ROOT DISTRIBUTION PATTERNS OF BANANA AND COLOCASIA IN COCONUT GARDENS

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **ROOT DISTRIBUTION PATTERNS OF BANANA AND COLOCASIA IN COCONUT GARDENS** 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.

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CERTIFICATE

Certified that the thesis entitled **ROOT DISTRIBUTION PATTERNS OF BANANA AND COLOCASIA IN COCONUT GARDENS** is a record of research work done independently by Ms. Suja Eapen under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to her.

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Dr.M. Abdul Salam,
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CERTIFICATE

We, the undersigned members of the Advisory Committee of Ms. Suja Eapen, a candidate for the degree of Master of Science in Agriculture with major in Agronomy agree that the thesis entitled **ROOT DISTRIBUTION PATTERNS OF BANANA AND COLOCASIA IN COCONUT GARDENS** may be submitted by Ms. Suja Eapen in partial fulfilment for the degree.

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To my loving parents

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Introduction

INTRODUCTION

Roots are vital organs of plants as they are responsible for the uptake of water and nutrients, besides providing anchorage. The amount and rate of nutrient uptake and utilisation of other soil resources by the plant greatly depends on the strength of the root system in terms of its lateral and vertical spread, absorptivity etc. Information on root activity and distribution patterns are essential to develop efficient fertilizer and water application techniques and to optimise plant population especially in multi-species production systems.

Coconut is the most important plantation crop of Kerala grown over an area of 8.64 lakh ha (Anon., 1994). Coconut based polyculture is one of the most important production systems prevalent in the homegarden agroforestry systems of Kerala. Wahid *et al*. (1993) reported that in well maintained coconut gardens, the lateral spread of most of the roots is upto 2 m from the plant while the vertical penetration is within 1m depth. Over 80 per cent of the active roots are confined to within an area of 2 m radius around the palm. In pure coconut plantations, about 75 per cent of the space is available for intercropping (Nair, 1979).

Several crops have been identified as suitable intercrops for coconut plantations. Among them *Colocasia* esculenta and banana are most important as they are commonly grown in coconut gardens both under rainfed and irrigated conditions.

The growth and productivity of any crop depends on their root system development which inturn is influenced by several crop, soil and environment related characteristics and the agronomic practices followed. The effects of shade on cocoa, (IAEA, 1975) and soil moisture regimes on coconut (IAEA, 1975), rice (Rudaraju and Varma, 1974) and nendran banana (Sobhana, 1985) on root distribution pattern have been studied earlier. No attempt seems to have been made so far to study the root distribution patterns of palayankodan banana and colocasia in relation to light and moisture environments.

The present project was undertaken to study the variation in the root distribution pattern of banana (var. palayankodan) grown in coconut gardens and in the open under rainfed and irrigated conditions. It was also aimed to study the root distribution patterns of colocasia (var. cheruchempu) grown in coconut garden and in the open under rainfed condition.

Review of Literature

REVIEW OF LITERATURE

The literature available on root distribution patterns of certain important crops are briefly reviewed below. The review is presented under the headings - methods of studying root system, root distribution patterns of crops and factors affecting root system development.

1. Methods of Studying Root System

1.1. Direct methods

The interest in root studies in crop plants was started early in eighteenth century with the studies of Hale in 1727 as reported by Bohm (1979). Sachs (1873) was the first who used this technique. **In this method** root growth is observed or recorded through glass windows placed against the soil profile. Root studies in undisturbed soil profiles were made for the first time by Mc Dougall (1916).

Weaver (1919) reported the method called **profile wall method.** The acceptance of the traditional profile wall method came when Oskamp and Batjer (1932) made intensive root studies on orchard trees by this method. In this method a trench was dug and the final working face of the profile was smoothened. Then the roots were exposed and mapping or counting of the roots were done immediately after exposing.

Weaver (1926) developed a **scientific excavation technique** to study root systems of crop plants. By this method the complete root system of a plant was exposed by carefully excavating the soil surrounding the individual roots. This method provided a clear picture of the entire root system of the plant as it exists naturally and the excavated root system was converted to quantitative data. But the method required large amount of physical labour and is very time consuming.

The time and labour consuming procedures for excavating the total root system of plants, especially of trees, led to modified and more economical techniques. Rogers (1932), Nutman (1933) and Krauss et al. (1934) utilized the **sector method** in their numerous tree root investigations. In this method only a sector of the total root containing area surrounding the tree was excavated.

To obtain informations about the roots in the upper soil horizon, small monoliths of about 20 cm square can be taken with a spade (Gorbing,1948). The **monolith method** required the taking of soil monolith and separating the soil from the roots by washing. Nelson and Allmaras (1969) suggested the modified soil monolith method in studying the root distribution pattern of crops. Monolith sampling methods provide washed root samples from which the root surface area, biomass, length and other morphological variables can be determined (Vogt and Persson, 1991). By this method both quantitative and qualitative studies of the roots were possible. But this method required large amount of labour.

One of the most common root study methods which combined pictorial presentation with quantitative determination of the root system of the plants is the **needle board method** (Schuurmann and Goedewagen, 1971). By this method a soil monolith with a representative sample of the root system was taken by means of a special wooden board. Needles or nails positioned on the board kept the roots nearly in their natural position while the soil was removed by soaking and washing. The root system can be investigated and photographed as an entirety or can be sectioned for more quantitative determination.

Subsequently modern techniques involving root cellars and underground root chamber (rhizotrones) were developed (Karnok and Kucharski, 1982). This facilitated more reliable and easy methods for studying root system. But this method incurs a very large initial cost. The aerial environment around a rhizotrone may be sufficiently different from that in field plot to significantly affect plant growth and function.

1.2. Indirect methods

The high input in time and labour required to obtain information about roots in the soil by direct observation or sampling methods has led to the development of indirect methods. This included the soil injection and plant injection techniques using radioisotopes. Unlike traditional methods, these techniques provided an undestructive means of evaluating the underground parts more precisely, quickly and easily with reduced labour and time.

Use of Radioisotopes in Root System Research

a. Soil Injection Technique

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). Considerable work has been done to study the root activity of plants with radioisotopes. The soil injection techniques developed by Hall et al. (1953) employing ^{32}P radioisotope has been widely used for studying the root activity patterns of plants. Several workers like Fox and Lipps (1964) and Russell and Ellis (1968) have suggested that root distribution and root activity in different soil depths can be accurately and easily assessed by studying the uptake of radioisotopes placed at specified depths 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.

Ashokan *et al*. (1989) studied the root activity pattern of cassava using ^{32}P soil injection technique. Wahid *et al*. (1989) studied the root system of cocoa using ^{32}P soil injection technique.

b. Plant Injection Technique

The ^{32}P plant injection technique for studying the root distribution of cereal roots was first described by Racz *et al*.(1964) and subsequently modified and improved by Rennie and Halstead (1964). In this technique the radioactive tracer was injected into the plant stem. After allowing time for the tracer to distribute throughout the plant, soil root samples were taken, and the tracer content measured in them. The amount of radioactivity gives a measure of the amount of active roots in the soil profile from where the core samples have been taken. Shrinivas and Subbiah (1973) studied the root distribution of bajra hybrids using ^{32}P plant injection technique. The root distribution pattern of high yielding rice varieties were studied by using ^{32}P plant injection techniques at Tamilnadu Agricultural University, Coimbatore by Kumaraswamy *et al*. (1977).

c. Leaf smearing technique

A new technique for root distribution studies of field crops was developed by Shrinivas et al. (1979) known as leaf smearing technique. In this technique the upper part of the stem of a tiller of barley was pulled out at pre-flowering stage resulting in the formation of a cup shaped cavity on leaf sheath. The desired amount of carrier free ^{32}P was placed in this cavity with the help of a microsyringe. Composite soil-root core samples were collected from around each treated plant and the tracer measured in them. This method gave consistently higher counts for all the depths as compared to plant injection techniques.

Other methods namely **gamma probe method** (Vittal and Subbiah, 1982) and **computerised root imaging technique** (Costigan et al., 1982 and Berntson, 1992) are also being used in recent years to study the root distribution pattern.

Root research under field conditions is not much developed. The reason for this is primarily methodological. The known methods are tedious, time consuming and the accuracy of their results are often not very great. The soil injection and plant injection techniques are now the common radioactive tracer techniques for root studies under field conditions.

2. Root Distribution Pattern of Crops

The root distribution pattern of certain important crops are reviewed here.

Banana

The lateral spread of banana roots extended to about 5.2 m from the plant (Fawcett, 1913). Majority of the roots were found confined to the top 15 cm soil, forming a dense surface mat. Most of the banana roots developed in the top soil (Sioussaram, 1968, Champion and Sioussaram, 1970). Godefroy (1969) stated that banana roots penetrated to a depth of 80 to 100 cm when grown in alluvial soils of Malagasy. Wardlaw (1972) found a horizontal extension of 4.5 to 5.1 m and a vertical extension of 135 cm under the most favourable conditions. The studies conducted by Sobhana (1985) using ^{32}P showed that nendran banana has a shallow root system with the bulk of the roots confined to the top 15 cm soil forming a dense surface mat. The roots are most active with in 30 cm depth and 20 cm lateral distance. In a crop geometry study, conducted by Ashokan (1986), it was revealed that in the cultivar palayankodan (AAB), the active roots were distributed upto a radial distance of 30 to 35 cm and to a depth of 25 to 30 cm at the peak vegetative phase.

Colocasia

Colocasia (var. thamarakkannan) has shallow and compact root system with majority of the roots confined to a lateral distance of 0-40 cm and to a depth of 9 cm in the soil (Mohankumar, 1993).

Rice

Subbarao and Sathe (1974) reported that most of the active roots of rice resided within the first 5 cm depth and root spread decreased with depth at each of the lateral distances. Root distribution patterns of high yielding rice varieties were studied at Tamilnadu Agricultural University, by Kumaraswamy et al. (1977) using ^{32}P plant injection technique. It was found that 55 to 75 per cent of the roots were concentrated in the soil zone covered by 10 cm lateral distance and 16 cm depth from the base of the plant and 80-85 per cent of the roots in the soil zone covered by 15 cm lateral distance and 24 cm depth. Similar reports on root distribution patterns were made by Cheema et al. (1979) and Tay (1982).

Salam (1993) reviewed the root distribution pattern of rice and reported that about 80-85 per cent of the roots were confined to the surface 10-15 cm soil layer. The lateral spread of the roots was also limited and about 95 per cent of the roots were found in the soil 10-15 cm laterally from the plant.

Wheat

About 90 to 95 per cent of wheat roots were located within 0 to 60 cm of the soil (Virmani, 1971). The root distribution pattern of nine wheat varieties grown in sandy loam alluvial soils indicated that 50 per cent of the roots were present in 0 to 80 cm layer (Katyal and Subbiah, 1971). Narang and Gill (1993) reviewed the root distribution pattern of wheat and reported that about 50 to 75 per cent of the roots were concentrated in the surface 8 cm of soil layer at 2.5 cm lateral distance from the plant.

Groundnut

Rao (1993) reported that in groundnut about 60 to 75 per cent of the roots were present in the top 30 cm of soil.

Sesamum

Joshi (1961) reported that in sesamum over 90 per cent of the roots were seen within 5 cm soil depth and 2.5 cm radial distance from the base of the plant. John (1993) reviewed the root distribution pattern of sesamum and reported that over 90 per cent of the roots were seen within 5 cm soil depth and 2.5 cm radial distance.

Cassava

Campos *et al*. (1975) observed that 95 per cent of the cassava roots were in the upper 0-30 cm soil layer. Lal and Maurya (1982) reported that eventhough cassava roots penetrated down to a vertical distance of 225 cm majority of the roots were concentrated within a depth of 60 cm and a lateral distance of 60 cm. Ashokan *et al*. (1989) reported that in cassava considerable root activity could be observed upto 60 cm depth and to a lateral distance of 20 cm from the base of the plant.

Cotton

Studies on the root distribution pattern of cotton indicated the existence of 83 per cent of root mass in the 0-15 cm soil layer, 12 per cent between 15 and 30 cm and the rest between 30 and 40 cm (Sankaran and Pothiraj, 1993).

Sugarcane

In sugarcane the bulk of the roots resided in the upper 20 cm of the soil (Lee, 1926 and Lee and Weller 1927). At grand growth stage, more than 60 per cent of the roots were present in the surface soil and the root mass decreased considerably with soil depth. More than 85 per cent of the total root dry mass could be recovered from the 0-40 cm soil depth (Lee and Weller, 1927).

Vegetables

In chillies only 50 per cent of the actively absorbing roots were found in the upper 20 cm of soil, though measurable root activity was also recorded at 103 cm depth (Hammes and Bertz, 1963).

Whitaker and Davis (1962) reported that the root system of all the economic cucurbits were extensive but shallow. Vittum and Flocker (1967) pointed out that cucurbits have a medium or deep root system. Doorenbos and Kassam (1979) reported that watermelon has a deep and extensive root system down to a depth of 1.5 to 2 m. The active root zone from where most of the water was extracted under adequate water supply was limited to the upper 1 to 1.5 m. Pumpkin and Squashes have a spreading but rather shallow root system (Choudhury, 1983). Lakshmanan (1985) found that the lateral spread and depth of root system of pumpkin was 235 cm and 85 cm respectively. Lakshmanan (1985) also reported that the maximum lateral spread of the root system of ashgourd was 285 cm and its vertical penetration was to 71 cm. Seshadri (1986) reported that generally cucurbits had a fairly long tap root with lateral roots, confined to a top layer of 60 cm except in cucurbita.

Pineapple

The roots of 12 month old pineapple grow to a depth of 1.3 cm and 95 per cent of the roots were confined to the top 20 cm of soil (Inforzato et al., 1968). Purseglove (1975) reported that in pineapple there are two types of roots -the axillary roots and the soil roots. Rajeevan (1993) reviewed the root distribution pattern of pineapple and reported that the soil roots which are shallow, form the main root system and in the variety 'cayenne' these are found to reach a depth of 30 cm (Collins, 1960) and spread laterally to 50 cm (Samson, 1980).

Papaya

Roots of papaya grows to a depth of 60 cm and a lateral distance of 20 cm and most of the secondary roots occur in the top 15 cm of the soil layer (Swabrick, 1964).

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 coastal clay soils of Malaysia, the highest root density was observed in the uppermost 50 cm soil layer (Jalil, 1982). Similarly, in an alluvial soil of northern 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 found to be confined within an area of two m radius around the plant (Wahid et al., 1993). The vertical spread of the majority of the roots were limited to 60 cm depth. However they observed that the surface 25 cm soil layer was practically devoid of roots.

Arecanut

The roots of areca palms radiate from all sides of the bole. Most of the roots reside very close to the palm, within 30-60 cm radius (Bavappa and Murthy, 1961). In an eight year old arecanut palm, 61 to 67 per cent of the roots were concentrated within a radius of 50 cm while a few extended beyond 100 cm as reported by Bhat and Leela (1969). Mohapatra et al. (1971) reported that a four year old areca palm had 96 per cent of its roots spread in a zone of 50 cm radius around the palm. Bhat (1978) reported that the areca roots penetrated to a depth of 2.6m. Khader et

Tsakiris and Northwood (1967). They found that the tap root of a three-and-a-half year-old tree extended to a depth of 3.2 m and had a diameter of 8.8 cm at a depth of 1.4 m. Khader (1986) studied the root distribution pattern of seedling raised cashew trees by excavation method and reported that over 67 per cent of thick roots (tap root and secondary and tertiary branches) and 26 per cent of the fine roots (fibrous roots developed from tap root and secondary and tertiary branches) were found within a radius of 50 cm from the base of the tree. In the 51 to 100 cm radial distance from the tree, about 16 per cent of the thicker roots and 20 per cent of the fine roots were found. Wahid et al. (1989) studied the root activity pattern of 20 year old cashew trees, raised from seedlings and growing on shallow laterite soil, by employing ^{32}P soil injection technique. The study revealed that cashew is a surface feeder with maximum concentration of roots at 0 to 15 cm soil layer. An area of two m radius around the tree accounted for about 72 per cent of the total active roots.

Rubber

Radiotracer studies for in situ measurement of root activity of rubber was made in Malaysia by Soong et al. (1971). The results indicated that the maximum root activity was concentrated with in 3.7 m from the tree although some root activity was found even upto six m. Qun (1984) also reported that the root activity in immature al. (1993) reviewed the root distribution of arecanut palm and reported that about 75 per cent of roots were confined within a radius of 100 cm from the trunk and penetrated to a depth of 2.6 m.

Oil Palm

Studies on the root activity pattern of oil palm had shown that the highest root activity was at the surface, at the 100 cm distance (IAEA, 1975). The root activity decreased beyond 300 cm distance as well as with increasing soil depth. About 70 to 80 per cent of the active roots in the 0 to 60 cm depth zone were located within the 0 to 20 cm depth with 50 to 60 per cent concentration at the soil surface.

Nair (1993) reviewed the root distribution pattern of oil palm and reported that majority of the active root system lies at 5 to 35 cm depth. The total quantity of absorbing roots extended to a radial distance of 3.5 to 4.5 m. The highest root activity was at the surface with in 100 cm laterally from the palm. Beyond 300 cm distance, there was a decrease in root activity and the root activity decreased with increasing soil depth.

Cashew

Root distribution pattern of young cashew trees growing on soils of loamy to sandy loam texture was reported by

Tsakiris and Northwood (1967). They found that the tap root of a three-and-a-half year-old tree extended to a depth of 3.2 m and had a diameter of 8.8 cm at a depth of 1.4 m. Khader (1986) studied the root distribution pattern of seedling raised cashew trees by excavation method and reported that over 67 per cent of thick roots (tap root and secondary and tertiary branches) and 26 per cent of the fine roots (fibrous roots developed from tap root and secondary and tertiary branches) were found within a radius of 50 cm from the base of the tree. In the 51 to 100 cm radial distance from the tree, about 16 per cent of the thicker roots and 20 per cent of the fine roots were found. Wahid et al. (1989) studied the root activity pattern of 20 year old cashew trees, raised from seedlings and growing on shallow laterite soil, by employing ^{32}P soil injection technique. The study revealed that cashew is a surface feeder with maximum concentration of roots at 0 to 15 cm soil layer. An area of two m radius around the tree accounted for about 72 per cent of the total active roots.

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Black Pepper

Wahid et al. (1993) reviewed the root distribution pattern of black pepper and reported that black pepper is generally a surface feeder with most of the feeder roots confined to an area of 30 cm from the vine though it can send roots down to 60 to 90 cm depth.

Coffee

Hatert (1958) studied the root system of robusta coffee and observed that the tap root extended to a depth of 90 cm while lateral roots formed a dense mass around the tree covering an area of 7 to 9 sq m.

Cocoa

Experiments conducted at Cocoa Research Institute, Ghana, indicated that the active root zone lie with in

7.5 cm surface soil layer, upto a lateral distance of 1.5 m (Ahenkorah, 1975). A major study conducted under a coordinated research project of the International Atomic Energy Agency (IAEA, 1975) also showed the highest root activity of cocoa in the upper 7.5 cm soil layer, with the maximum activity at 2.5 cm soil depth. Wahid and Kamalam (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.

From the above review it is clear that root distribution pattern vary with crop. While annual crops have a comparatively shallow root system the tree possess a deep and spreading root system. Among the annuals rice, wheat, sesamum etc. have a shallow root system and cassava, banana etc. have a comparatively deep root system.

3. Factors affecting root distribution

In a recently published book entitled "Rooting patterns of Tropical crops" (Salam and Wahid, 1993) the root distribution patterns of thirty important tropical crops have been described. It also describes the, development of root system and factors affecting root growth. Many factors involving crop, soil, environment, management etc., are reported to be influencing the behaviour of the root system which inturn influences the performance of the plant. The literature available on the factors affecting root system development are briefly reviewed below.

3.1. Crop factors

3.1.1. Growth phase

The growth and spread of rice roots increase progressively with age of the crop. Salam (1984) reported that during the early growth stages almost the entire roots of rice were confined to the surface 10 cm layer of the soil. At flowering the root spreads further to a depth of about 20 cm from the surface. From the panicle initiation stage onwards nearly 60 per cent of the total active roots were found within 10 cm laterally and vertically from the plant.

Rooting pattern of colocasia at different growth phases were studied by Mohankumar (1993). Majority of the roots in the early growth stage are confined to a lateral distance of 0-40 cm and to a depth of 5-8 cm in the soil. The maximum root production and activity occur during the grand growth phase (120 DAP). Majority of the roots at this stage were seen within a lateral distance of 0-30 cm and to a depth of

2 to 8 cm. At maturity phase, the root length as well as root mass decreased due to disintegration and most of the roots were seen within a lateral distance of 0-20 cm and to a depth of 9 cm. Similar variation in root system development due to change in growth phase were reported in sugarcane (Lee, 1927; Stevenson, 1936; Inforzato and Alvarez, 1957), tomato (Inforzato et al., 1970), coconut (Ouvrier and Brunin, 1974; IAEA, 1975; Sen 1983 and Avilan et al., 1984), cashew (Tsakiris and Northwood, 1967), apple (Vuorinone, 1958; Pasinova, 1960; Cripps, 1970 and Atkinson, 1974) and citrus (IAEA, 1975).

3.1.2. Variety

Studies conducted by Hurd (1968) revealed varietal differences in the root distribution pattern of spring wheat. Subbiah et al. (1968) reported that sonora 64, a two-gene dwarf wheat, had a more penetrating root system with high root density in the upper 15 cm depth than the NP series wheat which had a rather uniformly distributed root system, well spread out in all directions.

Similar variations in root system development due to varieties were reported in tobacco (Mc kee, 1967; Nagaraj and Gopalachari, 1977, 1979), groundnut (Gillier and Silvestre, 1969; Bhan and Misra, 1970; Huang and Ketring, 1987), wheat (Kamath, 1971; Katyal and Subbiah, 1971; Dev et al. 1980), castor (Reddy and Venkateswarlu, 1971), coconut

(Ouvrier and Brunin, 1974, Avilan et al., 1984 and Pomier and Bonneau, 1984), and cocoa (IAEA, 1975).

3.1.3. Planting material

Variations in root distribution pattern due to change in planting material (air layers and seedlings) were reported in cashew by Damodaran (1984) and Sulladmath et al. (1979).

3.2. Soil

3.2.1. Texture

Godefroy (1969) studied the root distribution pattern of banana in three different soils and found that the vertical distribution of the roots were strongly influenced by soil type and drainage. Compact soils, impermeable soil layer, high clay content and saturated soil conditions prevented or reduced the root growth.

Significant differences in root production in variety IR 20 due to variation in soil texture were observed by Salam and Subramanian (1988). The root production was higher in fine textured clay loam than in coarse textured sandy clay loam.

Similar variation in root system development was noticed due to variation in soil texture in crops like cocoa (Wessel, 1971), coconut (IAEA, 1975; Pomier and Bonneau, 1984), groundnut (Chopart and Nicow, 1976), corn (Babalola and Lal, 1977 and Logsdon, et al., 1987), tea (Ikegaya and Hiramine, 1978; Saikia, 1985 and Saikia, 1988) and cashew (Vidyadharan and Peethambaran, 1979; Khader and Kumar, 1985).

3.2.2. Soil moisture

Reiche (1972) reported that the total root yield was more in wheat plants receiving irrigation compared to moisture stressed plants. The root distribution pattern of rice varies with moisture regime in the soil. The active root zone shifts to the lower layers under drought condition (Bhattacharjee, et al., 1974). Rudaraju and Varma (1974) reported that in flooded soils, the root system of rice was compact and developed horizontally. The roots spread like a thick mat all over the surface layers. In the saturation regimes, the rice plants develop vertical root growth. An excessive delay in the first irrigation markedly affects deeper penetration of roots regardless of the frequency of the later irrigations (Singh, 1978 and Chaudhary and Bhatnagar, 1980). Kummerow (1980) found that water availability in the soil generally influence the growth, development and distribution of sugarcane roots and a high soil moisture generally results in a surface root system and a low soil moisture promotes a deep root system. Root activity studies, using ^{32}P conducted by Sobhana (1985) at the Kerala Agricultural University, India clearly indicated that the distribution of active roots varied significantly in irrigated and unirrigated conditions. Maximum root activity under irrigated condition was observed at 5 cm depth and at 20 cm lateral distance. The active root concentration decreased with the increasing soil depth. In rainfed banana, the highest root activity was obtained at 30 cm depth, 20 cm away from the plant. Similar differences in root system development was noticed due to differences in moisture environments in crops like tomato (Bloodworth et al., 1958; DeJong and Otinkarang, 1969), oil palm (Bachy, 1964 and IAEA, 1975), cocoa (Ahenkorah, 1975 and IAEA, 1975), coconut (IAEA, 1975), cucurbits (Loomis and Crandall, 1977; Zabara, 1978), cotton (Selvaraj and Palaniappan, 1977 and Al Khafat, 1985), sorghum (Kaigama, 1977 and Hundal and De Datta, 1984), potato (Grewal and Singh, 1978), pearl millet (Gregory, 1979), groundnut (Robertson, 1980) and tea (Saikia, 1985).

3.2.3 Soil aeration

Kawata et al. (1977) reported that in rice drainage is effective in increasing the number of roots and the rooting depth. Root growth in rice also depend on soil aeration (Vergara, 1979). Better aeration may result in a deep and well developed root system.

Beneficial effect of aeration in the better development of root system was reported in potato by Wiersum (1979).

3.2.4 Soil Salinity

Root activity of rice is affected by salt concentration in soil (Chol and Kim (1964). Certain varieties showed gradual decrease in rooting activity with increasing concentration of sodium chloride. The root volume and root dry weight were decreased by salinity and very few roots penetrated vertically down to 25 cm (Bal and Dutt, 1982).

3.3 Weather Factors

3.3.1. Temperature

Ong and Monteith (1985) reported that, the rate of root elongation of millet is a linear function of temperature with a base temperature of about 12°C. Hem (1982) and Peacock and Heinrich (1984) also reported variation in root system with temperature in sorghum.

3.3.2 Light

The influence of shade on root activity pattern of cocoa was studied in Ghana (IAEA, 1975). In the absence of shade, the root activity was found to be considerably higher than in its presence. Without shade root activity appeared to be higher at 90 cm distance from the tree whereas under shade, zone of higher activity seemed to be more wide spread.

Martin and Eckart (1933) reported that when sugarcane was grown under light conditions in a glass house a high quantum of root production was there. When light was partially cut off the root volume decreased to about 50 per cent. A further reduction in light intensity produced roots which were barely able to support the growth of the plants.

3.3.3. Season

Seasons tremendously influence the root growth and production in rice (Salam, 1984).

3.4. Agronomic Practices

3.4.1. Ploughing

Wiebing and Schepers (1977) worked out the impact of deep ploughing on the root characteristics of potato and reported that deep ploughing increased the penetration of the root. Root distribution in rice is decided by the depth of the ploughed soil (Vergara, 1979) to a greater extent. Miller and Martin (1987) observed that on sand sub-soiling promoted deep rooting and allowed potatoes to escape water stress. Variation in root distribution patterns due to changes in agronomic practices were reported in tea (Barbora et al., 1982; Yamashita et al. 1985) and due to deep ploughing in cotton (Turaev, 1983; Anon., 1984) and due to mulching in cotton (Wu et al., 1984). Method of planting also affects root system development in cashew (Tsakiris and Northwood, 1967).

3.4.2 Fertilisation

Balanced fertilization in wheat induces both, root and shoot growth (Brouwer and De Wit, 1969). Kumaraswamy et al. (1977) also observed a similar effect with respect to N and P nutrition of rice. Maizlish et al. (1980) reported variations in root activity due to nitrogen fertilization. Application of N and Zn does not change the percentage distribution of active roots of IR 20 rice in different soil zones. But root production in terms of root dry weight and root volume increases considerably due to N and Zn nutrition (Salam, 1984).

The role of nitrogen in increasing roots, has been reported by Kumar (1977), Singh (1978), Brar (1985) and Sharma (1987).

Similar variation in root system development of crops due to different nutrients and doses of nutrients were reported in groundnut (Bhan and Misra, 1970; Sivasankar et al., 1981), sorghum (Fluhler, 1977; Long, 1981; Venkateshwarlu and Venkatasubbaiah, 1984 and Krishnamoorthy and Iruthyaraj, 1984), cotton (Ibragimov and Nazarov, 1982), sunflower (Moore and Hirsch, 1983; Starcova and Vicherkova, 1985), pearlmillet (Kapur and Sakhor, 1985), pepper (Nybe, 1986) and pigeon pea (Subbarao, 1988; Narayanan and Syamala, 1989).

3.4.3. Plant spacing

Root shoot ratio can be varied by adjusting row spacing (Azam-Ali *et al.*, 1984). They found that the distribution of pearl millet roots was affected by spacing and that fewer roots grew deep into the profile when wider spacing was adopted. Wide spacing generally increased the root growth of groundnut plant (Bhan and Misra, 1970).

Variation in root system development due to change in planting density was reported in arecanut (Bavappa and Mathew, 1960; Bhat and Leela, 1969) and tea (Barua and Dutta, 1973; Borpujari, 1975 and Rahaman and Freed, 1977).

3.4.4. Intercropping

In intercropping systems, roots of two or more species share the same space and compete for moisture and nutrients. The root system of sole pigeon pea was compared with that of intercropped pigeon pea at International Crop Research Institute for Semi-Arid Tropics (Narayanan and Sheldrake, 1976). In intercropping system, the growth of pigeon pea roots were slow prior to the harvest of intercrop sorghum. Pigeon pea roots were influenced not only by the competition from companion crops, but also by its own roots. Chauhan and Singh (1987) recorded a significant effect of inter row spacing on the root growth of pigeon pea. Cocoa plants when grown mixed with arecanut showed more expansion of roots both laterally and vertically compared to sole cropped cocoa (Bhat, 1983). Variation in root system development due to intercropping was reported in groundnut (Gregory and Reddy, 1982) and cocoa (Bhat, 1983).

3.4.5. Application of growth stimulating insecticides

Root production and root activity of rice increased considerably following soil application of granular systemic insecticides like carbofuran. Root dry weight increased by 13 to 30 per cent. But the percentage distribution of roots in different soil zone of the rhizosphere did not change (Salam, 1984).

3.5. Diseases

Some of the diseases infecting the coconut palm affect the growth of roots also. Michael (1966) reported that a root wilt - affected coconut differed greatly from a healthy palm in root characteristics. In cadang_cadang affected coconut trees, primary roots were less in number and less healthy than those of a healthy tree (Magnaye, 1969).

From the review presented above it is clear that several factors involving crop, soil, weather and agronomic practices influence the root system development of crop plants. Among the crop factors varieties, growth phase and planting material are important. Soil texture, soil aeration, soil salinity and soil moisture level are important soil factors affecting root system development. Among the weather factors, light and temperature affects root growth and distribution considerably Ploughing, method of planting, fertilization, inter cropping etc. are certain important agronomic practices influencing root distribution.

Materials and Methods

MATERIALS AND METHODS

The present study was conducted at the Instructional Farm, Vellanikkara and at the Radiotracer Laboratory, College of Horticulture, Kerala Agricultural University, Vellanikkara. The main objective of the investigation was to study the root distribution pattern of banana in relation to light and moisture environments and that of colocasia in relation to light regimes.

The studies undertaken during the course of the investigation are as follows:-

Experiment I	Root distribution pattern of banana in relation to light and moisture environments
Experiment II	Root distribution pattern of colocasia in relation to light environment.

Location and climate

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 area enjoys a warm humid tropical climate, with a mean annual rainfall of 278 cm and mean relative humidity of 75 per cent. The maximum and minimum temperatures ranged from 28.5 to 36.2 and 22.6 to 24.7°C respectively. The weather data during the experimental period are given in Fig.1 and Appendix I.

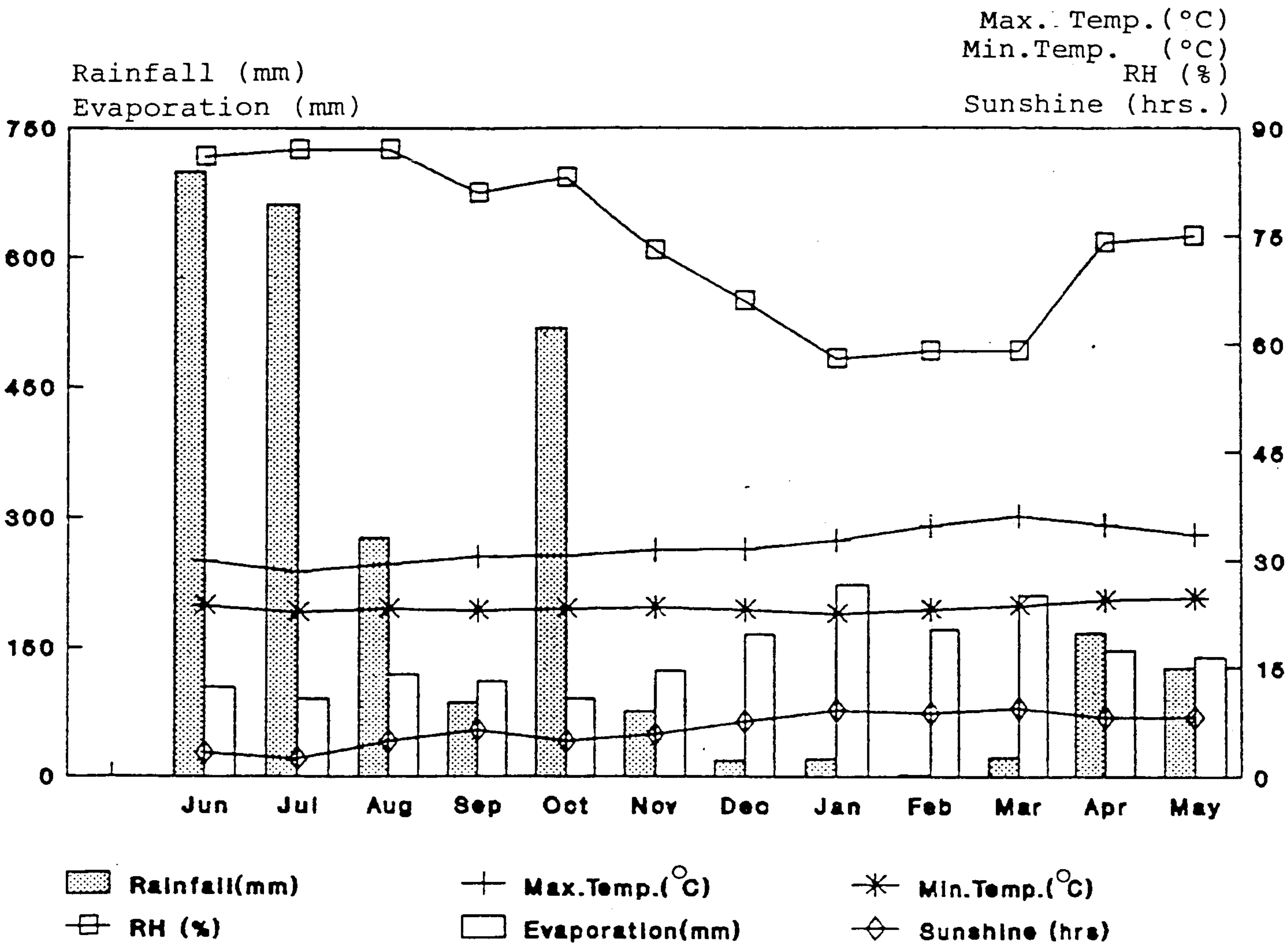


Fig.1. Meteorological data (monthly average) for the crop period (June 1993 - May 1994)

Soil

The soil of the experimental site is typical laterite belonging to the soil order oxisol. Texturally the soil is sandy clay loam with a bulk density of 1.34 g cm^{-3}.

1. Mechanical composition (Hydrometer method, Bouyoucos,1962)

Coarse sand	:	31.1 per cent
Fine sand	:	20.2 per cent
Silt	:	22.5 per cent
Clay	:	25.2 per cent

Chemical properties

Constituent	Content	Rating	Method used for estimation
Organic Carbon (per cent)	1.0	Medium	Walkley and Black method (Piper, 1950)
Total Nitrogen (per cent)	0.10	Medium	Microkjeldahl distillation method (Jackson, 1958)
Available N (kg ha^{-1})	331.5	Medium	Alkaline permanganate method (Jackson, 1958)
Available P (kg ha^{-1})	4.8	Low	Ascorbic acid method (Watanabe and Olsen, 1965)
Available K (kg ha^{-1})	216	Medium	Flame Photometry (Jackson, 1958)
pH (1:2.5 soil-water ratio)	5.8	Moderately acidic	pH meter method (Jackson, 1958)
EC (1:2.5 soil-water ratio ds m^{-1})	0.1	Safe	Conductivity bridge method (Jackson, 1958)
CEC (centi moles kg^{-1})	4.0	--	Ammonium acetate method (Jackson, 1958)

Physical constants

Field capacity (-0.3 bars)	18 per cent	Pressure plate method (Richards, 1947)
Wilting point (-15 bars)	11.2 per cent	Pressure plate method (Richards, 1947)
Maximum water holding capacity	30 per cent	Keen Raczhowski box method (Piper,1950)

3. Studies Undertaken

Experiment I. Root distribution pattern of banana in relation to light and moisture regimes

The objective of this experiment was to study the variation in root distribution patterns of banana (var. palayankodan) grown in coconut gardens as well as in the open under rainfed and irrigated conditions.

For the purpose of studying the root distribution pattern of banana, five lateral distances (L_{0-20}, L_{20-40}, L_{40-60}, L_{60-80}, L_{80-100} cm) and four depths (D_{0-20}, D_{20-40}, D_{40-60}, D_{60-80} cm) were considered. There were 20 treatment combinations with four replications. The treatments were as follows

$L_{0-20}D_{0-20}$

$L_{0-20}D_{20-40}$

$L_{0-20}D_{40-60}$

$L_{0-20}D_{60-80}$

$L_{20-40}D_{0-20}$

$L_{20-40}D_{20-40}$

$L_{20-40}D_{40-60}$

$L_{20-40}D_{60-80}$

$L_{40-60}D_{0-20}$

$L_{40-60}D_{20-40}$

$L_{40-60}D_{40-60}$

$L_{40-60}D_{60-80}$

$L_{60-80}D_{0-20}$

$L_{60-80}D_{20-40}$

$L_{60-80}D_{40-60}$

$L_{60-80}D_{60-80}$

$L_{80-100}D_{0-20}$

$L_{80-100}D_{20-40}$

$L_{80-100}D_{40-60}$

$L_{80-100}D_{60-80}$

The experiment was treated as in RBD. The layout plan is given in Fig.2. A single plant randomly chosen from every block formed a replication to study the distribution of roots.

To study the variation in root distribution pattern in relation to light and moisture environments, four such experiments were simultaneously laid out, two in a coconut garden (18 year old plantation with a shade level of 60 to 70 per cent shade) and two in the open. Of the two experiments laid out in the coconut garden, one was rainfed and the other irrigated. Similarly, of the two experiments laid out in the open, one was rainfed and the other irrigated.

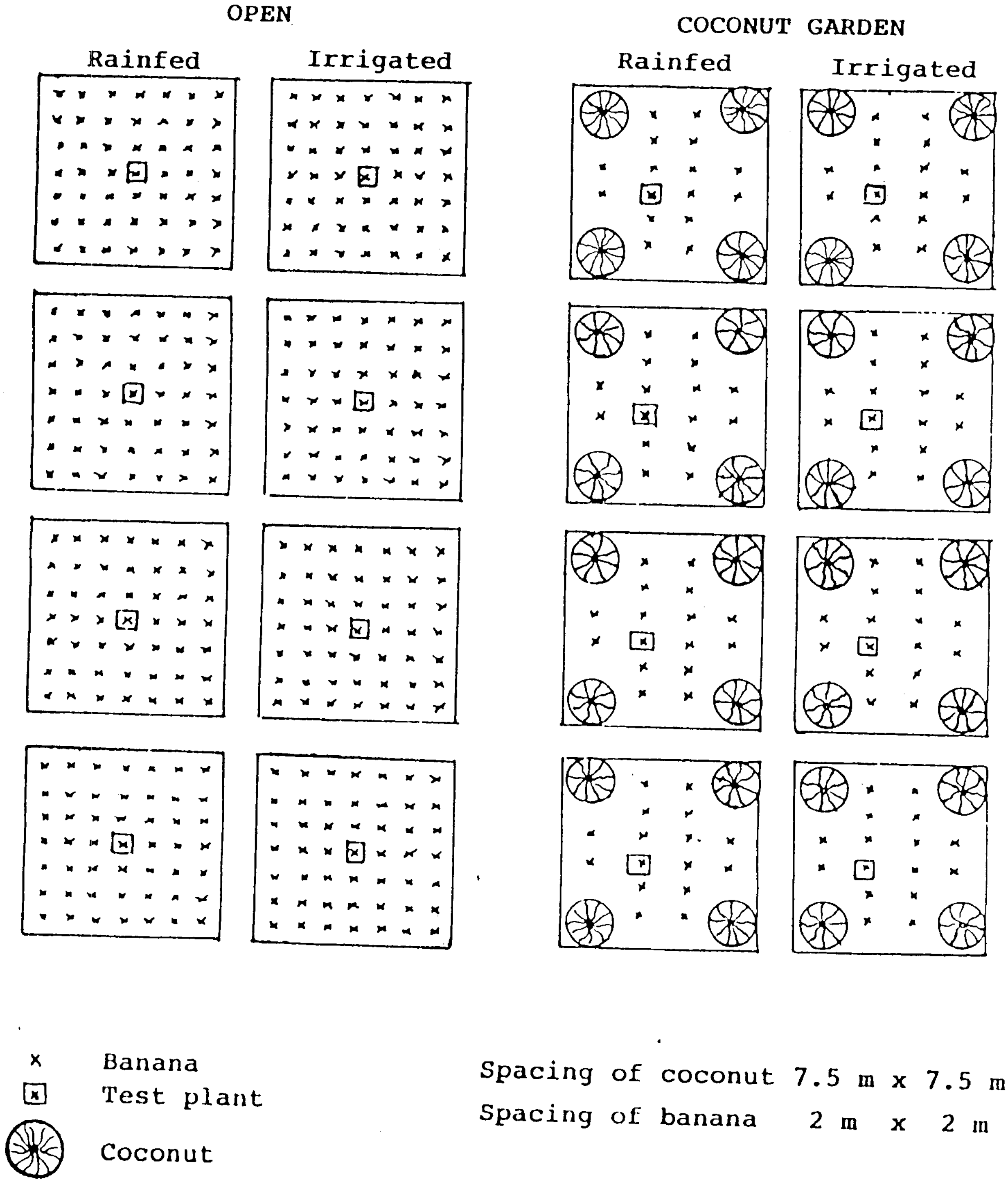


Fig.2 Lay out plan of banana var. palayankodan

In all the experiments, banana was planted with healthy suckers on July 15th with a uniform spacing of 2m x 2m. The plants were raised and maintained following the package of practices recommendations of Kerala Agricultural University (KAU, 1989). Fertilizers were applied uniformly at the rate of 100:200:400 g N, P_2O_5 and K_2O per plant and all the plants were maintained well. The plants intended to study the root distribution pattern under irrigated conditions were irrigated uniformly by maintaining a soil moisture regime ranging from zero to 50 per cent depletion of available water. Pot watering was done with 100 litres of water per plant at an interval of three to four days and the crop received 16 irrigations.

Root distribution studies

^{32}P Plant injection technique

One plant was randomly chosen from every block to study the root system. Root distribution study using ^{32}P plant injection technique (Rennie and Halstead, 1964) was conducted during the grand growth phase (180 days) in rainfed and irrigated banana grown under open condition and in the coconut garden. The banana plants were detopped two feet above the ground level a day in advance of ^{32}P application. Two holes were made on two sides of the pseudostem about 20 cm above the ground level and ^{32}P was injected (0.884 uci plant^{-1}) into the holes using a microlitre syringe (Plate 1).

Profile excavation technique

The root distribution pattern was also studied directly following the profile excavation technique using the needle board method (Schuurmann and Goedewagen, 1971) at different growth stages of the crop (Fig.3) viz., 60, 120, 180 and 240 days after planting (DAP). Four plants were exposed to study the root distribution pattern. A soil monolith containing a representative sample of the root system was excavated by means of a special wooden board. For this, a trench was dug at a distance of 1 m from the plant with the plant in the centre to a depth of 60 cm and the root system of the plant was excavated carefully by removing the soil surrounding the individual roots. Then the wooden board was placed against the profile wall. Needles or nails positioned in the board kept the roots in their natural position while the soil was removed by soaking and washing. The root system was then sectioned against different zones for quantitative determination. The dry weight of the roots collected from different sections were determined. Using the mean value obtained from four plants, the percentage of roots in each zone of the rhizosphere was calculated.

Plate 1. Method showing ^{32}P plant injection technique in banana var. palayankodan

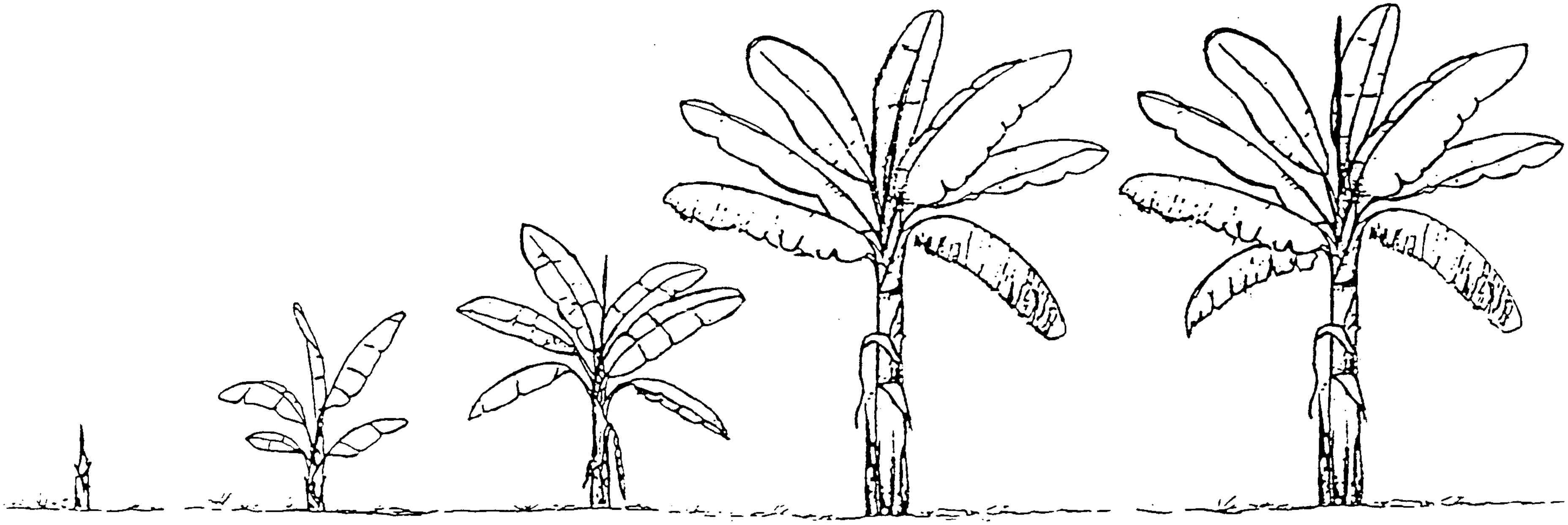


Fig. 3 Phenological phases of banana var. palayankodan

Observations Recorded

1. Radioactivity in the soil

Soil samples were taken ten days after ^{32}P injection, using a hand auger from five lateral distances (20, 40, 60, 80 and 100 cm) and four depths (20, 40, 60 and 80 cm). The root particles carried in the soil were also retained. For each treatment, samples were taken at four points from around the plant and combined (Fig.4). The composite samples were then air-dried and powdered using a mortar and pestle. For taking counts, one g of the sample was taken and digested using 15 ml of diacid mixture (2:1 nitric acid - perchloric acid). The digest was then made upto 25 ml. From this 20 ml was pipetted and transferred to a 20 ml vial. The radioactivity was determined by Cerenkov counting technique in a microprocessor controlled liquid scintillation system (Rackbeta of LKB Wallac Oy, Finland) adopting channel settings and computer programme recommended for tritium counting by liquid scintillation technique. The counts obtained were background corrected and subjected to statistical analysis after effecting suitable transformations of data.

2. Root dry matter production (RDMP)

The fresh root samples collected from the different zones of the rhizosphere were washed well, air dried and

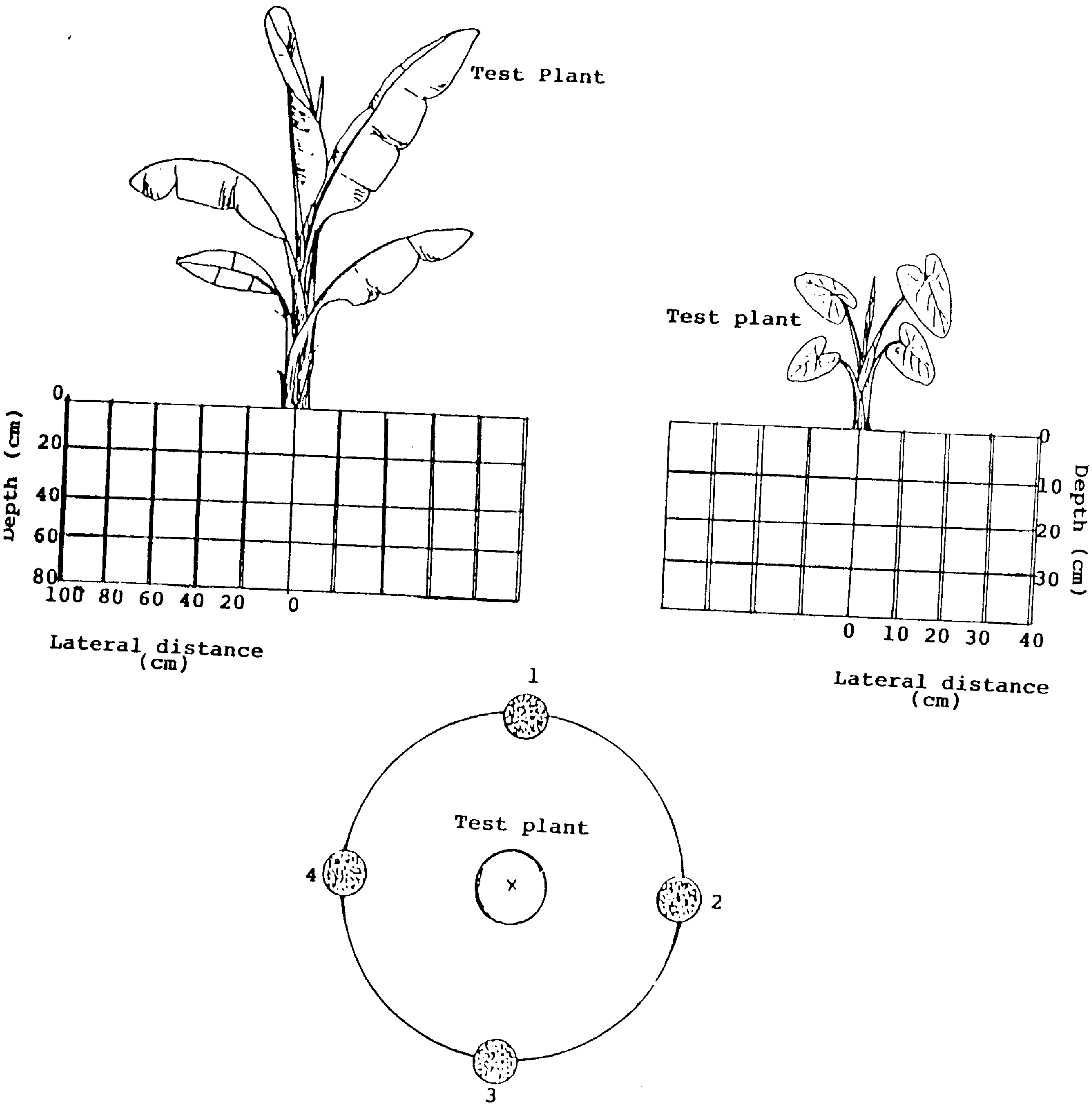


Fig. 4 Method showing the collection of soil-root core samples (numbers 1 to 4 indicates diagonally opposite collection points around the plant)

then oven dried (80°C) to constant weight and the dry weight recorded.

3. Root number

Number of roots present at each growth phase were counted and recorded.

4. Length of the longest root

The length of the longest root was measured from the base of the plant to the tip of the root and expressed in cm.

5. Height of the plant

The height of the pseudostem was measured from the ground level to the tip of the youngest leaf and expressed in cm.

6. Leaf number

Fully opened functional leaves (more than 50 per cent area green) present at each growth phase were counted and recorded.

Experiment II. Root distribution pattern of colocasia in relation to light regimes

The objective of this experiment was to study the variation in root distribution pattern of colocasia var.

cheruchempu grown in coconut gardens as well as in the open conditions. For this purpose four lateral distances (L_{0-10}, L_{10-20}, L_{20-30}, L_{30-40} cm) and four depths (D_{0-10}, D_{10-20}, D_{20-30}, D_{30-40} cm) were considered. There were 16 treatment combinations with six replications. The treatments were as follows:-

L_{0-10} D_{0-10}	L_{20-30} D_{0-10}
L_{0-10} D_{10-20}	L_{20-30} D_{10-20}
L_{0-10} D_{20-30}	L_{20-30} D_{20-30}
L_{0-10} D_{30-40}	L_{20-30} D_{30-40}
L_{10-20} D_{0-10}	L_{30-40} D_{0-10}
L_{10-20} D_{10-20}	L_{30-40} D_{10-20}
L_{10-20} D_{20-30}	L_{30-40} D_{20-30}
L_{10-20} D_{30-40}	L_{30-40} D_{30-40}

The experiment was treated as in RBD. The layout plan is given in Fig.3. A single plant randomly chosen from every block formed a replication to study the distribution of roots.

To study the variation in root distribution pattern in relation to light environment, two such experiments were simultaneously laid out, one in a coconut garden (18 year old plantation with a shade level of 60 to 70 per cent shade) and one in the open.

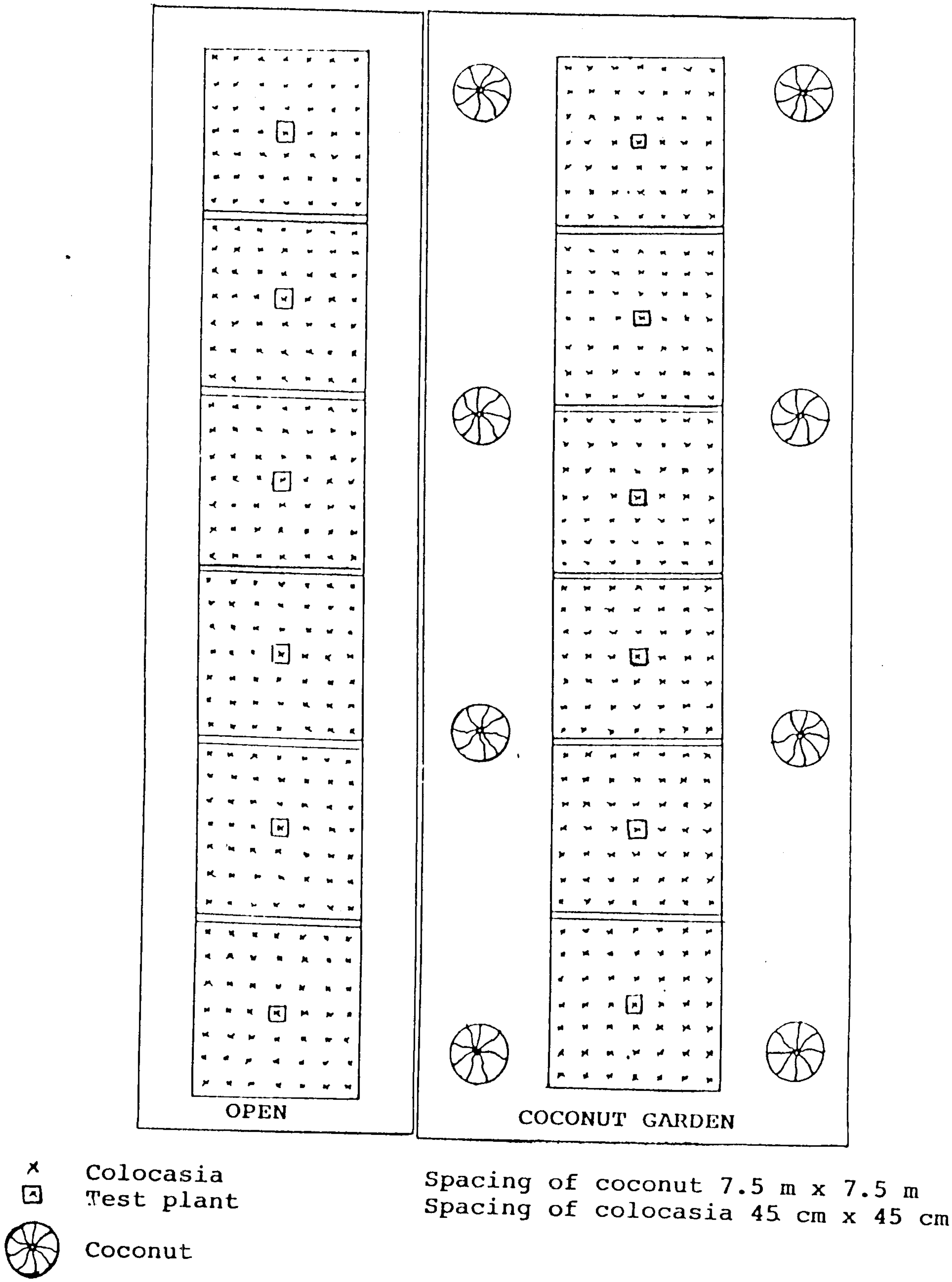


Fig.5 Lay out plant of colocasia var.cheruchempu

The crop was planted with side cormels on June 10th with an uniform spacing of 45 cm x 45 cm on beds. The plants were raised and maintained as per the package of practices recommendations of Kerala Agricultural University (KAU, 1989). Fertilizers were applied uniformly at the rate of 80:50:100 kg N, P_2O_5 and K_2O per hectare.

The root distribution pattern was studied using radiophosphorus following the plant injection technique (Rennie and Halstead, 1964) during the peak growth phase (120 days) of the plant.

^{32}P Plant injection technique

Root distribution studies using ^{32}P plant injection technique was done during the grand growth phase (120 days) in rainfed colocasia both in the open condition and in coconut garden. For this, the two oldest leaves at the base were removed and two holes were made on the main stem, one hole on each side. ^{32}P (40 uci $plant^{-1}$) was injected into the hole using a microlitre syringe (Plate 2). The shoot portions of the plant were removed two days after injection.

Profile excavation technique

Simultaneously the root distribution pattern was also studied by profile excavation technique using the needle

Plate 2. Method showing ^{32}P plant injection technique in colocasia var. cheruchempu

board method (Schuurmann and Goedewagen, 1971) at different growth stages of the crop viz. 60, 90, 120 and 150 days after planting (Fig. 6).

The procedure followed was same as described in experiment I, for direct method of root distribution study.

Observations recorded

1. Radioactivity in the soil

Soil root samples were taken 10 days after ^{32}P injection using a hand auger from four lateral distances (10, 20, 30 and 40 cm) and four depths (10, 20, 30 and 40 cm). For every treatment, four samples were taken from diametrically opposite four points of the plant and combined. The samples were then processed and the radioactivity recorded as described in experiment I.

2. Root dry matter production (RDMP)

In the direct excavation study root dry matter production was recorded at different stages of growth (60, 90, 120 and 150 DAP). The roots collected from the different zones were washed free of soil, air dried and then oven dried at 80°C to constant weight.

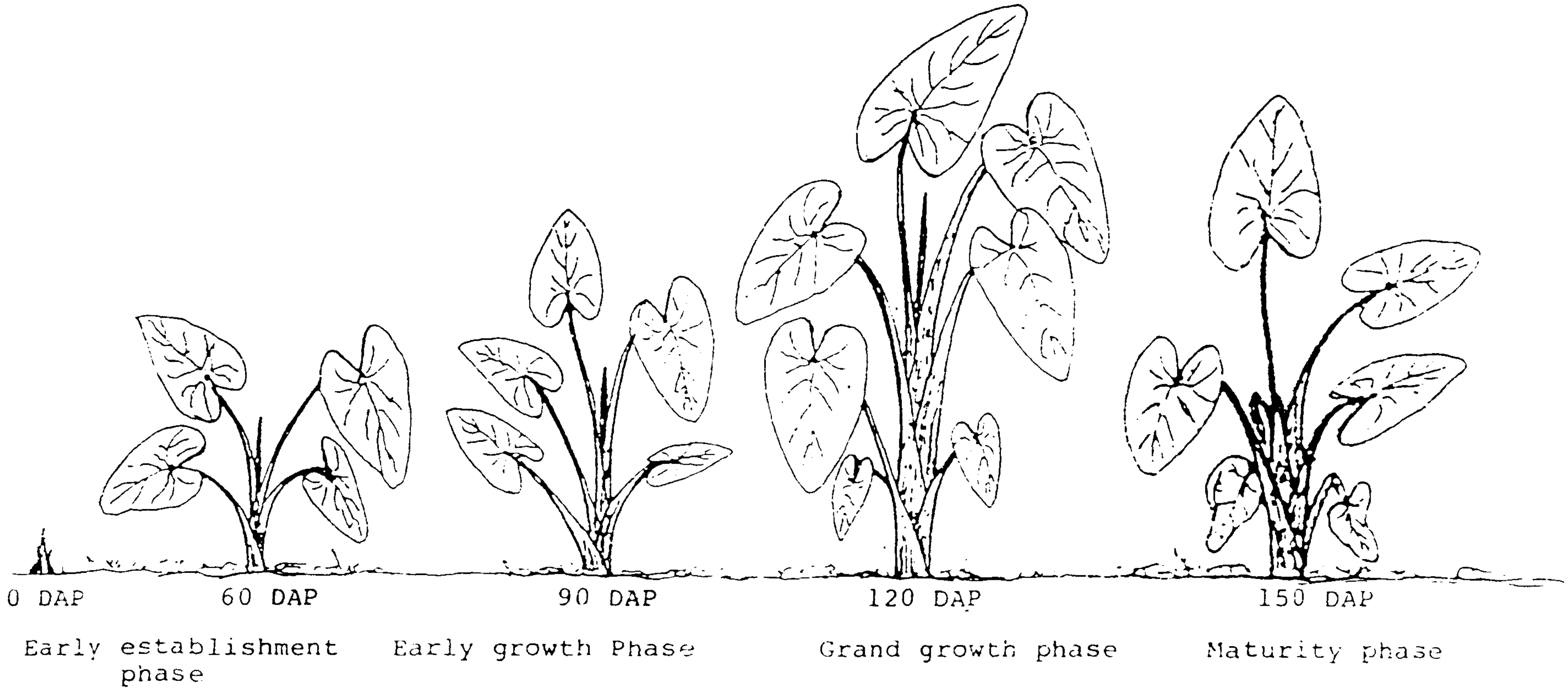


Fig.6 Phenological phases of colocasia var. cheruchempu

Results

8. Corm Yield

Five sample plants were harvested separately and weighed to get the individual plant yield. From this yield per hectare was calculated.

9. Nutrient uptake

The plants parts collected for the estimation of the DMP (aerial parts and tubers) were separately analysed for their nutrient (N, P & K) content. The N content of the sample was determined by microkjeldahl digestion and distillation method (Jackson, 1958). For the determination of P and K, triacid extract (HNO_3: H_2SO_4: $HClO_4$ in the ratio 10:1:4) was made use of. Phosphorus was determined by Vanadomolybdophosphoric yellow colour method (Jackson, 1958). Potassium was determined using EEL flame photometer. The total uptake of nitrogen, phosphorus and potassium were estimated from the nutrient contents and dry weight of the plant and tuber and expressed as kg ha^{-1}.

Statistical analysis

The data relating to the experiment I and II were statistically analysed applying the analysis of variance for randomised block design. In view of the wide variability in the data on radioactivity counts (cpm values), the data were subjected to $\sqrt{x+1}$ transformation prior to statistical analysis (Panse and Sukhatme, 1976). Correlation coefficients for the different growth characters with RDMP was worked out as per the technique suggested by Cochran and Cox (1950).

RESULTS

The results of the experiments conducted during the course of the investigation are presented below.

Experiment 1 Root distribution pattern of banana

A. ^{32}P Plant injection technique

1. Influence of light and soil moisture regimes on root production

The data on root production of banana measured in terms of the radioactivity in the rhizosphere soil as influenced by light and soil moisture regimes are presented in Table 1. The total radioactivity in the rhizosphere soil of banana grown in the open condition was considerably more compared to that grown in the coconut garden. Similarly the total radioactivity in the rhizosphere soil of rainfed banana was considerably more compared to that of irrigated banana. The effect of interaction between light and soil moisture regimes was also significant in this respect. The radioactivity in the rhizosphere soil of rainfed banana grown in the open was the highest and that of banana plants grown in coconut garden was the lowest.

2. Lateral distribution of roots

The amount of radioactivity as well as its percentage distribution in the rhizosphere soil differed between

Table 1. Radioactivity in the rhizosphere soil (cpm $\sqrt{x+1}$) of banana as influenced by light and soil moisture regimes

Light regimes Soil moisture regimes	Open	Coconut garden	Mean
Rainfed	3.30	1.79	2.55
Irrigated	2.53	1.93	2.23
Mean	2.91	1.86	

	Light/Soil moisture regimes	Interaction
SE m$\pm$	0.11	0.17
CD (0.05)	0.24	0.33

lateral distances and growing conditions (Table 2 and 3). The rhizosphere soil of banana upto a lateral distance of 20 cm contained the highest amount of radioactivity and it declined with increase in lateral distance. This particular zone accounted for 66.6 per cent of the total radioactivity observed in the entire root zone. About 92.6 per cent of the total rhizosphere radioactivity was noticed within a lateral distance of 60 cm around the plant and only 2.67 per cent of the radioactivity was observed beyond 80 cm laterally from the base.

The lateral distribution of radioactivity in the soil also differed with the growing conditions. The percentage distribution of radioactivity in the 0-20 cm lateral distance was more in the case of rainfed banana compared to irrigated banana. This trend was observable both in the open condition as well as in the coconut garden. In the open condition lateral spread beyond 80 cm was more with irrigated banana than rainfed ones. But in the coconut garden a reverse trend was observed.

3. Vertical distribution of roots

The amount of radioactivity as well as its percentage distribution vertically in the rhizosphere soil differed between soil depths and growing conditions (Table 4 and 5). The highest root activity was observed at the surface 0-20 cm soil layer and it declined with increase in depth. About

Table 2. Radioactivity in the rhizosphere soil (cpm $\sqrt{x+1}$) of banana at different lateral distances as influenced by growing conditions

Lateral distances (cm)	Growing conditions				
	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated	Mean
L_{0-20}	7.85	4.15	3.25	3.55	4.70
L_{20-40}	2.93	2.72	1.59	2.28	2.38
L_{40-60}	2.34	2.55	1.49	1.69	2.02
L_{60-80}	1.90	1.79	1.31	1.11	1.53
L_{80-100}	1.46	1.44	1.28	1.00	1.29
Mean	3.30	2.53	1.79	1.93	

	Lateral distance	Growing condition	Interaction
SE m$\pm$	0.18	0.17	0.38
CD (0.05)	0.36	0.33	0.75

Table 3. Percentage distribution of radioactivity in the rhizosphere soil of banana at different lateral distances as influenced by growing conditions

Lateral distances (cm)	Growing conditions				
	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated	Mean
L_{0-20}	80.74	54.14	67.36	64.30	66.64
L_{20-40}	8.73	19.22	11.98	24.84	16.19
L_{40-60}	5.26	15.99	9.44	8.33	9.76
L_{60-80}	3.43	6.60	6.37	2.53	4.73
L_{80-100}	1.83	4.05	4.85	0.00	2.68

	Lateral distance	Growing condition	Interaction
SE m$\pm$	0.36	3.34	6.91
CD (0.05)	0.70	6.58	13.62

Table 4. Radioactivity in the rhizosphere soil (cpm $\sqrt{x+1}$) of banana at different depths as influenced by growing conditions

Depth (cm)	Growing conditions				
	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated	Mean
D_{0-20}	4.83	3.27	2.55	2.64	3.32
D_{20-40}	4.01	2.64	1.83	2.17	2.66
D_{40-60}	2.36	2.24	1.54	1.74	1.97
D_{60-80}	1.99	1.97	1.22	1.15	1.58
Mean	3.30	2.53	1.79	1.93	

	Depth	Growing condition	Interaction
SE m$\pm$	0.17	0.17	0.34
CD (0.05)	0.33	0.33	0.66

Table 5. Percentage distribution of radioactivity in the rhizosphere soil of banana at different depths as influenced by growing conditions

Depth (cm)	Growing conditions				
	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated	Mean
D_{0-20}	55.14	38.89	57.42	45.55	49.25
D_{20-40}	32.02	25.21	22.59	34.31	28.53
D_{40-60}	7.93	21.75	15.57	16.17	15.36
D_{60-80}	4.90	14.15	4.42	3.99	6.87

	Depth	Growing Condition	Interaction
SE m$\pm$	1.07	2.14	6.19
CD (0.05)	2.12	4.20	12.19

49.3 per cent of the total radioactivity was observed in the surface 20 cm soil. Upto a depth of 40 cm from the surface 77.8 per cent of the radioactivity was found. Only 6.9 per cent of the total radioactivity was observed in the soil beyond a depth of 60 cm.

The depthwise distribution of radioactivity in the soil also differed with growing conditions. The radioactivity in the soil to a depth of 0-20 cm was more with rainfed banana compared to irrigated banana. This trend was noticed with the plants grown in the open condition as well as in the coconut garden. In the case of banana grown in the open radioactivity in the deeper layers beyond 40 cm was more with irrigated banana compared to rainfed ones. But this difference due to irrigation was not noticed with banana grown in the coconut garden.

4. Root distribution pattern

Root distribution pattern of banana measured in terms of radioactivity in the rhizosphere soil (Table 6 and Fig.7) and its percentage distribution at different zones of the rhizosphere soil(Table 7 and Fig.8) differed with growing condition. In the case of banana grown in the open, rainfed plants had 47.5 per cent of their roots in the root zone comprising 20 cm laterally around the plant and 20 cm vertically from the soil surface (Table 8). The corresponding value for irrigated banana was only 19.8 per

Table. 6. Radioactivity at the different zones of the rhizosphere soil (cpm $\sqrt{x+1}$) as influenced by growing conditions

Root zones	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated	Mean
	Growing conditions				
L_{0-20} D_{0-20}	13.84 (194.18)	5.28 (32.38)	5.42 (30.40)	4.90 (25.13)	7.36
L_{0-20} D_{20-40}	10.21 (103.78)	4.99 (25.23)	2.97 (7.90)	4.86 (22.73)	5.76
L_{0-20} D_{40-60}	4.14 (16.53)	3.35 (14.05)	2.82 (7.07)	2.95 (12.65)	3.32
L_{0-20} D_{60-80}	3.20 (9.78)	2.99 (13.38)	1.81 (2.55)	1.51 (2.05)	2.38
L_{20-40} D_{0-20}	3.39 (12.90)	3.45 (11.88)	1.89 (3.10)	3.62 (12.88)	3.09
L_{20-40} D_{20-40}	3.18 (9.28)	2.45 (7.58)	1.63 (2.83)	2.18 (4.38)	2.36
L_{20-40} D_{40-60}	2.86 (7.33)	2.56 (8.00)	1.55 (1.55)	2.06 (3.38)	2.26
L_{20-40} D_{60-80}	2.30 (4.45)	2.43 (5.78)	1.30 (0.80)	1.26 (0.78)	1.82
L_{40-60} D_{0-20}	2.99 (9.30)	3.32 (10.05)	2.19 (4.13)	2.24 (5.65)	2.69
L_{40-60} D_{20-40}	2.83 (7.20)	2.39 (6.70)	1.66 (2.60)	1.83 (4.38)	2.18
L_{40-60} D_{40-60}	1.84 (3.33)	2.45 (5.90)	1.11 (.028)	1.70 (8.71)	1.78
L_{40-60} D_{60-80}	1.67 (1.95)	2.03 (3.63)	1.00 (0.00)	1.00 (0.00)	1.43
L_{60-80} D_{0-20}	2.21 (5.35)	2.27 (4.90)	1.67 (2.05)	1.44 (1.33)	1.90
L_{60-80} D_{20-40}	2.13 (4.13)	1.95 (3.11)	1.48 (1.28)	1.00 (0.00)	1.64
L_{60-80} D_{40-60}	1.69 (3.35)	1.51 (1.55)	1.10 (0.25)	1.00 (0.00)	1.33
L_{60-80} D_{60-80}	1.57 (2.05)	1.42 (1.55)	1.00 (0.00)	1.00 (0.00)	1.25
L_{80-100} D_{0-20}	1.69 (3.35)	2.03 (3.63)	1.60 (2.00)	1.00 (0.00)	1.58
L_{80-100} D_{20-40}	1.69 (3.35)	1.42 (1.55)	1.41 (1.00)	1.00 (0.00)	1.38
L_{80-100} D_{40-60}	1.23 (0.78)	1.32 (1.03)	1.10 (0.25)	1.00 (0.00)	1.16
L_{80-100} D_{60-80}	1.19 (0.53)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.05
SE m$\pm$	0.76	0.96	0.47	0.66	
CD (0.05)	1.52	1.93	0.94	1.32	

Values in the paranthesis indicate mean of the actual counts

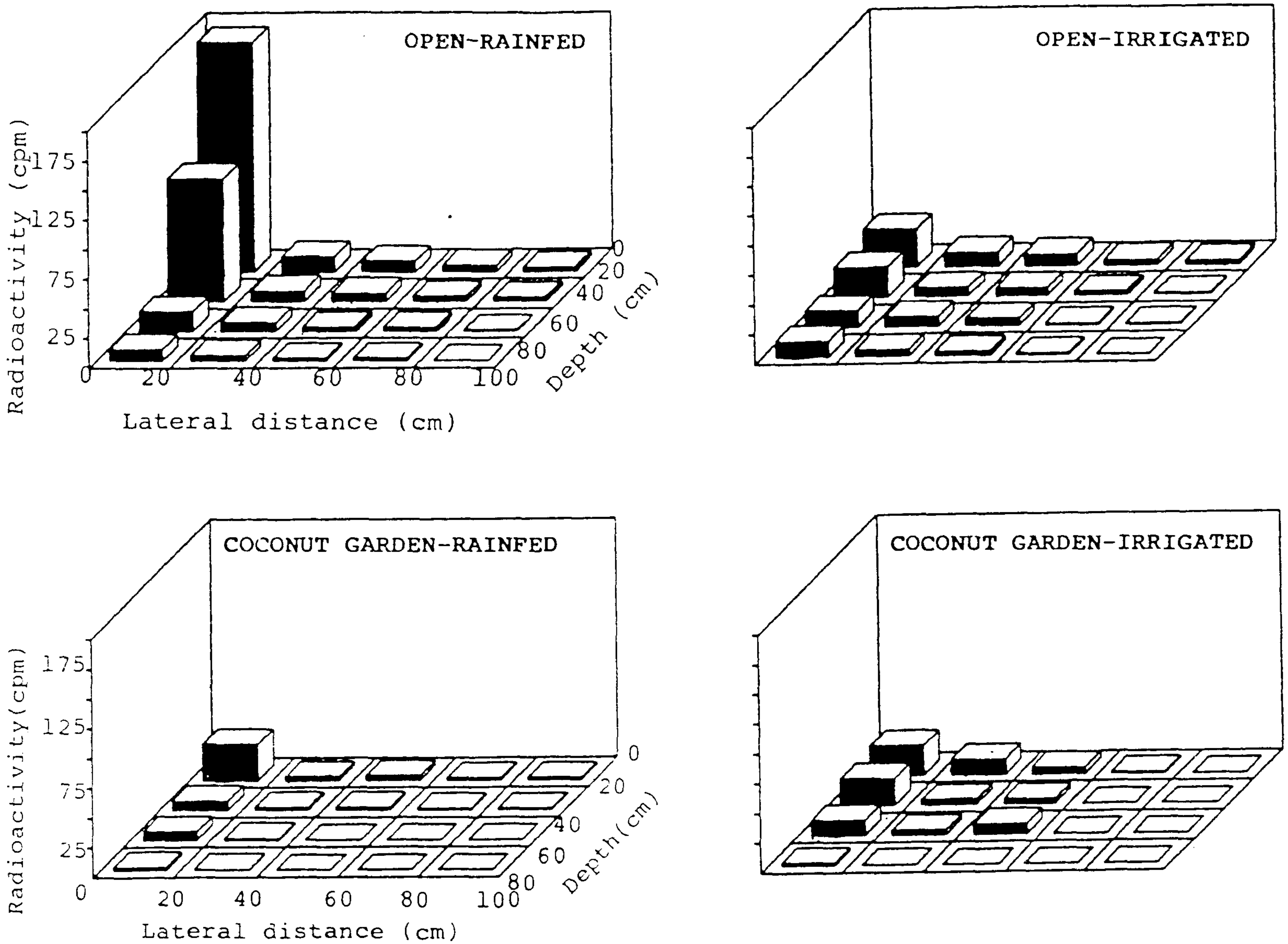


Fig.7 Radioactivity distribution patterns of banana var. palayankodan(180 DAP) as influenced by growing conditions

DAP - Days after planting

Table 7. Percentage distribution of radioactivity in different zones of the rhizosphere soil as influenced by growing conditions

Root zones	Growing conditions: Open-rainfed	Open-irrigated	Coconut garden rainfed	Coconut garden irrigated	Mean
L_{0-20} D_{0-20}	47.49	19.81	40.37	25.39	33.27
L_{0-20} D_{20-40}	26.22	15.26	12.20	27.04	20.18
L_{0-20} D_{40-60}	4.41	11.34	11.53	8.37	8.91
L_{0-20} D_{60-80}	2.63	7.73	3.25	3.50	4.28
L_{20-40} D_{0-20}	3.48	7.07	4.13	13.72	7.10
L_{20-40} D_{20-40}	2.31	4.00	3.89	4.54	3.69
L_{20-40} D_{40-60}	1.82	4.68	2.80	6.11	3.85
L_{20-40} D_{60-80}	1.12	3.48	1.16	0.48	1.56
L_{40-60} D_{0-20}	2.31	6.63	6.29	3.90	4.78
L_{40-60} D_{20-40}	1.74	3.35	2.71	2.73	2.63
L_{40-60} D_{40-60}	0.75	3.76	0.44	1.70	1.66
L_{40-60} D_{60-80}	0.76	2.26	0.00	0.00	1.33
L_{60-80} D_{0-20}	1.15	3.13	3.73	2.53	2.64
L_{60-80} D_{20-40}	1.03	1.77	2.25	0.00	1.26
L_{60-80} D_{40-60}	0.71	1.02	0.40	0.00	0.53
L_{60-80} D_{60-80}	0.55	0.69	0.00	0.00	0.31
L_{80-100} D_{0-20}	0.71	2.26	2.90	0.00	1.47
L_{80-100} D_{20-40}	0.73	0.84	1.55	0.00	0.78
L_{80-100} D_{40-60}	0.25	0.96	0.40	0.00	0.40
L_{80-100} D_{60-80}	0.15	0.00	0.00	0.00	0.04
SE m$\pm$	1.81	4.41	3.32	4.00	
CD (0.05)	3.64	8.84	6.64	8.00	

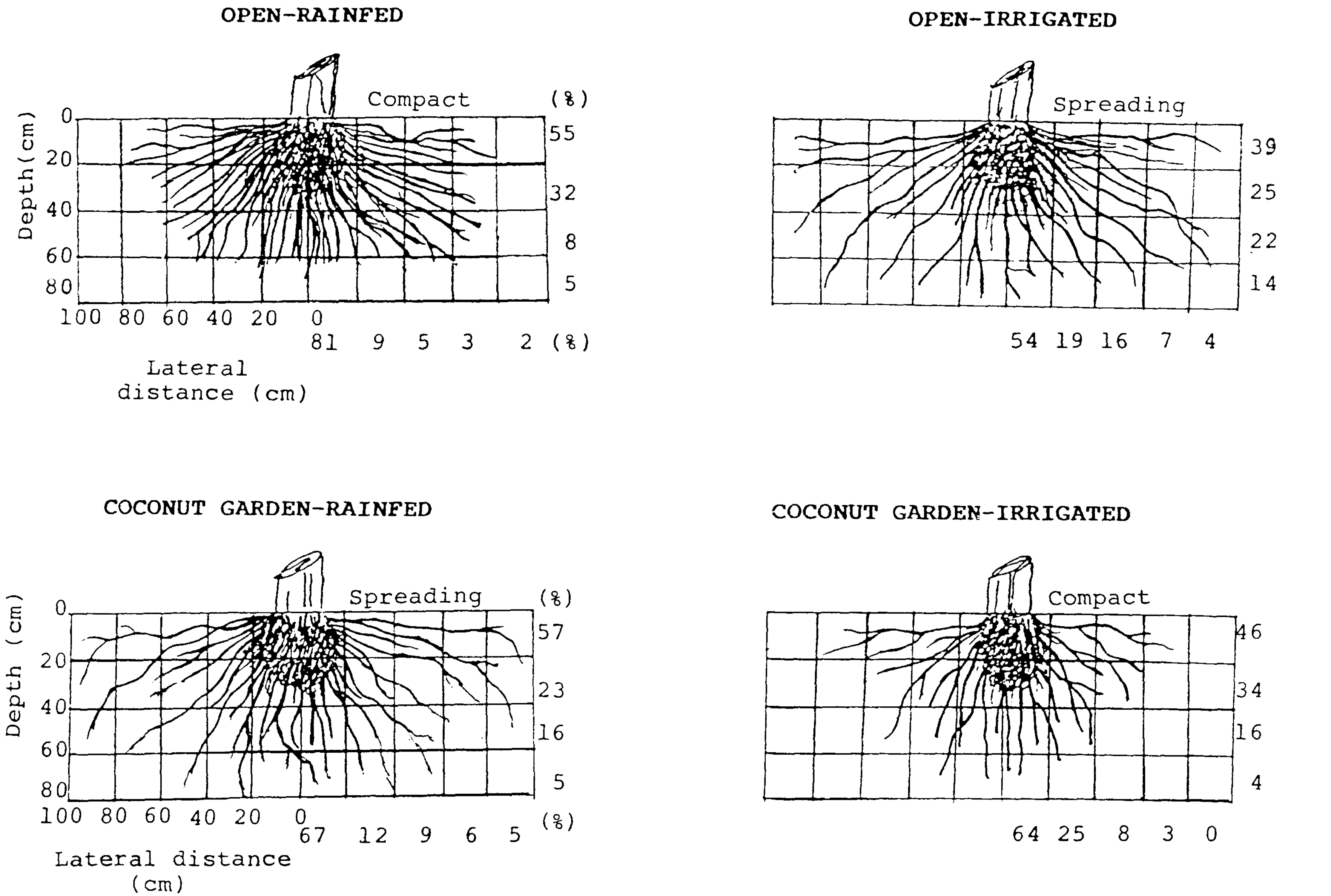


Fig.8 Root distribution patterns (based on % of radioactivity)of banana var. palayankodan (180 DAP) as influenced by growing conditions - ^{32}P plant injection technique

DAP - Days after planting

Table 8. Per cent of roots observed in certain zones of the rhizosphere as influenced by growing conditions (Extracts from Table 7)

Root zone	Growing conditions			
	Open-rainfed	Open-irrigated	Coconut garden rainfed	Coconut garden irrigated
L_{0-20} D_{0-20}	47.5	19.8	40.4	25.4
L_{0-40} D_{0-40}	79.5	46.2	60.6	70.6
L_{0-60} D_{0-60}	90.5	75.9	84.3	93.4
Beyond L_{0-60} D_{0-60}	9.5	24.2	15.6	6.5

cent. This difference between rainfed and irrigated banana noticed in the open condition was observable with the plants grown in the coconut garden also. In the open condition, while rainfed banana had 90.5 per cent of their roots in the soil 60 cm laterally around the plant and 60 cm vertically from the soil surface, irrigated banana had only 75.9 per cent of their roots in this zone. The corresponding values for rainfed and irrigated bananas in the coconut garden were 84.3 and 93.4 per cent.

In the case of rainfed banana grown in the open, about 90 per cent of the roots were seen in the root zone representing L_{0-60} D_{0-60} whereas in the case of irrigated banana grown in the open the same amount of roots could be seen in a root zone representing L_{0-60} D_{0-80} (Table 7).In the open condition the tendency of the roots of irrigated banana was to spread and that of rainfed banana was to be compact in the open condition. In the case of rainfed banana grown in the coconut gardens about 91 per cent of the roots were seen in the root zone representing L_{0-80} D_{0-60} whereas in the case of irrigated banana grown in the coconut garden more or less the same amount of roots could be seen in a root zone representing L_{0-60} D_{0-60} (Table 7). The rainfed banana developed a spreading root system and irrigated banana developed a compact root system in the coconut gardens.

B. Profile excavation technique

1. Influence of light and soil moisture regimes on root production

Root dry matter production(RDMP) varied considerably between rainfed and irrigated bananas with more amount of root production in rainfed banana (Table 9 and Fig.9). This trend was consistently seen with the plants grown in the open condition as well as in the coconut garden at all stages of plant growth. RDMP also differed considerably between plants grown in the open condition and in the coconut garden with more amount of root production by the plants grown in the open (Table 10 and Fig.10) and this trend was consistently seen at all stages of plant growth. The interaction between light and soil moisture regimes on RDMP was significant (Table 11 and Fig.11) with more root production in rainfed bananas grown in open (95 g plant^{-1}) and less root production with irrigated banana grown in the coconut garden (25.37 g plant^{-1}).

2. Variation due to phenological phases

The patterns of root production in relation to phenological phases differed with growing condition (Table 9 and 10). RDMP of rainfed banana grown in the open condition and in the coconut garden and irrigated banana grown in coconut garden increased with phenological phases and the highest root production was noticed at 240 DAP

Table 9. Root dry matter production of banana (g $plant^{-1}$) as influenced by light and soil moisture regimes at different phenological phases

	60 DAP*			120DAP			180DAP			240DAP			
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Overall mean
Rainfed	12.58	9.98	11.28	64.01	22.99	43.50	138.84	35.00	86.92	164.50	50.76	107.63	62.33
Irrigated	12.58	9.98	11.28	53.47	22.35	37.91	155.03	29.88	92.46	73.33	39.25	56.29	49.48
Mean	12.58	9.98	11.28	58.74	22.67	40.71	146.94	32.44	89.69	118.92	45.01	81.96	

	Light/Moisture	Phase	Interaction
SE m±	0.61	0.86	1.73
CD (0.05)	1.20	1.70	3.39

* Irrigation not commenced

Table 10. Root dry matter production of banana (g $plant^{-1}$) as influenced by light regimes at different phenological phases

	60DAP	120DAP	180DAP	240DAP	Mean
Open	12.58	58.74	46.95	118.92	84.30
Coconut garden	9.98	22.68	32.44	45.01	27.53
Mean	11.28	40.71	89.70	81.97	

	Light	Phase	Interaction
SE m±	0.61	0.86	1.22
CD (0.05)	1.20	1.70	2.40

DAP - Days after planting

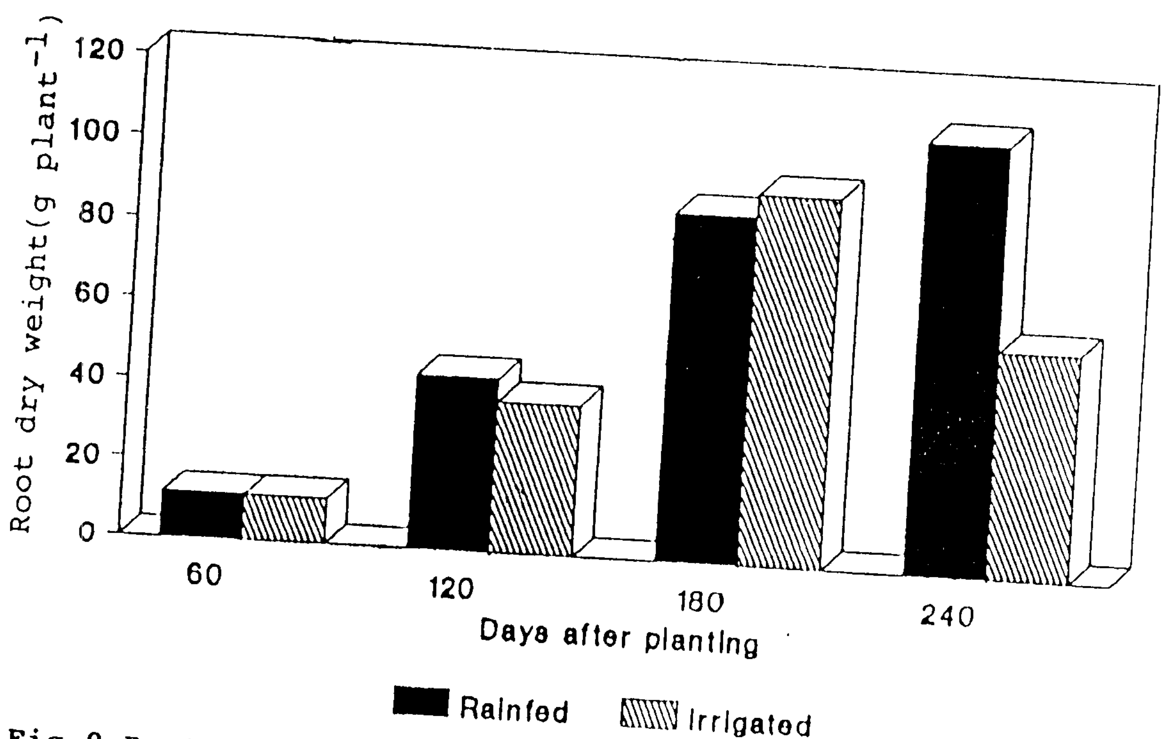


Fig.9 Root dry matter production of banana var. palayankodan as influenced by soil moisture regimes at different phenological phases CD (0.05) = 3.39

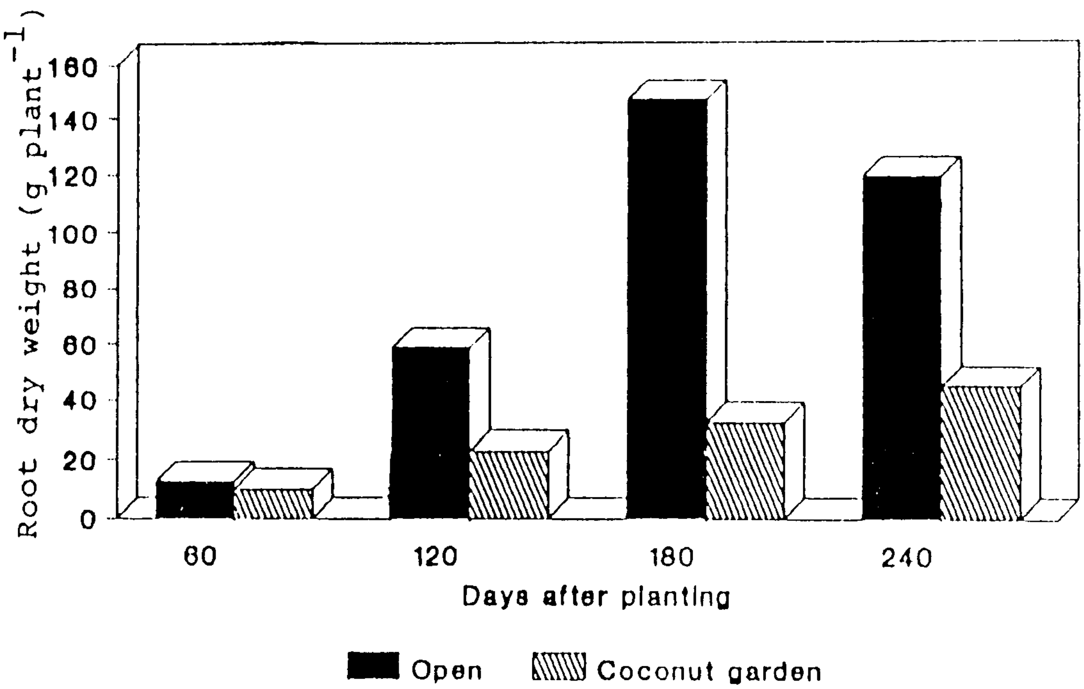


Fig.10 Root dry matter production of banana var.palayankodan as influenced by light environments at different phenological phases CD (0.05) = 2.4

Table 11. Mean root dry matter production (g plant^{-1}) of banana as influenced by light and soil moisture regimes

	Open	Coconut garden	Mean
Rainfed	94.98	29.65	62.33
Irrigated	73.60	25.37	49.48
Mean	84.30	27.53	

	Light regimes	Soil moisture regimes	Interaction
SE m$\pm$	0.86	0.86	1.72
CD (0.05)	1.70	1.70	3.42

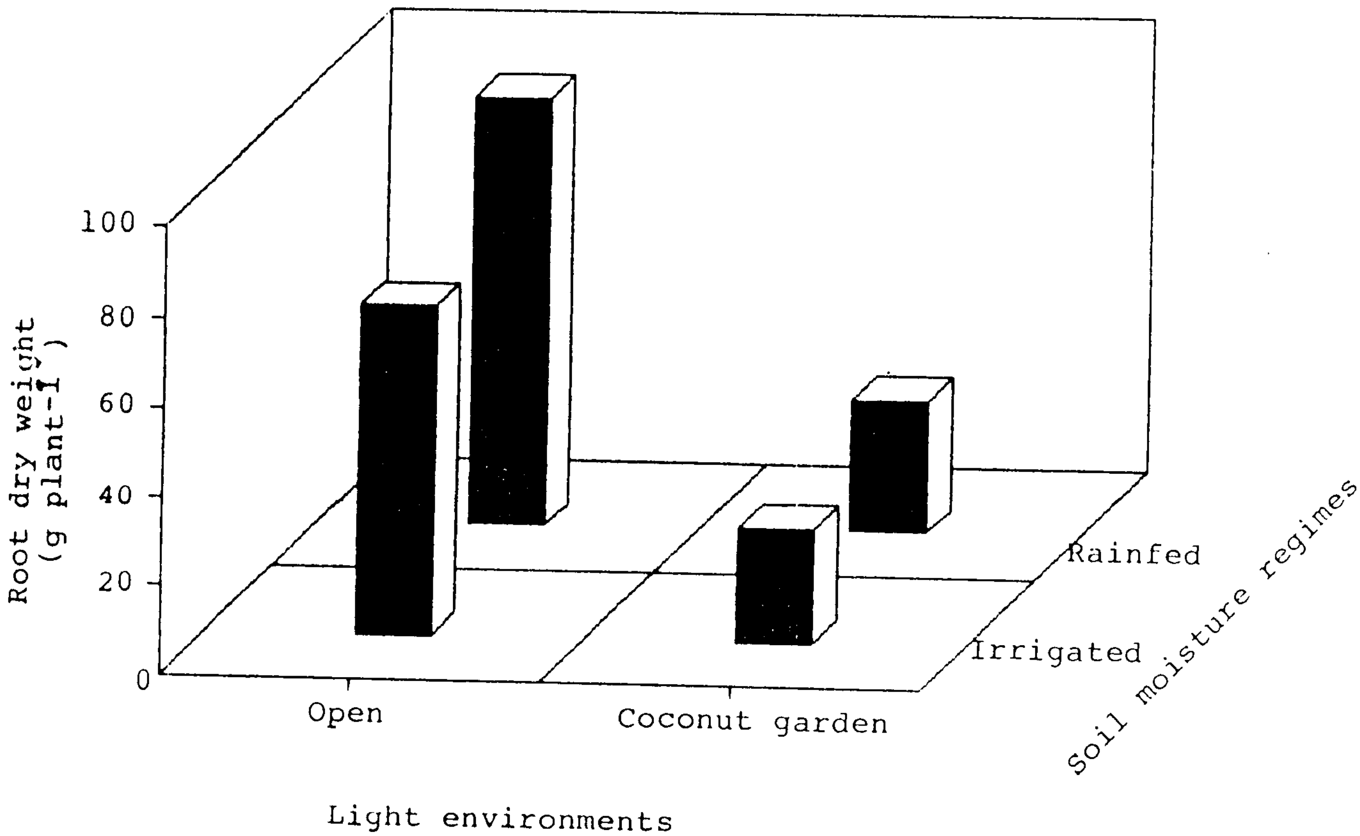


Fig.11 **Root dry matter production of banana var. palayankodan as influenced by light environments and soil moisture regimes** CD (0.05) = 3.39

(Table 9). On the other hand root production of irrigated banana grown in the open increased with phenological phases upto 180 DAP and declined thereafter. In general the root production with the plants grown in the open declined after 180 DAP while that of plants grown in the coconut garden increased progressively with age (Table 10). The mean data on RDMP in relation to phenological phases also showed a declining trend after 180 DAP (Table 10).

3. Lateral distribution of roots

The data on RDMP and its percentage distribution at different lateral distances during different growth stages are given in Table 12 and 13. Root production differed between lateral distances, showing a declining trend with increase in lateral distance. This trend was seen at all stages of plant growth. The RDMP as well as its percentage distribution was the highest in the rhizosphere soil 10 cm laterally around the base. On an average the root zone covering 30 cm laterally around the plant contained 97.11 per cent of the roots.

Root production at different lateral distances also varied with growing conditions. Rainfed plants showed a more laterally spreading root system than irrigated plants and this behaviour was more conspicuous with the plants grown in the open condition compared to those grown in the coconut garden.

Table 12. Root dry matter production (g plant^{-1}) at different lateral distances as influenced by growing conditons in relation to phenological phases

Lateral distance (cm)	60DAP*				Mean	120DAP				Mean	180DAP				Mean	240DAP				Mean	Overall mean
	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		
L 0-10	8.48	8.48	6.54	6.54	7.51	30.20	32.39	15.72	15.91	23.55	58.35	64.92	23.35	22.26	42.21	63.28	49.90	37.53	26.98	44.42	29.42
L 10-20	3.58	3.58	3.40	3.40	3.49	18.05	14.43	3.76	3.67	9.98	51.50	47.61	6.36	5.14	27.65	67.48	17.68	11.71	9.31	26.69	16.95
L 20-30	0.51	0.51	0.02	0.02	0.27	11.74	5.46	2.76	2.73	5.68	22.45	28.10	3.38	1.64	13.89	25.62	4.51	1.05	2.30	8.37	7.05
L 30-40	0.02	0.02	0.01	0.01	0.01	3.98	1.20	0.75	0.03	1.49	6.46	10.24	1.18	0.84	4.67	8.08	1.24	0.46	0.04	2.45	2.16
L 40-50	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.00	0.02	0.04	1.89	0.70	0.00	0.66	0.02	0.01	0.01	0.001	0.01	2.17
L 50-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	2.34	0.05	0.00	0.60	0.02	0.002	0.003	0.00	0.01	0.15
Total	12.54	12.54	9.96	9.96	11.28	63.96	53.52	22.98	22.32	40.7	138.84	155.10	35.04	29.88	89.70	164.52	73.32	50.76	38.28	81.95	57.92

	Lateral distance	Growing condition	Phase	Interaction
SE m±	0.17	0.04	0.14	0.71
CD (0.05)	0.33	0.06	0.28	1.39

Table 13. Root distribution (%) at different lateral distances as influenced by growing conditions in relation to phenological phases

Lateral distance (cm)	60DAP*				Mean	120DAP				Mean	180DAP				Mean	240DAP				Mean	Overall mean
	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-Rainfed	Open-Irrigated	Coconut garden-rainfed	Coconut garden-irrigated		
L 0-10	67.19	67.19	65.50	65.50	66.35	47.18	60.55	68.33	71.19	61.81	41.89	41.84	66.57	74.58	56.22	38.48	68.05	72.28	68.75	61.89	61.57
L 10-20	27.93	27.93	34.10	34.10	31.02	28.18	26.93	16.38	16.43	21.98	37.20	30.69	18.16	17.25	25.83	41.01	24.10	23.07	25.30	28.37	26.80
L 20-30	4.00	4.00	0.25	0.25	2.02	18.35	10.21	12.03	12.22	13.20	16.16	18.12	9.62	5.45	12.34	15.56	6.14	2.07	5.85	7.41	8.74
L 30-40	0.16	0.16	0.10	0.10	0.09	6.23	2.23	3.27	0.20	2.98	4.70	6.59	3.43	2.81	4.38	4.90	1.69	0.09	0.11	1.70	2.29
L 40-50	0.00	0.00	0.00	0.00	0.00	0.07	0.03	0.00	0.00	0.03	0.03	0.14	2.03	0.00	0.55	0.02	0.01	0.03	0.002	0.02	0.15
L 50-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.39	0.18	0.00	0.15	0.02	0.003	0.02	0.00	0.01	0.04

	Lateral distance	Growing condition	Phase	Interaction
SE m±	0.20	0.16	0.16	0.80
CD (0.05)	0.39	0.31	0.31	1.55

4. Vertical distribution of roots

The data on RDMP and its percentage distribution at different depths, during different growth stages are given in Table 14 and 15. RDMP differed between depths showing a declining trend with increase in soil depth. This trend was seen at all stages of plant growth. The RDMP as well as its percentage distribution was the highest in the surface soil(0-10cm). On an average root zone covering 30 cm vertically from the soil surface contained 93.3 per cent of the roots.

Quantity of roots observed at different depths varied with growing conditions. Rainfed plants in general developed a more deeper root system compared to irrigated ones. Between plants grown in the open conditions and in the coconut garden, plants grown in the open had deeper roots compared to plants grown in the coconut garden. The root system of rainfed banana grown in the open was deeper compared to the rainfed and irrigated bananas grown in the coconut garden.

5. Root distribution pattern

The data on RDMP and its percentage distribution in different zones of the rhizosphere as influenced by light and soil moisture regimes at different phenological phases

Table 14. Root dry matter production (g $plant^{-1}$) at different depths as influenced by growing conditions in relation to phenological phases

Depth (cm)	60DAP*				Mean	120DAP				Mean	180DAP				Mean	240DAP				Mean	Overall mean
	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		
D 0-10	7.52	7.52	8.09	8.09	7.81	29.43	24.16	12.14	12.98	19.68	60.85	69.45	14.14	14.73	39.78	60.00	31.99	23.46	19.92	33.84	18.16
D 10-20	2.78	2.78	1.66	1.66	2.22	21.32	17.56	6.10	6.29	12.82	44.22	49.91	8.06	7.81	27.50	45.25	23.53	16.39	13.64	24.70	16.81
D 20-30	1.28	1.28	0.22	0.22	0.75	9.25	8.41	2.58	2.74	5.75	22.98	24.75	4.82	3.66	14.05	26.38	9.66	6.95	5.09	12.02	8.14
D 30-40	0.65	0.65	0.01	0.01	0.33	3.08	3.35	2.17	0.34	2.23	8.06	6.02	3.97	2.54	5.15	17.82	6.72	1.95	0.55	6.76	3.62
D 40-50	0.36	0.36	0.00	0.00	0.18	0.93	0.00	0.00	0.00	0.23	2.10	2.94	2.56	1.14	2.19	12.38	1.43	1.07	0.05	3.73	1.58
D 50-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	1.95	1.47	0.01	1.03	2.69	0.003	0.95	0.00	0.91	0.49
Total	12.54	12.54	9.96	9.96	11.28	63.96	53.52	22.98	22.32	40.74	138.84	155.02	35.04	29.88	89.70	164.52	73.32	50.77	38.28	81.96	48.80

	Depth	Growing condition	Phase	Interaction
SE m±	0.17	0.03	0.14	0.70
CD (0.05)	0.33	0.06	0.28	1.39

Table 15. Root distribution(%) at different depths as influenced by growing conditions in relation to phenological phases

Depth (cm)	60DAP				Mean	120DAP				Mean	180DAP				Mean	240DAP				Mean	Overall mean
	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated		
D 0-10	58.54	58.54	81.00	81.02	69.78	45.96	45.17	52.79	58.08	50.50	43.84	43.71	40.35	49.31	44.30	36.48	43.62	65.89	50.74	49.18	53.44
D 10-20	21.63	21.63	16.66	16.66	19.15	33.30	32.84	26.51	28.14	30.20	31.74	32.20	23.04	26.13	28.28	27.51	32.09	40.45	34.77	33.71	27.34
D 20-30	9.98	9.98	2.15	2.15	6.07	14.45	15.72	11.24	12.26	13.42	16.62	15.94	13.75	12.25	14.64	16.01	13.17	16.97	12.97	14.78	11.97
D 30-40	5.05	5.05	0.14	0.14	2.60	4.81	6.27	9.44	1.51	5.51	5.78	3.88	11.34	8.54	7.39	10.83	9.17	4.84	1.40	6.56	5.52
D 40-50	2.78	2.78	0.00	0.00	1.39	1.46	0.00	0.00	0.00	0.73	1.52	1.91	7.30	3.82	3.64	7.53	1.95	2.65	0.12	3.06	2.21
D 50-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	1.28	4.21	0.04	2.01	1.63	0.003	2.34	0.00	0.99	0.75

	Depth	Growing condition	Phase	Interaction
SE m±	0.20	0.16	0.16	0.80
CD (0.05)	0.39	0.31	0.31	1.55

* Irrigation not commenced

are given in Table 16, 17, 18 and Fig. 12, 13, 14 and 15. Root distribution patterns of banana vary with light environments, soil moisture regimes and their interactions at all stages of plant growth.

In the coconut garden, the irrigated plants developed a compact root system close to the base while the rainfed plants developed a spreading root system. In contrast to this, in the open condition rainfed banana developed a compact root system whereas the irrigated banana developed a spreading root system.

In the case of rainfed banana grown in the coconut garden, at peak growth phase (180 DAP), 93.5 per cent of the roots were seen in the root zone representing L_{0-40} D_{0-50} whereas in the case of irrigated banana grown in this condition, more or less similar amount of roots could be seen in a root zone representing L_{0-30} D_{0-40}. In other words, rainfed banana grown in the coconut garden developed a spreading root system and irrigated banana developed a compact root system in the coconut garden.

In the case of rainfed banana grown in the open, 92.2 per cent of the roots were seen in the root zone representing L_{0-30} D_{0-40} whereas in the case of irrigated banana grown in this condition, about 93.9 per cent of the roots could be seen in a root zone representing L_{0-40} D_{0-40}.

Table. 16. Root dry matter production of banana (g plant^{-1}) at different root zones as influenced by light and soil moisture regimes at different phenological phases

Root zone	60DAP*					120DAP					180DAP					240DAP					
	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated	Mean	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated	Mean	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated	Mean	Open-rainfed	Open-irrigated	Coconut garden-rainfed	Coconut garden-irrigated	Mean	Over all mean
L_{0-10} D_{0-10}	4.82	4.82	5.89	5.89	5.36	12.45	15.39	8.88	9.88	11.65	24.80	23.33	10.12	10.23	17.12	23.91	20.53	16.15	13.11	18.43	13.14
L_{0-10} D_{10-20}	1.77	1.77	0.44	0.44	1.11	10.07	9.33	4.50	4.68	7.15	17.09	19.54	5.41	6.05	12.02	18.31	16.28	12.09	10.44	14.31	8.65
L_{0-10} D_{20-30}	1.24	1.24	0.19	0.19	0.72	4.61	5.41	1.04	1.28	3.09	10.70	14.91	2.57	2.57	7.69	11.51	6.48	5.42	2.88	6.57	4.52
L_{0-10} D_{30-40}	0.63	0.63	0.01	0.01	0.32	2.16	2.26	1.29	0.07	1.45	4.32	4.14	2.36	2.29	3.28	5.44	5.42	1.89	0.52	3.32	1.65
L_{0-10} D_{40-50}	0.02	0.02	0.00	0.00	0.01	0.91	0.00	0.00	0.00	0.23	1.18	1.95	1.86	1.12	1.53	3.63	1.19	1.04	0.04	1.48	0.81
L_{0-10} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	1.05	1.02	0.01	0.59	0.48	0.00	0.95	0.00	0.36	0.24
L_{10-20} D_{0-10}	2.23	2.23	2.18	2.18	2.21	8.75	5.32	1.57	1.81	4.36	19.63	22.67	2.28	2.25	11.71	20.72	8.56	6.34	5.17	10.20	7.12
L_{10-20} D_{10-20}	0.98	0.98	1.21	1.21	1.10	5.85	6.23	0.98	0.86	3.48	18.63	17.04	1.53	1.68	9.72	17.61	5.26	3.84	2.54	7.31	5.40
L_{10-20} D_{20-30}	0.01	0.01	0.02	0.02	0.02	2.58	1.85	0.95	0.82	1.55	9.49	5.29	1.23	0.95	4.24	9.38	2.63	1.47	2.19	3.92	2.43
L_{10-20} D_{30-40}	0.01	0.01	0.00	0.00	0.01	0.84	1.03	0.27	0.19	0.28	2.58	0.92	0.88	0.25	1.16	10.20	1.08	0.04	0.01	2.83	1.15
L_{10-20} D_{40-50}	0.34	0.34	0.00	0.00	0.17	0.03	0.00	0.00	0.00	0.01	0.82	0.85	0.25	0.02	0.49	7.96	0.15	0.02	0.01	2.04	0.68
L_{10-20} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.84	0.19	0.002	0.35	1.61	0.00	0.00	0.00	0.40	0.19
L_{20-30} D_{0-10}	0.46	0.46	0.01	0.01	0.24	6.13	2.81	1.42	1.27	2.91	12.84	13.07	1.27	1.42	7.15	10.60	2.25	0.74	1.63	3.81	3.53
L_{20-30} D_{10-20}	0.02	0.02	0.01	0.01	0.02	4.37	1.46	0.42	0.74	1.75	6.56	10.13	0.74	0.07	4.38	8.19	1.47	0.27	0.64	2.64	2.20
L_{20-30} D_{20-30}	0.02	0.02	0.00	0.00	0.01	1.19	1.13	0.44	0.64	0.85	1.85	4.09	0.57	0.14	1.66	4.57	0.51	0.03	0.01	1.28	0.95
L_{20-30} D_{30-40}	0.01	0.01	0.00	0.00	0.01	0.05	0.06	0.49	0.08	0.17	1.09	0.79	0.44	0.00	0.58	2.16	0.20	0.01	0.01	0.60	0.34
L_{20-30} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.01	0.22	0.00	0.14	0.10	0.08	0.00	0.00	0.05	0.05
L_{20-30} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.13	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.02
L_{30-40} D_{0-10}	0.01	0.01	0.01	0.01	0.01	2.05	0.62	0.27	0.02	0.74	3.50	7.57	6.22	0.83	3.03	4.76	0.65	0.24	0.01	1.42	1.30
L_{30-40} D_{10-20}	0.01	0.01	0.00	0.00	0.01	1.04	0.55	0.20	0.01	0.45	1.93	2.50	0.23	0.01	1.17	1.12	0.53	0.18	0.02	0.46	0.52
L_{30-40} D_{20-30}	0.00	0.00	0.00	0.00	0.00	0.86	0.03	0.16	0.00	0.26	0.93	0.04	0.30	0.00	0.32	0.89	0.04	0.03	0.01	0.24	0.21
L_{30-40} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.13	0.00	0.04	0.06	0.04	0.18	0.00	0.07	0.00	0.01	0.01	0.01	0.01	0.02
L_{30-40} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.15	0.00	0.06	0.70	0.01	0.00	0.00	0.18	0.06
L_{30-40} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.12	0.00	0.49	0.61	0.00	0.00	0.00	0.15	0.05
L_{40-50} D_{0-10}	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.00	0.02	0.01	1.70	0.23	0.00	0.49	0.00	0.00	0.00	0.001	0.00	0.13
L_{40-50} D_{10-20}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.14	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.01
L_{40-50} D_{20-30}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.04	0.14	0.00	0.05	0.02	0.00	0.00	0.00	0.01	0.01
L_{40-50} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.12	0.00	0.04	0.01	0.003	0.00	0.00	0.00	0.01
L_{40-50} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.00	0.03	0.00	0.002	0.01	0.00	0.00	0.01
L_{40-50} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.01	0.00	0.002	0.004	0.00	0.00	0.003
L_{50-60} D_{0-10}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1.13	0.01	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.07
L_{50-60} D_{10-20}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.65	0.01	0.00	0.17	0.01	0.00	0.00	0.00	0.00	0.04
L_{50-60} D_{20-30}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.01	0.00	0.10	0.02	0.00	0.00	0.00	0.01	0.03
L_{50-60} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.01
L_{50-60} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.01	0.00	0.02	0.00	0.002	0.003	0.00	0.00	0.01
L_{50-60} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.003
SE m±	0.07	0.07	0.04	0.04		0.06	0.06	0.06	0.10		0.82	0.62	0.06	0.07		0.38	0.13	0.10	0.10		
CD (0.05)	0.13	0.13	0.09	0.09		0.11	0.12	0.12	0.20		1.62	1.25	0.11	0.13		0.75	0.27	0.18	0.19		

* Irrigation not commenced

Table 17. Root distribution pattern(%) of banana at different zones as influenced by light and soil moisture regimes at different phenological phases

Root zone	60DAP* Open-rainfed	60DAP* Open-irrigated	60DAP* Coconut garden-rainfed	60DAP* Coconut garden-irrigated	60DAP* Mean	120DAP Open-rainfed	120DAP Open-irrigated	120DAP Coconut garden-rainfed	120DAP Coconut garden-irrigated	120DAP Mean	180DAP Open-rainfed	180DAP Open-irrigated	180DAP Coconut garden-rainfed	180DAP Coconut garden-irrigated	180DAP Mean	240DAP Open-rainfed	240DAP Open-irrigated	240DAP Coconut garden-rainfed	240DAP Coconut garden-irrigated	240DAP Mean	Over all mean
L_{0-10} D_{0-10}	37.86	37.86	59.01	59.01	48.44	19.45	28.77	38.62	44.22	32.77	17.87	15.04	28.90	34.25	24.02	14.54	28.00	31.82	33.38	26.94	33.04
L_{0-10} D_{10-20}	13.99	13.99	4.44	4.44	9.22	15.73	17.44	19.56	20.92	18.41	12.13	12.60	15.44	20.25	15.11	11.14	22.20	23.82	26.61	20.94	15.92
L_{0-10} D_{20-30}	9.99	9.99	1.93	1.93	5.96	7.21	10.11	4.54	5.74	6.90	7.74	9.60	7.33	8.60	8.32	6.99	8.84	10.68	7.33	8.44	7.41
L_{0-10} D_{30-40}	4.87	4.87	0.14	0.14	2.51	3.37	4.23	5.61	0.31	3.38	3.11	2.67	6.70	7.70	5.05	3.31	7.39	3.72	1.34	3.94	3.72
L_{0-10} D_{40-50}	0.47	0.47	0.00	0.00	0.24	1.42	0.00	0.00	0.00	0.36	0.85	1.26	5.30	3.75	2.79	2.21	1.62	2.05	0.09	1.49	1.22
L_{0-10} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.67	2.90	0.03	0.95	0.29	0.00	0.19	0.00	0.12	0.27
L_{10-20} D_{0-10}	17.33	17.33	21.8	21.8	19.57	13.67	9.95	6.84	8.08	9.64	14.18	14.62	6.51	7.53	10.71	12.60	11.67	12.49	13.17	12.48	13.10
L_{10-20} D_{10-20}	7.59	7.59	12.09	12.09	9.84	9.13	11.66	4.25	3.84	7.22	13.44	10.99	4.40	5.62	8.61	10.71	7.17	7.57	6.48	7.98	8.41
L_{10-20} D_{20-30}	0.11	0.11	0.22	0.22	0.17	4.03	3.46	4.11	3.67	3.82	6.87	3.40	3.50	3.18	4.24	5.69	3.58	2.90	5.59	4.44	3.17
L_{10-20} D_{30-40}	0.09	0.09	0.00	0.00	0.05	1.31	1.92	1.18	0.84	1.31	1.85	0.59	2.50	0.84	1.45	6.20	1.48	0.08	0.03	1.95	1.19
L_{10-20} D_{40-50}	2.81	2.81	0.00	0.00	1.41	0.04	0.00	0.00	0.00	0.01	0.59	0.55	0.71	0.07	0.48	4.84	0.20	0.04	0.03	1.95	1.19
L_{10-20} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.54	0.54	0.07	0.34	0.97	0.00	0.00	0.00	0.24	0.15
L_{20-30} D_{0-10}	3.58	3.58	0.12	0.12	1.85	9.58	5.26	6.17	5.69	6.68	9.23	8.43	3.62	4.75	6.51	6.45	3.06	1.46	4.15	3.78	4.71
L_{20-30} D_{10-20}	0.16	0.16	0.13	0.13	0.15	6.82	2.73	1.83	3.33	3.68	4.75	6.53	2.11	0.23	3.41	4.98	2.00	0.53	1.64	2.29	2.38
L_{20-30} D_{20-30}	0.18	0.18	0.00	0.00	0.09	1.87	2.11	1.92	2.86	2.19	1.34	2.64	1.63	0.47	1.52	2.76	0.69	0.06	0.04	0.89	1.17
L_{20-30} D_{30-40}	0.08	0.08	0.00	0.00	0.04	0.08	0.12	2.11	0.36	0.67	0.77	0.51	1.26	0.00	0.64	1.31	0.28	0.02	0.02	0.41	0.44
L_{20-30} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.63	0.00	0.17	0.06	0.11	0.00	0.00	0.04	0.05
L_{20-30} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.003	0.37	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.03
L_{30-40} D_{0-10}	0.07	0.07	0.10	0.10	0.08	3.21	1.16	1.17	0.09	1.41	2.54	4.88	0.63	2.78	2.71	2.89	0.89	0.47	0.03	1.07	1.32
L_{30-40} D_{10-20}	0.09	0.09	0.00	0.00	0.05	1.62	1.02	0.88	0.06	0.90	1.42	1.61	0.66	0.03	0.93	0.68	0.72	0.35	0.05	0.45	0.58
L_{30-40} D_{20-30}	0.00	0.00	0.00	0.00	0.00	1.35	0.05	0.68	0.00	0.52	0.67	0.02	0.86	0.00	0.39	0.54	0.05	0.06	0.02	0.17	0.42
L_{30-40} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.54	0.00	0.15	0.05	0.03	0.51	0.00	0.15	0.00	0.02	0.02	0.01	0.01	0.08
L_{30-40} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.43	0.00	0.12	0.42	0.01	0.00	0.00	0.11	0.06
L_{30-40} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.34	0.00	0.09	0.37	0.00	0.00	0.00	0.09	0.05
L_{40-50} D_{0-10}	0.00	0.00	0.00	0.00	0.00	0.07	0.03	0.00	0.00	0.03	0.01	0.01	0.66	0.00	0.17	0.00	0.00	0.00	0.002	0.00	0.05
L_{40-50} D_{10-20}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.40	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.03
L_{40-50} D_{20-30}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.003	0.02	0.40	0.00	0.11	0.01	0.00	0.00	0.00	0.003	0.03
L_{40-50} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.34	0.00	0.09	0.01	0.004	0.00	0.00	0.004	0.02
L_{40-50} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.20	0.00	0.09	0.01	0.004	0.02	0.00	0.016	0.02
L_{40-50} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.01	0.00	0.003	0.01	0.00	0.003	0.003
L_{50-60} D_{0-10}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.73	0.03	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.05
L_{50-60} D_{10-20}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.42	0.03	0.00	0.12	0.01	0.00	0.00	0.00	0.00	0.03
L_{50-60} D_{20-30}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.03	0.00	0.07	0.01	0.00	0.00	0.00	0.00	0.02
L_{50-60} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01
L_{50-60} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.02	0.00	0.003	0.01	0.00	0.00	0.01
L_{50-60} D_{50-60}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01
SE m±	0.52	0.52	0.04	0.04		0.08	0.11	0.18	0.04		0.47	1.61	0.18	0.04		0.24	0.18	4.10	0.18		
CD (0.05)	1.05	1.05	0.08	0.08		0.16	0.21	0.37	0.08		0.92	3.19	0.36	0..7		0.47	0.36	8.20	0.37		

* Irrigation not commenced

Table 18. Per cent of roots observed in certain zones of the rhizosphere as influenced by light and soil moisture regimes (Extracts from Table 17)

Moisture environ-ments	Root zone	120 DAP			180 DAP			240 DAP		
		Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean
Rainfed	$L_{0-20}D_{0-20}$	58.00	69.30	63.65	57.60	55.20	56.40	48.40	75.74	62.32
,,	$L_{0-40}D_{0-40}$	98.53	100.00	99.27	99.72	86.46	92.19	90.82	96.09	93.46
Irrigated	$L_{0-20}D_{0-20}$	67.90	77.00	72.45	3.10	67.60	60.35	69.10	79.70	74.40
,,	$L_{0-40}D_{0-40}$	99.97	100.00	99.99	93.9	96.22	95.09	98.15	99.99	99.03

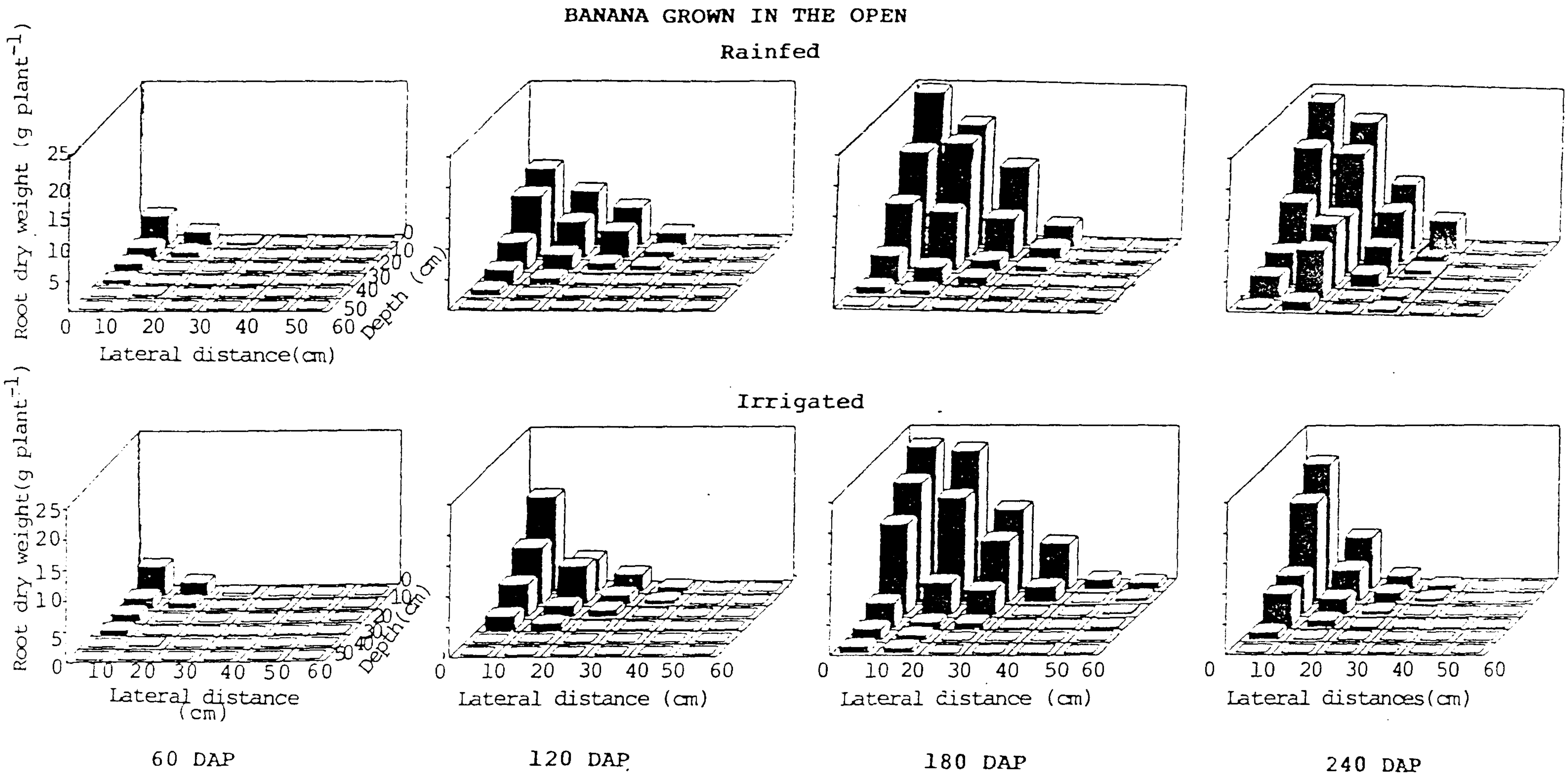


Fig.12 Root weight distribution patterns of banana var.palayankodan grown in the open as influenced by soil moisture regimes at different phenological phases

DAP - Days after planting

BANANA GROWN IN COCONUT GARDEN

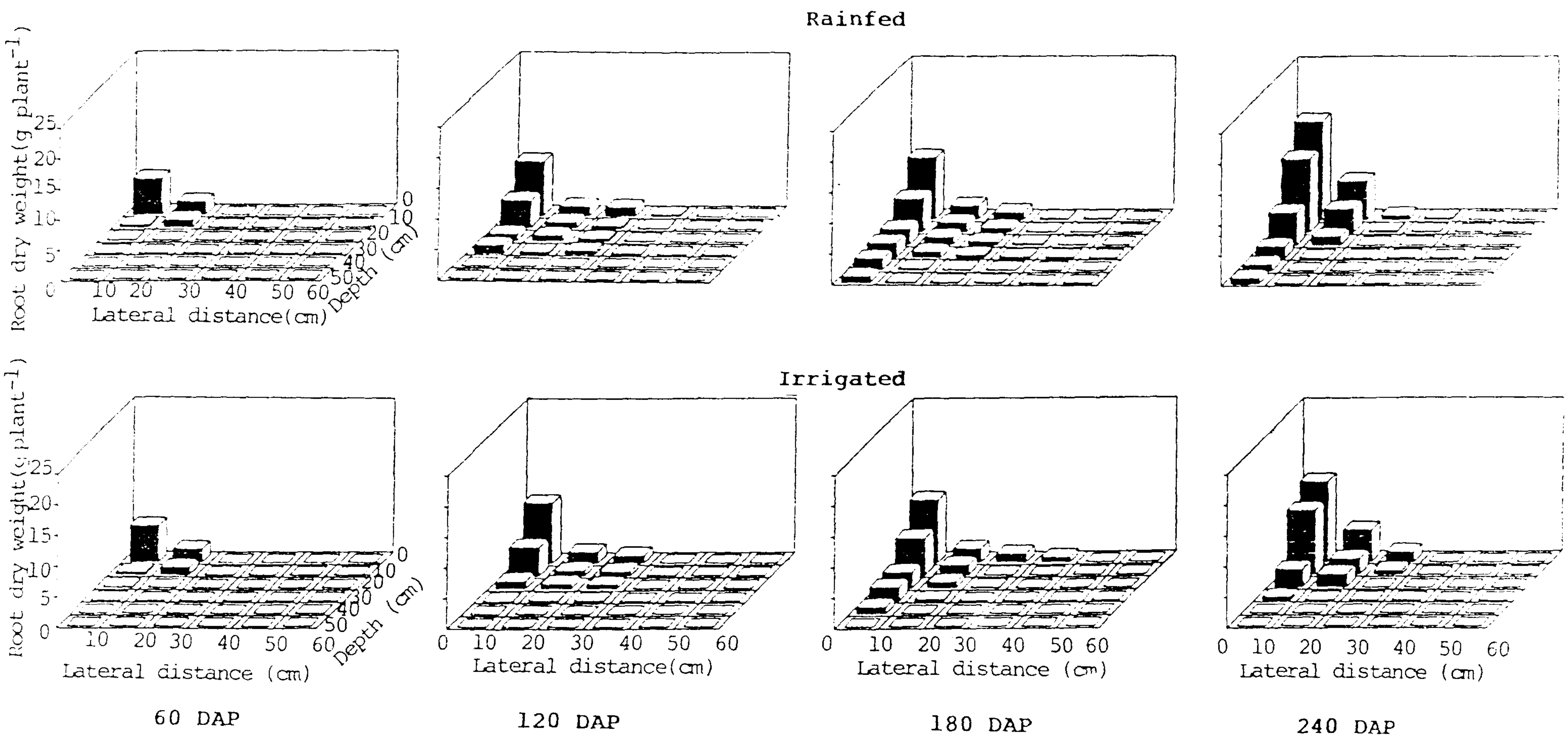


Fig.13 Root weight distribution patterns of banana var. palayankodan grown in coconut garden as influenced by soil moisture regimes at different phenological phases

DAP - Days after planting

BANANA GROWN IN THE OPEN

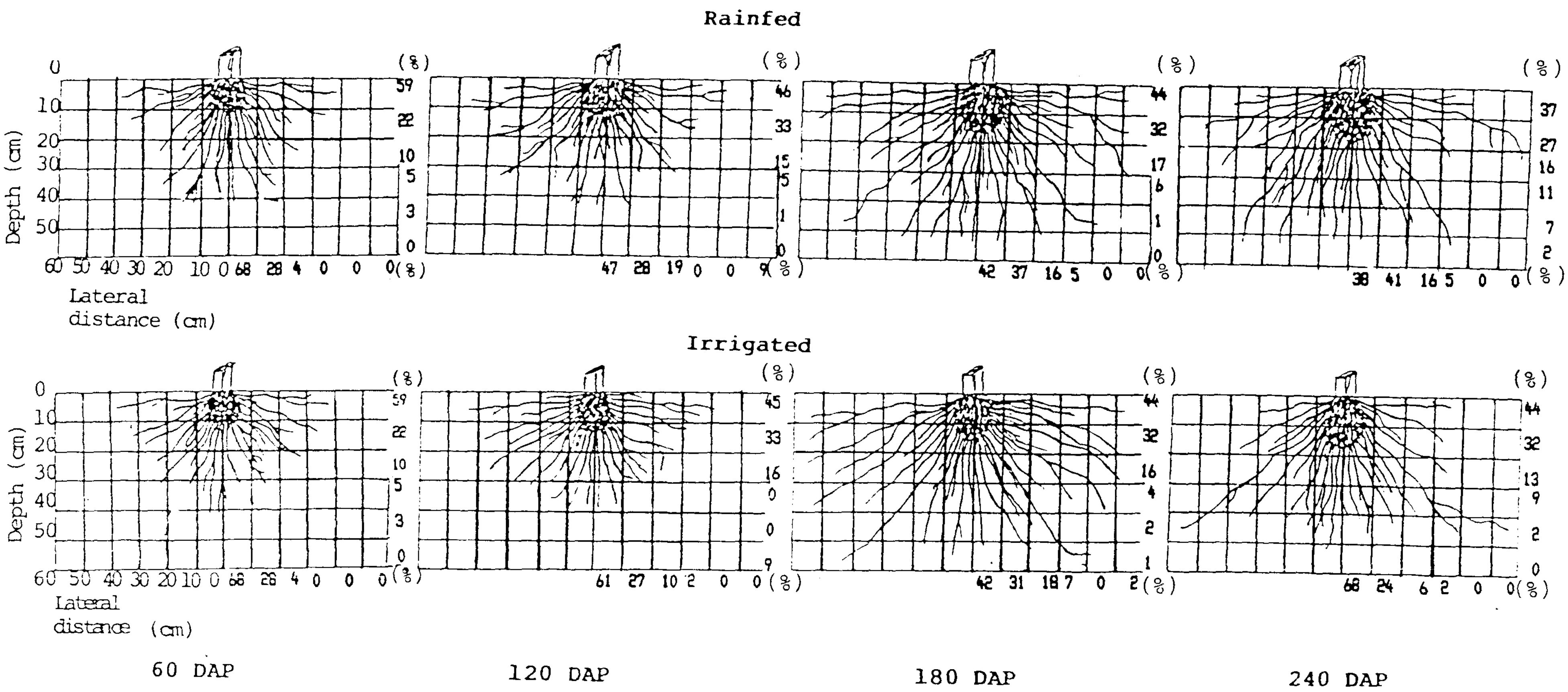


Fig. 14 Root distribution patterns (based on percentage of root dry weight) of banana var. palayankodan grown in the open as influenced by soil moisture regimes at different phenological phases

DAP = Days After Planting

BANANA GROWN IN COCONUT GARDEN

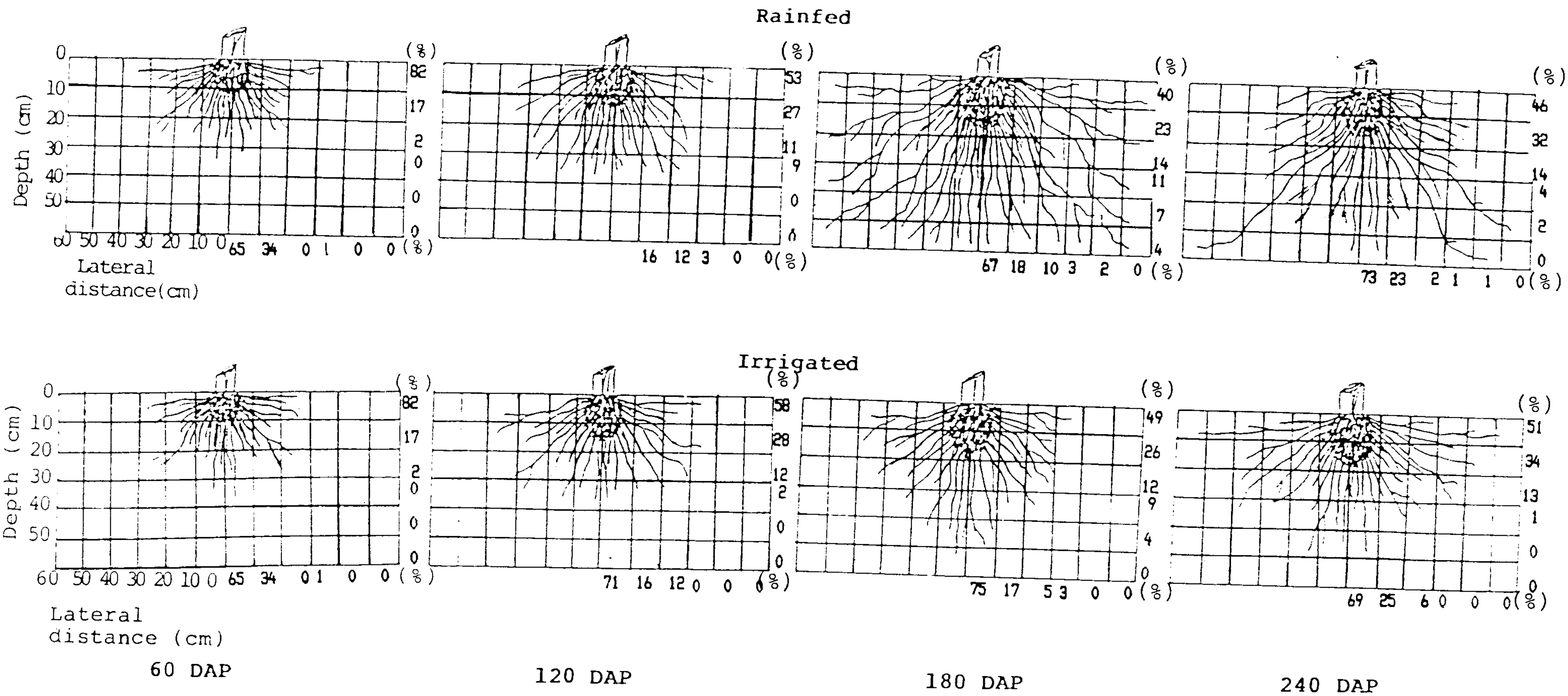


Fig.

Fig. 15 Root distribution patterns (based on percentage of root dry weight) of banana var. palayankodan grown in coconut garden as influenced by soil moisture regimes at different phenological phases

In other words, rainfed banana developed a compact root system and irrigated banana developed a spreading root system when grown in the open.

Number of roots

Root production in banana in terms of the number of roots produced per plant was considerably more with rainfed plants compared to irrigated ones. Plants grown in the open condition produced larger number of roots compared to those grown in the coconut garden (Table 19). This trend was consistently seen at all stages of plant growth. Number of roots produced per plant increased progressively with age and the root number was the highest at 240 DAP. The coefficients of correlation between number of roots per plant and RDMP per plant was significant and positive and the values ranged from 0.88 to 0.96 under different growing conditions.

Length of longest root

Rainfed plants produced longer roots compared to irrigated ones. Plants grown in the open produced longer roots compared to those grown in the coconut garden and this trend was consistently observed at all stages of plant growth (Table 20). The root length increased progressively with age upto 180 DAP and declined thereafter.

Table 19. Number of roots in banana as influenced by light and soil moisture regimes at different phenological phase

	60 DAP*			120 DAP			180 DAP			240 DAP			
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Overall mean
Rainfed	202	173	187.5	449.0	437.0	443.0	905.0	854	879.5	968.0	959.0	963.5	618.38
Irrigated	188	171	179.5	378.0	422.0	400.0	878.0	822	850.0	959.0	900.0	929.5	589.75
Mean	195	172	183.5	413.5	429.5	421.5	891.5	838	864.75	963.5	929.5	946.5	

	Light/soil moisture	Phase	Interaction
SE m±	0.9	1.9	7.7
CD (0.05)	1.8	3.9	15.79

* Irrigation not commenced

Table 20. Length of longest root in banana as influenced by light and soil moisture regimes at different phenological phases

	60 DAP*			120 DAP			180 DAP			240 DAP			
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Overall mean
Rainfed	49.83	41.40	45.62	47.83	41.87	44.84	68.17	61.60	64.88	67.27	54.20	60.74	54.02
Irrigated	49.83	41.40	45.62	40.10	41.83	40.97	63.17	51.27	57.22	57.93	53.30	55.62	49.79
Mean	49.83	41.40	45.62	43.97	41.85	42.91	65.67	56.44	61.06	62.60	53.75	58.18	

	Light/soil moisture	Phase	Interaction
SE m±	1.24	1.77	3.54
CD (0.05)	2.55	3.61	7.22

* Irrigation not commenced

Plant height

Height of banana plants differed with soil moisture regimes. The irrigated plants were taller than rainfed ones and this trend was seen at all stages of plant growth. The plants grown in the coconut garden were considerably taller than those grown in the open condition. Plant height progressively increased with advancement of age upto 240 DAP (Table 21).

Number of leaves

Leaf number was considerably more with irrigated banana compared to rainfed ones. Banana plants grown in the coconut garden produced more number of leaves compared to those grown in the open. There was a progressive increase in the leaf production with age and this trend was noticed upto 240 DAP (Table 22).

Experiment II Root distribution pattern of colocasia

A. ^{32}P plant injection technique

1. Influence of light regimes on root production

The data on root production of colocasia measured in terms of the radioactivity in the rhizosphere soil as influenced by light regimes are given in Table 23. The radioactivity in the rhizosphere soil of colocasia grown in the open condition was considerably more than that grown in the coconut garden (Fig. 16).

Table 21. Height of banana plants as influenced by light and soil moisture regimes at different phenological phases

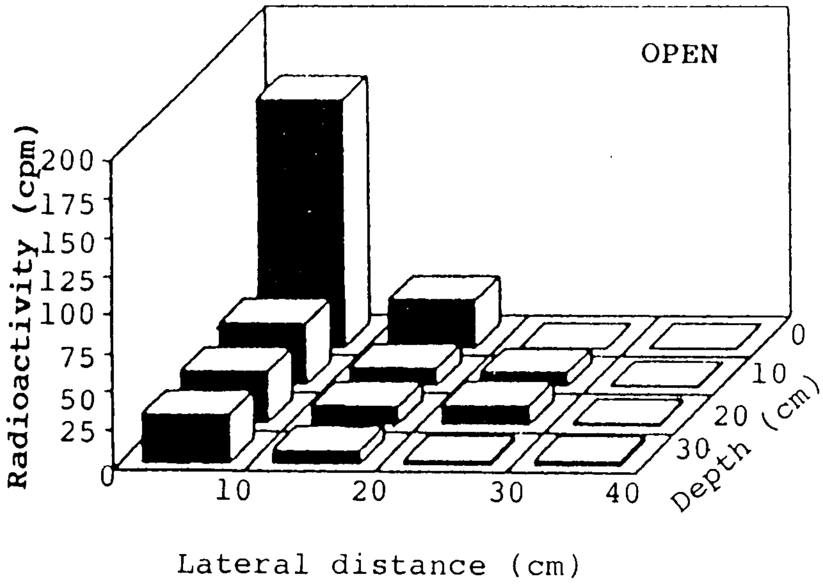
	60 DAP*			120 DAP			180 DAP			240 DAP			
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Overall mean
Rainfed	86.23	93.13	89.68	108.88	120.67	114.78	170.73	134.83	152.78	127.03	150.47	138.75	123.99
Irrigated	86.23	93.13	89.68	105.07	124.40	114.74	131.77	162.37	147.07	148.50	196.13	172.32	130.95
Mean	86.23	93.13	89.68	106.69	122.40	114.69	133.33	157.13	145.22	149.49	185.43	166.46	

	Light/soil moisture	Phase	Interaction
SE m±	0.59	0.85	1.71
CD (0.05)	1.23	1.74	3.49

* Irrigation not commenced

Table. 23. Radioactivity in the rhizosphere soil (cpm $\sqrt{x+1}$) of colocasia as influenced by light regimes

Light Environment	Radioactivity
Open	3.99
Coconut garden	2.67
Mean	3.33
SE m$\pm$	0.45
CD (0.05)	0.75



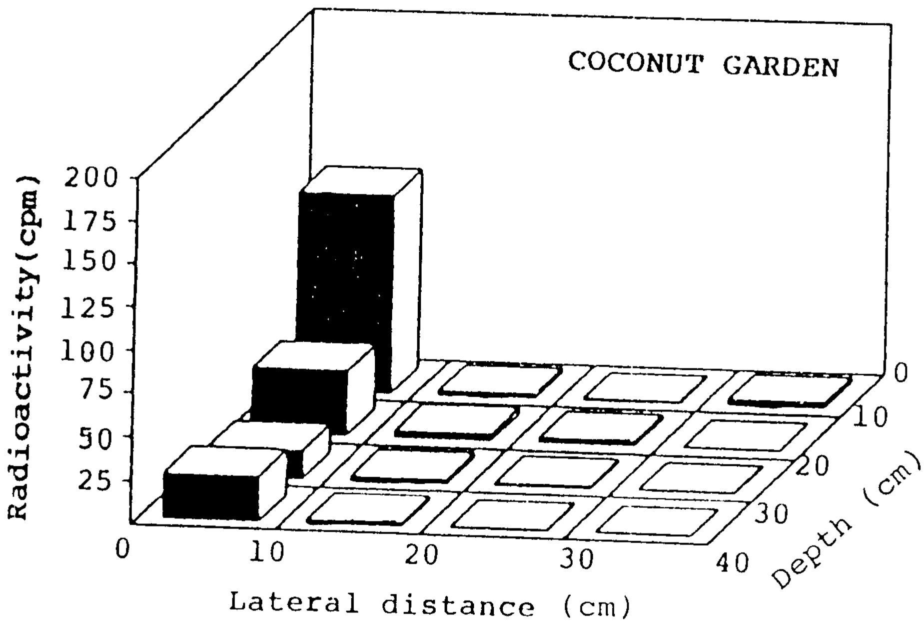


Fig.16 Radioactivity distribution patterns of colocasia Var.cheruchempu (120 DAP) grown in the open and in coconut garden

DAP - Days after planting

2. Lateral distribution of roots

The data on the radioactivity in the rhizosphere soil of colocasia and its percentage distribution at different lateral distances as influenced by light regimes are given in Table 24 and 25. The radioactivity in the rhizosphere soil as well as its percentage distribution differed with lateral distances. Radioactivity was the highest in the rhizosphere soil at a lateral distance of 10 cm around the plant and it declined gradually with increase in lateral distance. This trend was noticed with the plants grown in the open condition as well as in the coconut garden. This zone (L_{0-10}) contained 83.9 per cent of the total radioactivity (Table 25) observed in the entire root zone. Beyond 20 cm laterally from the plant base, only 5.7 per cent of the radioactivity was observed. Root concentration was more in the root zone 10 cm laterally around the plant with colocasia grown in the coconut garden, compared to those grown in the open.

3. Vertical distribution of roots

The data on the radioactivity in the rhizosphere soil of colocasia and its percentage distribution at different depths as influenced by light regimes are given in Table 26 and 27. The radioactivity was the highest in the top 10 cm soil layer accounting for 58 per cent of the total

Table 26. Radioactivity in the rhizosphere soil (cpm $\sqrt{x+1}$) of colocasia at different depths as influenced by light regimes

Depth (cm)	Light regimes: Open	Light regimes: Coconut garden	Mean
D_{0-10}	20.03	15.52	17.78
D_{10-20}	13.19	10.88	12.04
D_{20-30}	12.51	7.95	10.23
D_{30-40}	11.46	8.34	9.90
Mean	14.30	10.67	

	Depth	Light regimes	Interaction
SE m±	3.61	1.81	4.79
CD (0.05)	5.97	3.00	9.52

Table 27. Percentage distribution of radioactivity in the rhizosphere soil at different depths as influenced by light regimes

Depth (cm)	Light regimes: Open	Light regimes: Coconut garden	Mean
D_{0-10}	57.12	58.87	58.00
D_{10-20}	16.36	20.41	18.39
D_{20-30}	14.28	8.78	11.53
D_{30-40}	12.24	11.94	12.09

	Depth	Light regimes	Interaction
SE m±	0.35	0.21	5.16
CD (0.05)	0.68	0.35	8.54

Table. 24. Radioactivity in the rhizosphere soil (cpm $\sqrt{x+1}$) of colocasia at different lateral distances as influenced by light regimes

Lateral distance (cm)	Light regimes		Mean
	Open	Coconut garden	
L_{0-10}	36.71	24.97	30.84
L_{10-20}	13.64	7.08	10.36
L_{20-30}	7.93	5.64	6.79
L_{30-40}	5.58	5.00	5.29
Mean	14.30	10.67	

	Lateral distance	Light regimes	Interaction
SE m$\pm$	3.61	1.81	4.79
CD (0.05)	5.97	3.00	9.52

Table 25. Percentage distribution of radioactivity in rhizosphere soil at different lateral distances as influenced by light regimes

Lateral distance (cm)	Light regimes		Mean
	Open	Coconut garden	
L_{0-10}	77.07	90.63	83.85
L_{10-20}	16.26	4.74	10.50
L_{20-30}	5.38	2.53	3.96
L_{30-40}	1.29	2.09	1.69

	Lateral distance	Light regimes	Interaction
SE m$\pm$	0.41	0.21	7.99
CD (0.05)	0.68	0.35	13.32

radioactivity (Table 27) and it declined with depth. The surface soil to a depth of 20 cm contained 76.4 per cent of the total radioactivity and only 12.1 per cent of the radioactivity was noticed beyond 30 cm depth.

4. Root distribution pattern

The data on radioactivity and its percentage distribution at different zones of rhizosphere soil of colocasia as influenced by light regimes are given in Table 28 and 29. The radioactivity (Fig. 16) as well as its percentage distribution (Fig. 17) differed between the different zones, with more radioactivity in the root zones close to the plant and a declining trend with distance, both laterally and vertically from the plant base. This trend was observed with the plants grown in the open as well as in the coconut garden.

The root distribution pattern of colocasia varied with the light regimes under which it is grown. Colocasia grown in the coconut garden developed a deep compact root system whereas the plants grown in the open developed a deep spreading root system (Fig. 17). In the case of colocasia grown in the coconut garden, about 90.6 per cent of the roots were observed in the root zone 10 cm laterally from the plant base and 40 cm vertically from the soil surface (L_{0-10} D_{0-40}). Colocasia plants grown in the open had 92.3 per cent of the roots in the root zone comprising 20 cm

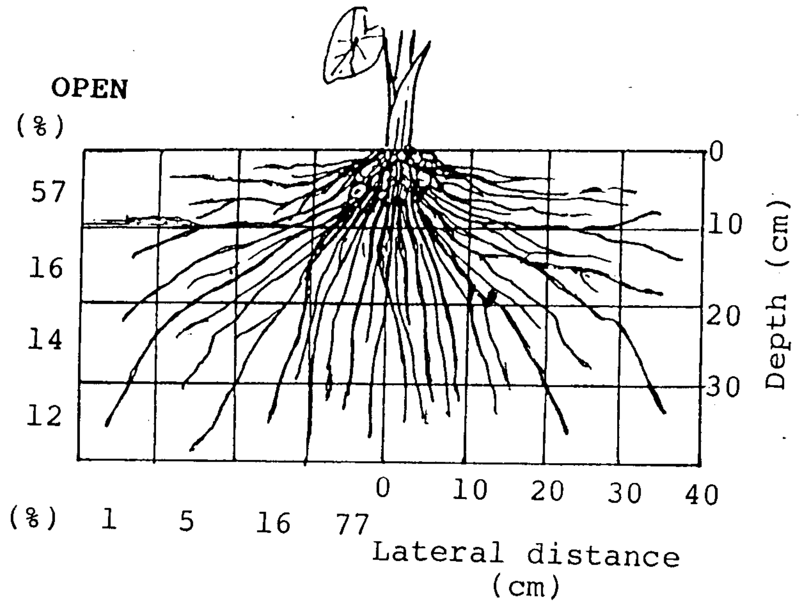
Table 28. Radioactivity (cpm $\sqrt{x+1}$) at the different zones of the rhizosphere soil of colocasia as influenced by light regimes

Root zone	Light regimes		Mean
	Open	Coconut garden	
L_{0-10} D_{0-10}	12.71 (161.15)	10.73 (114.38)	11.72
L_{0-10} D_{10-20}	6.33 (39.90)	6.15 (37.2)	6.24
L_{0-10} D_{20-30}	5.61 (33.84)	3.55 (15.62)	4.58
L_{0-10} D_{30-40}	5.40 (30.27)	4.55 (25.60)	4.98
L_{10-20} D_{0-10}	5.13 (30.10)	1.86 (2.61)	3.50
L_{10-20} D_{10-20}	3.24 (11.42)	1.86 (3.60)	2.55
L_{10-20} D_{20-30}	2.60 (11.12)	1.78 (2.53)	2.19
L_{10-20} D_{30-40}	2.67 (7.92)	1.59 (1.90)	2.13
L_{20-30} D_{0-10}	1.00 (0.00)	1.32 (1.03)	1.16
L_{20-30} D_{10-20}	2.29 (8.93)	1.74 (2.48)	2.02
L_{20-30} D_{20-30}	2.95 (12.22)	1.38 (1.22)	2.17
L_{20-30} D_{30-40}	1.69 (2.17)	1.21 (0.60)	1.45
L_{30-40} D_{0-10}	1.20 (0.52)	1.62 (2.67)	1.41
L_{30-40} D_{10-20}	1.34 (1.03)	1.14 (0.33)	1.24
L_{30-40} D_{20-30}	1.35 (1.21)	1.25 (0.68)	1.30
L_{30-40} D_{30-40}	1.70 (2.68)	1.00 (0.00)	1.35
SE m$\pm$	2.40	0.67	
CD (0.05)	4.78	1.20	

Values in paranthesis indicate mean of the actual counts

Table 29. Percentage distribution of radioactivity at different zones of the rhizosphere soil of colocasia as influenced by light regimes

Root zone	Light regimes: Open	Light regimes: Coconut garden	Mean
L_{0-10} D_{0-10}	48.40	55.51	51.96
L_{0-10} D_{10-20}	11.31	17.68	14.50
L_{0-10} D_{20-30}	8.88	6.61	7.51
L_{0-10} D_{30-40}	8.48	10.82	9.65
L_{10-20} D_{0-10}	8.60	1.21	4.91
L_{10-20} D_{10-20}	3.00	1.46	2.23
L_{10-20} D_{20-30}	2.21	1.21	1.71
L_{10-20} D_{30-40}	2.45	0.86	1.66
L_{20-30} D_{0-10}	0.00	0.60	0.30
L_{20-30} D_{10-20}	1.83	1.11	1.47
L_{20-30} D_{20-30}	2.80	0.57	1.69
L_{20-30} D_{30-40}	0.75	0.26	0.51
L_{30-40} D_{0-10}	0.12	1.54	0.83
L_{30-40} D_{10-20}	0.23	0.16	0.20
L_{30-40} D_{20-30}	0.38	0.39	0.39
L_{30-40} D_{30-40}	0.56	0.00	0.28
SE m$\pm$	2.66	2.57	
CD (0.05)	5.31	5.14	



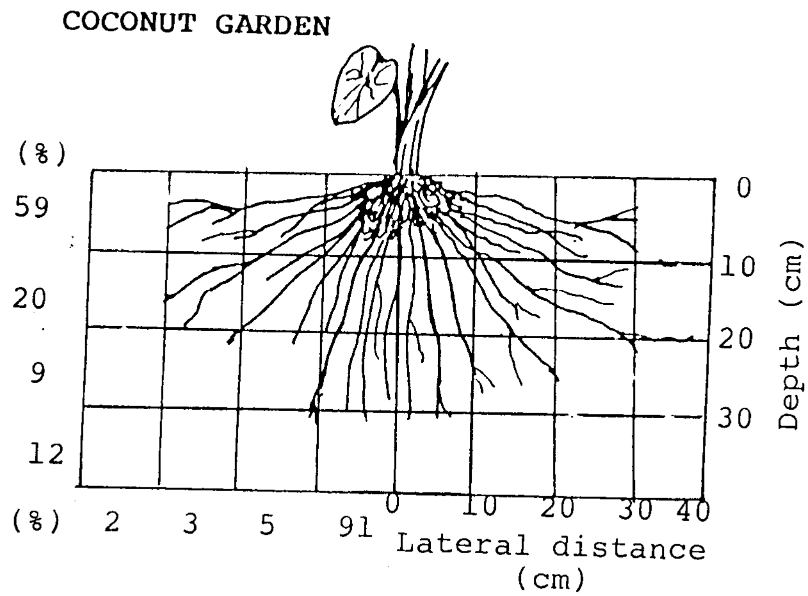


Fig.17 Root distribution patterns (based on % of radioactivity) of colocasia var. cheruchempu (120 DAP) grown in the open and in coconut garden - ^{32}P plant injection technique

DAP - Days after planting

laterally around the plant and 40 cm vertically from the soil surface (L_{0-20} D_{0-40}).

B. Profile excavation technique

1. Influence of light regimes on root production

Root dry matter production (RDMP) of colocasia was influenced by the light regimes under which it is grown. The colocasia plants grown in the open condition produced considerably more amount of roots compared to those grown in the coconut garden and this trend was consistently seen at all stages of plant growth (Table 30, Fig. 18). An adult colocasia plant (120 DAP) when grown in the open produced the highest amount of roots (10.08 g plant^{-1}).

2. Variation due to phenological phases.

Root production of colocasia increased with phenological phases upto 120 DAP and declined thereafter (Table 30). On an average, a colocasia plant at 60 DAP produced 5.11 g of roots per plant. At 90 DAP, the root weight increased to 6.57 g plant^{-1} and it further increased to 7.24 g plant^{-1} at 120 DAP. At 150 DAP, the root weight declined to 3.96 g plant^{-1}.

3. Lateral distribution of roots

The data on the RDMP and its percentage distribution at different lateral distances as influenced by light regimes

Table 30. Root dry matter production of colocasia (g $plant^{-1}$) as influenced by light regimes at different phenological phases

Phase/ Light regimes	60DAP	90DAP	120DAP	150DAP	Mean
Open	7.64	8.98	10.08	4.85	7.89
Coconut garden	2.58	4.16	4.40	3.07	3.55
Mean	5.11	6.57	7.24	3.96	

	Light regimes	Phase	Interaction
SE m±	0.18	0.25	0.37
CD (0.05)	0.36	0.51	0.72

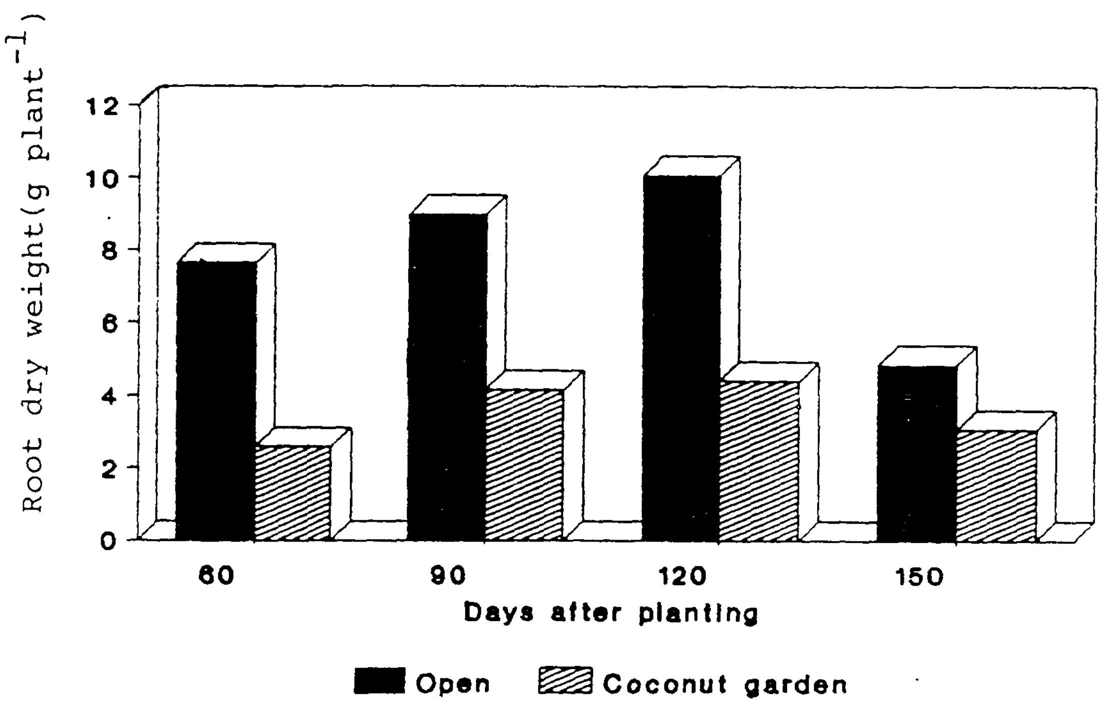


Fig.18 Root dry matter production of colocasia var.cheruchempu as influenced by light environments at different phenological phases CD (0.05) = 0.72

are given in Table 31 and 32. The RDMP as well as its percentage distribution differed with lateral distances. They were found to be the highest in the rhizosphere soil 10 cm laterally around the base and declined with increase in lateral distance. This trend was seen at all stages of plant growth. On an average the root zone covering 20 cm laterally around the plant contained 95.9 per cent of the roots.

The lateral distribution of roots was more with the plants grown in the open compared to those grown in the coconut garden (Table 32). While an adult colocasia plant grown in the open had about 10 g of roots per plant 20 cm laterally around the plant, only 4.3 g of roots per plant were found in this zone in the case of plants grown in the coconut garden. But this difference was not reflected in terms of lateral distribution of roots on a percentage basis.

4. Vertical distribution of roots.

The data on RDMP and its percentage distribution at different depths as in influenced by light environments are given in Table 33 and 34. RDMP and its percentage distribution differed between different depths and this trend was noticed at all stages of plant growth. The RDMP as well as its percentage distribution was the highest in the surface soil (0-10 cm) and it declined with increase in

Table 31. Root dry matter production (g $plant^{-1}$) of colocasia at different lateral distances as influenced by light regimes in relation to phenological phases

Lateral distance (cm)	60DAP			90DAP			120DAP			150DAP			
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Overall Mean
L_{0-10}	6.32	2.06	4.19	7.41	3.01	5.21	8.06	2.87	5.47	3.59	2.35	2.97	4.46
L_{10-20}	1.28	0.38	0.83	0.76	1.10	0.93	1.84	1.46	1.65	0.81	0.58	0.70	1.03
L_{20-30}	0.03	0.14	0.09	0.53	0.04	0.29	0.16	0.06	0.11	0.45	0.14	0.30	0.20
L_{30-40}	0.00	0.00	0.00	0.22	0.00	0.11	0.01	0.01	0.01	0.00	0.00	0.00	0.03
L_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	7.63	2.60	5.11	8.90	4.15	6.55	10.05	4.40	7.25	4.95	3.05	3.97	5.72

	Lateral distance	Light regimes	Phase	Interaction
SE m$\pm$	0.06	0.04	0.05	0.17
CD (0.05)	0.11	0.07	0.10	0.33

Table 32. Root distribution(%) at different lateral distances as influenced by light regimes in relation to phenological phases

Lateral distance (cm)	60DAP			90DAP			120DAP			150DAP			Overall Mean
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	
L 0-10	82.64	79.83	81.24	83.19	72.37	77.79	80.33	64.46	72.40	74.04	76.38	75.21	76.66
L 10-20	16.19	14.85	15.88	8.42	26.57	17.50	17.95	33.73	25.84	16.75	18.96	17.86	19.27
L 20-30	0.45	5.33	2.89	5.95	1.06	3.51	1.62	1.52	1.57	9.21	4.67	6.94	3.73
L 30-40	0.00	0.00	0.00	2.44	0.00	1.22	0.11	0.29	0.20	0.00	0.00	0.00	0.36
L 40-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Lateral distance	Light regimes	Phase	Interaction
SE m±	0.83	0.52	0.75	2.36
CD (0.05)	1.64	1.03	1.47	4.64

Table 33. Root dry matter production (g $plant^{-1}$) at different depths as influenced by light regimes in relation to phenological phases

Depth (cm)	60DAP			90DAP			120DAP			150DAP			Overall Mean
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	
D_{0-10}	5.22	1.77	3.50	5.91	2.86	4.39	7.91	3.35	5.63	2.26	1.51	1.89	3.85
D_{10-20}	1.13	0.31	0.72	1.42	1.02	1.22	1.58	0.79	1.19	1.54	1.26	1.40	1.13
D_{20-30}	1.01	0.32	0.67	0.93	0.19	0.56	0.46	0.16	0.31	1.05	0.31	0.68	0.56
D_{30-40}	0.28	0.18	0.23	0.72	0.10	0.41	0.12	0.10	0.11	0.00	0.00	0.00	0.19
D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	7.04	2.60	5.11	8.90	4.15	6.55	10.05	4.40	7.25	4.95	3.05	3.97	5.73

	Lateral distance	Light regimes	Phase	Interaction
SE m±	0.06	0.04	0.05	0.17
CD (0.05)	0.11	0.07	0.10	0.33

Table 34. Root distribution(%) at different depths as influenced by light regimes in relation to phenological phases

Depth (cm)	60DAP			90DAP			120DAP			150DAP			
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Overall Mean
D_{0-10}	68.25	68.65	68.45	65.84	68.63	67.24	78.48	76.81	77.65	46.78	49.05	47.92	65.32
D_{10-20}	14.80	11.96	13.38	15.86	24.36	20.11	15.73	17.37	16.55	31.68	40.97	36.33	21.59
D_{20-30}	13.33	12.39	12.86	10.34	4.57	7.46	4.58	3.68	4.13	21.54	9.99	15.77	10.06
D_{30-40}	3.63	7.00	5.32	7.96	2.44	5.20	1.20	2.13	1.67	0.00	0.00	0.00	3.03
D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Depth	Light regimes	Phase	Interaction
SE m±	0.83	0.52	0.75	2.36
CD (.0.05)	1.64	1.03	1.47	4.64

depth. On an average the root zone covering 30 cm vertically from the surface contained 97 per cent of the roots (Table 34).

The deeper penetration of roots was more with the plants grown in the open compared to those grown in the coconut garden (Table 34). While adult colocasia plants grown in the open had about 10 g of roots per plant 30 cm vertically from the soil surface, only 4.3 g of roots per plant were found in this zone in the case of plants grown in the coconut garden. But this difference was not reflected in the depthwise distribution of roots on a percentage basis.

5. Root distribution pattern

The data on RDMP and its percentage distribution at different zones of the rhizosphere of colocasia as influenced by light regimes at different phenological phases are given in Table 35, 36 and 37. The RDMP differed quantitatively due to change in light regimes (Fig. 18), but its percentage distribution in the soil profile (Fig. 20) remained more or less unaffected. At peak growth phase (120 DAP), about 93 per cent of colocasia roots were seen 20 cm laterally around the plant and 20 cm vertically from the soil surface (L_{0-20} D_{0-20}). The root distribution pattern of colocasia varied with phenological phases with less spread at the early phase (60 DAP) and a greater spread at mid

Table 35. Root dry matter production of colocasia (g plant^{-1}) at different root zones as influenced by light regimes at different phenological phases

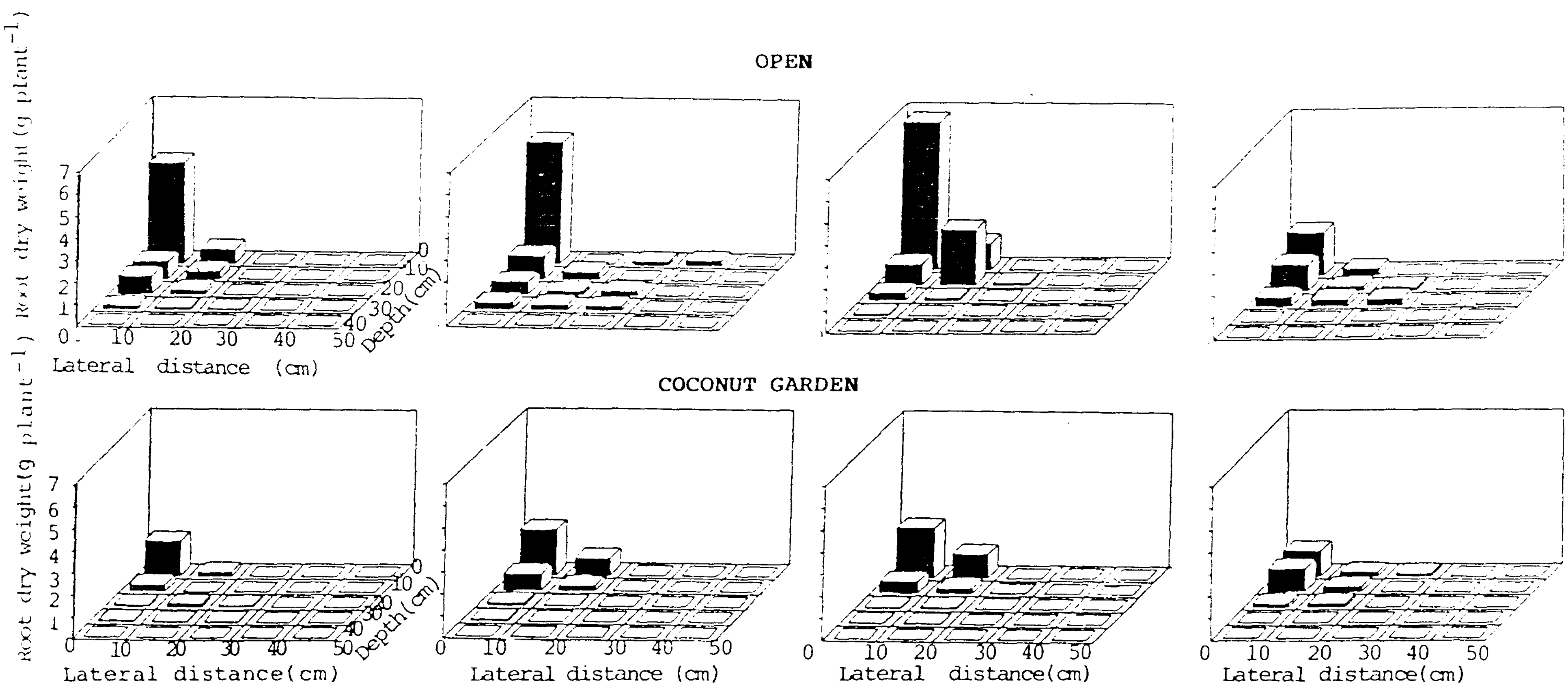
Root zones	60DAP			90DAP			120DAP			150DAP			Grand mean
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	
L_{0-10} D_{0-10}	4.57	1.58	3.08	5.53	2.06	3.80	6.70	2.25	4.48	1.97	1.16	1.57	3.23
L_{0-10} D_{10-20}	0.78	0.31	0.55	1.06	0.75	0.91	0.94	0.51	0.73	1.21	1.03	1.12	0.83
L_{0-10} D_{20-30}	0.82	0.09	0.46	0.57	0.13	0.35	0.33	0.06	0.20	0.42	0.16	0.29	0.33
L_{0-10} D_{30-40}	0.15	0.08	0.12	0.30	0.08	0.19	0.09	0.05	0.07	0.00	0.00	0.00	0.10
L_{0-10} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{10-20} D_{0-10}	0.65	0.19	0.42	0.01	0.78	0.40	1.20	1.09	1.15	0.29	0.20	0.25	0.56
L_{10-20} D_{10-20}	0.35	0.00	0.18	0.36	0.25	0.31	2.52	0.25	1.39	0.19	0.23	0.21	0.52
L_{10-20} D_{20-30}	0.19	0.14	0.17	0.15	0.05	0.10	0.11	0.08	0.10	0.32	0.15	0.24	0.15
L_{10-20} D_{30-40}	0.09	0.05	0.07	0.24	0.02	0.13	0.01	0.04	0.03	0.00	0.00	0.00	0.06
L_{10-20} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{20-30} D_{0-10}	0.00	0.00	0.00	0.15	0.02	0.09	0.00	0.00	0.00	0.00	0.14	0.07	0.08
L_{20-30} D_{10-20}	0.00	0.00	0.00	0.00	0.01	0.01	0.12	0.03	0.08	0.14	0.00	0.07	0.08
L_{20-30} D_{20-30}	0.00	0.09	0.05	0.21	0.01	0.11	0.02	0.02	0.02	0.30	0.00	0.15	0.17
L_{20-30} D_{30-40}	0.03	0.05	0.04	0.18	0.00	0.09	0.02	0.01	0.02	0.00	0.00	0.00	0.08
L_{20-30} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{30-40} D_{0-10}	0.00	0.00	0.00	0.22	0.00	0.11	0.01	0.01	0.01	0.00	0.00	0.00	0.06
L_{30-40} D_{10-20}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{30-40} D_{20-30}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{30-40} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{30-40} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{0-10}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{10-20}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{20-30}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SE m ±	0.08	0.01		0.01	0.01		0.16	0.09		0.05	0.01		
CD (0.05)	0.17	0.03		0.04	0.03		0.30	0.21		0.09	0.03		

Table 36. Root distribution pattern(%) of colocasia at different root zones as influenced by light regimes at different phenological phases

Root zones	60DAP Open	60DAP Coconut garden	60DAP Mean	90DAP Open	90DAP Coconut garden	90DAP Mean	120DAP Open	120DAP Coconut garden	120DAP Mean	150DAP Open	150DAP Coconut garden	150DAP Mean	Grand mean
L_{0-10} D_{0-10}	59.74	61.28	60.51	61.63	49.45	55.54	66.8	51.29	59.05	40.74	37.87	39.31	53.60
L_{0-10} D_{10-20}	10.18	11.96	11.07	11.82	18.04	14.93	9.36	10.78	10.07	24.71	33.41	29.06	16.28
L_{0-10} D_{20-30}	10.77	3.50	7.14	6.39	3.01	4.70	3.29	1.37	2.33	8.59	5.10	6.85	5.26
L_{0-10} D_{30-40}	1.95	3.09	2.52	3.35	1.88	2.62	0.89	1.01	0.95	0.00	0.00	0.00	1.52
L_{0-10} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{10-20} D_{0-10}	8.51	7.37	7.94	0.15	18.70	9.43	11.58	25.24	18.41	6.04	6.51	6.28	10.52
L_{10-20} D_{10-20}	4.62	0.00	2.31	0.04	6.03	5.04	5.18	5.84	5.51	4.00	7.56	5.78	4.66
L_{10-20} D_{20-30}	2.56	5.37	3.97	1.63	1.29	1.46	1.09	1.84	1.47	6.70	4.89	5.80	3.18
L_{10-20} D_{30-40}	1.23	2.10	1.67	2.61	0.56	1.59	0.10	0.81	0.46	0.00	0.00	0.00	1.86
L_{10-20} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{20-30} D_{0-10}	0.00	0.00	0.00	1.62	0.49	1.06	0.00	0.00	0.00	0.00	4.67	2.34	1.70
L_{20-30} D_{10-20}	0.00	0.00	0.00	0.00	0.30	0.15	1.19	0.75	0.97	3.00	0.00	1.50	1.31
L_{20-30} D_{20-30}	0.00	3.52	1.76	2.33	0.27	1.30	0.21	0.47	0.34	6.20	0.00	3.10	1.63
L_{20-30} D_{30-40}	0.45	1.81	1.13	2.00	0.00	1.00	0.22	0.31	0.27	0.00	0.00	0.00	0.60
L_{20-30} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{30-40} D_{0-10}	0.00	0.00	0.00	2.44	0.00	1.22	0.11	0.29	0.20	0.00	0.00	0.00	0.36
L_{30-40} D_{10-20}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{30-40} D_{20-30}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{30-40} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{30-40} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{0-10}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{10-20}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{20-30}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{30-40}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L_{40-50} D_{40-50}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SE m $\pm$	0.48	0.14		0.21	0.40		1.68	2.22		0.82	0.57		
CD (0.05)	0.98	0.29		0.43	0.80		3.37	4.47		1.64	1.14		

Table 37. Per cent of roots observed in certain zones of the rhizosphere as influenced by light regimes at different phenological phases (Extracts from Table 36)

	60DAP			90DAP			120DAP			150DAP		
	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean	Open	Coconut garden	Mean
L_{0-10} D_{0-10}	59.70	61.30	60.50	61.60	49.50	55.55	66.80	51.30	59.05	40.70	37.90	39.30
L_{0-20} D_{0-20}	83.00	80.70	81.85	77.55	92.20	84.88	93.00	93.10	93.05	75.40	85.40	80.40
L_{0-30} D_{0-30}	96.40	93.10	94.75	89.45	97.57	93.51	98.81	97.52	98.17	99.90	100.10	100.00
Beyond L_{0-30} D_{0-30}	36.5	7.00	5.33	10.40	2.46	6.43	1.32	2.41	1.87	0.00	0.00	0.00



60 DAP 90 DAP 120 DAP 150 DAP

Fig. 19 Root weight distribution patterns of colocasia var. cheruchempu grown in the open and in coconut garden at different phenological phases

DAP - Days after planting

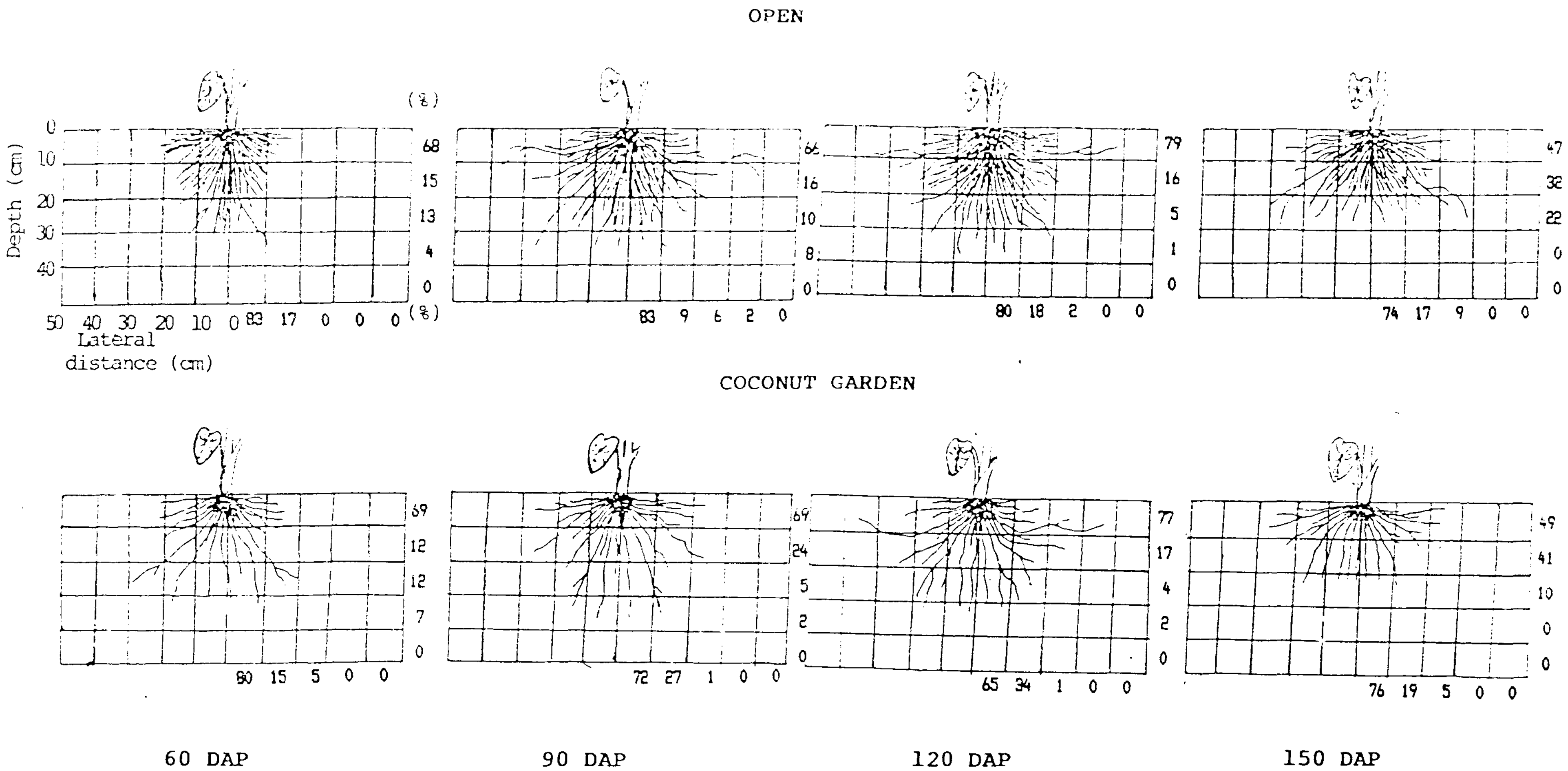


Fig. 20 Root distribution patterns (based on percentage of root dry weight) of colocasia var. cheruchempu grown in the open and in coconut garden at different phenological phases.

DAP - Days after planting

phase (90 to 120 DAP). Colocasia at advanced stages of growth (150 DAP) tended to be compact compared to that at grand growth phase (120 DAP).

Length of longest root

Colocasia plants grown in the open condition produced longer roots compared to those grown in the coconut garden. This was consistently noticed at all stages of plant growth (Table 38). Root elongation was observable upto 120 DAP and it decreased thereafter.

Plant height

The colocasia plants grown in the coconut garden were taller than those grown in the open condition (Table 39). This trend was noticed at all stages of plant growth. Plant height increased progressively upto 120 DAP and declined thereafter.

Number of tillers

Tiller production was more with colocasia grown in coconut garden compared to those grown in the open (Table 40). Tiller production increased with advancement of age upto 120 DAP and decreased thereafter.

Leaf number

Leaf production was considerably more with colocasia grown in coconut garden compared to plants grown in the

Table 38. Length of longest root of colocasia as influenced by light regimes at difffferent phenological phases

	60 DAP	90 DAP	120 DAP	150 DAP	Mean
Open	45.97	41.83	43.83	31.73	40.84
Coconut garden	40.67	39.00	41.07	30.57	37.83
Mean	43.32	40.42	42.45	31.15	

	Light regimes	Phase	Interaction
SE m±	0.58	0.82	1.16
CD (0.05)	1.24	1.76	2.49

Table 39. Height of colocasia as influenced by light regimes at different phenological phases

	60 DAP	90 DAP	120 DAP	150 DAP	Mean
Open	47.70	63.60	72.17	46.63	57.55
Coconut garden	52.77	68.03	75.07	49.63	61.38
Mean	50.23	65.82	73.62	48.13	

	Light regimes	Phase	Interaction
SE m±	0.85	1.20	1.70
CD (0.05)	1.82	2.58	3.64

open (Table 41). Number of green leaves increased with age of the plant upto 120 DAP and declined thereafter.

Total dry matter production

Total dry matter production of colocasia was more with the plants grown in the open compared to those grown in the coconut garden. Total dry matter production increased progressively with age of the plant and attained its peak at 150 DAP (Table 42).

Corm yield

Corm yield of colocasia (Table 43) was considerably more with the plants grown in the open (17.31 t ha^{-1}) compared to those grown in the coconut garden (11.63 t ha^{-1}). There was significant positive correlation between RDMP and corm yield. The coefficients of correlation between RDMP and corm yield were 0.99 and 0.88 respectively with colocasia grown in the open and in the coconut garden.

Nutrient uptake

Nitrogen uptake was more with the plants grown in the open (12.65 kg ha^{-1}) compared to those grown in the coconut garden (10.73 kg ha^{-1}). Phosphorus and potassium uptake were considerably more with the plants grown in the open compared to those grown in the coconut garden (Table 43). Colocasia grown in the open removed 2.73 kg P and 23.86 kg K per hectare.

Table 40. Number of tillers in colocasia as influenced by light regimes at different phenological phases

	60 DAP	90 DAP	120 DAP	150 DAP	Mean
Open	7.00	11.00	13.67	9.67	10.33
Coconut garden	10.33	11.67	14.33	9.33	11.42
Mean	8.67	11.33	14.00	9.50	

	Light regimes	Phase	Interaction
SE m±	0.44	0.62	0.88
CD (0.05)	0.94	1.33	1.88

Table 41. Number of green leaves of colocasia as influenced by light regimes at different phenological phases

	60 DAP	90 DAP	120 DAP	150 DAP	Mean
Open	5.33	8.67	10.67	5.00	7.42
Coconut garden	6.67	11.00	12.33	6.33	9.08
Mean	6.00	9.83	11.50	5.67	

	Light regimes	Phase	Interaction
SE m±	0.28	0.40	0.57
CD (0.05)	0.61	0.85	1.21

Table 42. Total dry matter productiion (g $plant^{-1}$) of colocasia as influenced by light regimes at different phenological phases

	60 DAP	90 DAP	120 DAP	150 DAP	Mean
Open	28.15	36.87	74.32	154.67	73.50
Coconut garden	26.85	39.19	80.77	132.30	69.78
Mean	27.50	38.03	38.77	143.49	

	Light regimes	Phase	Interaction
SE m±	0.38	0.76	5.11
CD (0.05)	0.82	1.64	10.95

Table 43. Corm yield and total N,P and K uptake of colocasia as influenced by light regimes

Nutrient uptake / Light regimes	Corm yield (t ha^{-1})	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
Open	17.31	12.65	2.73	23.86
Coconut garden	11.63	10.73	2.34	9.21
SE m±	0.70	0.04	0.08	1.54
CD (0.05)	3.01	0.07	0.14	2.76

Discussion

DISCUSSION

The results of the experiments conducted during the course of the investigation are discussed below.

Experiment I Root distribution pattern of banana

A ^{32}P Plant injection Technique

1. Root production

The root distribution pattern of banana var. Palayankodan grown in the coconut garden as well as in the open under rainfed and irrigated conditions were studied using ^{32}P plant injection technique at its peak vegetative phase (180 DAP). The amount of radioactivity observed in the rhizosphere soil was taken as a measure of root production.

From the results it is clear that root production in rainfed banana was considerably more than that of irrigated ones. Rainfed banana produced about 14 per cent more roots compared to irrigated ones (Table 1). It may be noted that the banana was planted during July and the rainfed plants received 1583.8 mm of rainfall from South West and North East monsoons. The irrigated plants received irrigation from September to February maintaining a soil moisture regime ranging from 0 to 50 per cent depletion of available water. From the weather data (Appendix 1 and Fig. 1) it is clear that the rainfed plants suffered due to moisture stress from September onwards. During periods of moisture stress it is natural that the plants tend to strengthen its absorbing system to meet the demand of water and mineral nutrients. For this purpose more photosynthates will be diverted for the production of more roots by a stressed plant compared to non-stressed ones. Under conditions of moisture stress, the plant roots will be compelled to grow deeper in search of soil moisture to meet the evapotranspiration demands. The number of roots (Table 19) as well as the length of the longest root (Table 20) were also more with rainfed plants compared to irrigated ones. Sobhana (1985) observed more root production with rainfed nendran banana compared to irrigated banana. Similar results were also reported in cocoa (Ahenkorah, 1975 and IAEA, 1975), coconut (IAEA, 1975), robusta banana (Krishnan and Shanmugavelu, 1980), sugarcane (Kummerow, 1980), sorghum (Hundal and De Datta, 1984) and in tea (Saikia, 1985)

Root production in banana is also influenced by the light environment under which it is grown. Root production was about 56 per cent more with banana grown in the open compared to that grown in the coconut garden (Table 1). It may be noted that in the 18 year old coconut garden in which the experiment was conducted, the light intensity was only 30 to 40 per cent of that observed in the open condition. Obviously, the availability of light in the coconut garden was a limiting factor for optimum levels of photosynthesis. This might have caused considerable reduction in the total dry matter production of the plant reflecting a similar reduction in root production as well. Decreased dry matter production in the shaded conditions compared to the plants grown in the open was reported in cocoa (IAEA,1975), sweet potato (Bai,1981), Vegetables (Krishnankutty, 1983) and in ginger (George, 1992).

It was also observed that the interaction between light and soil moisture regimes was significant on root production in banana. Root production was the highest with rainfed banana grown in the open and lowest with the rainfed banana grown in the coconut garden, showing 84 per cent reduction (Table 1). Though irrigation decreased root production in banana under open conditions, such an effect was not observable in the coconut garden. The results indicate that the rainfed plants in the open diverted more photosynthates to strengthen their root system, compared to the irrigated plants. But such a behaviour was not observable with the rainfed plants grown in the coconut garden. In other words root system development depends on the growing condition and the effect of irrigation on root production is different in the open condition and in the coconut garden. The rainfed plants in the coconut garden might not have suffered a severe moisture stress as it might have been experienced by the rainfed plants grown in the open. The rate of moisture loss through evapotranspiration by banana grown in the coconut garden, might have been less compared to those grown in the open, due to the difference in the micro-climates of these two environments.

2. Root distribution pattern

The percentage distribution of roots in each zone of the rhizosphere was computed as the ratio of the amount of radioactivity observed in each zone to that observed in the entire root zone. The root distribution of banana varies between lateral distances, vertical depths as well as due to their interactions. About 92.6 per cent of the root occur 60 cm laterally around the plant (Table 3) and 93.1 per cent of the total roots occur within 60 cm depth from the soil surface (Table 5).

Root distribution pattern of banana differ due to light environments and soil moisture regimes under which they are grown. The tendency of rainfed banana in the coconut garden was to develop a deep and spreading root system compared to irrigated ones. Rainfed banana in the coconut garden had 84.3 per cent of its roots (Table 8) in the root zone comprising 60 cm laterally around the plant and 60 cm vertically from the soil surface (L_{0-60} D_{0-60}). On the other hand irrigated banana in the coconut garden, contained 93.4 per cent of the roots in this particular root zone(Table 8).

Rainfed banana in the open had 90.5 per cent of its roots in the root zone comprising 60 cm laterally around the plant and 60cm vertically from the soil surface (L_{0-60} D_{0-60}), whereas irrigated bananas under open condition had only 75.9 per cent roots in this zone (Table 8). It was clear from the data that root system development of banana is a function of the light and soil moisture environment under which the plant is grown.

To delineate the active root zone of banana, the rhizosphere containing about 90 per cent of the roots (90 ± 5) was considered. The active root zone of banana depends on the growing conditions. Rainfed banana grown in the open had about 90 per cent of the roots (Table 7) in a root zone comprising 60 cm laterally around the plant and 60 cm vertically from the plant base (L_{0-60} D_{0-60}). Irrigated banana grown in the open had about 90 per cent of their root system (Table 7) in a root zone comprising 60 cm laterally around the plant and 80 cm vertically from the soil surface (L_{0-60} D_{0-80}). This means that rainfed banana grown in the open develops a compact root system and irrigated banana grown in the open develops a spreading root system (Fig. 8).

In the present study it was also found that the root dry matter production was considerably more with irrigated banana compared to rainfed banana, in the open conditions (Table 9). This difference in root dry matter production due to irrigation might have helped to develop a spreading root system by irrigated plants under open condition. The general growth and vigor of rainfed banana grown in the open was considerably less as evidenced from the data on the growth characters (Table 21 and 22). Though the rainfed plants in the open condition could produce more roots (Table 11), the plants fail to spread the roots in a larger area and the root system remained more or less compact. Rainfed banana grown in the open conditions have suffered heavily due to severe moisture stress resulting in a substantial reduction in growth. This severe moisture stress might be the reason for their failure to develop a better root system.

The root system development of banana grown in the coconut garden in relation to soil moisture regimes was different. Rainfed banana grown in the coconut garden had about 90 per cent of the roots (Table 7) in the root zone comprising 80 cm laterally around the plant and 60 cm vertically from the soil surface (L_{0-80} D_{0-60}). Irrigated banana grown in the coconut garden had more or less same amount of roots (Table 7) in the root zone comprising 60 cm laterally around the plant and 60 cm vertically from the soil surface (L_{0-60} D_{0-60}). The results indicate that the rainfed banana grown in the coconut garden developed a spreading root system and irrigated banana grown in the coconut garden developed a compact root system (Fig.8). The spreading root system of rainfed banana in the coconut garden can be considered as an adaptation by the plant to extract moisture under conditions of moisture stress. Irrigating banana in the coconut garden has resulted in the development of a compact root system. It can be seen from table 11 that the root production of irrigated banana in the coconut garden was considerably less compared to rainfed banana grown under the same condition and this decline in root production might be responsible for the observed trend. Development of a spreading root system by plants during conditions of moisture stress have been reported in rice (Bhattacharjee et al., 1974), cocoa (Ahenkorah, 1975), coconut (IAEA, 1975), cotton (Al Khafat, 1985) and in corn (Newell and Wilhelm, 1987).

It is clear that the root distribution pattern of banana differ with light environment (open and coconut garden) and soil moisture regimes (rainfed and irrigated) in which the plants are grown. The results suggest that while developing coconut based production systems involving palayankodan banana, due consideration should be given to the variation in the root system development of this plant in relation to light and soil moisture regimes.

B. Profile excavation technique

1. Root production

The root distribution pattern of banana was also studied directly following profile excavation technique (needle board method) at different stages of plant growth (early establishment phase, early vegetative phase, grand growth phase and pre-flowering phase) to compare the difference in root production and distribution patterns in relation to growing conditions. As observed with the ^{32}P plant injection technique, the root production was considerably more with rainfed banana compared to irrigated banana (Table 9). Similarly, the banana plant grown in the open condition produced more amount of roots compared to those grown in the coconut garden (Table 10). The reasons for the above results have been explained earlier.

Root production of banana increased with advancement of age, attained its peak at grand growth phase (180 DAP) and declined thereafter. This trend was observed with rainfed and irrigated bananas grown in the coconut garden as well as in the open conditions. Enhanced biomass production with age is a well known biological phenomenon observed in almost all plants. Similar increase in root production with age was reported in sugarcane (Stevenson, 1936), cashew (Tsakiris and Northwood, 1967), arecanut (Bhat, 1978), rice (Salam, 1984) and in coconut (Avilan, et al., 1984).

In the case of banana, a decline in RDMP was observed after 180 DAP. During profile excavation study of the root system, considerable amount of older roots have been seen decayed in the soil profile of aged plants indicating that a part of the root system was lost with advancement of age. This might be the reason for a decline in RDMP after 180 DAP. Similar decline in root production after 120 DAP has been reported in colocasia (Mohankumar, 1993).

The effects of light and soil moisture regimes on the number of roots per plant and the length of longest root (Table 19 and 20) were more or less the same as that observed with RDMP. The coefficients of correlation between RDMP and number of roots per plant were significant and positive (0.88 to 0.96)

2. Root distribution pattern

As observed with the ^{32}P plant injection technique, the root distribution pattern of banana varies with light intensity and soil moisture regime in which the plants are grown. In the coconut garden, the rainfed banana developed a spreading root system and the irrigated plants developed a compact root system, whereas in the open condition rainfed plant developed a compact root system and the irrigated plants developed a spreading root system (Fig. 14 and 15).

To delineate the active root zone, the rhizosphere containing about 90 per cent of the roots (90 ± 5) was considered. Accordingly it was found that rainfed banana grown in the coconut garden had about 93 per cent of the roots in a zone comprising L_{0-40} D_{0-50}. Irrigated banana grown in the coconut garden had more or less the same amount of the root system in a zone comprising L_{0-30} D_{0-40}. Rainfed banana in the open had about 92 per cent of the roots in a zone comprising L_{0-30} D_{0-40}. Irrigated banana in the open had about 93 per cent of the roots in a zone comprising L_{0-40} D_{0-40} (Table 17). The reasons for such a differential root distribution pattern of banana in relation to light and soil moisture regimes have already been explained. Ashokan (1986) reported that the active root zone of rainfed banana cultivar palayankodan, is the soil zone comprising 30 to 35 cm laterally around the plant and 25 to 30 cm vertically from the soil surface.

The results on root distribution pattern of banana obtained from the profile excavation technique and the ^{32}P plant injection technique were not closely agreeing. The reasons for such a variation is explained later under the heading "comparison of methods of root system research".

The root distribution patterns of banana in the soil profile also vary with phenological phases. A gradual increase in root spread was observed with age, attaining maximum root spread at its grand growth phase (180 DAP). After grand growth phase, the root system tended to be compact. This pattern is quite natural and the tendency of the plants in general is to spread and strengthen their root system gradually with age. The reduction in root spread at the advanced stage is due to the disintegration of older roots as evidenced from the data on RDMP (Table 10).

Comparison of the methods of root system study

The data on root distribution pattern of banana obtained from the ^{32}P plant injection technique and the profile excavation technique were compared to assess the variability of the results due to methods.

The active roots zones identified for banana by the two different methods were not closely agreeing. In the profile excavation technique, a smaller root zone (30 to 40 cm laterally around the plant and 40 to 50 cm vertically from the soil surface) was observed to contain about 90 per cent of the roots, whereas the same amount of roots could be seen only in a larger root zone (60 to 80 cm laterally around the plant and vertically from the soil surface) in the ^{32}P plant injection technique. This variation in the results due to change in method indicates that there exists difference in the efficiency between the two methods used for the study. In the profile excavation technique the root dry matter of individual root zones were quantified by profile excavation and extraction, washing, drying and weighing of roots. The root distribution pattern was determined as a ratio of the root dry weight of individual zones to the total root dry weight of the entire root zone, expressed as a percentage.

During profile excavation studies, it is quite probable that the minute rootlets and root hairs which travel away from the plant towards the lateral and vertical direction may escape from quantification, resulting in an under-estimation of the roots. This is one of the inherent disadvantages of this method. On the other hand, in the ^{32}P plant injection technique, the injected radiolabel is expected to travel throughout the plant system covering the entire root and shoot systems. In this method, the radioactivity observed in the soil-root core samples collected from different zones is taken as a measure of root activity in each zone. As such, the possible chances of under - estimation of the root spread do not exist in the tracer method. Hence it will be more appropriate to consider the results obtained from the ^{32}P plant injection technique as more reliable.

Growth characters

The plant height as well as leaf production were more with banana grown in coconut garden compared to those grown in the open (Table 21 and 22). Enhanced elongation of plants under shade was reported in cassava (Ramanujam et al., 1984 and Sreekumari et al., 1989), rice (Jadhav, 1987), potato (De Magante and Zaag, 1988), colocasia (Prameela, 1990) and clocimum (Pillai, 1990). Irrigated plants were taller and produced more leaves compared to rainfed ones. It is a well established fact that irrigation helps the plants to exploit the soil nutrient resources more effectively. Irrigated plants in the coconut garden were the tallest and leaf production was also more with these plants. Under shaded conditions auxins may accumulate in the plant which may ultimately enhance elongation and growth of plants. Irrigation in this condition can further enhance plant growth.

From the discussions presented so far the following conclusions can be drawn:

Root production in banana (Var. Palayankodan) vary with light regimes and the soil moisture regimes under which the plants are grown. Root production is more in the open condition compared to coconut garden. Rainfed banana produce more roots compared to irrigated ones. Root production is the highest with rainfed banana grown in the open and lowest with irrigated banana grown in the coconut garden.

Root distribution patterns vary with light and soil moisture regimes. Rainfed banana in the coconut garden develops a more laterally spreading root system and irrigated banana in this condition develops a compact root system. In the open condition, irrigated banana develops a more deep spreading root system and rainfed banana in this condition develops a compact root system. The active root zone of rainfed banana grown in the open is the rhizosphere coconut garden. In the coconut garden in which the experiment was conducted, the light intensity was only 30 to 40 per cent of that observed in the open condition. Obviously, the availability of light in the coconut garden was a limiting factor for optimum levels of photosynthesis for the colocasia grown in the coconut garden. A drastic reduction in total dry matter production was also observable with the colocasia grown in the coconut garden compared to those grown in the open, as evidenced from the data given in Table 42. Decline in dry matter production of colocasia grown in shaded conditions compared to those grown in the open was reported by Bai (1981) and Prameela (1990). Decreased rate of total dry matter production under shaded conditions might have resulted in a proportionate decline in the RDMP also under the shaded environment.

2. Root distribution pattern

The percentage distribution of roots in each zone of the rhizosphere was arrived as a ratio of the amount of radioactivity observed in each zone to that observed in the entire root zone.

The root distribution pattern of colocasia in the soil profile varies between lateral distances, vertical depths as well as due to their interactions. About 83.9 per cent of the roots occur 10 cm laterally around the plant and 88 per cent of the roots occur 30 cm vertically from the soil comprising L_{0-60} D_{0-60}, containing 90.5 per cent of the roots. The active root zone of irrigated banana in the open is the rhizosphere comprising L_{0-60} D_{0-80}, containing 90 per cent of the roots. The active root zone of rainfed banana in the coconut garden is the rhizosphere comprising L_{0-80} D_{0-60}, containing 90.7 per cent of the roots. The active root zone of irrigated banana in the coconut garden is the rhizosphere comprising L_{0-60} D_{0-60}, containing 93.4 per cent of the roots.

^{32}P plant injection technique is an effective method to study the root distribution pattern of banana.

Experiment II Root distribution pattern of colocasia

A. ^{32}P Plant injection technique

1. Root production

The root distribution pattern of colocasia var. cheruchempu grown in the open conditions as well as in coconut garden was studied using ^{32}P plant injection technique at its peak growth phase (120 DAP). The amount of radioactivity observed in the rhizosphere soil was taken as a measure of its root production.

The data on radio activity (Table 23) indicate that root production in colocasia (Fig. 16) grown in the open was 49.4 per cent more compared to the plants grown in the surface. The results indicate that the lateral spread of the roots is limited (about 20 cm) and the vertical spread is more (over 40 cm). The observation of a deeper root penetration beyond 40 cm depth is supported by the data on the length of longest root (Table 38).

Root distribution patterns of colocasia in the soil profile differ between the plants grown in the coconut garden and in the open conditions. The colocasia grown in the coconut garden developed a deep compact root system with 90.6 per cent of the roots in the root zone comprising 10 cm laterally around the plant and 40 cm vertically from the soil surface (L_{0-10} D_{0-40}). On the other hand colocasia grown in open condition developed a deep and spreading root system (Table 29) with 92.3 per cent of the roots in the root zone comprising 20 cm laterally around the plant and 40 cm vertically from the soil surface (L_{0-20} D_{0-40}). The results clearly indicate that the root distribution pattern of colocasia is influenced by the light regimes under which the plants are grown. The data on RDMP and total dry matter production (Table 30 and 42) explain this. The RDMP (Table 30) as well as total dry matter production (Table 42) of the plants grown in the coconut garden was considerably low compared to the plants grown in the open. The ability of the plants to produce more amount of roots under open conditions might have enabled them to develop a spreading root system. Decreased dry matter production by plants grown in the shaded condition compared to the plants grown in the open was reported in sweet potato (Bai, 1981), vegetables (Krishnankutty, 1983) and in ginger (George, 1992).

The results suggest that while developing coconut based production systems involving colocasia var.cheruchempu due consideration should be given to the differential root distribution pattern of colocasia var. cheruchempu in relation to light regimes.

B. Profile excavation technique.

1. Root production

The root distribution pattern of colocasia was also studied directly following profile excavation technique at different growth stages of the plant to compare the root production and distribution pattern in relation to growing conditions. The root production of colocasia grown in the open condition was more compared to those grown in coconut gardens (Table 30). The reason for a greater amount of root production with the plants grown in the open condition compared to those grown in the coconut garden have already been explained.

Root production of colocasia increased with age, attained its peak at grand growth phase (120 DAP) and declined thereafter (Fig. 18). Increase in root production with age is a well known biological phenomenon and is reported by many researchers. Mohankumar (1993) studied the pattern of root dry matter production of colocasia (Var. thamarakkannan) in relation to phenological phases and found that the RDMP increases with age upto 120 DAP and declined thereafter. The decline in RDMP at the advanced stage of plant growth might be due to the disintegration of roots during maturity phase.

2. Root distribution pattern

The root distribution pattern (percentage basis) of colocasia in the soil profile remained more or less the same with the plants grown in the coconut garden as well as with those grown in the open, (Fig. 20) although there was quantitative difference in RDMP due to change in light environment (Fig. 19). In the case of colocasia grown in the coconut garden as well as in the open, the root zone comprising 20 cm laterally around the plant and 20 cm vertically from the soil surface (L_{0-20} D_{0-20}) contained 93 per cent of the roots (Table 37). An enhanced root production observed with the plants grown in open condition, did not cause a change in the percentage distribution of roots in the soil profile, compared to plants grown in the coconut garden.

The results on the root distribution pattern of colocasia obtained from the ^{32}P plant injection technique and the profile excavation technique were not closely agreeing. The reason for such a variation in results due to change in the method of root system research is explained later under the heading "comparison of methods of root system research".

The root distribution pattern of colocasia varied with phenological phases with less root spread at the early phase (60 DAP). Maximum lateral and vertical spread was observed at the peak vegetative phase (120 DAP). The root system of colocasia at the advanced stage of plant growth tended to be compact. This pattern is quite natural and the tendency of the plants in general is to spread and strengthen their root system gradually with age. Similar pattern of root distribution and development in relation to phenological phases was reported in colocasia Var. thamarakkannan (Mohankumar, 1993).

Comparison of the methods of root system study

The data on root distribution pattern of colocasia obtained from the ^{32}P plant injection technique and the profile excavation technique were compared to assess the variability of the results between the methods. The results on the root distribution pattern of colocasia obtained from the two methods of root system study were not closely agreeing. In the former method (^{32}P plant injection technique), it was found that the root distribution pattern of colocasia differ between the plants grown in the coconut garden and in the open. It was also observed that colocasia grown in the coconut garden developed a deep compact root system with 90.6 per cent of the roots in the root zone comprising L_{0-10} D_{0-40} and the plants grown in the open developed a deep spreading root system with 92.3 per cent of the roots in a root zone comprising L_{0-20} D_{0-40} (Table 36). In the latter method (profile excavation technique), it was observed that root distribution pattern of colocasia did not vary due to light regimes (open and coconut garden) and about 93 per cent of the roots occur 20 cm laterally around the plant and 20 cm vertically from the soil surface. This variation in the results due to change in the method indicates that there exist differences in the efficiency between the two methods employed for the study. In the profile excavation technique, the root dry matter of individual root zones were quantified by profile excavation and extraction, washing, drying and weighing of roots. The distribution of roots in each zone of the rhizosphere was arrived at as a ratio of the root dry weight of each zone to the total root dry weight of the entire root zone, expressed as percentage.

During profile excavation, it is quite probable that the minute rootlets and root hairs that travel away from the plant towards lateral and vertical directions may escape quantification resulting in an under-estimation of the roots. This is one of the defects of this method. On the other hand, in the ^{32}P plant injection technique, the injected radiolabel is expected to travel the entire plant system covering the root and shoot systems. In this method the radioactivity observed in the soil-root core samples collected from different zones of the rhizosphere, is taken as a measure of root density in each zone. As such the chances of under estimation of root spread do not exist in the tracer method. Hence it will be more appropriate to consider the results obtained from the ^{32}P plant injection technique as more reliable.

Growth characters

The growth characters such as plant height, number of tillers per plant and the number of green leaves per plant were more with colocasia grown in the coconut garden compared to those grown in the open (Table 39, 40 and 41). On the contrary total dry matter production as well as the corm yield was more with the plants grown in the open (Table 42 and 43). Favourable effect of shade on plant height was reported in coleus and sweet potato (Bai and Nair, 1982), ginger and turmeric (Bai and Nair, 1982; Varghese, 1989), tomato (Kamaruddin, 1983), and in colocasia (Prameela,1990). Under shaded conditions, auxins may accumulate in the plants which may ultimately enhance elongation and growth of plants. Enhanced leaf production in coleus (Bai, 1981) and ginger and turmeric (Varghese, 1989) under shaded conditions was reported.

In the coconut garden in which the experiment was conducted the light infiltration was only about 30 to 40 per cent. Under this condition the availability of light might have been a limiting factor for continuing optimum levels of photosynthesis. Thus the total dry matter production and the corm yield became low compared to the plants grown in the open conditions. This might have been one of the important causes for the decreased total dry matter production and corm yield with colocasia grown in the coconut garden compared to those grown in the open. Decreased dry matter production at low light intensity was reported in crops such as cowpea (Dolan, 1972), beans (Crookston et al., 1975), rice (Rai and Murthy, 1977; Venketeswarlu and Srinivasan, 1978; Vijayalakshmi et al., 1987), *Colocasia esculenta* (Caesar, 1980) and in Soybean (Benjamin et al., 1981). Decline in yield due to shade has been reported in many crops like rice (Vijayalakshmi et al., 1987), cotton (Pandey et al., 1980), turmeric (Ramadasan and Satheesan, 1980), pulses (George, 1992), cowpea (Krishnankutty, 1983), cassava (Ramanujam et al., 1984; Okoli and Wilson, 1986) and in colocasia (Prameela, 1990 and Hemalatha, 1992).

There was significant positive correlation between RDMP and corm yield (r=0.88 to 0.99). The results suggest that any effort attempted to enhance the RDMP of colocasia would enable to enhance the corm yield of this crop.

The uptake of N, P and K by colocasia was considerably more with the plant grown in the open compared to those grown in the coconut garden. The data on RDMP (Table 30) explain this. The RDMP was about two times more with colocasia grown in the open compared to those grown in the coconut garden. The greater strength of the absorbing system of colocasia grown in the open condition enabled them to absorb more nutrients from the soil compared to the plants grown in the coconut garden.

From the foregoing discussions the following conclusions can be drawn:

The root production of colocasia var. cheruchempu is more in open condition than in coconut garden. The root distribution pattern of colocasia in the soil profile vary between the plants grown in the coconut garden and in the open. The root system of colocasia grown in the coconut garden is deep compact and that grown in the open is deep spreading. The active root zone of colocasia grown in the coconut garden lies 10 cm laterally around the plant and 40 cm vertically from the soil surface. The active root zone of colocasia grown in the open lie 20 cm laterally around the plant and 40 cm vertically from the soil surface.

^{32}P plant injection technique is an effective method to study the root distribution pattern of colocasia.

Summary

SUMMARY

An investigation was undertaken at the College of Horticulture, Vellanikkara during 1993-94 to study the root distribution patterns of banana and colocasia in coconut garden. The experiments were aimed to study the root distribution patterns of banana var. palayankodan grown in the open and in the coconut garden under rainfed and irrigated conditions. It was also aimed to study the variation in the root distribution patterns of colocasia var. cheruchempu grown in the coconut garden and in the open. A ^{32}P plant injection technique and a direct profile excavation technique were employed to study the root distribution patterns. The salient results of the investigation are summarised below.

Experiment I. Root distribution pattern of banana

Root production in banana varied between plants grown in the coconut garden and in the open. Root production was considerably more with banana grown in the open conditions compared to that grown in the coconut garden. Root production varied between irrigated and rainfed banana and it was considerably more with rainfed banana.

About 92.6 per cent of the banana roots occur 60 cm laterally around the plant. Depth wise, 93.4 per cent of the roots reside in the soil layer 60 cm from the surface.

The root distribution pattern of banana vary with growing conditions. Rainfed banana grown in the coconut garden developed a spreading root system and irrigated banana in the coconut garden developed a compact root system. Irrigated banana grown in the open tended to develop a spreading root system and rainfed banana grown in the open developed a compact root system.

The active root zone of banana varied with the growing conditions.

The active root zone of rainfed banana grown in the open is the rhizosphere comprising L_{0-60} D_{0-60}, containing about 90.5 per cent of the roots.

The active root zone of irrigated banana in the open is the rhizosphere comprising L_{0-60} D_{0-80}, containing 90 per cent of the roots.

The active root zone of rainfed banana in the coconut garden is the rhizosphere comprising L_{0-80} D_{0-60}, containing 90.7 per cent of the roots.

The active root zone of irrigated banana in the coconut garden is the rhizosphere comprising L_{0-60} D_{0-60}, containing 93.4 per cent of the roots.

Root production and distribution pattern of banana increased steadily with phenological phases upto 180 DAP and declined thereafter.

Root dry matter production was the highest with rainfed banana grown in the open (94.98 g plant^{-1}) and lowest with irrigated banana grown in coconut garden (25.37 g plant^{-1}).

^{32}P plant injection technique is an efficient method for root system studies in banana.

Experiment II Root distribution pattern of colocasia

Root production in colocasia var. cheruchempu differed due to light environments under which they are grown. Root production was the highest (7.09 g plant $^{-1}$) with colocasia grown in the open and lowest with colocasia grown in the coconut garden (3.55 g plant^{-1}).

The root distribution patterns of colocasia differ between the plants grown in the open and in the coconut garden. The root system of colocasia grown in coconut garden is deep compact and that of the plants grown in the open is deep spreading.

The active root zone of colocasia grown in the coconut garden is the rhizosphere comprising 10 cm laterally around the plant and 40 cm vertically from the soil surface containing 90.6 per cent of the roots.

The active root zone of colocasia grown in the open lies 20 cm laterally around the plant and 40 cm vertically from the soil surface containing 92.3 per cent of the roots.

Root production and distribution pattern of colocasia increased with phenological phases upto 120 DAP and declined thereafter.

^{32}P plant injection technique is found to be an efficient method for root system studies in colocasia.

References

REFERENCES

Ahenkorah, Y. 1975. Use of radioactive phosphorus in determining the efficiency of fertilizer utilization by cocoa plantation. Pl.Soil **42:**429-439

Al Khafat, S.K. 1985. Effect of soil water potential, irrigation method and plant density on cotton root growth under field conditions. J. agric. Water Resources Res. **4:** 31-44

Anon, 1984. Influence of ploughing and deep planting on growth of cotton root system. Shanghai Agric. Sci. Rech. **2:** 15-16

Anon., 1994. Estimates of crop production. The Hindu survey of Indian Agriculture. p. 122

Ashokan, P.K. 1986. Production potential of cassava based cropping systems.Ph.D. Thesis, Kerala Agricultural University, Vellanikkara, Kerala, India

Ashokan, P.K., Wahid P.A. and Sreedharan C. 1989. Root activity pattern of cassava in laterite soil. J. Root Crops **15:** 65-70

Atkinson, D. 1974. Some observations on the distribution of root activity in apple trees. Pl. Soil **40:** 333-341

*Avilan, L., Rivas, N. and Sucre, R. 1984. Estudio del Sistema radical del cocotero (Cocos nucifera). Oleagineux **39:** 13-23

Azam- Ali, S. N., Gregory, P. J. and Moneteith, J. L., 1984. Effect of planting density in water use and productivity of pearl miller (Pennisetun typhoides) grown in stored water. Expl. agric. **20:** 203-216

Babalola, O. and Lal, R. 1977. Subsoil gravel horizon and maize root growth: Gravel concentration and bulk density effect. Pl. Soil **46:** 337-346

*Bachy, A. 1964. Tropisme racinaire du palmier a huile. Oleagineux **19:**684

Bai, E. K. L. 1981. Shade response of common rainfed intercrops of coconut. M.Sc. (Ag.) Thesis, Kerala Agricultural University, Vellanikkara, Kerala, India

Bai, E. K. L. and Nair, R. V. 1982. Shade response of some common rainfed intercrops. Proc. 5th Annual Symp. on Pltn. Crops. Indian Society for plantation crops. p. 394-401

Bal, A.R. and Dutt, S.K. 1982. Rooting pattern of different crops as affected by soil salinity. Annual Report Central Soil Salinity Research Institute, Karnal, India

Balakrishnamurthy, T.S. 1977. Studies on the root activity of coconut using radioactive phosphorus. International Symposium on Increasing Crop and Animal Productiviy by Nuclear and Allied Techniques, IARI, New Delhi, Abstracts: p. 63-64

Barbora, B.C., Jain, N.K. and Rahaman, F. 1982. Root studies in young Tea. Two Bud **29:** 52-55

Barua, D.N. and Dutta, K.N. 1973. Distribution of shoots on the plucking surface of the tea bush and its relation to spacing. Two Bud **20:** 1-10

Bavappa, K.V.A. and Mathew, T. 1960. Effect of different spacings on the quality of arecanut seedlings. Arecanut J. **11:** 3-8

Bavappa, K.V.A. and Murthy,K.N. 1961. Morphology of arecanut palm. The root. Arecanut J. **12:** 65-72

Benjamin, L. E., Egli, D. B. and Leggett, J. E. 1981. Effect of leaf age and shading on the movement of ^{14}C through soybean leaf Can. J. Pl. Sci. **61:** 205-213

Berntson, G.M. 1992. A computer program for characterizing root system branching patterns. Pl. Soil **140:** 145-149

Bhan, S. and Misra, D.K. 1970. Effects of variety, spacing and soil fertility on root development in groundnut under arid conditions. Indian J. agric. Sci. **40:** 1050-1055

Bhat, S.K. and Leela, M. 1969. The effect of density of planting on the distribution of arecanut roots. Trop. Agric. Trin. **46:** 55-61

Bhat, S.K. 1978. Agronomic research in arecanut-a review. J. Pltn. Crops **6:** 67-80

Bhat, S.K. 1983. Plant interactions in a mixed crop community of arecanut (Areca. catechu. L.) and cocoa (Theobromo cacao L.). Ph.D. Thesis, University of Mysore, Mysore

Bhattacharjee, D.P., Ramakrishnayya, G. and Murthy, K.S. 1974. Root distribution study of rice varieties by ^{32}P injection technique under soil moisture deficit. Symposium on Uses of Radiation and Radioisotopes on Studies of Plant Nutrition, GB Pant University of Agriculture and Technology, Pantnagar, p. 569-577

Bloodworth, M.E., Burleson, C.A. and Cowley, W.R. 1958. Root distribution of some irrigated crops using undisturbed soil cores. Agron. J. **50:** 317-320

Bohm, W. 1979. Methods of Studying Root Systems. Ecological studies 33, Springer Verlag, Berlin Heidelberg, Newyork, p.188

Borpujari, N. 1975. Influence of spacing on the utilisation of soil moisture, root development and nutrient uptake. (unpubl) M.Sc. Thesis, Assam Agricultural University, Jorhat

Bouyoucos, C. J. 1962. Hydrometer method improved for making particle sized analysis of soil. Agron. J. **54:** 464-465

Brar, R. S. 1985. Water cum fertilizer management studies in planted maize. Ph.D. Thesis, Punjab Agricultural University, Ludhiana

Brouwer, R. and De Wit, C.T. 1969. A simulation model of plant growth with special attention to root growth and its consequences. Root Growth. W.J. Whittington (ed.) Butterworths, London, p. 224-244

Caesar, K. 1980. Growth and development of Xanthorona and Colocasia under different light and water supply conditions. Fd. Crop Res. **3:** 235-244

*Campos, A., Dos, R. and Sena, Z.F.D. 1975. Profundide do Sistema radicluar do aipin Maragopipe aos sete e a os doze messes de ciclo (the depth of cassava roots at seven and 12 months of age). Projects mandio Cruz das Almas, Brasil Convenio U.F.B.A/BRASCAN, Nordeste Serie Pesquisa, **2**: 65-70

*Champion, J. and Sioussaram, D. 1970. L'enracinement du bananier dane les conditions de la station de Neufchateau, Guadeloupe. Fruits **25**: 847-859

Chaudhary, T.N. and Bhatnagar, V.K. 1980. Wheat root distribution, water extraction and grain yield as influenced by time and rate of irrigation. Agric. Water Mgmt. **3**: 115-124

Chauhan, R.S and Singh, K.B. 1987. Root development and nutrient uptake in pigeon pea as influenced by levels of phosphorus and row spacing under rainfed conditions. Indian J. agric. Sci. 21: 7-10

Cheema, S.S., Chaudhari, U. and Chaudhari, M. R. 1979. Rooting pattern of three rice varieties. Crop Improv. 1: 58-62

Chol, H.O. and Kim, D.S. 1964. Studies on the tolerance of rice plants to salinity. Research Report. Office of Rural Development, Korea 1:131-138

Choudhury, B. 1983. Vegetables. National Book Trust of India, New Delhi. p. 151-161

Chopart, J.L. and Nicow, R. 1976. Influence du labour sur le development radiculaire de differents plantes cultivees au Senegal consequences sur lens alimentation hydrique. Agronomi Tropicale. **31**: 7-27

Cochran, W.G. and Cox, G.M. 1957. Experimental Designs. Asia Publishing House, New Delhi, p. 245

Collins, J.L., 1960. The Pineapple. Inter Science Publishers,Inc., New York, p. 216-217

Costigan, P. A., Rose, J. A. and Mc Burney, T. 1982. A microcomputer based method for the rapid and detailed measurement of seedling root system. Pl. Soil **69**: 305-309

Cripps, J.E.L. 1970. A seasonal pattern of apple root growth in Western Australia. J. Hort. Sci. **45**: 153-161

Crookston, R.K., Treharne, K.J., Lud ford, P. and Ozbun, J.L. 1975. Response of beans to shading. Crop. Sci. **15**: 412-416

Damodaran, V.K. 1984. Vegetative propagation of cashew-review of work done in Kerala. Rao, E.V.V.B. and Khan, H.H. (ed.) Cashew Research and Development, Proceedings of the International Symposium on Cashew, Cochin, Indian Society of Plantation Crops, p. 51-56

DeJong, E. and Otinkarang, E.S. 1969. Development of root distribution of irrigated tomatoes with ^{32}P injection technique. Canad. J. Pl. Sci. **49**: 69-74

De Magante, A. L. Zaag, P. V. 1988. The response of potato solanun spp. to photoperiod and light intensity under high tempeature. Potato Res. **31**: 73-83

Dev, G., Saggar, S., Singh, R. and Sidhu, C.S. 1980. Root distribution pattern of some wheat varieties in arid brown soil under rainfed condition. J. Nucl. Agric. Biol. **9**: 89-90

Dolan, D. D. 1972. Temperature, photoperiod and light intensity effect on growth of Pisun Sativum L. Crop Sci. **12**: 60-62

Doorenbos, J. and Kassam, A.H. 1979. Crop and Water. Water melon in yield response to water. FAO Irrigation and Drainage paper. **33:** 161-163

Fawcett, W. 1913. The Bananas. West Indian committee, London, p. 341

Fluhler, H. 1977. Field measured water uptake of sudan grass roots as affected by fertilization. Agron. J. **69:** 269-274

Fox, R.L. and Lipps, R.C. 1964. A comparison of stable strontium and ^{32}P as tracers for estimating alfalfa root activity. Pl. Soil **20:** 337-350

George, B. E. 1992. Evaluation of ginger cultivars for shade tolerance. M. Sc. (Ag.) Thesis. Kerala Agricultural University, Vellanikkara, Kerala, India

*Gillier, P. and Silvestre, P. 1969. L. arachide. G. P. Maisonneuve and Larose, ii, rue victor-cousin, Paris

*Godefroy, J. 1969. The development of banana roots in various soils - relationship with fertility. Fruits **24:** 101-104

*Gorbing, J. 1948. Die grundlagen der Gare in Praktischen Ackerbau. Hannover: Landbuchverlag, 2

Gregory, P.J. 1979. A periscope method for observing root growth and distribution in field soil. J. Exp. Bot. **30:** 205-214

Gregory, P.J. and Reddy, M.S. 1982. Root growth in an intercrop of pearlmillet/groundnut. Fd. Crops Res. **5**: 241-252

Grewal, S.S. and Singh, N.T. 1978. The effect of different moisture regimes on soil temperature and the yield and quality of potatoes in Northern India. Indian J. Agron. **23**: 130-136

Hales, S. 1727. Vegetable Staticks. McDonald, London, p.170

Hall, N.S., Chandler, W.F., Van Bavel, C.H.M., Reid, P.H. and Anderson, J.F. 1953. A tracer technique to measure growth and activity of plant root system. N. C. Agric. Exp. Stn. Tech. Bull. **101**: 40

Hammes, K.K. and Bertz, J.T. 1963. Root distribution and development of vegetable crops as measured by radioactive phosphorus injection technique. Agron. J. **55**: 329-333

*Hatert, J. 1958. Preliminary observations on the root system of robusta coffee. Bull. agric. congo. belge. **49**: 461-482

Hem, M. 1982. A relationship between sorghum root depth and soil temperature. M.Sc. Thesis, University of Nebraska, Lincoln, USA

Hemalatha, S. 1992. Evaluation of shade tolerant morphotypes of colocasia. M.Sc.(Ag.) Thesis. Kerala Agricultural University, Vellanikkara, Kerala, India

Huang, M. T. and Ketring, D. L. 1987. Root growth characteristics of peanut genotypes. J. Agric. Res. China **36**: 41-52

Hundal, S.S. and De Datta, S.K. 1984. Water table and tillage effects on root distribution, soil water extraction and yield of sorghum grown after wetland rice in a tropical soil. Fd. Crops Res. **9**:291-303

Hurd, E.A. 1968. Growth of roots of seven varieties of spring wheat at high and low moisture levels. Agron. J. **60**: 201-205

IAEA, 1975. Root Activity Pattern of Some Tree Crops. Technical Report series No.170, IAEA, Vienna. p.154

*Ibragimov, O. and Nazarov, M. 1982. Effect of topping on the root system of cotton. Khlop Royood Stoc. **7**: 36-37

*Ikegaya, K. and Hiramine, S. 1978. Soil structure of various ages of field derived tea from diluvial organic soil and effect of rainfall on the water movement in tea fields. Study tea **55**: 46-70

*Inforzato, R. and Alvarez, R. 1957. Distribution of the root system of the sugarcane variety Co-290 in a soil of the true terra rossa type. Bragantia **16**: 1-13

*Inforzato, R., Giacomelli, E.J. and Rochelle, L.A. 1968. Pineapple root system, 4, 8 and 12 month after planting at the beginning of the dry season in a red latersol soil. Bragantia **27**: 135-141

*Inforzato, R., Campos, H.R. and Camargo, L. 1970. Root system development in tomato plants of different ages. Bragantia **27**: 135-141

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall Inc., USA, p. 38-183

Jadhav, B. B. 1987. Effect of partial shading on the yield of rice. Indian J. agric. Sci. **57:** 515-516

Jalil, M.H.A. 1982. Studies on root distribution in coconuts. Abstr. Coconis Newsl. **4:** 6

John, S. 1993. Sesamum. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill publishing Co. Ltd. New Delhi, p. 104-107

Joshi, A.B. 1961. Sesamum - a Monograph, Indian Central Oilseeds Committee, Hyderabad, p.104

Kaigama, B.K. 1977. Root and top growth of irrigated and non-irrigated grain sorghum. Crop Sci. **1:**555-559

Kanaruddin, S. S. W.1983. The effect of shade on growth of tomato (Lycopersicum esculentum mill) and ease of rooting of its cuttings. MARDI Res. Bull. **11:** 187-192

Karnok, K.J. and Kucharski, R.T. 1982. Design and construction of a rhizotrone-lysimeter facility at the Ohio State University. Agron. J. **74:** 152-156

Kamath, M.B. 1971. Classification of some wheat and paddy varieties according to root distribution pattern. Proceedings of the symposium on Use of Radioisotopes in Agriculture and Animal Husbandry Research, 629-637

Kapur, M.L. and Sakhor, G.S. 1985. Rooting pattern, nutrient uptake and yield of pearl millet (Pennisetum typhoideum pers.) and cotton (Gossypium herbaceum) as affected by nutrient availability from the surface and subsurface soil layers. Fd. Crops Res. **10**: 77-86

Katyal, J.C. and Subbiah, B.V. 1971. Root distribution pattern of some wheat varieties Indian J. agric. Sci. **41**:786-790

KAU, 1989. Package of Practices Recommendations 'Crops'. Kerala Agricultural University, Directorate of Extension, Thrissur, p. 56, 182

Kawata, S., Katano, M. and Yamazaki, K. 1977. Root system formation in rice plants in ill drained and well drained paddy field conditions. Jap. J. Crop. Sci. **46**: 261-268

Khader, K.B.A. and Kumar, H.P. 1985. Root proliferation in cashew seedlings as influenced by soil texture. Indian Cashew J. **15**: 7-14

Khader, K.B.A. 1986. Distribution of cashew roots in the laterite soils of West Coast of India. Indian Cashew J. **17**: 9-15

Khader, K.B.A., Bhat, K.S. and Venugopal, K. 1993. Rooting patterns of Tropical Crops. Salam, M. A. and Wahid, P. A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 204-216

*Krauss, G., Wobst, W. and Gartner, G. 1934. Hamusauflage und Bodendurchwurzelung im Eibenstocker Granitgebiet. Tharandter Forstl. Jahrb. **85**: 290-370

Krishnamoorthy, V.V. and Iruthyaraj, M.R. 1984. Irrigation and phosphorus effects on root distribution and yield of sorghum. Sorghum Newsl. **27:** 55

Krishnan, B.M. and Shanmugavelu, K.G. 1980. Effect of different soil moisture depletion levels on the root distribution of bananas cv. Robusta. S. Indian Hort. **28:** 24-25

Krishnankutty, N. K. 1983. Shade response of common rainfed intercrops of coconut. Part II. Vegetables, M. Sc. (Ag.) Thesis. Kerala Agricultural University, Vellanikkara, Kerala, India

Kumar, R. 1977. Response of barley to stored soil moisture, supplemental irrigation and applied nitrogen. Ph.D. Thesis, Punjab Agricultural University, Ludhiana

Kumar, V. K. 1993. Rubber Rooting patterns of Tropical Crops. Salam, M. A. and Wahid, P. A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, P. 235-241

Kumaraswamy, K., Natarajan, C.P., Subramanian, T.L., Balasubramanian, S. and Krishnamoorthy, K.K. 1977. Studies on the root distribution of rice (Oryza sativa. L.) varieties using ^{32}P plant injection technique. Madras agric. J. **5:** 285-289

Kummerow, J. 1980. Adaptation of roots in water stressed native vegetation. Adaptation of Plants to Water and and High Temperature Stress. Turner, N.C. and Kramer, P.J. (ed.) Wiley Interscienco, p. 57-73

Kushwah, B.L., Nelliat, E.V., Markose, V.T. and Sunny, A.F. 1973. Rooting Pattern of Coconut. (Cocos nucifera L.) Indian J. Agron. **18:** 71-74

Lakshmanan, R. 1985. Scheduling of irrigation of cucurbitaceous vegetable. M.Sc.(Ag.) Thesis, Kerala Agricultural University, Vellanikkara, India

Lal, R. and Maurya, P.R. 1982. Root growth of some tropical crops in uniform columns. Pl. Soil **68:** 193-206

*Lee, H.A. 1926. Progress report on the distribution of cane roots in the soil under plantation conditions. Hawaii Planters Rec. **30:** 511-519

Lee, H.A. 1927. The distribution of the roots of sugarcane in the soil in the Hawaii islands. Pl. Physiol. **1:** 363-378

*Lee, H.A. and Weller, D.M. 1927. The progress of sugarcane roots in the soil at different stages. Asso. Hawaii Sugar Technol. **6:** 69-72

Logsdon, S. D., Reneav, R.S. and Parker, J. C. 1987. Corn seedling root growth as influenced by soil physical properties. Agron. J. **79:** 221-224

Long, F.L. 1981. The influence of sorghum-sudangrass roots on nutrient leaching. Agron. J. **73:** 537-546

Loomis, E.L. and Crandall, P.C. 1977. Water consumption of cucumber during vegetative and reproductive stage of growth. J. Am. Soc. Hort. Sci. **102:** 124-127

Lott, W.L., Satchell, D.P. and Hall, N.S. 1950. A tracer element technique in the study of root extension. Proc. Am. Soc. Hort. Sci. **55:** 27-34

Magnaye, A. B. 1969. Studies on the root system of healthy and cadang-cadang affected coconut trees. Philippines J. Pl. Industries **34**: 143-154

Maizlish, N. A., Fritton, D.D. and Kendall, W.A. 1980. Root morphology and early development of maize at varying levels of nitrogen. Agron. J. **72**: 25-31

Martin. J.P. and Eckart, R.C. 1933. The effect of various intensities of light on the growth of the H 109 variety of sugarcane. Hawaii Planters Rec. **37**:53-66

Mc Dougall, W.B. 1916. The growth of forest tree roots. Am. J. Bot. **3**: 384-392

Mc kee, G.C. 1967. Root growth in relation to top growth in catterton and wilson varieties of maryland tobacco. Bull. Univ. Md. Agric. Exp. Stn. 478

Michael, K. J. 1966. Studies on the root system of the coconut palm. Indian Cocon. J. **17**: 85-92

Miller, D. E. and Martin, M. W. 1987. The effect of irrigation regime and sub-soiling on yield and quality of three potato cultivars. Am. Potato J. **64**: 117-125

Mohankumar, C. R. 1993. Colocasia. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 133-139

Mohapatra, A. R., Bhat, N. T. and Khader, K.B.A. 1971. Principles and practices of fertilizer use in arecanut. Arecanut and Spices Bull. **11**:1-3

Moore, H. M. and Hirsch, A. M. 1983. Effect of boron deficiency on mitosis and incorporation of tritiated thymidine into nuclei of sunflower root tips. Am. J. Bot. **70**: 165-172

Nagaraj, G. and Gopalachari, N. C. 1977. Root distribution pattern of flue-cured tobacco in light and heavy soils. J. Nucl. Agric. Biol. **6**: 49-50

Nagaraj, G. and Gopalachari, N. C. 1979 Rooting pattern of some new varieties of flue-cured tobacco (Nicotiana tabacum). J. Nucl. Agric. Biol. **8**: 25-47

Nair, P. K. R. 1979. Intensive multiple cropping with coconut in India. Principles, Programme and Prospects. Varky Paul Paray, Berlin and Hamburg. p. 20-37

Nair, M. A. 1993. Oilpalm. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p.217-222

Narang, R. S. and Gill, M.S. 1993. Wheat. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 16-18

Narayanan, A. and Sheldrake,A. R. 1976. Comparison of growth and development of pigeonpea grown as a sole crop and intercropped with sorghum. Pulse physiology Annual Report Part I. International Crops Research Institute for the semi - Arid Tropics, Patancheru, India, p 19-45

Narayanan, A. and Syamala, R. 1989. Response of pigeonpea (Cajanus cajan (L.) Mill sp.) genotypes to aluminium toxicity. Proc. Int. Congr. Pl. Physiol. Feb. 15-20, 1988, Society for Plant Physiology and Biochemistry, New Delhi

Pandey, R.K., Singh, V. B. and Singh, B. K. 1980. Effect of reduced sunlight on growth and yield of chickpea. Indian. J. agric. Sci. **50**: 405-411

Panse, V.G. and Sukhatme, P.V. 1976. Statistical Methods for Agricultural Workers. ICAR, New Delhi, p. 347

*Pasinova, G. B. 1960. A study of the root sytem of fruit trees grown along high ways. Ved. Praco Ovocn Csazvy Holorousich **1**: 171-188

Peacock, J. M. and Heinrich, G. M. 1984. Light and temperature responses in sorghum. Agrometerology of Sorghum and Millet in the Semi-Arid Tropics. Proceedings of the International symposium, International Crops Research Institute for the Semi-Arid Tropics, Patencheru, p. 143-158

Pillai, R. R. 1990, Quality of oil of clocimum (Ocimum gratissimum Linn.) as influenced by stages of harvest and shade. M.Sc. (Ag.) Thesis, Kerala Agricultural University, Vellanikkara, Kerala,India

Piper, C.S. 1950. Soil and Plant Analysis. Academic Press, New York, p. 368

*Pomier, M. and Bonneau, X. 1984. Development du systeme racinarie du cocotier en fonction du milieu en cota d' Ivoire. Oleagineux **42**: 409-422

Prameela, P. 1990. Screening different morphoypes of colocasia Colocasia esculenta L. Schott) for shade tolerance. M. Sc. (Ag.) Thesis, Kerala Agricultural University, Vellanikkara, Kerala, India

Purseglove, J. W. 1975. Tropical crops - Monocotyledons, Longman group Ltd. London, p. 325

Nelson, W.W. and Allmaras, R.R. 1969. An improved monolith method for excavating and describing roots. *Agron*. *J*. **61**: 751-755

Newell, R. L. and Wilhelm, W. W. 1987. Conservastion tillage and irrigation effect on corn root development. *Agron*. *J*. **79**: 160-165

Nutman, F. J. 1933. The root system of *Coffea arabica* in typical soils of British East Africa. *Emp*. *J*. *Exp*. *Agric*. **1** : 211-284

Nybe, E. V. 1986. Investigations on the nutrition of black pepper (*Piper nigrum* L.). Ph.D. Thesis, Kerala Agricultural University, Vellanikkara, Kerala,India

Okoli, P.S.O. and Wilson, G. F. 1986. Response of cassava to shade under field conditions. *Fd*. *Crops Res*. **14**: 349-359

Ong, C. K. and Monteith, J. L. 1985. Response of pearl millet to light and temperature. *Fd*. *Crops Res*. **11**: 141-160

Oskamp, J. and Batjer, L. P. 1932. Soils in relation to fruit growing in New York Part II. Size, Production and rooting habit of apple trees on different soil types in the Hilton and Morton areas, Monroe country. *Cornell Univ*. *Agric*. *Exp*. *Stn*. *Bull*. **550**:45

*Ouvrier, M. and Brunin, G. 1974. Densites racinaires dans Vne cocoteraie industrielle and techniques d epandage des engrains. *Oleagineux* **29**: 15-17

Qun, L.C. 1984. Radiotracer studies on root activity and foliar spray of rubber trees (Hevea brasiliensis). Proceedings of the International conference on soils and nutrition of perennial crops, Aug, 13-15, 1984 Malaysian Society of Soil Science, Kuala Lumpur, p. 22-24

Qun, L.C. and Xingke, S. 1986. Distribution of root activity of young rubber trees. Chinese J. Trop. Crops. **7**: 24-28

Racz, G.J., Rennie, D.A. and Hutcheon, W.L. 1964. The ^{32}P injection method for studying the root system of wheat. Can. J. Soil Sci. **44**:100-108

Rahaman, F and Freed, M. 1977. Studies on spacing of tea. Proceedings of the Twenty Eight Tocklai Conference, Tea Research Association, Jorhat, p.8-15

Rai, R. S. V. and Murthy, K. S. 1977. Note on the the effect of low light intensity and submergence on late duration varieties of indica rice. Indian J. agric. Sci. **47** 367-369

Rajeevan, P. K. 1993. Pineapple. Rooting Patterns of Tropical Crops. Salam, M. A. and Wahid, P. A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 310

Ramadasan, A. and Satheesan, K.V. 1980. Annual Report, Central Plantation Crops Research Institute, Kasargode, Kerala, India, p. 813

*Ramanujam, T., Nair, M. G. and Indira, P. 1984. Growth and development of cassava (Manihot esculenta crantz) genotypes under shade in coconut garden. Turrialba. **34**: 267-274

Qun, L.C. 1984. Radiotracer studies on root activity and foliar spray of rubber trees (Hevea brasiliensis). Proceedings of the International conference on soils and nutrition of perennial crops, Aug, 13-15, 1984 Malaysian Society of Soil Science, Kuala Lumpur, p. 22-24

Qun, L.C. and Xingke, S. 1986. Distribution of root activity of young rubber trees. Chinese J. Trop. Crops. 7: 24-28

Racz, G.J., Rennie, D.A. and Hutcheon, W.L. 1964. The ^{32}P injection method for studying the root system of wheat. Can. J. Soil Sci. **44**:100-108

Rahaman, F and Freed, M. 1977. Studies on spacing of tea. Proceedings of the Twenty Eight Tocklai Conference, Tea Research Association, Jorhat, p.8-15

Rai, R. S. V. and Murthy, K. S. 1977. Note on the the effect of low light intensity and submergence on late duration varieties of indica rice. Indian J. agric. Sci. **47** 367-369

Rajeevan, P. K. 1993. Pineapple. Rooting Patterns of Tropical Crops. Salam, M. A. and Wahid, P. A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 310

Ramadasan, A. and Satheesan, K.V. 1980. Annual Report, Central Plantation Crops Research Institute, Kasargode, Kerala, India, p. 813

*Ramanujam, T., Nair, M. G. and Indira, P. 1984. Growth and development of cassava (Manihot esculenta crantz) genotypes under shade in coconut garden. Turrialba. **34**: 267-274

Rao, M. R. 1993. Groundnut. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 92-103

Reddy, K. S. and Venkateswarlu, J. 1971. Active root distribution of two castor varieties. Proc. Symp. Radn. Radioisotopes soil studies Pl. Nut., Bangalore, p 417-427

Reiche, V. H. 1972. Triticale, compared with other small grains in Tennesse. Tenn. Farm and Home Sci. **83:** 27-29

Rennie, D.A. and Halstead, E.H. 1964. A ^{32}P injection method for quantitative estimation of the distribution and extent of cereal grain roots (ed). IAEA, Vienna Isotopes and Radiation in Soil Plant Nutrition Studies. Proceedings of the symposium on the use of isotopes and radiation in soil-plant nutrition studies jointly organised by International Atomic Energy Agency and the Food and Agricultural Organization of the United Nations, 28 June-2 July 1965, Ankara, p. 489-504

Richards, L. A. 1947. Pressure membrane apparatus - construction and use. Agric. Engg. **28:** 451-454

Robertson, W. K. 1980. Effect of plant water stress on root distribution of corn, soybeans and pea nuts in sandy soil. Agron. J. **72:** 548-550

Rogers, W. S. 1932. The root development of an apple tree in a wet clay soil. J. Pomol. Hortic. Sci. **10:**219-227

Rudaraju, A. R. and Varma, S. C. 1974. Root distribution and root biomass production of rice under different soil water regimes in Entisole of Northern India. IRRI Newsl. **4:** 5

Russell, S.R. and Ellis, F.B. 1968. Estimation of the distribution of plant roots in soil. Nature 27: 582-583

*Sachs, J. 1873. Uber das Wachstum der Haupt-und Nebenwurzeln. Abr. Bot. Inst. 3: 395-477, 584-634.

Saikia, D. N. 1985. Influence to certain soil physical condition, nutrient availability their uptake and growth of tea. Ph.D. Thesis, Assam Agricultural University, Jorhat

Saikia, D. N. 1988. Bulk density, water holding capacity and feeder root distribution under tea plant. Proceedings of National Seminar on Current Trends in Soil Research, Indian Society of Soil Science, p. 12

Salam, M. A. 1984. Fertilizer insecticide interactions on growth root activity and yield of lowland rice Ph.D. Thesis, Tamilnadu Agricultural University, Coimbatore, India

Salam, M. A. and Subramanian, S. 1988. Influence of soil texture on rice crop performance. IRRI Newsl. 2:15

Salam, M. A. 1993. Rice. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 1-15

Salam, M. A. and Wahid, P. A. 1993. Rooting Patterns of Tropical Crops. Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 331

Samson, J. A. 1980. Tropical Fruits. Longman group Ltd., New York p. 208-245

Sankaran, S. and Pothiraj, P. 1993. Cotton. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 134-140

Schuurmann, J. J. and Goedewagen, M. A. J. 1971. Methods for the Examination of Root Systems and Roots. Wageninger pudoc, p. 250

Selvaraj, K. and Palaniappan, S.P. 1977. Studies on root growth and penetration of cotton in relation to soil strength and moisture regime. Curr. Res. **6**:10-11

Sen, L. 1983. Root zone studies in coconut under Gujarat conditions. Indian cocon. J. **14**: 4

Seshadri, V. S. 1986. Cucurbits. Vegetable crops in India. Bose, T. K. and Som , M.G. (ed.) Naya Prakash, Calcutta, p. 293-342

Sharma, B. D. 1987. Water and nitrogen uptake of wheat as related to nitrogen application rate and irrigation water regime. Ph.D. Thesis, Indian Institute of Technology, Kharagpur

Shrinivas, S. and Subbiah, B. V. 1973. Comparison of plant injection and leaf smearing technique with ^{32}P for root distribution studies of bajra (Pennisetum typhoides stapf.). Newsl. Indian Soc. Nucl. Tech. Agric. Biol. **2**: 42-45

Shrinivas, S., Subbiah, B. V. and Oza, A. M. 1979. Proceedings of the International Symposium. on Improving Crop and Animal Productivity by Nuclear and Allied Techniques, New Delhi p. 92

Sankaran, S. and Pothiraj, P. 1993. Cotton. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 134-140

Schuurmann, J. J. and Goedewagen, M. A. J. 1971. Methods for the Examination of Root Systems and Roots. Wageninger pudoc, p. 250

Selvaraj, K. and Palaniappan, S.P. 1977. Studies on root growth and penetration of cotton in relation to soil strength and moisture regime. Curr. Res. **6**:10-11

Sen, L. 1983. Root zone studies in coconut under Gujarat conditions. Indian cocon. J. **14**: 4

Seshadri, V. S. 1986. Cucurbits. Vegetable crops in India. Bose, T. K. and Som , M.G. (ed.) Naya Prakash, Calcutta, p. 293-342

Sharma, B. D. 1987. Water and nitrogen uptake of wheat as related to nitrogen application rate and irrigation water regime. Ph.D. Thesis, Indian Institute of Technology, Kharagpur

Shrinivas, S. and Subbiah, B. V. 1973. Comparison of plant injection and leaf smearing technique with ^{32}P for root distribution studies of bajra (Pennisetum typhoides stapf.). Newsl. Indian Soc. Nucl. Tech. Agric. Biol. **2**: 42-45

Shrinivas, S., Subbiah, B. V. and Oza, A. M. 1979. Proceedings of the International Symposium. on Improving Crop and Animal Productivity by Nuclear and Allied Techniques, New Delhi p. 92

Singh, K. 1978. Effect of soil moisture and nitrogen levels on Triticale as compared with wheat and barley. Ph.D. Thesis, Punjab Agricultural University, Ludhiana

*Sioussaram, D. 1968. Observations preliminaries Sur l' enracinement des bananiers dans les sols de la station de Neufchateau, Guadeloupe. Fruits 23:473-479

Sivasankar, A., Subbarao, I. V. and Reddy, P.R. 1981. Influence of seed size and phosphorus levels on root production and phosphorus uptake in groundnut (*Arachis hypogaea* L). Legume Res. **4**:78-82

Sobhana, A. 1985. Pattern of root activity in bananas under irrigated and rainfed conditions. M.Sc.(Hort.) Thesis, Kerala Agricultural University, Vellanikkara, India

Soong, N. K., Pushparaja, E., Singh, M.M. and Talibudeen, O. 1971. Determination of active root distribution of *Hevea brasiliensis* using radioactive phosphorus. Proceedings of symposium on soil fertility evaluation, New Delhi, p. 309-375

Sreekumari, N. T., Abraham, K. and Ramanujam, T. 1989. The performance of cassava under shade. J. Root Crops **14**: 43-52

Starcova, H. and Vicherkova, M. 1985. The importance of calcium for sunflower growth and water economy. Biologia **15**: 407-422

Stevenson, G.C. 1936. Investigations into the root development of the sugarcane in Barbados II. Further observation on root development in several varieties under one environment. Bull. 2, British West Indies Central Sugarcane Breeding Station

Subbarao, W. and Sathe, A. 1974. Root activity of high yielding varieties of rice. Proceedings of symposium on uses of radiation and radioisotopes in studies of plant nutrition. G B Pant University of Agriculture and Technology, Pantngar, P. 578-586

Subbarao, G.V. 1988. Salinity tolerance in Pigeon pea (*Cajanus cajan* (L.) Millsp) and its wild relatives. Ph.D. Thesis, Indian Institute of Technology, Kharagpur

Subbiah, B.V., Katyal, J.C., Narasimham, R.L. and Dakshinamurthi, C. 1968. Preliminary investigation on root distribution of high yielding wheat varieties. *Indian J. Appl. Radiat. Isot.* **19**: 385-390

Sulladmath, V.V., Krishnamurthy, K. and Rai, B.G.M. 1979. Cashew Research in Karnataka. Rao, E.V.V.B. and Khan, H.H. (ed.) *Cashew Research and Development*. Proceedings of the International Symposium on Cashew, Indian Society of Plantation Crops, Kasaragod, p.295

Swabrick, J.T. 1964. Growth and root distribution of shade plants. *Trop Agric. Trin.* **41**: 313-315

Tay, C.Y. 1982. Apparent rooting depth and relative root biomass distribution profile of four rice varieties. Proceedings of paddy workshop, Bumbong Lima, Province, Wellesley, Malaysia

Tsakiris, A. and Northwood, P.J. 1967. Cashewnut production in Southern Tanzania-IV. The root system of cashewnut tree. *East Afr. Agric. Forestry J.* **33**: 83-87

*Turaev, T. 1983. Density of cotton plants with deep soil loosening. Khlop Royood Stop. **10**: 24-25

Varghese, S. 1989. Screening of varieties of ginger and turmeric for shade tolerance. M. Sc (Ag.) Thesis, Kerala Agricultural University, Vellanikkara, Kerala, India

Venkateswarlu, B. and Srinivasan, T. E. 1978. Influence of low light intensity on growth and productivity in relation to population pressure and varietal reaction in irrigated rice. Indian J. Pl. Physiol. **27**: 162-170

Venkateshwarlu, J. and Venkatasubbaiah, V. 1984. Response of rabi sorghums to applied nutrients and sub-soil fertilization. Annual Sorghum Workshop, AICSIP Dharwad, India, p. 76-80.

Vergara, B.S. 1979. A Farmer's Primer on Growing Rice, International Rice Research Institute, Manila, Philippines, p. 55-64

Vidyadharan, K.K. and Peethambaran, C.K. 1979. Root studies in cashew air layers and seedlings. Rao, E.V.V.B. and Khan, H. H. (ed.) Cashew Research and Development. Proceedings of the International Symposium on cashew, Cochin, Indian Society of Plantation Crops, Kasargod, 1984, p.296

Vijayalakshmi, C., Natarajarathnam, N. and Sreerangaswamy, S. R. 1987. Effect of light stress on yield attributes in rice. Madras agric. J. **74**: 550

Virmani, S. M. 1971. Rooting pattern of dwarf wheats. Indian J. Agron. **16**: 33.35

Vittal, K.P.R. and Subbiah, B.V. 1982. Development of a gamma probe technique for monitoring root pattern of pearl millet under field conditions. J. Nuclear Agric. Biol. **11**: 15-17

Vittum, M.J. and Flocker, W.T. 1967. Vegetable Crops. Irrigation of Agricultural Lands. Hagan, R.M., Haise, H.R. and Edminster, J.W. (ed.) American Society of Agronomy, Wisconsin, USA, p. 674-685

Vogt, C. and Persson, H. 1991. Measuring growth and development of roots. Techniques and Approaches in Forest Tree Ecophysiology. Lassoie, J.P. and Hindey, T.M. (ed.) p. 477-501

*Vuorinone, J. 1958. Apple tree root systems. Mataloust. Aikakaus. **30**: 41-57

Wahid, P.A., Kamalam, N.V. and Sankar, S.J. 1985. A device for soil injection of ^{32}P solution in root activity studies of tree crops. J. Pltn. Crops **16**: 62-64

Wahid, P.A. and Kamalam,N.V. 1989. Root activity pattern of cocoa. J. Nucl. Agric. Biol. **18**: 153-156

Wahid, P. A., Kamalam, N. V., Ashokan, P.K. and Vidyadharan, K. K. 1989. Root activity pattern of cashew (Anacardium occidentale L.) in laterite soil. J. Pltn. Crops **17**: 85-89

Wahid, P. A., Kamalam, N. V. and Anilkumar, K. S. 1993. Coconut. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 188-203

Wahid, P.A., Khader, K.B.A. and Salam, M.A. 1993. Rooting Patterns of Tropical Crops. Salam, M.A. and Wahid, P.A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 318

Wahid, P.A., Sankar, S. J. and Nybe, E. V. 1993. Black pepper. Rooting Patterns of Tropical Crops. Salam, M. A. and Wahid, P. A. (ed.) Tata Mc Graw Hill Publishing Co. Ltd., New Delhi, p. 242-248

Wardlaw, C.W. 1972. Banana Diseases. Including Plantains and Abana, Longman group Ltd., London p. 40-42

Watanabe, F. S. Olsen, S. R. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCo_3$ extract from Proc. soil Sci. Soc. Am. **29**: 677-678

Weaver, J.E. 1919. The ecological Relations of Roots. Carnegie Institution of Washington Publ. Washington, p. 286

Weaver, J.E. 1926. Root Development of Field Crops. Mc Graw Hill Book Company, INC New York, p. 473

Wiebing, R. and Schepers, A. 1977. Growth and yield of potato on deep ploughed and non-deep ploughed peat land settlement soil at Borger compagine. Bedniifsontwikkeling **8**: 1136-1141

Wessel, M. 1971. Fertilizer requirement of Cocoa (Theobromo cacao L.) in South-Western Nigeria. Netherland J. Agric. Sci. **19**: 88-91

Whitaker, W.T. and Davis, U.N. 1962. Cucurbits-Botany Cultivation and Utilisation. Interscience Publishers, Inc., New York. p. 145-150

Wiersum, L.K. 1979. A comparison of the behaviour of some root system under restricted aeration. Netherland J. Agric. Sci. **27**: 92-98

*Wu, X.M., Zheng, P.X. and Yin, H.R. 1984. Measurement of cotton roots in plastic knitted bags. China Cottons **4**: 25-31

*Yamashita, L., Zusheng, L. and Wanfang, Z. 1985. Anatomical and biochemical studies during rooting in tea cutting. J. Tea Sci. **5**: 19-28

*Zabara, Y. M. 1978. The effect of irrigation on root distribution in cucumber grown on derno-podzolic soil. Referativny Zhurnal **8**: 429

*** Original not seen**

Appendices

Appendix 1

Weather data (weekly average) for the experimental period
(from 4-6-1993 to 3-6-1994)

Standard Week No.	Month and Date	Total rainfall (mm)	No. of rainy days	Temperature Max. °C	Temperature Min. °C	Relative humidity Forenoon%	Relative humidity Afternoon%	Sun shine hours	Evaporation mm/day
23	Jun 4-10	236.6	6	29.6	23.3	95	80	1.8	3.5
24	Jun 11-17	237.9	7	29.2	23.8	95	80	1.8	3.5
25	Jun 18-24	85.5	4	30.4	24.5	94	73	4.4	3.8
26	Jun 25-Jul1	186.4	5	29.2	23.6	94	82	2.9	3.3
27	July 2-8	188.9	6	28.6	22.7	95	78	2.0	3.1
28	July 9-15	167.8	7	28.7	22.6	92	83	1.8	3.1
29	July 16-22	128.1	6	28.9	22.9	94	76	2.8	2.9
30	July 23-29	101.0	6	28.0	23.1	94	80	2.9	3.1
31	July 30-Aug 5	96.4	6	29.1	23.7	95	76	3.6	3.8
32	Aug 6-12	54.9	4	29.9	23.5	95	75	4.6	3.9
33	Aug 13-19	66.3	6	29.2	23.1	93	78	3.3	3.7
34	Aug 20-26	61.9	4	29.8	23.2	96	74	5.6	4.0
35	Aug 27-Sept 2	33.6	2	29.8	23.5	95	73	6.5	3.4
36	Sept 3-9	23.7	2	29.4	23.0	93	75	3.9	3.05
37	Sept 10-16	11.5	1	30.7	23.1	93	69	7.5	3.45
38	Sept 17-23	23.2	3	31.7	23.4	94	63	8.3	4.1
39	Sept 24-30	14.9	1	31.0	23.2	91	65	6.7	3.9
40	Oct 1-6	149.8	6	29.8	23.4	93	82	3.8	2.9
41	Oct 7-13	181.5	5	29.3	23.2	95	78	2.1	2.5
42	Oct 14-20	102.7	4	31.2	23.2	90	74	4.9	2.8
43	Oct 21-27	83.4	2	31.9	23.5	92	72	6.3	2.8
44	Oct 28-Nov 4	3.2	0	32.5	24.2	80	63	7.1	3.8
45	Nov 5-11	58.3	3	30.4	23.9	84	70	4.0	3.5
46	Nov 12-18	12.7	2	31.8	23.0	91	66	5.6	3.0
47	Nov 19-25	1.2	0	31.8	23.1	72	54	7.6	4.6
48	Nov 26-Dec2	0.8	0	31.4	24.3	77	60	5.8	5.7
49	Dec 3-9	17.0	2	31.2	22.7	84	62	3.4	3.4
50	Dec 10-16	0.0	0	32.5	21.9	75	47	5.1	5.05
51	Dec 17-23	1.0	0	31.0	23.8	75	59	5.5	5.6
52	Dec 24-31	0.0	0	31.6	23.5	72	47	6.1	6.1
1	Jan 1-7	0.0	0	32.6	23.6	69	44	10.0	7.5
2	Jan 8-14	0.0	0	32.2	22.7	73	43	9.0	7.3
3	Jan 15-21	19.4	1	33.6	23.7	83	49	7.7	4.9
4	Jan 22-28	0.0	0	32.8	22.0	65	32	9.2	9.7
5	Jan 29-Feb 4	0.0	0	33.9	21.0	81	37	9.8	5.9
6	Feb 5-11	0.0	0	34.6	23.8	17	43	7.8	6.3
7	Feb 12-18	1.7	0	34.4	23.1	86	45	8.2	4.7
8	Feb 19-25	0.0	0	35.7	23.0	83	36	7.8	6.1
9	Feb 26-Mar 4	0.0	0	35.8	22.5	56	20	10.2	8.8
10	Mar 5-11	0.0	0	37.2	21.8	71	20	10.1	7.2
11	Mar 12-18	0.0	0	37.4	23.7	83	36	9.8	6.8
12	Mar 19-25	1.2	0	35.2	25.4	90	55	8.8	5.8
13	Mar 26-Ap 1	19.8	1	35.4	25.4	86	57	8.3	5.6
14	Ap 2-8	37.1	3	35.8	23.5	85	54	8.3	5.4
15	Ap 9-15	79.8	4	34.8	23.7	90	58	6.1	4.9
16	Ap 16-22	27.6	2	34.3	24.5	89	61	8.5	4.4
17	Ap 23-29	20.7	1	34.6	25.3	86	63	7.0	4.5
18	Ap 30-May 6	0.0	0	34.3	25.0	85	58	10.2	5.1
19	May 7-13	11.6	1	34.1	25.2	84	58	9.0	4.6
20	May 14-20	82.2	2	34.0	24.6	92	62	7.5	4.5
21	May 21-27	3.5	0	33.9	25.3	89	62	7.6	4.3
22	May 27-Jun3	171.8	7	30.2	22.8	95	80	0.0	2.6

Appendix II Abstract of Anova

Radioactivity and percentage distribution of radioactivity at the different zones of the rhizosphere soil of banana as influenced by light and soil moisture regimes

Source	Degrees of freedom	Mean square	
		Radioactivity (cpm $\sqrt{x+1}$)	Percentage radioactivity
Replication	3	0.796*	0.084*
Lateral distance (A)	4	118.854*	12.928*
Depth (B)	3	47.241*	4.989*
AB	12	11.715*	2.785*
Light regimes (C)	1	89.348*	9.135*
AC	4	12.700*	4.399*
BC	3	3.036*	1.490*
ABC	12	2.267*	1.280*
Soil moisture regimes(D)	1	7.797*	2.643*
AD	4	10.164*	3.042*
BD	3	2.779	1.450*
ABD	12	3.633*	1.530*
CD	1	16.458*	4.236*
ACD	4	12.724*	3.656*
BCD	3	4.101*	1.501*
ABCD	12	3.596*	1.307*
Error	237	1.147	0.114
Total	319		

* Significant at 5% level

Appendix III Abstract of Anova

Root dry weight and percentage root dry weight at the different zones of the rhizosphere of banana influenced by light and soil moisture regimes at different phenological phases

Source	Degrees of freedom	Mean square: Root dry weight (g)	Mean square: Percentage root dry weight
Replication (A)	3	1.018*	0.001*
Lateral distance (B)	5	1464.779*	1.144*
Depth (C)	5	1029.286*	0.804*
BC	25	252.931*	0.198*
Phase (D)	3	598.881*	0.468*
BD	15	138.183*	0.108*
CD	15	88.337*	0.069*
BCD	75	19.582*	0.015*
Light environment(E)	1	1432.148*	1.118*
BE	5	256.250*	0.200*
CE	5	215.024*	0.168*
BCE	25	35.184*	0.027*
DE	3	258.882*	0.202*
BDE	15	44.630*	0.035*
CDE	15	56.492*	0.044*
BCDE	75	9.273*	0.007*
Soil moisture regimes (F)	1	73.392*	0.057
BF	5	22.555*	0.018*
CF	5	2.620*	0.002*
BCF	25	1.601*	0.001*
DF	3	75.467*	0.059
BDF	15	15.193*	0.012*
CDF	15	5.976*	0.005*
BCDF	75	2.515*	0.002*
EF	1	32.338*	0.025*
BEF	5	22.465*	0.018*
CEF	5	2.740*	0.002*
BCEF	25	1.762*	0.001*
DEF	3	53.089*	0.041*
BDEF	15	13.789*	0.011*
CDEF	15	3.601*	0.003*
BCDEF	75	2.031*	0.002*
Error	1725	0.000	0.165
Total	2303		

* Significant at 5% level

Appendix IV Abstract of Anova

Growth characters of banana as influenced by light and soil moisture regimes at different phenological phases

Source	Degrees of freedom	Mean squere			
		Number of roots	Length of longest root	Plant height	Number of leaves
Replication	2	6.34	74.18*	3.54*	0.75
Phase (A)	3	175743.70*	973.69*	13358.97*	95.42*
Light regimes (B)	1	744.21*	614.90*	4887.40*	6.75
AB	3	285.63*	34.21	392.73*	0.53
Soil moisture regimes(C)	1	1092.54*	208.33*	235.19*	12.00
AC 3	3	3.52*	30.59	76.83*	1.00
BC 1	3	3.50*	21.87	437.12*	0.33
ABC 3	1	60.08	32.42	99.60*	1.56
Error	30	2.71	18.75	4.38	0.44
Total	47				

* Significant at 5% level

Appendix V Abstract of Anova

Radioactivity and percentage radioactivity at the different zones of the rhizosphere soil of colocasia as influenced by light regimes

Source	Degrees of freedom	Mean square: Radioactivity (cpm x+1)	Mean square: Percentage radioactivity
Replication	5	23.246*	0.282
Lateral distance (A)	3	422.91*	29.250*
Depth (B)	3	31.017*	8.530*
AB	9	30.004*	7.360*
Light regimes (C)	1	83.979*	3.266*
AC	3	18.604	0.650*
BC	3	7.552	1.435*
ABC	9	9.627	0.328*
Error	155	9.772	0.126
Total	191		

* Significant at 5% level

Appendix VI Abstract of Anova

Root dry weight and percentage root dry weight at the different zones of the rhizosphere of colocasia as influenced by light regimes at different phenological phases.

Source	Degrees of freedom	Mean square	
		Dry weight (g)	Percentage dry weight
Lateral distance (A)	4	17.395*	9.235*
Depth (B)	4	11.861*	6.298*
AB	16	8.155*	4.330*
Phase (C)	3	0.519*	0.276*
AC	12	0.320*	0.170*
BC	12	0.659*	0.350*
ABC	48	0.407*	0.216*
Light regimes (D)	1	4.503*	2.391*
AD	4	3.220*	1.709*
BD	4	1.716*	0.911*
ABD	16	1.843*	0.979*
CD	3	0.182*	0.097*
ACD	12	0.208*	0.110*
BCD	12	0.162*	0.086*
ABCD	48	0.162*	0.086*
Error	400	0.008	0.004
Total	599		

* Significant at 5% level

Appendix VII Abstract of Anova

Growth characters of colocasia as influenced by light regimes at different phenological phase

Source	Degrees of freedom	Mean Square				
		Length of longest root	Plant height	Number of tillers	Number of leaves	Total dry matter
Replication	2	3.668	1.04	0.88	4.63	10.46
Phase (A)	3	187.44*	908.49*	33.49*	49.61*	16548.5*
Light regimes(B)	1	54.60*	88.94*	7.04*	16.67*	84.65*
AB	3	4.37	1.72	3.71	0.33	245.28
Error	14	2.03	4.30	1.61	0.48	10.75
Total	23					

* Significant at 5% level

Appendix VIII Abstract of Anova

Nutrient uptake in colocasia as influenced by light environments

Source	Degrees of freedom	Mean square		
		N uptake	P uptake	K uptake
Replication	2	0.96	0.005	0.38
Light environment	1	0.40*	0.22*	307.30*
Error	2	0.004	0.02	4.57
Total	5			

* Significant at 5% level

ROOT DISTRIBUTION PATTERNS OF BANANA AND COLOCASIA IN COCONUT GARDENS

By

SUJA EAPEN

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

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ABSTRACT

An investigation was undertaken at the College of Horticulture, Vellanikkara during 1993-94 to study the root distribution patterns of banana and colocasia in coconut gardens. The experiments were aimed to study the root distribution patterns of banana var. palayankodan grown in the open and in the coconut garden under rainfed and irrigated conditions. It was also aimed to study the variation in the root distribution patterns of colocasia var. cheruchempu grown in the coconut garden and in the open. A ^{32}P plant injection technique and a direct profile excavation technique were employed to study the root distribution patterns. The salient results of the investigation are abstracted below.

BANANA

Root production of banana grown in the open was considerably more compared to that grown in coconut garden. Rainfed banana produced more roots compared to irrigated banana. The root distribution patterns of banana vary with growing condition. In the coconut garden, the root system of rainfed banana was spreading and that of irrigated banana was compact. When grown in the open condition, the root system of rainfed banana was compact and that of irrigated banana was spreading. The active root zones of

rainfed banana grown in the open, irrigated banana grown in the open, rainfed banana grown in the coconut garden and irrigated banana grown in the coconut garden were the root zones comprising L_{0-60} D_{0-60}, L_{0-60} D_{0-80}, L_{0-80} D_{0-60} and L_{0-60} D_{0-60} respectively.

COLOCASIA

Root production of colocasia was more with the plants grown in the open compared to that grown in the coconut garden. Root distribution patterns of colocasia differ between the plants grown in the coconut garden and in the open. The root system of colocasia grown in the coconut garden is deep compact and that of the plants grown in the open is deep spreading. The active root zone of colocasia in the open and in the coconut garden are the root zones comprising L_{0-20} D_{0-40} and L_{0-10} D_{0-40} respectively.

^{32}P plant injection technique is an efficient method for root system studies in both banana and colocasia.