method. In soil samples non-nutrient trace elements were detected. Titanium content was higher in sandy soil of Kayamkulam.

Laterite soils of Pilicode have lesser strontium content than similar soils in the diseased area. Strontium content of root of diseased palms was relatively higher and that of foliage is lower than healthy palms indicate that the translocation of strontium is hindered in diseased palms. The nickel content was higher in roots of diseased palms.

A study by Biddappa and Cecil (1984) and Biddappa (1985) on heavy metals deposition in root (wilt) affected palms revealed that higher accumulation of AI, Mn, Cu, and Co in the roots and Cr, Ti, Pb, Bl and Ga in the cabbage tissues of diseased palms. Biddappa and Khan (1985) investigated the status of heavy metal in coconut growing soils of Kerala and concluded that disease affected soils have higher content of diethylene triamine-penta acetic acid extractable Ba, Cr, Cd, Pb and Sr compared to healthy soils.

Khan *et al*. (1985) did not observe any relationship between the micronutrient composition of diseased palms and the disease index compared to healthy palms. Zinc and Mo both as soil application and foliar spray had no effect on incidence or intensity of the disease (Mathew *et al.*, 1986). A systematic micronutrient manurial experiment consisting of all combinations of two levels of each of Fe, Mn, Cu, Zn, B and Mo since field planting had shown that the disease was not related to micronutrient nutrition of the palm (Anon, 1986).

Valiathan *et al.* (1992) obtained results of higher content of cerium and lower content of magnesium in the leaves of root (wilt) diseased coconut palms. Valiathan *et al*. (1993) repeated the studies on different levels of Mg in healthy apparently healthy and diseased palms and confirmed the reciprocal relationship between lanthanide and magnesium levels. All the three different palms have shown obvious difference in the lanthanide and magnesium levels.

The field experiment to study the effect of different organic manures on the growth and productivity of palms in the root (wilt) prevalent areas revealed that by application of organic manures alone or in combination with inorganic fertilizers, the incidence of root (wilt) disease could not be controlled or arrested. By the end of fifth year 21.8 per cent of the palms had contracted the root (wilt) disease irrespective of the treatment (Anon, 1996).

Wahid *et al.* (1998) investigated the levels of major nutrients, micronutrients, rare earth elements (REEs), thorium and nutrient to rare earth element ratio in the foliage of apparently healthy and root wilt disease affected palms from three major soil types (entisols, ultisols and entisols). Major nutrients accumulation especially K, was noticed in leaves of diseased palms. Leaf Mg level of disease affected palms in laterite soil in disease affected areas was lower than in disease free area. Healthy and diseased palms did not differ in leaf Cerium, Samarium, Praseodymium, Lanthanum, Neodymium and Thorium. Gadolinium was significantly less in foliage of disease affected palms than healthy palms.

3.2.1 Physiological imbalance in root (wilt) affected palms.

Root (wilt) affected palms generally exhibited impaired metabolism. A number of physiological and biochemical derangements occur due to disease incidence. The rearrangements were noticed in water relations, root functioning, phenol metabolism, mineral nutrition, photosynthesis, respiration and other similar processes.

Michael (1964) studied the extent of root damage caused in two to ten year old diseased palms and reported that the number of functional roots and the diameter of the bole were drastically reduced. The percentage of dead roots was higher and the regenerating capacity of roots was also reduced. A single root of diseased palm absorbed 150 ml water per day compared to 250-500 ml by a root of a healthy palm (Davis, 1964). The uptake and transport of water through the trunk in diseased palms was reported to be 35 per cent less than that of healthy palms (Ramadasan, 1964).

Joseph and Jayasankar (1973) reported highest concentration of polyphenols in roots of healthy palms compared to roots of diseased palms. In spite of higher total reducing and non-reducing sugars in the leaves of diseased palms a depletion of these sugars occurred in roots of diseased palms indicating a derangement in translocation (Mathew, 1977).

Michael (1978) reported significantly higher rate of respiration in root (wilt) diseased palms compared to healthy ones.

Reduced utilisation of absorbed phosphorus in the synthesis of P constituted organic substances was reported in diseased palms (Dwivedi *et al.*, 1979). Root (wilt) diseased palms were seen to have higher stomatal frequency than that of healthy palms (Mathew, 1981).

Root (wilt) affected palms had consistently lower leaf water potential than the healthy palms at any given time (Rajagopal *et al.*, 1987). Rajagopal *et al.* (1989) reported decreased rate of flow of phloem sap from diseased palms compared to apparently healthy.

Vascular sap was collected from the inflorescences of apparently healthy and root (wilt) diseased coconut palms under aseptic conditions. The pH of the sap ranged from 6.8 to 7.5. Osmotic concentration was lower in the sap from the root (wilt) affected palms (540-620 mmol kg^{-1}) while apparently healthy palms showed higher values (790-850 mmol kg^{-1}). Direct analysis of the sap for sugars, protein, free amino acids, lipids and sterols showed discernible difference between the healthy and diseased palms. The major amino acids, sugars and organic acids were detected in the sap based on chromatographic studies. The possibility of utilizing this data in preparing the media for culturing mycoplasma-like organisms is discussed (Chempakam and Rajagopal, 1989).

3.3 Methods of radioisotope application

The traditional methods of investigating root activity of tree crops are of limited scope due to the labour involved in excavation, tracing and mapping of roots. Such methods can only provide an idea about total root distribution without distinguishing active and dead roots. In contrast isotopic technique provides a faster and reliable way of finding root distribution pattern. Mainly adopted techniques are plant injection technique (Racz *et al*., 1964) and soil injection technique (Hall *et al*., 1953). Usually ^{32}P, a hard beta emitter, is used for tracer studies because of shorter half life (14.3 days) and ease of measurement, even though others such as ^{15}N (IAEA, 1975) ^{86}Rb (Ellis and Barnes, 1973) and non-radioactive Sr were also used (Fox and Lipps, 1964). The radioactivity obtained in the plant from a particular zone of soil is proportional to the active roots in that zone. IAEA (1975) proposed the radioassay of suitable plant parts to determine the uptake of applied tracer from different root zone.

3.3.1. Root feeding

Biddappa et al. (1987) investigated the effect of root feeding of various metals *viz.* Pb, Cd, Al, Bi, Cr, Cu and Ba on the P, K, Ca and Mg concentration in the leaves of coconut palms**.** He observed that the amount of leaf phosphorus was reduced by all the metals compared with the control. The foliage concentration of K was increased by Bi and Cr, but decreased by Cd, Al and Ba. Concentration of Ca in leaf was enhanced by

Cd, Cr and Ba and reduced by Al and Pb. The Mg content in the leaves was low in palms receiving Al and Cr but increased by Pb.

Thirumalaisamy and Thangaraj (2000) conducted a field trial in Coimbatore to increase the nut production in coconut palms by root feeding of nutrient solution. Fresh active roots were selected and cut to expose the vessel and then roots were immersed in a polybag containing 200 ml nutrient solution (10 g muriate of potash/litre, 10 g urea/litre, 5 g zinc sulfate/litre, 1 g copper sulfate/litre, 2 g ferrous sulfate/litre, 2 g magnesium sulfate/litre, 10 ml planofix [NAA]/litre, 2 g borax/litre, 10 mg sodium molybdate/litre, 10 mg citric acid/litre). They classified the root as good, if it sucked the solution within 4-24 hours. The root was changed when it did not suck the solution. The rate of sucking was depended on sunlight and transpiration rate. When the nutrient solution was administered to suffering palms, healthy green canopy was developed within a year. Also size and number of the nuts increased. Suresh (2010) also conducted experiments to study the effect of root feeding of coconut tonic on yield and nutrient concentration of coconut in five farmers field at Puthalam village during 2006-07. The treatments followed were T_1: Control, T_2: soil application of recommended chemical fertilizers (urea 1.3 kg, SSP 2.0 kg and MoP 2.0 kg), T_3: Root feeding of coconut tonic alone, T_4: root feeding of TNAU tonic plus recommended chemical fertilizers by soil application. For each treatment 35 palms of west coast tall was selected. The treatment with root feeding of coconut tonic plus soil application of recommended fertilizers resulted in highest content of K (1.42 to 1.48 per cent) and also significantly higher number of nuts (71.2 nuts/palm/year in 2007 and 73.5 nuts/palm/year in 2008). It was followed by root feeding of tonic alone and lowest yield was obtained for control (48. nuts/palm/year in 2007 and 48.2 nuts/palm/year in 2008).

Ranjith *et al.* 2001 described a new technique for root feeding with pesticides for controlling insect and diseases affecting coconut. The technique was fast, reliable and cost effective. Many roots can be fed in a day. All the solution is absorbed because the solution comes down to the cut end as a result of gravity. The root injury is vey less, since a small part of root (about 10-15 cm length) is only needed to be exposed. Feeding can be done with all the exposed roots.

Bhaskaran *et al*. (2008) reported that coconut eriophyid mite can be managed by adopting root feeding using neemazol, if crown spraying is difficult. Neemazol F 5% reported a cumulative decrease of 62.6 per cent in the population of eriophyid mite compared to control. Also the damage to green nut was significantly lower in neemazol treated palms over untreated check.

Rao *et al.* (2004) studied the efficiency of different systemics through root feeding against black headed caterpillar of coconut. The efficiency of treatment containing 20 ml monocrotophos + 20 ml water was noticed from 2 days after root feeding and extends up to 80 days after root feeding. The peak mortality was 63.3 per cent at 10 days after root feeding. The efficiency decreased from 20 days after root feeding. In treatment with 10 ml monocrotophos + 10 ml water treatment the efficiency was observed from 3 days after root feeding and effective until 50 days after root feeding. The peak mortality reported was 66.7 per cent at 10 days after root feeding. Sujatha *et al.* (2003) conducted field trial to test the efficacy of various insecticides (monocrotophos, carbosulfan, fenphyroximate, Triazophos) through root feeding for managing coconut eriophyid mite. The most effective treatment was with 20 ml monocrotophos and 20 ml water, followed by 20 ml carbosulfan without water, 15 ml monocrotophos plus 15ml water and 10 ml fenphyroximate plus 10 ml water. The least effective treatment was with triazophos (20 ml+20 ml water)

3.3.2 Soil injection

The activity and development of plant root system in a natural soil profile was first studied using radioactive tracer by Lott *et al*. (1950) and by Hall *et al.* (1953). Soil injection technique has been widely used for estimating root activity pattern of tree crops. It involves injection of tracer into the soil at various depths and radial distances from the plant and determination of plant absorbed radioactivity. Several workers like Fox and Lipps (1964) and Russell and Ellis (1968) have proposed that root activity and root distribution in different depths of soil can be easily and precisely measured by studying the uptake of tracer placed at certain specific depth in the soil profile.

Wahid *et al.* (1985) developed a simple instrument for the soil injection of radioisotope. The device consists of a Lumac Dispensette fitted to a 1 L glass reservoir bottle of 3 mm thickness embedded in paraffin wax in a suitable plastic bucket (20 cm dia x 19 cm ht). It could inject 4-5 ml of radioactive solution per soil hole in root activity studies on tree crops and proved successful in terms of simplicity of use, ease of handling and radiation safety.

Ashokan *et al*. (1989) investigated the root activity pattern of tapioca using ^{32}P soil injection technique. Wahid *et al.* (1989a) studied the root distribution pattern of cashew upto 4 m lateral distance from the tree and 60 cm soil depth employing ^{32}P soil injection technique. They found that about 50 per cent of the roots are confining to the upper 15 cm of soil layer, so it is a surface feeder. About 72 per cent of the root activity was detected within 2 m radial distance from the tree. Wahid *et al.* (1989b) studied the root activity pattern of cocoa by ^{32}P soil injection technique and reported a similar result. The lateral spread of the tree was found to be around 150 cm. They reported that the roots of the neighbouring cocoa tree at a spacing of 3m are likely to overlap, so trees compete for nutrients and water.

Subramanian *et al.* (1980) studied the root distribution pattern of Bengal gram (Co-1) using ^{32}P soil injection technique and reported that it is a deep rooted medium spreading variety with roots confining to a lateral distance of 15 cm and depth of 25 cm. Ghildyal et al. (1974) conducted experiment using ^{32}P by soil injection technique and revealed that the spreading and large root systems of C306 and Sonalika were more concentrated at 66 cm on sandy loam soil, where as in compact root system of Kalyan Sona and UP301, the most active roots concentrated within a radius of 12 cm.

Fernandez and Rio (1961) carried out soil injection of Rb^{86} in seven year old coffee trees and tested the foliage for Rb^{86} at 7, 14 and 43 days after injection. They found that there was wide variation in uptake of Rb^{86} from tree to tree. The distribution of Rb^{86} in the foliages of any tree became more uneven with time. It was found that radioactivity was more in young leaves of the tree.

Semin and Cipko (1964) investigated the use of radioisotopes of Fe in studying chlorosis in fruit trees. The radioisotope was applied by different methods including soil injection, foliar application, shoot or root injections. The radioactive ^{59}Fe uptake was observed in chlorotic and healthy apple and cherry trees. It was found that after soil application of radioisotope, no ^{59}Fe was accumulated in aerial part of cherry trees. Also there was no movement of ^{59}Fe from sprayed leaves of apple to unsprayed leaves. But there was fast translocation of ^{59}Fe to all the part of crown of both cherry and apple trees after root injection. The highest radioactivity was noticed at the growing tips of the shoots and the lowest in the wood. The activity was more for vascular system and leaves of healthy trees compared to chlorotic trees.

Plamboeck *et al.* (2000) conducted cation uptake study using ^{134}Cs and ^{22}Na. The ^{134}Cs was injected between the mineral soil and the humus. The ^{22}Na was injected in the mineral soil at 20 cm depth. During 1995 and 1996 half of the experimental plot was subjected to desiccation and other half of the plot to irrigation during 1995, and desiccation during 1996. The ^{134}Cs concentration in the xylem sap, one month after the injections was reported to be highest in the irrigated plot compared to desiccated plot. During August 1995, the difference in the concentration of ^{134}C in the xylem sap was very high among the treatments. In 1995 the ^{22}Na in the xylem sap was also higher in the irrigated plot than desiccated plots, but was not significant. It was found that there were exponential relationship between the content ^{22}Na and ^{134}Cs in the xylem sap and the relative uptake of water from 0-10 cm mineral soil and humus. The uptake of injected ^{22}Na was more compared to injected ^{134}Cs, may be because of low Cs exchangeability in the soil. During 1996 (one year after injection) more amount of was ^{134}Cs found in the needles, wood, bark needles and cones on irrigated plots than desiccated plots. The concentration of^{134}Cs in the wood and stump accounted to nearly 80 per cent of the total uptake.

Kawasaki *et al*. (2004) investigated the uptake of ^{113}Cd by soyabean and subsequent translocation to the grain using soil injection method. They determined optimum application rate of ^{113}Cd-tracer for the experiment. It was 0.2 or 1 mg to each pot. Also examined the most critical stages by which Cd was absorbed through roots and was transferred to the seed using the ^{113}Cd-tracer technique. The activity was detected in almost all the soyabean seeds. The concentration of obtained from 0.2 mg of ^{113}Cd applied plot was 0.01 to 0.04 mg kg^{-1} and 1 mg applied plot was and 0.01 to 0.10 mg kg^{-1}.. They concluded that 0.2 mg of ^{113}Cd is enough to detect the tracer from seeds of soyabean. No negative effects were noticed in the growth of soyabean. The ^{113}Cd tracer was applied four times during different growth stages. The result indicated that the tracer concentration decreased significantly after the 3rd injection in soyabean seeds.

3.3.3. Plant/stem injection

The plant injection technique using ^{32}P tracer for the study of root distribution pattern of cereals were first described by Racz *et al*. (1964) and later it was modified and improved by Rennie and Halstead (1965). In this technique the tracer was injected in to the plant stem. Tracer was then allowed to distribute throughout the plant, after that soil and root samples were taken and measured for tracer content in them. The amount of radioactivity gives an account of the amount of the active roots in the soil profile.

Rediske et al. (1970) studied the distribution of dimethoate-P32 in Douglas-Fir employing stem injection. The dimethoate-P32 was injected into two 15year trees and distribution of the dimethoate-P32 was tracer, 39 days after injection. The results revealed that dimethoate-P32 was well disbursed in the upper 1/3 of the crown. There were measurable amounts of dimethoate-P32 in the top nodes of all the branches of both the trees. The highest activity was recorded 18 days after injection. The amount of insecticide was highest in the cortical tissue of cones and lowest in seeds and vascular tissue.

Shrinivas and Subbiah (1973) studied the root distribution pattern of bajra hybrid using ^{32}P plant injection technique. The root distribution pattern of high yielding varieties of rice was studied by Kumaraswamy *et al.* (1977) at Tamil Nadu agricultural University, Coimbatore. The result indicated that 80 to 85 per cent of the rice roots were confining to the top 15 cm of soil layer at a depth of 24 cm. About 55 to 77 per cent roots were found at a lateral distance of 10 cm and depth of 16 cm.

Nadarajan *et al*. (1980) tested the effectiveness of stem injections with various systemic insecticides in order to control coconut pest *Opisina arenosella* and *Raoiella indica* in India. Monocrotophos was found to be highly effective against the former pest. Application rate of 3.5 ml a.i./palm for 5-year-old coconut palms provided effective control of pest for 90 days, where as that at 7.0 ml a.i./palm for either 9-10 or 45 years old palms did same for 60 days. All the insecticides evaluated against R. indica showed toxicity to larvae, nymphs and adults at 2.5 and 5.0 ml a.i./palm. Phosphamidon was found to be slightly superior to all other insecticide. The residual levels of the insecticides in coconut meat and water 3 weeks after application were found to be within the tolerance limits fixed by WHO/FAO.

Tuzun *et al.* (1986) investigated the effect of stem injection with metalaxyl on growth of tobacco and protection against blue mould in the field. They conducted eight field experiments in Kentucky with Burley tobacco and three experiments in Puerto Rico with cigar and Burley tobacco during 1983-85, using metalaxyl-treated plants as a positive control in some, and untreated plants as negative controls in all experiments. They reported that plants receiving stem injections with metalaxyl had more fresh weight and height compared to control plants, unless stem injection was given at very early growth stages. The yield was enhanced up to 25 per cent than the controls at Kentucky locations. Stem injections also resulted in controlling the severity of blue mould in six experiments, where it was noticed.

Zhou and Smith (1996) reported that stem injection methods have proven more effective and less destructive compared to other methods like leaf and root feeding, in order to supply nutrients and other materials to growing plants. They conducted field experiment to evaluate stem injection technique for supplying water or sucrose solutions to maize stem. This technique delivered pressurized water or solutions using syringe needles which are attached to the stem using latex. The pressure was applied and solutions with sucrose at 0, 150 and 300 g/litre were injected into the stem over a period of 32 days. The rate of uptake was 5.1 ml solution/day per plant. When compared to sucrose the delivery of distilled water was easier. There was no difference in rates of uptake between solutions containing sucrose at 150 and 300 g/litre. This injection system is an efficient, simple and cheap method that can be used in the greenhouse or field.

Swanston and Myrold (1998) conducted experiment in Oregon to evaluate stem injection technique and subsequent partitioning of ^{15}N in the crown of red alder. During July 1994 ten 7 year old red alder (single-stemmed) were labelled using stem-injection method with $^{15}NO_3^-$ or $^{15}NH_4^+$. Leaves from different positions of crown including distal, medial, proximal, top and bottom were samples three and fifteen months after labelling. There was uniform distribution of ^{15}N in the crown region up to three months after labelling, but in the following year it was dilute in the top and distal position. A notable increase in the total concentration of N was evident towards the periphery. The total N concentration increases with increase in crown closure and size. It was concluded that the position of crown with respect to availability of light may be the most critical determinant in allocation of N in red alder leaves.

Bortier *et al*. (2001) tested EDU using stem injection technique in order to examine the effects of ozone exposure on *Populus nigra* during one growing season. The *Populus nigra* plants were repeatedly injected with water and with EDU solution (5 mg/plant) for 14-days interval. It was observed that EDU treated plants had less leaf injury, less chlorotic leaves and less shedding of leaves. So EDU is effective in preventing acceleration of senescence and visible ozone injury. EDU treated plants had higher photosynthetic rates, but were not significant.

Yousuf and Hussain (2000) reported that stem injection with different insecticide like dimethoate, sumithion, diazinon and acephate at a rate of 0.30, 0.40, 0.50 and 0.60 ml a.i cm^{-1} girth, can effectively control jaman leaf-miner. The highest rate of mortality (98.88 per cent) was reported for dimethoate at 0.60 ml a i cm^{-1} girth, 28 days after application. The residue of these insecticides in jaman fruits collected 20, 25 and 30 days after the application ranged from 0.003 to 0.053 ppm, which is below the permissible limits.

Silayo and Kiwango (2010) conducted trials in Saadan National Park to establish the best control methods for Azadirachta indica in the tropical forests. The various methods adopted were ring debarking, seedling uprooting, cutting and stem injection with glyphosate herbicide. It was found that stem injection with glyphosate was most effective compared to other control methods.

McMahon *et al*. (2010) demonstrated the application of potassium phosphonate (phosphite) by trunk injection for effectively controlling canker and *Phytophthora* pod rot (PPR) in Papua New Guinea. The field trial was conducted at south-east Sulawesi. Phosphonate was injected to 50 trees, water to 50 trees and 50 trees were left as control. The application rate of phosphonate was 16 g a.i per tree per year, based on the size of the tree. Trees were examined every month for PPR incidence, canker severity and for cocoa pod borer incidence and severity. Four month after injection, phosphonate treated trees showed negligible levels of canker. After 2.5 years there was significant reduction in PPR incidence in phosphonate treated trees. Incidence of cocoa pod borer did not significantly differ between treatments. Trunk injection of phosphonate can be used as a valuable option for managing PPR and stem canker.

Duker and Kubiak (2011a) tested the effect of prohexadione carboxylic acid (pca) by stem injection to prevent blossom infection caused by the fire blight pathogen on apple trees, as an alternative for streptomycin. There was no significant difference in applying 40 mg pca and streptomycin for 2 year old plant against blossom infection, under green house conditions. But injection with just 10 mg pca in 4 year old trees showed identical result as that of streptomycin application under field condition.

Duker and Kubiak (2011b) conducted studies to find out suitable substances to manage powdery mildew using stem injection in grape wine. Triazoles, penconazol, myclobutanil and tebuconazol were used as test substances. The efficiency of these substances was tested by xylem injections. The stem injection with tebuconazol was found to be superior over others.

Rolando *et al*. (2011) studied the effect of stem injection with systemic insecticide to control *Uraba lugens* (pest) on urban *Lophostemon confertus* trees in New Zealand. Stem injection of insecticides is a good means of controlling *U. lugens* in public places, where foliar application is not possible. Laboratory and field studies were performed during 2009 and 2010 to found out optimum dose rate of acephate against *U. lugens* larvae. The concentration tested were 0.0, 0.25, 0.50 and 1.00 g cm^{-1} tree diameter measured at breast height (dbh). The concentration of the injected solution changed across years. The highest mortality of 85-100 per cent was obtained at a dose of 1.00 g acephate injected cm^{-1} dbh. The lower dosage of 0.25 and 0.50 g acephate cm^{-1} were more effective during 2010 than 2009, may be due to the variation in volume of injected solution. It was concluded that stem injection should be done timely in order to coincide with the emergence of first instar.

Nair *et al*. (2014) used stem injection techniques to introduce ^{15}N into 13 mature, 9 to 13 m tall spruce trees and labelled it with distinct ^{15}N signature. They counted all the isotope injected and found that ^{15}N abundance was towards upper and middle crown portion in the foliage.

. 3.4 Absorption and translocation of radioisotope

Wiebe and Kramer (1954) performed experiment to study the relative proportion of radio isotopes absorbed behind the root tip at various distances and translocated to different parts of the seedling. The experimental material was barley seedlings and ^{35}S, ^{32}P, ^{45}Ca, ^{131}I, ^{86}Rb and ^{90} Sr were used as source of radioisotope. They developed absorption cells through which radioisotope could be given to any 3 mm region of a root and the remaining portion of root and other roots were placed in non-radioactive nutrient solution. All the radioisotopes moved downwards in the treated roots, ^{32}P and ^{35}S accumulated at the tip and remaining isotopes at few millimetres from the tip. Even though the tips absorbed the ions freely, very little upward translocation was occurred. Upward translocation was limited for Ca and Sr. Highest translocation was noticed at 30 to 50 mm. region from the tip of root, the region of greatest water absorption.

Kramer (1956) investigated the translocation of ions to different plant parts using radioisotopes. He found that radioactive isotopes were supplied to limited regions of roots, indicated that very less translocation of ions was occurred from the tip of the root to the shoot than from several centimetre behind the root tip. All most all the minerals entered in herbaceous plants through the root hair zone.

Bukovac (1958) studied the effect of stock-scion relationships and graft unions on nutrient absorption and translocation in higher plants using radioactive isotopes. He observed that rooted cuttings of M.XVI apple rootstocks absorbed more ^{32}P compared to M.VII and IX. Mclntosh scions on M. IX or M.VII absorbed less amount of ^{32}P compared to those on M.XVI or Delicious seedling stocks. Mclntosh on the dwarfing stocks absorbed less ^{45}Ca compared to vigorous stocks. There was no noticeable accumulation of ^{45}Ca or ^{32}P at the bud union. He also reported that tomato plants both genetically dwarf and non-dwarf absorbed equal amount of ^{32}P, but translocation to the root was more for non dwarf tomato plants. The tomato plants dwarfed by MH treatment accumulated less amount of ^{32}P than normal plants. There was no ^{32}P accumulation in grafted plants of tomato at the graft union, which did not appear to restrict ^{32}P translocation to upper plant parts. It was found that acropetal translocation radioactive Na, Cl, S, Mn, Ca, Fe, Cu, Zn, Sr, Rb, Ba and Mo from the roots was not impeded by the graft union. There was significant reduction in translocation of ^{32}P and complete restriction in translocation of ^{45}Ca, when "apex to apex" grafting of laterals of vigourous plants were done.

Eynard (1961) treated four apical leaves of a branch from a two branched vine seedling with ^{137}Cs and ^{32}P simultaneously. He observed that, 24 hours after application the rest of the leaves in that branch showed ^{137}Cs: ^{32}P ratios which were inversely proportional to the shoot apex distance. It indicated that initially the downward movement of P was faster compared to Cs. The leaves and roots of untreated branches were examined after 48 hours, almost constant ratio of both isotopes was observed in all untreated shoots.

Thellier (1962) studied the adsorption, distribution and translocation of boron (^{10}B) in radish. The uptake of B from dilute solutions was higher for young roots compared to older plants. The cotyledons showed 1000 ppm or more concentration of ^{10}B, while young roots rarely attained more than 150 ppm concentration.

Woods and Brock (1964) investigated the rate and extent of interspecific translocation of ^{45}Ca and ^{32}P. These tracers were injected into stumps of red maples, and found that ^{45}Ca and ^{32}P were observed in foliage of 19 other species (up to 24 ft from the donor red maples). The reason for this transfer may be either absorption by the acceptor species, by exudation from the donor or mutually shared mycorrhizal fungi.

Olson and Waller (1965) studied the redistribution of ^{137}Cs for two years in Liriodendron forest. ^{137}Cs was introduced into boles of *L. tulipifera* during May 1962. Maximum concentrations of ^{137}Cs in the canopy was attained during june and there after it decreased, due to downward movement to sol through roots, litter fall and leaching by rain. The concentration of ^{137}Cs in the canopy was reduced to half during 1963 compared to 1962. There was similar reduction in the stem tips (Twigs) also until late summer, there after the concentration increased in stem tips, because of the remobilization of ^{137}Cs to woody tissue from canopy leaves. Under storey vegetation, which were untagged also showed content of Cs within a few days, due to leaching by rain from the canopy. It was concluded that absorption by foliage is 103-104 times more important than soil for first two years after tagging.

Crossett (1966) investigated the movement of ^{86}Rb in the roots of *Hordeum vulgare*. He described an automatic system for estimating the radioisotope absorbed and translocated by plants in a controlled environment. He noticed that translocation rate enhanced with time, if ^{86}Rb was absorbed from 10^{-5} *M* solution by 10 to 14 days old seedlings. But a constant rate of translocation was noticed after an increase in the first 3 hours, if absorption was from highly concentrated solution. When radioactive barley seedlings were dipped in inactive solution of 10^{-5} *M* Rb, no movement of ^{86}Rb to the 10^{-5}M solution was observed.

Hartt and Kortschak (1967) conducted studies using labelled C, K, P, S and Ca in the physiology of sugarcane and found out that low root temperature decreases and retards the absorption and translocation of ^{32}P. The absorption and upward translocation of ^{45}Ca was slower. Absorption and translocation of ^{42}K was faster than^{32}P. The velocity of downward translocation of ^{32}P, ^{42}K and ^{35}S were similar to that of ^{14}C-photosynthate. It was observed that 5.5 hours after roots feeding of ^{42}K and ^{45}Ca, ^{42}K was distributed in the entire plant, while ^{45}Ca was not reached in the spindle. Ca entered the general plant circulatory system, since ^{45}Ca applied to the foliage of one stalk reached the foliage of other stalk of the same stool.

Wallace (1970) studied the effect of monovalent ion carrier on transport of Cs^{137} and Rb^{86} in bush bean plants. 10 days old bush bean seedlings were given ^{137}Cs or ^{86}Rb as nitrate or chloride containing 10^{-4}M $CaCl_2$. He studied the uptake ratio of ^{137}Cs or ^{86}Rb at 10^{-2} and 10^{-3} M concentration of various cations. ^{137}Cs uptake was decreased by all monovalent cations at 10^{-2} M, while at 10 $^{-3}$M some of the cations increased the uptake. The most effective cations were Cs and Rb. The translocation of ^{137}Cs to the shoots was increased by K at 10^{-3}M KNO_3. The ^{86}Rb uptake was reduced by Cs, K and Rb, K was the least effective cation. Nitrate salts increased the uptake of ^{88}Rb compared to ^{137}Cs. The result concluded that absorption and uptake of Cs, Rb and K were not similar.

Nowak and Czapla (1971) investigated the absorption and translocation of solutions containing labelled Na_2SO_4 in 2 year old seedlings of *Pinus sylvestris*. He found out that S was absorbed and translocated by the needles. S applied through the needles was mainly accumulated in the growing parts of the roots also in mycorrhizal zones.

Malakondaiah and Rao (1971) studied the foliar absorption of ^{32}P under saline and alkaline conditions. Groundnut plants with 2, 4 and 6 week old were grown in sand cultures having $NaH_2{}^{32}PO_4$. These plants were treated with 0.4 per cent NaCl or 0.2 per cent Na_2CO_3 solutions and found that root uptake of ^{32}P was decreased considerably, while absorption of ^{32}P applied on foliage increased because of high humidity, increased duration of application and addition of 10^{-5}M gibberellic acid in the rooting medium. Absorption of ^{32}P applied on foliage decreased with leaf age and also by the presence of 2 per cent sucrose in the nutrient medium. NAA (10^{-6}M) helped in the transportation of ^{32}P absorbed on foliage to the roots.

Sen and Deb (1974) determined the effects of Ca, Mg, Cu, Fe, K, P and Mn on uptake and transport of ^{65}Zn in wheat and maize plants in solution culture trials. The ^{65}Zn absorption was not similar in wheat and maize plants and varies with their age. About 75 per cent of the Zn absorbed retained in roots and only 10 per cent was transported to the foliage. The translocation of Zn to the above-ground parts was more in wheat compared to maize. The presence of P and all cations significantly reduced the Zn uptake and transport in maize (31days old), and no significant reduction was noticed in wheat (31 days old) and 16 days old maize. There was negligible Zn translocation was in the presence of Ca, Mg, K and Cu.

Reddy *et al*. (1974) studied the mechanism of Zn absorption in soyabean. Four soyabean cultivars were grown in solution containing 0.005-5 ppm ^{65}Zn. They observed that during the first 1 hour the absorption of Zn was faster, almost 50 per cent of the Zn was absorbed, followed by steady and slow uptake for the next 9 hours and again uptake rate increased for the next 2 hours. Application of Zn metabolic inhibitor (DNP) caused only 15 per cent reduction in Zn absorption and translocation at 0.005-0.05 ppm, but at 5 ppm the inhibition was negligible. It was concluded that absorption of Zn in soyabean was mainly through passive mechanism.

Lin *et al*. (1995) studied the uptake and translocation of ^{65}Zn and ^{54}Mn in balsam fir seedlings using radioisotopes, which was applied directly on main-stem surfaces or shoot in a growth chamber. The distribution and accumulation of both radioisotopes in various parts of seedlings mainly depend on tissue growth activity, distances between source and sink. Radioisotope absorption was significantly increased by acidic wetness. ^{54}Mn and ^{65}Zn were concentrated primarily in 1-year-old needles at the middle and top levels of the seedling crown. There were significant differences in accumulation between ^{54}Mn and ^{65}Zn in needles and twigs from foliar uptake. The absorption by seedlings 70 days after application was 24 -32 per cent of the remaining activities for ^{54}Mn and 25-30 per cent for ^{65}Zn. Less than 1 per cent of the absorbed isotopes was translocated from the bark application sites to other plant organs, whereas more than 54 per cent of the activity absorbed at 1year old shoots moved to the rest of the seedling.

Cumbus and Robinson (1977) demonstrated the ability of both 'adventitious' and 'basal' root systems of watercress to absorb mineral nutrients from surrounding media using radioisotopes ^{32}P, ^{86}Rb and ^{59}Fe on single whole plants cultured in a dual-medium-apparatus. Analysis of axillary shoots formed during a seven day experimental period showed that a greater proportion of phosphate and K gained from the ambient media was absorbed by the adventitious system, although there was a greater mass of basal root tissue. Extensive translocation of nutrients to growing organs occurred from absorption sites on both root systems.

Bapat *et al.* (2001) investigated the absorption and translocation of roots of intact plantlets from *in vitro* cultured shoot tips isolated from sword suckers of banana cultivars (Basrai, Nanjangud Rasthali, Saged Velchi) and a wild variety (Bheemkel). The cultivars were placed in an aerated absorption medium containing 0.1 mM $CaSO_4$ + 0.1 mM

H_3PO_4 labelled with ^{32}P for 24 and 48 hours. Leaf discs of uniform size (2.67 sq cm) were utilized for radioactive P uptake studies. The phosphate uptake of leaf discs from Bheemkel was higher compared to Basrai in terms of ^{32}P uptake per leaf disc and fresh weight. In an experiment to determine if varietal differences can be determined based on ^{32}P uptake, Safed Velchi recorded the highest uptake (103 nM/g fruit weight) after 4 hours in the aerated absorption medium containing ^{32}P. Differences in the ^{32}P uptake of Basrai and Nanjangud Rasthali were not significant after 4 hours of treatment. Highest ^{32}P absorption (780 nM/g fruit weight), translocation (262 nM/g fruit weight) and transport index (41.3) after 48 hours of treatment was observed in tissue culture

Fortunati *et al*. (2004) studied the uptake, translocation and loss of ^{134}Cs and ^{85}Sr in strawberry plants with respect to the age of contaminated foliage. Droplets of solution containing $^{134}CsCl$ and $^{85}SrCl_2$ were distributed over the surface of two foliage of a strawberry plant in order to contaminate it with radioisotope. Two young leaves of the plant were contaminated in one half and two old leaves in other half of the plants. Leaves were sampled on 1, 7 and 15 days after contamination. Before gamma analysis one half of the collected foliages were washed with double distilled water. Washing with double distilled water removed 45 per cent of the applied ^{85}Sr and 55 per cent of the applied ^{134}Cs. There was an increase in foliar absorption of both isotopes, which is evident from the decrease in activity removed after 15 of the study. No difference in activity removed was noticed in young and old foliages. "External loss" was more for contaminated old foliage than young foliage. Translocation was higher for^{134}Cs. The leaf to fruit translocation of ^{134}Cs is more for young leaves

3.5. Root activity pattern of tree crops

3.5.1. Fruit tree

Ulrich *et al*. (1947) conducted a study on the root activity pattern of grape vine using ^{32}P in red loam soil of California and reported irregular distribution of vine roots. Almost ninety per cent of roots were concentrated within 60 cm radius from the base and some lateral roots were observed at 2.5 cm distance from the vines. Dev *et al*. (1971) studied the root proliferation in three varieties of grapes at different depths using soil injection technique and concluded that roots occurring at 31 to 56 cm depths absorbed more amount of ^{32}P and so had more root activity in that region.

Bojappa and Singh (1973) investigated root activity of mango using ^{32}P and found that maximum root activity was up to 30 cm vertically and 2.4 m laterally in the soil. In one trial it was noted that 77 per cent root activity was up to 60 cm and in another trial it was found that 85 per cent activity up to 30 cm depth. In both the experiment 88 per cent of the absorption was observed at a peripheral zone of 3 m.

Atkinson (1974) carried out experiment to analyse the root distribution pattern in apple using selective placement of ^{32}P within rooting volume and concluded that maximum absorption of ^{32}P in 2 year-old trees of cultivar Cox/M9 was from 30 cm depth and from 90 cm depth in 25 year-old trees of cultivar Fortune/M9.

Experiments conducted to study the root activity pattern of 30 year old orange tree in fine sandy clay loam of Spain during summer and spring revealed that the maximum root activity during summer months was at 2 to 3 m distance from the tree and 30 cm depth. During early spring highest activity was observed near the tree at a distance of 50 cm and at 60 and 30 cm depth. The maximum root activity zone in mature trees of 30 years old was farther away from younger trees of 14 years old (IAEA, 1975). Studies conducted in Taiwan shown that maximum root activity was at a lateral distance of 100 cm and depth of 10 cm in 8 year old citrus tree during spring season and 12 year old citrus tree during winter season, the activity was highest near the surface soil within a lateral distance of 100 to 200 cm (IAEA, 1975). Chandra *et al*. (1979) reported that the highest absorption of ^{32}P was from 20 cm depth and radial distance of 60 cm in 'Eureka Round' lemon of the submontane Himalayan region.

3.5.2. Plantation crops

Soong *et al.* (1971) conducted experiment in *Hevea brasiliensis* seedling to study the uptake of ^{32}P using soil injection technique and reported that highest root activity was in a lateral distance of 3.6m from the tree.

Balakrishnamurthy (1971) studied root activity pattern of coconut using ^{32}P and revealed that maximum absorption was found at a lateral distance of 1 m from the palm and depth of 12 cm. The highest root activity was observed at the top soil layer of 0 to 30 cm and intensity was more during wet season. Kushwah *et al.* (1973) studied the root distribution pattern of coconut and reported that palms receiving regular fertilization and manuring showed highest number of roots. About 74 per cent of the produced roots were confined to a lateral distance of 2 m from the basin and depth of 120 cm.

Experiment carried out to study the efficacy of fertilizer utilization by coconut palms in Sri Lanka using radiotracer technique revealed that maximum nutrient uptake was observed at a lateral distance of 50 cm and decreases with increase in radial distance (IAEA, 1975). Highest activity was within a radius of 2 m and up to 10 to 45 cm depth. IAEA (1975) conducted experiments to investigate the root activity pattern of 15 and 60 year old coconut palms in Philippines during wet and dry season and revealed that maximum zone of root activity was at a lateral distance of 1 to 2 m and depth of 15 cm. Studies conducted in 50 year old coconut palm during wet and dry season in sandy loam of Sri Lanka showed that during wet season the highest root activity was at a distance of 1 m distance and 10 cm depth and in dry season it was at 0.5m distance and 10 cm depth.

Forde (1972) conducted a study in Nigeria using ^{32}P revealed that feeding roots of oil palm die back due to the effects of dry season drought. Dry and wet season experiments with coffee trees in Columbia revealed that the root activity at 30 cm lateral distance and 15 cm depth during wet season was significantly higher than at any other soil zones examined (IAEA, 1975). ^{32}P uptake was lower during dry season. Experiment on root activity pattern of coffee conducted in Kenya revealed two zones viz. near surface of soil up to a lateral distance of 82.5 cm and 30 cm lateral distance at a depth of 45 to 75 cm. It was also found that all roots of one year old coffee plants were concentrated in the top layer of 30 cm. The lateral spread of roots in two year old plants was up to 80 cm and 130 cm in adult trees (IAEA, 1975). Dry and wet season experiments conducted using ^{32}P tracer technique in Cacao garden in Ghana indicated that maximum root activity was in the top layer of 2.5 cm (IAEA, 1975)

The maximum root activity pattern of 7 year old bearing oil palm in Malaysia during wet season was found at a distance of 3m from the tree. About 70 to 80 per cent of the active roots occurred within a depth of 0 to 20 cm. In Ivory Coast maximum root activity was found at a depth of 0 to 20 cm. Root activity during wet season is more intense and confined to surface soil unlike in dry season where the activity decreases steeply with depth (IAEA, 1975).

Materials and methods

3. MATERIALS AND METHODS

The project entitled "Absorption and translocation of ^{32}P by root (wilt) affected coconut palms" was conducted in the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Kerala Agricultural University during 2014-2016. In order to achieve the objectives mentioned in chapter 1, experiments were conducted at farmers field in Mannarkad, Chittur, Chavakkad, Kayamkulam and RARS Pattambi. The details of experiment, materials used, methodologies followed are given in this section.

Two separate experiments were conducted as detailed below.

Experiment 1

3.1 Basic characterisation of three different soil types having root (wilt) affected palms

Three major soil types *viz.* laterite, sandy and black cotton soil where root (wilt) was observed were selected for the study.

3.1.1 Selection of the palms

Three types of palms namely healthy palms (palms from disease free area), apparently healthy palms (healthy palms from disease affected area) and diseased palms were identified from three soil types (laterite, sandy and black cotton soil). The apparently healthy and diseased palms in laterite soils were selected from Mannarkad and the healthy palms from RARS, Pattambi. Samples in black cotton soils were collected from Chittur area. In sandy soil, apparently healthy and diseased palms were collected from Kayamkulam and healthy palms from Chavakkad.

3.1.2 Processing of soil samples and analysis

Four morphologically uniform palms of same age were selected from each group of palms and soil samples were collected from two depths *viz*. 0-20 and 20-40 cm from the basin. The soil samples were air dried, processed and sieved through 2 mm sieve. The processed soil samples were characterised with respect to pH, Electrical Conductivity (EC), organic carbon (OC), available nutrients (P, K, Na, Ca, Mg, S, Fe, Mn, Cu, Zn, B and Cl), cation exchange capacity (CEC) and anion exchange capacity (AEC). The procedures adopted for the characterisation of soil samples are given in table 1.

Diseased palm

Apparently healthy palm

Healthy palm

Table 1. Methodology for analysis of soil samples

Sl. No.	Soil parameter	Method	Reference
1	pH	Potentiometric method using a pH meter (1: 2.5 soil: water suspension)	Jackson (1958)
2	EC	Conductivity bridge using conductivity meter (1:2.5 soil: water suspension)	Jackson (1958)
3.	Organic carbon	Wet digestion	Walkley and Black (1934)
4	Available Phosphorus	Extraction using Bray No. 1/ Olsen reagent and estimation colorimetrically by reduced molybdate ascorbic acid blue colour method using spectrophotometer	Bray and Kurtz (1945) Watanabe and Olsen (1965)
5	Available Potassium	Extraction by neutral normal ammonium acetate and estimation using flame photometer	Jackson (1958)
6	Available Calcium and Magnesium	Extraction by neutral normal ammonium acetate and estimation using Atomic Absorption Spectrophotometer	Jackson (1958)
7	Available Sulphur	Extraction using 0.15 per cent $CaCl_2$ and estimation turbidometrically by $BaCl_2$ using spectrophotometer	Williams and Steinbergs (1959)
8	Available Iron, Manganese, Zinc and Copper	Extraction using 0.1M HCl and estimation by using Atomic Absorption Spectrophotometer	Sims and Johnson (1991)
9	Available	Extraction with hot water and estimated	Berger and Truog,

	Boron	colorimetrically by Azomethane-H using spectrophotometer.	1939; Gupta, 1972
10	Available Chlorine	Extraction by distilled water and titration with silver nitrate (Mohr's titration)	Doughty (1924)
11	Available Sodium	Extraction by neutral normal ammonium acetate and estimation using flame photometer	Jackson (1958)
12.	Exchangable cations and CEC	Extraction with 0.1M $BaCl_2$, and estimation using Atomic Absorption Spectrophotometer	Hendershot and Duquette (1986)
13	AEC	Extraction with 0.01M phosphoric acid and estimation using ascorbic acid blue colour method	Baruah and Borthakur (1997) Watanabe and Olsen (1965)

3.1.3 Analysis of plant sample

Leaf samples were collected from 14th frond as suggested by Fremond *et al.* (1966), from the experimental palms. From the selected palms, 14th leaf starting from the first fully opened one was sampled. Middle portion of the five leaflets from both side of the centre portion of the frond were separated. Only leaf lamina after removing the midrib was taken. The leaf lamina was cleaned with moist cotton to remove the dust, cut into small pieces and dried at 70-72^{0}C in hot air oven. The dried samples were powdered, digested and analysed for N, P, K, Na, Ca, Mg, S, Fe, Mn, Cu, Zn, B and Cl (Table 2).

Table 2. Methodology followed for plant analysis

Sl. No.	Parameter	Method
1	Nitrogen	CHNS (Model: Elementar's vario EL cube)
2	Phosphorus	Nitric:perchloric acid (9:4) digestion followed by filtration. Vanabdomolybdate phosphoric yellow colour in nitric acid system (Piper, 1966)
3	Potassium	Nitric:perchloric acid (9:4) digestion followed by filtration. Flame photometry determination (Jackson, 1958)
4	Calcium and magnesium	Nitric:perchloric acid (9:4) digestion followed by filtration and ICP- OES determination (Piper, 1966)
5	Sulphur	CHNS (Model: Elementar's vario EL cube)
6	Iron, manganese, zinc, copper	Nitric:perchloric acid (9:4) digestion followed by filtration and ICP- OES determination (Piper, 1966)
7	Boron	Nitric:perchloric acid (9:4) digestion followed by filtration. The filtrate was collected and estimated colourimetrically by Azomethane-H using spectrophotometer (Gupta, 1972)
8	Chlorine	Digestion with nitric acid and titration using potassium thiocyanate with iron as indicator (Burns and Muraca, 1960)
9	Sodium	Nitric:perchloric acid (9:4) digestion followed by filtration. Flame photometry determination (Jackson, 1958)

3.1.3.1 Net Ionic Equlibrium Ratios of index leaf

The ratios with respect to exchangeable monovalent K^+ to exchangeable divalent cation (Ca^{2+}, Mg^{2+}, Fe^{2+} and Mn^{2+}) and trivalent cation (Al^{3+}) , expressed as cmol(+) kg^{-1} leaf samples were computed.

Experiment 2

Absorption and translocation of ^{32}P in all the three types of palms in laterite soil were studied. Before ^{32}P in order to make homogeneous soil conditions, soil and plant samples were tested and soil test based fertilizer combinations were applied during the onset of south west monsoon. Another set of samples were also collected and analysed before application of ^{32}P.

3.2.1 Studies on soil and leaf characteristics based on soil test based fertilizer recommendation

In this experiment the effect of soil test based fertilizer combination including organic manures and micronutrients on the soil and foliar nutrient level of each palm were studied. The experiment was conducted in laterite soil with three types of palms (healthy, apparently healthy and diseased). Nine palms were selected from each group. Soil and plant samples collected from the experimental palms and basins of the palms were analysed and soil test based fertilizer combinations were applied to make homogeneous soil conditions. NPK fertilizers were applied as per POP recommendation of KAU, in addition to these organic manures @ 25kg/palm and micronutrients like $CuSO_4$, $ZnSO_4$, MgSO4 and Borax were applied as per the requirement. Three months after fertilizer application samples were again collected and analysed.

3.2.1.1 Soil sampling

Soil samples were collected from two depths 0-20 and 20-40 cm before and after fertilizer application and analysed for physico-chemical and chemical properties including pH, EC, organic carbon, available nutrients (P, K, Na, Ca, Mg, S, Fe, Mn, Cu, Zn, B and Cl), CEC and AEC.

3.2.1.2 Leaf analysis

Samples from 14th frond of selected palms were collected, cleaned, oven dried, digested and analysed for N, P, K, Na, Ca, Mg, S, Fe, Mn, Cu, Zn, B and Cl before and after fertilization.

3.2.2 Absorption and translocation of ^{32}P by coconut palms

Experiment was conducted at Thachempara and RARS Pattambi. Three different methods were employed for application of radioisotope in three types of palms. The different methods of radioisotope application are detailed below.

3.2.2.1 Padding technique

Two layered pads were prepared with rubber tube, lining material and absorbent cotton. Rubber tube was cut in the form of a sheet and over that a thick layer of absorbent cotton was placed. The cotton layer was covered using lining material and then another layer of rubber tube sheet with its middle portion removed was glued over the cotton pad. Two small holes were made on the top of the pad on which two micropipette tips were placed in order to inject the radioisotope solution into the cotton pad. Such two pads having a capacity of holding 16 ml solution were wrapped around the coconut tightly after making abrasions on the trunk at a height of one meter from the ground. Radioisotope solution was poured into the cotton pad through micro tips for absorption through the trunk.

3.2.2.2 Root feeding

Four active young roots were excavated from each palm. The roots were then inserted to a polythene tube containing radioisotope solution. Each tube was filled with 8 ml of solution. Soil below the tubes was excavated to seat the tubes for full immersion of roots and tubes were sealed to avoid spillage.

3.2.2.3 Soil injection of ^{32}P using dispenser at different radial distance and depth

PVC pipes of 5 cm diameter (8 pipes/palm) were inserted at different radial distances (50, 100 and 150 cm) and depths (20, 40 and 60 cm). Radioisotope solution was applied @ 4 ml/palm using dispenser.

For all the three methods radioisotope was applied @ 1.7 mCi/palm (32 ml/palm)

Cotton padding technique

Plate 4 Cotton pad

Plate 5 Scrapped coconut trunk

Plate 6 Cotton pad glued on trunk

Plate 7 Radioisotope application

Root feeding

Plate 8 Active roots inserted in polythene cover

Plate 9 Radioisotope application

Soil injection

Plate 10 PVC pipes inserted at different radial distances and depths

Plate 11 Radioisotope application

3.2.2.4 Soil and leaf sampling for radioassay

After application of ^{32}P, leaflets from both side of middle portion of the 14^{th} frond were collected on 1^{st}, 15^{th} and 30^{th} days after application. The leaves were dried in an oven at $70\text{-}72^{0}C$, cut into small pieces, digested and radioassayed. Rhizosphere soil and roots were also collected at 15^{th} and 30^{th} day from the basin excluding the applied site. Available P in soil was extracted using Bray's extractant and radioassayed.

3.3 Statistical analysis

All the data were subjected to statistical analysis. Analysis of variance in CRD was made in OPSTAT package.

Results

4. RESULTS

The results of the experiment conducted to study the “Absorption and translocation of ^{32}P by root (wilt) affected coconut palms” with two experiments to achieve the objectives are presented in this chapter. The experiments were conducted at Mannarkad, Chittur, Kayamkulam, Chavakkad and RARS Pattambi.

Experiment 1

4.1.1 Basic characterisation of three coconut growing soil types of Kerala

The soil samples collected from laterite (A1), sandy (A2) and black cotton soil (A3), around the basin of three different group of coconut palms namely diseased (B1), apparently healthy (B2) and healthy (B3), at 0-20 cm (surface) and 20-40 cm (subsurface) depth were subjected to various analysis for the estimation of different electro chemical properties like pH, EC, CEC, AEC, Organic carbon and pool of available nutrients *viz.* P, K, Ca, Mg, Fe, Mn, Zn, Cu, B, Na and Cl. The data are presented hereunder.

4.1.1.1pH

The data on pH of different soil types of three different groups of palms are furnished in table 3. The pH of the surface soil ranged from 5.29 to 8.30. The lowest pH was recorded in healthy palms of sandy soil and the highest in healthy palms of black cotton soil. There was a significant difference in soil pH among different soil types. Laterite and sandy soils are acidic in nature, while black cotton soil is alkaline. There was no significant difference among soils of different types of coconut palms within the same soil type.

The pH values of subsurface soil varied from 5.08 to 7.80 (Table 3). Diseased palms in sandy soil recorded least pH values, while healthy palms in black cotton soil registered the highest values. It was noted that as the depth increases the pH decreases. There was no significant different in pH between soils under different palms.

Table 3. pH of surface and subsurface soil

	Surface soil				Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	5.72	5.68	5.65	5.68	5.47	5.56	5.35	5.46
A2	5.36	5.42	5.29	5.35	5.08	5.15	5.14	5.12
A3	7.89	7.59	8.30	7.92	7.64	7.48	7.80	7.64
Mean B	6.32	6.23	6.41		6.06	6.07	6.09	

Surface soil C.D (A) - 0.16; C.D (B) - NS; C.D (AxB) - 0.27

Subsurface soil C.D (A) - 0.16; C.D (B) - NS; C.D (AxB) - NS

4.1.1.2 EC

The values of EC of surface soil were between 0.01 to 0.18 dS m^{-1} (Table 4). Healthy palms in laterite soil showed lowest EC and apparently healthy palms in sandy soil recorded highest EC. EC shows a significant variation among different soil types.

The subsurface EC ranged from 0.03 to 0.15 dS m^{-1} (Table 4). The lowest EC was registered for healthy palms of laterite soil and the highest for apparently healthy palms of sandy soil.

Table 4. Electrical conductivity (EC) of surface and subsurface soil (dS m^{-1})

	Surface soil				Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	0.13	0.08	0.01	0.04	0.04	0.05	0.03	0.05
A2	0.13	0.18	0.17	0.16	0.11	0.15	0.14	0.13
A3	0.08	0.09	0.15	0.12	0.06	0.05	0.08	0.06
Mean B	0.11	0.12	0.12		0.08	0.08	0.08	

Surface soil C.D (A) - 0.02; C.D (B) - NS; C.D (AxB) - 0.04

Subsurface soil C.D (A) -0.02; C.D (B) - NS; C.D (AxB) - 0.03

4.1.1.3 Organic carbon

The values of organic carbon in the surface soil were recorded between 0.26 to 0.54 per cent (Table 5). Apparently healthy palms of sandy soil reported lowest values for organic carbon and highest values by diseased palms of black cotton soil.

The subsurface soil reported a variation in organic carbon from 0.07 to 0.48 per cent (Table 5). The lowest values were observed in healthy palms of sandy soil and highest in healthy palms of black cotton soil.

Table 5. Organic carbon content of surface and subsurface soil (%)

Surface soil					**Subsurface soil**			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	0.39	0.38	0.40	0.39	0.30	0.32	0.33	0.32
A2	0.31	0.26	0.28	0.28	0.26	0.14	0.07	0.15
A3	0.54	0.50	0.52	0.52	0.43	0.45	0.48	0.45
Mean B	0.41	0.38	0.40		0.33	0.30	0.29	

Surface soil C.D (A) - 0.04; C.D (B) - NS; C.D (AxB) - NS

Subsurface soil C.D (A) -0.04; C.D (B) - NS; C.D (AxB) - 0.08

4.1.1.4 Available Phosphorus

The data on available P status of surface soil is given in table 6. The lowest value of 26.25 kg ha^{-1} was noticed in the apparently healthy palms of black cotton soil and the highest value of 95.25 kg ha^{-1} was observed in apparently healthy palms of laterite soil.

The subsurface content of P was noticed between 22.12 to 89.06 kg ha^{-1} (Table 6). As the depth increases, the content of P decreases. The subsurface showed same trend as that of surface soil. The lowest and the highest values were recorded by apparently healthy palms of black cotton and laterite soil respectively.

Table 6. Available P content of surface and subsurface soil (kg ha^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	90.5	95.25	84.41	90.05	80.75	89.06	79.24	83.02
A2	62.63	60.6	58.64	60.62	52.78	54.93	55.58	54.43
A3	27.99	26.25	28.23	27.49	24.87	22.12	25.19	24.06
Mean B	60.37	60.7	57.09		52.8	55.37	53.33	

Surface soil C.D (A) - 4.3; C.D (B) - NS; C.D (AxB) - NS

Subsurface soil C.D (A) -4.16; C.D (B) - NS; C.D (AxB) - NS

4.1.1.5 Available Potassium

The surface soil showed a range of 100.50 to 184.50 kg ha^{-1}(Table 7). Available K was found to be low in diseased palms of black cotton soil and high in apparently healthy palms of sandy soil.

The subsurface potassium varied from 68.88 to 165.63 kg ha^{-1}(Table 7). Diseased Palms of black cotton soil recorded the lowest value and apparently healthy palms of sandy soil showed the highest value.

Table 7. Available K content of surface and subsurface soil (kg ha^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	168.13	184.5	139.88	164.17	149	149.88	120.75	139.88
A2	131	179.38	178.38	162.92	125.63	165.63	159	150.08
A3	100.5	118.25	132.88	117.21	68.88	89.5	102	86.79
Mean B	133.21	160.71	150.38		114.5	135	127.25	

Surface soil C.D (A) - 24.61; C.D (B) - NS; C.D (AxB) - NS

Subsurface soil C.D (A) - 21.03; C.D (B) - NS; C.D (AxB) – NS

4.1.1.6 Available Calcium

The status of available Ca in the surface soil is given in the table 8. The content varied from 147.82 to 587.43 mg kg^{-1}, with apparently healthy palms of sandy soil recorded the lowest content and diseased palms of black cotton soil reported the highest value.

The subsurface soil showed a range of 41.36 to 570.73 mg kg^{-1} (Table 8). The lowest value was noticed in apparently healthy palms of sandy soil and the highest in healthy palms of black cotton soil.

Table 8. Available Ca content of surface and subsurface soil (mg kg^{-1})

	Surface soil				Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	353.89	368.51	306.17	342.86	312.03	335.55	247.55	298.38
A2	170.09	147.82	166.93	161.61	64.53	41.36	51.01	52.3
A3	587.43	556.49	580.98	574.96	545.33	544.7	570.73	553.58
Mean B	370.47	357.61	351.36		307.3	307.2	289.76	

Surface soil C.D (A) - 24.86; C.D (B) - NS; C.D (AxB) - 43.05

Subsurface soil C.D (A) - 23.25; C.D (B) - NS; C.D (AxB) - 40.26

4.1.1.7 Available Magnesium

The surface soil contained Mg in the range of 30.69 to 119.03 mg kg^{-1} (Table 9). A significant difference in Mg content was noticed among soil types and palms. Among soil types the content was significantly lower for sandy soil and higher for black cotton soil. Among different group of palms diseased and apparently healthy palms showed comparable values and healthy palms showed least values.

The values of subsurface Mg were between 17.36 to 113.75 mg kg^{-1} (Table9). Subsurface soil also showed significant difference in Mg between palms and soils. The lowest value was obtained for apparently healthy palms of sandy soil and highest for healthy palms of black cotton soil.

Table 9. Available Mg content of surface and subsurface soil (mg kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	36.56	33.67	32.3	34.18	25.48	29.27	31.74	28.83
A2	46.64	32.08	30.69	36.47	37.98	17.36	23.13	26.16
A3	104.8	119.03	96.93	106.92	113.75	92.92	89.7	98.79
Mean B	62.67	61.59	53.31		59.07	46.52	48.19	

Surface soil C.D (A) - 6.3; C.D (B) - 6.3; C.D (AxB) - 10.91

Subsurface soil C.D (A) - 9.22; C.D (B) - 9.22; C.D (AxB) – NS

4.1.1.8 Available Sulphur

The values of surface S content ranged from 3.23 to 6.66 mg kg^{-1} (Table 10). S content varied significantly among the soil types. Diseased palms of laterite soil reported lowest value and diseased palms of black cotton soil recorded highest value.

The subsurface S content showed similar trend as that of surface S content. It ranged from 1.97 to 4.81 mg kg^{-1} (Table 10), with diseased palms of laterite and black cotton soil reported lowest and highest value respectively.

Table 10. Available S content of surface and subsurface soil (mg kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	3.23	3.81	4.09	3.71	1.97	2.79	2.52	2.43
A2	4.35	4.85	5.04	4.74	2.77	3.88	3.48	3.37
A3	6.66	6.64	6.49	6.6	4.81	4.68	4.61	4.7
Mean B	4.75	5.1	5.21		3.18	3.78	3.53	

Surface soil C.D (A) - 0.57; C.D (B) - NS; C.D (AxB) - NS

Subsurface soil C.D (A) - 0.73; C.D (B) - NS; C.D (AxB) – NS

4.1.1.9 Available Iron

The Fe content in the surface soil ranged from 112.35 to 148.80 mg kg^{-1}(Table 11). The lowest value was observed for apparently healthy palms of black cotton soil and highest for apparently healthy palms of laterite soil. There was significant variation in Fe content among different soil types.

The subsurface soil showed a variation in Fe content from 86.08 to 141.78 mg kg^{-1} (Table 11). Root (wilt) affected palms in black cotton soil showed very low content of Fe, while apparently healthy palms of laterite soil reported higher Fe content. Fe content in subsurface soil varied significantly between different types of soil.

Table 11. Available Fe content of surface and subsurface soil (mg kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	145.53	148.8	128.5	140.94	138.15	141.78	121.65	133.86
A2	128.5	132.5	128.5	129.83	121	122.87	120.66	121.51
A3	117.95	112.35	113.33	114.54	86.08	90.73	93.13	89.98
Mean B	130.66	131.22	123.44		115.07	118.46	111.81	

Surface soil C.D (A) - 19.01; C.D (B) - NS; C.D (AxB) - NS

Subsurface soil C.D (A) - 14.1; C.D (B) - NS; C.D (AxB) – NS

4.1.1.10 Available Manganese

The Mn content in the surface soil differs significantly among both palms and soil types. The lowest content of 11.85 mg kg^{-1} was reported in black cotton soil and highest content of 63.98 mg kg^{-1} in laterite soil (Table 12). Among different group of palms apparently healthy palm showed lowest content, while higher content was observed in healthy palms.

The subsurface content of Mn also differs significantly between soils and palms. It ranged from 6.70 to 68.33 mg kg^{-1} (Table 12). The lowest value was for diseased palms of sandy soil and the highest for healthy palms of laterite soil.

Table 12. Available Mn content of surface and subsurface soil (mg kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	25.92	49.43	73.98	49.78	17.63	32.55	68.33	39.5
A2	22.62	24.77	22.77	23.39	6.69	7.29	13.13	9.04
A3	16.42	11.85	16.49	14.92	12.53	10.35	13.78	12.22
Mean B	21.65	28.68	37.75		12.29	16.73	31.74	

Surface soil C.D (A) - 19.01; C.D (B) - NS; C.D (AxB) - NS

Subsurface soil C.D (A) - 14.1; C.D (B) - NS; C.D (AxB) – NS

4.1.1.11 Available Zinc

The values of Zn in surface soil were between 0.50 to 1.38 mg kg^{-1} (Table 13). All the three types of soil showed comparatively similar values. But the palms differ significantly. Soils under diseased palms showed lowest value and healthy palms showed highest value.

The subsurface Zn also showed significant variation among palms. It ranged from 0.27 to 0.65 mg kg^{-1} (Table 13). Lowest value was registered by diseased palms and the highest by healthy palms.

Table 13. Available Zn content of surface and subsurface soil (mg kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	0.5	0.85	1.38	0.91	0.27	0.43	0.58	0.43
A2	0.67	0.74	1.22	0.88	0.27	0.38	0.65	0.43
A3	0.74	0.76	1.34	0.95	0.3	0.38	0.45	0.37
Mean B	0.64	0.78	1.31		0.28	0.39	0.56	

Surface soil **C.D (A) - NS; C.D (B) - 0.28; C.D (AxB) - NS**

Subsurface soil **C.D (A) - NS; C.D (B) - 0.15; C.D (AxB) – NS**

4.1.1.12 Available copper

The Cu content of surface soil was between 0.61 to 4.36 mg kg^{-1} (Table 14). There was significant difference in Cu content between palms and soil types. Among different groups of palms apparently healthy palm registered lowest values and healthy palm registered highest values. Sandy and laterite soil showed lowest and highest value respectively.

The subsurface Cu ranged from 0.41 to 3.65 mg kg^{-1} (Table 14). Diseased palms showed significantly lower content and healthy palms showed significantly higher content. Among soil types black cotton soil recorded lower content, while laterite soil reported significantly higher Cu content.

Table 14. Available Cu content of surface and subsurface soil (mg kg^{-1})

Surface soil					**Subsurface soil**			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	0.77	0.63	4.36	1.92	0.47	0.45	3.65	1.52
A2	0.74	0.61	2.8	1.38	0.41	0.87	1.09	0.79
A3	0.78	0.8	2.27	1.28	0.88	0.68	1.2	0.92
Mean B	0.76	0.68	3.15		0.59	0.66	1.98	

Surface soil **C.D (A) - 0.39; C.D (B) - 0.39; C.D (AxB) - 0.68**

Subsurface soil **C.D (A) - 0.27; C.D (B) - 0.27; C.D (AxB) – 0.46**

4.1.1.13 Available Boron

There was significant difference between B content among soils and palms. The surface B ranged from 0.20 to 0.65 mg kg^{-1} (Table 15). The lowest B content was observed in healthy palms, while diseased and apparently healthy palms recorded significantly better values. Sandy soil and laterite soil recorded lowest and highest B content respectively.

The subsurface B showed a similar trend as that of surface B. It differs significantly among soils and palms. The values were between 0.16 to 0.56 mg kg^{-1} (Table 15). Laterite soil reported significantly higher B content than sandy soil and black cotton soil. Also healthy palms reported significantly higher value.

Table 15. Available B content of surface and subsurface soil (mg kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	0.57	0.58	0.65	0.6	0.47	0.51	0.56	0.51
A2	0.25	0.2	0.23	0.23	0.18	0.16	0.18	0.17
A3	0.21	0.26	0.32	0.26	0.16	0.18	0.28	0.2
Mean B	0.34	0.35	0.4		0.27	0.28	0.34	

Surface soil C.D (A) - 0.05; C.D (B) - 0.05; C.D (AxB) - NS

Subsurface soil C.D (A) - 0.05; C.D (B) - 0.05; C.D (AxB) - NS

4.1.1.14 Available Chlorine

The Cl content varied from 50.70 to 94.21 mg kg^{-1} (Table 16). Sandy soil registered higher content for Cl. Comparatively similar values were recorded for laterite and black cotton soils. Lowest value was noticed for apparently healthy palms and highest for healthy palms. Palms did not differ significantly with respect to Cl content.

The values of subsurface Cl content were between 28.81 to 82.21 mg kg^{-1}(Table 16). Healthy palms of black cotton soil showed lowest content and healthy palms of sandy soil reported higher content. Sandy soil differs significantly in Cl content.

Table 16. Available Cl content of surface and subsurface soil (mg kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	58.39	50.71	53.65	54.25	36.72	40.03	43.83	40.19
A2	91.61	89.58	94.21	91.8	76.02	76.63	82.92	78.52
A3	55.27	53.2	58.56	55.67	30.87	30.85	28.81	30.18
Mean B	68.42	64.5	68.8		47.87	49.17	51.85	

Surface soil C.D (A) - 11.64; C.D (B) – NS; C.D (AxB) - NS

Subsurface soil C.D (A) - 8.74; C.D (B) – NS; C.D (AxB) - NS

4.1.1.15 Available Sodium

The Na content in the surface soil was recorded between 27.25 to 58.38 mg kg^{-1} (Table 17). Na was found to be lowest in healthy palms of black cotton soil and comparatively higher values were recorded for diseased palms of sandy soil.

The subsurface Na also reported similar trend as that of surface Na. It ranged from 22.25 to 35.50 mg kg^{-1} (Table 17). Sandy soil showed significantly higher Na content. Soils under diseased palm reported highest content of Na.

Table 17. Available Na content of surface and subsurface soil (mg kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	27.25	29.63	31.88	29.58	24.63	24.13	25.88	24.88
A2	58.38	54.13	55	55.83	35.5	32.63	31	33.04
A3	34.63	32	25.75	30.79	27	25.38	22.25	24.88
Mean B	40.08	38.58	37.54		29.04	27.38	26.38	

Surface soil C.D (A) - 4.67; C.D (B) – NS; C.D (AxB) - NS

Subsurface soil C.D (A) - 4.3; C.D (B) – NS; C.D (AxB) - NS

4.1.1.16 Exchangeable cations and cation exchange capacity (CEC)

The $BaCl_2$ exchangeable cation status in surface of the three type of soil under study is presented in Table 19. The exchangeable Na, K, Ca, Mg, Mn and Al were in the range of 1.36 to 1.92, 0.35 to 0.58, 1.15 to 6.06, 0.96 to 4.21, 0 to 0.06, 0 to 0.06 cmol(+) kg^{-1}. The exchangeable Mn and Al were very negligible in quantity. The exchangeable Fe, Cu, Zn were under non detectable range. The highest CEC (12.32 cmol(+) kg^{-1}) was reported for black cotton soil and lowest (4.41 cmol(+) kg^{-1}) for sandy soil (Table 18). There was significant variation in CEC between different types of soil. But CEC was similar among various categories of palms.

The exchangeable cations in the subsurface soil varied from Na (1.30 to 1.89 cmol(+) kg^{-1}), K (0.30 to 0.53 cmol(+) kg^{-1}), Ca (1.09 to 6.02 cmol(+) kg^{-1}), Mg (0.92 to 4.18 cmol(+) kg^{-1}), Mn (0 to 0.03 cmol(+) kg^{-1}), Al (0 to 0.02 cmol(+) kg^{-1}) (Table 19). As the depth increased, exchangeable cations showed a decreasing trend. The CEC was in the range of 4.26 to 12.04 cmol(+) kg^{-1} (Table 18). The lowest CEC was noticed for sandy soil and significantly highest for black cotton soil.

Table 18. CEC of surface and subsurface soil (cmol(+) kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	7.11	7.12	7.17	7.13	6.93	6.99	7.02	6.98
A2	4.46	4.41	4.42	4.43	4.26	4.27	4.28	4.27
A3	12.31	12.28	12.32	12.3	11.95	11.99	12.04	11.99
Mean B	7.96	7.94	7.97		7.71	7.75	7.78	

Surface soil C.D (A) - 0.69; C.D (B) – NS; C.D (AxB) - NS

Subsurface soil C.D (A) - 0.69; C.D (B) – NS; C.D (AxB) - NS

Table 19. Exchangeable cations in surface and subsurface soil

Soil/palm type	Ex. Na		Ex. K		Ex. Ca		Ex. Mg		Ex. Fe		Ex. Cu		Ex. Zn		Ex. Mn		Ex. Al	
	surface	Subsurface	Surface	Subsurface	surface	Subsurface	Surface	Subsurface	Surface	Subsurface	surface	Subsurface	Surface	Subsurface	surface	Subsurface	Surface	Subsurface
	cmol(+) kg^{-1}																	
A1B1	1.59	1.55	0.44	0.4	3.25	3.2	1.78	1.75	ND	ND	ND	ND	ND	ND	0.03	0.02	0.02	0.01
A1B2	1.58	1.53	0.43	0.4	3.24	3.23	1.82	1.8	ND	ND	ND	ND	ND	ND	0.03	0.02	0.02	0.01
A1B3	1.55	1.49	0.4	0.38	3.29	3.26	1.85	1.84	ND	ND	ND	ND	ND	ND	0.05	0.03	0.03	0.02
A2B1	1.92	1.89	0.43	0.36	1.15	1.09	0.96	0.92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
A2B2	1.9	1.86	0.35	0.32	1.18	1.14	0.98	0.95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
A2B3	1.89	1.85	0.36	0.3	1.18	1.15	0.99	0.98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
A3B1	1.38	1.35	0.58	0.5	6.06	5.94	4.18	4.13	ND	ND	ND	ND	ND	ND	0.06	0.02	0.05	0.01
A3B2	1.37	1.36	0.54	0.53	6.04	5.95	4.2	4.1	ND	ND	ND	ND	ND	ND	0.07	0.03	0.06	0.02
A3B3	1.36	1.3	0.52	0.49	6.1	6.02	4.21	4.18	ND	ND	ND	ND	ND	ND	0.07	0.03	0.06	0.02

4.1.1.17 AEC

The values of AEC in the surface soil were between 2.13 to 5.26 cmol(-) kg^{-1}(Table 20). The soil types differ significantly with respect to AEC. The lowest AEC was observed for black cotton soil and highest for sandy soil. There was no significant difference in AEC among palms.

The AEC in the subsurface soil ranged from 1.96 to 5.20 cmol(-) kg^{-1} (Table 20). Black cotton soil reported lowest AEC and sandy soil registered highest value. As like AEC of surface soil, subsurface AEC also showed significant difference among soil types.

Table 20. AEC of surface and subsurface soil (cmol(-) kg^{-1})

Surface soil					Subsurface soil			
Soils/palms	**B1**	**B2**	**B3**	**Mean A**	**B1**	**B2**	**B3**	**Mean A**
A1	3.48	3.44	3.42	3.45	3.18	3.12	3.1	3.13
A2	5.26	5.24	5.2	5.23	5.2	5.18	5.15	5.18
A3	2.18	2.16	2.13	2.16	2.06	1.99	1.96	2
Mean B	3.64	3.61	3.58		3.48	3.43	3.4	

Surface soil **C.D (A) - 0.69; C.D (B) – NS; C.D (AxB) - NS**

Subsurface soil **C.D (A) - 0.69; C.D (B) – NS; C.D (AxB) - NS**

4.1.2 Plant analysis

Leaf samples were collected from diseased, apparently healthy and healthy palms under laterite, sandy and black cotton soil. The analytical data on nutrient content in leaf is presented hereunder.

4.1.2.1 Nitrogen

The plant available nitrogen was found to be varied from 1.16 to 2.66 per cent (Table 21). Significant variation was observed in leaf N content among different palms and soil types. Diseased palms of sandy soil reported significantly lower value and healthy palms of black cotton soil registered significantly higher value.

Table 21. Content of Nitrogen in the index leaf (%)

Soils/palms	B1	B2	B3	Mean A
A1	1.65	1.68	1.7	1.68
A2	1.16	1.25	1.26	1.22
A3	1.76	2.61	2.66	2.34
Mean B	1.52	1.85	1.87	

C.D (A) - 0.14; C.D (B) – 0.14; C.D (AxB) - 0.24

4.1.2.2 Phosphorus

The P content in the foliage was between 0.09 to 0.1 per cent (Table 22). Comparatively similar P content was observed in foliage of different palms under different soil types. The lowest value was reported for diseased and apparently healthy palms of sandy and laterite soil respectively. The highest value was for diseased and apparently healthy palms of black cotton soil and sandy soil respectively.

Table 22. Content of Phosphorus in the index leaf (%)

Soils/palms	B1	B2	B3	Mean A
A1	0.11	0.09	0.11	0.10
A2	0.09	0.15	0.10	0.11
A3	0.15	0.11	0.12	0.12
Mean B	0.11	0.12	0.11	

C.D (A) - NS; C.D (B) – NS; C.D (AxB) - 0.03

4.1.2.3 Potassium

The leaf potassium levels varied from 0.33 to 0.94 per cent (Table 23). The K content significantly differs among different type of soil and palms. Among different palms diseased palms in all the three soil types recorded significantly superior K content, while healthy palms registered lowest content. Palms in sandy soil reported highest value. The K content in palms of healthy and black cotton soil are on par.

Table 23. Content of Potassium in the index leaf (%)

Soils/palms	B1	B2	B3	Mean A
A1	0.85	0.68	0.45	0.66
A2	1.05	1.02	0.80	0.96
A3	0.94	0.71	0.33	0.66
Mean B	0.94	0.83	0.53	

C.D (A) - 0.08; C.D (B) – 0.08; C.D (AxB) - 0.14

4.1.2.4 Calcium

The values of calcium in the foliage were between 0.33 to 0.80 per cent (Table 24). Palms and soils differ significantly with respect to Ca. It was noticed that diseased palms recorded significantly lower value and healthy palms registered significantly better value under all the soil types. Among different types of soil the Ca content was highest in palms of laterite soil.

Table 24. Content of Calcium in the index leaf (%)

Soils/palms	B1	B2	B3	Mean A
A1	0.33	0.47	0.80	0.53
A2	0.38	0.38	0.58	0.45
A3	0.39	0.42	0.54	0.45
Mean B	0.37	0.42	0.64	

C.D (A) - 0.05; C.D (B) – 0.05; C.D (AxB) - 0.09

4.1.2.5 Magnesium

The content of Mg in the leaf tissue is given in table 25. The Mg content ranged from 0.12 to 0.57 per cent. Mg also showed same trend as that of Ca. There was significant difference among palms and soils. The lowest Mg content was recorded for diseased palms and significantly higher values for healthy palms. Palms under sandy soil showed lowest value and highest value were observed for black cotton soil.

Table 25. Content of Magnesium in the index leaf (%)

Soils/palms	B1	B2	B3	Mean A
A1	0.15	0.15	0.33	0.21
A2	0.12	0.14	0.30	0.19
A3	0.27	0.32	0.57	0.39
Mean B	0.18	0.20	0.40	

C.D (A) - 0.03; C.D (B) – 0.03; C.D (AxB) - 0.05

4.1.2.6 Sulphur

The S content in the leaf were between 0.14 to 0.24 per cent (Table 26). Only the soil types differ significantly. Among soil types, palms under laterite soil were significantly superior to palms under sandy and black cotton with respect to S content. Diseased palms reported lowest values and healthy palms reported highest value.

Table 26. Content of Sulphur in the index leaf (%)

Soils/palms	B1	B2	B3	Mean A
A1	0.23	0.23	0.24	0.23
A2	0.14	0.17	0.20	0.17
A3	0.18	0.21	0.22	0.20
Mean B	0.18	0.20	0.22	

C.D (A) - 0.03; C.D (B) – NS; C.D (AxB) - NS

4.1.2.7 Iron

The content of Fe in the foliage was given in table 27. The values were between 182.17 to 364.05 ppm. There was significant difference between leaf Fe content among palms and soil types. The lowest Fe content was observed for diseased palms of sandy soil and highest content was estimated for healthy palms of laterite soil.

Table 27. Content of Iron in the index leaf (ppm)

Soils/palms	B1	B2	B3	Mean A
A1	263.85	284.25	364.05	304.05
A2	182.17	186.83	280.07	216.36
A3	271.29	261.34	319.47	284.03
Mean B	239.1	244.14	321.2	

C.D (A) - 24.67; C.D (B) – 24.67; C.D (AxB) - NS

4.1.2.8 Manganese

The data on leaf Mn content is given in the table 28. The values were observed between 29.95 to 325.55 ppm. The diseased palms showed lowest value in all the soil types while healthy palms recorded significantly highest value. Soil types also varied significantly in Mn content. Among soils, laterite soil recorded highest and sandy recorded lowest.

Table 28. Content of Manganese in the index leaf (ppm)

Soils/palms	B1	B2	B3	Mean A
A1	173.5	180.2	325.55	226.42
A2	49.25	95.88	161.01	102.05
A3	29.95	51.2	153.85	78.33
Mean B	84.23	109.09	213.47	

C.D (A) - 21.37; C.D (B) – 21.37; C.D (AxB) – NS

4.1.2.9 Zinc

The content of Zn in the foliage varied from 16.40 to 60.25 ppm (Table 29). There was significant difference between palms and soil type with respect to Zn. The lowest value was noticed in diseased palms and highest in healthy palms. Among soil types lowest content was reported for sandy soil and highest for black cotton soil.

Table 29. Content of Zinc in the index leaf (ppm)

Soils/palms	B1	B2	B3	Mean A
A1	23.85	30.6	56.89	37.11
A2	16.4	31.05	35.25	27.57
A3	28.55	55.6	60.25	48.13
Mean B	22.93	39.08	50.8	

C.D (A) - 5.78; C.D (B) – 5.78; C.D (AxB) - 10.02

4.1.2.10 Copper

The data on leaf Cu content is presented in the table 30. The content ranged from 4.45 to 8.40 ppm. The Cu content varied significantly with respect to palms and soil types. The lowest content was estimated in diseased palms. The healthy palms recorded significantly highest value followed by apparently healthy palms. Among soil types, black cotton soil recorded highest value, while laterite and sandy soil reported comparatively similar value.

Table 30. Content of Copper in the index leaf (ppm)

Soils/palms	B1	B2	B3	Mean A
A1	4.45	5.53	8.4	6.13
A2	5.7	6.3	6.7	6.23
A3	7.38	7.62	7.75	7.58
Mean B	5.84	6.48	7.62	

C.D (A) - 0.87; C.D (B) – 0.87; C.D (AxB) - 1.51

4.1.2.11 Boron

The content of B in the leaf ranged from 3.33 to 6.13 ppm (Table 31). Significant variation was noticed among soil and palms with respect to B content. The lowest value was estimated in diseased palms and highest values in healthy palms. Among soil types sandy soil recorded lowest value and laterite soil reported highest value.

Table 31. Content of Boron in the index leaf (ppm)

Soils/palms	B1	B2	B3	Mean A
A1	5	4.98	6.13	5.37
A2	3.33	3.53	3.58	3.48
A3	3.65	4.23	4.1	3.99
Mean B	3.99	4.24	4.6	

C.D (A) - 0.43; C.D (B) – 0.43; C.D (AxB) - NS

4.1.2.12 Chlorine

The values of Cl in leaf sample were in the range of 0.38 to 0.61per cent (Table 32). The Cl content differs significantly among soil. The content was lowest for diseased palms of black cotton soil and highest for healthy palms of sandy soil.

Table 32. Content of Chlorine in the index leaf (%)

Soils/palms	B1	B2	B3	Mean A
A1	0.57	0.53	0.53	0.54
A2	0.57	0.58	0.61	0.58
A3	0.38	0.39	0.4	0.39
Mean B	0.5	0.5	0.51	

C.D (A) - 0.06; C.D (B) – NS; C.D (AxB) - NS

4.1.2.13 Sodium

The leaf Na content was varied from 0.54 to 0.86 per cent (Table 33). There was significant variation among different soil types with respect to Na content. The laterite soil recorded lowest content while sandy soil reported significantly highest content. The content did not differ significantly among soils under different palms.

Table 33. Content of Sodium in the index leaf (%)

Soils/palms	B1	B2	B3	Mean A
A1	0.58	0.55	0.54	0.55
A2	0.86	0.84	0.83	0.84
A3	0.68	0.65	0.64	0.66
Mean B	0.70	0.68	0.67	

C.D (A) – 0.04; C.D (B) – NS; C.D (AxB) – NS

4.1.2.14 Net Ionic Equilibrium (NIE) ratio

Net ionic equilibrium ratio is $(K/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$. It ranged from 1.88 to 6.43 (Table 34). The NIE was found to be highest for diseased palms and it was lowest for healthy palms. The NIE ratio was significantly influenced by both the types of palms and soil types.

Table 34. Net Ionic Equilibrium (NIE) ratio of index leaf

Soils/palms	**B1**	**B2**	**B3**	**Mean A**
A1	6.43	2.54	1.88	3.62
A2	5.98	3.64	2.54	4.05
A3	5.83	2.34	2.29	3.48
Mean B	6.08	2.84	2.24	

C.D (A) – 0.32; C.D (B) – 0.32; C.D (AxB) – 0.56

Experiment 2

The second experiment "Absorption and translocation of nutrients in coconut palm using ^{32}P" was conducted at Mannarkad and RARS Pattambi, where the soil is laterite. Before ^{32}P application soil from 0-20cm and 20-40 cm depth and plant samples from index leaf of three groups of palms were analysed and soil test based fertilizer combinations including organic manures and micronutrients were applied during the onset of south west monsoon in 2014, in order to make homogeneous soil conditions. NPK fertilizers were applied as per POP recommendation, along with that organic manure @ 25 kg/palm, also $CuSO_4$, $MgSO_4$ and $ZnSO_4$ were applied as per the requirement of each palm. After fertilizer application another set of plant and soil samples were collected and analysed for different electro chemical properties like pH, EC, CEC, AEC, Organic carbon and pool of available nutrients *viz.* P, K, Ca, Mg, Fe, Mn, Zn, Cu, B, Na and Cl. The data are presented hereunder

4.2.1 Characterisation of laterite soil before and after fertilization

Soil samples were collected initially before fertilizer application and analysed for different electro chemical properties like pH, EC, CEC, AEC, organic carbon and pool of available nutrients *viz.* P, K, Ca, Mg, Fe, Mn, Zn, Cu, B, Na and Cl. Three month after fertilizer application another set of soil and plant samples were collected and analysed for different physico-chemical and chemical properties as mentioned above. The results are presented here under.

4.2.1.1 pH

The pH of soil at 0-20 cm depth before fertilization, under different types of palms varied from 5.70 to 5.77 (Table 35). The pH was highest for diseased soil. The pH of both apparently healthy and healthy soil was similar. The soil was acidic in reaction. The pH at 20-40 cm depth ranged from 5.35 to 5.49. Soil of diseased palms and healthy palms reported lowest value and apparently healthy palms recorded highest value. There was no significant difference in pH values between soils under different group of palms.

The surface pH of different types of palms after fertilization varied from 5.89 to 5.95 (Table 35). Apparently healthy soil reported lowest pH and highest by soil under healthy palms. The soil was slightly acidic in reaction. After lime application pH showed a slight increment. The pH at 20-40 cm depth ranged from 5.61 to 5.69. The subsurface pH also showed same trend as that of surface pH. There was no significant difference in pH values between soils under different group of palms. Soil of apparently healthy palms reported lowest value and healthy palms recorded highest value.

4.2.1.2 EC

The values of EC before fertilizer application for surface soil were between 0.07 to 0.11 dS m^{-1} (Table 35). The lowest value was estimated in apparently healthy and healthy soil and highest in diseased soil. There was significant difference in EC between palms. The subsurface soil recorded EC in the range of 0.06 to 0.07 dS m^{-1}. The soils of healthy palm reported lowest EC. The highest value for EC was noticed in soil under healthy and apparently healthy palms. The EC values of different palms under laterite soil were comparatively similar.

After fertilizer application the values of EC for surface soil were became 0.13 to 0.19 dS m^{-1}(Table 35). The lowest value was noticed in healthy soil and highest in diseased soil. There was no significant difference in EC between palms after fertilization. The subsurface soil recorded EC in the range of 0.08 to 0.09 dS m^{-1}. The soils of healthy and diseased palms reported lowest EC. The highest value for EC was noticed in soil under apparently healthy palms.

4.2.1.3 Organic Carbon

The value in the surface soil ranged from 0.38 to 0.39 per cent before fertilization (Table 35). The lowest content was reported to be in apparently healthy soil. The diseased and healthy soil had similar value for organic carbon. No significant difference was noted between soils under different groups of palm. The subsurface content of organic carbon was indicated in table 35. The lowest value of 0.30 per cent was observed in diseased soil and highest value of 0.33 per cent was noticed in healthy soil. The organic carbon was comparatively similar for different palms.

The organic carbon content in the surface soil after fertilization ranged from 0.44 to 0.46 per cent (Table 35). The lowest content was observed for apparently healthy soil. The diseased and healthy soil had similar value for organic carbon. No significant difference was noted between soils of different groups of palm. All the soils under different group of palms were uniform after fertilization. The subsurface content of organic carbon was indicated in table 35. The lowest value of 0.32 per cent was reported for diseased soil and highest value of 0.34 per cent was noticed in healthy soil.

4.2.1.4 Available Phosphorus

The status of available P before fertilizer application in the surface soil is given in the table 35. The values varied from 88.88 to 92.66 kg ha^{-1}. The lowest content was observed in healthy soil, while highest in diseased affected area. The subsurface P content was observed between 77.48 to 84.62 kg ha^{-1}. Soils of diseased area reported lowest value and soil of apparently healthy area reported highest value. But there was no significant difference in P content with respect to soils under different groups of palms.

The P status at 0-20 cm depth after fertilizer application increased to a ranged of 91.96 to 95.02 kg ha^{-1} (Table 35). The P content increases after fertilization and it is similar for all the soil under different palm. The lowest content was observed in apparently healthy soil, while highest in diseased affected area. The subsurface P content was between 80.52 to 85.88 kg ha^{-1}. Soils of diseased area registered lowest value and soil of apparently healthy area reported highest value. But there was no significant difference in P content with respect to soils under different groups of palms after fertilization.

4.2.1.5 Available Potassium

Table 35 shows the content of K in surface soil before fertilizer application. It ranged from 151.06 to170.44 kg ha^{-1}. The soils under different group of palms were comparatively similar in K content. The lowest value was reported for healthy soil and highest for apparently healthy soil. The K content at 20-40 cm depth was between 116.56 to 143.56 kg ha^{-1}. No significant difference was noticed between soils of different palms. The healthy soil recorded lowest value and diseased soil reported highest value for K.

The content of K after fertilizer application in surface soil was given in table 35. It varied from 266.78 to 276.89 kg ha^{-1}. The soils belonging to different group of palms were comparatively same with respect to K content. Diseased soil reported lower value and healthy soil registered highest value. The K content at 20-40 cm depth was between 133.61 to 148.56 kg ha^{-1}. There was no significant difference in K content between soils under different categories of palms. The healthy soil recorded lowest value and apparently healthy soil reported highest value for K.

4.2.1.6 Available Calcium

The data indicating the status of available Ca in the surface soil before fertilizer application is given in table 35. The content varied from 304.97 to 357.52 mg kg^{-1}. The lowest content was observed for healthy soil and highest for diseased soil. There was significant difference in Ca content between soils of different palms. The subsurface soil showed a range of 249.21 to 325.16 mg kg^{-1}. Subsurface soil showed same trend as that of surface soil. The soils under different group of palms differ significantly. Soils of healthy palms showed lowest value, while that of diseased palm showed significantly higher value.

The available Ca in the surface soil after fertilization varied from 353.35 to 362.31 mg kg^{-1}(Table 35). The lowest content was observed for apparently healthy soil and highest for healthy soil. There was no significant difference in Ca content between soils of different palms. Soils are more or less homogeneous. The subsurface soil showed a range of 313.51 to 331.61 mg kg^{-1}. The soils under different group of palms did not differ significantly. Soils of healthy palms showed lowest value, while that of diseased palm showed higher value, which was not significant.

4.2.1.7 Available Magnesium

The values of Mg at 0-20 cm depth before fertilization were between 26.93 to 27.29 mg kg^{-1}(Table 35). There was no significant difference in Mg content among different palms. The lowest value was reported by healthy soil and highest by apparently healthy soil. The Mg content at 20-40 cm depth is given in Table 35. The lowest value was reported for diseased soil with content of 26.39 mg kg^{-1} and highest value for healthy soil with content of 26.84 mg kg^{-1}.

The content Mg in surface soil after fertilization increased and it was between 28 to 29.05 mg kg^{-1} (Table 35). After fertilizer application soil became homogeneous and comparatively similar with respect to Mg content. There was no significant difference in Mg content among different palms. The lowest value was reported by healthy soil and highest by apparently healthy soil. The Mg content of subsurface soil is given in Table 35. The lowest value was reported for healthy soil with Mg content of 24.29 mg kg^{-1} and highest value for diseased soil with Mg content of 25.56 mg kg^{-1}. Only slight variation was shown by soils under different group of palms and they were also non significant.

4.2.18 Available Sulphur

The available S in the surface soil before fertilization varied from 5.79 to 6.07 mg kg^{-1} (Table 35). The lowest content was observed in apparently healthy soil, while highest in diseased palms. The subsurface content was found to be lowest (3.26 mg kg^{-1}) in apparently healthy soil and highest (3.60 mg kg^{-1}) in healthy soil.

The available S at 0-20 cm depth after fertilizer application showed a slight increase and it ranged from 7.09 to 8.92 mg kg^{-1} (Table 35). The lowest S content was associated with healthy soil, while highest with diseased palms. The variation in S content among palms was not significant. The subsurface content was found to be lowest (3.45 mg kg^{-1}) in diseased soil and highest (4.10 mg kg^{-1}) in healthy soil. There was no significant difference in S content. All the soils were homogeneous after fertilisation.

4.2.1.9 Available Iron

The available Fe content in the surface soil before fertilization was between 132.10 to 148.34 mg kg^{-1} (Table 35). The available Fe varied significantly with respect to soils under different group of palms. The lowest value was estimated for healthy soils and significantly higher value for apparently healthy soil. The subsurface Fe content also showed similar variation as that of surface Fe. It ranged from 120.70 to 143.31 mg kg^{-1}. Healthy soils registered lowest value and apparently healthy soils reported significantly higher value.

After fertilizer application content of available Fe in the surface soil increased and it was between 162.88 to 166.79 mg kg^{-1} (Table 35). There was no significant variation in available Fe with respect to soils under different group of palms after fertilization. The lowest value was estimated for apparently healthy soils and highest value for diseased soil. The subsurface Fe content ranged from 144.90 to 154.68 mg kg^{-1}. Only slight increment in Fe content was noticed in subsurface soil. The diseased soils registered lowest value and apparently healthy soils reported higher value, but were not significant.

4.2.1.10 Available Manganese

The available Mn content in the surface soil before fertilizer application was recorded between 67.18 to 72.39 mg kg^{-1} (Table 35). There was significant variation in available Mn among soils of different group of palms. The Mn content was found to be lowest for diseased soil and highest for healthy soil. The Mn content at 20-40 cm depth varied from 40.6 to 49.62 mg kg^{-1}. It also showed same trend as that of surface Mn content. The lowest content was recorded for diseased soil and significantly highest content for healthy soil.

The value of available Mn in the surface soil after fertilizer application was between 65.38 to 71.17 mg kg^{-1} (Table 35). There was no significant variation in available Mn among soils of different group of palms. The Mn content was reported to be lowest for diseased soil and highest for healthy soil. The Mn content of subsurface soil ranged from 36.00 to 45.03 mg kg^{-1}. The lowest value was reported for healthy soil and highest value for diseased soil. The soil became more or less homogeneous after fertilization

4.2.1.11 Available Zinc

The value before fertilization in the surface soil ranged from 0.42 to 1.25 mg kg^{-1} (Table 35). The lowest content was reported to be in diseased soil. The healthy soil reported significantly higher value for available Zn. Significant difference was noted between soils of different groups of palm. The subsurface content of Zn was indicated in Table 35. The lowest value of 0.23 mg kg^{-1} was observed in diseased soil and highest value of 0.62 mg kg^{-1} was noticed in healthy soil. There was significant variation in Zn content among soils under different group of palms.

The value of Zn in the surface soil after fertilizer application ranged from 1.18 to 1.27 mg kg^{-1} (Table 35). Diseased soil reported lowest content and healthy soil recorded highest value for Zn. After fertilization the variation of Zn content in soil was reduced and no significant difference was noted between soils of different groups of palm. The subsurface content of Zn is given in Table 35. The lowest value (0.60 mg kg^{-1}) was observed in diseased soil and highest value (0.67 mg kg^{-1}) was noticed in healthy soil. There was no significant variation in Zn content at 20-40 cm depth.

4.2.1.12 Available Copper

The status of available Cu in the surface soil before fertilizer application was given in table 35. The content varied from 0.61 to 3.90 mg kg^{-1}. The lowest content was observed for apparently healthy soil and highest for healthy soil. There was significant difference in Cu content between soils of different palms. The subsurface soil showed a range of 0.44 to 3.38 mg kg^{-1}. The soils under different group of palms differ significantly. Soils under diseased palms showed lowest value, while that of healthy palm showed significantly higher value.

The data indicating the status of available Cu in the surface soil after fertilization is presented in table 35. The content ranged from 3.6 to 4.01 mg kg^{-1}. A uniform increase in Cu content was noticed after fertilization in all the soil under different palms. The lowest content was observed for diseased soil and highest for healthy soil. There was no significant difference in Cu content between soils of different palms. The subsurface soil showed a range of 2.40 to 2.74 mg kg^{-1}. The soils under different group of palms did not differ significantly. Soils of apparently healthy palms showed lowest value, while that of healthy palm showed higher value.

4.2.1.13 Available Boron

The status of available B at 0-20 cm depth before fertilizer application varied from 0.55 to 0.60 mg kg^{-1} (Table 35). The lowest content was observed in diseased affected soil, while highest in healthy soil. The subsurface B content was observed between 0.48 to 0.52 mg kg^{-1}. Soils of diseased area reported lowest value and soil of apparently healthy area reported highest value. But there was no significant difference in B content with respect to soils under different groups of palms.

The values of available B after fertilization varied from 0.44 to 0.46 mg kg^{-1} (Table 35). The lowest content was noticed in healthy soil, while highest content in apparently healthy and diseased soil. The subsurface B content was observed between 0.31 to 0.35 mg kg^{-1}. Apparently healthy soil reported lowest value and diseased affected soil reported highest value. But there was no significant difference in B content with respect to soils under different groups of palms for both the depth after fertilizer application

4.2.1.14 Available Chlorine

Before fertilization available Cl in the surface soil ranged from 55.57 to 60.73 mg kg^{-1} (Table 35). The lowest S content was associated with apparently healthy soil, while highest content with diseased soils. The subsurface Cl content was found to be lowest (42.21 mg kg^{-1}) in diseased soil and highest (46.94 mg kg^{-1}) in apparently healthy soil.

The available Cl in the surface soil after fertilizer application varied from 59.04 to 63.98 mg kg^{-1} (Table 35). The lowest Cl content was noticed in soils under healthy palms, while highest content in soils around diseased palms. The subsurface Cl content was found to be lowest (42.73 mg kg^{-1}) in diseased soil and highest (47.48 mg kg^{-1}) in healthy soil. There was no significant variation in Cl content both at 0-20 cm and 20-40 cm depth.

4.2.1.15 Available Sodium

Table 35 shows the content of Na in surface soil before fertilizer application. It ranged from 31.61 to 28.67 mg kg^{-1}. The soils under different group of palms were comparatively similar in Na content. The lowest value was reported for diseased soils and highest for healthy palms. The Na content at 20-40 cm depth was between 23.61 to 26.17 mg kg^{-1}. No significant difference was noticed between soils of different palms. The diseased soil recorded lowest value and healthy soil reported highest value for Na.

The content of Na ranged from 25.78 to 28.11 mg kg^{-1} in surface soil after fertilizer application (Table 35). The soils under different group of palms were comparatively similar in Na content. The lowest value was reported for apparently healthy soils and highest for diseased palms. The Na content at 20-40 cm depth was between 16.94 to 17.72 mg kg^{-1}. The apparently healthy soil recorded lowest value and diseased soil reported highest value for Na. No significant difference was noticed between soils of different palms at both the depth after fertilization.

4.2.1.16 Exchangeable cations and CEC

The exchangeable cations in the surface soil before fertilizer application was in the range of Na (1.40 to 1.51 cmol(+) kg^{-1}), K (0.41 to 0.49 cmol(+) kg^{-1}), Ca (3.30 to 3.48 cmol(+) kg^{-1}), Mg (1.71 to 1.95 cmol(+) kg^{-1}), Mn (0.03 cmol(+) kg^{-1}), Al (0.01 to .02 cmol(+) kg^{-1}) (Table 36). The CEC varied from 7.06 to 7.28 cmol(+) kg^{-1} (Table 35). The lowest value was reported for root (wilt) affected soil and highest for healthy soils, but the variation in CEC was not significant among palms. In the subsurface soil the exchangeable cations Na, K, Ca, Mg, Mn and Al ranged from 1.38 to 1.48, 0.40 to 0.44, 3.24 to 3.33, 1.69 to 1.77, 0.01 and 0.01 to 0.02 cmol(+) kg^{-1} respectively (Table 35). The lowest value of CEC was for apparently healthy palm (6.87 to 6.97 cmol(+) kg^{-1}) and highest (6.90 cmol(+) kg^{-1}) for healthy palm, but did not differ significantly.

The status of $BaCl_2$ exchangeable cations in surface laterite soil after fertilization is presented in table 36. There was only slight increase in exchangeable cations status after fertilizer application. The exchangeable Na, K, Ca, Mg, Mn and Al were in the range of

1.47 to 1.51, 0.48 to 0.50, 3.42 to 3.5, 1.85 to 1.96, 0.02 to 0.03 and 0.01 to 0.02 cmol(+) kg^{-1} respectively. The exchangeable Mn and Al were very negligible in quantity. The exchangeable Fe, Cu and Zn were under non detectable range. The highest CEC (7.44 cmol(+) kg^{-}) was reported for healthy soil and lowest (7.44 cmol(+) kg^{-}) for root (wilt) affected soil (Table 35). There was no significant variation in CEC between different types palms. The exchangeable cations in the subsurface soil varied from Na (1.38 to 1.48 cmol(+) kg^{-1}), K (0.41 to 0.45 cmol(+) kg^{-1}), Ca (3.26 to 3.35 cmol(+) kg^{-1}), Mg (1.70 to 1.79 cmol(+) kg^{-1}), Mn (0.10 cmol(+) kg^{-1}), Al (0.10 to 0.20 cmol(+) kg^{-1}) (Table 36). As the depth increased, exchangeable cations showed a decreasing trend. The CEC was in the range of 6.90 to 6.95 cmol(+) kg^{-1} (Table 35). The lowest CEC was noticed for diseased soil and highest for healthy soil. Palms did not differ significantly.

4.2.1.17 AEC

The values of AEC before fertilizer application were between 3.36 to 3.42 cmol(-) kg^{-1} (Table 35). The diseased soil recorded highest AEC and healthy soil reported low value. There was no significant difference among palms. The subsurface AEC was in the range of 3.34 to 3.37 cmol(-) kg^{-1}. The highest value was obtained for healthy palms and lowest for diseased palms. Palms did not differ significantly.

The values of AEC in the surface soil were between 3.35 to 3.38 cmol(-) kg^{-1}, after fertilization (Table 35). There was no significant variation among palms with respect to AEC. The lowest AEC was observed for healthy soil and highest for diseased soil. The AEC in the subsurface soil ranged from 3.34 to 3.37 cmol(-) kg^{-1}. Healthy soil reported lowest AEC and diseased soil registered highest value. As like AEC of surface soil, subsurface AEC also showed no significant difference among soil types.

Table 35. Characterisation of laterite soil before and after fertilizer application

Soils/palms	pH	EC	OC	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Cl	Na	CEC	AEC
		(dS m^{-1})	(%)	kg ha^{-1}		mg kg^{-1}										cmol(+) kg^{-1}	cmol(-) kg^{-1}
Surface soil before fertilizer application																	
A1B1	5.77	0.11	0.39	92.66	159.06	357.52	26.93	6.07	147.48	67.18	0.42	0.68	0.55	60.73	28.67	7.06	3.42
A1B2	5.71	0.07	0.38	91.58	170.44	357.49	27.29	5.79	148.34	71.26	0.81	0.61	0.56	55.57	31.11	7.18	3.38
A1B3	5.71	0.07	0.39	88.88	151.06	304.97	27.15	6.02	132.1	72.39	1.25	3.9	0.6	57.55	31.61	7.28	3.36
C.D	**NS**	**NS**	**NS**	**NS**	**NS**	**32.17**	**NS**	**NS**	**7.50**	**NS**	**0.27**	**0.39**	**NS**	**NS**	**NS**	**NS**	**NS**
Subsurface soil before fertilizer application																	
A1B1	5.35	0.07	0.30	77.48	143.56	325.16	26.39	3.33	141.94	49.62	0.23	0.44	0.48	42.21	23.61	6.88	3.34
A1B2	5.49	0.07	0.31	84.62	138.28	318.17	26.83	3.26	143.31	40.6	0.48	0.46	0.52	46.94	25.72	6.87	3.35
A1B3	5.35	0.06	0.33	83.29	116.56	249.21	26.84	3.6	120.7	48.37	0.62	3.38	0.5	46.12	26.17	6.9	3.37
C.D	**NS**	**NS**	**NS**	**NS**	**NS**	**34.83**	**NS**	**NS**	**5.73**	**NS**	**0.16**	**0.31**	**NS**	**NS**	**NS**	**NS**	**NS**
Surface soil after fertilizer application																	
A1B1	5.91	0.19	0.46	95.02	266.78	361.76	28.74	8.92	166.79	65.38	1.18	3.6	0.46	63.98	28.11	7.33	3.38
A1B2	5.89	0.15	0.44	91.96	268.33	353.35	29.05	8.57	162.88	69.88	1.22	3.81	0.46	61.63	25.78	7.38	3.36
A1B3	5.95	0.13	0.46	92.24	276.89	362.31	28.01	7.09	166.51	71.17	1.28	4.01	0.44	59.04	27.94	7.44	3.35
C.D	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Subsurface soil after fertilizer application																	
A1B1	5.65	0.08	0.32	80.52	147.67	331.61	25.56	3.45	144.9	40.51	0.6	2.46	0.35	42.73	17.72	6.92	3.37
A1B2	5.61	0.09	0.33	85.88	148.56	319.23	24.71	3.56	154.68	36	0.61	2.4	0.31	47.01	16.94	6.9	3.35
A1B3	5.69	0.08	0.34	83.4	133.61	313.51	24.29	4.1	149.34	45.03	0.67	2.74	0.33	47.48	17.39	6.95	3.34
C.D	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 36. Exchangeable cations in surface and subsurface soil before and after fertilizer application

Soils/palm	Ex.Na		Ex.K		Ex.Ca		Ex.Mg		Ex.Fe		Ex.Cu		Ex.Zn		Ex. Mn		Ex.Al	
	surface	Subsurface	Surface	Subsurface	Surfaces	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	surface	Subsurface	surface	Subsurfaces	surface	Subsurface
	cmol(+) kg^{-1}																	
Before fertilization																		
A1B1	1.51	1.48	0.49	0.44	3.30	3.24	1.71	1.69	ND	ND	ND	ND	ND	ND	0.03	0.01	0.02	0.02
A1B2	1.46	1.43	0.46	0.42	3.40	3.30	1.82	1.70	ND	ND	ND	ND	ND	ND	0.02	0.01	0.02	0.01
A1B3	1.40	1.38	0.41	0.40	3.48	3.33	1.95	1.77	ND	ND	ND	ND	ND	ND	0.03	0.01	0.01	0.01
After fertilization																		
A2B2	1.51	1.48	0.50	0.45	3.42	3.26	1.85	1.70	ND	ND	ND	ND	ND	ND	0.03	0.01	0.02	0.02
A2B3	1.47	1.43	0.49	0.42	3.50	3.31	1.88	1.72	ND	ND	ND	ND	ND	ND	0.02	0.01	0.02	0.01
A3B1	1.49	1.38	0.48	0.41	3.48	3.35	1.96	1.79	ND	ND	ND	ND	ND	ND	0.02	0.01	0.01	0.01

ND - Not Detectable

4.2.2 Plant analysis before and after fertilization

The leaf samples were collected before and after the application of fertilizer from diseased, apparently healthy and healthy palms and analysed for N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Cl and Na. The results obtained are presented below.

4.2.2.1 Nitrogen

The N content in the foliage before fertilizer application was between 1.90 to 2.59 per cent (Table 37). Significant variation in N content was observed in foliage of different palms. The lowest value was reported for diseased palms and significantly highest value was for healthy palms.

The leaf N after fertilization increased from initial values. It varied from 1.93 to 2.87 per cent (Table 37). Healthy palm showed more accumulation of N in the foliage compared to diseased palm. Different palms differ significantly with respect to N content. The lowest value was reported for diseased palms and significantly highest value was for healthy palms.

4.2.2.2 Phosphorus

The plant available P before fertilization was found to be varied from 0.10 to 0.11 per cent (Table 37). There was only slight variation in P content among the palms. The apparently healthy palms recorded lowest values, while healthy and diseased palms reported similar P content.

The P content in the foliage after fertilizer application was between 0.12 to 0.16 per cent (Table 37). There was significant variation in P content among different categories of palms. The diseased palms recorded lowest values, while healthy palms reported higher P content. P also followed same trend as that of N after fertilization. Uptake of P was more for healthy palms.

4.2.2.3 Potassium

Before fertilizer application leaf potassium level ranged from 0.49 to 0.90 per cent (Table 37). K content significantly differs among different palms. Among different palms diseased palms recorded significantly superior K content, while healthy palms registered lowest content. K accumulation is more in root (wilt) affected palms.

The leaf potassium content after fertilization ranged from 1.06 to 1.53 per cent (Table 37). The K content in the foliage increased by the application of fertilizer. The increase was more for diseased palms followed by apparently healthy palms. Healthy palm recorded lowest content among the palms. The K content significantly differs among different palms. It was noticed that K tend to accumulate more in disease affected palms.

4.2.2.4 Calcium

The calcium content in the leaf before fertilizer application was between 0.36 to 0.78 per cent (Table 37). Palms differ significantly with respect to Ca content. It was observed that diseased palms recorded significantly lower value and healthy palms registered significantly better value for Ca.

After fertilization the Ca content in the foliage of healthy palms increased from 0.78 to 0.84 per cent (Table 37). The values of calcium in the leaf of diseased palms decreased to 0.34 per cent. Palms differ significantly with respect to Ca content. It was noticed that diseased palms recorded significantly lower value and healthy palms registered significantly better value for Ca even after soil test based fertilization.

4.2.2.5 Magnesium

The content of Mg before fertilization in the leaf tissue is given in table 37. Mg content ranged from 0.15 to 0.29 per cent. Mg also showed same trend as that of Ca. There was significant difference among palms with respect to Mg. The lowest Mg content was recorded for diseased palms and significantly higher values for healthy palms. The apparently healthy palm had slightly higher Mg content than diseased palms.

The content of Mg in the foliage after fertilization increased from a value of 0.29 to 0.35 per cent in healthy palms, while the increase in diseased affected palm was very less (0.15 to 0.16 per cent). As the severity of the diseased increases the uptake of Mg was also affected. Healthy palms showed more uptake of Mg, followed by apparently healthy and least by root (wilt) affected palms (Table 37).

4.2.2.6 Sulphur

The S content in the leaf was recorded between 0.23 to 0.24 per cent (Table 37). Diseased palms reported lowest values and apparently healthy and healthy palms reported highest value. There was no significant difference in S content among the palms.

The leaf S content after fertilization ranged 0.24 to 0.29 per cent (Table 37). Diseased palms reported lowest values and apparently healthy reported highest value. The S content tends to increase in the foliage of healthy palm after fertilization, where as it remain same for diseased palms. Significant variation in S content was noticed among palms.

4.2.2.7 Iron

The content of Fe in the foliage before fertilizer application was given in table 37. The values were between 168.80 to 266.62 ppm. There was significant variation with respect to Fe content among foliage of different palms. The lowest value was observed in diseased palms and highest value was noticed in healthy palms.

The content of Fe in the foliage after fertilization became 168.97 to 292.61 ppm (Table 37). There was significant difference in leaf Fe content among palms, even after soil test based fertilizer was applied. The lowest value was observed in diseased palms and highest value was noticed in healthy palms. The increase in Fe content was more for healthy palms compared to diseased palms.

4.2.2.8 Manganese

The leaf Mn content was observed between 180.24 to 326.22 ppm before fertilizer application (Table 37). The diseased palms showed lowest value, while healthy palms recorded significantly highest value followed by apparently healthy palms. Mn also shows same trend as that of Ca, Mg and Fe.

After fertilizer application same trend was followed. The leaf Mn content varied from 173.14 to 366.49 ppm (Table 37). In diseased palms a decrease in Mn content was noticed, while in healthy palm the content increased after fertilization. Mn also showed same trend as that of Ca, Mg and Fe.

4.2.2.9 Zinc

The content of Zn in the foliage before application of fertilizer varied from 26.96 to 34.02 ppm (Table 37). There was significant difference between palms with respect to Zn. The lowest value was noticed in diseased palms and significantly highest value in healthy palms.

After application of fertilizer the Zn content in foliage was 26.43 to 39.59 ppm (Table 37). Significant difference was noticed between palms with respect to Zn. Decreasing trend was noticed in diseased palms and increasing trend was observed in healthy palm.

4.2.2.10 Copper

The data on leaf Cu content before fertilisation is presented in table 37. The content ranged from 3.98 to 6.98 ppm. Cu also showed same trend as that of Ca, Mg, Fe, Mn and Zn. The Cu content varied significantly with respect to palms. The lowest content was estimated in diseased palms. The healthy palms recorded significantly highest value followed by apparently healthy palms.

The Cu content in the leaf after fertilization varied from 4.04 to 7.3 ppm (Table 37). It varied significantly with respect to palms, even after the application of fertilizer. The lowest content was noticed in diseased palms. The healthy palms registered significantly highest value followed by apparently healthy palms. In diseased palms only slight increase in Cu content was observed after soil test based fertilization.

4.2.2.11 Boron

The B content in the leaf was recorded between 4.99 to 5.82 ppm (Table 37). There was significant variation in B content among the palms. The diseased palms reported lowest content and healthy palm recorded highest content.

After fertilizer application also the B content in the leaf varied significantly. It was between 5.20 to 6.10 ppm (Table 37). The diseased palms reported lowest content and healthy palm recorded significantly highest content. The increment in foliage B concentration is more for healthy palms.

4.2.2.12 Chlorine

The leaf Cl content varied from 0.51 to 0.54 per cent before fertilization (Table 37). Palms showed only slight variation in Cl content and it was not significant also. The lowest value was recorded by healthy palms while diseased and apparently healthy palms showed similar content.

After application of fertilizer the Cl content became 0.54 to 0.58 per cent (Table 37). Palms showed slight variation in Cl content and it was not significant also. The content was more for healthy palms and less for apparently healthy and diseased palms.

4.2.2.13 Sodium

The content of Na in the foliage before fertilisation was observed between 0.58 to 0.64 per cent (Table 37). There was no significant difference in Na content among palms. The apparently healthy palm showed lowest value, while diseased palms reported highest value.

The leaf Na after fertilisation was between 0.56 to 0.61 per cent (Table 37). There was no significant difference in Na content among palms. The healthy palm showed lowest value, while diseased palms reported highest value. The accumulation of Na is more for root (wilt) affected palms, but was not significant.

Table 37. Leaf nutrient content in coconut palms before and after fertilization

Soils/palms	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Cl	Na
	(%)						(ppm)					(%)	
Leaf nutrients before fertilization													
A1B1	1.9	0.11	0.9	0.36	0.15	0.23	168.8	180.24	26.96	3.98	4.99	0.54	0.64
A1B2	2.56	0.1	0.67	0.43	0.16	0.24	177.31	195.51	29.62	5.49	5.09	0.54	0.58
A1B3	2.59	0.11	0.49	0.78	0.29	0.24	266.62	326.22	34.02	6.98	5.82	0.51	0.59
C.D	**0.22**	**NS**	**0.08**	**0.11**	**0.03**	**NS**	**23.21**	**35.66**	**4.7**	**1.28**	**0.58**	**NS**	**NS**
Leaf nutrients after fertilization													
A1B1	1.93	0.12	1.53	0.34	0.17	0.24	168.97	173.14	26.43	4.04	5.2	0.55	0.61
A1B2	2.69	0.13	1.25	0.5	0.26	0.29	178.94	209	30.68	5.51	5.4	0.54	0.58
A1B3	2.87	0.16	1.06	0.84	0.35	0.28	292.61	366.49	39.59	7.3	6.1	0.58	0.56
C.D	**0.09**	**0.02**	**0.20**	**0.06**	**0.04**	**0.04**	**16.92**	**26.08**	**3.31**	**1.51**	**0.48**	**NS**	NS

NS – Not Significant

4.2.4 Absorption and translocation of ^{32}P by coconut palms

^{32}P was applied to three type palms namely diseased (B1), apparently healthy (B2) and healthy (B3) by three methods namely cotton pad technique (M1), root feeding (M2) and soil injection (M3). The index leaf was sampled at 1, 15 and 30 days after application and radioassayed for ^{32}P activity. The results obtained are given below.

4.2.4.1 ^{32}P counts in the sample, 24 hours after application

The ^{32}P count in the leaf sample 24 hours after application was significantly influenced by both method of application and type of palms. The counts ranged from 263.00 cpm g^{-1} to 581.67 cpm g^{-1} (Table 38). Among different palms diseased palms showed lowest count and healthy palms obtained higher count rates. The count rate of ^{32}P in root (wilt) affected palms was highest, when cotton pad method was followed and for healthy palms root feeding was best. The count rate obtained in the roots and soil after 24 hours is negligible except for soil injection method.

Table 38. ^{32}P counts in the leaf sample, 24 hours after application

Palms/methods	M1	M2	M3	Mean B
B1	331.33 (2.51)	263.00 (2.41)	297.33 (2.47)	297.22 (2.47)
B2	386.00 (2.59)	347.67 (2.54)	342.00 (2.53)	358.56 (2.55)
B3	388.67 (2.59)	581.67 (2.77)	380.67 (2.58)	450.33 (2.65)
Mean M	368.67 (2.56)	397.45 (2.58)	340.00 (2.53)	

C.D (M) – 0.05; C.D (B) – 0.05; C.D (MxB) – 0.08

The data in the parenthesis are log-transformed values

4.2.4.2 ^{32}P counts in the sample 15 days after application

The count varied from 1,206.30 to 31,254.07 cpm g^{-1} (Table 39). There was significant difference among method of application and type of palms with reference to the count rate of ^{32}P. Maximum count was obtained 15 days after application. The highest count was recorded by healthy palms and lowest by disease affected palms. Among different method of application root feeding account for highest count in healthy palms whereas cotton pad technique showed highest count in the case of diseased palms. For apparently healthy palm root feeding was the best method, since it provided higher count rate. It was noted that count rate in soil and roots after 15 days was zero, except for soils in which soil injection was done.

Table 39. ^{32}P counts in the leaf sample, 15 days after application

Palms/methods	M1	M2	M3	Mean B
B1	29,111.26 (4.46)	1,206.30 (3.08)	6,840.93 (3.83)	12,386.16 (3.79)
B2	20,702.50 (4.26)	11,523.34 (4.03)	7,263.84 (3.82)	13,163.23 (4.04)
B3	25,210.09 (4.39)	31,254.07 (4.49)	16,710.64 (4.21)	24,391.60 (4.36)
Mean M	25,007.95 (4.37)	14,661.24 (3.87)	10,271.80 (3.95)	

C.D (M) – 0.16; C.D (B) – 0.16; C.D (MxB) – 0.28

4.2.4.3 ^{32}P counts in the sample, 30 days after application

The count rate obtained after 30 days was between 25,158.66 to 1,068.38 cpm g^{-1} (Table 40). There was a decrease in ^{32}P count after 30 days. The count after 30 days showed same trend as that of 15 days after application. The ^{32}P count significantly varied among different type of palms and method of application. The healthy palm reported highest count, while diseased palms registered lowest count. Root feeding was reported to be the best method of radioisotope application for healthy palms. In the case of diseased palms cotton pad technique was significantly superior to other method of application. The count rate obtained in roots and soil after 30 days of application is similar to the count rate at 24 hours and 15 days after application.

Table 40. ^{32}P counts in the leaf sample, 30 days after application

Palms/methods	**M1**	**M2**	**M3**	**Mean B**
B1	17,850.07 (4.25)	1,068.38 (2.97)	3,984.57 (3.56)	7,634.34 (3.59)
B2	15,352.98 (4.15)	6,135.37 (3.75)	4,842.06 (3.64)	8,776.80 (3.84)
B3	18,049.49 (4.26)	25,158.66 (4.40)	9,105.28 (3.95)	17,437.81 (4.20)
Mean M	17,084.18 (4.22)	10,787.47 (3.70)	5,977.30 (3.71)	

C.D (M) – 0.19; C.D (B) – 0.19; C.D (MxB) – 0.33

Discussion

5. DISCUSSION

The results of the present study given in section 4 are discussed critically with supporting evidences as well as the related studies from the literature. Absorption and translocation studies were also carried to unravel the absorption and translocation pattern of nutrients in diseased palms compared to healthy palms.

Experiment 1

Three soil types (laterite, sandy and black cotton soil) from two depth (0-20 and 20-40 cm) and three types of palms (diseased, apparently healthy and healthy palms) have been characterised initially. This was carried out with the objective of understanding nutrient imbalance if any, in root (wilt) affected palms compared to healthy palms.

5.1 Basic characterisation of major coconut growing soils of Kerala

5.1.1 pH

The data on pH of both surface and subsurface of three soil types are presented in table 3 (Fig.1). The data on soil pH clearly indicated that laterite and sandy soil were confronted with the problem of acidity. The laterite soil is moderately acidic with a variation in pH from 5.65 to 5.72, while sandy soil is strongly acidic with pH ranged from 5.29 to 5.42. The acidic nature of parent rock, leaching of bases due to high rainfall and intensive weathering condition are the factors contributing to acidity. The black cotton soil of Chittur area comes under the neutral to alkaline range with a mean value of 7.92, which is highest among the collected samples. There was distinct variation in pH with depth. The pH was found to decrease with depth. No significant difference was noticed in pH among different palms.

5.1.2 EC

The EC was lowest for laterite soil with mean value of 0.08 dS m^{-1}. The process of laterisation, which leads to leaching out of basic cations and accumulation of iron and aluminium oxides on surface horizon, would have lowered the EC. The highest EC was obtained for sandy soil due to the presence of more amount of soluble salt like sodium and chlorine, since the location was near to sea and hence was influenced by sea water. EC also tend to decrease with depth, it also showed similar trend as that of surface EC (Fig. 2).

Fig.1 pH of different soil types under different palms

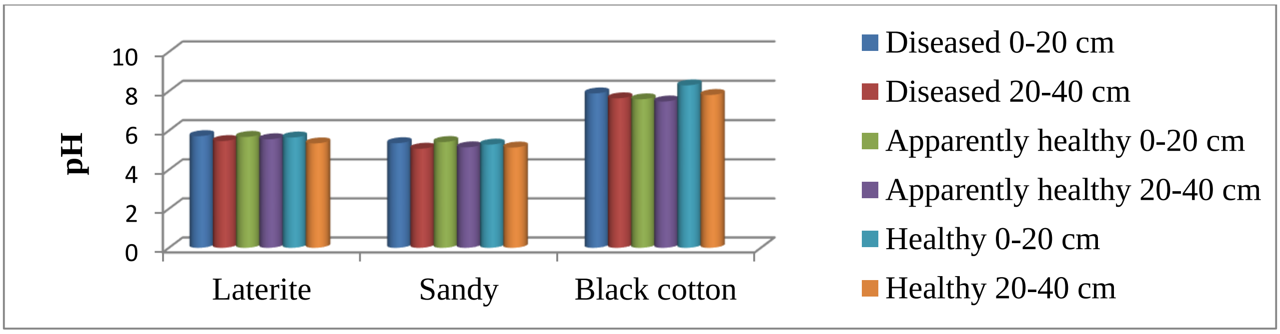


Fig. 2 EC of different soil types under different palms

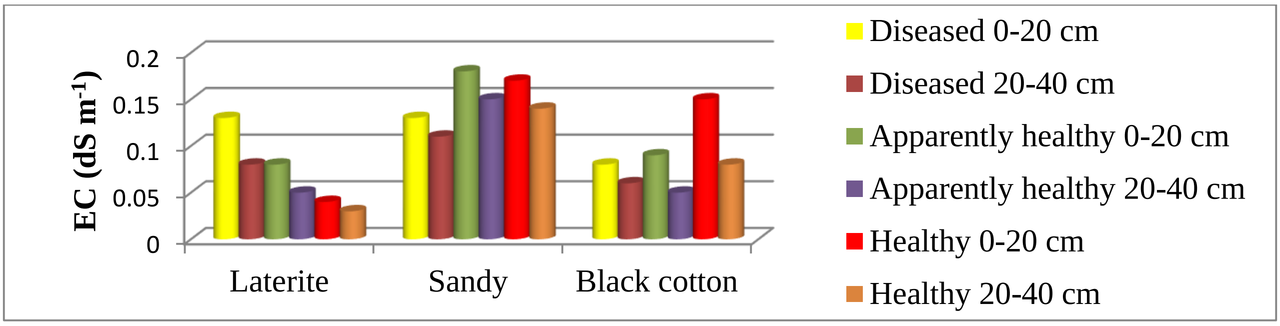


Fig. 3 CEC of different soil types under different palms

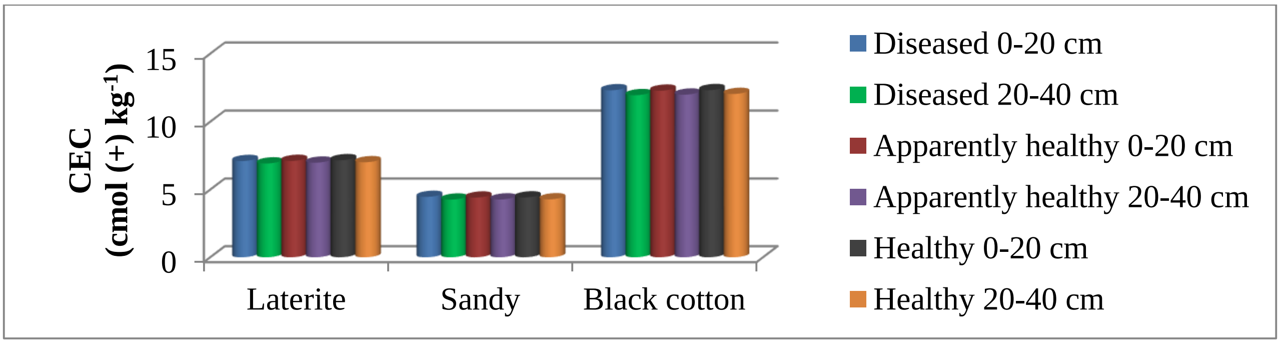
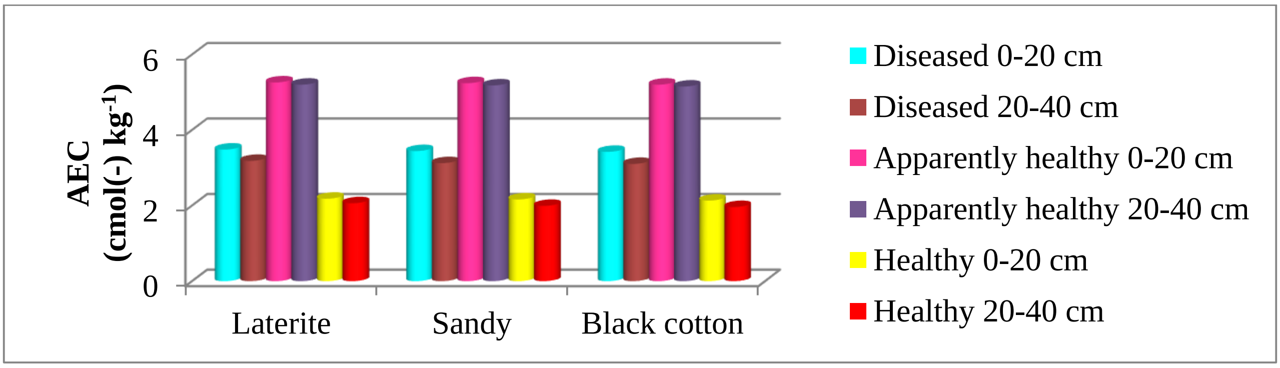


Fig. 4 AEC of different soil types under different palms



5.1.3 CEC and AEC

The lowest CEC was observed in sandy soils and highest in black cotton soil (Fig. 3). Sandy soil with very little organic matter and clay having low CEC, but heavy clay soils with high level of organic matter have a much greater capacity to hold cations. Both the clay particles and the organic matter have negatively charged sites that can attract and hold positively charged particles. Lower the CEC, the faster will be the decline in soil pH with time which emphasis sandy soils need to be limed more frequently than clay soils.

The AEC was higher for sandy soil and lower for black cotton soil (Fig. 4). Dean and Rubins (1947), reported that the sandy soil which do not have excess amount of Ca or Mg, substitute phosphate ion for hydroxyl ion. An appreciable amount of AEC may occur only on those soils containing high amount of Al and Fe oxides or hydroxides with low amount of soil organic substances. This may be the reason for higher AEC of sandy soil. Soils containing montmorillonite generally exhibit low AEC, this contributes to the lower AEC in black cotton soil. Both AEC and CEC decrease with depth. As the depth increases the organic matter and basic cations also decreases, and there by CEC also decreases. The higher AEC in sandy soil might also be due to over estimation of bound phosphorus resulting from interference of silica.

5.1.4 Organic carbon

The data on nutrient status of major coconut growing soils are presented in table 5 (Fig. 5). The sandy soil reported lowest value for organic carbon with mean value of 0.28 per cent in surface soil and 0.15 per cent in subsurfaces soil followed by laterite soil (0.39 per cent in surface soil and 0.32 per cent in subsurface soil). There was no significant difference in organic carbon among soils around different palm within same soil type. Both the soils (laterite and sandy) were deficient in organic carbon. The low organic carbon of sandy soil might be due to the association of free or labile organic matter which is easily lost from light textured sandy soil. Low organic carbon content of laterite soil is characteristic of tropical soil. Rapid mineralisation and decomposition of organic matter under high temperature of the area leads to its depletion (Brady, 1988). The organic carbon content in black cotton soil is in medium range. The soils under different categories of palms show almost similar status of organic carbon.

5.1.5 Available Phosphorus

The available P was found to be highest in laterite soil followed by sandy soil and lowest in black cotton soil for both surface and subsurface soil (Fig. 6). The available P in soil around different group of palms within same soil type was more or less similar. High P in sandy soil might be due to continuous application of P fertilizers and less P fixation. In general the availability of P is low in laterite soils due to fixation by Fe and Al. But the result obtained in the present study indicated that laterite soil contain high amount of available P, due to continuous application of P fertilizers, which might have saturated the P binding sites. This result is in agreement with the result obtained by Deepa (1995) in laterite soils. The increase in the available P content may be due to high sesquioxide and kaolinite clays content, having high P adsorption capacities. They rapidly adsorb added soluble phosphates since the soil is acidic in nature, and they slowly become available during the course of time.

5.1.6 Available Potassium

The highest content of available K in the surface soil was recorded for laterite soil followed by sandy soil and lowest by black cotton soil (Fig. 7). In the subsurface soil the K content was more for sandy soil followed by laterite and deficient in black cotton soil. The content of K in sandy as well as laterite soil is in medium range for both surface and subsurface soil. It may be because of intensive leaching and also due to dominance of 1:1 type low activity clay which could not retain K at all. The dominant clay mineral in black cotton soil is montmorillonite (2:1 mineral), where the K fixation is reported to be more. The content of available K in soils around diseased palms was comparatively less compared to healthy and apparently healthy palms. The lower level of available K in soil around diseased palms had been reported by many workers (Menon *et al*., 1950, 1952; Sankarasubramoney *et a*l., 1954, 1955, 1956; Pandalai *et al*., 1958a, 1958b; Menon, 1961; Verghese 1961; Lal, 1964, 1968). The result obtained in this study agrees with their reports. Low K status of soil may be one of the reasons for expressing the root (wilt) symptom.

5.1.7 Available Calcium

The content of calcium ranged from 147.82 to 587.43 mg kg^{-1} in surface soil and 41.36 to 570.73 mg kg^{-1} in subsurface (Fig. 8). Black cotton soil reported highest amount of Ca followed by laterite and lowest by sandy soil for both surface and subsurface samples. Samples under different palms of same soil type did not differ significantly with respect to available Ca. Sandy soils were deficient in Ca, while laterite soils and black cotton soils were sufficient in Ca. The nature of clay influences the availability of Ca in the soil. Higher content of Ca in black cotton soil is due to the presence of 2:1 type clay mineral and low leaching. High Ca status of laterite soil may be due to continuous liming of soil as well as due to less frequency in rainfall.

Fig. 5 Organic carbon of different soil types under different palms

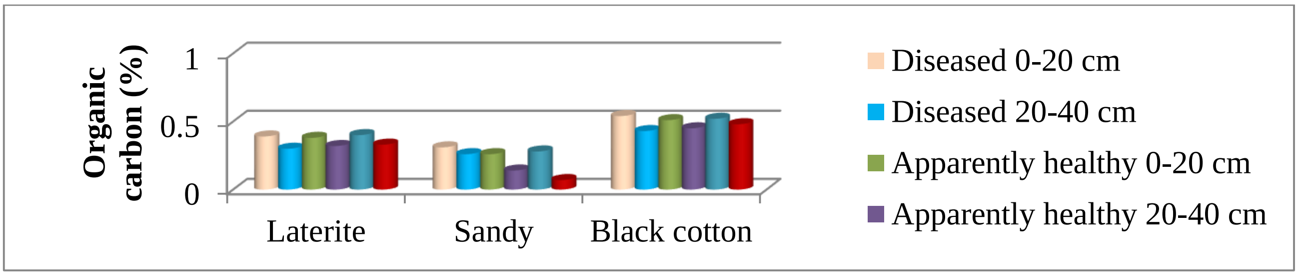


Fig. 6 Available P of different soil types under different palms

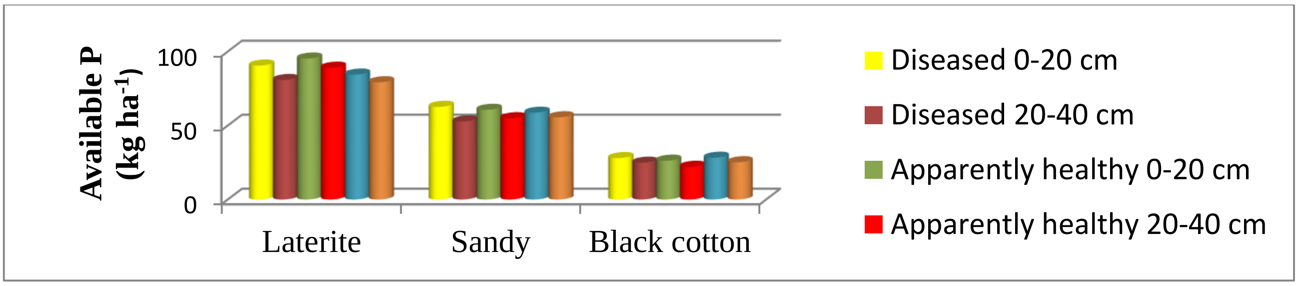


Fig. 7 Available K content of different soil types under different palms

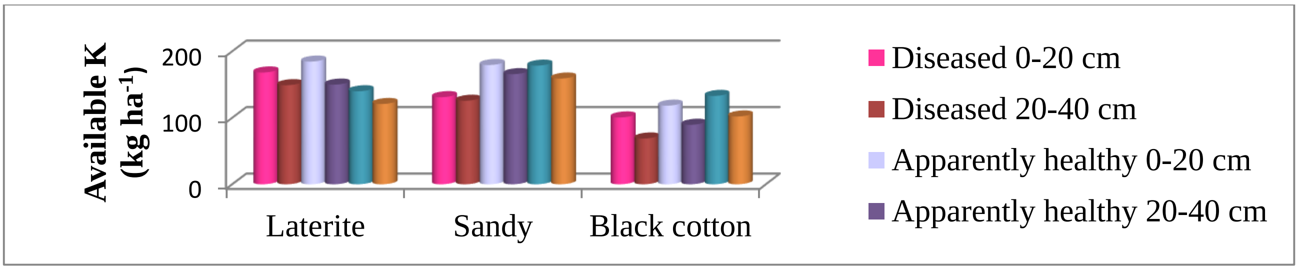
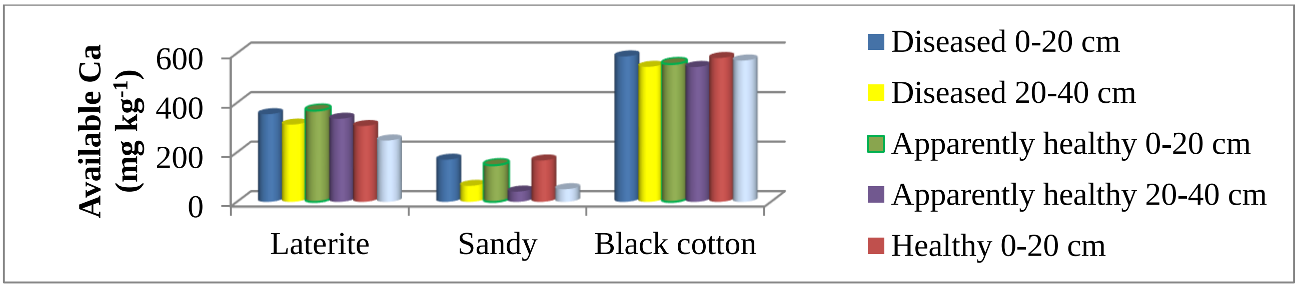


Fig. 8 Available Ca content of different soil types under different palms



5.1.8 Available Magnesium

Major coconut growing soils of Kerala was found to be deficient in available Mg. It ranged from 30.69 to 119.03 mg kg^{-1} in surface soil and 17.36 to 113.75 mg kg^{-1} in subsurface soil (Fig. 9). The lowest Mg content was reported for sandy soil followed by laterite and highest by black cotton soil. The soils with low pH and CEC and high content of K or Ca decreases Mg availability to the crop. Leaching due to heavy rainfall also may cause low availability of Mg in the soil. There was significant difference in Mg content among soils under different palms within same soil type. Comparatively more amount of Mg was observed in soils under diseased palms compared to healthy palms except in apparently healthy soil of surface samples of black cotton soil. This may be due to less uptake of Mg by diseased palms resulting in Mg accumulation.

5.1.9 Available Sulphur

The available S content ranged from 3.23 to 6.66 mg kg^{-1} in surface soil and 1.91 to 4.81 mg kg^{-1} in subsurface soil (Fig. 10). The surface soil except black cotton soil and all the subsurface soil was found to be deficient in sulphur content. The low content of S in the soil might be due to the leaching loss of sulphate ions and may be due to the adsorption of sulphate ions by Fe and Al oxides in laterite soil (Brady, 1988). It may also be attributed to low organic matter status.

5.1.10 Available Iron

The Fe content in surface and subsurface soil varied from 112.35 to 148.80 mg kg^{-1} and 86.08 to 141.78 mg kg^{-1} respectively (Fig. 11). The Fe content was very high in all the soil at both the depth. Presence of oxides of Fe and leaching of basic cations from the surface layers of the soil due to heavy rainfall may be the reason for high Fe content. The soils differ significantly with respect to Fe content and it was highest for laterite soil, which is the characteristic of laterite soil (Padmam, 1992).

5.1.11 Available Manganese

The available Mn in the surface soil was between 11.85 to 63.98 mg kg^{-1} and 6.70 to 68.33 mg kg^{-1} in subsurface soil (Fig. 12). All the soils are sufficient in available Mn. Highest value was reported for laterite soil. The values reported by Padmam (1992) based on studies conducted on the permanent manurial trials at Pattambi also comes under this range. More amount of Mn was reported from soils around healthy soil. Pillai *et al.* (1975) also observed that soils of diseased area have lower level of Mn. This result lends support to the finding of the present study.

Fig. 9 Available Mg content of different soil types under different palms

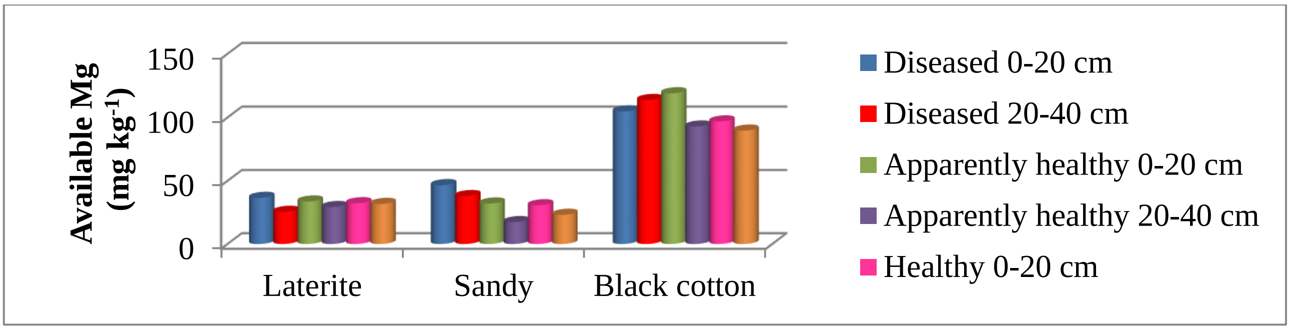


Fig. 10 Available S content of different soil types under different palms

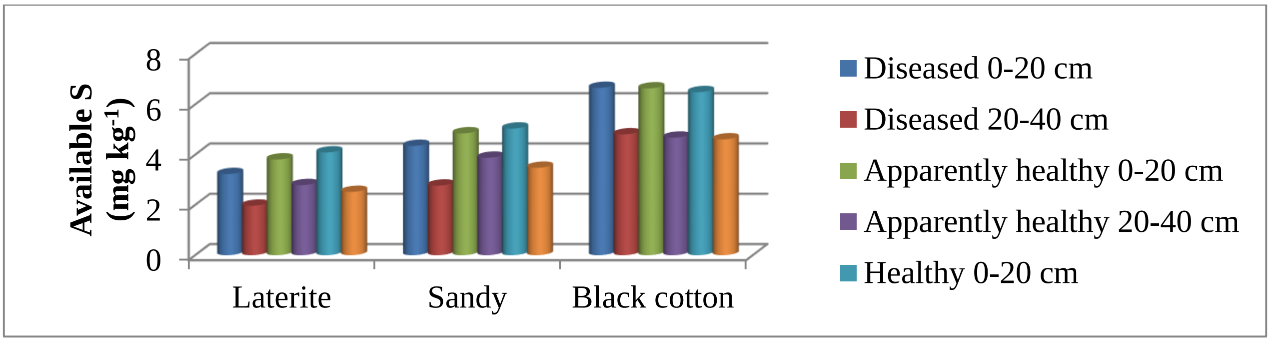


Fig. 11 Available Fe content of different soil types under different palms

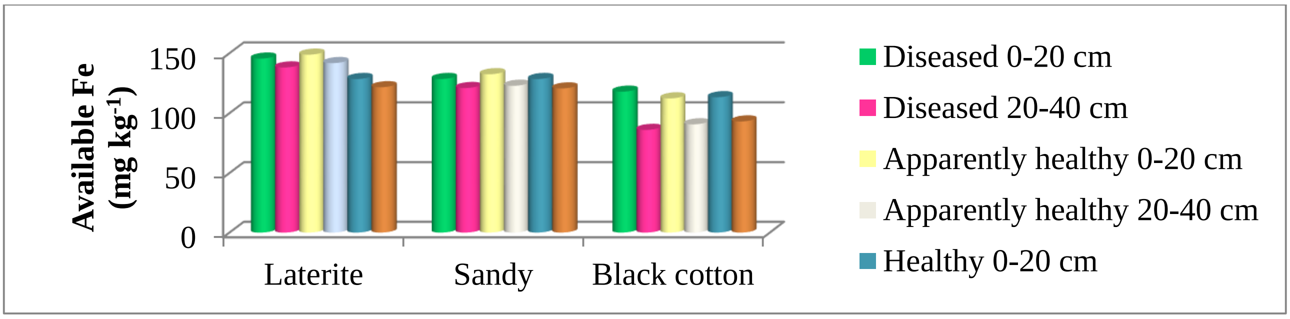
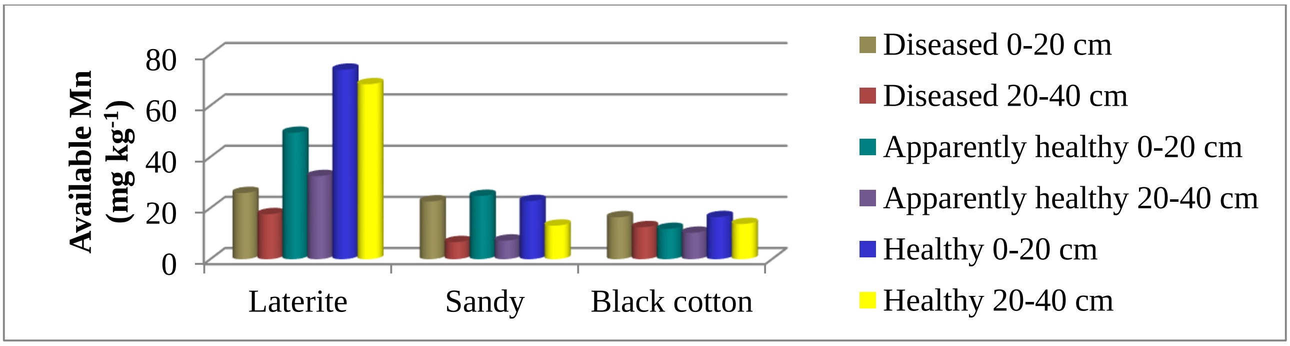


Fig. 12 Available Mn content of different soil types under different palms



5.1.12 Available Zinc

The content of Zn ranged from 0.50 to 1.38 mg kg^{-1} in surface soil and 0.27 to 0.65 mg kg^{-1} in subsurface soil (Fig. 13). All the three soils were significantly deficient in Zn (<1 mg kg^{-1}). The lowest content was observed in sandy soil and highest content in black cotton soil. There was significant difference with respect to Zn content around soils of different palms within same soil type. Higher content of Zn was noticed in soils around healthy palms compared to apparently healthy and diseased palms. The result was also in agreement with the findings of Sankarasubramoney *et al.* 1954, 1955, 1956 and Pandalai *et al.* 1958a, 1958b, 1959a and 1959b.

5.1.13 Available Copper

Available Cu in the surface and subsurface was found to be highest in laterite soil with a mean value of 1.92 mg kg^{-1} and 1.52 mg kg^{-1} respectively (Fig. 14). The surface soil is sufficient in Cu content, while in subsurface soil all the soil except laterite was deficient in available Cu. Copper is retained very strongly in organic soils and such in soluble complexes are responsible for low availability of Cu in black cotton soil. There was a significant variation in Cu content among palms and soil type. Among different palms soils around healthy palms showed more Cu content than diseased. Similar result was also reported by Biddappa and Cecil (1984) and Biddappa (1985).

5.1.14 Available Boron

The hot water extractable boron in the surface soil ranged from 0.20 to 0.65 mg kg^{-1} and 0.16 to 0.56 mg kg^{-1} in the subsurface soil (Fig 15). Boron was deficient in sandy and black cotton soil both in surface and subsurface. This might be due to leaching of soluble form of B along with bases under the influence of tropical climate. Boron was sufficient in laterite soil, due to regular boron application. Significant variation was observed among soil around different palms within similar soil type. B estimated was higher in soil around healthy palm.

5.1.16 Available Chlorine

The content of Cl ranged from 50.70 to 94.21 mg kg^{-1} in surface soil and 28.81 to 82.21 mg kg^{-1} in subsurface soil (Fig. 16). The content varied significantly among soil types. High Cl content was reported for sandy soil, since the location is near to sea and hence was influenced by sea water.

5.1.17 Available Sodium

The Na content was between 27.25 to 58.38 mg kg^{-1} in surface soil and 22.25 to 35.50 mg kg^{-1} in subsurface soil (Table 17). There was significant variation in Na content among soil type. The content was more for sandy soil and lowest for laterite soil for both the depth (0-20 and 20-40 cm). The content was comparatively similar for soils around different group of palms. Vicinity to the sea may be the reason for higher Na content in sandy soil.

5.1.17 Exchangeable cations

In all the soil except sandy soils, the dominant cation in the exchangeable site was calcium, where as exchangeable Na was the dominant cation in sandy soils. The reason for low value of exchangeable Ca in sandy soil could be that the parent material on which soil has developed is poor in bases (Tomasic *et al*., 2013) resulted from leaching of bases under tropical humid environment.

The order of dominance of exchangeable cations was Ca> Mg> Na> K> Mn> Al in laterite soil, Na> Ca> Mg> K in sandy soil and Ca> Mg> Na> K> Mn> Al in black cotton soil. Exchangeable Fe, Cu and Zn were under non detectable level in laterite and black cotton soil, in addition to this exchangeable Al and Mn in sandy soil was under non detectable level (Table 19).

Fig. 13 Available Zn content of different soil types under different palms

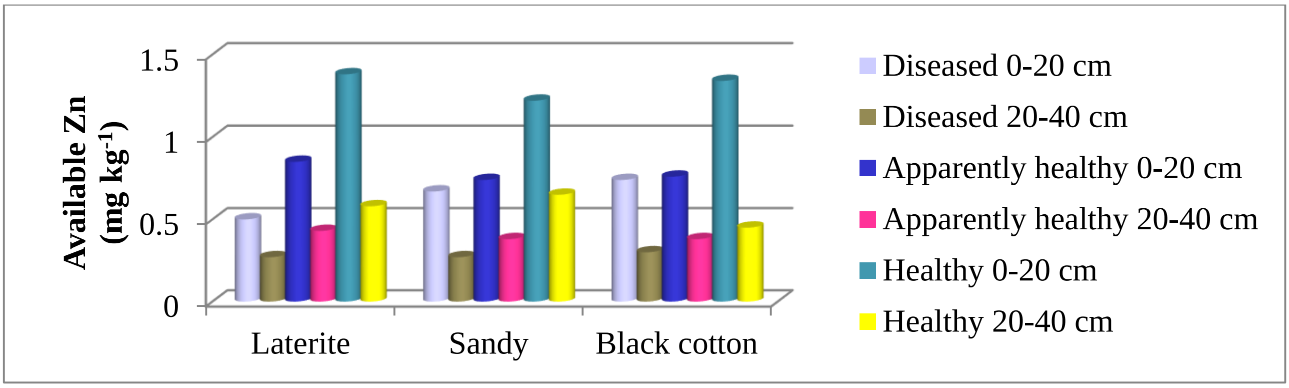


Fig. 14 Available Cu content of different soil types under different palms

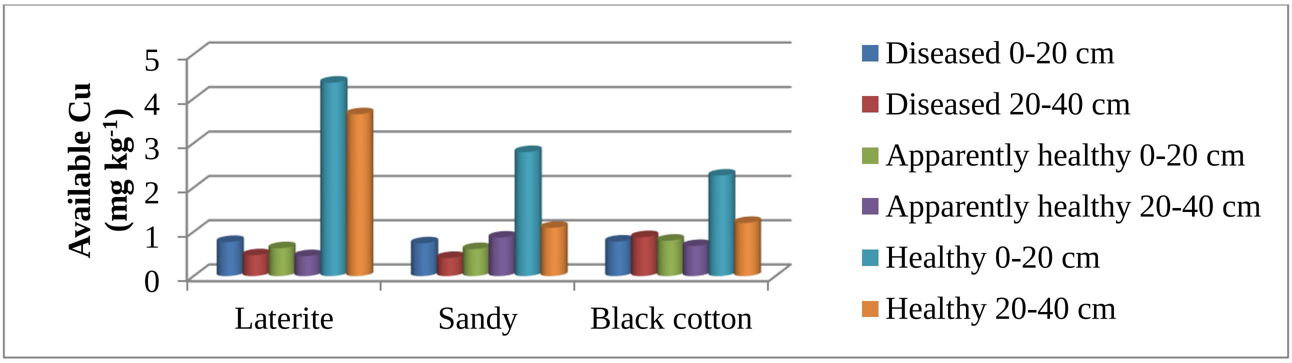


Fig. 15 Available B content of different soil types under different palms

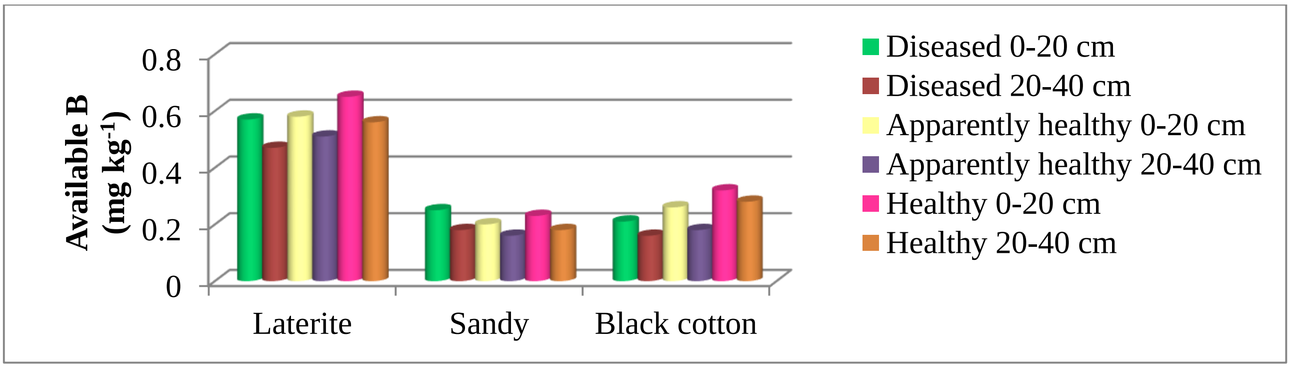
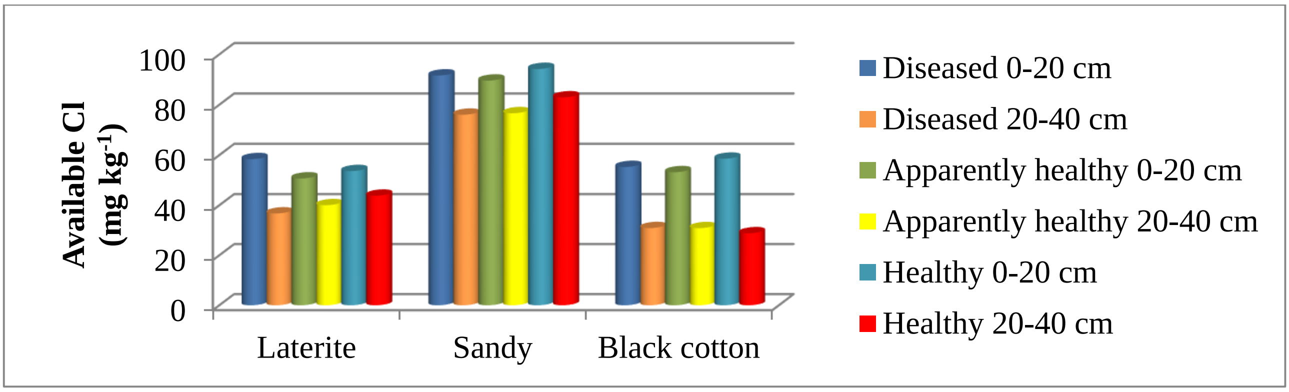


Fig. 16 Available Cl content of different soil types under different palms



5.2 Plant anlaysis

5.2.1 Primary nutrients

The N, P and K content in the index leaf varied from 1.16 to 2.66, 0.09 to 0.1 and 0.33 to 0.94 per cent respectively (Fig. 17, 18, 19). There was significant difference in nitrogen content among both palms and soil types. The N content was highest for palms in black cotton soil and lowest for palms in sandy soil. This is in proportion to organic matter content. Among palms, diseased palms tend to accumulate less N compared to healthy palms. The reason may be due to inadequate absorption of N from the soil to disease affected palms. No significant variation was noticed in P absorption by different palms in different soil, which may be due to low requirement of P by the crop compared to N. There was a significant difference in available K content among palms under different soil type. Available K was found to be accumulated more in the diseased palms compared to healthy palms. Wahid *et al.* (1998) and Sankarasubramoney *et al.* (1952) also got similar finding. This may be due to two reasons; either physiological processes, that convert constituents in the plant sap to prepared food product may get impaired or by inadequate translocation of these plant product to other parts of the plant. More data is required to arrive at clear cut conclusion. Rhind *et al.* (1937) also reported the accumulation of most needed element in the phyllody affected sesamum plants.

5.2.2 Secondary nutrients

The leaf Ca was in the range of 0.33 to 0.80 per cent, Mg was between 0.12 to 0.57 per cent and S varied from 0.14 to 0.24 per cent (Fig. 20, 21, 22). There was significant variation in Ca and Mg content among different soils and also in palms. But for S significant variation was noticed only among different soil types and not within palms in same soil type. The Ca and Mg content of healthy palms were significantly higher than that of diseased palms. Healthy palms in all the soil type absorb more amount of Ca and Mg compared to diseased palms. Compared to the critical levels of Ca and Mg (Ca-0.5% and Mg- 0.3 %, critical levels according to IRHO standards), the content of same in samples collected from diseased areas were considerably lower. Pillai (1959) and Cecil (1969) also reported lower level of Ca and Mg in the foliage of diseased palms. The Ca and Mg content of apparently healthy palms were also significantly lower than healthy palms as well as below the critical limit. It indicates that even though the apparently healthy palms do not show any visible symptoms of the disease, but they suffer from Ca and Mg deficiency, may be in a state of hidden hunger. The present study indicates that disease affected palms lacks adequate levels of Ca and Mg in the foliage pointing to the deficiency of these elements in the tissues. This may be due to lack of active roots or due to limited rate of regeneration of new roots in disease affected palms which will affect the absorption of nutrients from the soil.

Fig. 17 Leaf Nitrogen content of different type palms under different soil

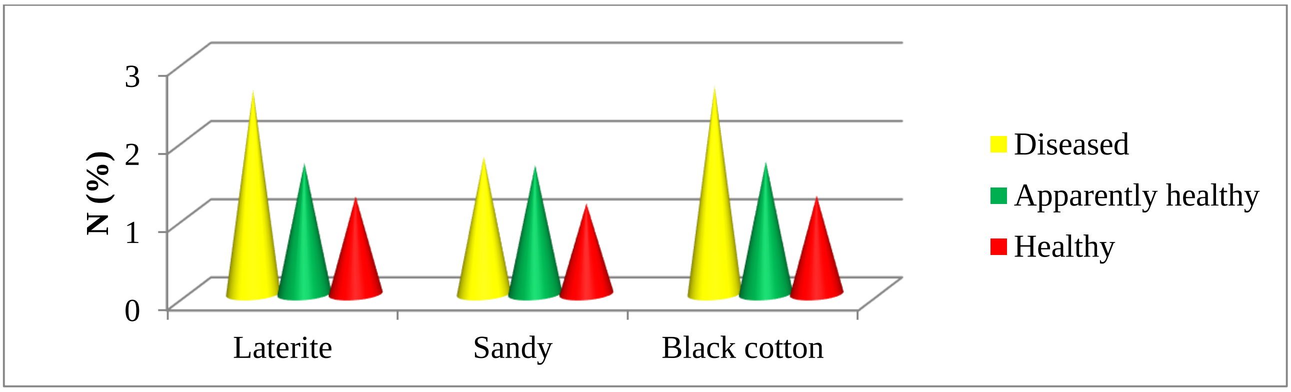


Fig. 18 Leaf Phosphorus content of different type palms under different soil

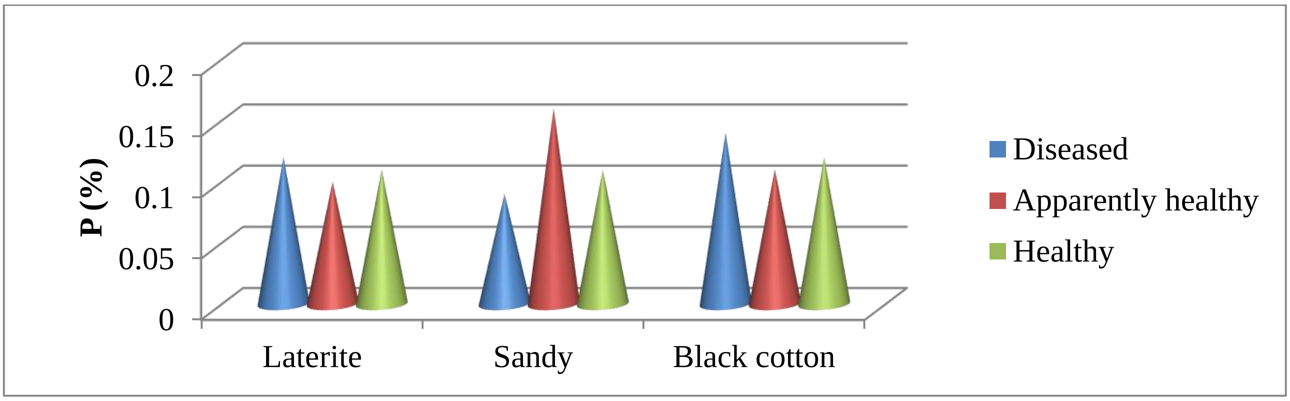


Fig. 19 Leaf Potassium content of different type palms under different soil

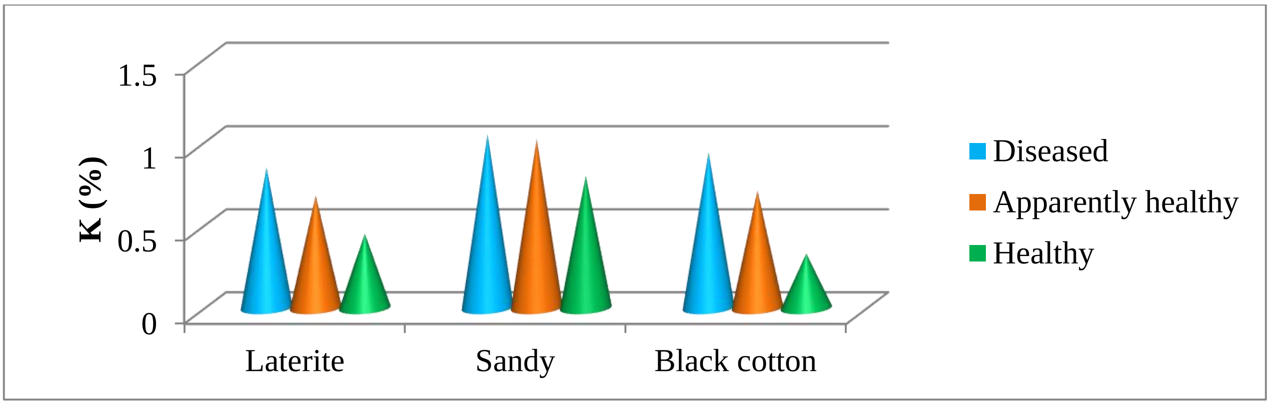


Fig. 20 Leaf Calcium content of different type palms under different soil

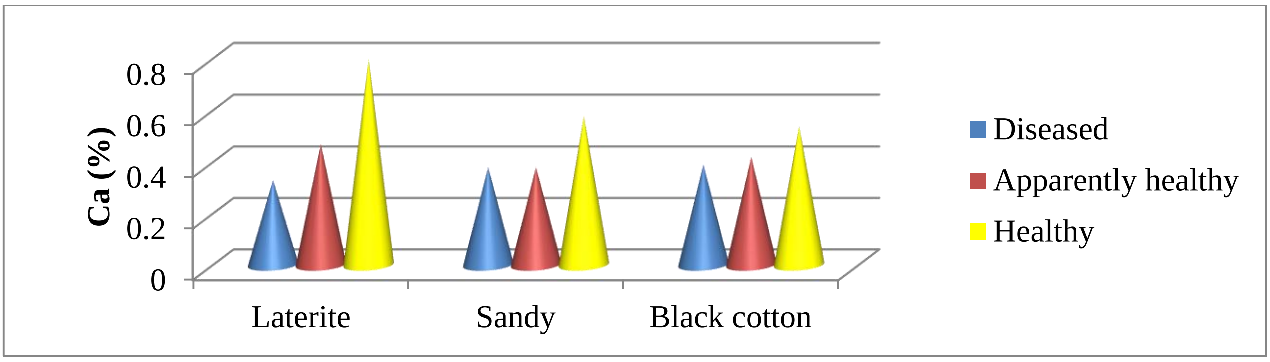


Fig. 21 Leaf Magnesium content of different type palms under different soil

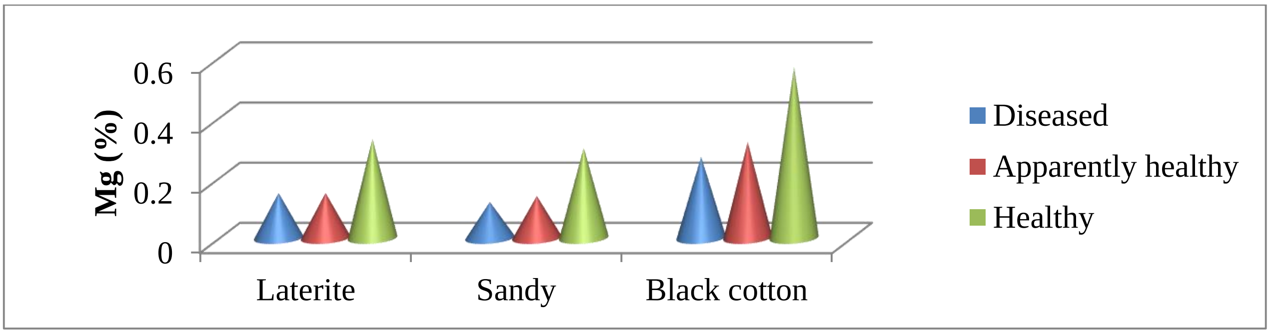


Fig. 22 Leaf Sulphur content of different type palms under different soil

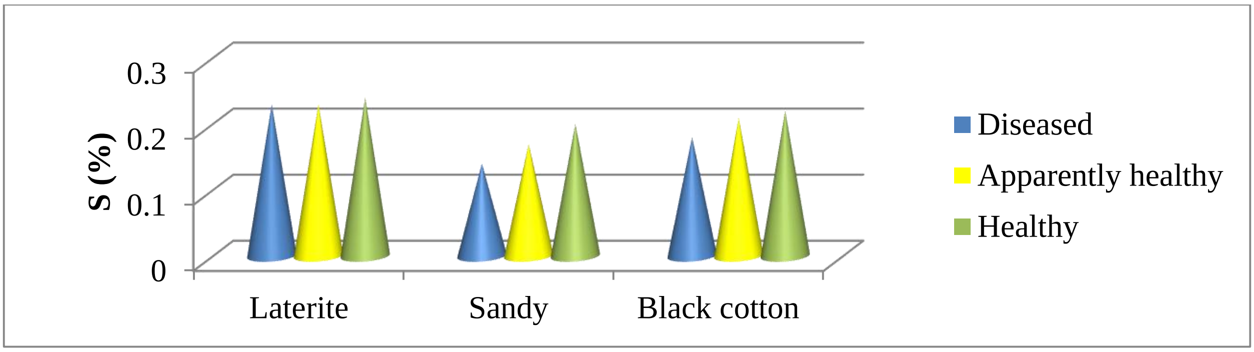
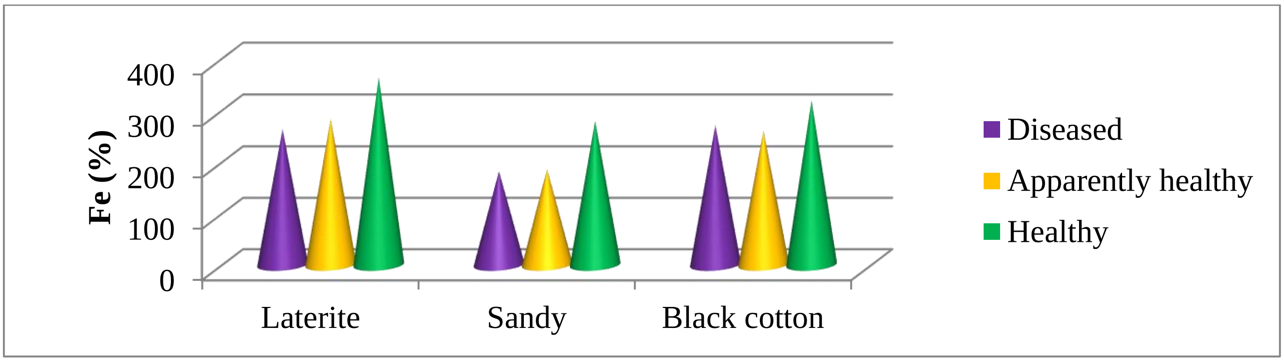


Fig. 23 Leaf Iron content of different type palms under different soil



5.2.3 Micronutrients

Fe, Zn, Mn, Cu and B also showed similar trend as that of Ca and Mg (Fig. 23, 24, 25, 26 and 27). All these elements differ significantly both between the palms and between the soil types. Fe and Mn were high in palms under laterite soil, while Zn and Cu content were high in palms under black cotton soil. This may be due to high content of these elements in the respective soil. Generally healthy palms showed a tendency to accumulate all these elements in the foliage, while the content is significantly lower in foliage of root (wilt) affected palms. This may be due to restriction in absorption and translocation of these elements by the roots of disease affected palms from the soil.

5.2.4 Cl and Na

The content of Cl in the foliage ranged from 0.38 to 0.61 per cent (Table 32) and that of Na was 0.50 to 0.91 (Table 33) per cent. The Cl content varied significantly in palms of different soil type. Na also showed a significant difference between different soil types, the palms growing under sandy soils having the highest content of both Na and Cl. The highest content of Na was reported for diseased palms compared to healthy palms, but it was not significant.

Fig. 24 Leaf Manganese content of different type palms under different soil

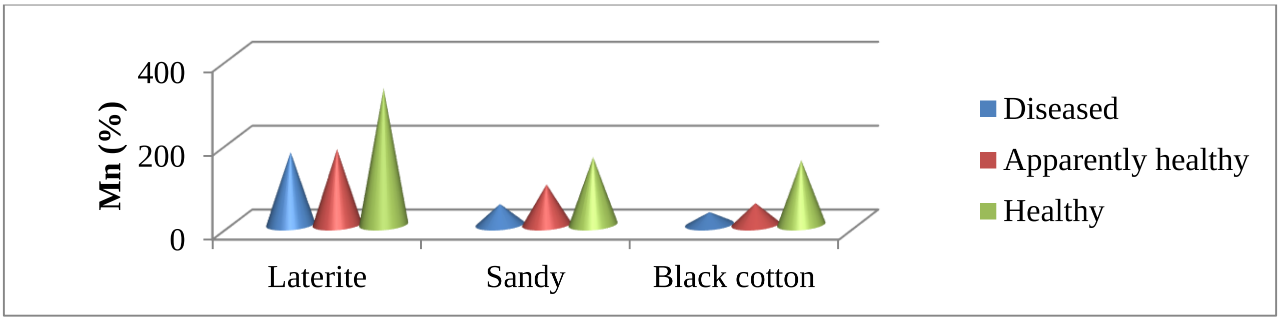


Fig. 25 Leaf Zinc content of different type palms under different soil

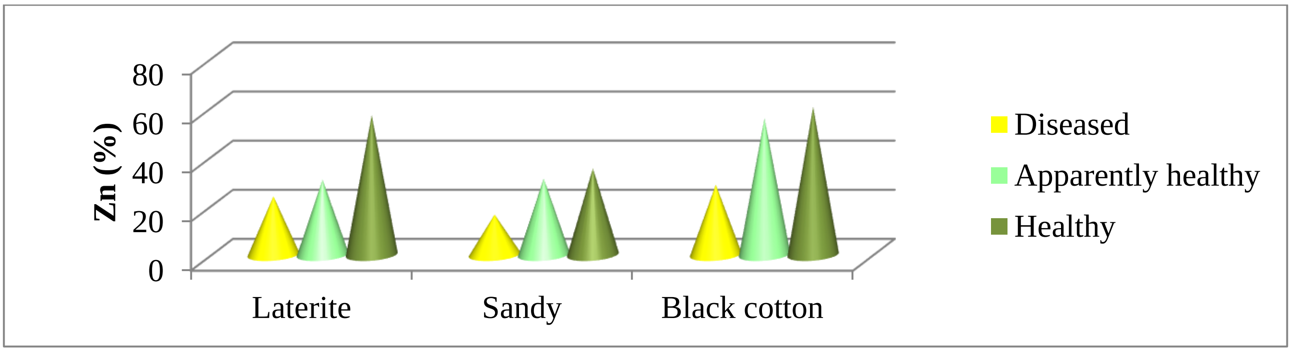


Fig. 26 Leaf Copper content of different type palms under different soil

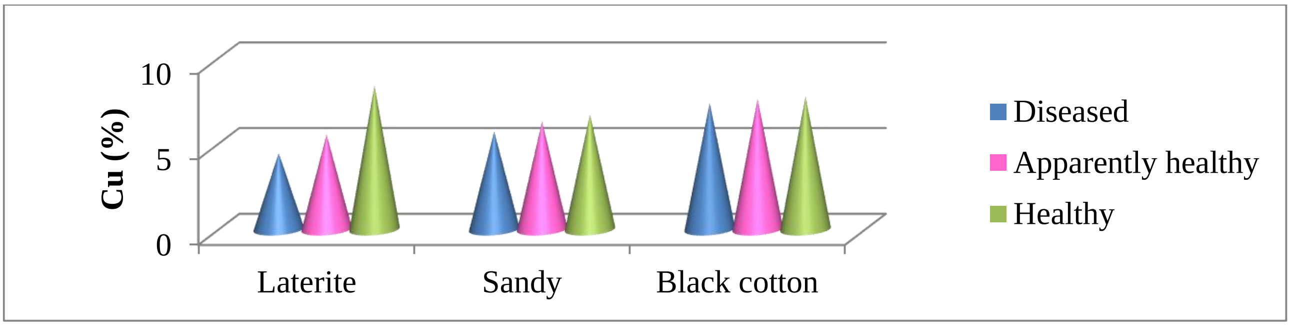
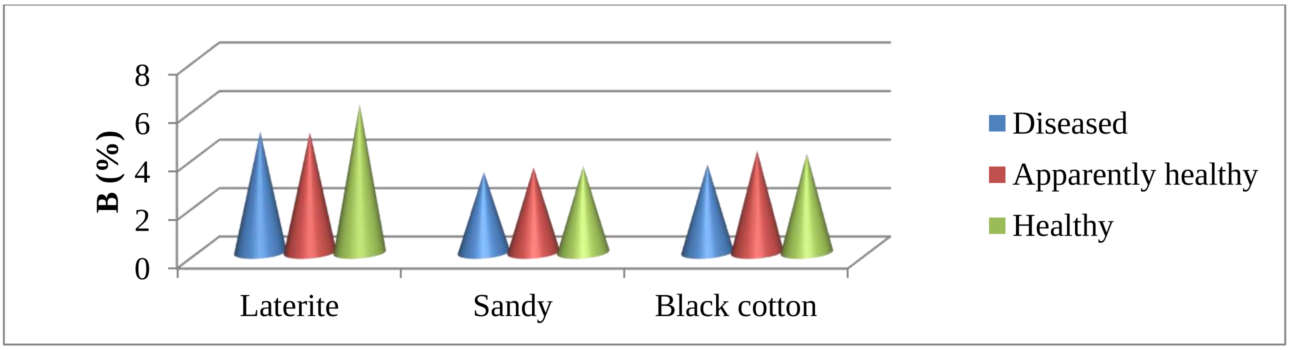


Fig. 27 Leaf Boron content of different type palms under different soil



5.2.5 Net Ionic Equilibrium ratio

It ranged from 1.88 to 6.43. The NIE was found to be highest for diseased palms and lowest for healthy palms. The optimum range of NIE is 1.64 to 4.86 for index leaf of coconut (Priya, 2003). The NIE ratio of healthy palms and apparently healthy palms were under this range, but diseased palms showed a deviation from this range. The NIE ratio of diseased palms was more than 4.86, indicating that there is imbalance in nutrients. Also the graph of NIE with exchangeable K showed that the R^2 value was found to be higher for healthy palms (99 %) compared to diseased palms, emphasising high rate of absorption by healthy palms (Fig. 28, 29 and 30).

Fig. 28 Net Ionic Equilibrium ratio *vs* Exchangeable K of diseased palms

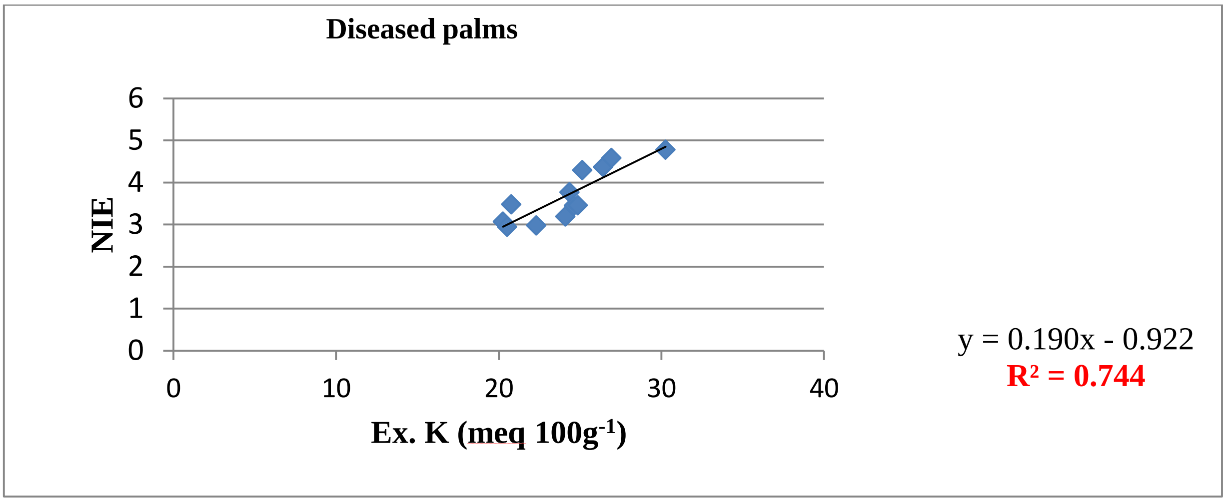


Fig. 29 Net Ionic Equilibrium ratio *vs* Exchangeable K of apparently healthy palms

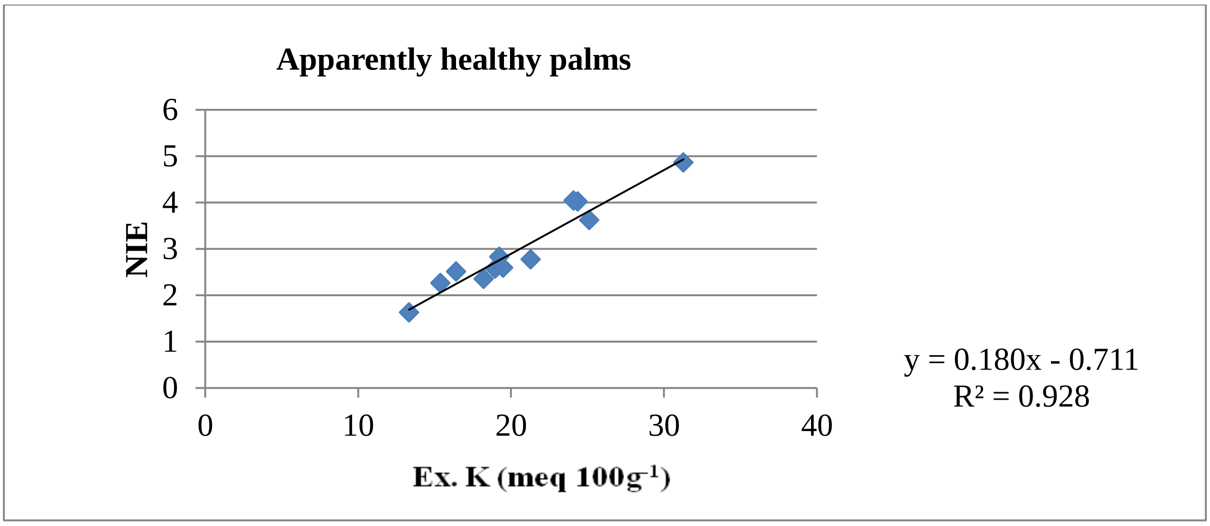
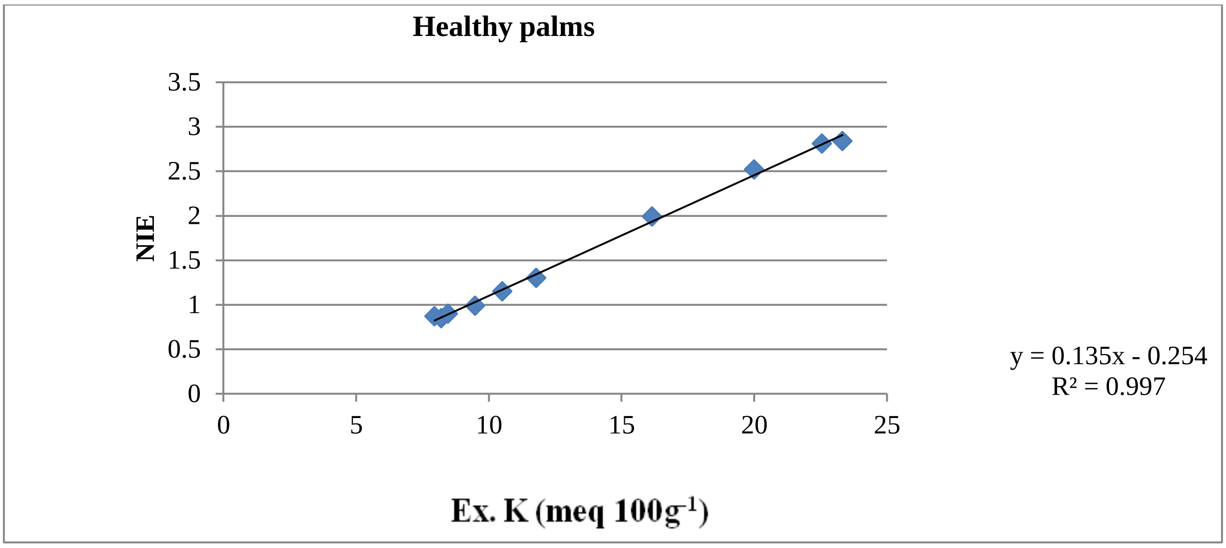


Fig. 30 Net Ionic Equilibrium ratio *vs* Exchangeable K of healthy palms



Experiment 2

In order to provide homogeneous soil condition, laterite soil was tested for all the major and micronutrients and soil test based fertilizers were applied to the basins of experimental palms.

5.3 Characterisation of laterite soil before and after fertilization

5.3.1 Electrochemical properties of soil

Before fertilization the pH ranged from 5.7 to 5.77 and it increased to 5.89 to 5.95 as a result of liming. The soil was slightly acidic in nature, which is the characteristic of laterite soil. There was no significant variation in pH of soils around different palms. Subsurface pH also increased as a result of liming. Electrical conductivity also showed a slight increment after application of fertilizers, this may be due to the increase in soluble salts from the fertilizer. The range of CEC before and after fertilizer application was 7.06 to 7.28 cmol(+) kg^{-1} and 7.33 to 7.44 cmol (+) kg^{-1}, respectively due to increase in pH dependent negative charges. There was only slight increase in CEC after fertilization due to the increase in exchangeable cations. Before fertilization the AEC was in the range of 3.36 to 3.42 cmol (-) kg^{-1} it became 3.35 to 3.38 after fertilization (Table 35).

5.3.1 Organic carbon and primary nutrients

The organic carbon before fertilization varied from 0.38 and 0.39 per cent and it increased to 0.46 per cent after application of fertilizers and manures, due to the addition of organic matter in the soil. The P and K content before and after fertilization are given in table 35. It was noted that the content of organic carbon, P and K became more or less similar for soil under all the palms, as a result of soil test based fertilizer application (Table 35).

5.3.2 Secondary nutrients

The surface and subsurface content of Ca, Mg and S before and after fertilizer application is presented in table 35. Before fertilizer application only Ca showed a significant difference among different group of palms, while Mg and S were comparatively similar for soil under all the palms. Highest Ca content was observed in soils around diseased palms, which may be due to less uptake of Ca by root (wilt) affected palms. After soil test based fertilizer application the soil was homogeneous with respect to all the nutrients (Table 35).

5.3.3 Micronutrients

Before application of fertilizer, soils under three groups of palms differ significantly with respect to Fe, Mn, Zn and Cu. The Fe was lowest in soils around healthy palms. It may be due to the uptake of Fe from soil by healthy palms through active roots. The Mn, Zn, and Cu content was found to be more for soils under healthy palms, which may be due to frequent application of fertilizers to these palms. After fertilizer application the content of these elements in soils under all type of palms became uniform and there was no significant variation in micronutrient content (Table 35).

5.3.4 B, Cl, Na

The content of B, Cl, and Na before and after fertilizer application in surface and subsurface soil is furnished in table 35. The content of these elements before and after fertilization was more or less similar.

5.3.4 Exchangeable cations

The dominant cation in the exchangeable site was calcium for soils under all type of palms. The order of dominance of exchangeable cations was Ca> Mg> Na> K> Mn> Al in laterite soil before and after fertilizer application. There was no significant difference in exchangeable cations among soils under different palms (Table 36).

5.4 Plant analysis

The data on plant analysis of all the palms under laterite soil before and after fertilizer application was given in table 37.

5.4.1 Primary nutrient

The N, P, and K content of the foliage before fertilizer application varied from 1.90 to 2.59, 0.10 to 0.11 and 0.49 to 0.90 per cent, respectively (Fig. 31). After fertilizer application the content became 1.93 to 2.87, 0.12 to 0.16 and 1.06 to 1.53 per cent, respectively (Fig. 32). There was significant variation in N, P and K content in foliage even after soil test based fertilizer was applied. The per cent increment in content of N and P after application of fertilizer was more in foliage of healthy palms, due to higher rate of absorption of these nutrients from the soil by active roots of healthy palms. But K was found to be accumulated more in diseased palms, which was also reported by Wahid *et al.* (1998) and Sankarasubramoney *et al.* (1952). This may be due to impaired physiological process that block the conversion of nutrient constituents into stored plant product or due to restricted transport of nutrients from leaf to other palms.

Fig. 31 N, P, K, Ca, Mg, S and Na content in the leaf before fertilizer application

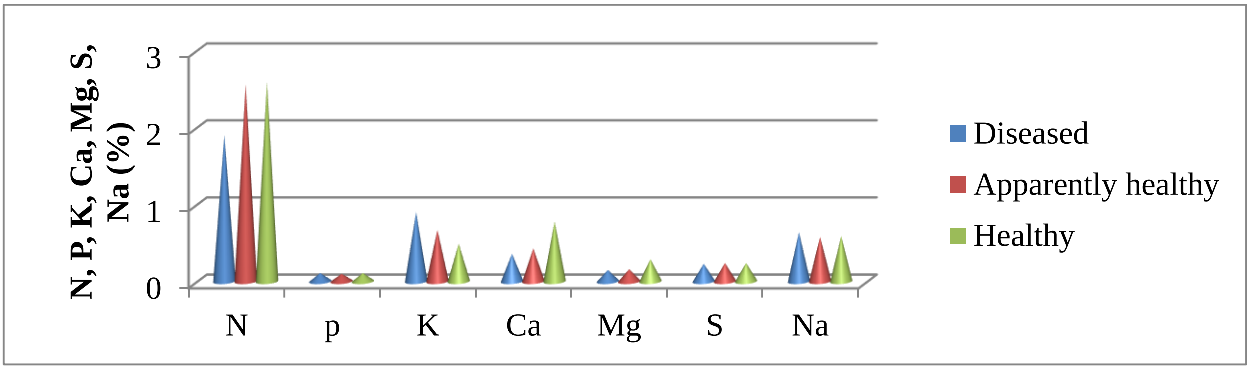
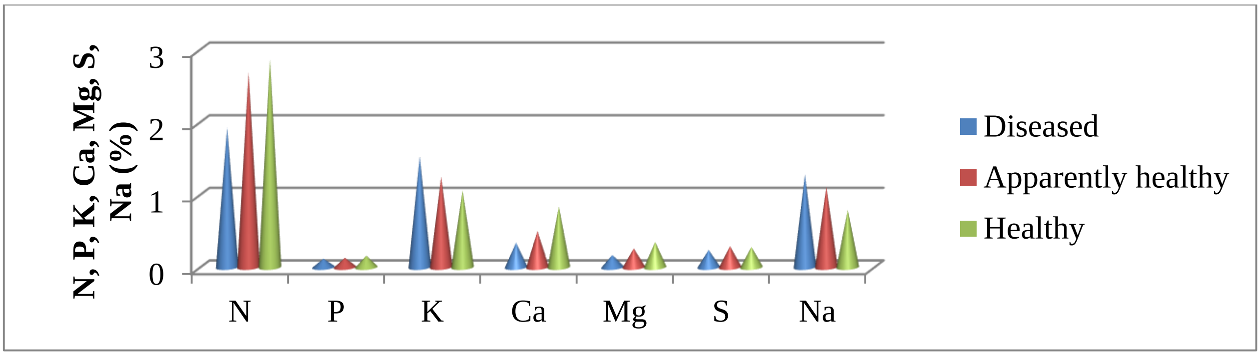


Fig. 32 N, P, K, Ca, Mg, S and Na content in the leaf after fertilizer application



5.4.2 Secondary nutrients

Before application of fertilizer the Ca, Mg and S content was between 0.38 to 0.78, 0.15 to 0.39 and 0.23 to 0.24 per cent, respectively (Fig. 31) and after fertilization it was 0.34 to 0.84, 0.16 to 0.35 and 0.24 to 0.29 per cent, respectively (Fig 32). There was significant difference in all these elements even after soil test based fertilization. The Ca content tend to increase in healthy palms after fertilization, while it decreased in diseased palms, may be because of less absorption or movement of Ca from soil to foliage of diseased palms or due to the lack of active roots. Same trend was followed in Mg and S content, where the increment in leaf nutrient was more for healthy palms than diseased palms, due to higher absorption by healthy palms. The Ca and Mg content in the foliage of diseased and apparently healthy palms were below critical limit. The result obtained was in accordance with the finding of Pillai (1959).

5.4.3 Micronutrients

The content of Fe, Mn, Zn and Cu in the leaves before and after fertilization is presented in table 35 (Fig. 33, 34, 35, 36). Even after the soil became uniform in terms of micronutrients after soil test based fertilizer application, the content of these nutrients in the foliage of all the palms varied significantly. Before and after fertilization it was noticed that micronutrients tend to accumulate more in healthy palms and its content was lower in diseased palms, may be due to restriction in absorption and translocation of nutrients in diseased palms.

5.4.4 B, Cl, Na

The B content before fertilization varied from 4.99 to 5.82 ppm (Fig. 35) and it increased after fertilization (Fig. 36). There was significant difference in B content among palms before and after fertilization. The content was less in the foliage of diseased palms compared to healthy palms, which may be due to restriction in translocation of B through roots of diseased palms.

The Cl content before and after fertilization was not significant among different types of palms. The increment in Cl content after fertilization was very negligible. The Na content in the foliage decreased after fertilization, since no Na fertilizer was applied (Fig 31, 32).

Fig. 33 Fe, Mn and Zn content in the leaf before fertilizer application

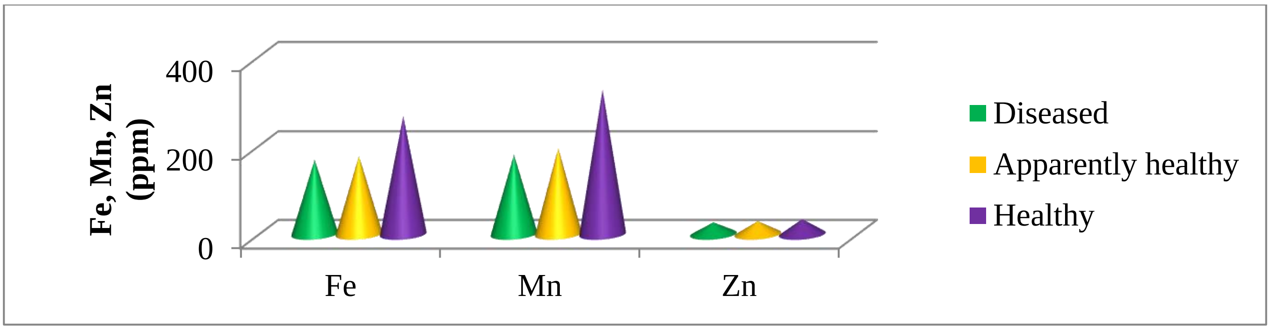


Fig. 34 Fe, Mn and Zn content in the leaf after fertilizer application

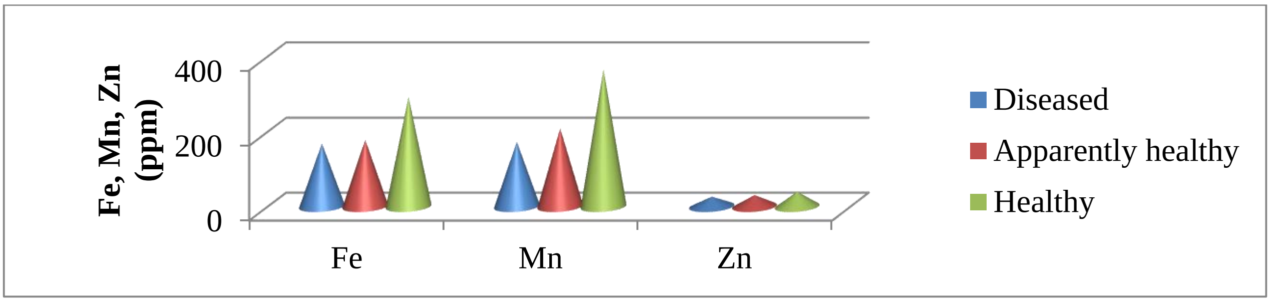


Fig. 35 Cu and B content in the leaf before fertilizer application

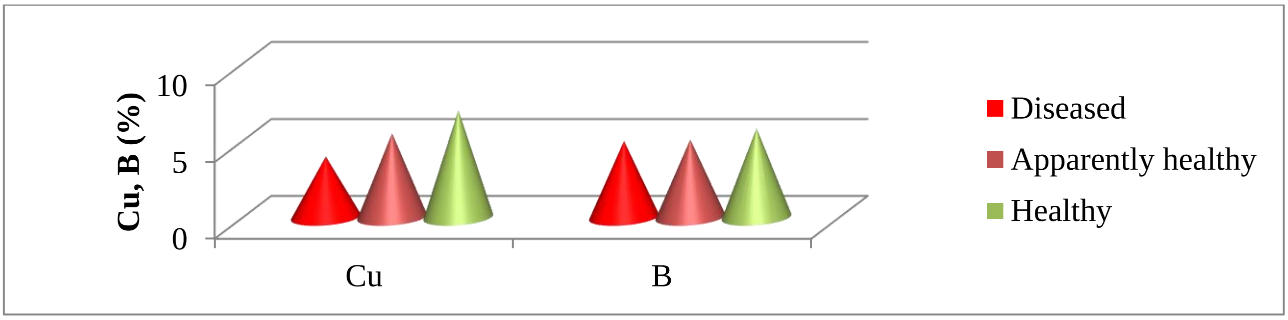
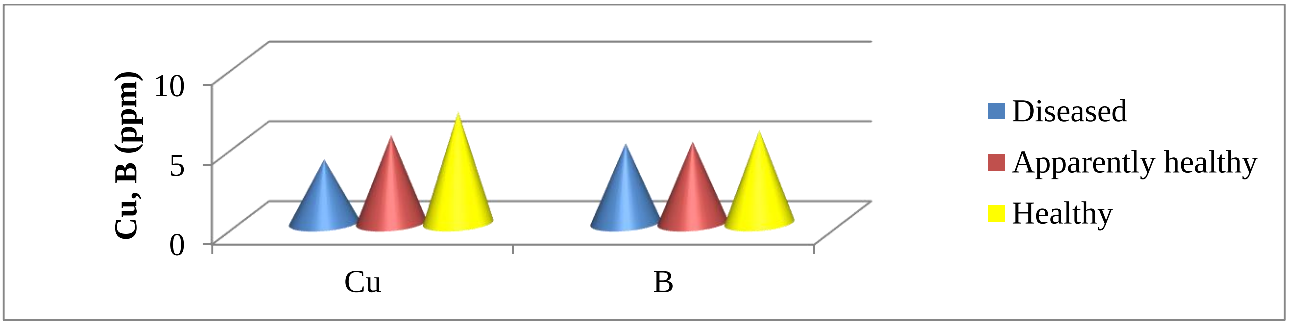


Fig. 36 Cu and B content in the leaf after fertilizer application



5.5 Absorption and translocation of ^{32}P by coconut palms

The experiment was carried out with an objective to unravel the absorption and translocation pattern of root (wilt) affected palms compared to healthy palms.

5.5.1 ^{32}P counts in the sample 24 hours after application

The absorbed radioactivity due to ^{32}P is expressed as counts per minute per unit dry weight (cpm g^{-1}).The count rate was significantly influenced by both the method of application and type of palms (Fig. 37). Healthy palms recorded highest count rate with root feeding method, this may be due to the presence of fresh and active roots, which can translocate the nutrients faster without any blockage. The count rate obtained by root feeding in diseased palms was very less, which may be due to some restriction in absorption and translocation through roots or presence of inactive roots. But for disease affected palms the best method was cotton pad technique. The highest count rate obtained by this method in diseased palm was due to the direct entry of nutrients to the conducting vessels through live tissues of the trunk.

5.5.2 ^{32}P counts in the sample 15 days after application

^{32}P counts 15 days after application showed a similar trend as that of 24 hours after application (Fig 38). Here the count rate obtained is much more compared to 24 hours after application, indicating that 24 hours was not adequate for the full absorption of the applied activity.

5.5.2 ^{32}P counts in the sample 30 days after application

The ^{32}P counts 30 days after application showed same trend as that of 15 days after application with respect to the absorption pattern among different palms (Fig 39). The count rate tended to decrease in all the palms after 30 days, due to dilution effect of completely absorbed activity. The ^{32}P count after 15 days and 30 days after radioisotope application in roots and soil was negligible except for soils/roots in which soil injection was done.

Fig. 37 ^{32}P counts 24 hours after application

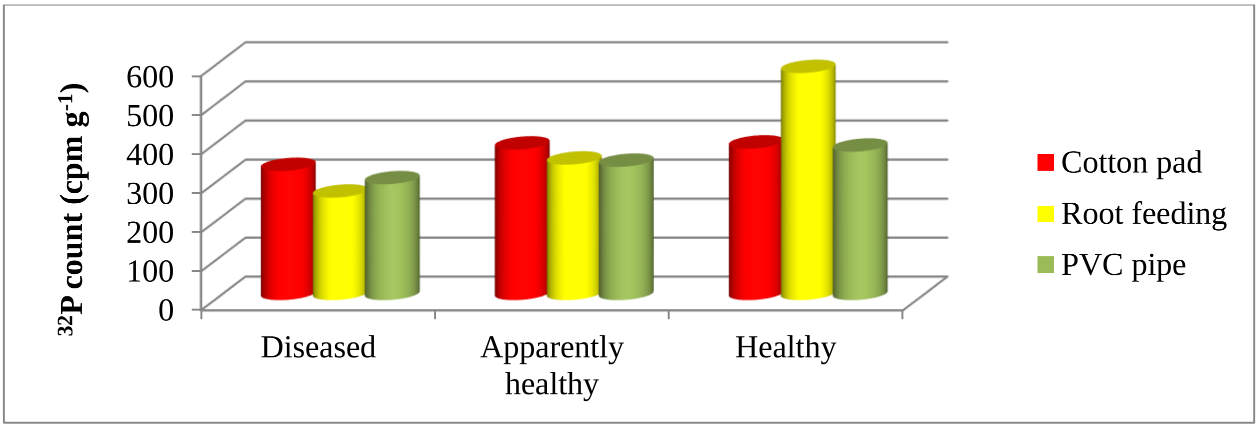


Fig. 38 ^{32}P counts 15 days after application

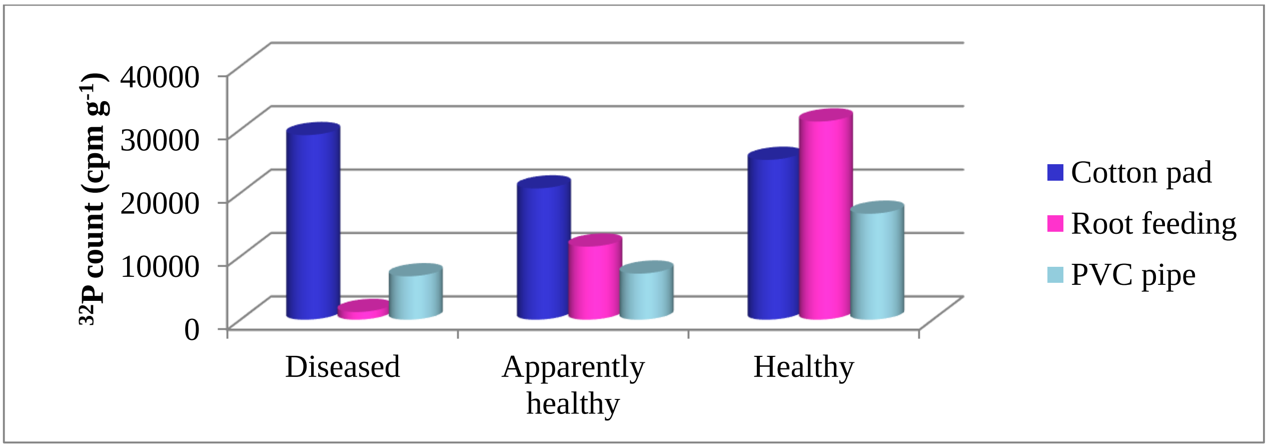
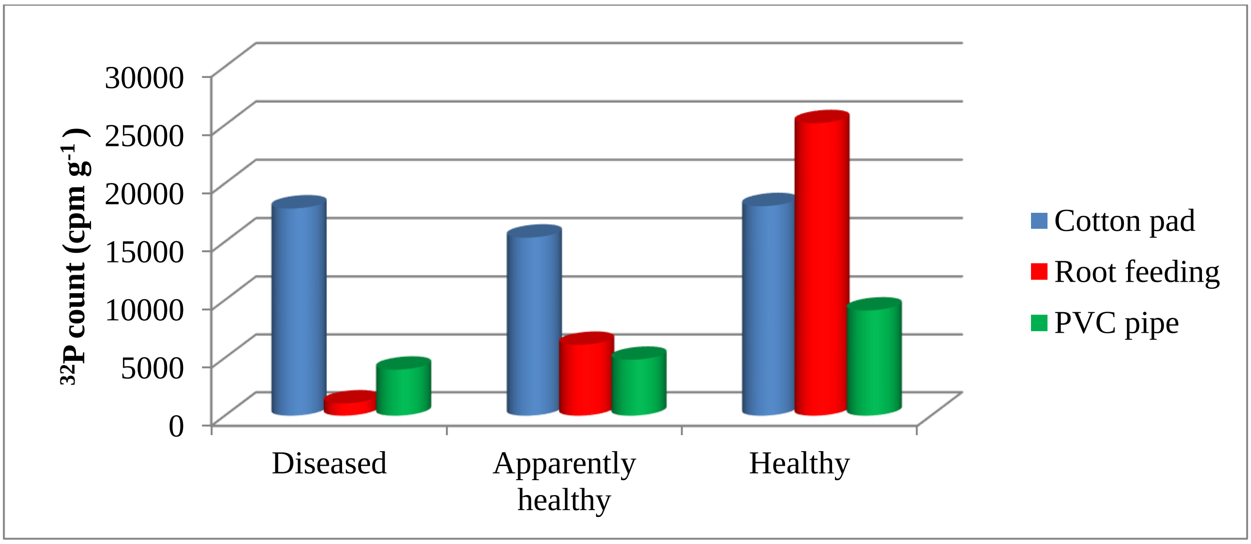


Fig. 39 ^{32}P counts 30 days after application



Summary

6. SUMMARY

To study the absorption and translocation of ^{32}P by root (wilt) affected coconut palms, three types of palms namely healthy, apparently healthy and diseased palms were identified from three soil types of Kerala (laterite, sandy and black cotton soil), where root (wilt) disease is prevalent. Four morphologically uniform palms of same age were selected from each group of palms and soil samples were collected from two depth 0-20 cm and 20-40 cm from the basin. Plant samples were also collected from the identified palms. Soil samples were characterized with respect to pH, EC, CEC, AEC, available nutrients (P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Cl and Na) and exchangeable cations. Plant samples were also characterized for N, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Cl and Na. Absorption and translocation of nutrients in coconut palm were studied using radioactive ^{32}P in laterite soil. Before ^{32}P application, in order to make homogeneous soil conditions, soil and plant samples were tested and soil test based fertilizer combinations including organic manures and micronutrients were applied. Three months after fertilizer application soil and plant samples were again collected and analysed for pH, EC, CEC, AEC, available nutrients (P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Cl and Na) and exchangeable cations and also plant samples for all the nutrients mentioned above. Three different methods (cotton pad technique, root feeding and soil injection) were employed for ^{32}P application. After ^{32}P application the leaf samples were collected on 24 hours, 15 and 30 days after application and radioassayed. Soil and roots samples were also collected from the coconut basin after 15 and 30 days after application and radioassayed for the presence of ^{32}P in the root exudates. The salient results of the study are summarised and listed below.

- The initial characterisation of the three different soil types (laterite, sandy and black cotton) indicated that there was significant variation in all the physico-chemical and chemical properties among the soil types.
- Laterite soil recorded highest value for available P, K, Fe, Mn, Cu, and B compared to other soil types.
- High values of EC, Cl, Na and AEC were obtained for sandy soil.
- Black cotton soil registered highest value for pH, organic carbon, Ca, Mg, S, Zn and CEC among different types of soil.

- Among soils under different palms within same soil type it was noticed that there was significant variation in content of Mg, B, Zn and Cu. The contents of Zn, Cu and B were highest for soils under healthy palms and it was deficient in soils under diseased palms. The content of Mg was significantly higher in soils under diseased palms.
- Among different palms it was noticed that K was accumulated more in the foliage of diseased palms, while the concentrations of N, Ca, Mg, Fe, Mn, Zn, Cu and B were more in the foliage of healthy palms. This data indicated that the root (wilt) affected palms is in a state of unbalanced nutrition.
- Before application of fertilizer in laterite soil the contents of Zn and Cu were more for soils around healthy palms and the content of Ca and Fe was more in soils around diseased palms.
- After fertilizer application the soil became more or less similar with respect to the nutrient content.
- The contents of nutrients before fertilizer application varied significantly among the palms. The contents of N, Ca, Mg, Fe, Mn, Zn and Cu were significantly more in the foliage of healthy palms and K was more in the foliage of diseased palms.
- After application of fertilizer same trend was seen, in addition to this S and B also tended to accumulate more in the foliage of healthy palms.
- On comparing the nutrient status of soil before and after the application of fertilizer, it was seen that before fertilization there was variation in some nutrients in soils around diseased palms compared to healthy palms, and it became more or less homogeneous with respect to soil nutrient status after soil test based fertilizer application, but this homogeneity is not reflected in nutrient content of the foliage even after application of fertilizer. Though there was a slight increase in nutrient status of diseased palms after fertilization, the rate of increase was comparatively less with respect to healthy and apparently healthy palms. This showed that by integrated nutrient management targeting soil application cannot fully manage the root (wilt) disease.
- In absorption and translocation studies using ^{32}P, it was observed that the radioactive phosphorus absorption was more for healthy palms compared to diseased palms, 24 hours after application. For healthy palms the count rate was

more for root feeding, while in diseased palms highest count rate was obtained by using cotton pad technique. The count rate was significantly influenced by both method of application and type of palms.

- ^{32}P count, 15 days after application also showed the same trend as that of 24 hours. The count rate in the foliage was more compared to 24 hours after application, indicating that 24 hours is not sufficient for full absorption of the absorbed activity.
- The absorption pattern among different palms after 30 days of application was similar to that of 24 hours and 15 days after application. The count rate tended to decrease 30 days after application.
- The ^{32}P counts, 24 hours, 15 days and 30 days after radioisotope application in roots and soil was negligible except for soils/roots in which soil injection was done indicating that there was no downward translocation of ^{32}P from the leaf to the soil/roots.
- Result of radioactive studies clearly showed that soil application of fertilizer was less effective in root (wilt) affected palms compared to healthy palms. Nutrient imbalance was one of the major problem noticed in root (wilt) affected palms, so it should be corrected first by proper method of application. Among different methods tested cotton pad technique is a promising technique of delivery of nutrient into root wilt affected palms especially for micronutrients, which need less quality compared to major nutrients.

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ABSORBTION AND TRANSLOCATION OF ^{32}P BY ROOT (WILT) AFFECTED COCONUT PALMS

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ABSTRACT OF THE THESIS

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Abstract

An investigation entitled "Absorption and translocation of ^{32}P by root (wilt) affected coconut palms" was conducted in the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Vellanikkara. Two separate experiments were conducted in farmers' fields at Mannarkkad, Chittur, Chavakkad, Kayamkulam and RARS, Pattambi. Three types of palms namely healthy, apparently healthy and diseased palms were identified from three soil types of Kerala (laterite, sandy and black cotton soil), where root (wilt) disease was prevalent. Four morphologically uniform palms of same age were selected from each group of palms and soil samples were collected from two depths; 0-20 cm and 20-40 cm from the basin. Index leaf samples (14th leaf) were also collected from the experimental palms. Soil samples were characterized for different physico-chemical properties and plant samples for N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Cl and Na.

Absorption and translocation of nutrients in coconut palm were studied using radioactive phosphorus in laterite soil. Before ^{32}P application, in order to make homogeneous soil conditions, soil and plant samples were analysed and soil test based fertilizer combinations including organic manures and micronutrients were applied. Three months after fertilizer application, soil and plant samples were again collected and analysed. Three different methods (cotton pad technique, root feeding and soil injection) were employed for ^{32}P application. The index leaf samples were collected at 24 hours, 15 and 30 days after application and radioassayed.

The result of basic characterisation of soil showed that all the physico-chemical properties varied significantly among different soil types. Laterite soil recorded the highest value for available P, K, Fe, Mn, Cu and B. High values of EC, Cl, Na and AEC were obtained for sandy soil. Black cotton soil registered the highest values for pH, organic carbon, Ca, Mg, S, Zn and CEC. Among soils under different palms within same soil type, there was significant variation in the content of Mg, B, Zn and Cu. Among different palms K accumulated more in the foliage of diseased palms, while the concentrations of N, Ca, Mg, Fe, Mn, Zn, Cu and B were more in the foliage of healthy palms, indicating nutritional imbalance in the root (wilt) affected palms.

Before application of fertilizer in laterite soil, the contents of nutrients were not homogeneous among soils under different palms. After fertilizer application, the soil became more or less similar with respect to the nutrient content. The contents of N, Ca,

Mg, Fe, Mn, Zn and Cu were significantly more in the foliage of healthy palms and K was more in the foliage of diseased palms before fertilization. Even after application of fertilizer same trend was observed. Though there was a slight increase in nutrient status of diseased palms after fertilizer application, the rate of increase was comparatively less with respect to healthy palms. This showed that integrated nutrient management targeting soil application cannot fully manage the root (wilt) disease.

In absorption and translocation studies using ^{32}P, it was observed that the absorption of radioactive phosphorus was more for healthy palms compared to diseased palms, after 24 hours, 15 days and 30 days of application. For healthy palms, the count rate was more for root feeding method, while in diseased palms highest count rate was obtained by using cotton pad technique. The count rate in the foliage after 15 days was more when compared to 24 hours after application and it tended to decrease 30 days after application.

Nutrient imbalance was one of the major problems noticed in root (wilt) affected palms, so it should be corrected first by proper method of application. Among the different methods tested, cotton pad technique can be a promising technique of delivery of nutrient into root wilt affected palms especially for micro nutrients, which needs less quantity compared to major nutrients.