ROOT LEVEL INTERACTIONS IN COCONUT COCOA SYSTEM

BY

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Root level interactions in coconut cocoa system"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or any other similar title of any other University or Society.

Vellanikkara
28·09·1996

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CERTIFICATE

Certified that the thesis entitled **Root level interactions in coconut cocoa system** is a record of the research work done independently by **Ms. Vandana Venugopal** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship or other similar titles to her.

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We, the undersigned members of the Advisory Committee of **Ms.Vandana Venugopal**, a candidate for the degree of **Master of Science in Agriculture** with major in **Agronomy**, agree that the thesis entitled **Root level interactions in coconut cocoa system** may be submitted by Ms.Vandana Venugopal, in partial fulfilment of the requirement for the degree.

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To my parents

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Introduction

INTRODUCTION

Kerala, the major coconut producing state in the country, has an area of 8.64 lakh hectares under this crop (Anon., 1994). Coconut based polyculture is one of the most important production systems prevalent in homesteads of Kerala. In pure coconut plantations about 75 per cent of the space is available for intercropping (Nair, 1979) and the active root zone of coconut utilises only 25 per cent of the available land area and the remaining area could be profitably exploited by raising subsidiary crops. Cocoa could be successfully cultivated as a mixed crop of coconut. Kerala accounts for 76 per cent of the area and 78 per cent production of cocoa in India (Anon., 1995).

Though cocoa has been identified as a compatible intercrop (Nelliat *et al.*, 1976; Shepherd *et al.*, 1976; Barrant, 1978; Thomas, 1978; Nair, 1979; Khader *et al.*, 1984; Anilkumar and Pillai, 1988), there is no information available on their root level interaction. The present trend in agriculture is to utilise the land and aerial space to the maximum by resorting to multi species cropping systems with compatible crop combinations. In such a polyculture system, the spacing of the crops largely depends on the competitive and complementary interactions at the root-shoot levels, for nutrients, water and light. The effects of plant interactions are complex and varied in a mixed crop situation. The above ground interactions are already dwelled deep. Underground root competition for moisture and nutrients is relatively more important in mixed and intercrop systems than above ground competition for light. In short, the advantage or disadvantage in a mixed crop stand is primarily decided by the root-level interaction among the component species. Competition for soil resources among different components of a crop community occurs if the depletion zones around individual root systems overlap. The degree of overlap would influence intensity of the competition effects. In this context a knowledge of the extent of root overlapping among the component crops of the mixed system is of considerable importance.

Determining the fertilizer requirement of sole crop itself is a complex procedure. The problem is more complex under mixed cropping. The data necessary to arrive at a judicious fertiliser policy are thus varied and numerous; one important factor being the root level interaction and nutrient depletion pattern of component crops.

In pure stands of both coconut and cocoa at the recommended spacings it is assumed that root level interaction is at its minimum. However there is no data available to justify this assumption. It was observed that in the case of tree crops there was lot of intermingling of roots from neighbouring trees of the same species (IAEA, 1975). Season as well as the water availability in the soil generally influences the growth, development and distribution of roots. This indicates the importance of variation in root activity with season and soil moisture. No attempt seems to have been made so far to study the absorption of nutrients by coconut in relation to season and moisture environments.

The present project was undertaken to study the root level interactions in the pure stands as well as in their mixed stands of both coconut and cocoa and nutrient depletion pattern of component crops. It was also aimed to look into the changes in the root activity of coconut with season round the year.

Review of Literature

REVIEW OF LITERATURE

The literature available on the different aspects pertaining to the present study are classified under the following heads.

1. Plant community interactions in multispecies crop combinations
2. Use of radioisotopes in root activity studies
3. Root activity studies in coconut and cocoa
4. Root activity studies in mixed crop stand
5. Seasonal effects on the physiological activity of plant roots
6. Nutrient dynamics in coconut based mixed crop stands

2.1 Plant community interactions in multispecies crop combinations

Nair (1978) reported that plant community interactions in intensive crop combinations with perennials are of greater magnitude and different nature than in the case of sole crops. Plant interactions have been referred to as 'interference effects' (Harper, 1961) or 'neighbouring effects' (Trenbath and Harper, 1973). Interaction between the components of the multispecies crop combinations may result in sharing of growth factors and cause changes in the physical and biological variable in the ecosystem. Manifestations of such complemetary interaction involve favourable ecoclimate, increased activity of beneficial rhizosphere micro-organisms and better efficiency in the use of native and applied nutrients. Other interaction effects include annidation, allelopathy, plant parasites, economic complementarity etc. But normally in a plant community, interference between plants lower absorption or interception rates of growth factors relative to those in isolated plants and competition will begin. Therefore, interaction between neighbouring plants with respect to growth factors are often described to as forms of competition - for the growth factors absorbed through both leaves (light and Co_2) and roots (water, nutrients and oxygen). A knowledge of plant community interactions in crop combinations are indispensable in the design of mixed and intercropping systems. The underlying principle behind combination culture of coconut is one of 'ecodevelopment', which aims at maximum utilisation of resources through rational choice and management of crops that can be successfully grown under or between these perennial crops. The yield advantages or disadvantages of intercropping systems is the resultant of several interacting components. The reason for competitive or complementary effects among the component crops in such systems have not been clearly understood.

2.1.1 Root level interactions

According to Trenbath (1974) the advantages in some mixed crop situations is due to the difference in the rooting pattern which occurs due to the mutual avoidance of different root systems. There is a tendency for crops to avoid areas that have already been depleted of resources by an associated crop. The roots of crop plants of adjacent rows intermix in intercropping, depending on the row spacing and crop species involved. This may have implications of root competition for water and nutrient uptake between the species. The presence of the roots of one species may change the course of development of the roots of the other crop. The root system of sole pigeon pea was compared with that of intercropped pigeon pea at ICRISAT (Narayanan and Sheldrake, 1976). In the intercropping system the growth of pigeon pea roots was slow prior to the harvest of intercrop sorghum. Pigeon pea roots are influenced not only by the competition from companion crops but also by its own roots. Gregory and Reddy (1982) studied the root systems of groundnut/pearlmillet intercropping system in comparison with rooting pattern of the monocrops. The pattern of rooting was intermediate between the two monocrops.

Under mixed crop condition, the orientation and spread of cocoa roots get modified considerably. Bhat (1983) reported that cocoa plants when grown mixed with arecanut showed more expansion of roots both laterally and vertically compared to sole cropped cocoa. In the sole crop situation, over 67 per cent of the roots were seen in the 0-50 cm soil layer where as only about 40 per cent of the total roots could be found in this layer in the mixed garden. Further, the preponderance of fine roots in the top 50 cm soil layer in the sole crop situation was about twice that in the mixed crop.

In intercropping systems, roots of two or more species share the same space and compete for moisture and nutrients. The characters which contribute to success in competition for soil factors include early and fast penetration of roots through soil (McCown and Williams, 1968), high root density (Andrews and Newman, 1970), high productivity of actively growing roots (Slatyer, 1967; Barley, 1970) and a high uptake potential for the nutrients (Bowen, 1973).

In crop combinations with coconuts, where the canopies of components occupy different vertical layers, the coconut palm is not subjected to competition for factors which are absorbed through leaves. But they could be subjected to competition for factors absorbed by roots. The other crops grown with coconuts could be subjected to short supply of one or all these factors (Nair, 1978).

Water, nutrients and oxygen are taken up from the soil by the roots. The uptake of dissolved nutrients or oxygen by a root surface establishes a concentration gradient, down which further supplies of the substance diffuse towards the roots (Dunham and Nye, 1974). Similar is the case with water. The movement of nutrients, oxygen and water to the root depletes the soil of these factors in the vicinity of the root. Competition for soil factors among different components of a crop community begins when the depletion zones around individual root systems overlap, although competition among individual roots of the same plant may begin earlier. In many situations, the density of active absorbing roots is such that the depletion around adjacent roots overlap and there is a significant decline in the average concentration of solute throughout the zone exploited by roots (Nye *et al.*, 1975; Nye and Tinker, 1977). The distance of the depletion zone depends on a variety of factors. The depletion zone for water and mobile ions like nitrates which are carried away passively in moving soil water extends to much longer distance than for nutrients like phosphates and adsorbed cations (NH_4, K, Ca, Mg) which are at low concentrations in soil water and therefore move almost exclusively by slow diffusion (Brewster and Tinker, 1970). This narrowness of non mobile nutrients tends to prevent competition for these nutrients between root systems of different crops in a crop combination except at high density of roots. The knowledge of the pattern of active roots of different crops alone and in a crop combination, thus becomes important.

2.2 Use of radioisotopes in root activity studies

Studies on roots are of prime importance in plant nutrition as it is responsible for the absorption of soil nutrients and extraction of soil moisture besides its function to anchor the plants. Despite the importance of the root system, studies on it have been very few primarily because of the difficulties encountered in examining roots in their natural environment. Now a days it has been found that isotopic techniques serve as a quick and reliable means for root system studies. The development and activity of plant root system in a natural soil profile was first measured with a radioactive tracer by Lott *et al.* (1950) and by Hall *et al.* (1953).

Among the isotopic techniques, two methodologies are followed. One is plant injection technique (Racz *et al.*, 1964) and subsequently improved and modified by Rennie and Halstead (1964). This is used for studying the root distribution pattern in small plants. Another method is soil injection technique for studying the root activity patterns of tree crops. Several workers like Fox and Lipps (1964) and Russel and Ellis (1968) have suggested that root distribution and root activity in different soil depths and lateral distances from the plant can be accurately and easily assessed by studying the uptake of radioisotopes placed at specified spots in the soil. Wahid *et al.* (1985) developed a simple device for soil injection of ^{32}P solution which is very successful in root activity studies.

For radiotracer studies generally^{32}P a hard beta emitter is used because of its convenient half life (14.3 days) and ease of measurement. ^{32}P is a slowly diffusing nuclide and with its restricted mobility in the soil and its rapid absorption and translocation in the plant, the position of the label can be correlated wiith root activity (Hall *et al.*, 1953; Nye and Tinker, 1977; Vose, 1980). Sometimes other nuclides like ^{15}N, ^{86}Rb and nonradioactive Sr (Fox and Lipps, 1964; Ellis and Barnes, 1973; IAEA, 1975) are also used.

The recovery of radioactivity in the plant from a particular soil zone is determined by the proportion of active roots in that zone. This will serve as an index of nutrient uptake rate. The determination of total radioactivity absorbed by the plant is a difficult preposition in the case of trees unlike in the small plants. In such cases IAEA (1975) recommended the radioassay of a suitable plant part to evaluate the uptake of the applied label from various root zones.

2.3 Root activity studies in coconut and cocoa

Root system studies concerning fine root dynamics, root biomass and root architecture of trees are scattered. Most of the root studies using ^{32}P were made in monocrop situations.

2.3.1 Root activity studies in cocoa

Experiments conducted at the Cocoa Research Institute, Tafo, Ghana, indicated that the most active root zone lay within 7.5 cm surface soil layer upto a lateral distance of 1.5 m (Ahenkorah, 1975). The results of a major study conducted under a co-ordinated research project of IAEA (1975) showed the highest root activity of cocoa in the upper 7.5 cm soil layer with the maximum activity often at 2.5 cm soil depth. Wahid *et al.* (1989) studied the root activity pattern of cocoa using ^{32}P and found that more than 85 per cent of the feeder roots were found within a radius of 150 cm around the tree. They also observed that a substantial portion of the roots lie near the soil surface within 15 cm depth. The preponderance of feeder roots were found upto 60 cm soil depth beyond which root activity declined sharply.

2.3.2 Root activity studies in coconut

Kushwah *et al.* (1973) observed that in a well maintained coconut garden over 82 per cent of the roots resided in 31 to 120 cm soil depth and only 8.7 per cent of the roots went below 120 cm. The density of roots in the surface 30 cm soil layer was quite negligible. Radioisotope studies conducted at Philippines had indicated that the zone of the highest root activity lie at 15 cm depth and within one to two metre area around the tree (IAEA, 1975). Balakrishnamurthy (1977) also reported that the roots of coconut were most active in the surface soil, to a depth of 10 cm. In caostal clay soils of Malaysia, the highest root density was observed in the upper most 50 cm soil layer (Jalil, 1982). Similarly in Venezuela, the coconut roots were found to concentrate in the top 30 cm soil layer within an area of 1.5 m radius (Avilan *et al.*, 1984). In a nine year old coconut plantation, over 80 per cent of the active roots were confined within an area of 2 m radius around the palm and the vertical spread of majority of roots was limited to 60 cm depth (Anilkumar and Wahid, 1988). Cintra *et al.* (1992) observed that in dwarf coconuts, around 70 per cent of total roots and 65 per cent of fine roots were within a radius of 1 m around the stem and 90 per cent of total roots and 85 per cent of fine roots within 1.5 m radius around the stem. Cintra *et al.* (1993) reported that in tall coconut cultivars, around 70 per cent of roots were found within a radius of 1 m around the stem and at a depth between 0.1 to 0.5 m.

2.4 Root activity studies in mixed crop stand

Studies of root activity pattern of crops are important in understanding the extent of soil space explored by component species in polyculture in view of competitive or complementary root-level interactions taking place among them

(Willey, 1979). As the studies on root level interaction in mixed stands of coconut and cocoa by employing radiotracer techniques are scarce, similar studies in other mixed crop stands are also reviewed.

Lawton *et al.* (1954) studied the uptake of ^{32}P by brome grass and alfalfa grown in mixed stand. They have concluded that more efficient use of phosphorus was from the surface in the case of brome grass and from a depth of 3 to 6 inches in the case of legume. The root competition for the radiophosphorus by species grown in intercropping systems including corn-field bean, corn-sesame, corn-castorbean, castorbean-sesame were studied by Lai and Lawton (1962). They have observed that corn was the most effective feeder of fertilizer phosphorus. Its roots penetrated the less extensive root system of beans and sesame to obtain P banded close to other component crops and in contrast there was little cross feeding between adjacent rows of beans or sesame. Cooper and Ferguson (1964) found that the vertical and lateral growth of alfalfa, birds foot trefoil and orchard grasses were reduced when grown as a companion crop with barley. Barley was able to compete with forage seedlings for moisture and nutrients early in the established period due to rapid root growth. Absorption of ^{32}P by component species in some grass-legume and cereal-legume mixtures had been reported (De *et al.*, 1984).

Studies on complementary or competitive interactions in nutrient uptake among the plants in mixed cultures involving widely spaced crops/trees are very few. In a cassava-banana-elephant foot yam intercropping system it was found that radiophosphorus applied to the root zone of one of the component species was absorbed not only by the treated plant but also by the neighbouring plants (Asokan *et al.*, 1988). In this system banana was found to be the most dominant species and accumulated the major portion of radioactivity recovered by the root system. Sankar (1988) analysed root activity patterns of black pepper vine and various support trees in relation to the root competition. It was found that 90 per cent of root activity was confined to a radial distance of 30 cm from the vine. Pepper vines trailed on *Erythrina* sp. had a larger lateral root spread than those trailed on teak poles. George (1994) studied the root interaction in a silvi-pastoral system and he concluded that 65-85 per cent of the fine roots responsible for water and nutrient absorption were concentrated in the 0-15 cm layer of the soil profile. George *et al.* (1995) evaluated the root competition in poly culture systems involving combinations of four tree species and four grass species based on ^{32}P recovery by each species in mixed and sole crop situations. They found that grass species in sole crop situations absorbed more ^{32}P than in mixed systems. None of the grass species when grown in association with tree components affected the absorption of ^{32}P by trees.

2.5 Seasonal effects on the physiological activity of plant roots

The physiological activity of plant roots is influenced by seasonal effects (IAEA, 1975).

With the banana in Uganda the wet season and dryseason pattern of root activity were essentially the same. The differences between the root activity near the soil surface and at lower depths were less in dry weather (IAEA, 1975).

Experiments were carried out to study the root activity pattern of 30 years old orange trees in summer and spring at Spain (IAEA, 1975). This indicated that during summer months, the highest activity was at 200 to 300 cm distance from the trees and at 30 cm depth. Early in spring, highest root activity was observed near the tree (50 cm distance) at 30 and 60 cm depth. In mature 30 year old trees, the zone with highest root activity was farther away from the tree than in younger trees of 14 years (IAEA, 1975). In Taiwan 8 years old citrus trees, (IAEA, 1975) the highest root activity was at 10 cm depth and at a lateral distance of 1 m in the spring season. For 12 years old citrus trees in the winter season, the activity was higher near the soil surface within 1 to 2 m lateral distance.

^{32}P injection experiments were carried out to study the root activity pattern of young 17 year old and bearing oil palms in wet and dry seasons in Malaysia and Ivory Coast (IAEA, 1975). In Malaysia during the wet season, the highest root activity was found at the soil surface at a distance of 3 m from the tree. About 70-80 per cent active roots were within 20 cm depth. In Ivory Coast, highest root activity was observed at same depth. Wet season activity was more intense and confined to the surface unlike in dry season where the activity showed a steep decline with depth.

In Kenya, coffee plants showed highest root activity at 45-75 cm depth and 30 cm lateral distance in dry season as opposed to highest activity near the surface at 15 cm depth and 82.5 cm distance in the wet season. Wet and dry season experiment in fruiting coffee trees in Columbia indicated that in wet season root activity at 30 cm distance at 15 cm depth was significantly higher than at any other soil zone tested. In dry season, no indication was obtained of the zones of high and low root activities. Uptake was low in dry season (IAEA, 1975).

In rice, the root production and thereby the root activity was more in summer than in the dry months (Salam, 1984).

In cashew, highest root activity and absorption peak was noticed at 'flushing and early flowering' phase which extended from September to December. Root activity was the lowest during 'maturity and harvesting' phase (March to June) (Bhaskar *et al.*, 1995).

2.5.1 Seasonal effects on root activity of coconut and cocoa

Cocoa

Root activity in the wet season was found to be approximately six times that in the dry season as observed in ^{32}P studies (IAEA, 1975; Ahenkorah, 1975). In rainy season, when the soil moisture was in abundance, the root activity of the tree was more in the surface soil layer (upto 7.5 cm) than in lower horizons. On the contrary, in the dry season the root activity was uniform throughout the profile (Ahenkorah, 1975). It is generally expected that root activity will be more at lower depths during dry season because of the probable loss of moisture from the soil surface and consequent deeper root penetration. The apparent lack of variation in the root activity between depths in dryseason may be due to a uniform moisture profile in soil as a result of mulch and shade in cocoa gardens. Results of the experiments carried out at Ghana using tracer technique (IAEA, 1975) revealed that in both wet and dry seasons the effect of distance on root activity was not significant but there was an indication of high root activity near the soil surface at a distance of 90-150 cm.

Coconut

Wet and dry season experiments carried out in 50 year old coconut palms in sandy loam soil in Srilanka (IAEA, 1975) indicated that root activity in wet season was the highest at 1 m distance at 10 cm depth. In dry season root activity was the highest at 0.5 m distance at 10 cm depth. Activity at lower depths and greater distances were high in the dry season. Similar experiments in Phillipines (IAEA, 1975) reported that the highest zone of root activity was at 1-2 m distance and upto 15 cm depth.

2.5.2 Effect of moisture regime on root activity

The active root zone shifts to the lower layers under drought conditions (Bhattacharjee *et al.*, 1974). When water is supplied uniformly throughout the soil profile, the upper layers are depleted of water first. Plants then take up water from increasingly greater depths. Regular moisture supply through frequent irrigation or rainfall may limit the root system to lower depths. The intensity of root activity was considerably reduced under conditions of moisture stress (IAEA, 1975).

From a study conducted by Mathavan *et al.* (1985) on soil moisture status in a monocrop of tea/cloves and tea intercropped with cloves, moisture in the top 30 cm soil depth during the peak drought was 18.7 per cent for monocrops and 29 per cent in the mixed stand. This pattern is repeated at 30-60 cm and 60-90 cm soil depths. This is related to the root distribution in the soil profile.

Root activity studies, using ^{32}P conducted by Sobhana (1985) at KAU indicated that the distribution of active roots varied significantly in irrigated and unirrigated conditions. In rainfed banana the highest root activity was obtained at 30 cm depth and in irrigated banana at 5 cm depth at a lateral distance 20 cm. As lateral distance increased from 20 cm to 120 cm a reduction was noticed in the root activity under both irrigated and rainfed conditions. Sobhana *et al.* (1989) reported that more extensive and deep root system developed under rainfed condition enabling the plant to extract soil moisture and nutrients from deeper soil layers. Similar variation in root system development due to different moisture environments was observed in crops like cocoa (Ahenkorah, 1975 and IAEA, 1975), coconut (IAEA, 1975) and oilpalm (IAEA, 1975). Medeiros *et al.* (1987) reported that in cocoa, activity of fine roots was associated with rainfall and subsequent changes in soil humidity. Irrigation of cashew trees increased ^{32}P absorption compared to unirrigated trees (Bhaskar, 1992). In the coconut garden, the root system of rainfed banana was spreading and that of irrigated banana was compact whereas in the open the condition was reverse (Eapen, 1994).

2.6 Nutrient dynamics in coconut based mixed crop stands

Plant-soil ecosystem represented a three dimensional cut out of vegetation, cover and root zone (Nair, 1979) and a complexity of such a system was seen in the high density cropping, especially with perennials. In monocropping and multiple cropping systems, the integrated interaction effect of crop on soil helps in conservation and depletion of nutrients. Depletion refers to the nutrient removal from the system through harvesting of crop produce both edible and non edible. Nutrient depletion in high density cropping is a dynamic process and the nutrient pool will be unevenly tapped for resources by the component crops. The components of nutrient enrichment includes rainwater, fertilisers and organic manures, organic recycling, crop residue addition and native soil nutrients and that of nutrient depletion are leaching, volatilisation, microbial immobilisation, fixation and plant produce utilisation (Biddappa *et al.*, 1984).

It was seen that the yield of coconut and the intercrop was reduced when the intercrops was not manured (CPCRI, 1971). The yield depressions caused by an added second crop was greater when soil fertility was low than when it was high (Stanford *et al.*, 1973). It was seen that when irrigation combined with adequate supply of nutrients through manures and fertilizers was done not only that cocoa came up well but the manincrop, coconut was either not adversely affected or was benefitted by the presence of cocoa. When it became difficult to provide irrigation and fertilizer application following the price slump in the 1980's coconut yield also declined in mixed crop situations. The results from research stations at the same time consistently showed beneficial effects of coconut-cocoa association the magnitude of which was as much as 50 per cent (Nair *et al.*, 1996).

The importance of crop combinations in the context of nutrient economy in coconut based systems has been indicated in the system analysis studies by Khanna and Nair (1977). They surmised that the presence of more plant cover as in a crop combination system increases the plant cycling fraction of nutrients and thereby reduces the direct loss of nutrients in percolating water.

Leela and Bhaskaran (1978) observed improvement in soil available N, P, K and Ca status of coconut intercropped with groundnut.

Sadanandan *et al.* (1991) reported that there was an increase in soil fertility in N, P, K, Ca, Mg and micronutrient status in coconut-pepper mixed cropping system.

Biddappa *et al.* (1993) studied the nutrient profile, balance and input-output of nutrient in a coconut-fodder system and found that coconut-grass system enriched over control plot in organic carbon, nitrogen, manganese and copper in the surface soil while the nutrients in the lower profile was low. In the system, P, K, Ca and Mg were on net loss over control.

2.6.1 Nutrient dynamics in coconut-cocoa system

Soil physico-chemical characteristics as influenced by depth and lateral distance from coconut palm was studied by Anilkumar (1987). They observed significant variations in the concentration of available P, exchangeable K, Ca, available Mn, Zn and Cu at different lateral distances from the palm. But the concentration of organic carbon, exchangeable Mg and available Fe were found to be more or less same at all lateral distances from the palm. Of the different chemical characteristics studied, only organic carbon content available P, Fe, Mn and Zn were influenced by depth. They obtained positive correlations between root activity and organic carbon, available P, K, Mn and Zn.

Investigations on the fertility status of the soil under coconut-cocoa mixed cropping have shown marked improvement compared with that of the sole crop stand of coconut. The improvement in soil fertility has been, to a large extent, attributed to the addition of organic matter by the periodic shedding of cocoa leaves and the consequent intense microbial activity in the rhizosphere region of the crop mix (Nelliat *et al.*, 1976). Available phosphorus content in the coconut rhizosphere wherein cocoa was grown (double hedge) was reported to be 65 ppm compared to 41 ppm in single hedge plots and 20 ppm in control coconut sole crop (Nair and Rao, 1977). Varghese *et al.* (1978) reported that the amount of organic matter added to the soil through shed leaves and pruning of cocoa under single and double hedge systems of planting was found to be 818 and 1985 kg/ha/year respectively (oven dry weight). Nutrient concentration of cocoa leaves were reported to be 2.84% N, 0.26% P and 1.73% K on dry weight basis (Eernstman, 1968).Then it was assumed that about 50 kg N, 11 kg P_2O_5 and 35 kg K_2O were returned to the soil every year through leaf fall of cocoa under double hedge system of mixed cropping. Because of large amount of biomass addition, the organic carbon content of soils under mixed cropping with cocoa was also found to be higher than that under pure palm stands. This was noted especially in the top 15 cm depth. This helped in recycling considerable quantities of plant nutrients, besides improving organic carbon status. Opankule (1991) reported that 89, 75 and 67 per cent of tree uptake of Fe, Cu and Zn respectively are returned annually through litterfall in cocoa agroecosystem.

Materials and Methods

MATERIALS AND METHODS

Three experiments were conducted to evaluate the root level interactions and nutrient dynamics in mixed as well as pure stands of coconut and cocoa. It was also envisaged to study the seasonal influence on the root activity of coconut around the year.

The experimental fields were located at 10° 32’ N latitude and 76° 10’ E longitude at an altitude of 22.25 m above mean sea level. The weather data during the experimental period are given in Appendix I.

3.1 Cropping history and the cultural practices adopted

The sole stand of coconut palms were planted in 1976 at a spacing of 7.5 m and sole cocoa was planted in 1989 at a spacing of 3 m. In the coconut plantation intercropped with cocoa, the cocoa was planted in 1989 in between the coconut palms planted in 1976 in a single row. In all cropping systems, fertilizers were applied routinely.

In the case of cocoa basins of 1 m radius were cleared of weed prior to the application of fertilizers. Urea, superphosphate and muriate of potash each (a) 250 g/plant was mixed and applied in shallow channels at 75 cm radius and covered with soil. The fertilizers were applied twice annually coinciding with monsoonal rains May-June and September-October. Organic manure was not applied as there is a large return of organic debris to the soil from cocoa.

Basins of 2 m radius were cleared of weeds around coconut palm. FYM was applied (a) 15 kg-25 kg/palm during July-August and $MgSO_4$ (a) 500 g during

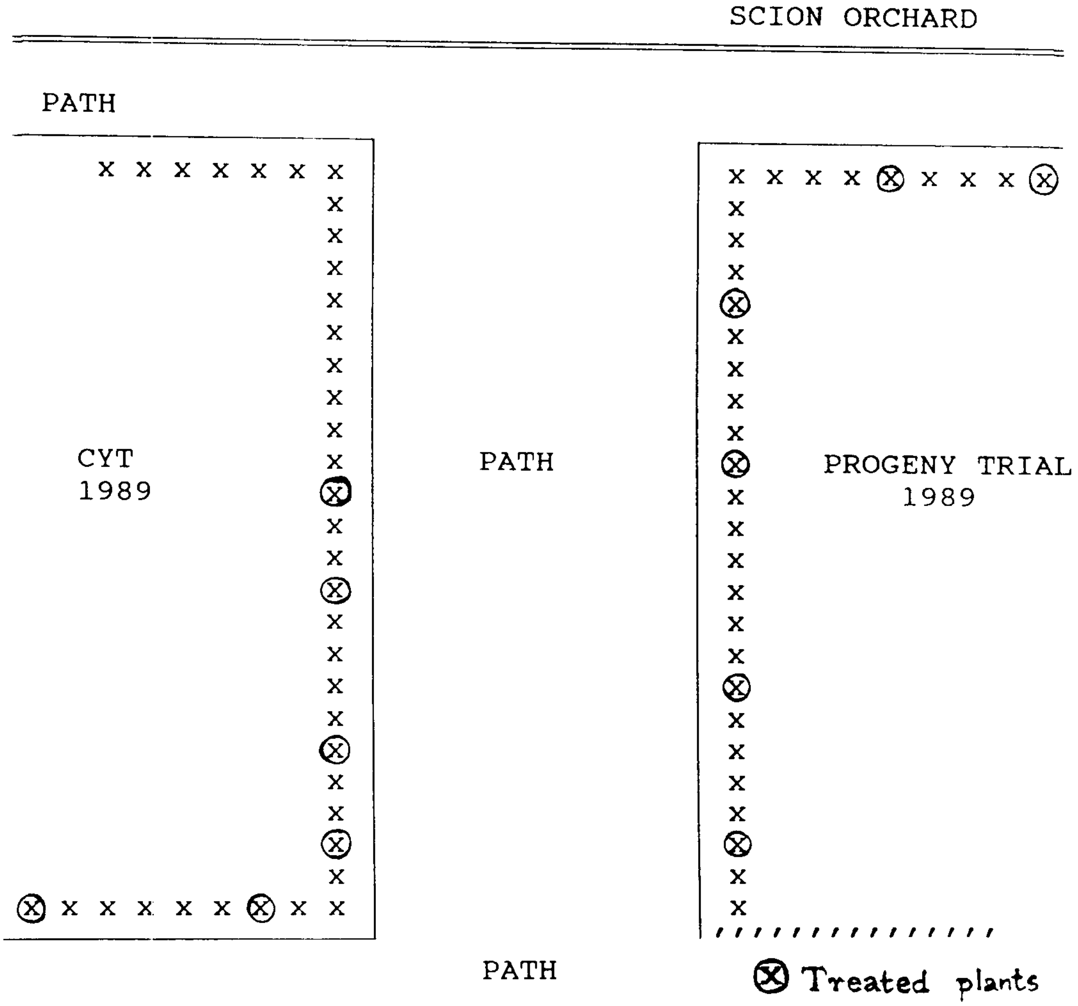


Fig.1 Layout of experimental field with pure stand of cocoa

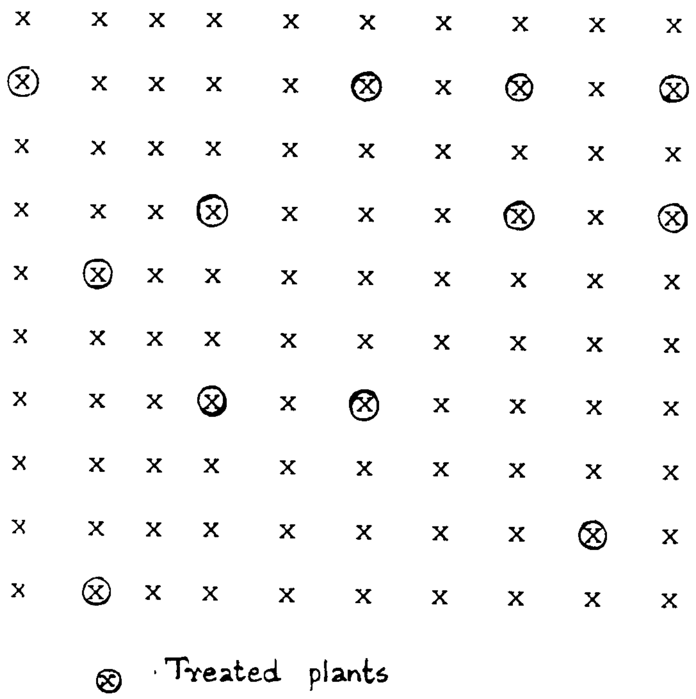


Fig.2 Layout of experimental field with pure stand of coconut

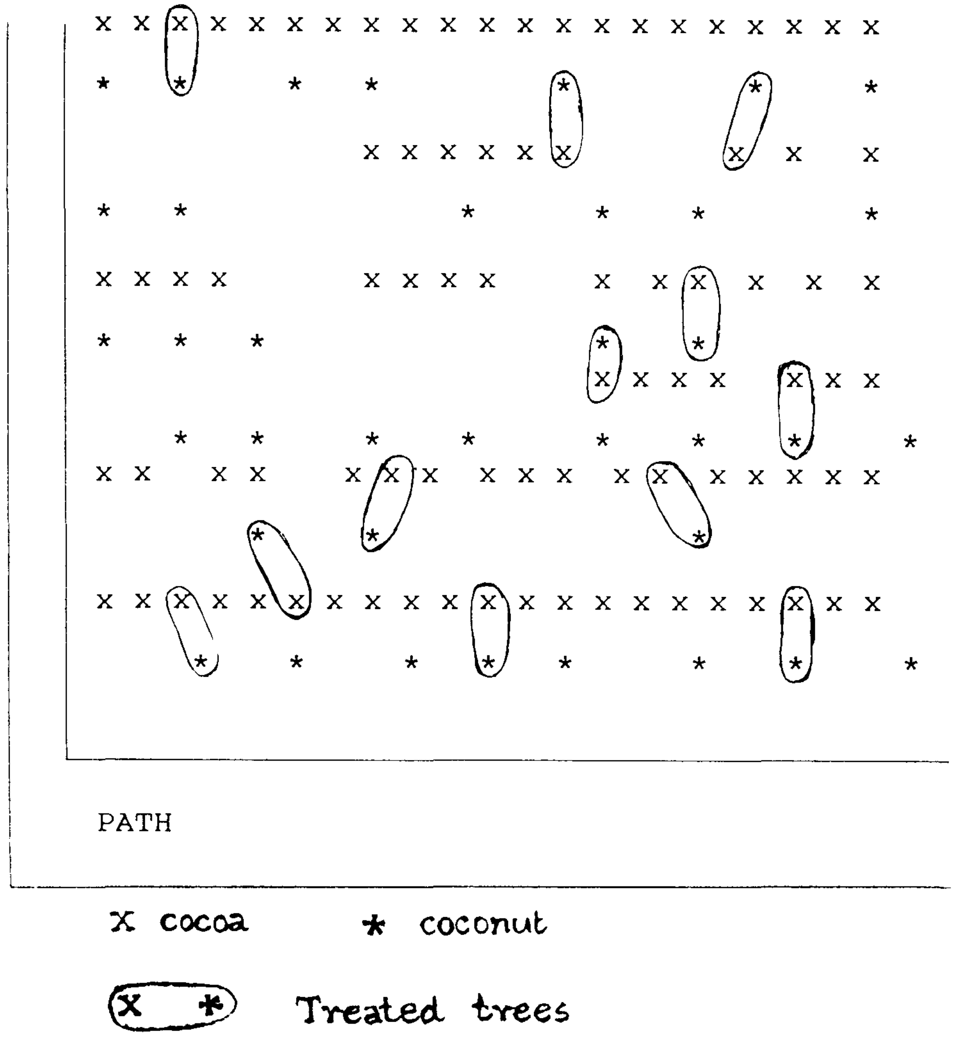


Fig.3 Layout of experimental field with mixed stand of coconut and cocoa

August-September. 0.34:0.17:0.58 kg $N:P_2O_5:K_2O$ kg/palm in the form of urea, mussoriephos and muriate of potash were applied during August-September in the basins. They were mixed and raked in.

In mixed crop stand, both the crops are manured separately as above.

An existing plantation of twenty year old coconut trees planted at a spacing of 7.5 m x 7.5 m and growing under uniform fertilizer and management conditions was used for the third experiment.

3.2 Experiment I: Root activity in mixed and pure stands of coconut and cocoa

The present study was carried out making use of experimental fields at two different locations. Mixed stand of coconut and cocoa as well as pure stand of coconut were located at the Instructional Farm, Vellanikkara. The soil type was laterite with a pH of 4.7 and 5.0 respectively. The field under Cadbury-KAU Co-operative Cocoa Research Project was utilised to study the root activity in pure stand of cocoa. The soil type was laterite with a pH of 5.3. The lay out of the fields are given in Fig. 1, 2 and 3.

In the sole stand, coconut palms were spaced at 7.5 m x 7.5 m and cocoa at 3 m x 3 m. In mixed stand, the cocoa was planted in between the coconut palms in a single row at a spacing of 3 m.

Root level interaction was studied employing ^{32}P soil injection technique (IAEA, 1975). The leaves were sampled at 15 days interval for a period of three months after ^{32}P application. The sampling was preponed or postponed at times due

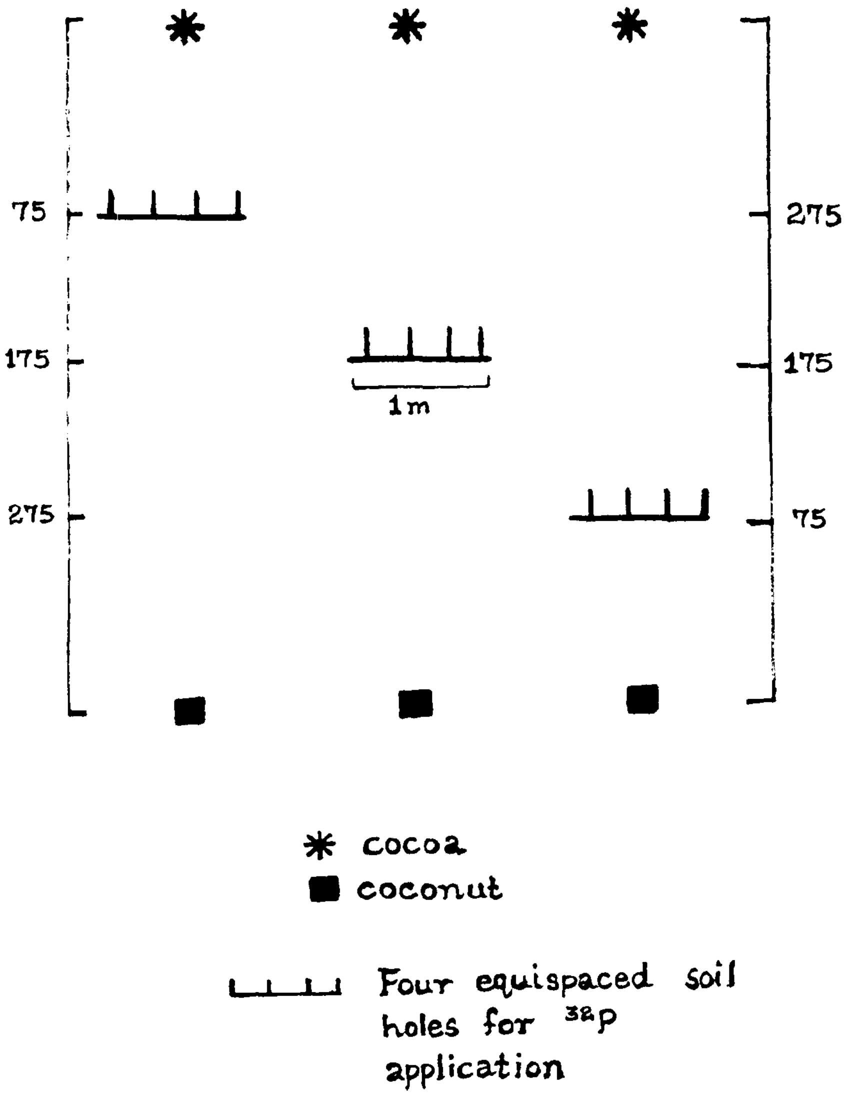


Fig.4 Method of P-32 application in mixed and pure stands of coconut and cocoa

to unavoidable reasons. The leaf samples were dried and radioassayed for ^{32}P content. The details of the treatments were as follows:

Cropping systems	: 3	Coconut alone
		Cocoa alone
		Coconut + cocoa

Mode of application

Plants were selected randomly in such a way to avoid root interaction between adjacent treated plants. The soil basins of the selected plants were cleared of weeds over an area of 3 m radius around the trunk. In the experience, four equidistant soil holes were taken in a line of 1 m length in between coconut and/or cocoa according to the treatments mentioned below:

Lateral distances : 3 (75, 175 and 275 cm)
Depths : 2 (30 and 60 cm)
No. of replications : 2
Design : CRD

In pure stands of coconut and cocoa these lateral distances were taken from the trunk of respective crops. But in coconut-cocoa mixture, the lateral distances 75, 175 and 275 cm were chosen with respect to coconut. The distance between the rows of coconut and cocoa is 3.5 m. Hence a point which is 75 cm away from coconut will be 275 cm distant from cocoa. Similarly the points 175 and 275 cm away from the coconut will be 175 cm and 75 cm distant from cocoa. This is illustrated in Fig. 4.

The holes dug using the soil auger at different lateral distances and depths were plugged with PVC access tubes (2 cm diameter) about 10-15 cm jutting outside the hole. The access tubes were closed at the open ends with polythene cover and rubberband to prevent filling up during the rains. At the time of ^{32}P application, the polythene cover was removed from the PVC tube and 2 ml of radioactive solution at a carrier level of 1000 ppm P was applied into each tube using a laboratory dispenser suitable for repeated delivery of fixed volume of solution (Wahid *et al.*, 1988). The total radioactivity applied per tree was 2 mCi (74 MBq). After dispensing, the radioactivity remaining on the inside of the access tube was washed down with a jet of water prior to its removal from the hole. Finally the hole was filled back with the soil removed from it. The inclusion of carrier in the ^{32}P solution was to minimise the soil fixation of the applied label (IAEA, 1975).

These lateral distances and depths were chosen as the highest root density was observed in these soil zones for these plant species (Anilkumar and Wahid, 1988; Wahid *et al.*, 1989a).

3.3 Experiment II: Soil nutrient depletion in the sole and mixed stand

In this experiment, soil samples were drawn from different depths and lateral distances from mixed as well as pure stands of coconut and cocoa at the time of start of experiment I. The soil samples were analysed for organic carbon, available P, K ca, Mg, S Zn, Mn, Fe and Cu. The details of the experiment includes.

Design	: CRD
No. of replications	: 3

Table 1. Details of the analytical methods used in the study

Soil characteristic	Extractant used	Soil to solution ratio	Time of shaking	Method of estimation	Reference
Organic carbon	-	-	-	Walkley-Black (Titrimetric)	Jackson (1958)
Available P	Bray I	1:10	5 min	Ascorbic acid blue colour (Spectrophotometer 660 nm)	Watanabe and Olsen (1965)
Available K	N.NH$_4$OAc pH 7	1:5	"	Direct reading after dilution (Flame photometer)	Jackson (1958)
Available Ca	"	"	"	Direct reading after dilution using SrCl$_2$ as releasing agent (AAS 422.7 nm)	Jackson (1958) and Page (1982)
Available Mg	"	"	"	" (AAS 285.2 nm)	"
Available S	NaOAc-HOAc pH 4.8	1:5	30 min	Turbidimetric (Spectrophoto meter 440 nm)	Hesse (1971)
Available Fe	Double acid HCl 0.05 N + H$_2$SO$_4$ 0.025 N	1:10	15 min	Orthophenan throline method (Spectrophotometer 490 nm)	Jackson (1958)
Available Mn	"	"	"	Direct reading AAS 279.5 nm	Page (1982)
Available Zn	"	"	"	" AAS 213.9 nm	Page (1982)
Available Cu	"	"	"	" AAS 324.8 nm	Page (1982)

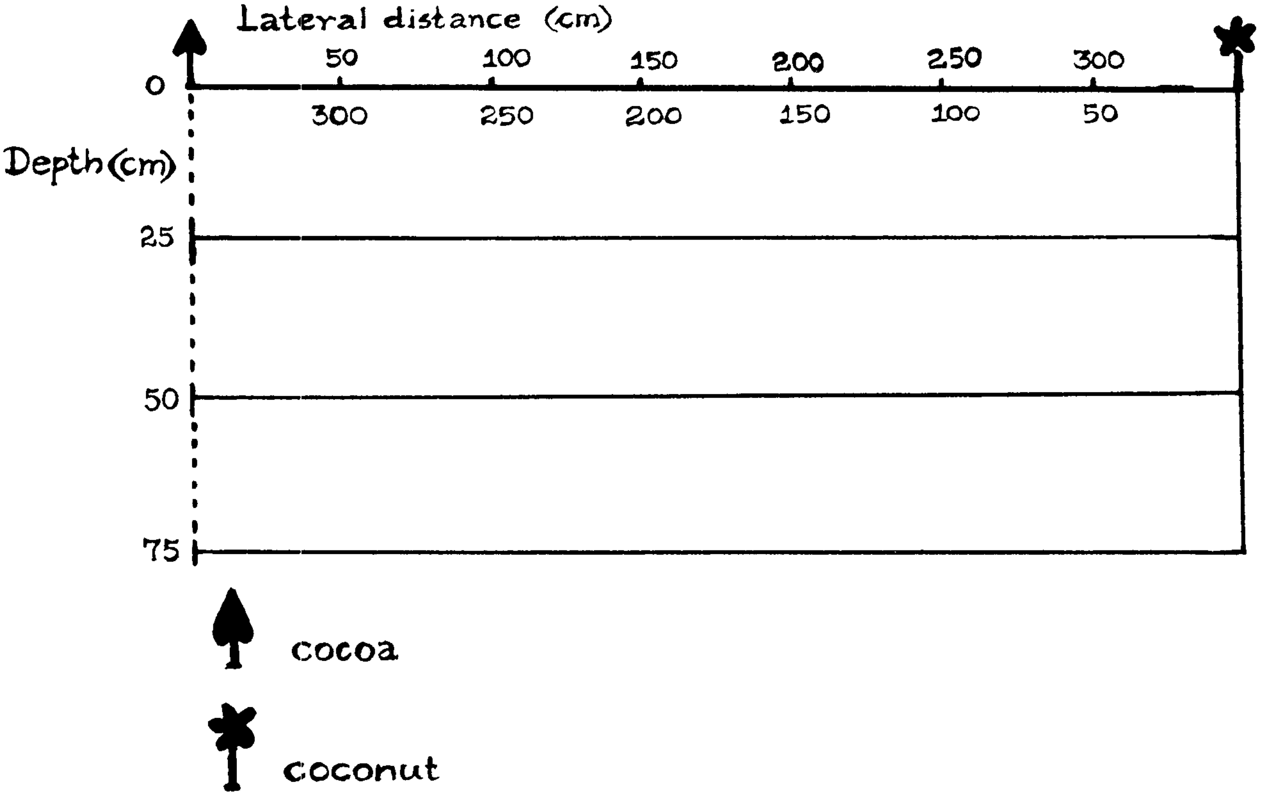


Fig.5 Method of collecting soil samples from different depths and lateral distances in mixed stand of coconut and cocoa

Lateral distances

For coconut : 50, 100, 150, 200, 250, 300 and 350 cm
For cocoa : 50, 100 and 150 cm
For mixture : 50, 100, 150, 200, 250 and 300 cm
(distance with respect to coconut)

The lateral distance in mixture with respect to coconut and cocoa is given in Fig. 5.

Depths

For all systems : 25, 50, 75 and 100 cm

Samples were not drawn from 100 cm soil depth due to the rocky patches at this depth.

The soil samples collected according to the treatments mentioned above were air-dried and sieved through 2 mm mesh prior to analysis. The details of methods used in chemical analysis and presented in Table 1.

3.4 Experiment III: Seasonal effects on the root activity of coconut

The experimental field for this study was located at College of Horticulture, Vellanikkara. To study the activity of roots during different season, a ^{32}P soil-injection technique was used. Here ^{32}P was applied to the monocrop of coconut at a particular lateral distance (50 cm) and at two different depths thrice for a period of one year. Leaves from the treated plants were sampled and radioassayed

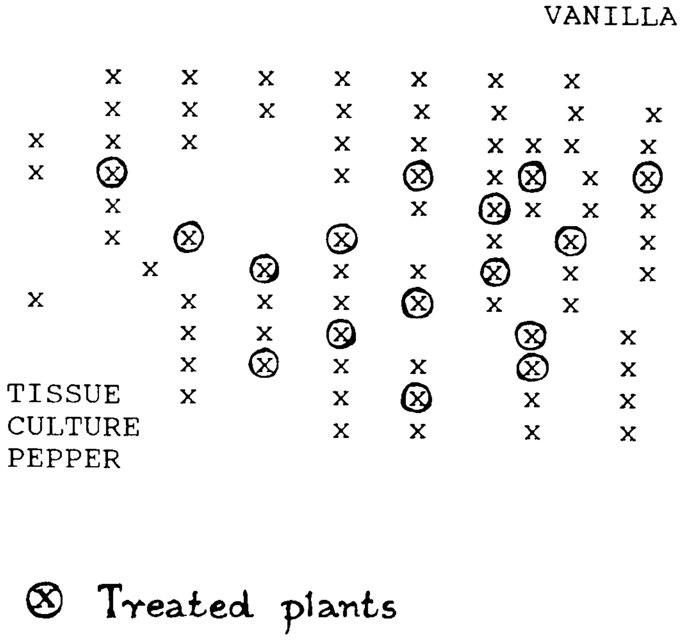


Fig.6 Layout of coconut field where seasonal effect on P-32 absorption was studied

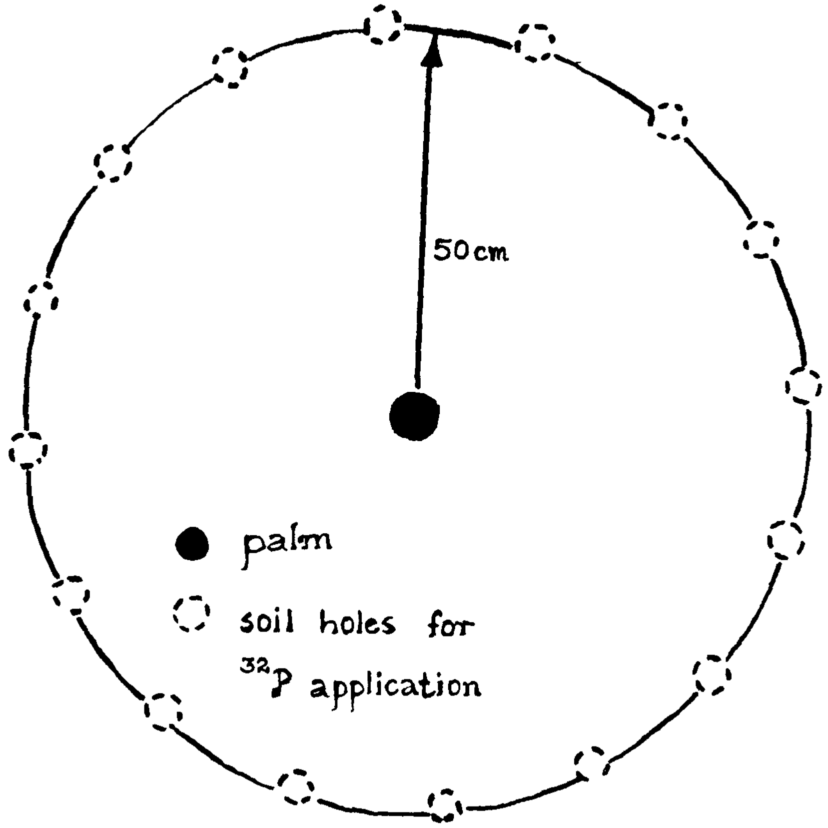


Fig.7 Method of P-32 application in full circle around the palm

at 15 days interval. The layout of the experimental field is given in Fig. 6. The details of the treatments are given below.

Treatments

Depths of application : 2 (20 and 75 cm)

Moisture regimes : 2 (Rainfed and Irrigated)

No. of replication : 2

Design : CRD

Sixteen trees were selected for this experiment randomly. Single tree formed an experiment unit. They were distantly chosen to avoid root interaction between adjacent treated plants. Equally spaced 16 soil holes were dug to the required depth along the circumference of a circle of radius of 50 cm (Fig. 7 ^{32}P was applied just as in the case of experiment I except that the access tubes were left as it is required for subsequent ^{32}P injection at different seasons. It was observed that the period of four months provided between two successive applications were adequate to bring down the radioactivity to negligible levels in the leaf due to previous application.

This experiment was also aimed to study the effecet of irrigation during summer on the absorption of applied ^{32}P. For this purpose, eight trees of sixteen trees chosen above were left rainfed from June to November and irrigated from December to May and remaining 8 trees were left rainfed throughout. The details of the same are furnished in Fig. 6. Basin irrigation was given to these palms at an interval of seven days over a circular area of 2 m around each palm. The quantity and frequency of irrigation were so chosen as to maintain the moisture regimes above 50 per cent of the available water holding capacity in the 75 cm soil layer.

Moisture content of the soil was recorded gravimetrically at monthly intervals from three depths (0-25, 25-50 and 50-75 cm) under both moisture regimes. In this case two replications were maintained. Monthly observations on moisture content of the soil from December-May is given in Appendix II.

3.5 Leaf sampling and radioassay

The extent of absorption of the soil applied radioactivity by the plant was measured by radioassay of leaf samples as follows. The leaf samples from the treated plants were collected following the method suggested by IAEA (1975). In the case of coconut, leaflets from the 6th leaf (the first leaf being the youngest fully opened leaf) and in the case of cocoa, the first mature leaf were used for the radioassay. According to IAEA (1975) in coconut and cocoa trees, the absorbed ^{32}P was found to be distributed uniformly in leaves around the tree even when the fertilizers were applied in a strip on the side of tree. Hence no specific pathways were involved in its translocation. The leaf samples were dried at 65-70°C in a hot-air oven and after grinding were acid-digested. The digests were radioassayed by cerenkov counting technique (Wahid *et al.*, 1985) in a liquid scintillation system, Wallac 1409, Finland.

The count rates (cpm) were corrected for background and decay and the total radioactivity absorbed by the plant was then estimated. The count rates were not expressed in dpm as the counting efficiency of the instrument for ^{32}P remained constant at 32 per cent during the experimental period.

3.6 Statistical analysis

The data were statistically analysed by applying the analysis of variance for factorial experiment in completely randomized design. In view of the wide variability in count rates, the data were subjected to log transformation prior to analysis of variance (Panse and Sukhatme, 1985). Assuming that the extent of absorption of applied ^{32}P from different depths and lateral distances by the plants is a function of relative root activity in the different soil zones, the percentage root activity at a particular depth and lateral distance was computed as follows.

$$\text{Root activity (\%)} = \frac{\text{Mean cpm values for the treatment}}{\text{Total cpm for all the treatments}} \times 100$$

Results

RESULTS

The following experiments were conducted during the course of this investigation and the results of the same are presented in this chapter.

1. Pattern of ^{32}P absorption by coconut and cocoa in pure and mixed stand
2. Pattern of root activity in pure and mixed stand of coconut and cocoa
3. Soil nutrient depletion in the sole and mixed stand
4. Seasonal effects on the root activity of coconut

4.1 Pattern of ^{32}P absorption by coconut and cocoa in pure and mixed stand

In this experiment, radiophosphorus was applied employing soil injection technique (IAEA, 1975) in between coconut and/or cocoa. Leaves were sampled and radioassayed for ^{32}P at 15 days interval for a period of 3 months. In this study, comparisons were made on the uptake of the radiolabel between sole crop of coconut and mixed crop of coconut: between sole crop of cocoa and mixed crop of cocoa.

4.1.1 Recovery of ^{32}P in the leaf as influenced by crop stand

The data relating to the absorption of ^{32}P by coconut and cocoa in sole and mixed stand is furnished in Table 2. It was observed that the uptake of ^{32}P was more or less uniform in pure and mixed stand of coconut and cocoa. This was indicated by their statistical non-significance. However, in general absorption of ^{32}P was higher when these crops were grown alone. In sole as well as mixed coconut, there was a sharp increase in the uptake of ^{32}P after 46 days of ^{32}P application (Fig. 8). The difference in the uptake between sole and mixed situation remained

Table 2. Absorption of ^{32}P by sole and mixed stand of coconut and cocoa at 30, 46 and 78 DAA of ^{32}P to the soil (log cpm g^{-1} leaf)

	Days after ^{32}P application		
	30	46	78
Coconut sole	1.515 (33)	1.933 (86)	2.230 (170)
Coconut mixed	1.120 (13)	1.772 (59)	1.835 (68)
SEm±	0.138	0.149	0.199
CD(0.05)	NS	NS	NS
Cocoa sole	1.498 (31)	2.080 (120)	2.943 (877)
Cocoa mixed	1.445 (28)	2.225 (168)	2.745 (556)
SEm±	0.239	0.173	0.163
CD(0.05)	NS	NS	NS

Parentheses denote cpm/g leaf
NS - Non significant
DAA - Days after application

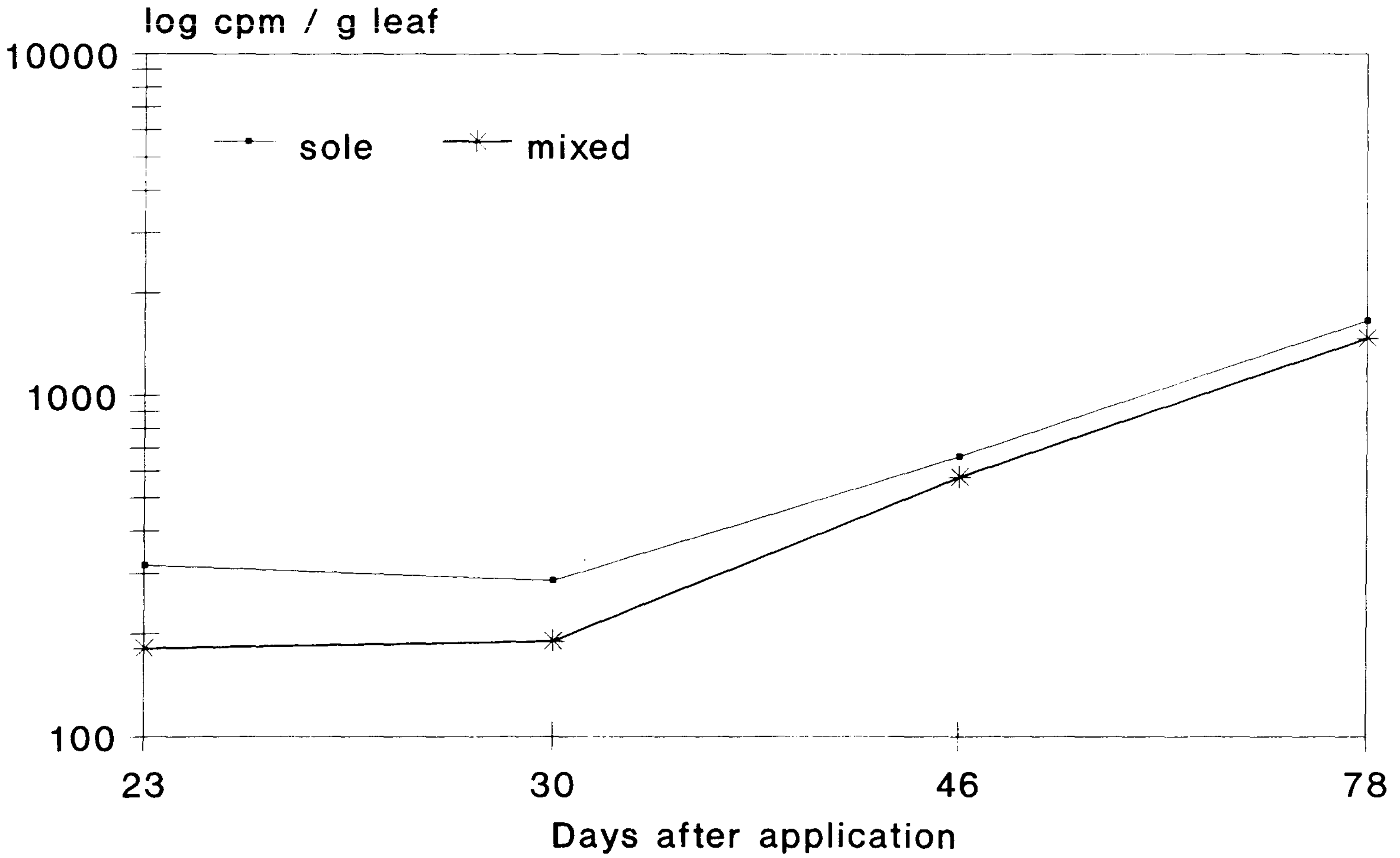


Fig.8 Uptake of soil applied P-32 in sole and mixed coconut as a function of time

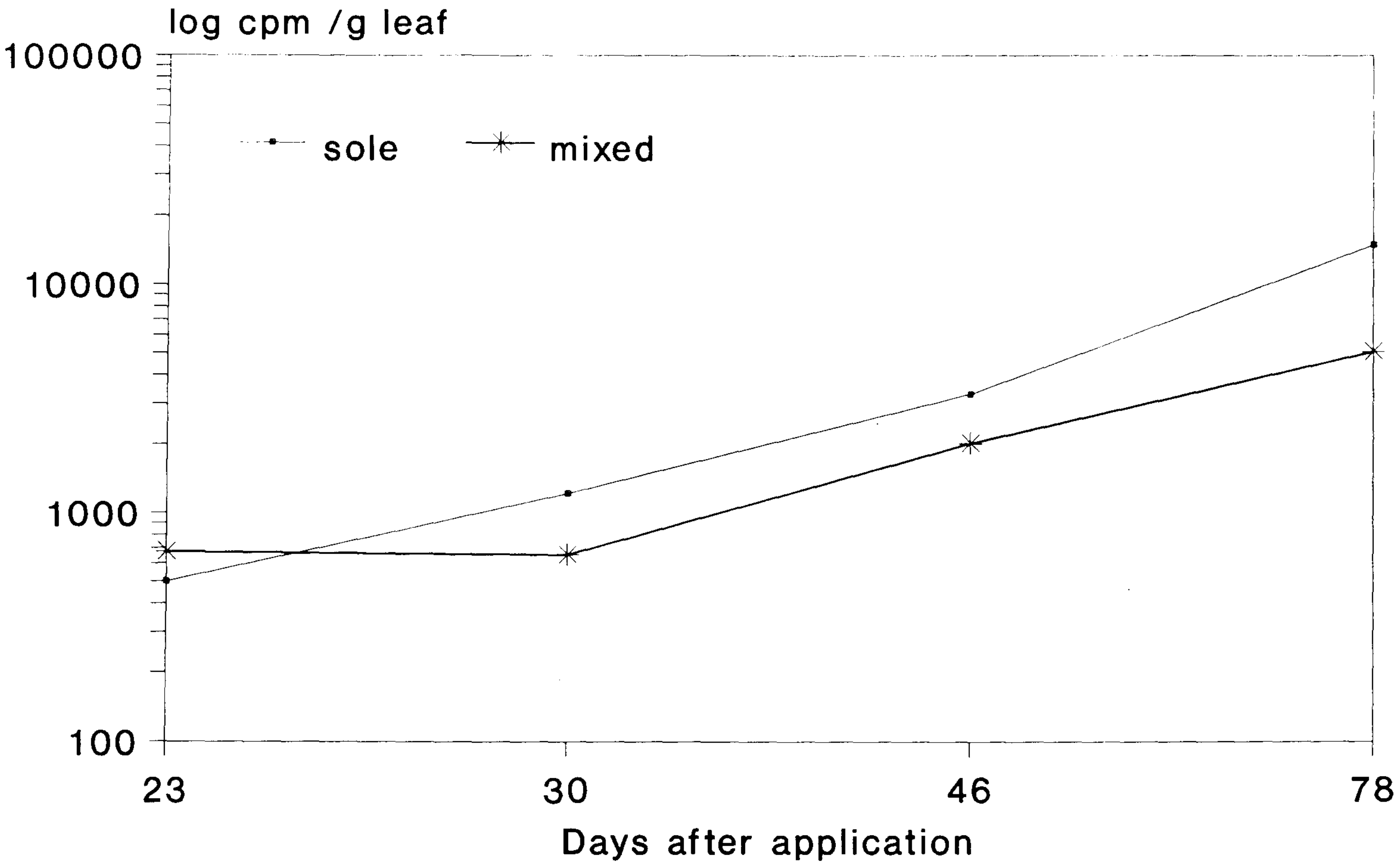


Fig.9 Uptake of soil applied P-32 in sole and mixed cocoa as a function of time

almost same throughout the experimental period in coconut. But in cocoa after 30 days of ^{32}P application, the difference between the sole and mixed cocoa with respect to the absorption of ^{32}P was very much conspicuous (Fig. 9). It was also seen that the quantity of ^{32}P absorbed increased with time. The overall absorption increased from 317, 181, 501, 676 cpm g^{-1} leaf on 23rd day to 1662, 1472, 14843, 5094 cpm g^{-1} leaf on 78th day in sole coconut, mixed coconut, sole cocoa and mixed cocoa respectively.

4.1.2 Recovery of ^{32}P in the leaves as influeced by lateral distance and depth in mixed and sole crop situations

The data on the recovery of radiolabel in the leaves of coconut and cocoa at 23, 30, 46 and 78 days after ^{32}P placement are given in Table 3 to 10 and Fig. 10 to 17 respectively. It was seen from the data that the absorption of the radiolabel was more or less same from the various radial distances in the sole and mixed stand of coconut and cocoa at all sampling intervals except at 78 DAA. AT 78 DAA, the uptake by coconut from the lateral distances of 75 and 275 cm was significantly higher than that from 175 cm. The uptake from these lateral distances was approximately 15 times more than that from 175 cm. It was at this lateral distance of 175 cm that the least uptake of ^{32}P was observed by coconut. In the case of sole and mixed cocoa, no significant difference in the uptake of ^{32}P was observed between the lateral distances of 75 and 175 cm. The uptake from these lateral distances was significantly higher than that from 275 cm. At both depths (30 and 60 cm) in mixed coconut and at 60 cm in sole coconut the ^{32}P absorption from the lateral distances of 75 and 275 cm was significantly higher than that from 175 cm. However, significant differences were observed with respect to depth of placement at 23 and 30 DAA in sole and mixed coconut. The absorption of ^{32}P was not significantly influenced by

Table 3. ^{32}P activity (log cpm g^{-1}) recovered in the leaves of coconut palms at 23 days after application of ^{32}P to the soil as affected by cropping situation, depth and lateral distance of application

Lateral distance	75 cm		175 cm		275 cm		Mean		Mean
Cropping situation	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	
Depth									
30 cm	1.961 (91)	1.786 (61)	1.957 (90)	1.053 (11)	1.523 (33)	1.460 (29)	1.814 (65)	1.433 (27)	1.623 (42)
60 cm	1.533 (34)	0.575 (4)	1.337 (22)	0.816 (7)	0.463 (3)	1.489 (31)	1.112 (13)	0.960 (9)	1.036 (11)
Mean	1.747 (56)	1.180 (15)	1.647 (44)	0.934 (9)	0.994 (10)	1.474 (30)			
Mean	1.464 (29)		1.291 (20)		1.234 (17)				

CD(0.05) for comparison of
Lateral distance : NS
Depth : 0.480
Cropping situations : NS
Interactions : NS
NS - Non significant
Figures in parentheses indicate retransformed values

Table 4. ^{32}P activity (log cpm g^{-1}) recovered in the leaves of coconut palms at 30 days after application of ^{32}P to the soil as affected by cropping situation, depth and lateral distance of application

Lateral distance	75 cm		175 cm		275 cm		Mean		Mean
Cropping situation	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	
Depth									
30 cm	1.872 (74)	1.613 (41)	1.699 (50)	1.476 (30)	1.334 (22)	1.678 (48)	1.635 (43)	1.589 (39)	1.612 (41)
60 cm	1.500 (32)	0.757 (6)	1.375 (24)	0 (1)	1.314 (21)	1.199 (16)	1.396 (25)	0.652 (4)	1.024 (11)
Mean	1.686 (49)	1.185 (15)	1.537 (34)	0.738 (6)	1.324 (21)	1.439 (27)			
Mean	1.435 (27)		1.137 (14)		1.381 (24)				

CD (0.05) for comparison of

Lateral distance : NS

Depth : 0.425

Cropping situation : NS

Interactions : NS

NS - Non significant

Figures in parentheses indicate retransformed values

Table 5. ^{32}P activity (log cpm g^{-1}) recovered in the leaves of coconut palms at 46 days after application of ^{32}P to the soil as affected by cropping situation, depth and lateral distance of application

Lateral distance	75 cm		175 cm		275 cm		Mean		Mean
Cropping situation	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	
Depth									
30 cm	2.002 (100)	2.168 (147)	2.105 (127)	1.871 (74)	2.030 (107)	2.050 (112)	2.046 (111)	2.030 (107)	2.030 (107)
60 cm	1.848 (70)	1.716 (52)	1.743 (55)	0.934 (9)	1.867 (74)	1.890 (78)	1.819 (66)	1.513 (33)	1.666 (46)
Mean	1.925 (84)	1.942 (87)	1.924 (84)	1.402 (25)	1.949 (89)	1.970 (93)			
Mean	1.934 (86)		1.663 (46)		1.959 (91)				

CD(0.05) for comparison of
Lateral distance : NS
Depth : NS
Cropping situation : NS
Interaction : NS
NS - Non significant
Figures in parentheses indicate retransformed values

Table 6. ^{32}P activity (log cpm g^{-1}) recovered in the leaves of coconut palms at 78 days after application of ^{32}P to the soil as affected by cropping situation, depth and lateral distance of application

Lateral distance	75 cm		175 cm		275 cm		Mean		Mean
Cropping situations	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	
Depth									
30 cm	2.647 (444)	2.551 (356)	2.552 (356)	1.142 (14)	2.406 (255)	2.470 (295)	2.535 (343)	2.054 (113)	2.294 (197)
60 cm	2.446 (279)	2.477 (300)	1.087 (12)	0 (1)	2.244 (175)	2.369 (234)	1.925 (84)	1.615 (41)	1.770 (59)
Mean	2.546 (352)	2.514 (327)	1.819 (66)	0.571 (4)	2.325 (211)	2.419 (262)			
Mean	2.530 (339)		1.195 (16)		2.372 (236)				

CD(0.05) for comparison of

Lateral distance : 0.749

Depth : NS

Cropping situation : NS

Interactions : NS

NS - Non significant

Figures in parentheses indicate retransformed values

Table 7. ^{32}P activity (log cpm g^{-1}) recovered in the leaves of cocoa trees at 23 days after application of ^{32}P to the soil as affected by cropping situation, depth and lateral distance of application

Lateral distance	75 cm		175 cm		275 cm		Mean		Mean
Cropping situation	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	
Depth									
30 cm	1.853 (71)	2.189 (155)	1.488 (31)	2.002 (100)	1.304 (20)	1.787 (61)	1.548 (35)	1.993 (98)	1.770 (59)
60 cm	1.719 (52)	1.199 (16)	1.949 (89)	1.228 (17)	0.965 (9)	1.217 (16)	1.544 (35)	1.215 (16)	1.380 (24)
Mean	1.786 (61)	1.694 (49)	1.718 (52)	1.615 (41)	1.135 (14)	1.502 (32)			
Mean	1.740 (55)		1.667 (46)		1.318 (21)				

CD(0.05) for comparison of
Lateral distance : NS
Depth : NS
Cropping situation : NS
Interactions : NS
NS - Non significant
Figures in parentheses indicate retransformed values

Table 8. ^{32}P activity (log cpm g^{-1}) recovered in the leaves of cocoa trees at 30 days after application of ^{32}P to the soil as affected by cropping situation, depth and lateral distance of application

Lateral distance	75 cm		175 cm		275 cm		Mean		Mean
Cropping situation	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	
Depth									
30 cm	2.010 (102)	2.100 (126)	1.592 (39)	0.795 (6)	1.357 (23)	1.692 (49)	1.653 (45)	1.529 (34)	1.591 (39)
60 cm	1.864 (73)	1.301 (20)	2.162 (145)	0.900 (8)	0 (1)	1.881 (76)	1.342 (22)	1.361 (23)	1.351 (22)
Mean	1.937 (86)	1.701 (50)	1.877 (75)	0.848 (7)	0.679 (5)	1.787 (61)			
Mean	1.819 (66)		1.362 (23)		1.233 (17)				

CD(0.05) for comparison of

Lateral distance : NS

Depth : NS

Cropping situation : NS

Interactions : NS

NS - Non significant

Figures in parentheses indicate retransformed values

Table 9. ^{32}P activity (log cpm g^{-1}) recovered in the leaves of cocoa trees at 46 days after application of ^{32}P to the soil as affected by cropping situation, depth and lateral distance of application

Lateral distance	75 cm		175 cm		275 cm		Mean		Mean
Cropping situation	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	
Depth									
30 cm	2.786 (611)	2.682 (481)	2.108 (128)	2.172 (149)	1.610 (41)	2.376 (238)	1.610 (41)	2.410 (257)	2.216 (164)
60 cm	2.111 (129)	2.014 (103)	3.366 (2323)	1.814 (65)	1.418 (26)	2.295 (197)	2.298 (197)	2.041 (110)	2.090 (123)
Mean	2.45 (282)	2.348 (223)	2.737 (546)	1.993 (98)	1.514 (33)	2.335 (216)			
Mean	2.289 (195)		2.245 (176)		1.925 (84)				

CD(0.05) for comparison of
Lateral distance : NS
Depth : NS
Cropping situation : NS
Interactions : NS
NS - Non significant
Figures in parentheses indicate retransformed values

Table 10. ^{32}P activity (log cpm g^{-1}) recovered in the leaves of cocoa trees at 23 days after application of ^{32}P to the soil as affected by cropping situation, depth and lateral distance of application

Lateral distance	75 cm		175 cm		275 cm		Mean		Mean
Cropping situation	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	
Depth									
30 cm	3.707 (5093)	2.821 (662)	3.234 (1714)	3.033 (1079)	1.911 (81)	2.721 (526)	2.951 (893)	2.858 (721)	2.905 (804)
60 CM	3.400 (2512)	2.615 (412)	3.119 (1315)	2.648 (445)	2.289 (195)	2.633 (430)	2.936 (863)	2.632 (429)	2.784 (608)
Mean	3.554 (3581)	2.718 (522)	3.176 (1499)	2.840 (692)	2.100 (126)	2.677 (475)			
Mean	3.136 (1368)		3.008 (1019)		2.389 (245)				

CD(0.05) for comparison of

Lateral distance : NS
Depth : NS
Cropping situation : NS
Interaction : NS
NS - Non significant
Figures in parentheses indicate retransformed values

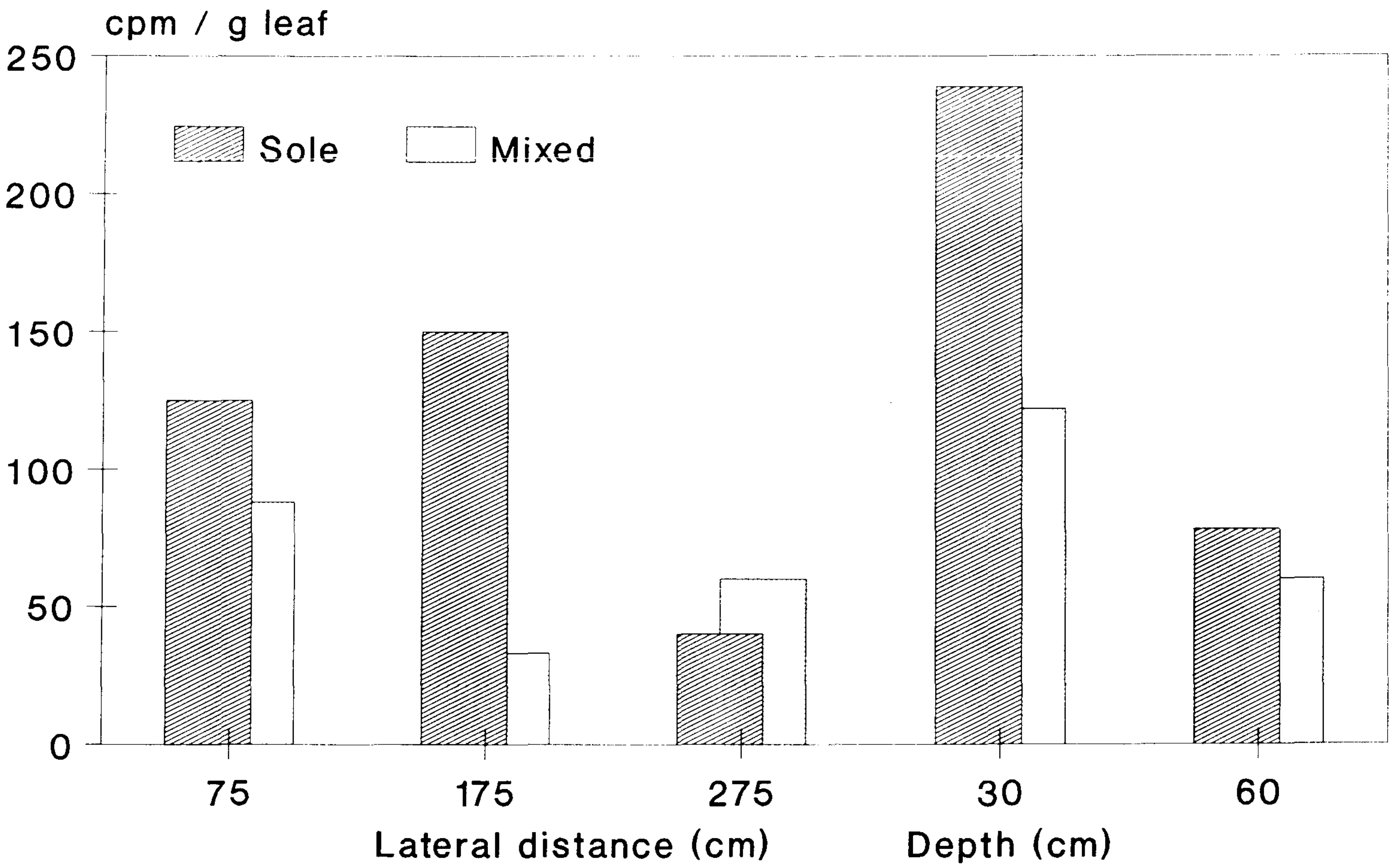


Fig.10 Uptake of soil applied P-32 at different lateral distances and depths in sole and mixed coconut at 23 DAA

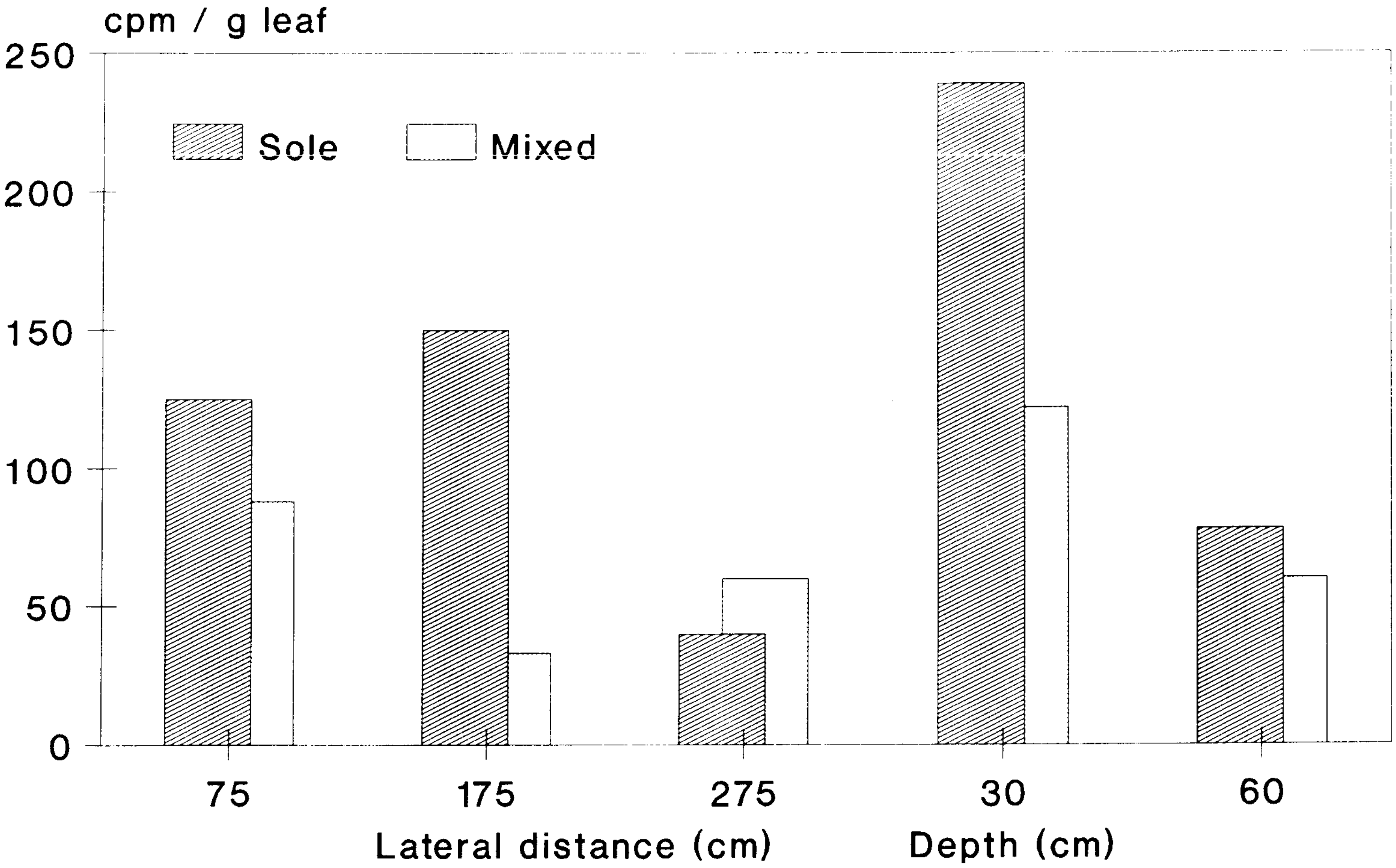


Fig.10 Uptake of soil applied P-32 at different lateral distances and depths in sole and mixed coconut at 23 DAA

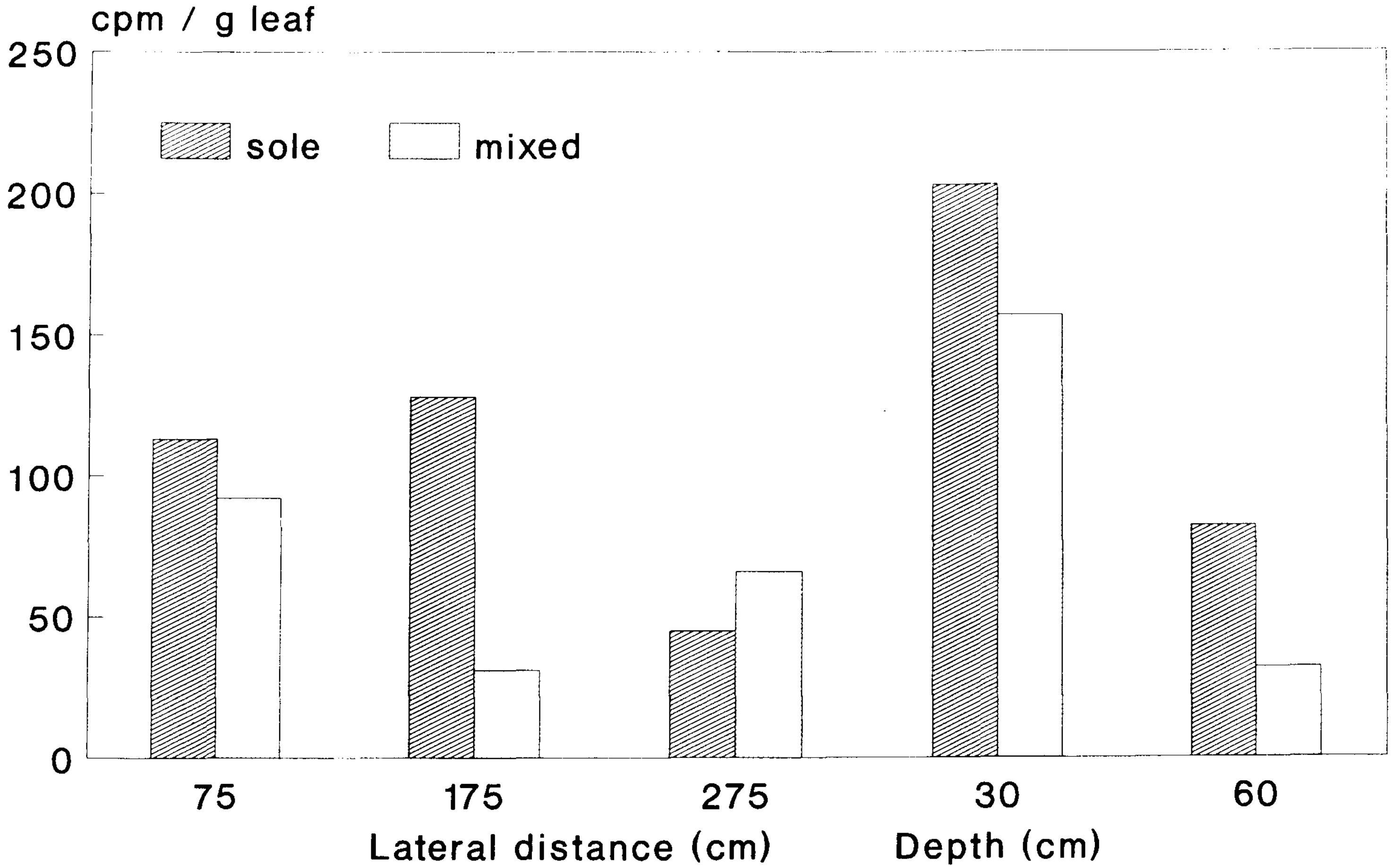


Fig.11 Uptake of soil applied P-32 at different lateral distances and depths in sole and mixed coconut at 30 DAA

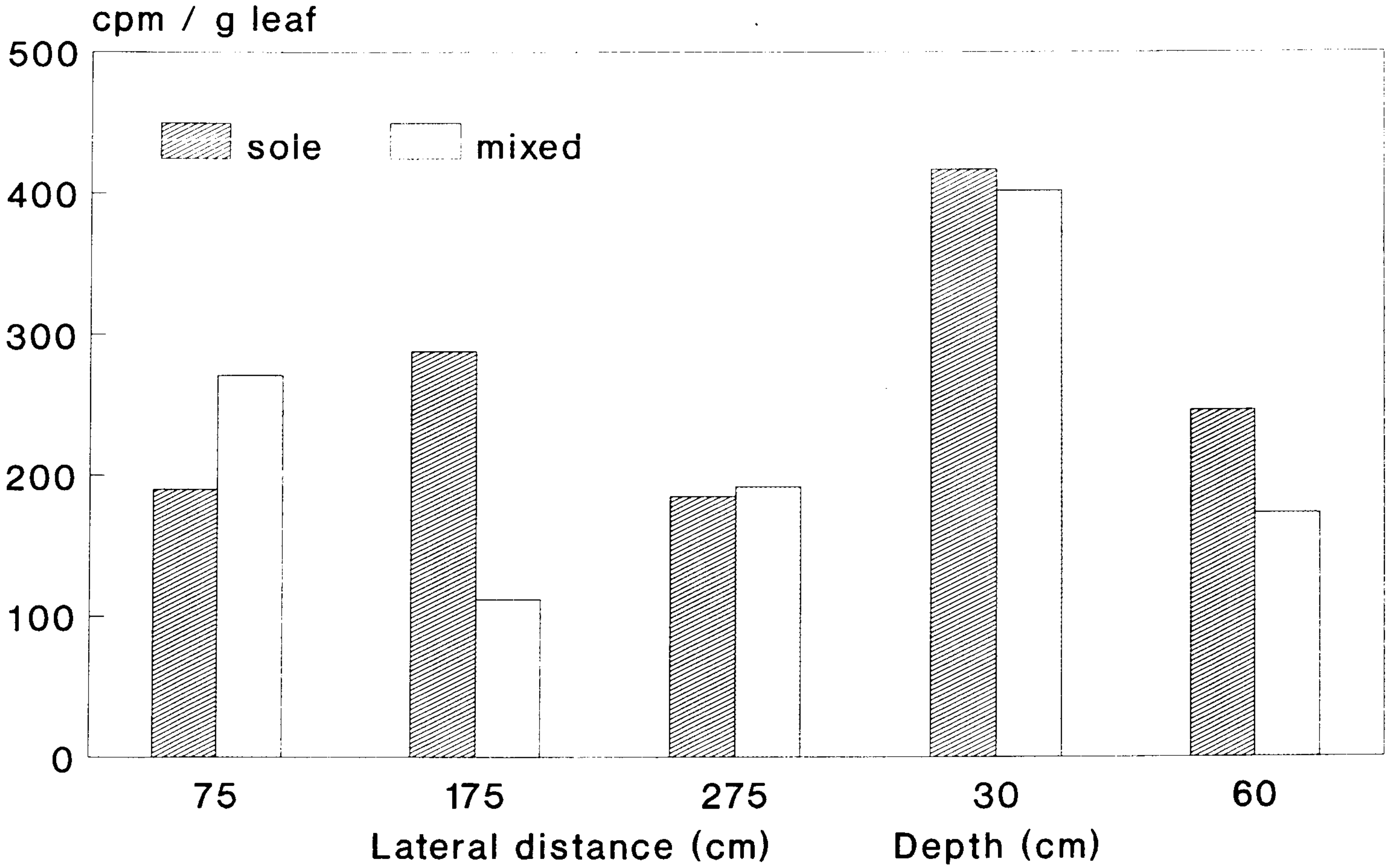


Fig.12 Uptake of soil applied P-32 at different lateral distances and depths in sole and mixed coconut at 46 DAA

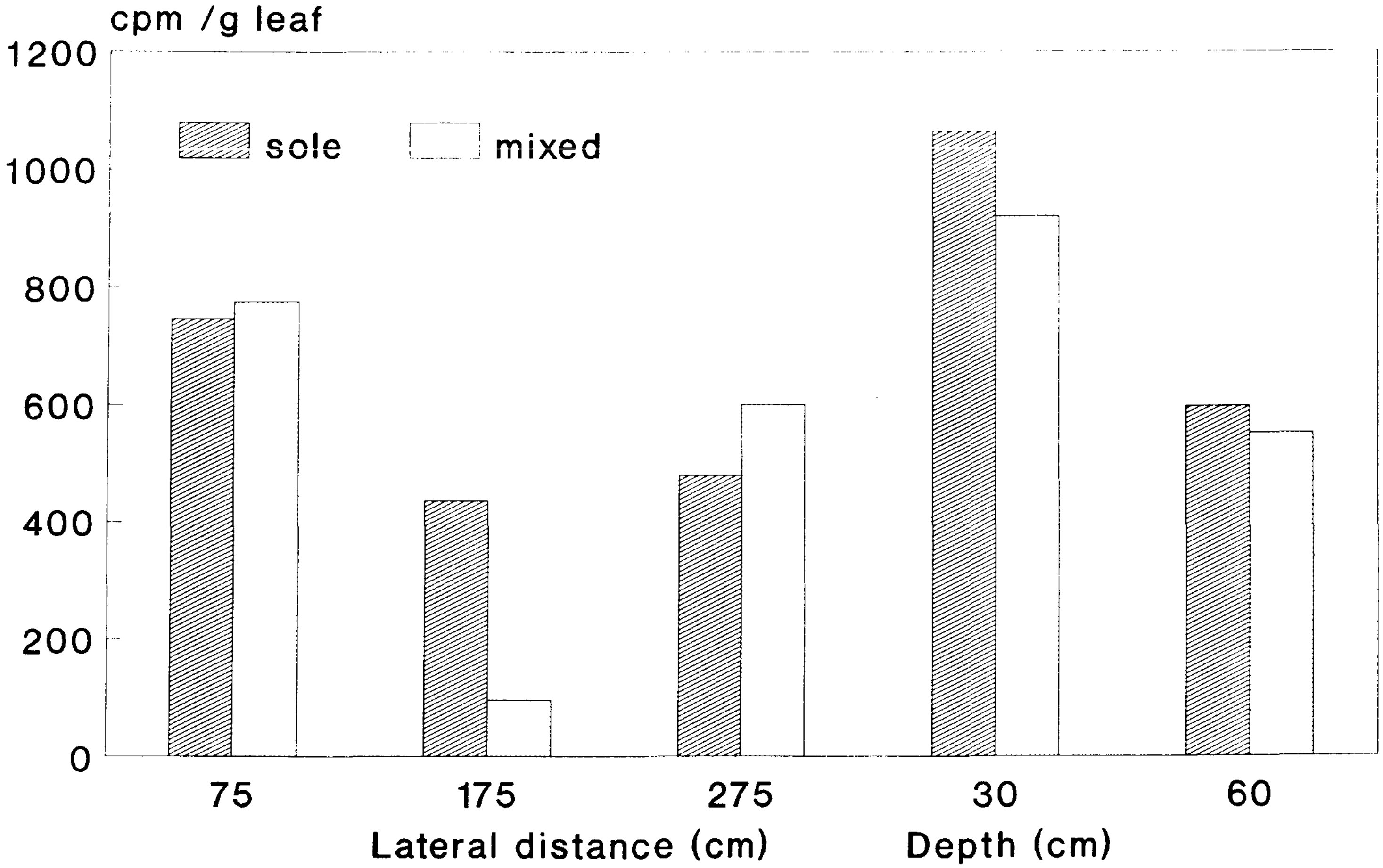


Fig.13 Uptake of soil applied P-32 at different lateral distances and depths in sole and mixed coconut at 78 DAA

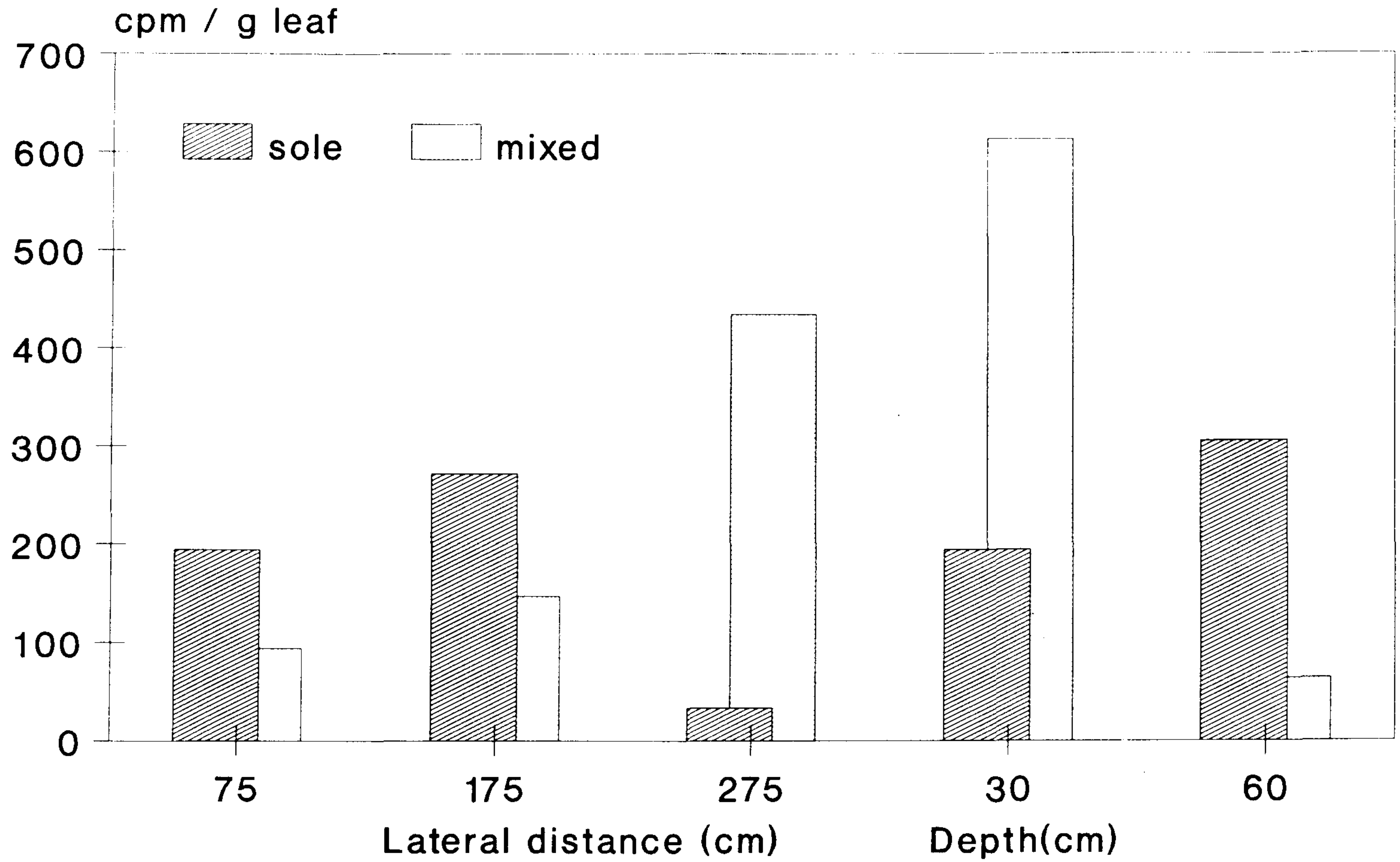


Fig.14 Uptake of soil applied P-32 at different lateral distances and depths in sole and mixed cocoa at 23 DAA

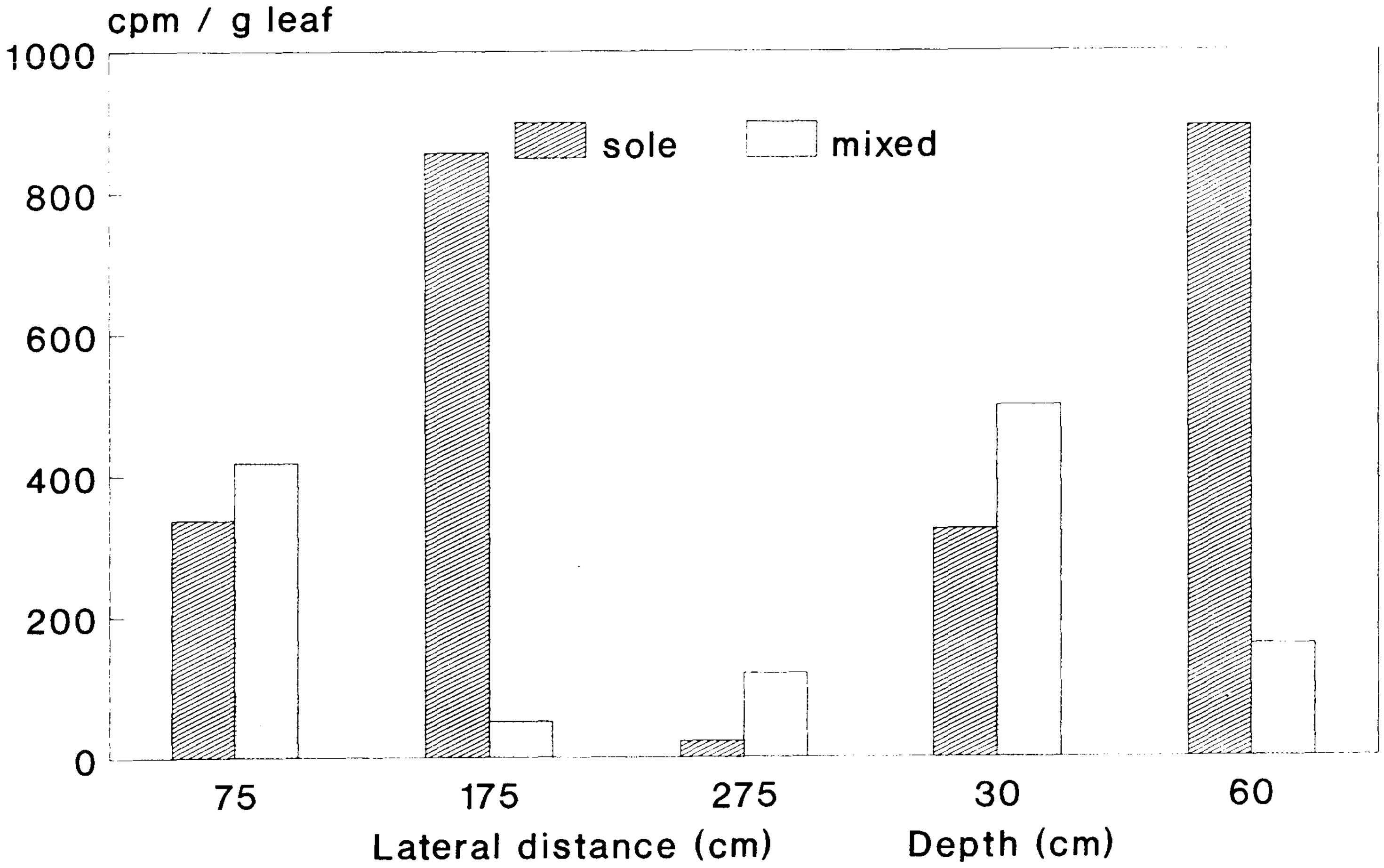


Fig.15 Uptake of soil applied P-32 at different lateral distances and depths in sole and mixed cocoa at 30 DAA

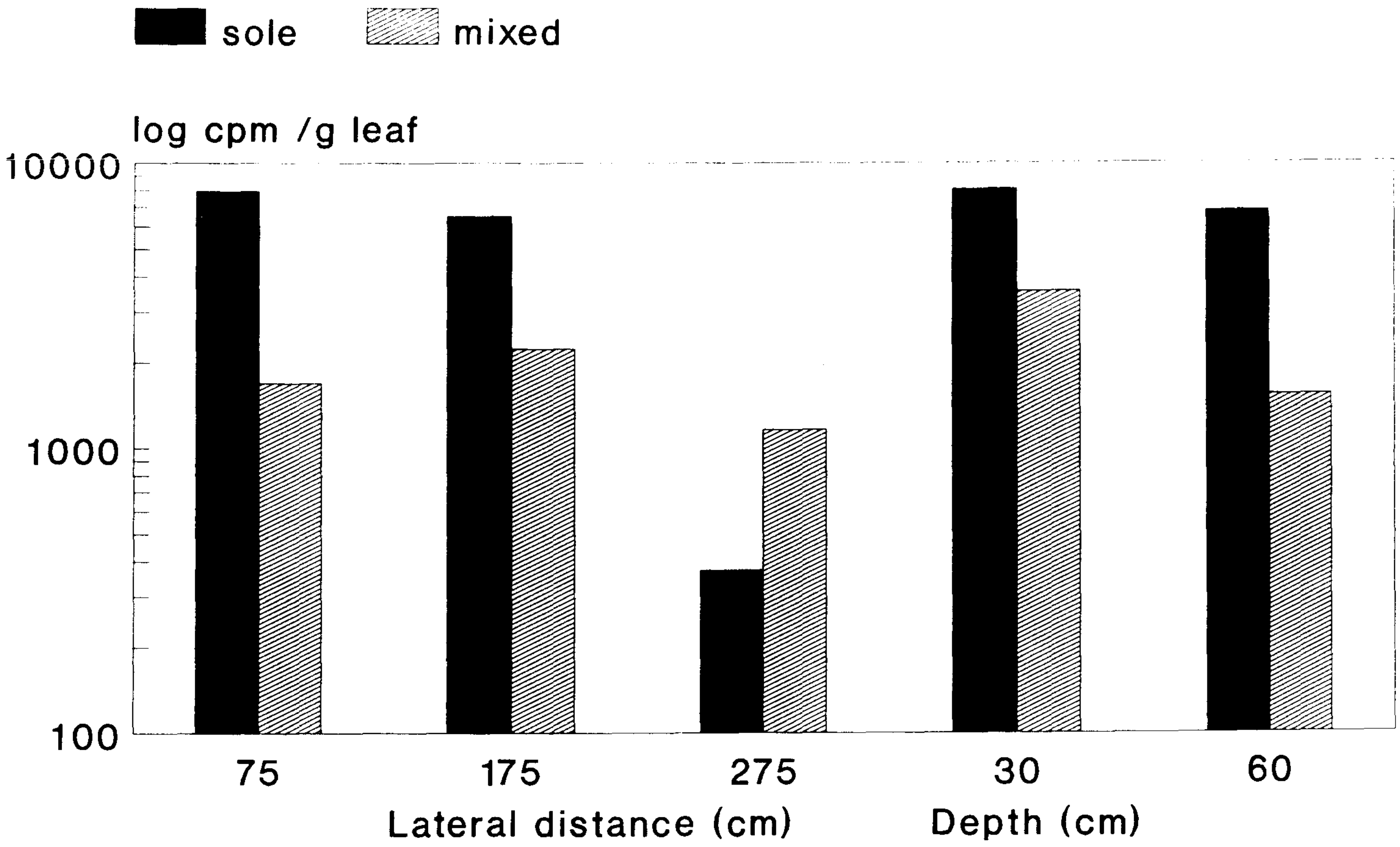


Fig.16 Uptake of soil applied P-32 at different lateral distances and depths in sole and mixed cocoa at 46 DAA

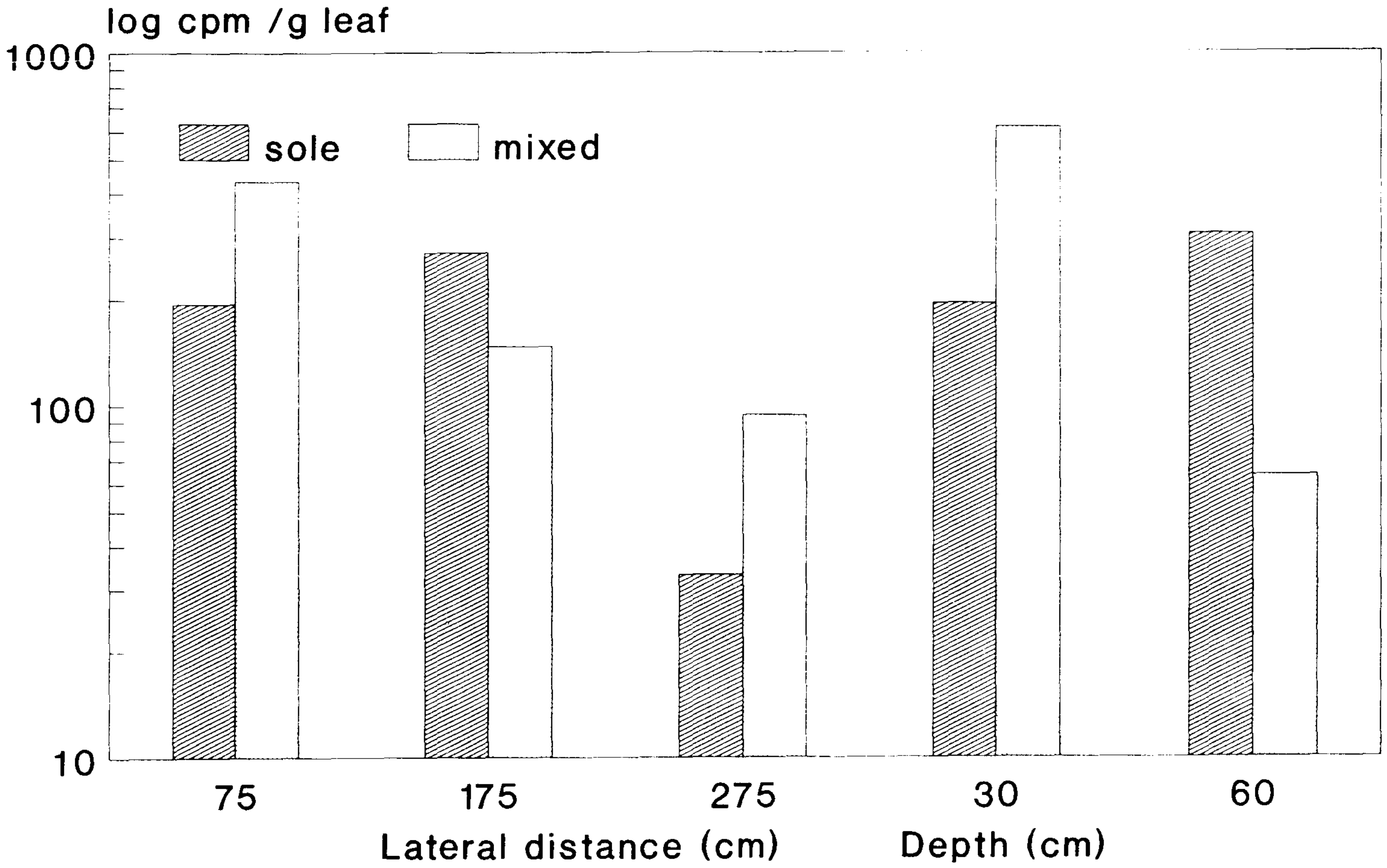


Fig.17 Uptake of soil applied P-32 at different lateral distances and depths in sole and mixed cocoa at 78 DAA

depth of placement at 46 and 78 DAA. The recovery of ^{32}P in the leaves of coconut in both sole and mixed stand was in general greater when the radiolabel was applied in the surface 30 cm soil layer. The increase in the uptake of ^{32}P by coconut from 30 cm depth was most significant at 23 and 30 DAA. In sole and mixed cocoa, the uptake of radiolabel did not differ significantly between the various depths tested. The uptake of ^{32}P by both sole and mixed cocoa was more or less uniformly distributed in top 60 cm soil layer. The crop stand-depth, crop stand-lateral distance, lateral distance-depth and crop stand-lateral distance-depth interactions in the absorption of ^{32}P were not significant in cocoa and coconut systems at any of the sampling interval. Though not significant it was observed that the uptake of ^{32}P by both coconut and cocoa in the mixed stand was higher than that of sole crop at 275 cm at all the sampling intervals (Fig. 10 to 17). It was from the lateral distance of 175 cm that the mixed crop of both coconut and cocoa recorded the least uptake compared to the sole crop at all sampling days.

At 75 cm, in coconut absorption of ^{32}P was higher in sole stand at 23 and 30 DAA, but later it was more in mixture at 46 and 78 DAA. In the case of cocoa upto 46 DAA, the uptake of ^{32}P was greater in sole stand thereafter at 78 DAA the uptake was more in mixed stand. At both depths of 30 and 60 cm the ^{32}P uptake was more in sole stand in coconut as compared to mixed stand at all sampling intervels. In cocoa at 60 cm depth, the ^{32}P uptake was higher in sole stand at all intervals of sampling. But at 30 cm soil layer, the uptake of ^{32}P was more in mixed stand upto 46 DAA and thereafter at 78 DAA the uptake was higher in sole cocoa.

The absorption of ^{32} P by sole and mixed stand of coconut and cocoa at different lateral distances and depths as a function of time is depicted in Fig. 18

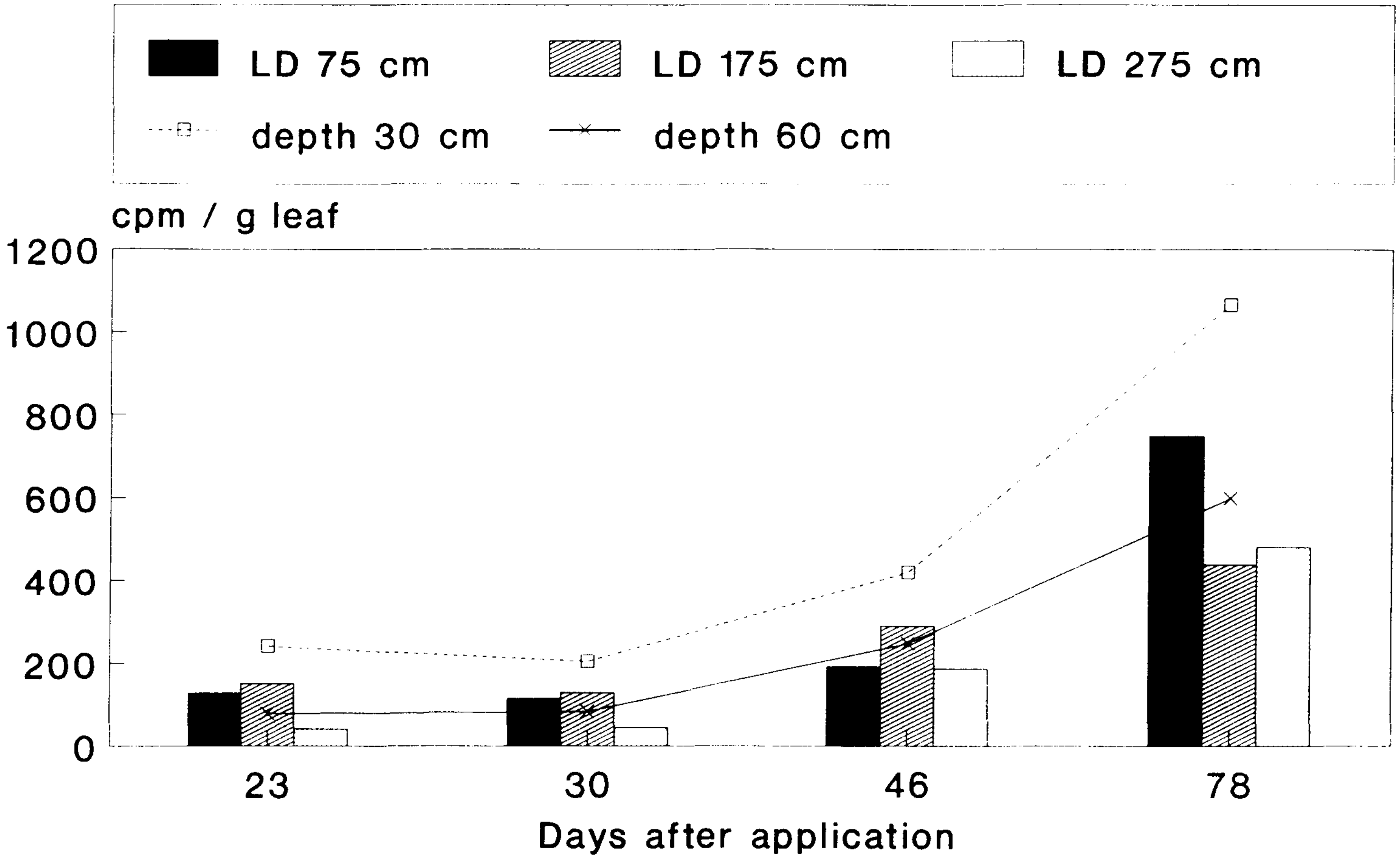


Fig.18 Uptake of P-32 by sole coconut after application of P-32 at different lateral distances and depths with time

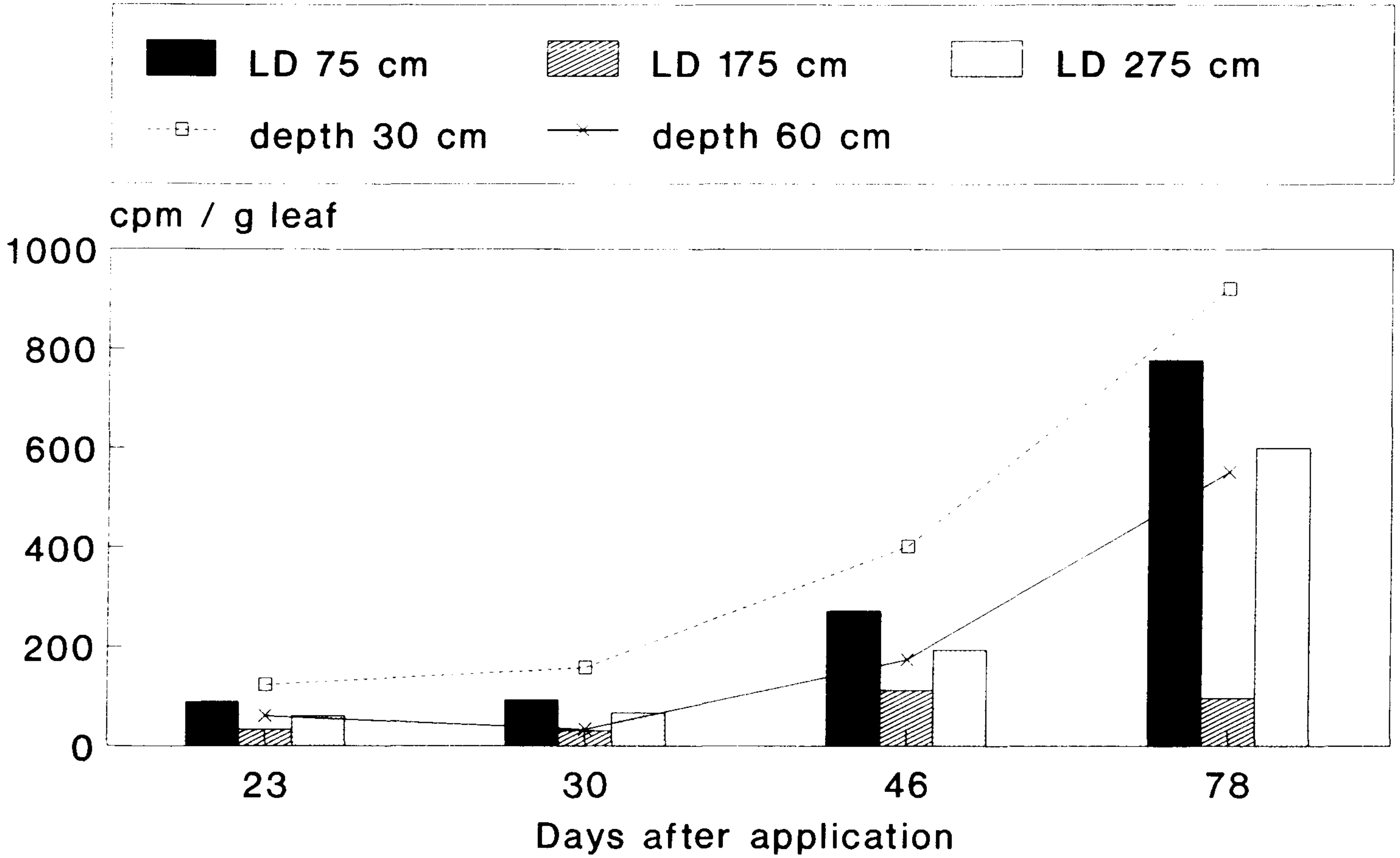


Fig.19 Uptake of P-32 by mixed coconut after application of P-32 at different lateral distances and depths with time

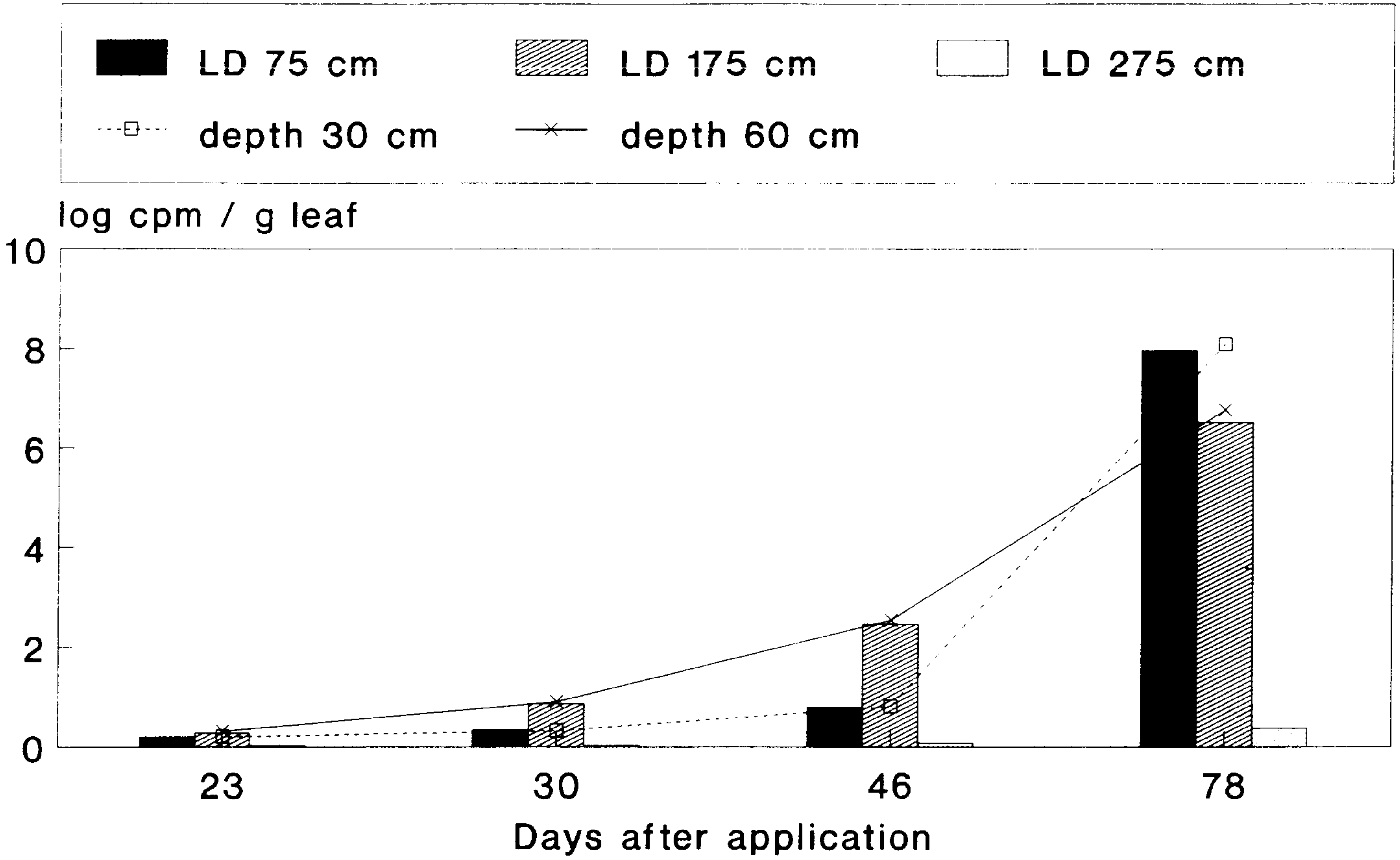


Fig.20 Uptake of P-32 by sole cocoa after application of P-32 at different lateral distances and depths with time

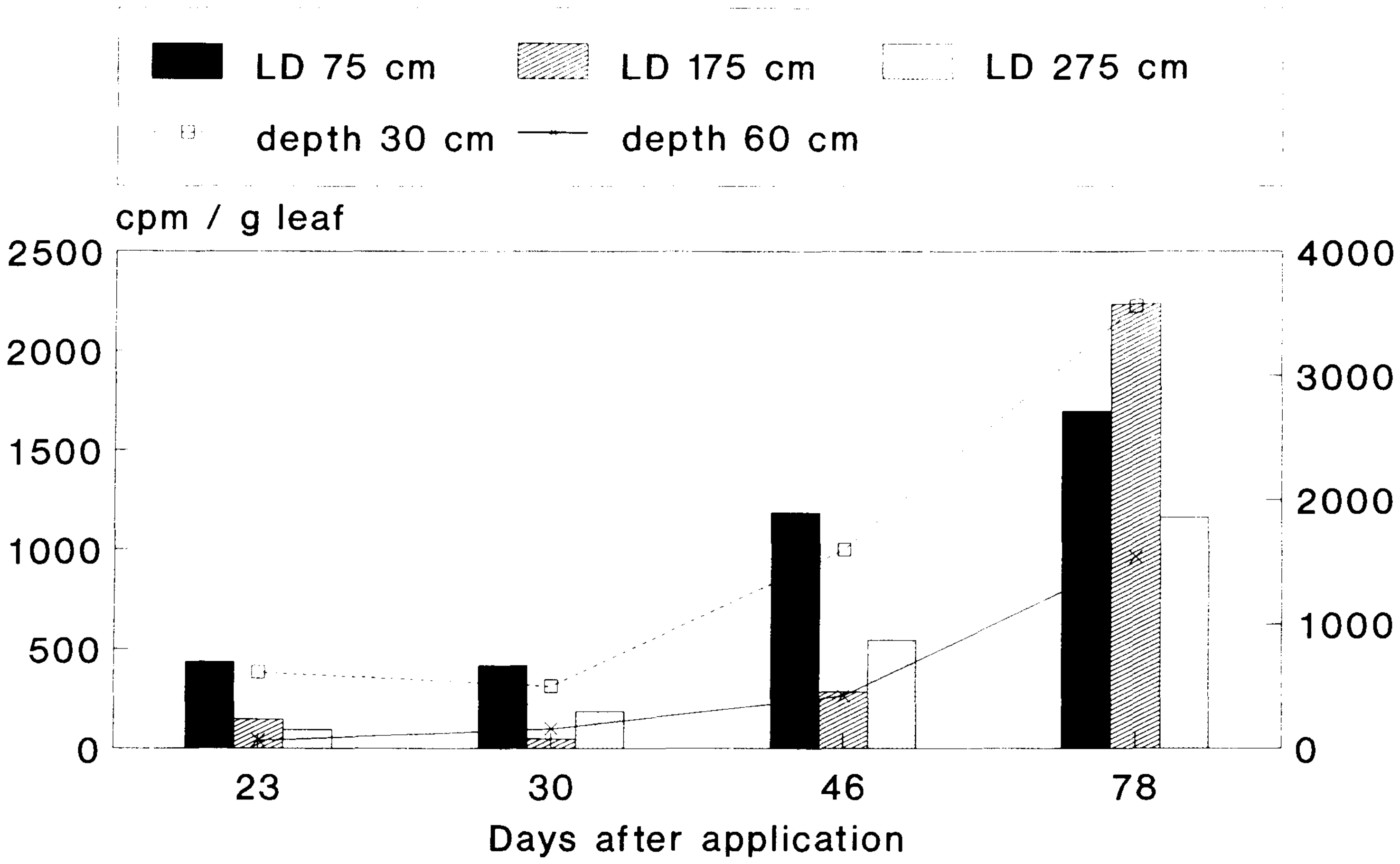


Fig.21 Uptake of P-32 by mixed cocoa after application of P-32 at different lateral distances and depths with time

to 21. In sole coconut absorption of ^{32}P increased with time from both depths of ^{32}P application. Same was the case with mixed coconut. In both cropping situations uptake was higher from 30 cm. The absorption of ^{32}P at all lateral distances decreased at 30 DAA thereafter increased in sole coconut where as in mixed stand the absorption of radiolabel from all lateral distances of application remained more or less same at 23 and 30 DAA. Though the absorption at 75 and 275 cm increased with time, the uptake at 175 cm lateral distance decreased with time. In sole coconut, ^{32}P uptake was more at 175 cm at all sampling intervals except at 78 DAA where the uptake was greater at 75 cm. In mixed coconut, ^{32}P uptake was greater at 75 cm lateral distance, modest at 275 cm and least at 175 cm at all sampling intervals (Fig. 18 and 19).

In both sole and mixed cocoa there was an increase in the uptake of ^{32}P with time (Fig. 20 and 21). In sole cocoa, upto 60 days the ^{32}P uptake was greater from 60 cm depth than from surface soil layer but thereafter the absorption was more when ^{32}P was placed at 30 cm depth. As regards to lateral distance, the recovery of ^{32}P increased with time at 75 and 275 cm and at a lateral distance of 175 cm, the uptake decreased at 30 DAA thereafter it increased with time. In mixed cocoa, maximum uptake of ^{32}P was noted 75 cm laterally upto 46 DAA. At 78 DAA, recovery of ^{32}P in the leaves was at peak when ^{32}P was placed at 175 cm lateral distance. In sole cocoa, at all sampling intervals except at 78 DAA, uptake of radiolabel was highest at 175 cm but at 78 DAA, the highest uptake was recorded 75 cm laterally.

4.2 Pattern of root activity in pure and mixed stand of coconut and cocoa

The experiment was aimed to study the root activity in mixed as well as pure stands of coconut and cocoa. The percentage root activity at different lateral distances and depths were worked out from the corresponding mean cpm values of first experiment using the formula

$$\text{Root activity (\%)} = \frac{\text{Radioactivity (cpm) recovered in the leaf for the treatment}}{\text{Total radioactivity (cpm) recovered for all the treatments}} \times 100$$

The radioactivity recovered in the leaf by absorption of radiolabel from different soil zones reflect the relative density of active roots in these zones. In this study, comparisons were made on the percentage root activity of sole crop of coconut and mixed crop of coconut : between sole crop of cocoa and mixed crop of cocoa. Root activity patterns of coconut and cocoa in mixed stand in comparison with that of pure stands of coconut and cocoa were important in getting an insight into the vertical and lateral spread when intercropped; root competition, if any, between coconut and cocoa; delineation of the soil zone of maximum nutrient absorption by these crops.

4.2.1 Root activity pattern of sole and mixed stand of coconut

The percentage root activity at 78 DAA at different lateral distances and depths were worked out for coconut and is given in Table 11. In sole coconut, the percentage root activity at 30 cm depth for 75, 175 and 275 cm radial distances

Table 11. Root activity of sole and mixed crop of coconut at different lateral distances and depths (%) at 78 days after application

Lateral distance	75 cm		175 cm		275 cm		Total	
Cropping situation	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed
Depth								
30 cm	27	31	22	7	15	25	64	63
60 cm	18	22	4	0	14	15	36	37
Total	45	53	26	7	29	40		

were 27, 22 and 15 per cent whereas at 60 cm depth it was 18, 5 and 13 per cent respectively. In mixed coconut the percentage root activity at 30 cm depth was 31, 7 and 25 per cent whereas at 60 cm depth 22, 0 and 15 per cent for 75, 175 and 275 cm lateral distance from the palm. It was observed that over 70 per cent of root activity was confined to within a lateral distance of 175 cm from the tree of which almost 50 per cent within 75 cm in sole and in mixed stand; 60 per cent within 175 cm of which 53 per cent within 75 cm. It was seen that the percentage root activity was very much lower at 175 cm than even at 275 cm in mixture. The vertical spread of the roots indicated that over 60 per cent of the roots explored upto 30 cm soil depth in both situations (Fig. 22).

The root activity observed at 23, 30, 46 and 78 DAA is presented in Table 12. The pattern of root activity is more or less same as that at 78 DAA. It was seen that there was a general increase in the root activity with time. It was also observed that coconut was more or less a surface feeder within 30 cm layer in sole and mixed stand. It was interesting to note that in the presence of cocoa coconut roots avoided the soil zone at 175 cm averaged over depth. The percentage root activity at 175 cm at 23, 30, 46 and 78 DAA was only 18, 17, 19 and 7 in mixed crop as against 47, 45, 43 and 26 in the sole stand.

4.2.2 Root activity pattern of sole and mixed stand of cocoa

The percentage root activity at different lateral distances and depths were worked out for cocoa in both cropping systems (Table 13). The results indicated that the root activity was negligible at the lateral distance of 275 cm in sole stand both at 30 and 60 cm depths. The root activity at 75 and 175 cm lateral distance at 30 cm depth was 35 and 18 per cent and at 60 cm depth, 19 and 26 per cent respectively.

Table 12. Percentage root activity of sole and mixed stand of coconut

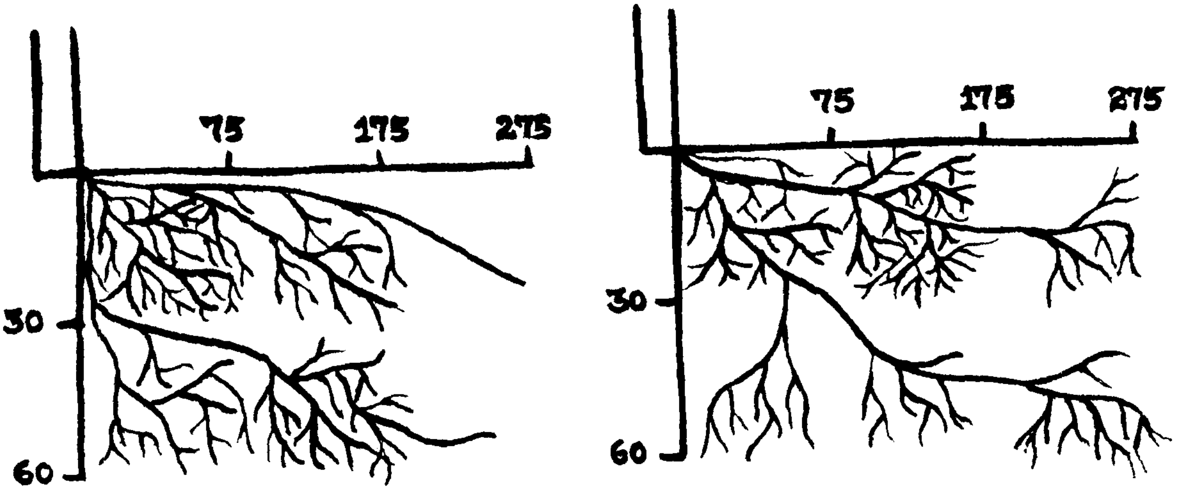
Days after ^{32}P application	Lateral distance						Depths			
	75 cm		175 cm		275 cm		30 cm		60 cm	
	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed
23	40	48	47	18	13	34	73	67	27	33
30	40	48	45	17	15	35	71	83	29	17
46	29	47	43	19	28	34	63	70	37	30
78	45	53	26	7	29	40	64	63	36	37

Table 13. Root activity of sole and mixed crop of cocoa at different lateral distances and depths (%) at 78 days after application of ^{32}P

Lateral distance	75 cm		175 cm		275 cm		Total	
Cropping situation	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed
Depth								
30 cm	35	24	18	35	1	11	54	70
60 cm	19	9	26	9	1	12	46	30
Total	54	33	44	44	2	23		

a) sole stand of cocoa

c) mixed stand of cocoa



b) sole stand of coconut

d) mixed stand of coconut

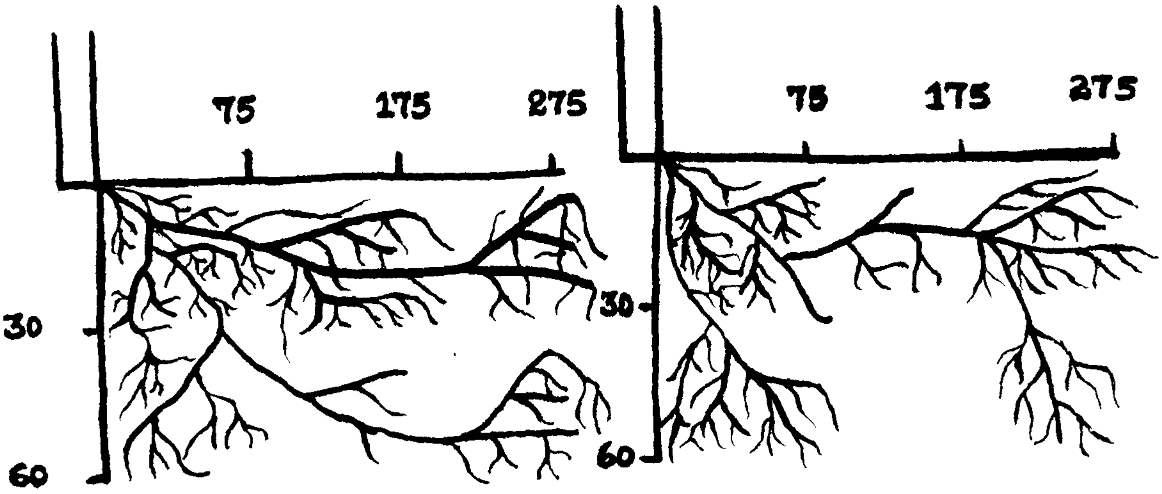


Fig.22 Root distribution pattern(based on % of radioacivity)in sole and mixed crop of coconut and cocoa

This pointed out that in sole stand, higher root activity was at 175 cm for 60 cm depth and at 75 cm for 30 cm depth. In the mixed stand high root activity was observed at the lateral distance of 275 cm during all the sampling intervals against the negligible root activity for the sole crops (Table 13, Fig. 22). An area of radius 175 cm around the tree accounted for about 58 per cent and 77 per cent of root activity in sole and mixed stand respectively. In mixture, the root activity (%) at 30 cm depth for 275, 175 and 75cm was 11, 35 and 24 per cent and at 60 cm was 12, 9 and 9 per cent respectively. In the absence of coconut, cocoa foraged deeper layers of soil more efficiently than in its presence (Table 14). Nearly three-fourth of root activity was confined to the surface 30 cm soil layer in the mixed stand of cocoa. In the sole cocoa, the roots explored deeper layers better than surface layer upto 46 days. At 78 DAA it was more or less evenly distributed at 30 and 60 cm depths.

4.3 Soil nutrient depletion in the sole and mixed stand

In this experiment soil samples were drawn from different depths and lateral distances from mixed as well as purestands of coconut and cocoa. The soil samples were analysed for organic carbon, available P, K, Ca, Mg, S, Fe, Mn, Zn and Cu.

4.3.1 Soil chemical characteristics in pure and mixed stand of coconut as influenced by depth and lateral distance

Available phosphorus, potassium, zinc and copper showed no significant variation between soils of sole stand and mixed stand of coconut. However, organic carbon, available Ca, Mg, S, Fe and Mn varied significantly in sole and mixture. It was observed that the secondary elements were in higher concentration in mixture

Table 14. Percentage root activity of sole and mixed stand of cocoa

Days after ^{32}P application	Lateral distance						Depths			
	75 cm		175 cm		275 cm		30 cm		60 cm	
	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed
23	39	64	54	22	7	14	39	91	61	9
30	28	63	70	8	2	29	27	76	73	24
46	24	59	74	14	2	27	24	79	76	21
78	54	33	44	44	2	23	54	70	46	30

whereas organic carbon, available Fe and Mn were high in soils of sole coconut (Table 15).

The crop stand - depth interactions were significant for available Mg and Zn (Table 16 and 17). It was noted that in sole system as well as in mixed system as the depth increased the content of available Mg in the soil decreased. In mixture, the content of available Mg at 25 cm depth was significantly superior to that at 50 cm and 75 cm. The magnesium content at 50 cm and 75 cm did not differ significantly in the mixed system. In sole stand, the Mg content at all depths were homogeneous. At all depths, available Mg content in mixed stand was significantly higher than that in sole stand. It was observed that the content of available zinc increased with increasing depth in both sole and mixed system. But in sole stand, the zinc content was homogeneous at all depths. In mixture, the content of available Zn at 50 and 75 cm soil layer was homogeneous and was significantly higher than that at 25 cm depth. At all depths, the available Zn content was homogeneous between sole and mixed stand except for 75 cm soil layer. At 75 cm, the available Zn content in mixed stand was significantly higher than that in sole stand of coconut. For organic C, available P, K, Ca, S, Fe, Mn and Cu the crop stand-depth interaction remained non-significant.

The crop stand-lateral distance interactions were not statistically significant in the case of available P, K, Ca, S, Zn and Cu. They showed significant variations in organic carbon, available Mg, Fe and Mn content between sole and mixed stand of coconut.

In the case of organic carbon, except at 150 and 250 cm from coconut the content was significantly higher in sole stand than mixed stand. In sole coconut

Table 15. Chemical characteristics of the soil in coconut systems as influenced by crop stand

	Org. C %	Av. P ppm	Av. K ppm	Av. Ca ppm	Av. Mg ppm	Av. S ppm	Av. Fe ppm	Av. Mn ppm	Av. Zn ppm	Av. Cu ppm
Sole coconut	2.22	9.96	161.89	250.05	50.95	52.04	14.84	89.43	62.64	3.79
Mixed coconut	1.88	8.97	179.78	345.83	80.68	66.98	12.31	81.73	74.40	3.73
SEm±	0.029	0.91	8.36	8.36	2.15	2.96	0.26	1.66	6.07	0.21
CD(0.05)	0.109	NS	NS	31.26	8.03	11.07	0.95	6.22	NS	NS

NS - Non significant

Table 16. Interaction between crop stand and depth in coconut for available Mg (ppm)

	Depth (cm)		
	25	50	75
Coconut sole	51.94	51.60	49.31
Coconut mixed	92.86	79.72	69.45
SEm ±	3.7145		
CD (0.05)	10.469		

Table 17. Interaction between crop stand and depth in coconut for available Zn (ppm)

	Depth (cm)		
	25	50	75
Coconut sole	52.82	60.72	74.39
Coconut mixed	25.68	82.47	115.06
SEm±	10.508		
CD (0.01)	39.32		

upto 150 cm with increasing lateral distance, organic carbon content decreased thereafter at 200 cm there was a significant increase and at 250 cm showed a decline followed by an increase at 300 cm. In mixture after 200 cm with increasing lateral distance, organic carbon decreased. Upto 200 cm, the organic matter distribution did not follow a characteristic pattern (Table 18).

Table 19 present the interaction between crop stand and lateral distance in coconut systems for available Mg. It was observed that with increasing lateral distance the available Mg content decreased upto 250 cm and thereafter increased in sole stand. In mixture it decreased upto 150 cm then increased at 200 cm and decreased thereafter. At 50, 100 and 200 cm lateral distance, there was significant variation in available Mg content between sole and mixed stand. But at 150, 250 and 300 cm, marked variation was absent. The content of available Mg at all lateral distances in sole coconut was comparable. The available Mg at 50 and 100 cm radial distance was significantly greater than that at 150, 200, 250 and 300 cm which were more or less same.

At all lateral distances the available Fe content was high in sole coconut and it showed marked variation at 100, 150 and 200 cm (Table 20) between sole and mixed stand. In mixture upto 200 cm with increased lateral distance there was a decrease in available Fe concentration and thereafter it increased. In sole coconut, available Fe increased upto 150 cm then decreased upto 250 cm and at 300 cm it showed an increase.

From Table 21 it was noticed that upto a lateral distance of 100 cm available Mn was higher in mixed coconut than that in sole and from 100 cm onwards the reverse trend was observed. It was at 100 cm, available Mn content was maximum in both sole and mixed stand.

Table 18. Interaction between crop stand and lateral distances in coconut for organic carbon (%)

	Lateral distance (cm)					
	50	100	150	200	250	300
Coconut sole	2.389	2.333	2.033	2.478	1.967	2.133
Coconut mixed	2.033	1.753	1.833	2.013	1.900	1.760
SEm±	0.0715					
CD(0.01)	0.268					

Table 19. Interaction between crop stand and lateral distances in coconut for available Mg (ppm)

	Lateral distance (cm)					
	50	100	150	200	250	300
Coconut sole	62.08	60.97	45.83	44.86	42.08	49.86
Coconut mixed	118.49	105.56	65.14	79.03	61.67	54.17
SEm±	5.253					
CD(0.01)	19.657					

Table 21. **Interaction between crop stand and lateral distance in coconut for available Mn (ppm)**

	Lateral distance (cm)					
	50	100	150	200	250	300
Coconut sole	92.12	95.61	88.40	89.24	81.46	89.77
Coconut mixed	93.72	101.63	79.77	73.41	73.48	68.39
SEm±	4.069					
CD(0.05)	11.468					

The lateral distance-depth interaction showed statistical significance for available Mg, Ca and S in coconut systems. As the relevance of these data is not much, it is not presented.

The crop stand-depth-lateral distance interaction showed significance for available iron in coconut (Table 22). At 25 and 75 cm depth the maximum available iron content was noticed at 150 cm from sole coconut and at 50 cm soil layer, it was highest at 200 cm laterally. In mixture at 25 and 50 cm soil depth, the highest available Fe content was recorded at 300 cm away from coconut and at 75 cm depth maximum iron was nearer to coconut trunk (50 cm laterally).

4.3.2 Soil characteristics in pure and mixed stand of cocoa as influenced by depth and lateral distance

Available P, S and Zn did not vary significantly between soils of pure and mixed stand of cocoa (Table 23). Organic C, available K, Ca, Mg, Fe, Mn and Cu showed marked variation between the two systems of cocoa. The concentrations of organic carbon, available K, Ca, Mg were significantly higher in soils of mixed cocoa than in sole crop. Soils of sole cocoa recorded higher concentration of available Fe, Mn and Cu. Micronutrients in available form except Zn were nearly double in sole stand of cocoa as compared to mixed cocoa.

The lateral distance-depth interaction was significant only in the case of available Fe in cocoa systems. For all other elements studied, this interaction was found to be non-significant. However, the data are not presented considering its little relevance.

Table 22. Interaction between crop stand, lateral distance and depth in coconut for available iron (ppm)

	Lateral distance (cm)	Depth (cm)		
		25	50	75
Coconut sole	50	12.84	13.047	14.9
	100	14.35	14.283	16.82
	150	16.617	13.573	21.08
	200	14.763	15.723	14.833
	250	12.84	13.733	13.597
	300	12.633	13.733	17.720
Coconut mixed	50	11.193	11.673	16.55
	100	10.643	12.223	13.113
	150	10.917	12.427	12.497
	200	10.573	11.123	11.053
	250	11.263	11.880	14.35
	300	12.633	14.213	13.320
SEm±		1.0810		
CD(0.05)		3.047		

Table 23. Chemical characteristics of the soils as influenced by crop stand in cocoa

	Org. C %	Av. P ppm	Av. K ppm	Av. Ca ppm	Av. Mg ppm	Av. S ppm	Av. Fe ppm	Av. Mn ppm	Av. Zn ppm	Av. Cu ppm
Cocoa sole	1.57	4.182	94.07	219.4	49.40	44.21	27.04	123.16	53.23	7.77
Cocoa mixed	1.90	4.779	111.26	345.0	64.96	50.41	12.27	71.76	69.48	3.97
SEm±	0.047	0.467	5.333	13.141	3.08	2.35	0.810	5.257	8.466	0.348
CD(0.05)	0.134	NS	15.31	37.73	8.84	NS	2.33	15.09	NS	0.999

NS - Non significant

The crop stand-depth interaction was found to be significant in the case of available Cu alone. At all depths, the content of available Cu in sole stand was significantly greater as compared to soils of mixed stand of cocoa (Table 24). In mixture, the concentration of available Cu at all depths were on par with one another. In mixture the highest concentration was recorded at 25 cm (4.244 ppm) as in the case of sole cocoa (10.278 ppm). In sole stand, the content of available Cu decreased markedly with depth. The crop stand-depth interaction showed non-significance for organic C, available P, K, Ca, Mg, S, Fe, Mn and Zn in cocoa systems.

The crop stand-lateral distance interaction were non-significant for organic C, available Mg, S, Fe, Mn,Zn and Cu. Hence the data are not presented. However, the concentration of available P, K and Ca differed markedly as influenced by the interaction between lateral distance and crop stand. The data are given in Tables 25 to 27.

For available P, at all lateral distances except 150 cm, the content was higher in sole stand of cocoa (Table 25). But at 150 cm the content of available P was markedly higher in mixture (5.92 ppm). It was almost double than that of sole cocoa. The concentration of available P at all lateral distances were on par with one another.

At 50 cm, the content of available K was higher in sole cocoa where as at 100 and 150 cm lateral distance, available K was more in mixture (Table 26). Within the sole stand, available K was significantly greater at 50 cm (121 ppm). In mixed cocoa, the highest available K was recorded at 150 cm away from cocoa trunk.

Table 24. Interaction between crop stand and depth in cocoa systems for available copper (ppm)

	Depth (cm)		
	25	50	75
Cocoa sole	10.278	7.156	5.878
Cocoa mixed	4.244	3.767	3.889
SEm+	0.6023		
CD(0.05)	1.729		

Table 26. Interaction between crop stand and lateral distance in cocoa systems for available K (ppm)

	Lateral distance (cm)		
	50	100	150
Cocoa sole	120.667	69.111	92.44
Cocoa mixed	86.889	117.778	129.111
SEm±	9.2363		
CD(0.05)	26.52		

Table 25. Interaction between crop stand and lateral distance in cocoa systems for available P (ppm)

	Lateral distance (cm)		
	50	100	150
Cocoa sole	4.951	4.733	2.862
Cocoa mixed	3.938	4.480	5.920
SEm ±	0.8086		
CD(0.05)	2.321		

Table 27. Interaction between crop stand and lateral distance in cocoa systems for available Ca (ppm)

	Lateral distance (cm)		
	50	100	150
Cocoa sole	219.722	233.194	205.278
Cocoa mixed	292.222	332.361	410.417
SEm±	22.76		
CD(0.05)	65.34		

The available Ca content increased with increasing lateral distance in mixed cocoa. Irrespective of the depth, the concentration of available Ca was higher in the mixture. The available Ca content at all lateral distances in sole stand were on par with one another. The content of available Ca in mixture at 150 cm was significantly superior to that at 50 and 100 cm (Table 27).

The crop stand-lateral distance-depth interactions were non-significant for all elements studied in cocoa systems.

4.4 Seasonal effects on the root activity of coconut

In this experiment, ^{32}P was applied to the monocrop of coconut at a particular lateral distance (50 cm) and at two different depths (20 and 75 cm) at every four months for a period of 1 year. The influence of irrigation on the uptake of radiolabel was also studied in the experiment. Leaves from the treated plants were radioassayed at 15 days interval.

4.4.1 Effect of season on ^{32}P absorption

Significant differences were observed in the absorption of ^{32}P for the different depths of placement tested and between wet and dry season (Table 28). At 20 cm, the uptake of ^{32}P was 136 and 9 cpm g^{-1} leaf respectively during wet and dry season whereas at 75 cm it was 77 and 28 cpm g^{-1} leaf respectively. In the wet season, the uptake was higher near the soil surface (20 cm) whereas in the dry season highest uptake was noted at lower depths (75 cm). At 20 cm soil depth, the absorption of ^{32}P during wet season was significantly higher (approximately 15 times) than that during dry period. But at 75 cm depth there was no significant

Table 28. ^{32}P uptake by coconut palm as influenced by different depths and season (log cpm g^{-1} leaf)

	Depth (cm)		
	20	75	Mean
Wet season	2.132(136)	1.889(77)	2.010(102)
Dry season	0.967(9)	1.447(28)	1.207(16)
Mean	1.55(35)	1.668(47)	

CD(0.05) for comparison of Depth : NS
CD(0.01) for comparison of Season : 0.730
CD(0.2) for comparison of Depth x Season : 0.458

Figures in parentheses indicate retransformed values
NS - Non significant

difference in the uptake of ^{32}P between dry and wet season. Uptake of ^{32}P averaged over different depths of placement was higher during wet season as compared to drier months. The absorption of ^{32}P during wet and dry season was 102 and 16 cpm g^{-1} leaf respectively. However, the uptake of ^{32}P averaged over the season seemed to be nonsignificant for both 20 and 75 cm depth of placement of ^{32}P.

4.4.2 Root activity pattern of coconut as influenced by season and depths of ^{32}P placement

The percentage root activity of coconut during wet and dry season at different depths were given in Table 29. During wet season, 54 per cent of roots explored 20 cm surface layer where as 31 per cent of roots foraged deeper layers (75 cm). Similarly in dry season, the roots explored 4 per cent at 20 cm soil depth and 11 per cent at 75 cm. The total root activity during wet and dry season was 85 and 15 per cent respectively which indicated that root activity was maximum during wet season. At both depths the percentage root activity was more or less similar. It was 58 and 42 per cent respectively at 20 and 75 cm soil layer.

4.4.3 Effect of irrigation on ^{32}P absorption

The recovery of the soil applied ^{32}P in coconut as influenced by irrigation and depth of placement of radiolabel at different months are given in Appendix-III. The monthly rainfall data during the experimental period is also furnished in Appendix I.

The month wise uptake of ^{32}P as influenced by irrigation is presented in Table 30. The effect of irrigation was statistically significant during February and April. The irrigation had no significant influence on the uptake of radiolabel during

Table 29. Root activity of coconut palm as influenced by depths and season (%)

	Depth (cm)		
	20	75	Total
Wet season	54	31	85
Dry season	4	11	15
Total	58	42	

Table 30. Recovery of ^{32}P at different moisture regimes and depths during summer months (cpm g^{-1} leaf)

	December	January	February	March	April	May
Irrigated	1649	2292	9127	11743	859	1983
Rainfed	1642	1820	5376	10949	265	1478
SEm±	242	324	1004	2458	107	247
CD(0.05)	NS	NS	3094	NS	330	NS
20	2132	2604	8134	12861	849	2307
75	1158	1509	6369	9832	275	1154
SEm±	242	324	1004	2458	107	247
CD(0.05)	746	998	NS	NS	330	761
Moisture regime x Depth						
CD(0.05)	NS	NS	NS	NS	468	NS

NS - Non significant

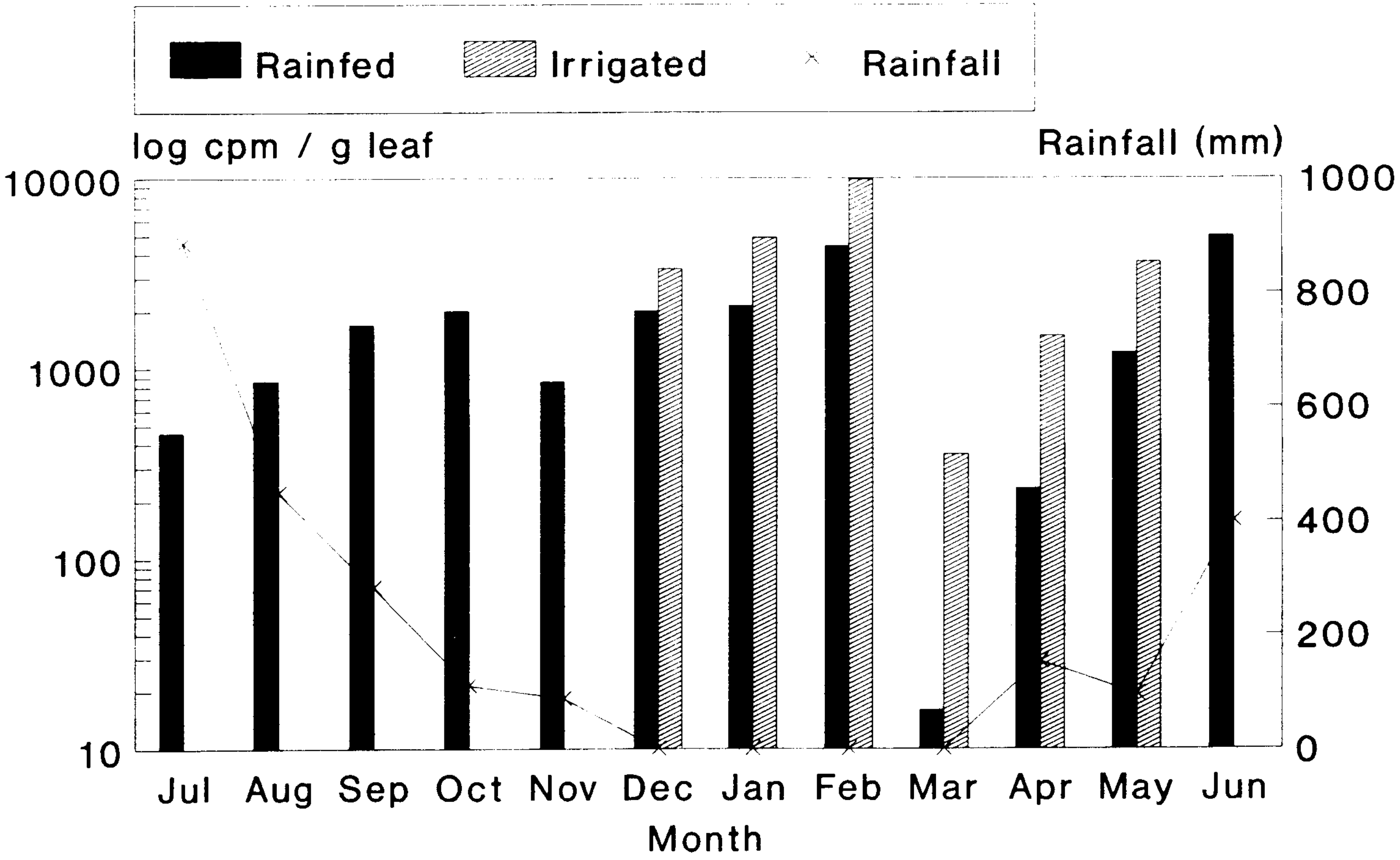


Fig.23 Seasonal variation in the uptake of P-32 applied at 20 cm soil depth between rainfed and irrigated coconut

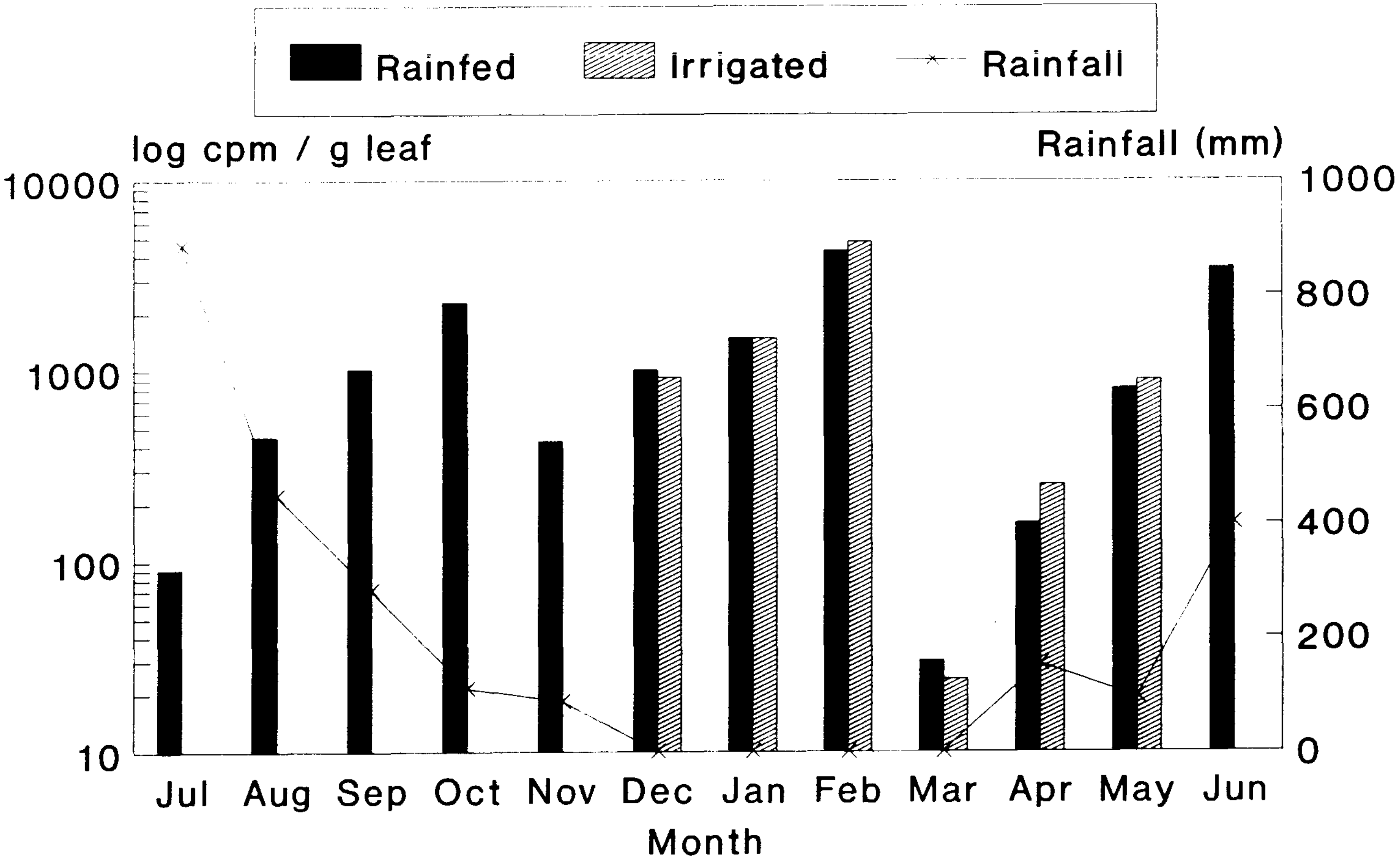


Fig.24 Seasonal variation in the uptake of P-32 applied at 75 cm soil depth between rainfed and irrigated coconut

rest of the summer months. The uptake of ^{32}P from different depths showed statistical significance during all summer months except for February and March. In all these cases the absorption from 20 cm depth was higher than that from 75 cm. During February and April, irrigation improved ^{32}P uptake by 1.7 and 3.2 times more than that in rainfed palms (Fig. 23 and 24). The moisture regime-depth interaction was nonsignificant during December-May except April. The uptake was maximum at 20 cm soil layer under irrigated condition. The ^{32}P absorption was more or less uniform from both depths when the coconut was grown rainfed (Table 31).

4.4.4 Root activity pattern of coconut as influenced by different moisture regimes and depths during summer months

At 20 cm depth, during all summer months, root activity was higher under irrigated condition (Table 32). At 75 cm depth, except during December and May, root activity was at its peak under irrigated condition. It was also observed that the percentage root activity was same during March at 75 cm soil depth. Root activity under irrigated condition was more than rainfed situation when averaged over depth at all summer months. Similarly under irrigated condition root activity was higher at surface layers. When coconut was grown rainfed, roots explored deeper layers (75 cm) better during February and March. During rest of the summer months, root activity was more in the surface layer itself. More than 50 per cent of coconut roots explored 20 cm layer when averaged over moisture regimes.

Table 31. Uptake of ^{32}P by coconut as influenced by interaction between moisture regimes and depth in April (cpm g^{-1} leaf)

Depth	Irrigated	Rainfed
20 cm	1353	345
75 cm	364	186
SEm ±	152	
CD(0.05)	468	

Table 32. Percentage root activity of coconut at different moisture regimes and depths during summer months

Summer months	Depths (cm)					
	20		75		Total	
	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
December	31	34	19	16	50	50
Total	65		35			
January	27	37	17	19	44	56
Total	64		36			
February	17	39	20	24	37	63
Total	56		44			
March	19	33	24	24	43	57
Total	52		48			
April	15	60	9	16	24	76
Total	75		25			
May	25	41	18	16	43	57
Total	66		34			

Discussion

DISCUSSION

5.1 Pattern of ^{32}P absorption by coconut and cocoa in pure and mixed stand

5.1.1 Recovery of ^{32}P in the leaf as influenced by cropstand

In this experiment comparisons were made on the absorption of ^{32}P by coconut and cocoa in sole and mixed stand. Absorption of ^{32}P did not differ significantly between cocoa/coconut in sole stand and in mixture. However, in general, ^{32}P uptake was higher when these crops were grown alone (Table 2).

These results indicate that as far as these two crops are grown together, they may not exert either any competitive/complementary effects. Lack of a positive influence on ^{32}P uptake in coconut based cropping system can be explained based on the growth habit of component crops in an intercropping system. The reason for non-significance in ^{32}P uptake between sole and mixed cocoa can be explained based on the observation by Wahid *et al.*, (1989a). They reported that in view of the lateral spread over 150 cm, the roots of adjoining cocoa trees spaced three metres apart are likely to overlap and compete for water and nutrients. This explains that the competition in sole and mixed stand of cocoa will then be of same extent. In the case of coconut, Nair (1979) reported that the palm is amenable to intensive crop combinations at most periods of its life. Taking an over all view of the growth habit of the palm, of the pattern of its utilization of soil and solar energy and of the interception of light by its canopy, the life span of the palm could be divided into three distinct phases from the point of view of intensive cropping. The first phase lasts from planting till the full development of canopy (about 8 years). During this period the interspaces could be utilized for growing annuals. As the canopy of the palm develops gradually much scope for intercropping. The period from 8 to 25 years is the second phase when the coverage of the canopy is low due to short trunk height. There is very limited scope for intercropping. During the period after 25 years of age of the palms, there is gradual increase in the magnitude of light penetration to the ground, decrease in apparent ground coverage and increase in trunk height. This period is the most important from the point of view of intensive cropping. In the present study the coconut palms were of 20 years old. However, the shade levels under coconut canopy are highly variable depending mainly on the spacing given to coconut, extent of canopy development, age of palms etc. It has been estimated that daily mean values of light infiltration through the coconut canopy ranges from about 7 per cent to as much as 86 per cent depending on these factors (Abraham and Nair, 1995). More over cocoa is a shade tolerant crop and it has been found to be the most promising perennial intercrop in coconut systems at CPCRI. The experimental results at CPCRI indicate that the growth and yield behaviour of cocoa plants has been quite comparable to, if not better than, that of the plants in a few pure cocoa plantations in the nearby areas.

In the present study, neither competitive nor complementary effect on ^{32}P uptake by the component crops were observed. However, in a study conducted by Ashokan *et al.* (1988) a decrease in the ^{32}P uptake by elephant foot yam (*Amorphophallus companulatus* Blume.) when it was grown in association with banana [*Musa* (AAB) 'Mysore'] and/or cassava (*Manihot esculenta* Crantz.). On the other hand banana recorded increased ^{32}P uptake when it was mixed with elephant foot yam or cassava. Thus there can exist competitive and/or complementary interactions in ^{32}P uptake depending on the nature of the associated crop species. In another study conducted by George *et al.* (1995) there was neither competitive nor complementary interaction with respect to ^{32}P uptake in a silvi-pastoral system where acacia and ailanthus were grown with congo signal, guinea grass, hybrid napier and teosinte. However, casuarina and leucaena when grown mixed with any one of the four grass species showed higher ^{32}P uptake compared to their respective sole crop situations.

The quantity of ^{32}P absorbed by cocoa and coconut in both sole and mixed stand (Fig. 8 and 9) increased with time. Increase in the recovery of ^{32}P in the leaves over time has been reported by Anilkumar and Wahid (1988) for coconut; Wahid *et al.* (1989a, 1989b) for cocoa and cashew; George *et al.* (1995) for acacia, casuarina, leucaena and ailanthus. Implicit in this increasing recovery of the radiolabel from 23 to 78 DAA is perhaps the active growth of roots and also duration of absorption.

5.1.2 Recovery of ^{32}P in the leaves as influenced by lateral distance and depth in mixed and sole crop situations

The differences in ^{32}P absorption at different lateral distances were not significant upto 46 DAA in sole and mixed stand of coconut and cocoa suggesting a uniform distribution of active roots (Table 3 to 10). In general it was observed that in the case of sole coconut the uptake of ^{32}P was more or less uniform upto a lateral distance of 275 cm. In a study conducted by Anilkumar and Wahid (1988) it was observed that the absorption of ^{32}P by sole crop of coconut was more or less uniform from various radial distances namely 30, 60, 100, 150 and 200 cm from the palm at all sampling intervals. Though not significant in mixed coconut, a substantial reduction in ^{32}P uptake was observed at the lateral distance of 175 cm compared to that at 75 and 275 cm.

In the case of cocoa, both in sole and mixed situations, the uptake of ^{32}P was least at 275 cm at all sampling intervals though the difference was statistically significant only at 78 DAA (Table 10). In general the uptake of the radiolabel by cocoa was confined to a lateral distance of 175 cm. This is in confirmity with the findings of Wahid *et al.* (1989a) who observed that the uptake of ^{32}P was mainly confined to an area of radius of 150 cm around the tree. They also observed that absorption decreased with increasing radial distance from the tree beyond 150 cm.

With respect to the depth of application, the uptake of radiolabel from 30 cm soil layer was significantly higher than that at 60 cm in both sole and mixed coconut. There are many reports suggesting that coconut palm is a surface soil feeder. Radio isotope studies conducted at Philippines had indicated that the zone of the highest root activity lie at 15 cm depth (IAEA, 1975). Balakrishnamurthy (1977) had also reported that the roots of coconut are most active in the surface soil. In a study conducted by Avilan *et al.* (1984) it was observed that coconut roots were concentrated in the top 30 cm soil layer. Anilkumar and Wahid (1988) had also observed that the vertical spread of the majority of the coconut roots were limited to 60 cm soil depth.

The uptake of radiolabel by sole as well as mixed stand of cocoa was not significantly influenced by the depth of application. There was more or less uniform uptake of the radiolabel upto the depth of 60 cm. According to Wahid *et al.* (1989a) the preponderance of feeder roots of cocoa were found upto 60 cm soil depth beyond which the root activity declined sharply. Many tree species are found to have most of their feeder roots concentrated in the surface soil layer (Jonsson *et al.*, 1988; Rubigwa *et al.*, 1992).

Thus it can be seen that there was distinct difference in the root activity pattern of the component crops in the coconut-cocoa system. With respect to the vertical spread while the coconut roots were confined to the top 30 cm soil, the cocoa roots were uniformly spread upto a depth of 60 cm. The lateral spread of the roots was mainly found within the radial distance of 75 cm for both the crops. While coconut roots explored effectively a lateral distance of 275 cm from the trunk, cocoa roots were more or less limited to a radial distance of 175 cm. This difference in the root activity pattern of the component crops makes it a compatible crop combination.

5.2 Pattern of root activity in pure and mixed stand of coconut and cocoa

The root activity pattern of coconut and cocoa grown alone and in mixture were studied using ^{32}P soil injection technique. The study was carried out during the monsoon season when soil moisture availability was not limiting, the extent of absorption of ^{32}P could be considered to reflect the amount of root activity (Wahid *et al.*, 1989a). Therefore root activity characterisation at this time may probably represent root interactions of the largest possible magnitude.

5.2.1 Root activity pattern in pure and mixed stand of coconut

From the results, it was clear that over 60 per cent of roots in both cropping situations explored 30 cm surface soil layer (Table 11 and 12). This was also observed by IAEA (1975) and Anilkumar and Wahid (1988).

The percentage root activity at 175 cm lateral distance was higher in sole system as compared to mixed coconut. Similarly the active roots at 275 cm was high in mixture in comparison to sole stand of coconut. Maximum root activity was noticed at 75 cm in mixed coconut. IAEA (1975) reported that coconut showed highest root activity near the trunk. Reports by Avilan *et al.* (1984); Anilkumar and Wahid (1988) and Cintra *et al.* (1993) were in confirmity with the result of the present investigation that highest root activity was noticed within two metre radius in coconut.

5.2.2 Root activity pattern in pure and mixed stand of cocoa

In cocoa the roots foraged deeper layers in sole stand whereas in mixture preponderance of active roots were found to be in the 30 cm soil surface (Table 13 and 14). The intense and regular cultural operations may lead to the suppression of the upward elongation of the root zone also support the view. The difference in root activity with respect to depth in sole and mixed cocoa can be probably due to the variation in moisture in the soil profile which in turn depends on soil type (IAEA, 1975). The preponderance of active roots of cocoa in the surface soil was supported by the results of Ahenkorah (1975) and Wahid *et al.* (1989a).

In sole cocoa the root activity was very much negligible at 275 cm from cocoa. In sole cocoa maximum activity of roots was found at a lateral distance of 175 cm (Table 13 and 14). In mixture the most active root zone was within 75 cm from the cocoa trunk.

From the pattern of distribution of active roots in sole and mixed stand of coconut and cocoa at different depths and lateral distances, we can infer that there is no overlapping of the active roots of the two species in mixture. Instead they avoid the soil areas occupied by one thereby plants complement each other in sharing growth factors and result in better utilization of growth factors. The beneficial interactive effects of the crop combination of coconut and cocoa was reported at CPCRI (Nair, 1979).

5.3 Soil nutrient depletion in the sole and mixed stand

A comparison of the changes in the soil chemical properties between the sole and mixed stand of coconut and between the sole and mixed cocoa in relation to depth and lateral distance from the palm were studied by analysing the soil samples corresponding to lateral distances and depths considered in the root activity experiment. These experiments are carried out in fields where the application of fertilizers are regular.

5.3.1 Soil chemical characteristics in pure and mixed stand of coconut as influenced by depth and lateral distance

The results of this study showed that the secondary elements were in higher concentration in mixture whereas organic carbon, available iron and Mn were high in soils of sole coconut (Table 15). The increase in organic carbon content in the sole coconut may be related with root activity. Nelliat *et al.* (1976) reported a marked improvement in organic matter content of the soil in coconut-cocoa system through periodic shedding of cocoa leaves and intense microbial activity in rhizosphere of the soil. The result of the present study is contradictory to this report. This high organic carbon in sole stand can be attributed to the regular application of organic manure in that field. Martin (1977) suggested that there could be significant formation of soil organic matter during active root grwoth, much of it directly from the root tissue without the intervention of soil microfauna. Anilkumar (1987) reported that the increase in organic carbon content with increase in root activity may be due to the organic matter incorporation into soil during degeneration of roots while the increased availability of nutrients such as Mn may be as a result of the release of root exudate with chelating property with increasing rate of applied N, available Mn decrease markedly. Application of muriate of potash may increase available K as well as organic carbon. It may be reasonably expected that K application would have promoted root growth which in turn would have increased the organic carbon content of the soil. The exchangeable Ca increase with increasing rates of super phosphate application due to the influence of Ca in fertilizer material on replacing K from the exchange sites in soil. In these soils which are acidic, the mobility of P is limited due to fixation by large amount of sesquioxides.

In both cropping situations, content of available Mg decreased with increasing depth (Table 16) and this was in confirmity with the result obtained by Anilkumar (1987). Available Zn increased with increasing depth in both sole and mixed coconut (Table 17).

At all lateral distances, the organic C and available Fe contents were high in sole stand (Table 18 and 20). At 100 cm lateral distance the available Mn was maximum in both sole and mixture (Table 21). In sole coconut upto 250 cm available Mg decreased and it showed an increase at 300 cm (Table 19).

Organic C in general decreased with increasing lateral distance can be attributed to the process of steady release of carbohydrate rich organic matter from actively growing roots represent energy input into the soil ecosystem. This was observed by Nair and Varghese (unpublished).

5.3.2 Soil chemical characateristics in pure and mixed stand of cocoa as influenced by depth and lateral distance

Significantly high concentration of organic C, available K, Ca and Mg were recorded in soils of mixed cocoa and available Fe, Mn and Cu in sole cocoa (Table 23). The high available Fe, Mn and Cu are expected to return to soil through litter fall in cocoa agroecosystem. This was in confirmity with that reported by Opankule (1991). Heavy build up of exchangeable cations may be through application of fertilizers (like K - Muriate of Potash, Ca - Superphosphate/Mussoriephos, Mg - Magnesium sulphate) in mixed stand.

The cropstand-depth interaction was found to be significant for copper alone in cocoa systems (Table 24). The content of available Cu decreased with increasing depth. In coconut this pattern was reported by Anilkumar (1987). The highest concentration was recorded at 25 cm depth in both sole and mixed cocoa.

In mixture available P, K and Ca content increased with increasing lateral distance. But in sole stand of cocoa, available P content decreased with lateral distance. In the case of available K a decrease at 100 cm and for available Ca an increase at 100 cm as compared to 50 cm from sole cocoa (Table 25 to 27).

5.4 Seasonal effects of the root activity of coconut

In this experiment ^{32}P was applied along the circumference of a circle with a radial distance of 50 cm. Radiolabel placement within a circle of 50 cm radius round the tree resulted in considerably higher uptake by the treated tree (IAEA, 1975). In trees like coconut in which root activity is highly concentrated near the tree, it is likely that placement in the zone of highest root activity of an individual tree leads to maximum utilization.

5.4.1 Effect of season on ^{32}P absorption

The experiment was conducted to study the differential absorption pattern of ^{32}P placed at two different depths during wet and dry season. Radioassay of leaf samples collected during these seasons revealed that the uptake was more during wet season. Same result was obtained by IAEA (1975) in the experiment conducted at Philippines with coconut. But in Srilanka, the pattern was similar during wet and dry season. In our study coconut showed highest root activity near soil surface (20 cm) in wet season as opposed to highest uptake from 75 cm depth in dry season (Table 28). These effects reflect the seasonal moisture variations in the soil profile. The seasonal variations illustrate the importance of soil moisture to root activity (IAEA, 1975). They suggested that root activity patterns would be determined by the density of live roots, soil moisture and nutrient availability. When soil moisture is not limiting and under conditions of uniform nutrient availability, highest uptake of nutrients would be from the zones where the density of live roots is highest. The significantly higher uptake from the soil surface in wet weather is due to the higher density of live roots (54%) at this position (Table 29). In dry seasons, as the soil surface dries out, there would be relatively more root activity at lower depths where moisture availability is likely to be higher (11% of active roots at 75 cm as against 4% at 20 cm) even though there may be no change in the density of live roots in the soil profile.

5.4.2 Effect of irrigation on ^{32}P absorption

During summer, the trees were irrigated to maintain the soil moisture regime around 50 per cent depletion from the field capacity. From the data it is clear that irrigation improved absorption of ^{32}P significantly during February and April as compared to rainfed palms (Table 30). During all the summer months the uptake was more under irrigated condition though the difference was not significant during December, January, March and May. Another possibility is due to the peculiarily of the soil type which may have a higher water retention capacity as a result of which even during summer months they maintain more or less uniform moisture content in the soil profile as under irrigated condition. This can be the reason for the non significance in ^{32}P uptake between palms grown under rainfed and irrigated condition. This will be coupled with the less uptake of nutrients during cold months (December and January) and low rate of root production under irrigated condition. Bhaskar *et al.* (1995) reported that summer irrigation enhance greater absorption of ^{32}P by cashew tree. This further confirm the result of the present investigation. Many tree species are reported to exhibit marked temporal variations in spatial distribution of fine root mass (Persson, 1983; Srivasthava *et al.*, 1986) depending on edaphic and climatic factors.

Summary

SUMMARY

An investigation was undertaken at Instructional Farm, Vellanikkara; Cadbury - KAU Co-operative Cocoa Project Farm, Vellanikkara; College of Horticulture and at Radio Tracer Laboratory, Kerala Agricultural University during the period 1994-96 to study the root level interactions in coconut-cocoa system. The following studies were undertaken during the course of the investigation.

I. Root activity in mixed and purestands of coconut and cocoa
II. Soil nutrient depletion in the sole and mixed stand
III. Seasonal effects on the root activity of coconut

The salient results of the investigation are summarised below.

The uptake of ^{32}P did not differ in pure and mixed stand of coconut and cocoa.

The quantity of ^{32}P absorbed by sole and mixed stand of coconut and cocoa increased with time irrespective of depth and lateral distance.

The uptake of the radiophosphorus recorded maximum from a depth of 30 cm in both cropping situations of coconut.

Sole cocoa and mixed cocoa did not differ in the uptake of the radiolabel from the various depths tested.

The absorption of ^{32}P from the various radial distances remained more or less same in the sole and mixed stand of coconut at all sampling intervals except at 78 days after application. Same is the case with respect to mixed and sole cocoa. In coconut the uptake from 75 and 275 cm lateral distance was approximately 15 times more than that from 175 cm. In cocoa the uptake from 75 and 175 cm was significantly higher than that from 275 cm.

The vertical spread of the roots indicated that over 60 per cent of the roots explored upto 30 cm soil depth in sole and mixed coconut. About 50 per cent of the root activity was found within a radial distance of 75 cm from the tree in both systems of coconut.

Nearly 75 per cent of the feeder roots were confined to the surface 30 cm soil layer in the mixed stand of cocoa. Nevertheless, the preponderance of feeder roots were found upto 60 cm soil depth in sole stand. A substantial portion of the roots lie at a radius of 175 cm in sole and mixed cocoa.

Available P, K, Zn and Cu did not differ between soils of sole and mixed stand of coconut. The available Ca, Mg and S were significantly more in mixed coconut whereas organic carbon, available Fe and Mn were markedly high in sole stand. The interaction between cropstand and depth was significant for available Mg and Zn in coconut and that between cropstand and lateral distance was significant for organic carbon, available Mg, Fe and Mn.

The concentration of organic carbon, available K, Ca and Mg were significantly higher in soils of mixed cocoa than in sole crop. Soils of sole cocoa recorded higher concentration of available Fe, Mn and Cu. At all depths, the content of available Cu was greater in sole stand of cocoa. In both systems of cocoa, maximum copper content was noticed at 25 cm depth. Available P, K and Ca contents showed significant variation in sole and mixed cocoa at different lateral distances.

The seasonal influence on the uptake of radiolabel was significant. The uptake of ^{32}P was more during wet season as compared to dry season in coconut.

During wet season the absorption of ^{32}P was concentrated from the surface soil layers whereas during dry season, higher uptake of radiolabel was observed from deeper layers. About 54 per cent of the root activity was confined to the top 20 cm of soil layer. Over 85 per cent of the root activity was found during wet season as compared to dry season.

Irrigation improved ^{32}P uptake in coconut only during February and April in significant amounts. The uptake was maximum from 20 cm soil depth under irrigated condition. The ^{32}P absorption was more or less uniform from both depths when coconut was grown rainfed.

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* Originals not seen

Appendices

APPENDIX-1

Weather data at monthly intervals during the experimental period (june 1995-June 1996)

Months	Air temp. mean maximum °C	Air temp. mean minimum °C	Air temp. mean °C	Mean Relative humidity (%)	Rainfall (mm)	Rainy days	Evaporation (mm)	Sunshine hours	Mean Sunshine house	Mean wind speed (km)
1995										
June	31.6	23.1	27.4	86	500.4	19	103.7	109.6	3.7	3.7
July	29.9	23.2	26.6	89	884.7	26	88.5	65.6	2.1	2.1
August	30.6	23.7	27.1	86	448.7	22	96.4	115.5	3.7	2.6
September	30.1	23.5	26.8	82	282.5	13	97.7	184.4	6.1	4.2
October	33.2	23.2	28.2	78	100.4	8	113.8	257.7	8.3	1.3
November	31.3	22.5	26.9	80	88.4	5	89.1	196.7	6.5	0.6
December	32.5	21.3	26.9	57	-	-	195.9	319.5	10.3	3.9
1996										
January	33.1	22.4	27.8	53	-	-	208.6	292.7	9.4	3.3
February	34.7	23.4	29.1	53	-	-	200.9	286.1	9.9	6.1
March	36.4	24.3	30.4	60	-	-	219.2	281.3	9.3	5.5
April	34.6	25.0	29.8	73	152.0	7	157.0	248.4	8.3	1.8
May	32.8	25.2	29.0	77	95.4	4	135.0	240.1	7.7	2.3
June	30.5	23.8	27.2	85	400.3	16	103.4	140.1	4.7	2.0

APPENDIX-II

Soil moisture content at different depths during summer months

	Rainfed (means of 2 replications)		Irrigated (means of 2 replications)	
	0-25	50-75	0-25	50-75
December	8.8	11.3	13.5	15.21
January	10.4	12.8	15.5	15.01
February (2 weeks not irri.)	7.2	8.3	12.3	13.7
March	10.0	13.0	12.1	15.0
April	11.6	10.6	12.0	12.9
May	8.2	11.3	14.3	17.0

APPENDIX-III

Recovery of soil applied ^{32} (cpm g^{-1} leaf in coconut as influenced by irrigation and different depths of placement of radiolabel

	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
50x20 rainfed	511	1177	2180	3523	1002	2006	2140	4412	16	234	1267	3835
50x20 irrigated	**	**	**	**	**	3354	4871	9826	353	1480	3622	**
50x75 rainfed	102	607	1602	3135	424	1013	1486	4284	30	158	806	3499
50x75 irrigated	**	**	**	**	**	924	1486	4779	24	252	894	**

ROOT LEVEL INTERACTIONS IN COCONUT COCOA SYSTEM

BY

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ABSTRACT OF A THESIS

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ABSTRACT

An investigation was undertaken at the Kerala Agricultural University during 1994-96 to study the root level interactions in pure and mixed stand of coconut and cocoa. The study was also aimed to assess the extent of soil nutrient depletion in coconut-cocoa systems. The seasonal effects on the root activity of coconut was also assessed. The most important findings of the investigation are abstracted below.

Absorption of soil applied ^{32}P did not differ in pure and mixed stand of coconut and cocoa.

Coconut was a surface feeder in both cropping situations where the active roots were concentrated upto a depth of 30 cm.

^{32}P uptake was not much influenced by lateral distance or depth of placement of radiolabel in pure and mixed cocoa.

Maximum root activity was noticed at 30 cm depth in both pure and mixed stand of coconut. The lateral spread of the roots was more or less uniform upto a distance of 275 cm in both sole and mixed stand.

Cocoa also was a surface feeder with active roots distributed uniformly upto a depth of 60 cm. Majority of the roots traverse a horizontal distance of 175 cm in sole and mixed cocoa.

The available Ca, Mg and S were markedly high in mixed coconut whereas organic carbon, available Fe and Mn were high in sole coconut. Available

P, K, Zn and Cu were more or less uniform in both sole and mixed stand of coconut.

The organic carbon, available K, Ca and Mg were significantly high in soils of mixed cocoa whereas available Fe, Mn and Cu were more in soils of sole cocoa. Available P, S and Zn were in more or less same concentration in soils of both sole and mixed cocoa.

The ^{32}P uptake was higher during wet season as compared to dry season in monocrop of coconut. The absorption was more from the surface layers during wet season and roots explored deeper soil layers during dry season. Irrigation in general improved absorption of radiolabel in coconut. The uptake was more from the surface soil under irrigated conditions than that under rainfed condition.