PATTERN OF ROOT ACTIVITY IN BANANAS UNDER IRRIGATED AND RAINFED CONDITIONS

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Pattern of root activity in bananas under irrigated and rainfed conditions" 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 other similar title of any other University or Society.

Vellanikkara,
6 - 6 - 1985.

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CERTIFICATE

Certified that this thesis entitled "Pattern of root activity in bananas under irrigated and rainfed conditions" is a record of research work done independently by Miss. Sobhana, A., 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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We, the undersigned members of the Advisory Committee of Miss. Sobhana, A., a candidate for the degree of Master of Science in Horticulture with major in Horticulture, agree that the thesis entitled "Pattern of root activity in bananas under irrigated and rainfed conditions" may be submitted by Miss.Sobhana, A., in partial fulfilment of the requirement for the degree.

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INTRODUCTION

INTRODUCTION

The important part played by the roots in the life of a plant has long been recognised. Roots are the means by which plants come in contact with the soil and as such deserves great attention. For the proper growth of a plant, not only the total quantity of the nutrients present in the soil is important but the capacity of the root system to extract the available water and nutrients is also important. The behaviour of the root system in soil depends on different soil factors such as texture, nutrients, aeration, moisture content, temperature and the management practices followed which all contribute to the performance of the crop, ultimately resulting in the yield.

A knowledge of the rooting habits of crops is useful in determining the exact site of fertiliser application for the effective and economic utilization of the nutrients and to develop proper cultural practices. The information on the rooting pattern of a crop can also be usefully employed for evaluating the suitability of crops for the dry conditions. Studies on the root activity of different crops also provide much information about the potential for multiple crop and crop sequence under different growing seasons.

Banana is known to be extremely demanding of nutrients and therefore addition of fertilisers is of highest importance in its cultivation. Banana is grown in Kerala as an irrigated as well as rainfed crop. Information on the active root distribution under these two conditions is therefore very valuable for developing efficient and economic fertiliser application. But relatively little is known of their growth behaviour under these management conditions. The present study on the rooting pattern of banana cultivar 'Nendran' was undertaken with the following objectives.

1. To study the root distribution pattern of banana as influenced by the irrigated and non-irrigated conditions.

2. To locate the most active root zone employing radioactive ^{32}P.

The studies on the translocation of the absorbed radioactive material might provide useful information of the accumulation of nutrients in different parts of the plant. Hence attempts were also made to study the absorption and translocation pattern of ^{32}P under irrigated condition in banana.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The interest in root studies in crop plants started early in eighteenth century, with the studies of Hale in 1727 as reported by Bohm (1979). The increased fertiliser use in crop plants in fact necessitated the understanding of the root system which actually led to the discovery of more and more methods for root studies. Consequently Weaver (1926) developed scientific excavation technique. Later the discoveries of profile wall method (Oskamp and Batjer, 1932) and monolith method (Pavlychenko, 1937) led to more studies concerning roots.

The introduction of radiotracers to root research by Hall *et al.* (1953) seems to be an important landmark in the field of root studies. Improved techniques like construction of modern root laboratories and rhizotrons (Karnok and Kucharski, 1982), facilitated more reliable and easy methods for studying root systems.

1. Root distribution pattern of crop plants

1.1 Fruit plants

Root studies are extremely important in crop plants for evaluating their producing capacity in a given soil and to develop suitable cultural practices for maximising the yield. The direct methods provide clear picture of the entire root system of a plant as it exists naturally. Fawcett (1913) observed that in banana the laterally spreading roots generally extended to a distance of 5.2 m and descended to a depth of 75 cm in the soil, with majority of the roots confining to a depth of 15 cm. He found maximum extension to a depth of 140 cm and noted that growth rates of root tips reached upto 60 cm per month. Riopel and Steeves (1964) found that roots of banana developed in longitudinal groups of four from the upper portion of the rhizome. Godefroy (1969) stated that banana roots penetrated to a depth of 80-100 cm when grown in alluvial soils of Malagasy.

The studies conducted at the Indian Agricultural Research Institute, New Delhi by soil auger sampling technique revealed that the feeder roots of mango were mainly confined very close to the tree at a distance of 60 cm and a depth of 15 cm about 90 per cent of the feeder roots were within the peripheral 180 cm (Bojappa and Singh, 1975). The concentration of roots decreased with increasing distances from the tree and depth of soil. Average spread of roots of guava was found to be at 7 feet 2 inches away from the tree and laterals were found to develop seven inches below the surface of soil (Burns and Kulkarni, 1920). In pineapple roots developed to a depth of 1.2 m and when 12 months old, 95 per cent of the roots were confined to the top 20 cm of soil (Inforzato et al., 1968).

Some of the earlier studies made in apple by Oskamp (1932) and Sweet (1933) showed a rooting depth of 6.5 feet for a matured 'Baldwin' apple in a well drained soil. Vuorinen's (1958) reports indicated a rooting depth of 40 to 50 cm in younger apple trees which increased with age upto 1 m in favourable soil condition. He also opined that in young apple trees the root system extended relatively faster than the crown and extended 1 to 1.5 m beyond it. Examination of a 26 year old Jonathan apple (Tamasi, 1959) in a sandy soil showed that the roots occupied an area of 134 sq. m while the crown occupied 44 sq.m, thus 69 per cent of the roots occupying under the crown spread. According to Rasinova (196[illegible]) about 30 to 60 per cent of the roots were present at 20 to 40 cm layer of soil in a 14 to 40 year old apple tree. Maximum length of horizontal root in a four year old apple tree was found to be 16.1 feet while maximum depth of growth was 11.2 feet (Doll, 1961). Babuk (1971) reported that most of the roots of apple were present in 80-100 cm layer of soil.

Weaver and Bruner (1927) found a maximum depth of 37 inches and lateral spread of 12 inches for 'Dunlop' variety of strawberry grown in silt loam soil of Nebraska.

Root excavation studies of 'Concord' vine by Doll (1958) on a terraced vineyard in Iowa revealed that in fertile soil the vines extended laterally to 22 feet and vertically to 14.5 feet. Root concentration was maximum in the surface one foot though a dense network of roots had penetrated the upper six feet (Doll,1958). Most of the roots of grape vine were usually located in the upper 1.5 m of soil but they could penetrate much deeper to 3 m or more as reported by Kasimatis (1967). At the Agricultural College, Coimbatore, the root distribution pattern of grape varieties viz., Anab-e-shahi, Kali Saheb, Pachadraksha, Bangalore Blue, Muscat and Hamburg were studied by excavation (Chelam, 1974) and it was found that many of the growing roots were confined to a depth of 90 cm, most of them being in the 20 to 40 cm depth.

Burns and Kulkarni (1920) reported that for a 'Santra' plant the roots extended upto 13 feet 6 inches. Studies in Sicily on roots of sour orange by Baldini (1957) revealed that most of the roots were confined between 10 and 20 cm laterally, and at a depth of 40 to 70 cm. The rooting depth reached a maximum of 1.5 m in open loose soil whereas it was only 1 m in compact soil. Aiyappa and Srivastava (1968) studied the root system of healthy and chlorotic trees of young (2.5 years old) mandarin orange in Coorg district and concluded that the roots penetrated to 2.24 m vertically and 3.51 m laterally in healthy ones as against 1.99 and 1.79 m in severely chlorotic trees. Aiyappa *et al.* (1968) observed maximum concentration of feeder roots in the top 60 cm soil in 3.5 year old mandarin. Bargioni (1959) reported that roots of cherry grown in Verona district extended faster than the tops and 80 to 90 per cent remained in the top 50 to 60 cm of soil.

Maliga and Tamasi (1957) studied the root distribution pattern of 24 year old walnut tree grown in sandy soil. The root density beneath the crown was nearly three times than outside it. About 60 per cent of the roots were found at a depth of 40 to 60 cm and 88 per cent between 40 and 220 cm. According to Chernobai (1971) most of the walnut roots spread horizontally in 30 to 85 cm deep soil layer. The vertical roots of apricot variety 'Paviot' was found to reach a depth of 2.9 to 3.9 m when grafted on most of the root stocks. About one-third of the root system was present in the superficial layers between zero and 20 cm (Lupescu, 1961).

Ballantyne (1916) reported that the roots of 'King' peach penetrated upto a depth of 9.5 feet and 'Bartlette' pear roots extended over 20 feet wide and nine feet deep. The greatest concentration of pear roots was found to be between two and eight feet from the trunk as reported by Aldrich (1935). Cockroft and Wallbrick (1966) studied the root distribution of peach and pear trees by auger technique and found that the highest concentration of roots was confined to the top three feet of soil.

According to Christensen (1947) 70 per cent of roots of raspberry var. Norfolk Giant existed in the upper 25 cm of soil and maximum root length recorded was 180 cm.

Swarbrick (1964) found that papaya root system extended to a depth of two feet and about nine inches in diameter and most of the secondary roots arose from the top six inches of the soil profile.

1.2. <u>Plantation crops</u>

Arrillage and Gomez (1940) in Puerto Rico observed that 95 per cent of the root system of coffee was confined in the upper 12 inches of the soil and only four per cent in the 12 to 24 inches of the soil while 24-48 inches level contained less than one per cent only. Trees having heaviest tops were found to possess maximum roots. Diameter of trunk seemed to be an external indicator for the comparative extent of root system than spread of branches or height of the tree. Hatert (1958) studied the root system of robusta coffee and observed that the tap root extended to a length of 90 cm while lateral and secondary roots formed a dense mass around the tree covering an area of 7 to 8 sq.m. The root system of one year old coffee plants grown in loamy sand in Salvador was found to be concentrated in the top 30 cm layer of soil (Castro, 1960). Bavappa and Murthy (1961) reported that in arecanut the root concentration was maximum at 60 to 90 cm from the base of the palm. In an eight year old arecanut palm 61 to 67 per cent of the roots were concentrated within a radius of 50 cm while few extended beyond 100 cm as reported by Bhat and Leela (1969). They also found that 86 to 79 per cent of the root were within a depth of 50 cm of soil. The second soil layer 50 to 100 cm deep contained 18 to 23 per cent of the roots. The greatest depth of penetration of roots was 2.6 m. More than 80 per cent of the roots were within a radius of 1 to 1.25 m from the trunk. Root studies conducted in coconut at Veppamkulam (Anon, 1970) revealed that a great majority of the roots were confined to 16 to 60 cm layer of the soil.

Mc Creary *et al.* (1943) studied the root distribution of cocoa growing in different soils of Trinidad by excavation and found that the stout laterals occurred in the top 12 to 16 inches soil layer. Pataraya (1968) observed greatest concentration of feeding roots at a depth of 10 to 30 cm and minimum roots in the 50 to 60 cm layer of soil. Trerada and Chobe (1971) reported from Brazil that 90 to 98 per cent of the roots were in the upper 40 cm of soil layer in a 2 to 4 years old pepper plant. About 85 to 90 per cent of the roots were found in the upper 30 cm layer of soil.

1.3. Other crops

Inforzato and Alvarez (1957) described the root system of the sugarcane variety Co-290 and the roots were found to reach a depth of 2.1 m at six months age and 3.3 m at maturity. The mass of living roots were greatest at 12 months age and some roots dried off between 12 and 18 months. Ghildyal and Satyanarayana (1969) found that for rice var. 'Rupsail' most of the roots were concentrated in the upper seven cm soil layer in sandy silty and clayey soils. A study of the root system of tomato plants as reported by Inforzato *et al.* (1970) revealed that 63 per cent of the roots occurred in the upper 10 cm layer of soil. Within 25 days the root system reached a depth of 1.3 m and 2.5 m within 75 days. Paz-Vergara et al. (1980) recorded 85 per cent of roots of sugarcane within the 60 cm soil layer.

2. Root distribution under moisture stress

A knowledge of the root system may help to explain the difference in drought resistance exhibited by crop plants (Cook, 1943). When moisture supply is limited the roots will have a tendency to go deeper and to distant soil layers in search of water. As reported by Doss et al. (1960), Thurgett (1958) concluded that relatively dry soil conditions induced the plants to develop a more extensive root system. This conclusion had been confirmed with the reports of other workers like Jean and Weaver (1924), Weaver (1926), Weaver and Bruner (1927), Weaver and Himmel (1930), Russel et al. (1940), Lipps and Fox (1964), Dennis (1966) and Peters (1967). Weaver and Himmel (1930) found that rooting depth increased with decreasing water content until the soil became too dry for root growth.

2.1. Fruit plants

Aldrich et al. (1935) found a positive correlation between root concentration and available soil moisture in pear. Hubbard (1938) and Cahoon et al. (1961) observed that infrequent irrigation in banana induced more deeper and extensive root system while frequent irrigation restricted the root system to the top surface of the soil. Eremeev (1960) stated that in dry soil the absorbing roots of apple were very short, 2 to 4 mm in length with a reddish brown colour. According to Pasinova (1960), in 14 to 40 year old apple trees about 30 to 60 per cent of roots were present at 20 to 40 cm depth and the root density increased with declined soil moisture level.

Cahoon et al. (1961) found that in Citrus on an average 58, 31, 9.5 and 1.5 per cent roots were distributed at 1, 2, 3 and 4 feet depths respectively under frequently irrigated conditions. But when irrigation frequency was reduced, the percentage of roots at the above depths were found to be 42, 38, 18 and 2 respectively indicating less surface roots under reduced irrigation. In irrigated soils of Azerbajdzan most of the roots of apple trees were distributed in the 20 to 75 cm soil layer and horizontal roots extended more than those of vertical roots (Babaev, 1968). Black (1968) stated that the mass of banana roots was not affected much by moisture stress, through a slight increase in the number of roots was observed with higher moisture stress. Investigations carried out at Tamil Nadu Agricultural University, Coimbatore, on the root distribution pattern of banana var. Robusta revealed that the root development was generally influenced by the soil moisture conditions (Krishnan and Shanmughavelu, 1979). As water content got depleted from the soil, the root extension occurred in other areas where the availability of water was ample.

2.2. Other crops

In cocoa, Wood (1975) reported that the tap root developed to 45 cm on soils with high water table while much deeper development was seen where water logged conditions did not occur. According to Burton et al. (1954) 93.6 per cent of the roots of drought susceptible carpet grasses were confined to the upper 2 feet of soil whereas only 65.0 to 68.8 per cent of the roots of highly drought tolerant grass occurred in this layer. Gingrich and Russel (1956) reported that as soil moisture tension increased from one to 12 atmospheres progressively smaller increase in radicle elongation, fresh weight and dry weight of roots were found in corn. Hurd et al. (1957) found that roots developed in wheats with limited moisture supply were finer and had more and longer branches than roots developed under favourable soil moisture conditions. Bloodworth et al. (1958) studied the root distribution of some irrigated crops like cotton and tomatoes and found that in irrigated areas a large percentage of roots occupied the first six inches thus indicating more surface roots under ample moisture supply. Effective rooting depth decreased as soil moisture level increased in both warm season forage grasses (Doss et al., 1960) and in cool season forage grasses (Bennet and Doss, 1960). Hurd (1968) reported that in wheat var. 'Thatcher' the roots penetrated quickly in dry soils than in wet, loamy and clayey soils. At harvest considerable increase in spread of roots was observed in drought resistant strain whereas disintegration of perepheral roots was seen in drought susceptible ones. Lupton et al. (1974) studied the root system of normal and semi dwarf cultivars of winter wheat in England and observed that soil and climatic conditions influenced rooting depth and distribution more than that influenced by genetic make up of the plant. Mayaki et al. (1976) observed that in soybean 67 per cent of the roots were distributed in the zero to 15 cm layer and 89 per cent in the zero to 15 cm layer and 83 per cent in the zero to 90 cm layer in unirrigated soil. Ellis et al. (1977) found that in barley majority of the roots were confined in the top 12.5 cm of soil when the rainfall was more, but a higher percentage of roots were distributed in deeper soil layers when the rainfall was limiting. The findings of Sivakumar *et al.* (1977) and Boyer *et al.* (1980) indicated that under drought condition the soybean root profile was characterised by a low root density in the dry surface layer and a maximum proliferation in the deeper and wetter soil layers.

Surface root development in sugarcane by irrigation was reportedly Paz-Vergara *et al.* (1980). The studies conducted by Garay and Wilhelm (1983) in soybean under Nebraska conditions revealed that roots were concentrated in the surface 15 cm layer for the first sample and after 30 days of drought root density was found to be greatest at 90 to 120 cm layer. About 80 per cent of the roots were found within the zero to 120 cm layer. In general roots appear to proliferate in soil zones with lowest water content.

3. Root distribution as affected by different soil conditions and other factors

Rogers (1952) stated that the age and variety of plant and various soil factors like texture, nutrients, aeration, moisture and temperature influenced behaviour of the root system which in turn largely controls the performance of the plant. Soil management practices also affected plant growth mostly through its influence on the environment of the roots. Root depth may be limited by the occurrence of a water table, harden and shallow soils or by a zone of toxic materials in the soil. Nitrogen fertilizers also stimulated root growth near the soil surface rather than in deeper horizons, with abundant water supply (Bloodworth _et al._, 1958).

3.1. _Fruit plants_

Root distribution studies in three apple varieties by Serebeov (1966) showed that the depth of root growth depended on the level at which the impermeable layer occurred and on its mechanical composition. Molganov (1966) reported that chlorosis susceptible plums produced most of their roots in the 25 to 60 cm layers of soil while chlorosis resistant ones produced most of their roots initially in the top 20 cm of soil and later in 10 to 50 cm layer. The results of root distribution studies in healthy and variously chlorotic 35 years old mandarin trees by Aiyappa and Srivastava (1968) showed that the roots penetrated downward to depths of 2.47, 2.16 and 1.85 m respectively in healthy, slightly chlorotic and severely chlorotic trees. Lateral root spread of the above trees were 2.93, 2.45 and 2.36 m respectively. Cripps (1970) stated that under mediterranean climatic conditions of Western Australia, winter dormancy appeared to influence the root growth of young apple trees. In older fruting trees it was observed that root extension was most rapid in late spring and early summer and little root growth was made in late summer. In coarse sands and gravelly soils, roots of grapevine penetrated to a depth of 7.5 m or more (Weaver, 1976). Gousseland (1983) observed that in banana cultivar 'Giant Cavendish' the initial root growth was markedly influenced by the mother plant and later root growth was restricted by anaerobic conditions, nematodes and soil compaction.

3.2. <u>Other crops</u>

The work done by Hardy (1944) indicated that in nutrient deficient compact clays or in sandy soil having high water table the root system of cacao was characterised by a lengthy tap root, widely spread superficial lateral root and well marked fibrous surface root-mat. As the application of nitrogen fertilisers increased, nitrogen content of the roots and organic content of the soil increased slightly and root weight per acre remained at high level as reported by Holt and Fisher (1960).

Magnaye (1969) made a detailed study on the root system of coconut palms affected by cadang disease and found that primary roots were less numerous in the affected palms compared to healthy. In palms growing on sandy loam, most of the primary and secondary roots were found in 1 to 3 feet from the tree base and at a depth of 2 to 3 feet. The root studies carried out in coconut palm at Vappamkulam (Anon, 1970) indicated that the number of roots increased with the increase in the level of applied fertilizers. It was found that palms under regular cultivation and receiving good manuring produced highest number of roots (4016) (Kushwah *et al*., 1973).

4. Root activity patterns using radiotracer technique

Many methods with radioactive isotopes have gained significance in root studies during last three decades. They have been used in recent times to determine the distribution pattern of active roots, both in terms of area around the individual tree and also its rooting depth. Unlike traditional methods, tracer techniques provide an undestructive means of evaluating the underground parts more precisely, quickly and easily with reduced labour and time. Conventional methods have the difficulty in distinguishing the living roots from the nonactive roots. Ever since Lott *et al.* (1950) and Hall *et al.* (1953) studied the plant root systems in natural soil profile, with radioactive tracers, considerable work has been done to study the root activity of plants with radioisotopes. Several workers like Hall *et al.* (1953), Fox and Lipps (1964), Russel 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 radio tracers placed previously at specified depths in the soil.

4.1. Fruit plants

Ulrich *et al.* (1947) in a study, on 25 year old grape vine grown under red loam soils of California, using ^{32}P, found that the roots were irregularly distributed around the vine and it was estimated that 90 per cent of the roots were within a radius of two feet around the base. Walmsly and Twyford (1968) conducted some studies in heavy clay and sandy loam soils of West Indies to find out the zones of nutrient uptake by 'Robusta' banana using ^{32}P soil injection technique. Radioactive ^{32}P was injected at specified spots and the plants were grown at different distances from the active spot. No radioactivity was detected in plants growing more than eight feet away from the radioactive soil, in any of the sites and they concluded that the feeding roots of 'Robusta' banana did not extend for more than a circle of eight feet radius in both heavy and light soils. It was also evident that most of the plants in sandy loam soil had no feeding roots extending beyond four feet.

Dev *et al.* (1971) while studying the proliferation of roots at different depths in grape varieties, Beauty seedless, Bedana and Humrods by ^{32}P soil injection technique showed that the roots at a depth of 31 to 56 cm absorbed more ^{32}P and thus more root activity existed in this region. Atkinson (1974) observed that in a two year old apple tree the absorption of ^{32}P from the 30 cm depth was greatest and in a 25 year old apple apple cultivar absorption was greatest from 90 cm.

Bojappa and Singh (1974) in their studies using ^{32}P in mango found that two distinct zones of higher root activity were perceptible in 18 year old tree. Highest absorption of ^{32}P was from the zone close to the trunk at a distance of 120 cm and at a depth of 15 cm followed by a second peak near the surface (3 m distance). Absorption rate decreased with an increase in soil depth. About 77.4 per cent of the root activity was noticed at a depth of 60 cm in the first trial while in the second trial 84.6 per cent of root activity was observed at a depth of 30 cm.

Root activity studies in two year old banana var. 'Nakatongu' in dry and wet seasons at Makerere University in Uganda using radioactive ^{32}P showed that in wet season, maximum root activity occurred near the surface of soil at a distance of 40 cm from the plant (IAEA, 1975). The root activity decreased slightly to 15 cm and 30 cm depths and sharply declined at 60 cm depth during the wet season. In the dry season highest root activity was found at a distance of 40 cm and 80 cm. It was evident that during dry season highest root activity occurred at distant zones indicating an extensive development of root system. Moreover, during this season lateral roots were found to be very active at 120 cm and 160 cm distances at depths of 30 and 15 cm respectively.

The experiments carried out in 30 year old orange trees grown under sandy loam soils in Spain using ^{32}P soil injection technique revealed that during summer highest root activity (70 per cent) occurred at 3 m distance from the tree at a depth of 30 cm while very low activity was observed at 50 to 100 cm distance. In an experiment on eight year old citrus trees in Taiwan, highest root activity was observed at a distance of one metre and at a depth of 10 cm (IAEA, 1975). In 12 year old citrus trees during winter the root activity was maximum near the soil surface at one to two metre distance. While in mature 30 year old citrus trees, the zones of highest root activity were farther away from the tree than in younger trees. Studies conducted at Taiwan showed that there was little effect of season on the distribution pattern of root activity in citrus (IAEA, 1975).

4.2. Plantation crops

Soong et al. (1971) from the ^{32}P studies in rubber, observed maximum root activity at a distance of 12 feet from the tree. In a study on the root activity pattern of coconut, Balakrishnamurthy (1971) observed maximum uptake of ^{32}P from one metre distance of the palm, at a depth of 12 cm. Greatest root activity was observed in the upper layers of soil between zero to 30 cm, close to the palm within 150 cm and the activity was more during the wet season.

Studies on root activity of the tree crops reported by IAEA (1975) are summarised in the following paragraphs.

In Ceylon radiotracer studies showed that the efficiency of fertiliser application was greater when placed at 10 cm depth than on the surface in coconut palm. The uptake of nutrients was maximum at lateral distance of 50 cm and decreased with increase in radial distance. Root activity was very high within a radius of two metres and at a depth of 10 to 45 cm. The studies conducted on 15 and 60 year old coconut trees var. Laguna typica in Philippines revealed that the activity was similar in trees of both age groups. The highest activity was at 1 to 2 m distance and at a depth of 15 cm. Results of the experiments carried out during wet and dry seasons on 50 year old coconut palm grown in sandy loam soil at Marandawila indicated that about 80 per cent of the total activity was within 0.5 to 1 m distance during wet season while during dry season the activity at lower depths and greater distances was high.

The root activity pattern of young and bearing oil palm during wet and dry seasons in Malaysia and Ivory Coast was studied. In Malaysia during wet season the highest root activity was found at the soil surface at a distance of three metres from the tree. About 70 to 80 per cent of active roots were in zero to 20 cm depth, with 50 to 60 per cent being concentrated near the soil surface. Studies of Ivory Coast also revealed highest root activity at zero and 20 cm depth. During wet season, root activity was more intensive and confined to the surface unlike in dry season.

Wet and dry season experiments in coffee in Colombia indicated that during wet season root activity was significantly higher at 30 cm distance and 15 cm depth than at any other positions tested. During dry season no indication of the zone of low and high activity was observed except on 20th day sampling when roots were more active at 45 cm depth and 30, 60 and 90 cm distances. In Kenya two zones of high activity were seen, one at the soil surface upto a distance of 82.5 cm from the tree base and the other at 45 to 75 cm depth zone at a distance of 30 cm from the tree. When soil moisture is not limiting as in wet season, it was the surface soil that showed highest activity and once the top soil dried out activity was highest at 45 to 75 cm depth zone, at a distance of 30 cm from the tree. In a study on one year old coffee plants grown in sandy loam soil of Salvador it was revealed that nearly all the roots were concentrated in the top 30 cm layer. In adult trees tap root reached a depth of 50 cm.

The wet and dry season experiments conducted at Ghana in cocoa using tracer technique revealed the presence of highest activity in the upper 7.5 cm layer with maximum activity at the 2.5 cm depth. During both wet and dry seasons the effect of distance on root activity was not significant. Studies on the influence of shade revealed that under shade the zone of higher activity was more widespread in both wet and dry seasons, while in the absence of shade the root activity was highest at 90 cm distance.

4.3. Other crops

Basset *et al.* (1970) reported that under irrigated condition, the tap root of cotton grew at an average rate of 2.5 cm per day reaching a depth of 183 cm as evidenced by ^{32}P studies. Lateral roots grow only at half of this rate. With the onset of flowering two-third of the total activity was found to be confined at the top 30 cm. Root activity at lower depths intensified as the season progressed resulting in a relatively uniform activity throughout the first 122 cm. Reddy and Vekateswarelu (1971) studied the active root distribution of two castor varieties by ^{32}P soil injection and found that the high yielding mutant HPR-1 had more extensive root system than the long duration local variety HC-8.

In annual crops also root studies had been done employing radiotracers. Root activity studies in alfalfa by Lipps *et al.* (1957) revealed the presence of three zones viz., surface soil where activity was high in spring and decreased during dry weather, zone of minimum activity in unfavourable chemical environment and a zone of secondary activity in moist soil above water table. Using stable strontium and ^{32}P as tracers Fox and Lipps (1964) observed higher root activity in the surface horizons which received intermittent moisture and low activity associated with poor chemical environment. Mc Clure and Harvey (1962) using ^{32}P in sorghum hybrid, found significant root growth after flowering upto fifth week and little growth afterwards. Roots were present at a depth of 9.5 inches and at a distance of 22 inches. Hames and Berts (1963) stated that roots of carrots were active to a depth of 30 inches while in onion and chilli about 80 per cent of the active roots were in the upper eight inches of soil. Nahr *et al.* (1966) observed greatest absorption at 70 cm depth and at a horizontal spread of 60 cm in sorghum. Nakayama and Bavel (1968) found that about 90 per cent of the root activity of sorghum plants occurred in the top 36 inches and lateral 15 inches. Virmani and Dhaliwal (1969) studied the corn root system by ^{32}P and found that about 90 per cent of its active roots were present in the upper 40 cm of soil but at tasseling and grain setting stages the root activity at 40 to 60 cm was only 20 per cent. Dejong and Otinkarang (1969) revealed that in irrigated tomato 75 per cent or more of the active roots were present in a core of 25 cm diameter and at 45 cm depth. Ellis and Burns (1973) reported that 82 per cent of the living roots of barley grown on sandy loam soil at Oxford were concentrated in the upper 2.5 to 22.5 cm layers of soil which was indicated by the absorption of ^{86}Rb.

Virmani (1971) from the ^{32}P plant injection studies conducted on two tall and dwarf wheat varieties reported that about 90 to 95 per cent of roots were located within zero to 60 cm of the soil. The root distribution pattern of nine wheat varieties grown in sandy loam alluvial soils of Indian Agricultural Research Institute indicated that 50 per cent of the roots were in zero to 8 cm layer (Natyal and Subbiah, 1971). Soni et al. (1972) studied the root distribution pattern of wheat varieties in the medium black soils of Madya Pradesh under irrigated and unirrigated conditions and found that there was less proliferation under unirrigated condition compared to irrigated conditions. Marykutty (1978) from her study on root activity pattern of wheat grown under loamy soil of Udaipur reported that varieties Heera and 1577 were shallow rooted with 62 to 68 per cent of root system confined to a depth of 8 cm while HDM 1593 was deep rooted with only 43.2 per cent roots in the 8 cm soil layer.

Sriniwas (1980) determined the root activity and soil feeding zones of five bajra hybrids in Udaipur by ^{32}P placement and found that more than 44 per cent of root activity occurred in the soil layer of zero to 15 cm depth at a lateral distance zero to 10 cm. Subramanian et al. (1980) studied root distribution pattern of bengal Gram var. Co.1 using ^{32}P soil injection technique at Coimbatore and stated that it was a deep, medium spreading type with the roots extending to a lateral distance of about 15 cm and to a depth of about 25 cm.

Studies on the root distribution pattern of high yielding rice varieties by ^{32}P plant injection technique at Tamil Nadu Agricultural University, Coimbatore by Kumaraswamy et al. (1977) showed that 80 to 85 per cent of roots were concentrated in the soil zone of 15 cm distance at 24 cm depth and about 55 to 75 per cent of roots were concentrated at 10 cm lateral distance and at 16 cm depth. Studies conducted by Singh et al. (1982) on rice revealed that maximum roots were present at zero to 15 cm and minimum roots at 45 to 60 cm depth while distribution of roots at lateral distances of zero to 15 cm and 15 to 30 cm were not much different. Prolonged drought resulted in soil moisture depletion in the upper zones of soil which in turn produced more number of roots in varieties like IR-24, IET-1991 and Cauvery.

5. Translocation studies using radiotracers

Fujiwara and Suzuki (1957) using ^{14}C showed that a majority of photosynthates in rice were translocated from the leaves and sheaths to the panicle. Ota et al. (1958) demonstrated the accumulation of starch in the straw of rice before heading and its subsequent translocation after heading. Ueno et al. (1967) applied ^{14}C to the leaves of Italian rye grass and traced the translocation of labelled assimilates to various parts and suggested that the assimilates did not readily move down to the non functional roots and the rate of translocation of assimilates to the underground organs depended on the age of the individual leaf and tiller of the shoot system. They found that flower initiation retarded the translocation to assimilates to other parts as they tended to move to the flower. In banana after shooting male flowers accumulated maximum ^{32}P (Walmsley and Twyford, 1968).

Joy (1964) found that when ^{14}C was supplied to sugar beet leaves, young growing leaves utilized assimilated ^{14}C for their own growth while fully expanded leaves translocated much of their photosynthates to the roots and young leaves. In *Cucurbita species* Webb and Gorham (1963) demonstrated a multidirectional pattern of movement of carbohydrates. Georgiev (1967) demonstrated that ^{32}P introduced through the root system translocated normally to the scion in grafts of melon on squash when the leaves were retained on the rootstocks. However, the P content of scions was decreased considerably when melon was grafted on defoliated stocks since the ^{32}P was held in the graft unions. Highest concentration of ^{32}P was observed in younger leaves than older ones as pointed out by Walmsley and Twyford (1968) in 'Robusta' banana and Nanman (1966) and Triefimova (1968) in maize. Rao *et al*. (1971) studied the P content of lamina, petioles and buds of grapes at different nodal positions of the shoot samples on the 18th day and showed that the total P content was highest in the petioles followed by the laminae and bud at all nodal positions.

A study on banana var. Robusta (Walmsley and Twyford, 1968a) showed that nutrients were translocated from parents to followers at all stages of growth. When ^{32}P was introduced to followers the parents also became radioactive, which made them conclude that anyone plant on the stool was never independent of the others. The study also revealed that in the early vegetative stages, radioactive phosphate was distributed evenly with the nonactive phosphate. The ^{32}P studies also indicated that uptake of phosphorus was rapid during vegetative phase from two to three months of planting. Ryle and Powell (1972) studied the export and distribution of ^{14}C labelled assimilates from each leaf on the shoots of _Lolium temulentum_ during reproductive and vegetative growth. The study revealed that the developing leaves at the top of the shoot were receiving about the same proportion of the carbon from each leaf as did the developing inflorescence.

Maturity of the plant also greatly influenced the distribution and translocation ^{14}C to the various plant parts (Balasko and Smith, 1973). At the time of initiation of stem elongation roots and leaves were the primary sink of photosynthates.

Using radioactive iron Brown _et al_. (1960) showed that enough iron was supplied from the cotyledons to maintain a green plant upto the first trifoliate leaf stage in soybean.

For studying the translocation pattern of calcium in groundnut labelled ^{45}Ca was fed through the roots by Chahal and Virmani (1972) and they noted that about

60 per cent of the ^{45}Ca was in the leaves as against 13.8 per cent in the pods. When absorbed through the fruiting organs, 88.3 per cent of the calcium was retained in pods and while the vegetative parts retained only traces.

MATERIALS AND METHODS

MATERIALS AND METHODS

The experiments were carried out in the Department of Pomology and Floriculture, College of Horticulture, Vellanikkara during the year 1983-84 to find out the distribution pattern of roots of banana var. Nendran under irrigated and unirrigated conditions and to trace out the translocation of absorbed ^{32}P inside the plant.

The experimental fields were located at a latitude of 10° 32' N and longitude of 76° 10'E at an altitude of 22.25 m above mean sea level which comes under a typical warm humid tropical climate. The rainfall data for the years 1983 and 1984 are furnished in Appendix-I.

The soil of the experimental fields was well drained and acid laterite. To study the soil nutrient status, samples were collected from a soil depth of about 20 cm as per the methods suggested by Piper, (1942). The organic carbon was determined by Walkley and Black method as described by Jackson (1958). Chloromolybdate blue colourimetry (Bray No.1) was used for the estimation of available phosphorus and exchangeable potassium was determined by Jackson's (1958) method. Available calcium and magnesium were also determined by Jackson's (1958) method. The mechanical and chemical properties of the soil are given below:

Mechanical and chemical properties of the soil

Total sand (%)	..	55.20
Silt (%)	..	15.30
Clay (%)	..	29.50
Available phosphorus (ppm)	..	21.10
Exchangeable potassium (ppm)	..	620.00
Available calcium (ppm)	..	215.25
Available magnesium (ppm)	..	19.50
Organic carbon (%)	..	0.77

Planting and management practices

The field was prepared during September for the irrigated crop and in February for the rainfed crop. Three months old uniform suckers of Nendran were planted in pits of size 50 x 50 x 50 cm at a spacing of 2 x 2 m. Cultural practices were followed as suggested by Package of practices, Kerala Agricultural University (Anon, 1982). A fertiliser dose of 190:115:300 g N:P:K respectively was given in two equal split doses, first dose two months after planting and second dose four months after planting for the irrigated crop and irrigated the field thrice a week. For the rainfed crop the fertilisers were applied in the third and fifth months after planting.

1. Observations recorded for root distribution studies

The untreated healthy plants from the experiment laid out for root activity studies were used for taking root observations at monthly intervals. The whole plant was uprooted without disturbing the root system after making small trench around the plant at a sufficient distance so that minimum damage was caused to the roots. The distance varied according to the growth stage of the plant. After digging out the plant the pseudostem was removed leaving a small portion of it on the rhizome. The rhizomes were washed in running water without injuring the roots. After removing all the soil particles and dirt adhering to it, observations were made on number, length and diameter of roots. The fresh and dry weights of the roots were also recorded. These observations were taken from planting till the crop was nine months old.

2. Root activity studies

The fields were laid out in 4^2 factorial experiment in randomised block design with three replications. The layout of the field is illustrated in Fig.1. For the placement of ^{32}P, there were four lateral distances and four depths thus constituting 16 treatments each being replicated thrice. Thus there were 48 treatments plants for each experiment. Border plants were also maintained

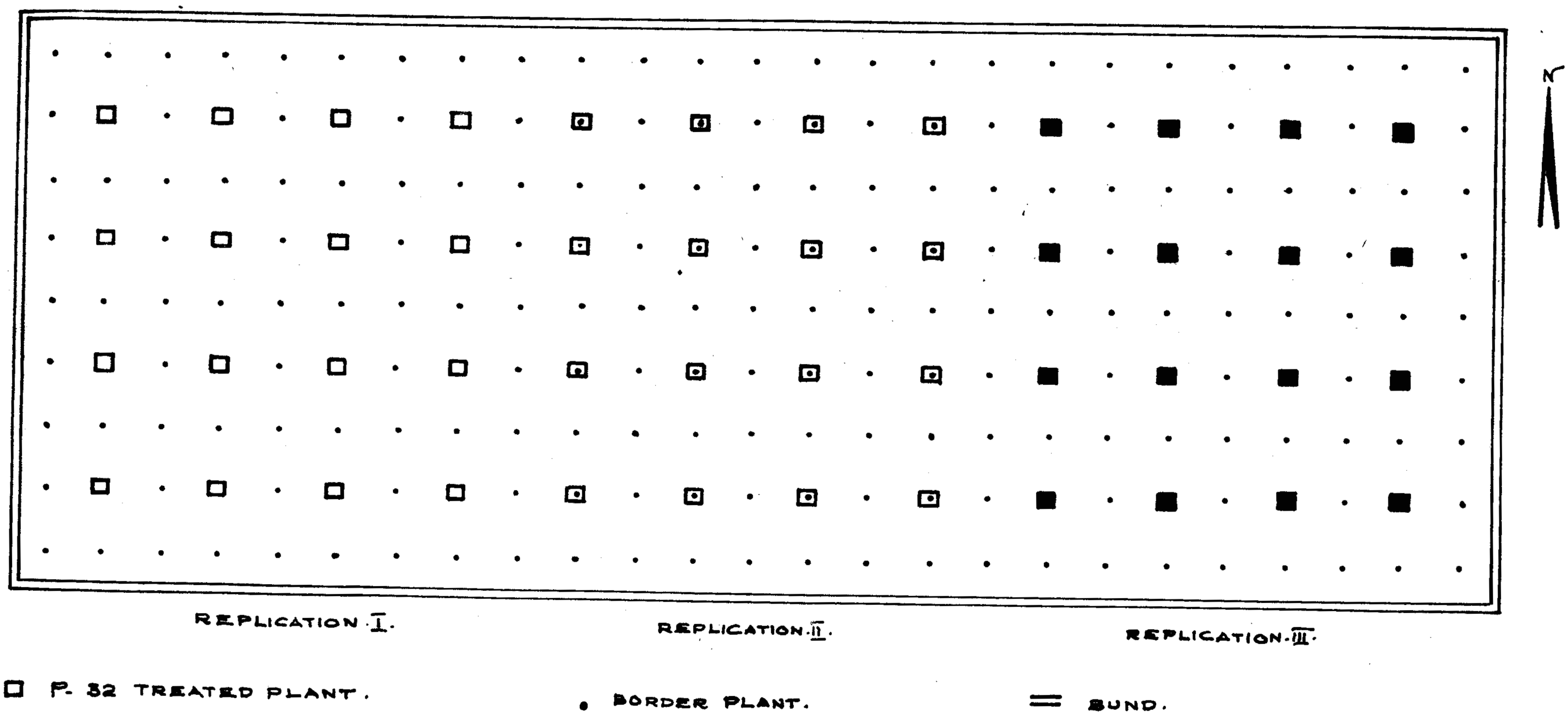


FIG: 1. LAYOUT OF THE FIELD EXPERIMENTS

for each treatment plant. The details of the treatment combinations are furnished below.

Treatment Number	Lateral distance (cm)	Depth (cm)
T_1	20	5
T_2	40	5
T_3	80	5
T_4	120	5
T_5	20	15
T_6	40	15
T_7	80	15
T_8	120	15
T_9	20	30
T_{10}	40	30
T_{11}	80	30
T_{12}	120	30
T_{13}	20	60
T_{14}	40	60
T_{15}	80	60
T_{16}	120	60

2.1. Injection of radioactive ^{32}P in the soil

The ^{32}P application was done around the plants when they were four months old under both the irrigated and rainfed conditions. Single plant was used as experimental unit. The plants surrounded by eight border plants were selected and numbered serially. The area around these experimental plants was cleaned well and 16 equidistant holes were taken around each treatment plant at equal depths in a ring which varied according to the treatment. Holes were made using 2 cm diameter tube auger one day in advance and plugged with PVC tubes of same diameter to prevent entry of water in case it rained.

Injection of the desired volume of ^{32}P into the soil was done with a dispensette fabricated exclusively for this purpose (Sankar, 1988). The dispensette was connected to a reservoir bottle which was embedded in praffin wax contained in a plastic bucket (Fig.2 and Plate I). The field operation details of this device is illustrated in Plate II. The reservoir bottle could hold one litre of radio active solution. The radioactivity used per plant was two millicurie which necessitated to a total of 96 mCi radioactive ^{32}P solution for 48 plants. A carrier solution of 1000 ppm P (as potassium dihydrogen orthophosphate) was included in these experiments to reduce the fixation of ^{32}P by soil through isotopic exchange. Each ml of experimental solution contained 125 mCi radioactive ^{32}P. The radiation dose at the outer surface of the

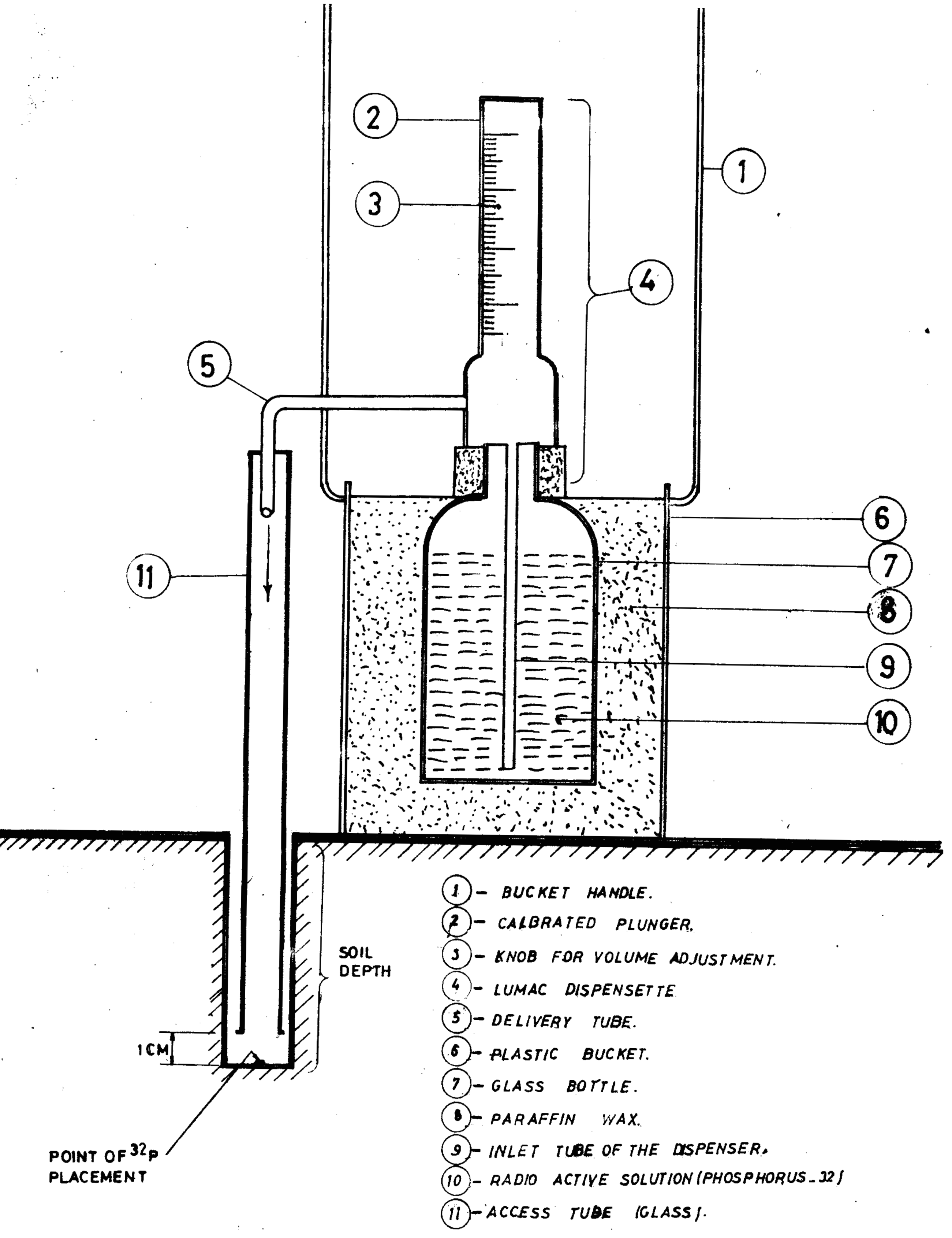
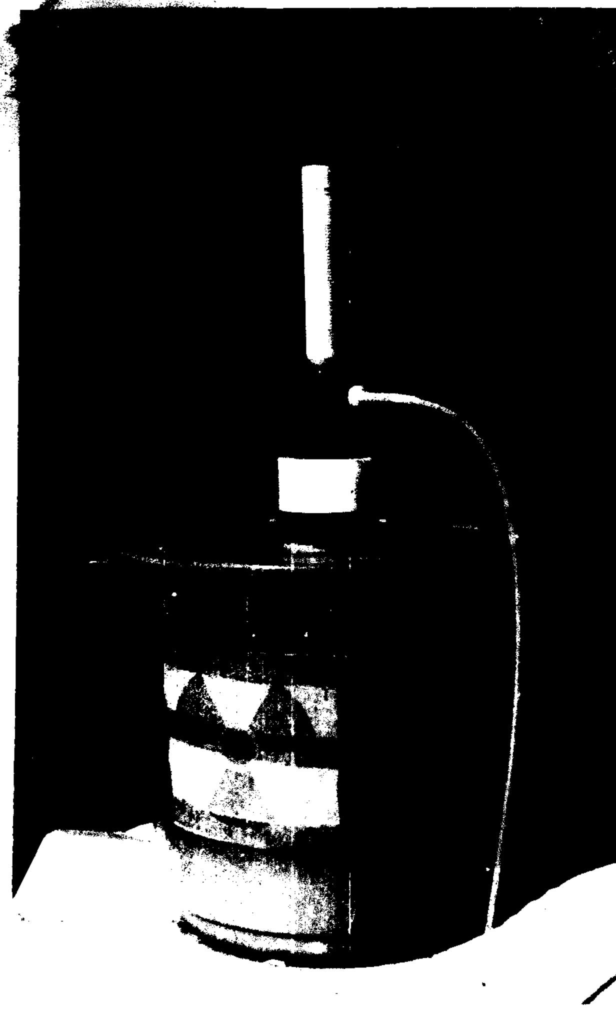


FIG. 2 DEVICE FOR SOIL INJECTION OF ^{32}P SOLUTION

Plate I The device for soil injection of ^{32}P solution.

Plate II Illustration of the soil injection of ^{32}P solution



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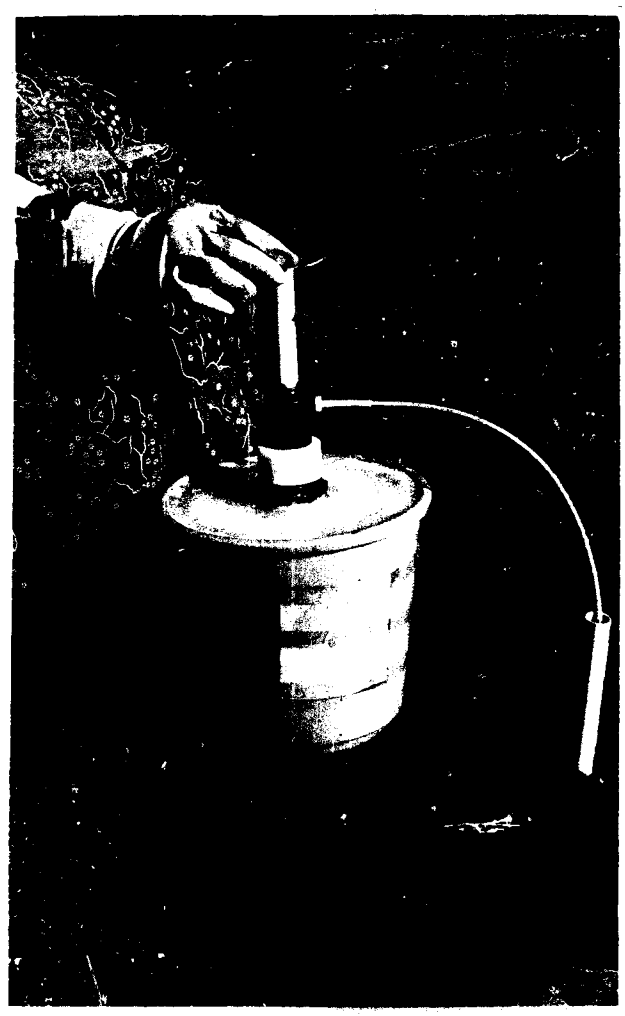


II

bucket filled with prepared ^{32}P solution was found to be less than 10 mr/h.

To dispense 3 ml of radioactive solution containing 375 µCi ^{32}P, the volume adjusting knob of the dispensette was loosened and its pointer brought to the 3 ml mark on the plunger. By smooth up and down motion of the plunger the set volume of solution could be accurately dispensed into the access tube through which it reached the PVC tube and thus to the required depth. Thus 48 ml of radioactive solution was injected to each plant through 16 holes so as to get 2 mCi radioactive ^{32}P. Immediately after injection, the access tube and PCV tube were washed with a jet of distilled water (about 4 m to 5 ml) to drain off any radioactivity sticking to the inside of the tubes. The PVC tubes were removed carefully after washing the bottom side of it with distilled water. The holes were subsequently filled with soil.

2.2. Analysis of leaf samples

Third fully opened leaf from the top was used for sampling and analysis (IAEA, 1975). First sample was taken 15 days after the application of ^{32}P and the subsequent samples were taken at 15 days intervals from both irrigated and rainfed crops. For analysis, lamina of about 15 cm length at the middle portion of the leaf was taken from both sides of the midrib. Samples were dried in hot airoven at 70°C for 48 hours. Dried samples were made into small pieces and digested in diacid mixture containing equal parts of perchloric acid and nitric acid and radio assay of ^{32}P was done in a Liquid Scintillation Counter employing Cerenkov counting technique (Wahid et al., 1985). Total phosphorus of the digest was estimated by Vanadomolybdate yellow colourimetry (Jackson, 1958). The count rates were corrected for decay to a common reference time after background correction. Specific ativities (Cpm/mg P) were also used for calculating the percentage of active roots in different soil zones.

Percentage of active roots at a particular soil zone =

$$\frac{^{32}P \text{ recovery from that zone} \times 100}{\text{Total } ^{32}P \text{ recovered from all the zones tried.}}$$

2.3. Morphological observations

The following morphological observations were also recorded at the time of ^{32}P application and during the sampling periods, when the plants were four to six months age.

a. Height of the plant

The height was measured from the base of the pseudostem unto the axil of the youngest leaf and recorded in cm.

b. Girth of the pseudostem

Girth was recorded at about 25 cm height.

c. Number of leaves

Number of fully opened leaves was recorded.

3. Translocation studies using ^{32}P

This experiment was conducted to trace out the mobility and distribution of absorbed ^{32}P inside the plant. ^{32}P was applied into the soil around six flowered plants in the irrigated field by the method described earlier. The radiotracer was applied at a zone, 30 cm deep and 20 cm away from the plant. This soil layer was used for ^{32}P injection because of the maximum recovery of ^{32}P from this zone under the irrigated condition as revealed by the first experiment. The samples after radio assay were collected on the first day after application and subsequently at 5, 15 and 20 days intervals from the treated plants. All the leaves, present on the plant, male flowers, female flowers, fruits and bract were sampled for analysis. Sampling of fruits, male flowers and bracts were done from the top of the bunch and proceeded downwards as time advanced. Radio assay of the collected samples was done as described earlier. The counts after background and decay corrections were utilised for finding out the concentration of ^{32}P in the various parts tested. This gave an idea of the accumulation and translocation of nutrients in different tissues of banana at the time of shooting and harvest.

<u>Statistical analysis</u>

The data recorded on both ^{32}P counts and specific activities were analysed statistically by applying analysis of variance technique with logarithmic transformation, as suggested by Panse and Sukhatme (1967) for factorial experiments.

RESULTS

RESULTS

The results of the investigations on root distribution, root activity and translocation of ^{32}P in banana grown under irrigated and unirrigated conditions are presented below.

1. Root distribution

1.1. Number of roots

The data presented in Table 1 indicated that there was difference in the number of roots of banana grown under irrigated and rainfed conditions. The total number of roots although increased markedly from planting till flowering under both the conditions, the number of roots tended to be more under rainfed condition, maximum being 321, while it was only 282 under irrigated condition.

1.2. Growth of roots

As growth proceeded, elongation of roots was observed under both the conditions as shown by the data presented in Table 1. Increase in the mean length of roots was observed upto flowering and the rate of elongation seemed to be more under rainfed condition. The increase

Table 1. Root growth under irrigated and rainfed conditions

Months after planting	Total number		Mean length (cm)		Mean diameter (cm)		Fresh weight (g)		Dry weight (g)	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
1	22	27	9.0	15.1	0.3	0.4	30.9	69.5	3.5	6.8
2	57	58	19.3	25.3	0.3	0.5	78.0	183.0	6.8	17.5
3	88	112	32.8	35.3	0.4	0.5	180.0	212.5	10.1	21.5
4	129	150	69.5	78.0	0.5	0.7	310.0	363.0	29.8	33.8
5	210	282	98.2	112.5	0.6	0.9	435.0	461.0	43.0	47.1
6	274	302	129.8	132.1	0.8	1.0	552.5	682.0	56.3	69.5
7	278	318	140.1	148.5	0.9	1.1	690.8	890.0	60.0	83.0
8	280	319	142.5	159.0	0.9	1.1	795.0	1008.0	72.5	100.2
9	282	321	149.3	169.5	1.0	1.2	883.0	1090.0	80.0	105.0

in the diameter of root was almost similar under both the growing conditions.

1.3. Fresh weight and dry weight of roots

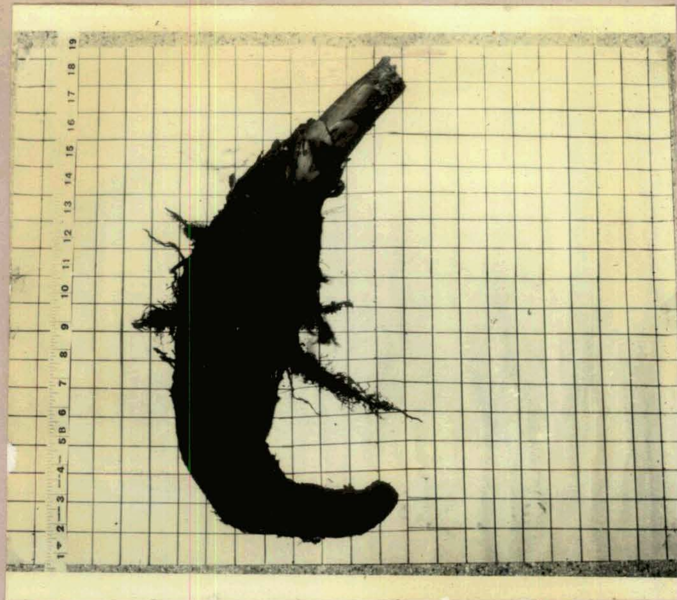
At all stages of growth, the banana grown under rainfed conditions recorded higher fresh and dry weights of roots. At the late vegetative phase the roots of rainfed banana had a fresh weight of 461 g per plant and that of irrigated banana was 435 g. Corresponding dry weights were 47.1 g and 43.8 g respectively. A fresh weight of 1.09 kg was observed in a nine month old (flowered) rainfed banana which was also greater than that under irrigated condition (883 g). The corresponding dry weights were 105 g and 80.1 g under rainfed and irrigated conditions respectively (Table 1). The developmental pattern of root system under both irrigated and rainfed conditions is depicted in Plates III to VI and illustrated in Fig. 3 to 7.

2.1. Root activity under irrigated condition

The indirect method of finding active root zone employing radioactive tracers is based on the assumption that the concentration of the tracer absorbed from a particular distance and soil depth is directly proportional

Plate III Monthly root distribution pattern of irrigated crop.

1) One month after planting
2) Two months after planting
3) Three months after planting
4) Four months after planting
5) Five months after planting



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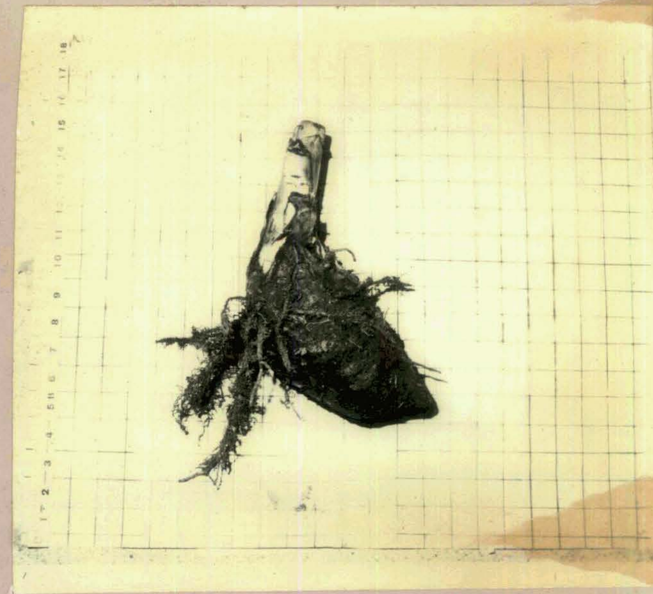

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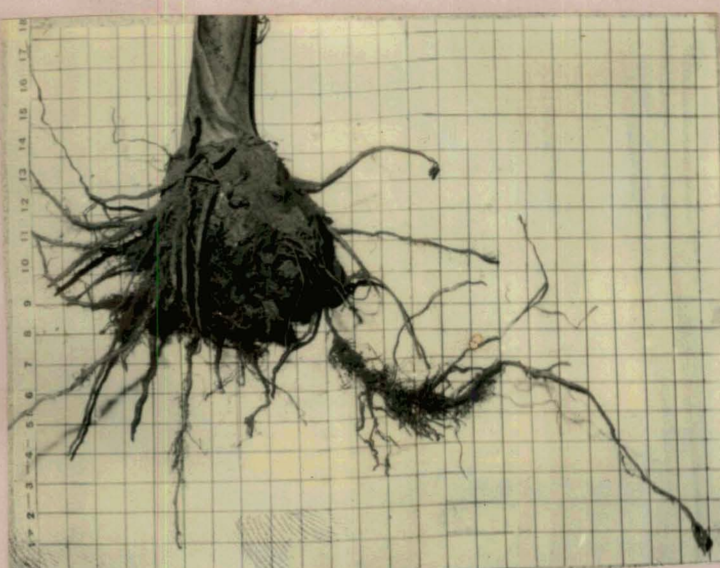

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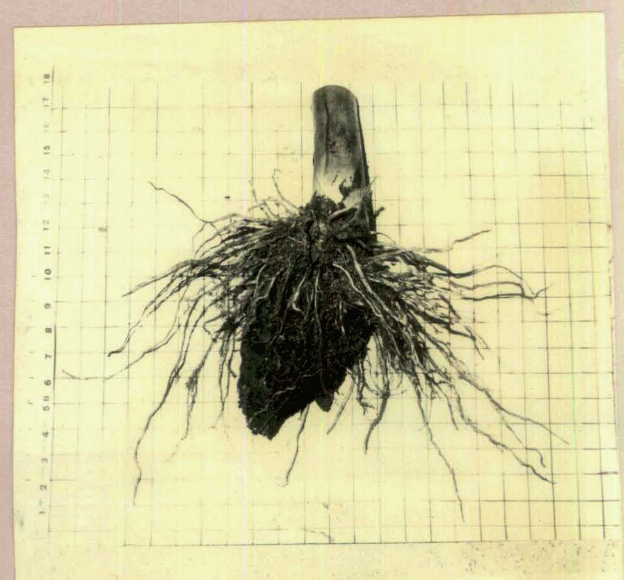

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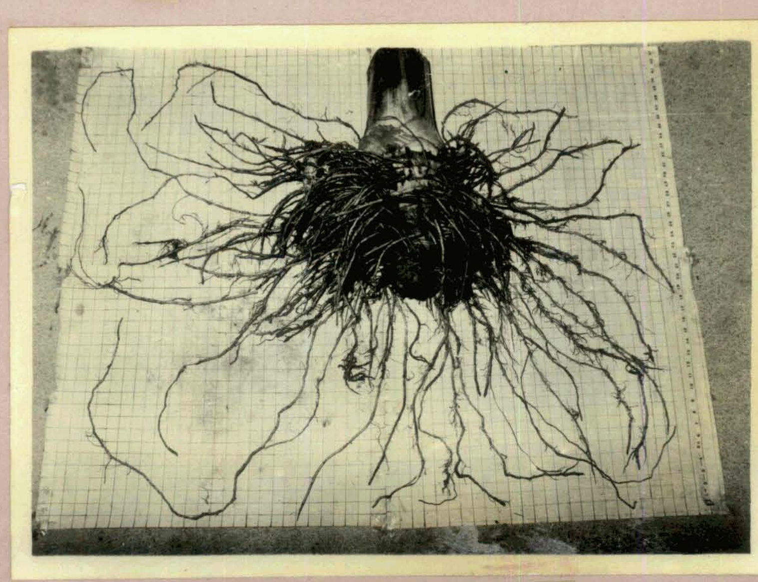

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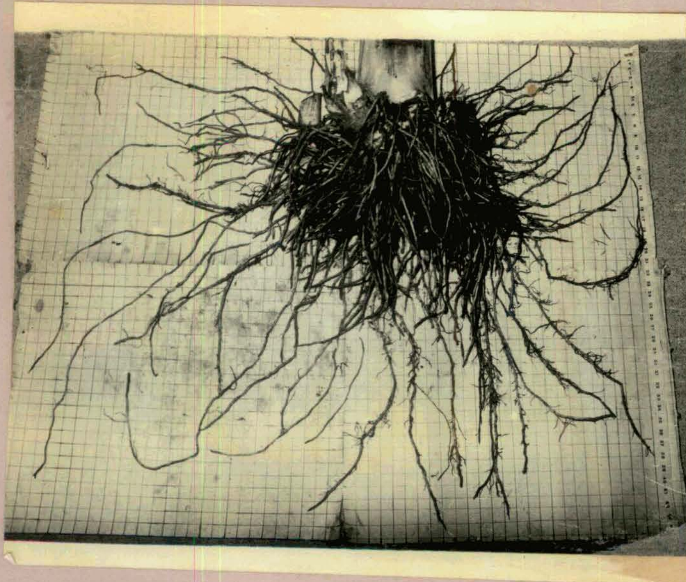
Plate IV Monthly root distribution pattern of irrigated crop

6) Six months after planting
7) Seven months after planting
8) Eight months after planting
9) Nine months after planting



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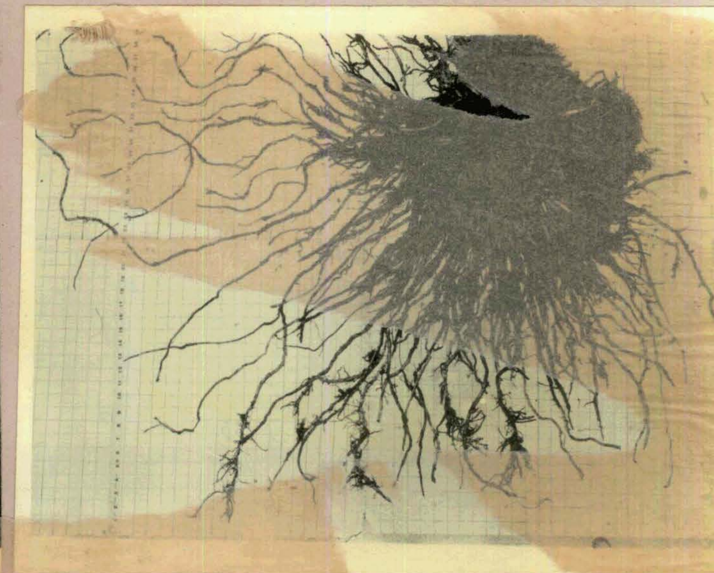

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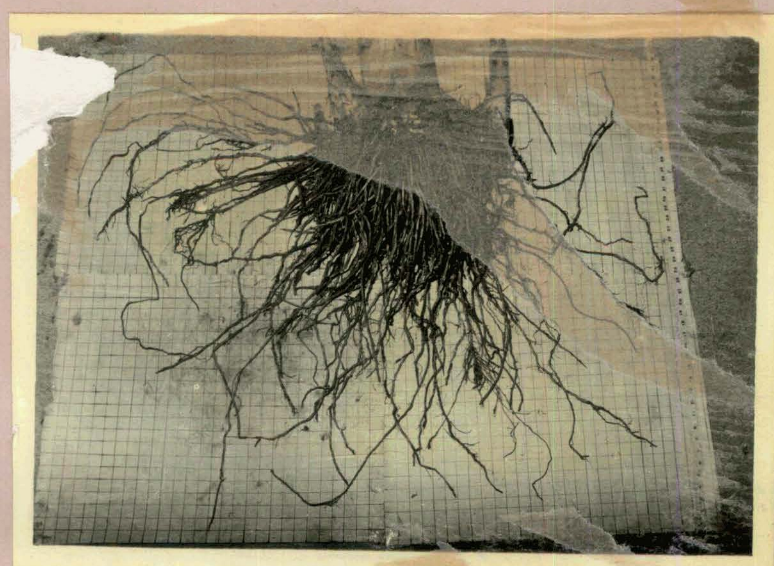

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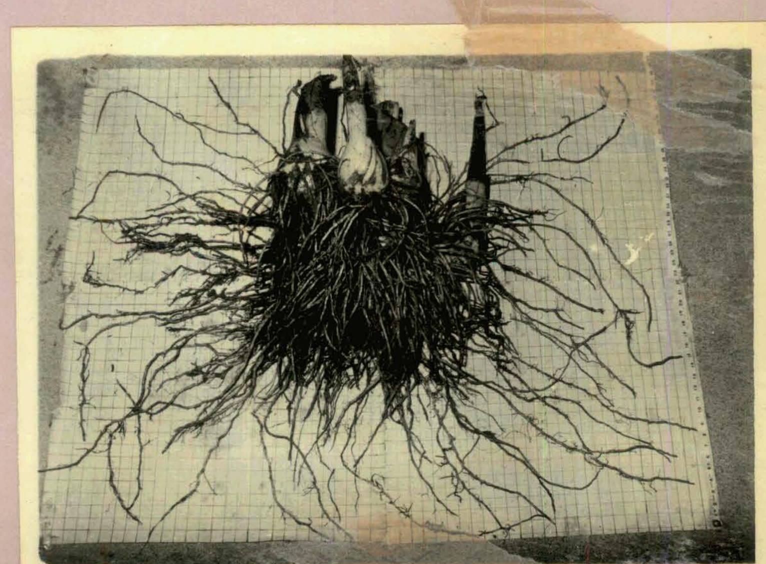

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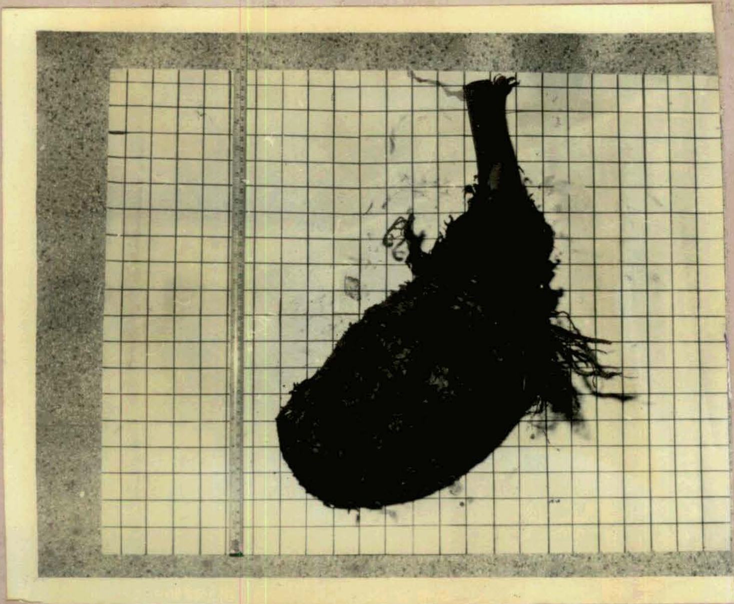
Plate V Monthly root distribution pattern of rainfed crop

1) One month after planting
2) Two months after planting
3) Three months after planting
4) Four months after planting
5) Five months after planting



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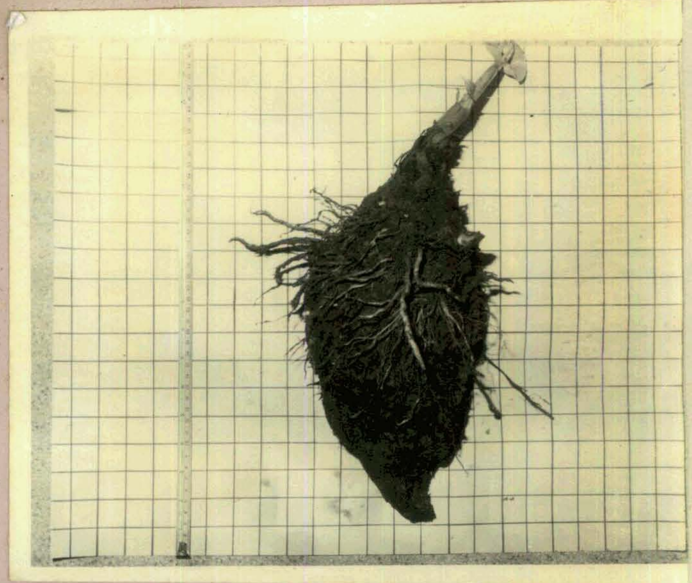

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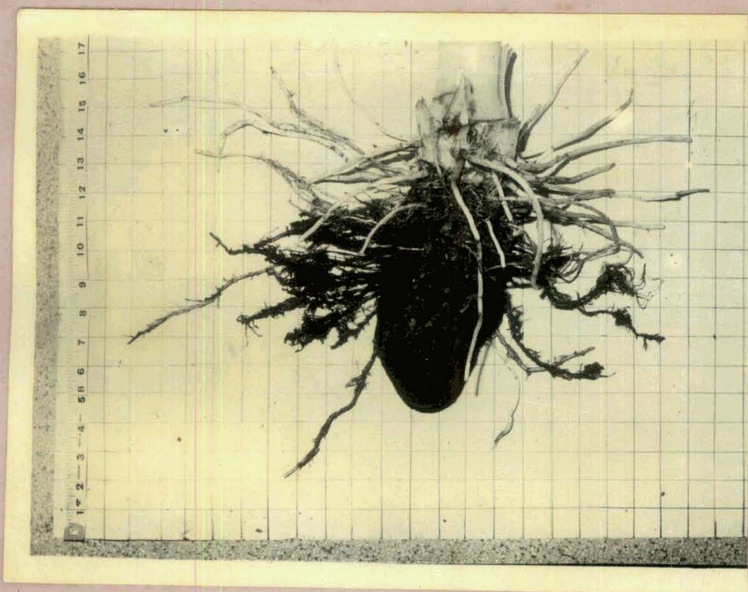

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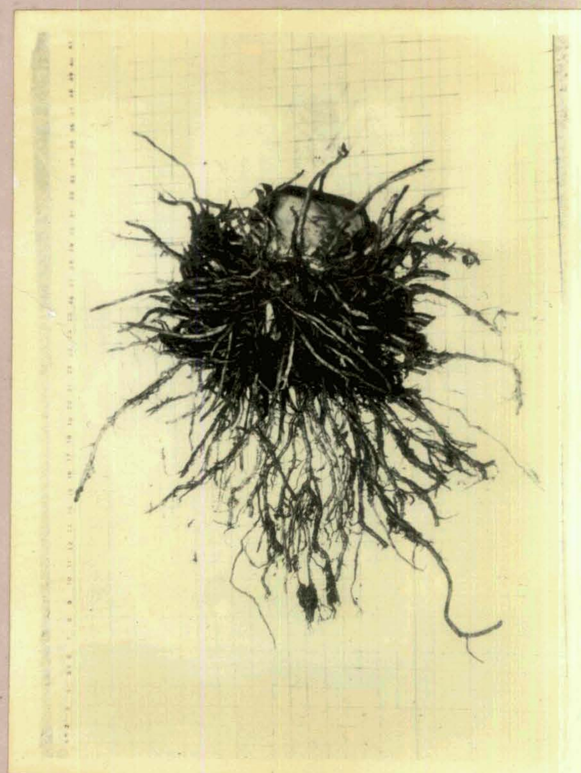

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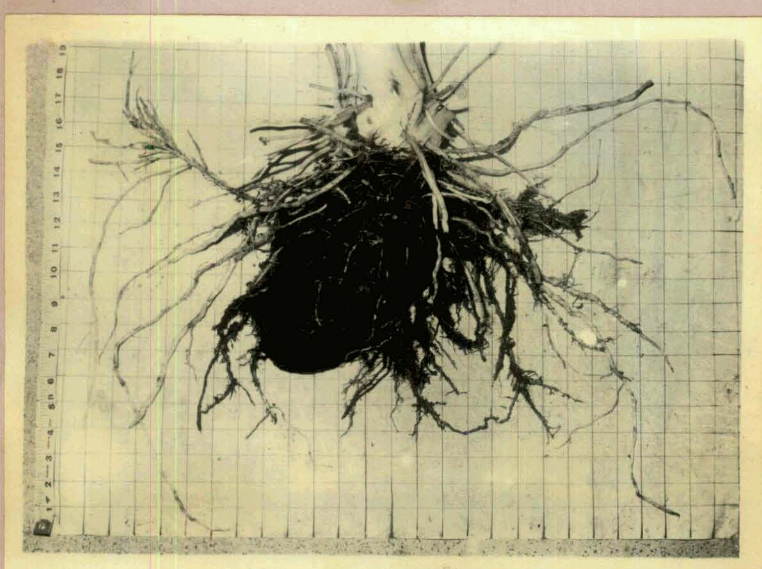

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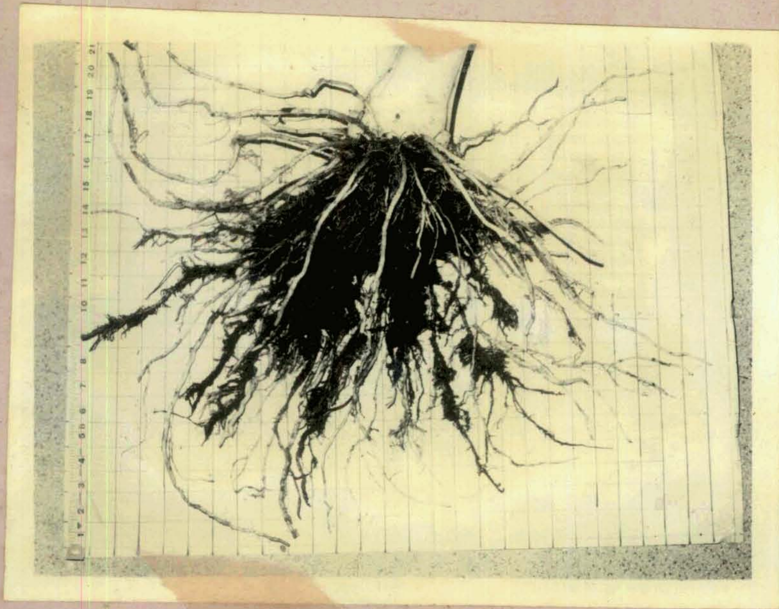
Plate VI Monthly root distribution pattern of rainfed crop

6) Six months after planting
7) Seven months after planting
8) Eight months after planting
9) Nine months after planting



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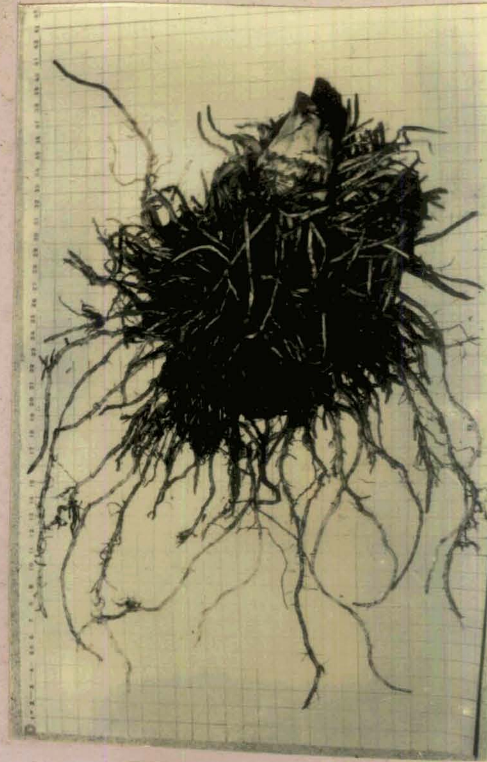

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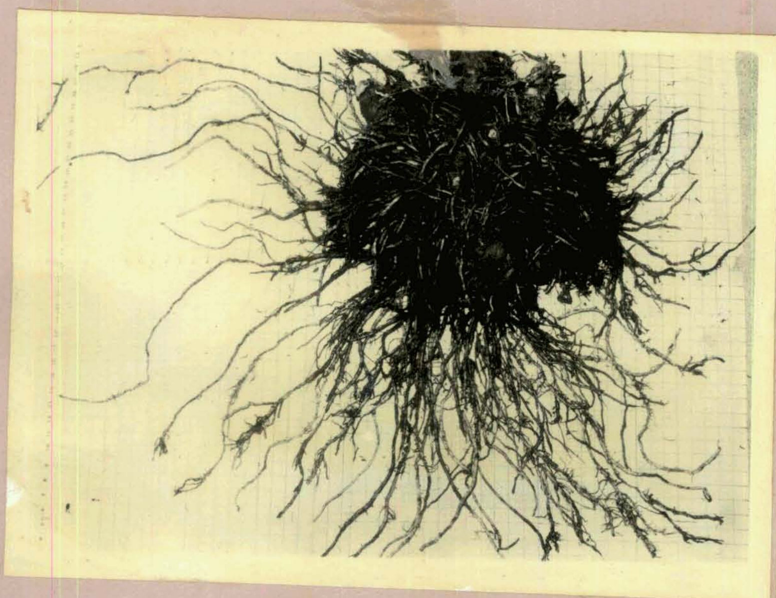

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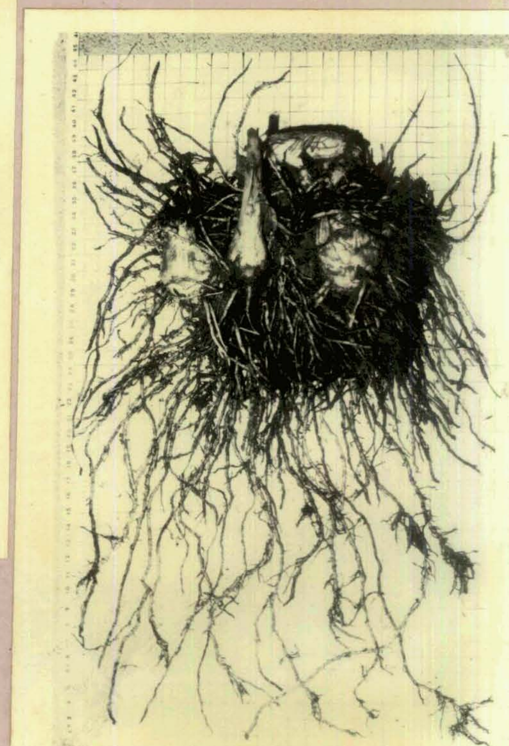

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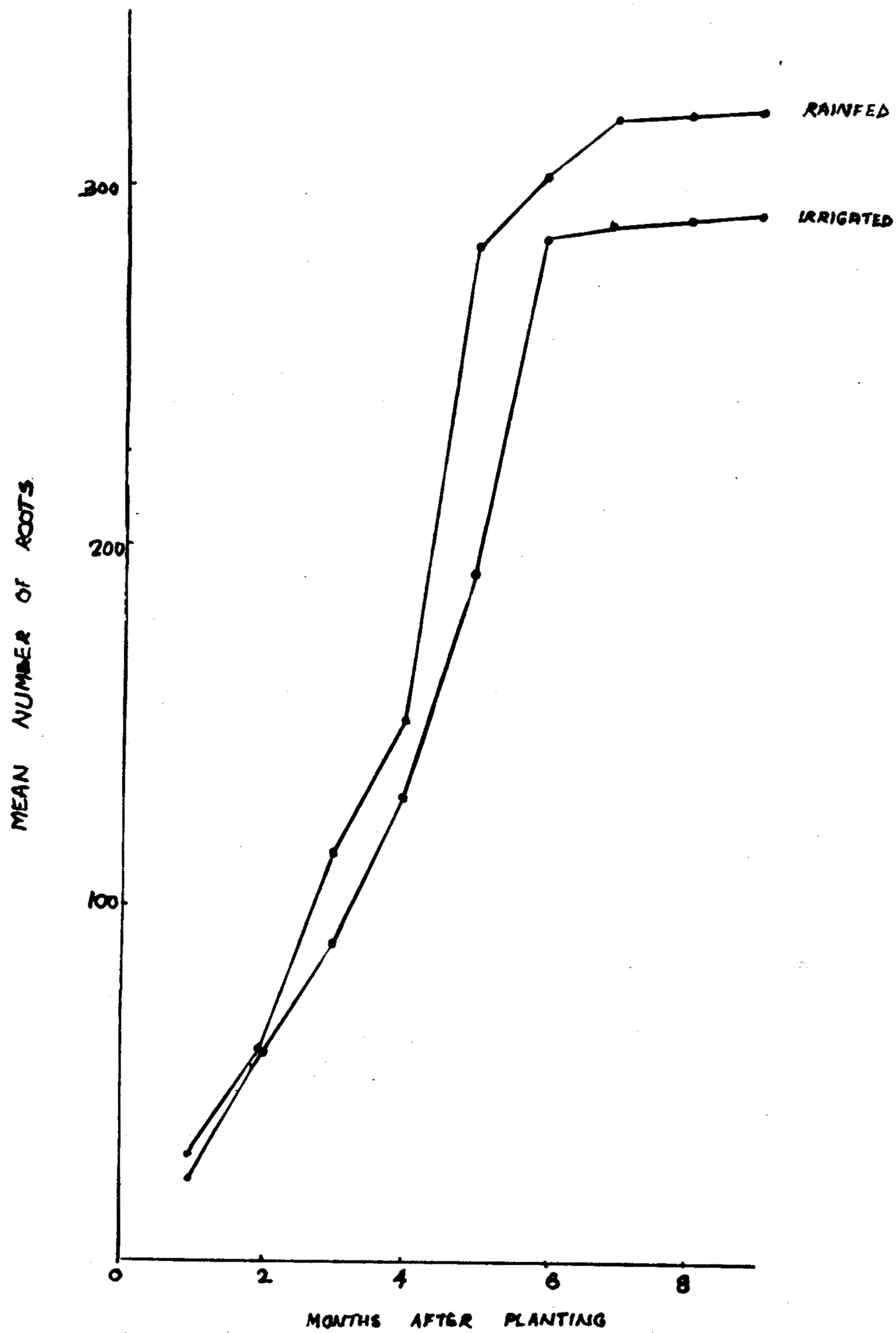

Fig. 3 NUMBER OF ROOTS PER PLANT AT MONTHLY INTERVALS

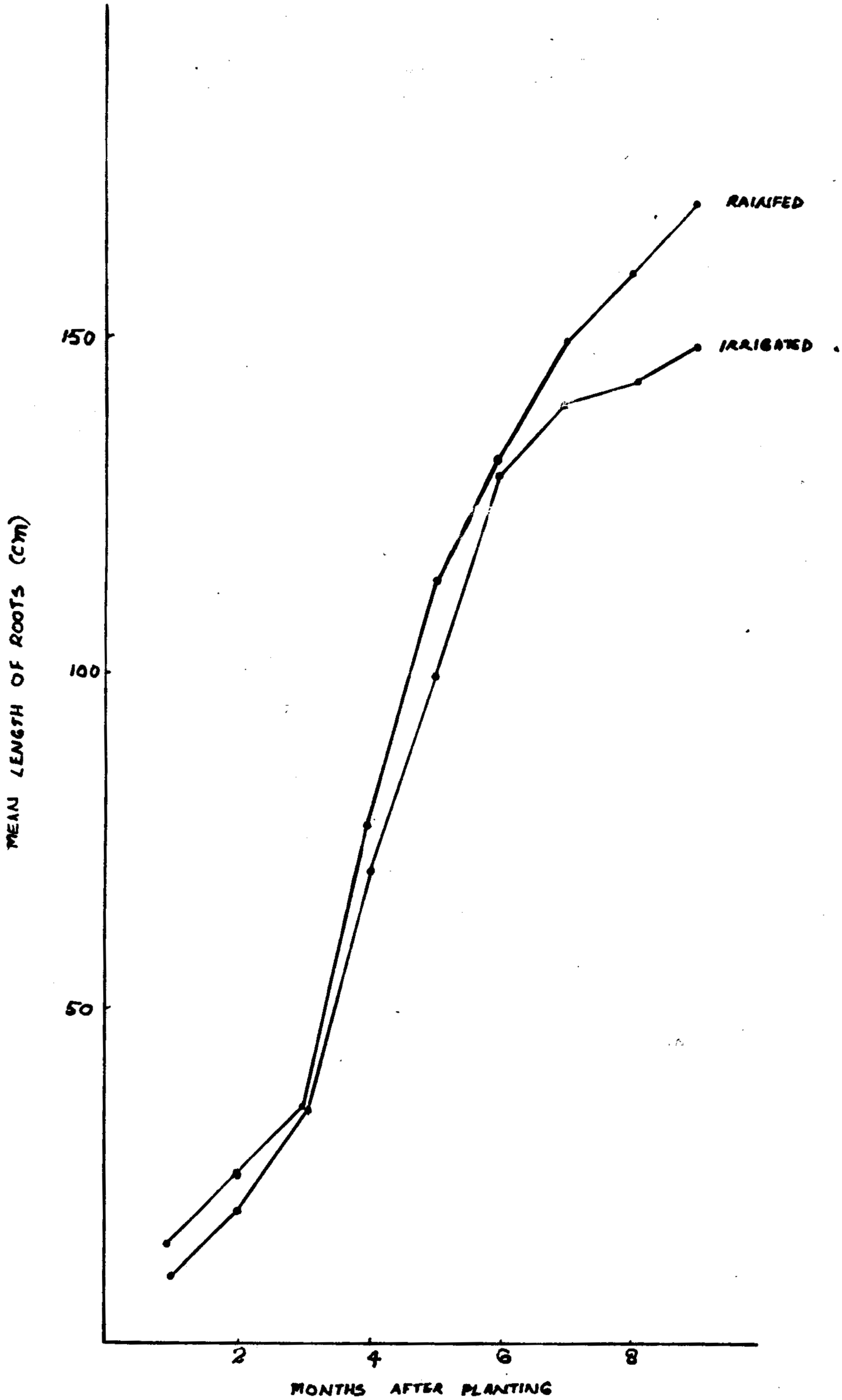

Fig. 4 MEAN LENGTH OF ROOTS AT MONTHLY INTERVALS

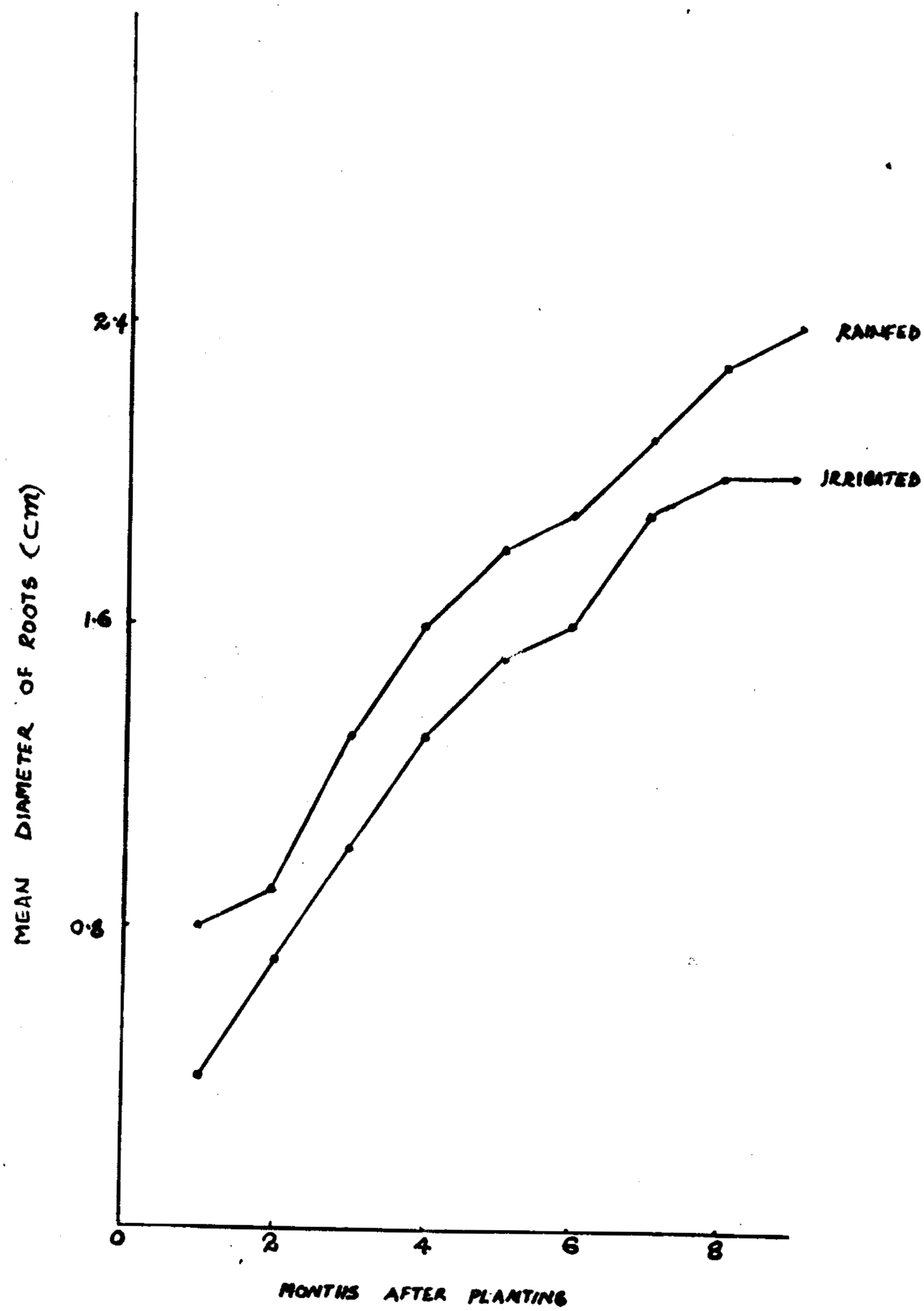

Fig-5 MEAN DIAMETER OF ROOTS AT MONTHLY INTERVALS

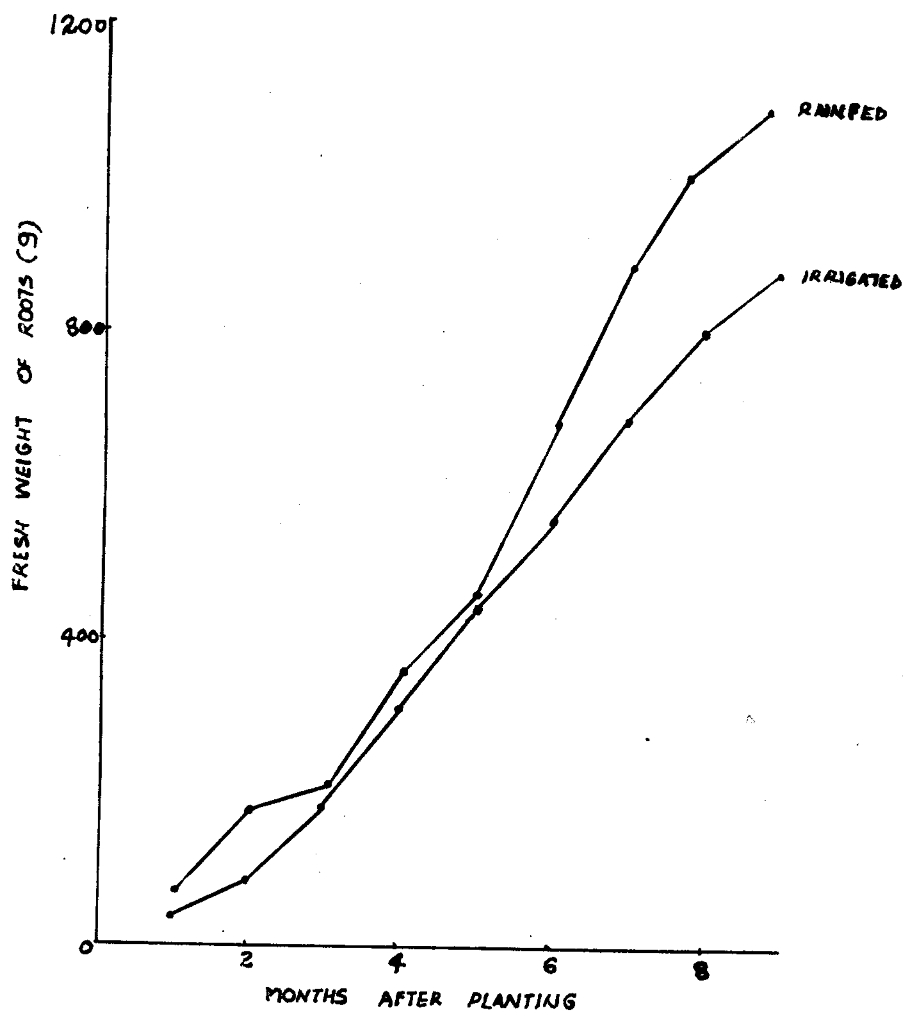

Fig. 6 FRESH WEIGHT OF ROOTS AT MONTHLY INTERVALS

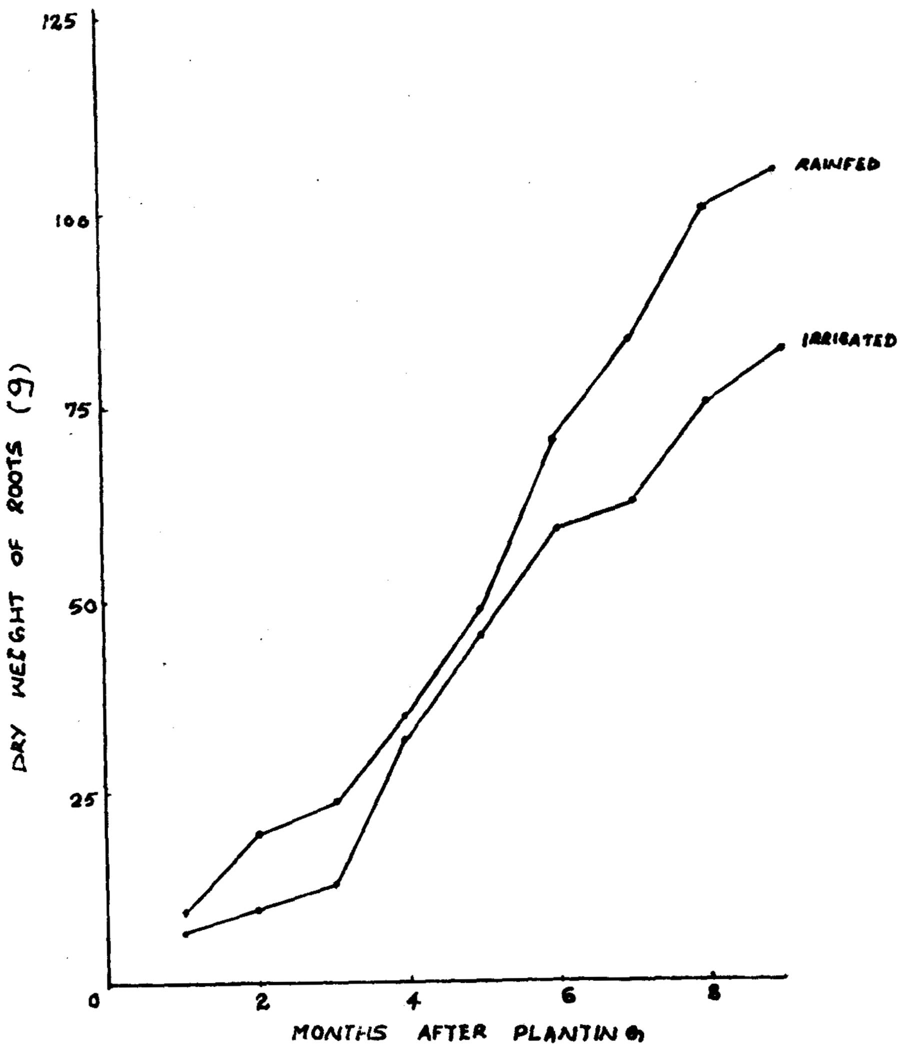

Fig.7 DRY WEIGHT OF ROOTS AT MONTHLY INTERVALS

to the density of active roots distributed in that zone of the soil.

The ^{32}P counts obtained from the leaves sampled 15 days after its injection to the soil and their corresponding specific activities are furnished in Table 2 and 3 respectively. Maximum count was obtained from the treatment site, 5 cm deep and 20 cm away from the pseudostem. As the depth increased from 5 cm to 60 cm the density of active roots decreased from 36.42 per cent to 9.76 per cent, but did not show statistical significance. The reduction of root activity was also observed at increasing distances. It is clear from Table 4 that the highest percentage of active roots (78.85%) was observed at 20 cm which was significantly higher than the root activity at 40 cm (16.85%). The difference between 80 and 120 cm placements was however, not significant (Appendices II and III). The specific activities also indicated a similar trend (Appendix III). The lowest percentage of root activity was observed at 120 cm distance (2.02%). The percentage of active roots at different depths and lateral distances are graphically depicted in Fig. 8 and 9.

Mean values of ^{32}P counts obtained after 30 days of application are furnished in Table 5. A significant

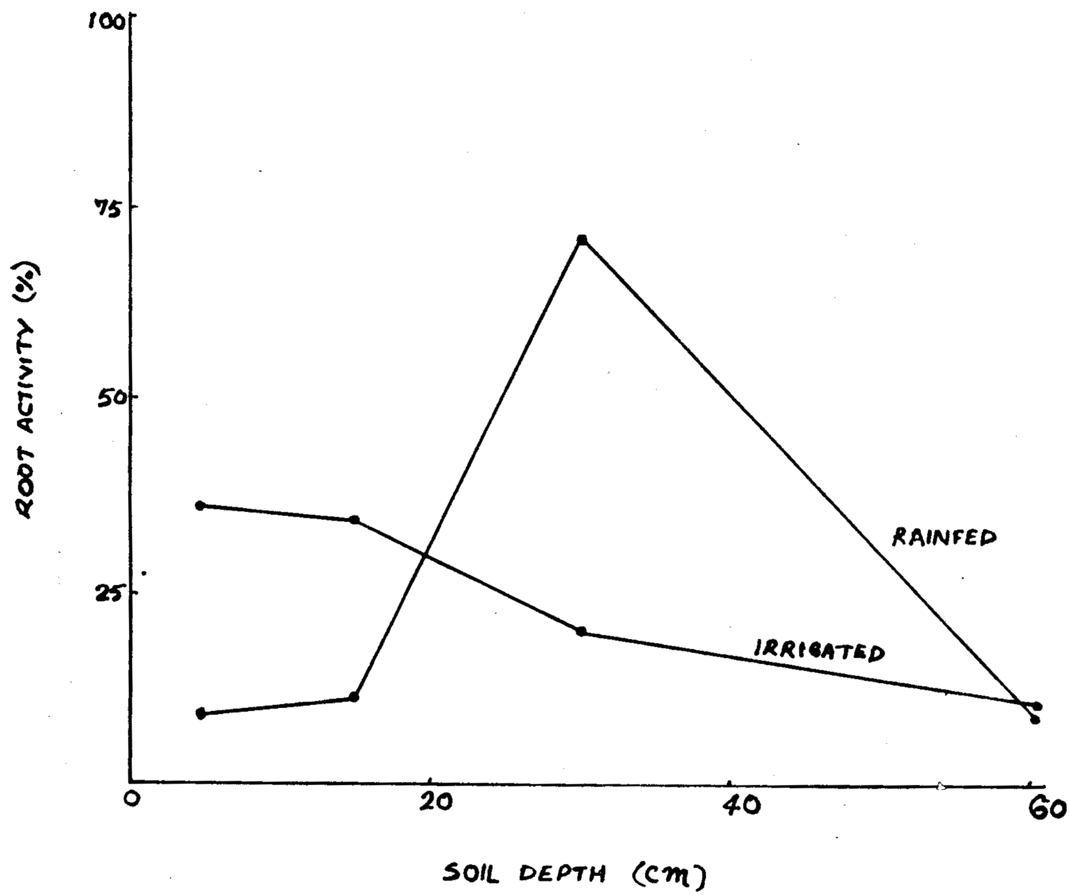

Fig. 8 PERCENTAGE ROOT ACTIVITY AT VARIOUS SOIL DEPTHS, 15 DAYS AFTER P-32 APPLICATION

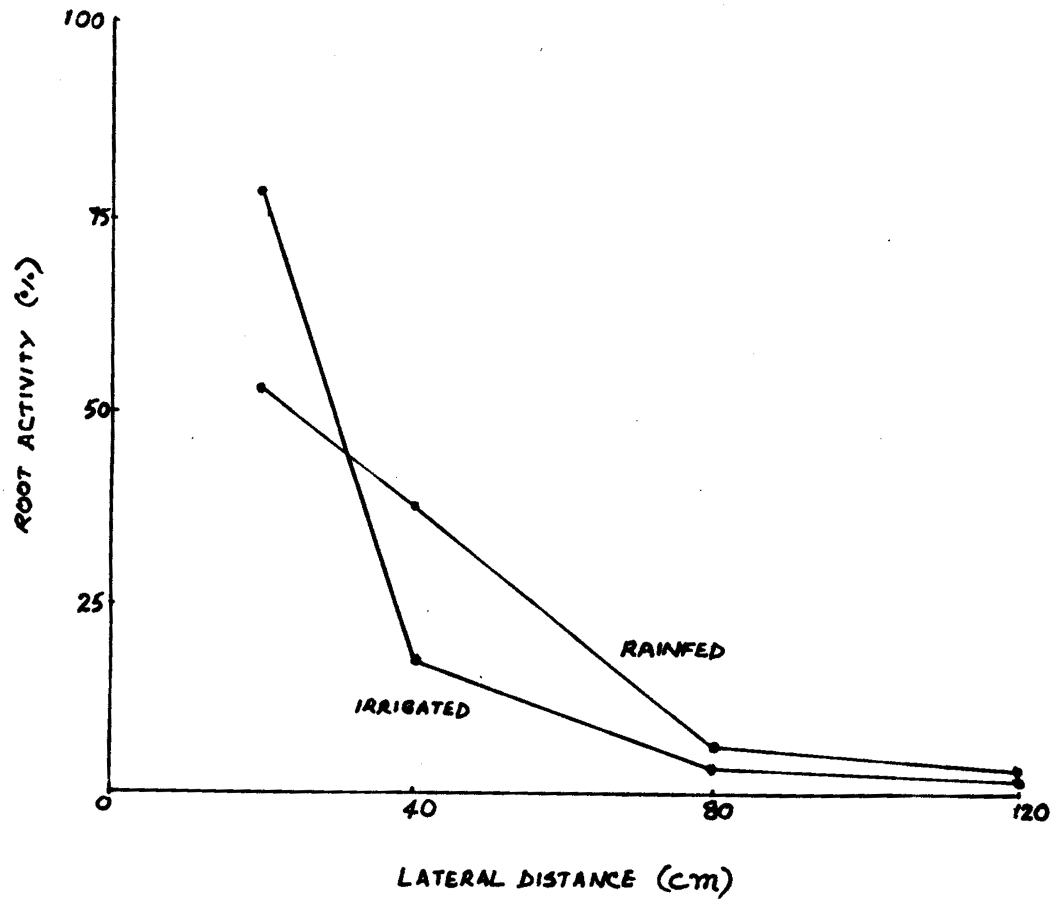

Fig. 9 PERCENTAGE ROOT ACTIVITY AT VARIOUS LATERAL DISTANCES, 15 DAYS AFTER P-32 APPLICATION

Table 2. Recovery of ^{32}P in the leaves of irrigated crop (Cpm/g) 15 days after application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.431*	2.690	2.328	1.737
	(2694.9)**	(489.6)	(212.7)	(54.7)
15	3.390	2.644	2.007	1.758
	(2452.7)	(440.7)	(101.6)	(57.3)
30	3.152	2.577	1.552	1.929
	(1418.7)	(377.3)	(35.7)	(85.0)
60	2.639	2.263	1.516	1.677
	(435.7)	(183.4)	(32.8)	(47.5)

CD = 0.368 SEm = 0.127

* Transformed values

** Parentheses indicate retransformed values.

Table 3. Specific activities (Cpm/mg P) of the leaves of irrigated crop - 15 days after ^{32}P application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.083*	2.386	2.034	1.433
	(1210.3)**	(243.1)	(108.0)	(27.1)
15	3.070	2.326	1.643	1.462
	(1174.5)	(211.9)	(44.0)	(29.0)
30	2.871	2.241	1.247	1.562
	(742.6)	(174.3)	(17.7)	(36.5)
60	2.304	1.958	1.225	1.376
	(201.3)	(90.8)	(16.8)	(23.77)

CD = 0.378 SEm = 0.131

* Log transformed values

** Parentheses indicate the retransformed values.

Table 4. Percentage distribution of root activity under irrigated condition - 15 days after ^{32}P application

Depth (cm)	Lateral distance (cm)				
	20	40	80	120	Total
5	29.93	4.41	1.62	0.46	36.42
15	28.18	4.68	0.91	0.43	34.20
30	14.87	3.69	0.27	0.78	19.61
60	5.08	4.07	0.26	0.35	9.76
Total	78.06	16.85	3.06	2.02	

difference was noticed between the counts of ^{32}P obtained from different lateral distances from the plant (Appendix II). Maximum absorption of ^{32}P occurred when the tracer was placed 30 cm deep and 20 cm away from the plant (22.2%). The same trend was noticed in the specific activities also (Table 6 and Appendix III). However, the difference in ^{32}P uptake from various soil layers were not significant (Appendix II). It may be noted that significantly highest percentage of active roots (63.90%) was seen at 20 cm away from the plant which was significantly higher than the root activity at 40 cm distance (31.02%) (Table 7). As the distance increased from 20 to 120 cm the density of active roots decreased from 63.90 per cent to 1.55 per cent. The graphical representation of the percentage root activity at different depths and lateral distances is given in Fig. 10 and 11.

After 45 days of ^{32}P application density of active roots was highest at a soil zone, 20 cm away from the plant and 30 cm deep from the soil surface (Table 8). The data on specific activities furnished in Table 9 also showed a similar trend. The percentage of active roots at this site was 23.95 (Table 10). Significantly greater amount of active roots were seen at 20 cm lateral distance (14.89%) followed by 40 cm distance (9.46%). However,

Table 5. Recovery of ^{32}P in the leaves of irrigated crop (Cpm/g) - 30 days after application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.628*	3.078	2.790	2.128
	(4241.5)**	(1197.2)	(617.2)	(134.4)
15	3.785	3.536	2.464	2.212
	(6102.0)	(3436.0)	(291.4)	(163.1)
30	3.881	3.429	2.460	2.325
	(7596.0)	(2686.0)	(288.6)	(211.3)
60	3.790	3.597	2.372	1.951
	(6172.4)	(3954.5)	(235.4)	(89.3)

CD = 0.320 SEm = 0.111

* Log transformed values

** Parentheses indicate the retransformed values

Table 6. Specific activities (Cpm/mg P) of the leaves of irrigated crop - 30 days after ^{32}P application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.316*	2.771	2.529	1.846
	(2069.2)**	(589.7)	(337.9)	(70.2)
15	3.481	3.223	2.130	1.930
	(3027.9)	(1669.4)	(134.9)	(85.1)
30	3.571	3.119	2.155	2.029
	(3722.1)	(1316.2)	(143.0)	(106.9)
60	3.481	3.334	2.090	1.666
	(3024.5)	(2158.2)	(123.1)	(46.3)

CD = 0.325 SEm = 0.113

* Log transformed values

** Parentheses indicate the retransformed values

Table 7. Percentage distribution of root activity under irrigated condition - 30 days after ^{32}P application

Depth (cm)	Lateral distance (cm)				
	20	40	80	120	Total
5	11.83	6.62	1.35	0.29	20.29
15	14.94	8.19	0.64	0.42	24.19
30	22.20	6.34	0.86	0.64	30.04
60	14.93	9.87	0.78	0.20	25.78
Total	63.90	31.02	3.63	1.55	

Table 8. Recovery of ^{32}P in the leaves of irrigated crop (Cpm/g) - 45 days after application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.775*	3.248	3.153	2.658
	(5951.8)**	(1769.7)	(1422.5)	(455.5)
15	4.010	3.860	3.009	2.718
	(10238.1)	(7249.4)	(1021.6)	(521.9)
30	4.161	3.622	2.923	2.924
	(14491.9)	(4188.4)	(838.2)	(839.6)
60	4.069	3.877	2.796	2.509
	(11709.6)	(7532.1)	(625.1)	(323.2)

CD = 0.317 SEm = 0.110

* Log transformed values

** Parentheses indicate retransformed values

Table 9. Specific activities (Cpm/mg P) of the leaves of irrigated crop - 45 days after ^{32}P application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.452*	2.941	2.853	2.359
	(2828.8**)	(872.3)	(713.3)	(228.7)
15	3.730	3.560	2.747	2.417
	(5367.9)	(3629.4)	(558.6)	(261.3)
30	3.858	3.340	2.628	2.625
	(7217.9)	(2188.7)	(424.6)	(422.0)
60	3.748	3.617	2.518	2.204
	(5593.2)	(4137.2)	(329.8)	(160.0)

CD = 0.323 SEm = 0.112

* Log transformed values

** Parentheses indicate retransformed values

Table 10. Percentage distribution of root activity under irrigated condition - 45 days after ^{32}P application

Depth (cm)	Lateral distance (cm)				
	20	40	80	120	Total
5	7.71	7.41	1.89	0.52	17.53
15	13.41	9.46	1.83	0.60	25.30
30	23.85	5.49	1.11	1.07	31.52
60	14.89	9.46	0.92	0.38	25.65
Total	59.86	31.82	5.75	2.57	

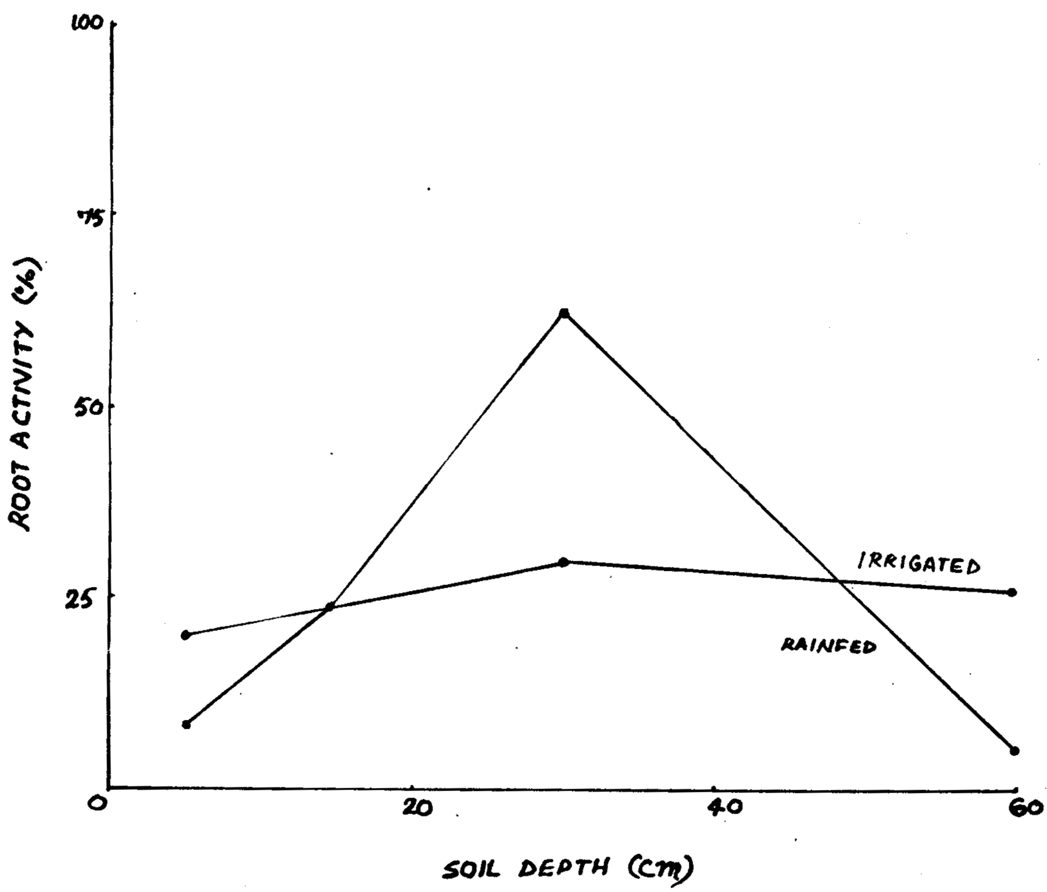

Fig.10 PERCENTAGE ROOT ACTIVITY AT VARIOUS SOIL DEPTHS, 30 DAYS AFTER P-32 APPLICATION

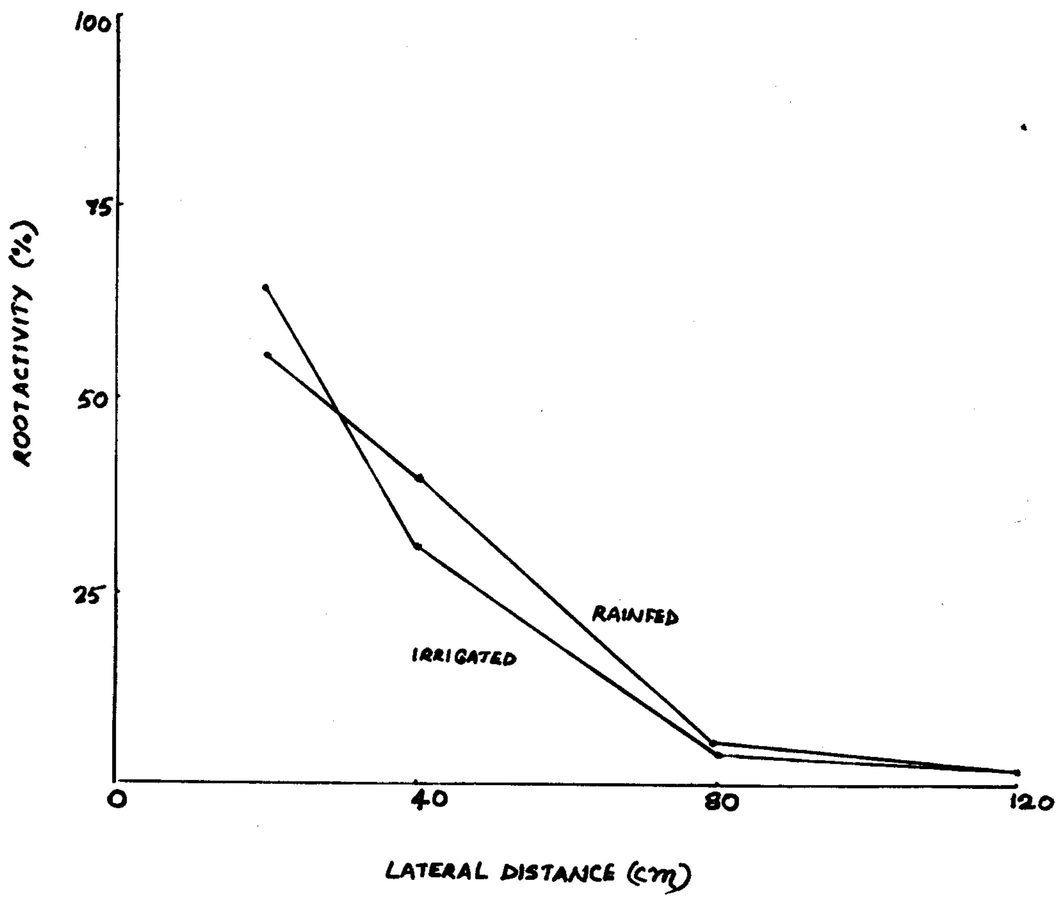

Fig. 11 PERCENTAGE ROOT ACTIVITY AT VARIOUS LATERAL DISTANCES, 30 DAYS AFTER P-32 APPLICATION

the concentration of active roots did not differ significantly at 80 cm and 120 cm lateral distances (Appendices II and III). A gradual reduction in the percentage of active roots (from 59.86 to 2.57%) was seen from 20 cm to 120 cm away from the plant. Different depths of ^{32}P placements did not have significant effect on the ^{32}P counts. However, highest percentage (31.52%) was observed at 30 cm depth (Table 10) and the least (17.53%) at 5 cm depth. The percentage of active roots at different treatment sites are graphically depicted in Fig.12 and 13.

The ^{32}P counts absorbed from different treatment sites and their specific activities, 60 days after ^{32}P application, are furnished in Tables 11 and 12. The data indicated that the difference in the recovery of ^{32}P from 20 cm and 40 cm distances was not significant (Appendices II and III). The percentage root activity at 20 cm distance was 47.27 and that at 40 cm was 36.65% (Table 13). The absorption of ^{32}P from 80 and 120 cm lateral distances were significantly lower than that from 20 or 40 cm. Significant difference was not noticed between different depths of ^{32}P placements eventhough highest percentage (33.81%) of active roots was observed at a depth of 30 cm and the lowest at 5 cm depth (18.29%). A maximum percentage of 23.18 was thus observed at a treatment site, 20 cm

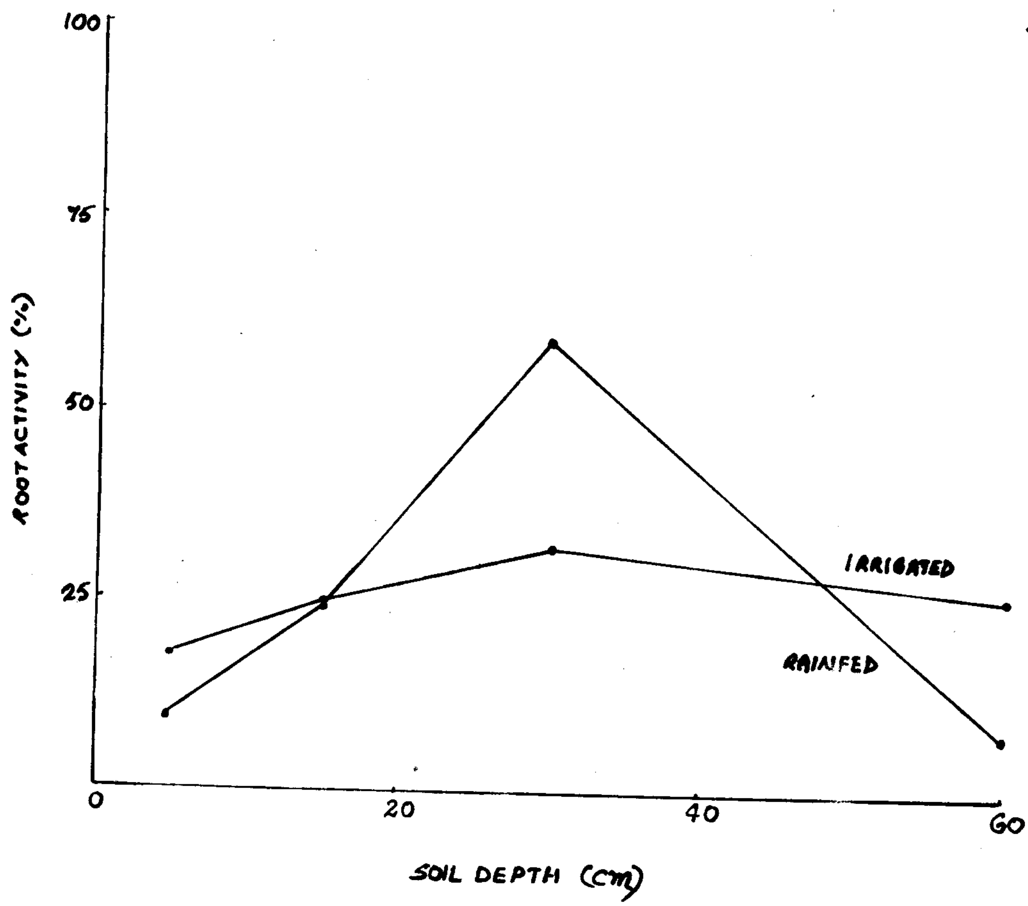

Fig.12 PERCENTAGE ROOT ACTIVITY AT VARIOUS SOIL DEPTHS, 45 DAYS AFTER P-32 APPLICATION

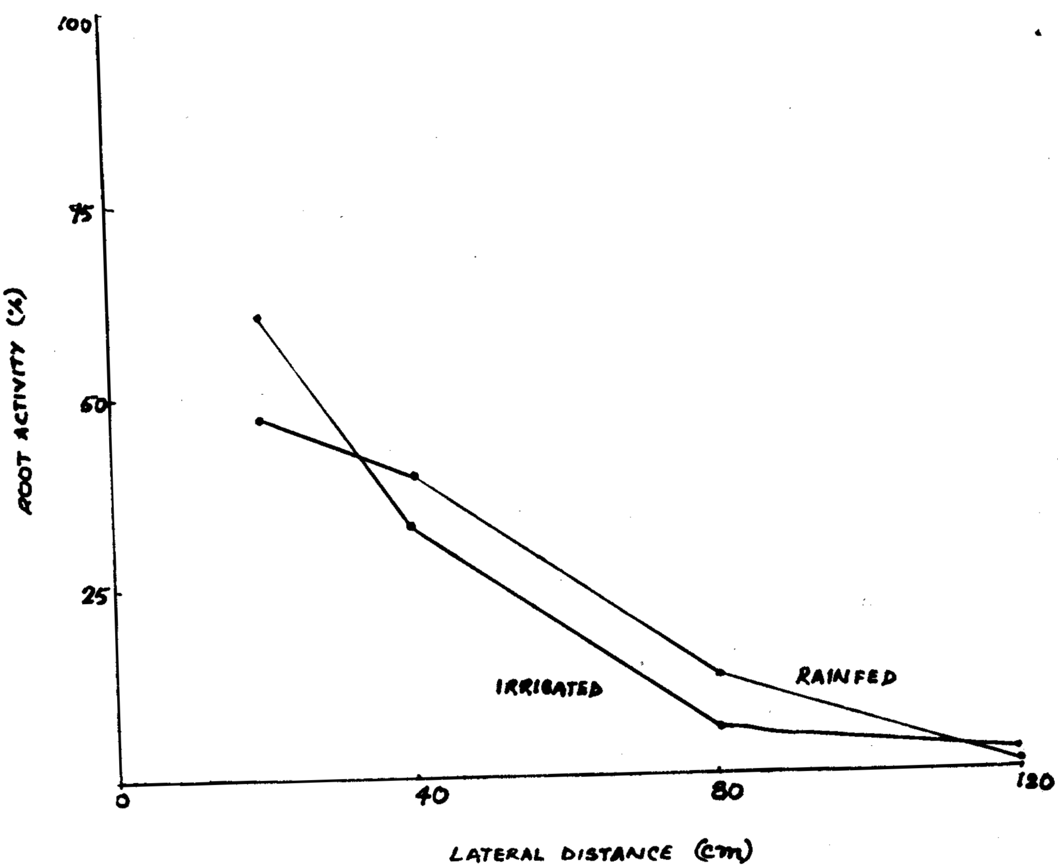

Fig. 13 PERCENTAGE ROOT ACTIVITY AT VARIOUS LATERAL DISTANCES, 45 DAYS AFTER P-32 APPLICATION

Table 11. Recovery of ^{32}P on the leaves of irrigated crop (Cpm/g) - 60 days after application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.721*	3.500	3.399	3.380
	(5257.2)**	(3165.0)	(2508.3)	(2398.7)
15	4.054	4.060	3.378	2.627
	(11319.4)	(11484.0)	(2387.9)	(424.0)
30	4.266	3.894	3.293	3.005
	(18460.5)	(7835.8)	(1963.9)	(1012.7)
60	3.866	4.120	3.151	2.132
	(7347.2)	(13176.8)	(1415.8)	(135.5)

CD = 0.373 SEm = 0.129

* Log transformed values

** Parentheses indicate retransformed values

Table 12. Specific activities (Cpm/mg P) of the leaves of irrigated crop - 60 days after ^{32}P application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.365*	3.117	3.024	3.008
	(2315.0)**	(1309.7)	(1056.2)	(1019.5)
15	3.690	3.704	3.026	2.244
	(4895.4)	(5062.1)	(1061.6)	(175.5)
30	3.895	3.522	2.937	2.630
	(7846.0)	(3328.3)	(865.7)	(426.5)
60	3.491	3.744	2.768	1.768
	(3094.3)	(5548.6)	(585.9)	(58.6)

CD = 0.374 SEm = 0.130

* Log transformed values

** Parentheses indicate retransformed values

Table 13. Percentage distribution of root activity under irrigated condition - 60 days after ^{32}P application

Depth (cm)	Lateral distance (cm)				
	20	40	80	120	Total
5	4.98	6.64	3.99	2.68	18.29
15	10.38	11.26	3.81	0.43	25.88
30	23.18	7.39	1.88	1.36	33.81
60	8.73	11.36	1.80	0.14	22.03
Total	47.27	36.65	11.48	4.61	

away from the plant and 30 cm deep from the surface of soil. The percentage root activity at different treatment sites are graphically illustrated in Fig. 14 and 15.

2.2. Root activity under rainfed condition

Fifteen days after application, maximum amount of ^{32}P was absorbed from 30 cm depth and 20 cm distance from the pseudostem (Tables 14 and 15) which was significantly higher than from the other treatment sites (Appendices IV and V). The percentages of activity at this treatment site was 41.28 (Table 16). There was no significant difference between the ^{32}P counts applied at 20 and 40 cm distances. However, 20 cm distance had a maximum of 52.92 per cent active roots. The percentage root activity decreased with increasing distances from 52.92 per cent to 3.12 per cent. The distances of 80 and 120 cm had almost similar amounts of ^{32}P. Among the various depths tried, root activity was highest at 30 cm (70.94%). The differences were not significant among other treatment depths (Appendix IV). The percentage of active roots at different treatment depths and distances are graphically depicted in Fig. 8 and 9.

The samples drawn 30 days after ^{32}P application showed significant differences in the absorption of ^{32}P

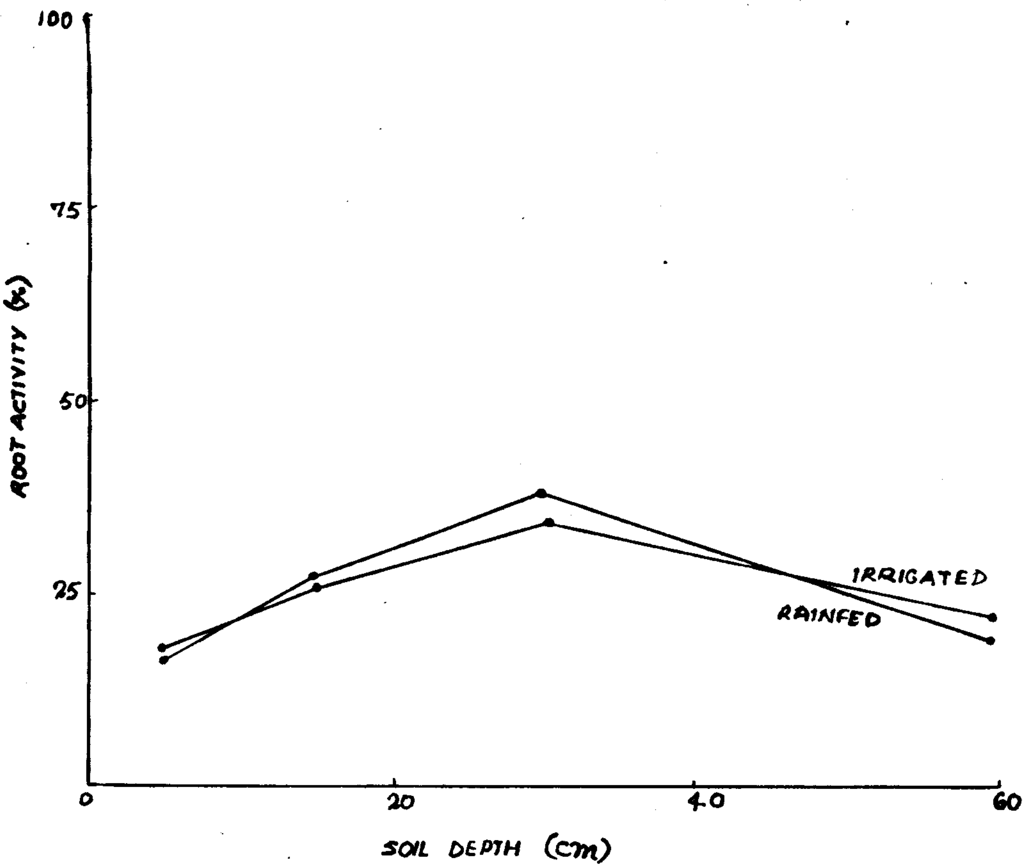

Fig. 14 PERCENTAGE ROOT ACTIVITY AT VARIOUS SOIL DEPTHS, 60DAYS AFTER P-32 APPLICATION

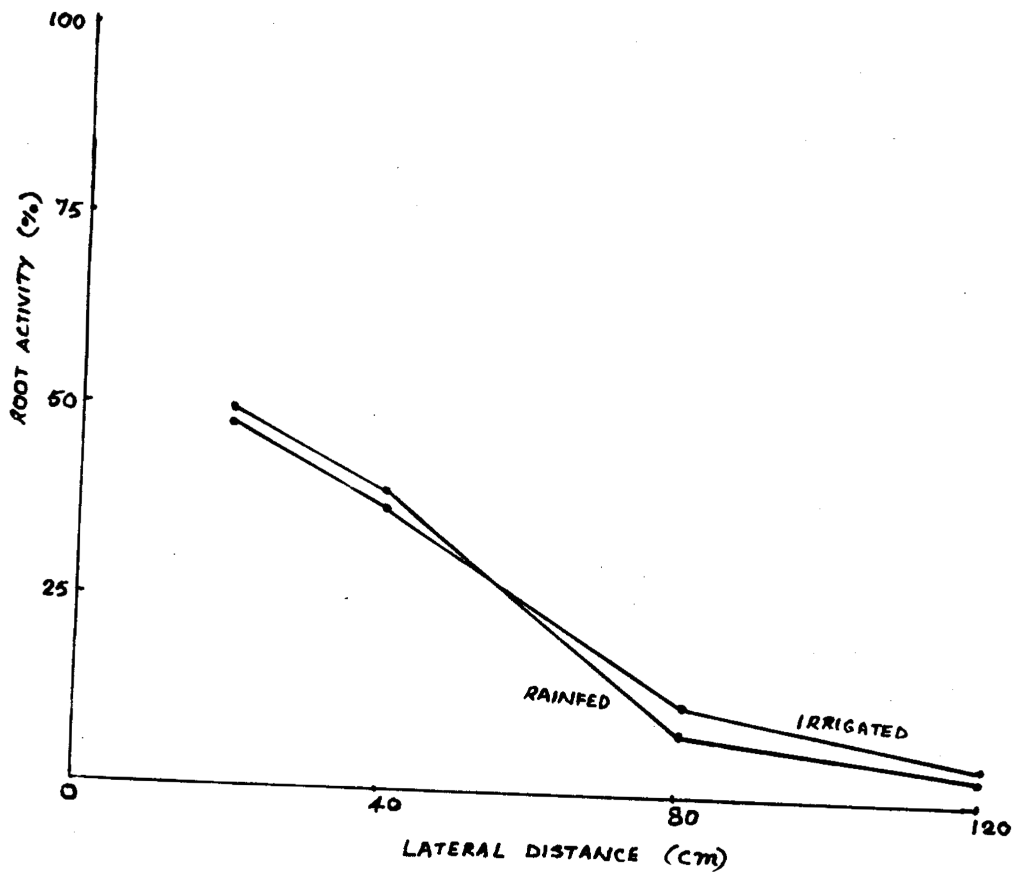

Fig.15 PERCENTAGE ROOT ACTIVITY AT VARIOUS LATERAL DISTANCES, 60 DAYS AFTER P-32 APPLICATION

Table 14. Recovery of ^{32}P in the leaves of rainfed crop (Cpm/g) - 15 days after application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	2.671*	2.733	2.348	2.400
	(468.6)**	(540.6)	(222.8)	(251.1)
15	3.062	2.631	2.345	2.139
	(1153.3)	(427.9)	(221.2)	(137.6)
30	3.969	3.571	2.810	2.266
	(9310.1)	(3724.8)	(645.8)	(184.6)
60	2.871	2.934	2.615	2.192
	(743.5)	(859.4)	(412.5)	(155.4)

CD = 0.300 SEm = 0.104

* Log transformed values

** Parentheses indicate retransformed values

Table 15. Specific activities (Cpm/mg P) of the leaves of rainfed crop - 15 days after ^{32}P application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	2.858*	2.877	2.387	2.568
	(721.9)**	(753.8)	(243.6)	(370.0)
15	3.300	2.786	2.548	2.258
	(1994.5)	(610.8)	(353.1)	(181.2)
30	4.111	3.737	3.370	2.518
	(12899.3)	(5460.7)	(2342.7)	(329.6)
60	3.033	3.105	2.802	2.429
	(1077.9)	(1273.1)	(634.6)	(268.8)

CD = 0.314 SEm = 0.109

* Log transformed values

** Parentheses indicate retransformed values

Table 16. Percentage distribution of root activity under rainfed condition - 15 days after ^{32}P application

Depth (cm)	Lateral distance (cm)				
	20	40	80	120	Total
5	1.79	5.35	0.86	1.11	9.11
15	6.70	2.39	0.85	0.62	10.56
30	41.28	26.52	2.42	0.72	70.94
60	3.15	3.6	1.96	0.67	9.38
Total	52.92	37.86	6.09	3.12	

between various depths and distances (Appendices IV and V). Maximum absorption of the radio label was observed from a soil depth of 30 cm (62.25%), which was significantly higher than the other depths (Tables 17 and 18). The density of active roots was more at 15 cm (23.51%) than at 5 cm (7.96%) and 60 cm (6.32%). When the different lateral distances were considered, root activity was significantly high at 20 cm (54.38%) and 40 cm (39.8%) than at 80 and 120 cm distances (Table 19). The density of active roots was highest (31.91%) in a soil zone, 30 cm deep and 40 cm distant from the plant. The reduction in the root activity at distant zones can be realised from Fig.11. The percentage activity at different soil depths are shown in Fig.10.

The data after 45 days of ^{32}P application furnished in Tables 20 and 21 show a significantly higher root activity at 30 cm depth (59.27%) than the rest which, however, did not differ significantly between themselves (Appendices IV and V). The highest percentage of root activity was noticed at a treatment site, 40 cm away from the plant and at 30 cm depth (26.34%) (Table 22). However, the density of active roots at 20 cm (46.68%) and 40 cm (38.49%) did not differ significantly eventhough they

Table 17. Recovery of ^{32}P in the leaves of rainfed cop (Cpm/g) - 30 days after application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.425*	3.198	2.792	2.641
	(2663.6)**	(1579.0)	(620.0)	(437.6)
15	4.198	3.380	2.643	2.435
	(15758.3)	(2400.3)	(439.6)	(272.3)
30	4.553	4.447	3.055	2.672
	(35724.9)	(27958.2)	(1135.9)	(470.0)
60	3.096	3.327	2.939	2.408
	(1246.6)	(2122.8)	(869.6)	(256.1)

CD = 0.396 SEm = 0.137

* Log transformed values

** Parentheses indicate retransformed values

Table 18. Specific activities (Cpm/mg P) of the leaves of rainfed crop - 30 days after ^{32}P application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.496*	3.219	2.937	2.677
	(3136.8)**	(1654.0)	(864.2)	(475.2)
15	4.303	3.505	2.811	2.464
	(20078.9)	(3200.3)	(647.8)	(290.9)
30	4.608	4.486	3.152	2.677
	(40518.9)	(30613.3)	(1417.9)	(475.3)
60	3.141	3.449	3.068	2.560
	(1382.9)	(2811.1)	(1170.4)	(362.9)

CD = 0.397 SEm = 0.137

* Log transformed values

** Parentheses indicate retransformed values

Table 19. Percentage distribution of root activity under rainfed condition - 30 days after ^{32}P application

Depth (cm)	Lateral distance (cm)				
	20	40	80	120	Total
5	3.79	3.06	0.62	0.47	7.94
15	20.97	1.96	0.36	0.22	23.51
30	28.61	31.91	1.30	0.43	62.25
60	1.01	2.87	2.20	0.23	6.31
Total	54.38	39.80	4.48	1.35	

Table 20. Recovery of ^{32}P in the leaves of rainfed crop (Cpm/g) - 45 days after application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.931*	3.750	2.773	2.576
	(8528.0)**	(5617.8)	(593.4)	(376.9)
15	4.435	3.814	2.728	3.130
	(27199.7)	(6516.6)	(534.8)	(1349.8)
30	4.624	4.618	3.780	2.686
	(42088.4)	(41542.5)	(6019.6)	(484.9)
60	3.490	3.794	3.110	2.549
	(3089.6)	(6220.0)	(1288.4)	(354.3)

CD = 0.391 SEm = 0.136

* Log transformed values

** Parentheses indicate retransformed values

Table 21. Specific activities (Cpm/mg P) of the leaves of rainfed crop - 45 days after ^{32}P application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	4.393*	4.016	3.142	2.881
	(24711.2)**	(10387.0)	(1388.2)	(760.3)
15	5.056	4.144	3.230	3.615
	(113750.9)	(13922.6)	(1698.1)	(4120.4)
30	5.067	4.770	4.336	3.207
	(116721.8)	(58915.1)	(21653.3)	(1609.1)
60	3.952	4.183	3.653	3.352
	(8958.8)	(15236.8)	(4502.4)	(2249.5)

CD = 0.442 SEm = 0.153

* Log transformed values

** Parentheses indicate retransformed values

Table 22. Percentage distribution of root activity under rainfed condition - 45 days after ^{32}P application

Depth (cm)	Lateral distance (cm)				
	20	40	80	120	Total
5	5.50	3.59	0.37	0.21	9.67
15	18.04	3.69	0.33	1.40	23.46
30	21.53	26.34	10.97	0.43	59.27
60	1.61	4.87	1.77	0.18	8.43
Total	46.68	38.49	13.44	2.22	

Table 23. Recovery of ^{32}P in the leaves of rainfed crop (Cpm/g) - 60 days after application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	4.176*	4.130	3.303	2.959
	(15000.4)**	(13478.8)	(2007.9)	(909.3)
15	4.460	2.240	3.660	3.049
	(28813.6)	(17374.0)	(4572.4)	(1120.6)
30	4.476	4.562	3.910	3.449
	(29946.8)	(36476.0)	(8125.2)	(2813.2)
60	4.321	4.173	3.601	3.067
	(20931.3)	(14878.3)	(3987.4)	(1166.4)

CD = 0.236 SEm = 0.082

* Log transformed values

** Parentheses indicate retransformed values

Table 24. Specific activities (Cpm/mg P) of the leaves of rainfed crop - 60 days after ^{32}P application

Depth (cm)	Lateral distance (cm)			
	20	40	80	120
5	3.895*	3.878	3.016	2.686
	(7861.9)**	(7551.1)	(1037.5)	(485.7)
15	4.224	3.972	3.355	2.791
	(16742.0)	(9376.6)	(2264.3)	(618.5)
30	4.176	4.305	3.674	3.181
	(14988.3)	(2018.3)	(4724.7)	(1518.6)
60	4.048	3.896	3.328	2.785
	(11167.5)	(7876.4)	(2127.3)	(608.9)

CD = 0.246 SEm = 0.085

* Log transformed values

** Parentheses indicate retransformed values

grown under rainfed condition. When grown under irrigated condition more active roots were observed in the surface layers than in deeper soil zonations. The differences in the absorbed ^{32}P at different sampling intervals between irrigated and rainfed crops may be realised from Fig.16.

2.3. Morphological characters at the time of sampling

Significant difference was observed between the height, girth and number of leaves in the two crops grown under irrigated and rainfed conditions. During the sampling periods (from four months age to six months age) significantly high values were obtained for height, girth and number of leaves in crop grown under irrigated condition, compared to rainfed crop indicating robust growth of irrigated crop (Appendices VI, VII and VIII).

3. Translocation of ^{32}P in leaves, flowers and fruits

The data on the concentration of ^{32}P in the various leaves with respect to their positions at different stages after shooting are graphically represented in Fig.17.

Just after shooting, before the appearance of male and female flowers, seventh leaf had the maximum quantity of ^{32}P. The concentration increased gradually from the topmost leaf to the seventh and decreased thereafter in the

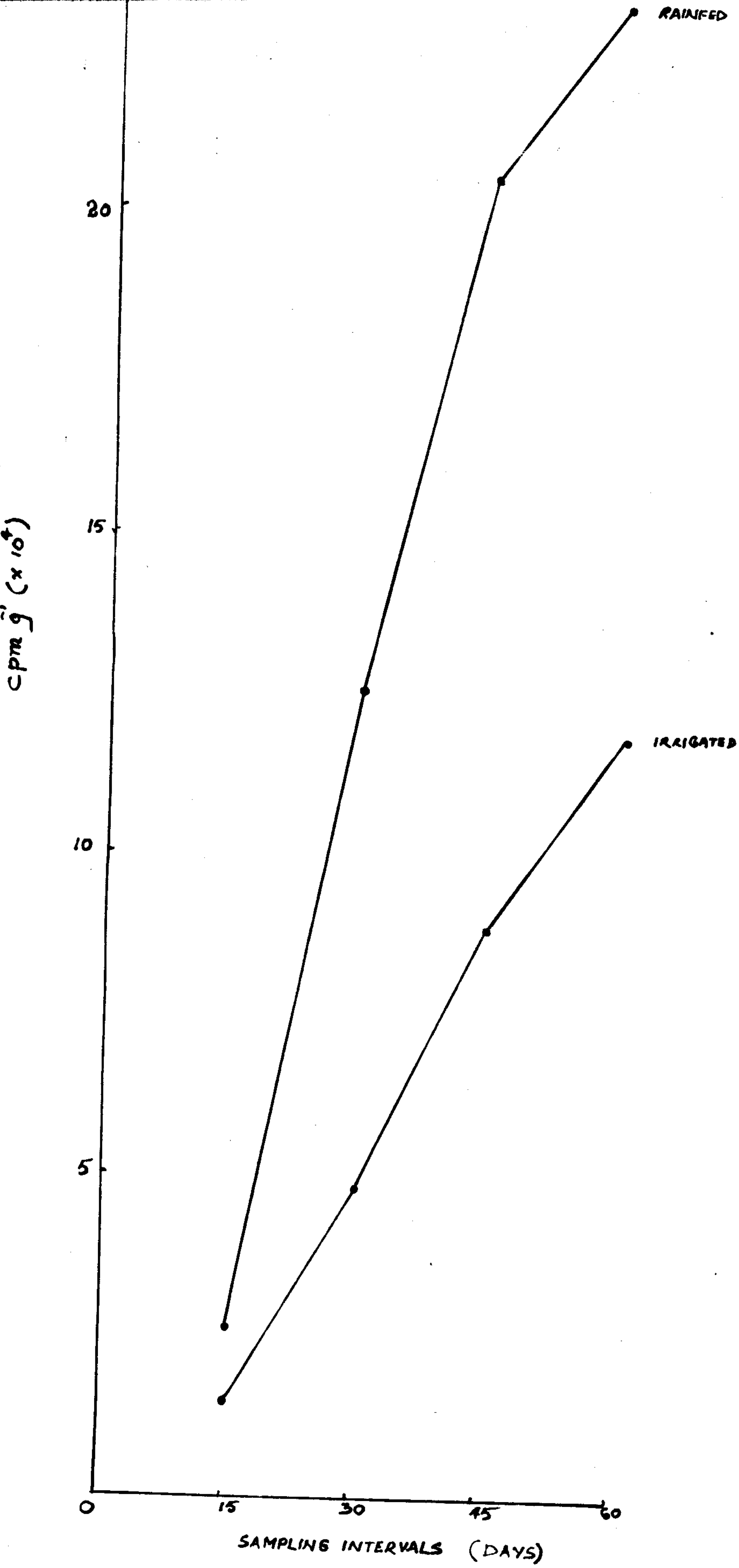

Fig.16 ABSORPTION OF ^{32}P AT DIFFERENT SAMPLING INTERVALS

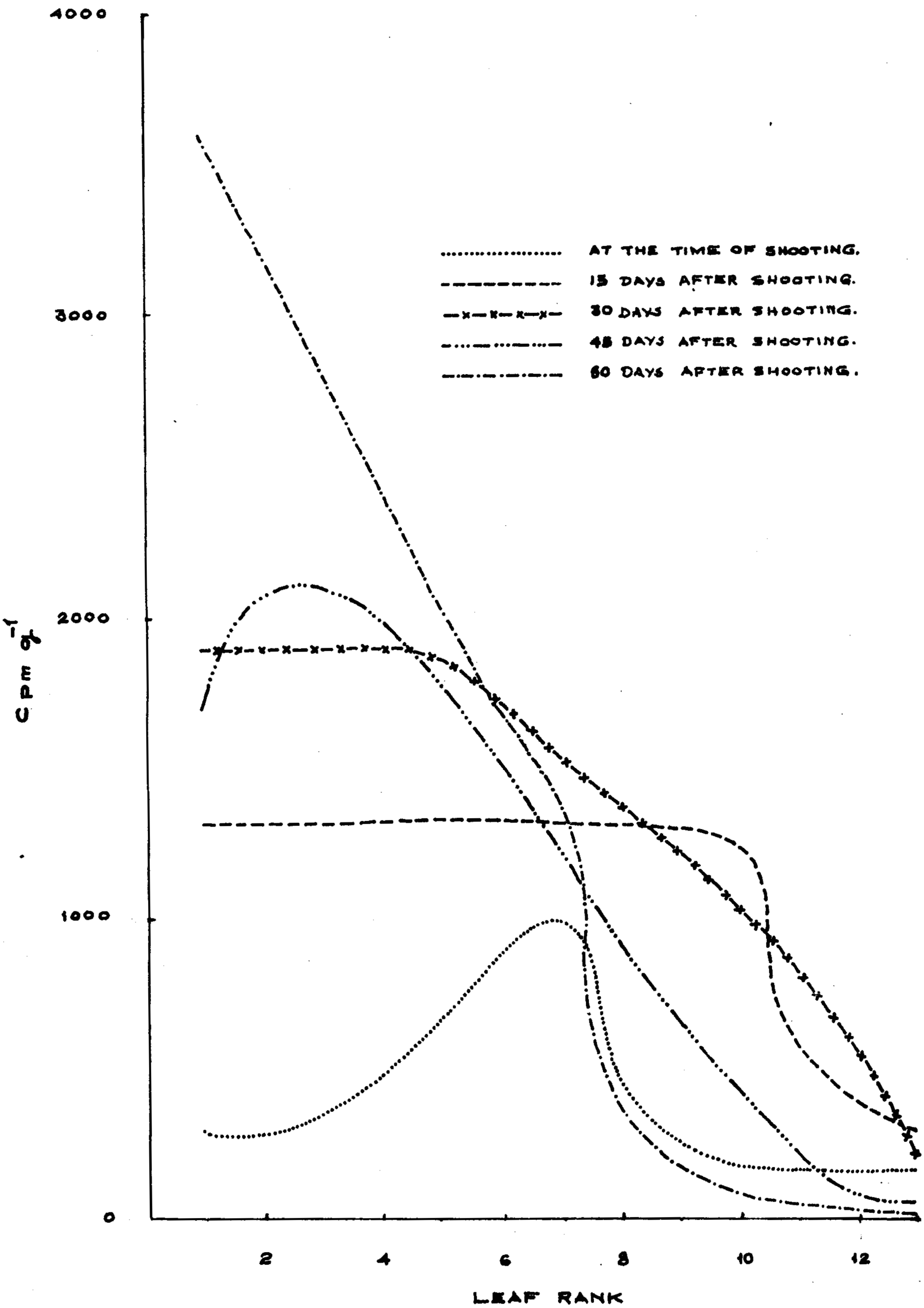

FIG: 17. DISTRIBUTION OF ^{32}P IN RELATION TO LEAF POSITION AFTER SHOOTING lower leaves. Fifteen days after shooting, ^{32}P got accumulated in all the functional leaves (from first to tenth) almost uniformly. The concentration was low in mature lower leaves. The counts in leaves, obtained one month after flowering showed that ^{32}P accumulated mostly in the first five leaves from the top. A gradual reduction in ^{32}P was seen from the sixth leaf to the 13th leaf. The ^{32}P counts from the samples, 45 days after shooting, indicated that the third leaf had the maximum accumulation and from the third leaf it went on decreasing till the thirteenth leaf. Two months after shooting, as the fruits reached maturity, the concentration of ^{32}P in the leaves decreased in all the leaves, first leaf however maintaining the highest concentration. Among the different reproductive organs, male flower accumulated maximum ^{32}P throughout the period of development of bunches (Fig.18). In the fruits also the concentration of ^{32}P increased with the fruit development and maturity but the ^{32}P count was low in fruits compared to male flowers except in the fifteenth day sample. The accumulation of ^{32}P in bract increased till one month after bunch emergence but after that a gradual reduction was noticed. The absorption of ^{32}P by the fruits and male flowers also increased with the development of fruits and became almost steady after one month.

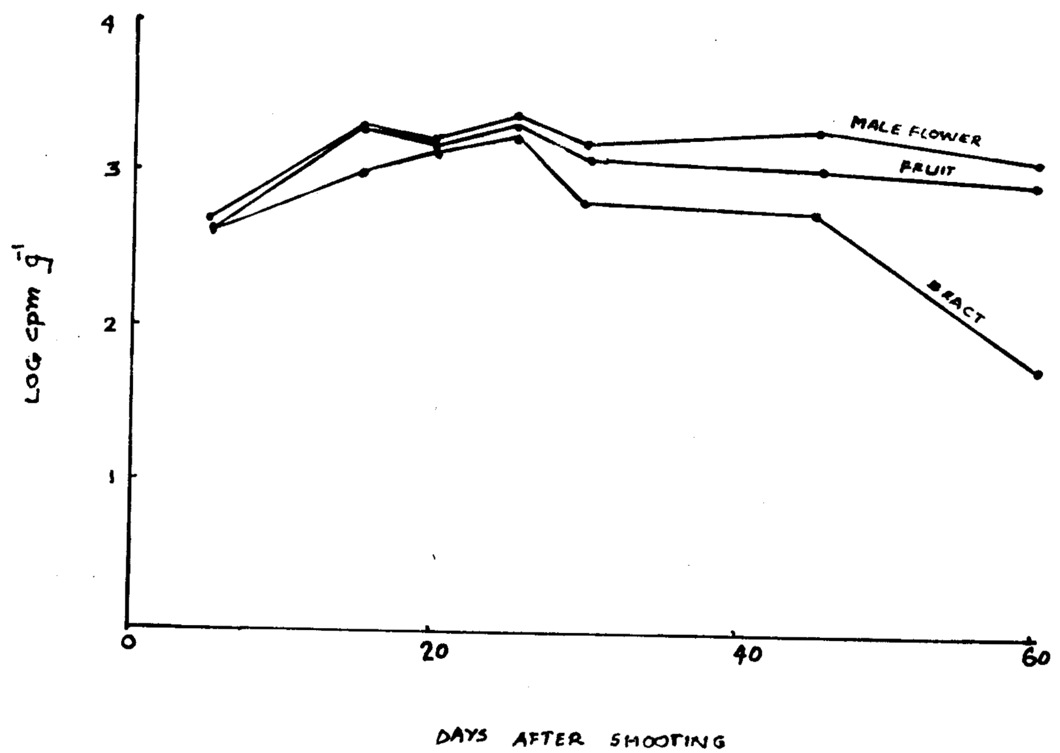

Fig. 18 DISTRIBUTION OF ^{32}P IN VARIOUS REPRODUCTIVE PARTS AFTER SHOOTING

DISCUSSION

DISCUSSION

In any crop there is an optimum and active root profile that is mainly responsible for the absorption of major part of the nutrients and water from the soil. The root profile is often influenced by soil and other environmental factors. Proper understanding of the root activity and root distribution pattern, therefore is necessary for proper and economic utilization of fertilizer in crop management which in turn is essential for maximising the yield.

The present series of studies were undertaken in the Department of Pomology and Floriculture, College of Horticulture, Kerala Agricultural University during the period 1983-84, in order to understand the root activity and root distribution pattern of the Nendran variety of banana under two distinct systems of cultivation viz. irrigated and rainfed conditions.

Root growth and distribution

The root system of banana was described by Fawcett (1921) and Simmonds (1959). In the present study an average number of 282 and 321 roots were observed under the irrigated and rainfed conditions respectively.

According to Summerville (1944) a healthy corm possessed 200 to 300 roots while Robin and Champion (1962) observed a maximum of 500 roots in healthy banana plant. Mean length of roots was found to be more under irrigated condition than rainfed. In the present study distinction could not be made between vertically and horizontally oriented roots as reported by Summerville (1939). According to Swarbrick (1964), the roots grew horizontally upto 3 to 3.6 m. It was observed that some of the roots had a length of more than 2 m. Wardlaw (1972) reported a maximum horizontal extension of 4.5 to 5.1 m and vertical extension of 135 cm under most favourable conditions. During the development of the root, a growth rate of 60 cm per month was observed, which is confirmatory with the findings of Fawcett (1921) and Wardlaw (1972).

In the present study a uniform root thickness of 0.3 to 1.25 cm was observed under both irrigated and non-irrigated conditions which was also reported by Swarbrick (1964) and Simmonds (1966).

Since the water and minerals which a plant uses are obtained from the soil through the absorption by the root and root hairs, it is obvious that the root system must be sufficient to cater the needs of the plant for its proper growth and production. Under dry conditions when the moisture is limited, the roots tended to go deeper and distant soil layers in search of moisture as observed in this investigation. More number of long and thicker roots were observed in the unirrigated crop which clearly showed that the same variety of banana behaved differently under two sets of management conditions. More number of roots under drought conditions was also reported by Singh _et al_. (1982). The development of surface roots under irrigated condition and extensive root system in the unirrigated field have been reported by Hubbard (1938), Cahoon _et al_. (1961), Black (1968) and Krishnamurthy and Shanmughavelu (1976) in banana, and Hurd (1968) in wheat. Similar conclusions were also drawn by Jean and Weaver (1924), Weaver (1926), Aldrich _et al_. (1935), Knoch _et al_. (1957), Bloodworth _et al_. (1958), Dennis (1966), Peters _et al_. (1967), Sivakumar _et al_. (1977), Ellis _et al_. (1977), Boyer _et al_. (1980), Paz-vergara _et al_. (1980) and Karimi _et al_. (1983). The increased fresh and dry weights of roots under rainfed condition observed might be due to more number of lengthy and thicker roots produced under such conditions. This has also been reported by Russel _et al_. (1940) in corn.

<u>Root activity pattern under irrigated and rainfed conditions</u>

The extensive use of various forms of radio-isotopes in recent years had provided an extremely useful tool for root distribution studies without disturbing the root system. The root activity patterns in different soil zones have been reported in different annual crops (Lott *et al*., 1950; Hall *et al*., Hammes and Berts, 1961; Lipps *et al*., 1957; Mc Clure and Harvey, 1962; Hahr, 1966; Nakayama and Bavel, 1968; Virmani and Dhaliwal, 1969; Dejong and Otinkarang, 1969; Virmani, 1971; Katyal and Subbiah, 1971; Soni *et al*., 1972; Ellis and Burns, 1973; Kumaraswamy *et al*., 1977; Marykutty, 1978; Sriniwas, 1980; Subramanian *et al*., 1980; Singh *et al*., 1982). Ulrich *et al*. (1947) in grapes, Walmsley and Twyford (1968) in banana, Basset *et al*. (1970) in cotton, Reddy and Venkateswarlu (1971) in castor, Balakrishnamurthy (1971) in coconut, Bojappa and Singh (1974) in mango and Atkinson (1974) in citrus collected very detailed studies on root activity using radioisotopes. The root activity patterns of coconut, banana, coffee, Citrus and oil palm have been reported by IAEA (1975).

The tracer technique to study the root activity pattern of a crop is based on the comparison of the recovery of the radiolabel in the leaf (or in any other plant part) resulting from the absorption from various soil depths and lateral distances from the plant under test. The reliability of this method has been tested in various crops like coconut, citrus, oil palm, coffee, cocoa and banana (IAEA, 1975). The radioactivity recovered in the leaf is considered as an index of the relative abundance of active roots in various soil zones. The studies reported in this thesis have clearly indicated that the distribution of active roots varied significantly between irrigated and unirrigated crops.

No significant effect of different depths was noticed on the root activity under irrigated condition except on the first sample which had maximum root activity at 5 cm depth. The active root concentration decreased with increasing depths in the first sample of irrigated crop taken 15 days after ^{32}P application. Studies on root distribution and behaviour by Bennet and Doss (1960), Bloodworth et al. (1958), Pumphery and Koehler (1958) have also indicated that root concentrations were greatest at shallow soil depths and decreased with depth in the soil under irrigated condition. In all the rest three samples of the present study, deeper layers were also found to have active roots as the shallow soil depths. This could take place since the soil profile was uniformly wetted with moisture and first absorption was from a shallow depth beneath the plant and then successively from lower depths as moisture supply was depleted as stated by Davis (1941), Russel et al. (1940) and Taylor and Haddock (1956). In the rest of the samples, taken at 15 days intervals, significant difference was not noticed between the different depths on the root activity of irrigated banana. Since there is no need of penetrating to deeper layers of soil in the irrigated field, a uniform distribution of active roots may be expected under irrigated condition.

The greatest root activity was obtained at 30 cm depth for rainfed banana which was significantly higher than that of other depths in all the sampling intervals. The uniform root activity for all depths under irrigated condition and highest activity at 30 cm depth for the rainfed banana clearly indicated low production of roots on the surface layers for rainfed crop compared to irrigated. Dev et al. (1980) also reported the deep spreading root system under dry conditions in wheat. Evidently, roots grow and forage deeper into the soil in search of water when moisture supply is limited.

The percentage root activity at 30 cm depth for rainfed crop was found to decrease from the 15th sample (70.94 per cent) to 60th sample (37.7 per cent). This might be due to the high amount of rains obtained in these sampling intervals, which might have induced active roots to grow at the surface layers also. In the irrigated banana maximum root activity was observed at 20 cm distance, which was at 40 cm for the rainfed banana. This further indicates the extensive development of active roots under dry conditions. Thus a greater concentration of active roots was observed at a soil zone 20 cm distant and 30 cm deep under the irrigated condition and 40 cm distant and 30 cm deep under rainfed condition. The decrease in root activity at far the distances (40, 80 and 120 cm) in rainfed crop was not as great as observed in irrigated crop which also indicates more extension of active roots under rainfed condition. Sufficient amounts of active roots are needed in the lower depths of soil under unirrigated conditions because the capillary movement of water towards the surface root zone is slow under dry conditions as stated by Jean and Weaver (1924), Kmoch *et al.* (1957), Danielsen (1967) and Dennis (1986). Karimi *et al.* (1983) suggested that the water stress during the day was just enough to reduce the leaf expansion but this did not severely restrict the photosynthesis. As a result the assimilates were diverted from the non-expanding leaves into the roots resulting in their increased development. The experiments conducted in banana (Uganda), orange trees (Spain), coconut (Philippines), oil palm (Malaysia), coffee (Colombia) cocoa (Ghana) also revealed highest root activity near the tree at the surface in winter and spring whereas in summer it was maximum at distant regions and deeper soil layers as reported by IAEA (1975).

In the present study for all the depths and distances of ^{32}P placement, uptake increased with time as indicated by Fig.25. Balakrishnamurthy (1971) also reported the increased uptake with time in coconut.

Higher counts of ^{32}P were obtained for rainfed crop than irrigated at all stages. This may be explained as given below. Morphological characters like height of the plant, girth and number of leaves were significantly low for rainfed crop compared to irrigated. But the quantity of ^{32}P applied to each treatment plant being the same (2 mCi) under both the conditions, per gram absorbance might be more by the plants under rainfed condition, than under irrigation. The possibility of the absorbed ^{32}P getting distributed to a larger area in the case of irrigated crop thus reducing the counts per gram of the plant cannot be ruled out. It could also be attributed to the more extensive development of root system under rainfed condition.

Further detailed investigations in root activity and distribution in different varieties of banana under different management practices will be of interest.

<u>Translocation of ^{32}P in banana plant after shooting</u>

The experiment was conducted to study the absorption and translocation of ^{32}P applied to soil at later stages of plant growth. The soil application of ^{32}P was done at 30 cm depth and at a lateral distance of 20 cm in irrigated 'Nendran'.

The counts made on the different parts of plant for a period of two months showed that banana continues to absorb nutrients even after flowering to an appreciable extent. Translocation of assimilates in plant parts depends upon age of the plant as well as its physiological development. In bananas the absorption of nutrients is related to developmental physiology and is generally more during the early and late vegetative stages (Simmonds, 1966). The basis for the application of fertiliser within 4 to 5 months of planting is that after flower development the plant absorbs only very little quantity of nutrients from the soil. However, some of the recent studies conducted elsewhere, indicated that banana continued to absorb nutrients even at flowering and bunch development stages. In Kerala, some farmers are found to apply fertilisers even after shooting to improve the size and quality of the fruits. The results of the present study show that the later application of fertilisers in banana is not altogether ill conceived.

Although leaf production ceased with shooting, about six to seven leaves remained functional for another two months more. In these leaves ^{32}P got accumulated and during the course of fruit development and subsequently translocated to the developing inflorescence. The topmost youngest leaves which initially acted as sink, when fully matured translocated to the developing inflorescence. Simultaneously, the developing inflorescence drops the nutrients absorbed, either directly or through the leaves, to its different parts. Whether the green bunches that develop are photosynthetically active and favour the increase in size of the hands with additional supply of nutrients is an aspect for further detailed investigation. However, the results of the present investigation had clearly shown that the flowers and fruits that developed later absorbed nutrients. In rice Fujiwara and Suzuki (1959) demonstrated the movement of photosynthates from the leaves and sheaths to the panicle, using ^{14}C.

The study on the absorption and translocation of soil injected ^{32}P to different parts of banana plant after flowering indicated that younger leaves had the maximum uptake of ^{32}P compared to older leaves. The higher concentration of ^{32}P in the younger leaves of banana was also observed by Joy (1964), Walmsley and Twyford (1968), Triefimova (1958), and Kannan (1969). The older leaves when fully expanded and fully matured tend to translocate much of their photosynthates to the young developing leaves or to the fruit. Two months after flowering a uniform decrease was seen in the ^{32}P counts from the first leaf to the last. The study also revealed that both young leaves and inflorescence received almost the same quantity of ^{32}P. The more accumulation of fertiliser phosphorus in the leaves at the fruiting stage of banana var. 'Robusta' was also observed by Walmley and Twyford (1968). Ryle and Powell (1972) observed almost equal distribution of ^{32}P in the topmost young developing leaves and inflorescence of Lolium.

The developing bunches being more powerful sinks compared to the leaves, it is only logical to conclude that a major part of the absorbed nutrients find their way to the developing fruits. The ^{32}P counts taken in the present study for a period of two months showed that the

^{32}P accumulated in the fruits rapidly declined during the last phase of fruit development which coincided more or less with the maturity of the fruits. In other words once the fruit attained three-fourth or more maturity, the rate of absorption decreased considerably. An interesting observation made in the study was that the male flowers continued to accumulate ^{32}P in greater amounts compared to leaves, female flowers and developing fruits, which indicate that the male flowers somehow are capable of drawing nutrients even when the plant growth is restricted. Higher absorption of ^{32}P by male flowers of banana was also reported by Walmsley and Twyford (1968). Probably the hearts being meristematically active, are efficient sinks for nutrients. Several observations made earlier had shown that removal of hearts favour the development of fruits in banana.

The requirement of photosynthates is more for female flowers compared to male flowers as the translocation of nutrients will be more with the advancement of maturity. One month after shooting ^{32}P concentration of the bract decreased which indicated a further movement of photosynthates from the bract to developing female flowers. Since the radioactive ^{32}P is distributed throughout the plant, the rate of uptake of fertiliser into a particular tissue could be determined by nothing the radioactivity in that particular tissue.

SUMMARY

SUMMARY

The present investigations were carried out in the department of Pomology and Floriculture, College of Horticulture, Vellanikkara on banana var. 'Nendran' during a period of 1983 to 1984 with the following objectives.

(1) To study the root distribution pattern of banana as influenced by irrigated and non-irrigated conditions, (2) to locate the most active root zone of banana employing radioactive ^{32}P and (3) to trace out the translocation of the absorbed ^{32}P inside the plant at the time of shooting and after that.

The following conclusions were made based on the present investigations.

1) The monthly development of the roots indicated greater number of roots under rainfed condition than under irrigated. Longer and thicker roots were observed under unirrigated condition during the growth of the plant. Fresh and dry weights of roots were high under rainfed condition than in plants which received irrigation.

2) Maximum concentration of active roots (29.93%) in the irrigated crop was observed at a soil zone covered by 20 cm lateral distance and 5 cm depth from the base of the plant, at the 15th day sampling time. In the rainfed crop, at the 15th day sampling time, a maximum percentage (41.28) of active roots was observed in a soil zone, 20 cm away from the plant and 30 cm deep.

3) Maximum percentage (22 to 24 per cent) of active roots was observed at a soil zone, 20 cm away and 30 cm deep in all the sampling times except in 15th day sample under irrigated condition, whereas under rainfed condition, the maximum percentage of active roots (18 to 32 per cent) was observed at a soil zone covered by 40 cm distance and 30 cm depth at the different sampling periods except 15th day sample.

4) The percentage root activity decreased with increasing lateral distances under both irrigated and rainfed conditions. At a lateral distance of 120 cm, the minimum percentage of active roots at all the sampling intervals under the two sets of conditions was obtained.

5) Significant effect was not noticed between the different depths on the percentage of active roots under

irrigated condition whereas at 30 cm depth significantly high concentration of active roots were seen at all the sampling intervals for the rainfed crop.

6) Translocation studies conducted in irrigated banana indicated that maximum ^{32}P was concentrated in the male flower followed by female flowers when the reproductive organs alone are considered. But in the case of leaves, topmost younger leaves had maximum ^{32}P absorbed and got decreased to the lower matured leaves.

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*Original not seen

APPENDICES

Appendix - I

Monthly rainfall received during the years 1983 and 1984

Year	Monthly rainfall (mm)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1983	0	0	0	0	37.4	387.2	580.6	754.7	494.6	149.8	60.2	24.4
1984	0	27.0	18.9	109.2	40.6	853.1	730.4	260.2	158.6	323.7	7.8	-

Appendix - II

Analysis of variance of ^{32}P recovery data (Cpm/g) of the irrigated crop

Source	Degree of freedom	Mean squares			
		15 days after ^{32}P application	30 days after ^{32}P application	45 days after ^{32}P application	60th day after ^{32}P application
Depth	3	0.62*	0.04	0.10	0.19
Distance	3	5.04**	6.81**	4.32**	3.72**
Interaction	9	0.13	0.11	0.13	0.37
Error	30	0.20	0.15	0.14	0.20

* Significance at 5 per cent probability level

** Significance at 1 per cent probability level

Appendix - III

Analysis of variance of specific activities (Cpm/mg P) of the irrigated crop

Source	Degree of freedom	Mean squares			
		15 days after ^{32}P application	30 days after ^{32}P application	45 days after ^{32}P application	60 days after ^{32}P application
Depth	3	0.60*	0.03	0.12	0.20
Distance	3	5.00**	6.65**	4.28**	3.74**
Interaction	9	0.12	0.13	0.14	0.37
Error	30	0.21	0.15	0.15	0.20

* Significance at 5 per cent probability level

** Significance at 1 per cent probability level

Appendix - IV

Analysis of variance of ^{32}P recovery data (Cpm/g) of the rainfed crop

Source	Degrees of freedom	Mean squares			
		15 days after ^{32}P application	30 days after ^{32}P application	45 days after ^{32}P application	60 days after ^{32}P application
Depth	3	1.03**	1.34**	1.24**	0.44**
Distance	3	1.99**	4.35**	5.50**	4.04**
Interaction	9	0.23	0.39	0.33	0.02
Error	30	0.13	0.23	0.22	0.08

* Significance at 5 per cent probability level

** Significance at 1 per cent probability level

Appendix - V

Analysis of variance of specific activities (Cpm/mg P) of rainfed crop

Source	Degrees of freedom	Mean squares			
		15 days after ^{32}P application	30 days after ^{32}P application	45 days after ^{32}P application	60 days after ^{32}P application
Depth	3	1.48**	1.17**	1.21*	0.45**
Distance	3	1.82**	4.28**	4.61**	4.06**
Interaction	9	0.20	0.43	0.40	0.03
Error	30	0.14	0.23	0.28	0.09

* Significance at 5 per cent probability level

** Significance at 1 per cent probability level

Appendix - VI

Analysis of variance of the data relating to height at various sampling intervals under irrigated and rainfed conditions

Source	Degrees of freedom	Mean squares				
		At the time of ^{32}P application	15 days after ^{32}P application	30 days after ^{32}P application	45 days after ^{32}P application	60 days after ^{32}P application
Treatment	1	188239.6**	226689.9**	267231.5**	244925.0**	200111.4**
Error	47	174.5	156.6	168.0	185.7	193.6

** Significance at 1 per cent probability level

Appendix - VII

Analysis of variance of the data relating to girth at various sampling intervals under irrigated and rainfed conditions

Source	Degrees of freedom	Mean squares				
		At the time of ^{32}P application	15 days after ^{32}P application	30 days after ^{32}P application	45 days after ^{32}P application	60 days after ^{32}P application
Treatment	1	4213.5**	4118.6**	4186.7**	4041.7**	3918.4**
Error	47	13	13.8	14.5	14.3	12.5

** Significance at 1 per cent probability level

Appendix - VIII

Analysis of variance of the data relating to number of leaves at various sampling intervals under irrigated and rainfed conditions

Source	Degrees of freedom	Mean squares				
		At the time of ^{32}P application	15 days after ^{32}P application	30 days after ^{32}P application	45 days after ^{32}P application	60 days after ^{32}P application
Treatment	1	570.4**	600.0**	555.8**	380.0**	250.3**
Error	47	0.88	1.1	1.14	0.4	0.71

** Significance at 1 per cent probability level

PATTERN OF ROOT ACTIVITY IN BANANAS UNDER IRRIGATED AND RAINFED CONDITIONS

By

SOBHANA, A.

ABSTRACT OF THE THESIS

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ABSTRACT

The experiments were undertaken with an objective to find out the most active root zone of banana var. 'Nendran' employing radioactive ^{32}P. These were conducted in the College of Horticulture, Kerala Agricultural University, Vellanikkara, during the year 1983-'84. The field experiments were laid out in Randomised Block Design, with three replications and the plants were raised under normal conditions.

While taking into consideration the number, length and diameter fresh and dry weights of roots, all these were found to be more for the rainfed crop than the irrigated. This explains the enhanced production of roots under conditions of moisture stress.

The radioactivity was injected at four months age of the plant. The area around each experimental plant was injected with ^{32}P solution with the help of a dispensette. The different lateral distances used for the ^{32}P injection were 20 cm, 40 cm, 80 cm and 120 cm and the different depths were 5 cm, 15 cm, 30 cm and 60 cm. The third leaf was radioassayed and the ^{32}P counts were used for finding out the percentage of active roots at the various treatment sites.

The results of radiotracer studies indicated that maximum percentage of active roots was located at a soil zone covering 20 cm distance and 30 cm depth from the base of the plant under irrigated condition, at five and six months age of the plant. The rainfed crop had its maximum Percentage of active roots at a soil zone of 30 cm deep and 40 cm away from the plant. As the lateral distances increased from 20 cm to 120 cm, a reduction was noticed in the percentage activity of roots accordingly, under both irrigated and unirrigated conditions. But the root activity was not significantly different at different depths for the irrigated crop, which was significant for the rainfed crop.

Under high moisture stress roots tend to forage into deeper layers of soil for getting the available water. Hence deeper soil zones had more active roots under unirrigated conditions, compared to irrigated crop, which had more surface active roots.

An experiment was also organised to study of the translocation of absorbed ^{32}P to various parts of the plant after flowering under irrigated condition. It was observed that male flowers had maximum concentration of ^{32}P followed by female flowers or fruits. Of the various leaves, topmost younger leaves were found to build up more ^{32}P than matured leaves, indicating a translocation to the developing immature leaves.