STUDIES ON THE ROOT ACTIVITY PATTERN OF BLACK PEPPER (*Piper nigrum* L.) EMPLOYING RADIOTRACER TECHNIQUE

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Studies on the root activity pattern of black pepper (*Piper nigrum* L.) employing radiotracer technique" 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.

College of Horticulture,
Vellanikkara,
April 1985.

JAYASREE SANKAR, S.

CERTIFICATE

Certified that this thesis, entitled "Studies on the root activity pattern of black pepper (*Piper nigrum* L.) employing radiotracer technique" is a record of research work done independently by Smt.Jayasree Sankar, S. 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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INTRODUCTION

INTRODUCTION

The most popular among the spices is the dried matured whole berry of the evergreen perennial climbing vine, black pepper known botanically as *Piper nigrum* L. The stout glabrous climbing herb is indigenous to the Malabar coast of Kerala preferring a humid tropical climate.

The Indian pepper enjoyed monopoly in the world market till the turn of the nineteenth century when Indonesia and other countries also entered the pepper trade. In India, pepper is an export-oriented crop contributing half the country's foreign exchange earnings. In 1955 the country's production was 40 per cent of world's pepper output while the other pepper producing countries like Indonesia, Malaysia and Brazil accounted for only 25, 24 and 1 per cent respectively. The corresponding figures for the year 1981 were 20, 22, 20 and 32 per cent respectively. Productivity of black pepper in India fell from 266 kg/ha in 1949-50 to 243 kg/ha in 1980-81. These figures project the sad picture of India's present day situation in black pepper production. Though India can boast of its top most position in cultivated area under black pepper (1.11 lakh ha), it comes only fourth in production in the world contributing 27,000 tonnes of black pepper. Brazil which had barely started production in the 1950's has gone up in production substantially and today, it leads both in production and export. India, the world's top most producer of black pepper for centuries, has thus been relegated to the stature of an ordinary producer.

Seventy nine per cent of the total production of pepper in India is from Kerala with 90 per cent of the total area which is indicative of the importance of the crop in the state's economy. The average yield of pepper in Kerala is estimated to be 279 kg/ha as against 4067 kg/ha in Malaysia. One of the reasons often attributed to the low productivity of the vines in Kerala is the sparse use of fertilizers. Fertilizers being the most expensive input in crop production, their judicious management assumes importance from the point of view of economy.

A knowledge of the root activity pattern is a valuable pre-requisite for developing a scientific method of fertiliser application to any crop. The traditional methods of studying the root distribution are based on physical examination of the roots after excavation, use of dyes as tracers etc. Such techniques, apart from being laborious, can only provide a picture of the total root distribution (active, dormant and dead roots). In contrast, isotopic techniques offer a quick and reliable means of determining either the distribution of active roots or the total roots. The former is studied by soil injection of a radiotracer while the latter is studied through plant injection technique. Information on the distribution of active roots and the soil zones of maximum nutrient absorption is of value in formulating a rational method of fertilizer application. In black pepper no work has been so far done on these aspects. The present study was, therefore, designed with the following objectives:

- To examine in detail the distribution patterns of active roots in black pepper vines trailed on live standard (erythrina) and on teak pole (dead support).
- To evaluate the density of active roots of erythrina in the rhizosphere of black pepper.
- To assess the magnitude of root competition for applied-P between the vine and the live standard.
- To compare the nutrient removal by the vine and erythrina and
- To examine whether the climbing roots of the vine are capable of nutrient absorption.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Research on root system is of particular importance as roots are responsible for the uptake of water and nutrients besides providing anchorage to the plant. An understanding of the root density, their lateral and vertical spread is essential for developing a scientifically sound and efficient method of fertilizer use in crop gardens. Literature relevant to the root distribution pattern of especially tree crops is briefly reviwed here.

2.1. Root distribution pattern of perennial tree crops

The classical methods of investigating root systems include excavation, needle board method, monolith method etc. Such methods have been in vogue to study the overall root distribution patterns of crop plants irrespective of the type and function of the roots. Despite the cumbersome and often time-consuming nature of the methods, root systems of several fruit trees and plantation crops have been studied.

2.1.1. Fruit trees

Vertifical distribution of roots upto a depth of 2.5 m was recorded from an excavation study of mature Baldwin apple on a well-drained soil (Oskamp, 1932). Seet (1933) observed a deeper root penetration in better drained soil. In young trees, the root system spreads vertically faster than the crown and may extend to 1.5 m beyond it. Under favourable soil conditions, the roots may go deep upto 1 m with age (Vuorinen, 1958). Excavation of root system of 26 year old tree of Jonathan on Malus sylvestris (Tamasi, 1959) in a sandy soil revealed that the diameter of the root system was 1.9 times that of the crown. The area occupied by the roots was 134 m^2 and that occupied by the crown was 44 m^2 with 69 per cent of the roots located under the crown spread. Eremeev (1960) opined that in dry soil the absorbing roots of apple are very short (2 to 4 mm) with a reddish brown colour. Pasinova (1960) reported that in 14 to 40 year-old apple trees about 30 to 60 per cent of the roots are within a depth of 20 to 40 cm and that soil moisture content declined with increasing root density in a given layer. The excavation studies on the extent and habit of root growth of 1 to 4 year-old Jonathan apple on terraced loess soil indicated that the roots grew 75 cm vertically and 75 cm radially in one-year-old trees while the 4 year-old ones showed vertical and horizontal spread of 335 and 482 cm respectively (Doll, 1961). According to Kolesnikov (1962), depth of root penetration may vary with soil type, variety of the apple tree and the root growth depends largely on soil moisture condition. Studies conducted by Weller (1966) indicated the highest density of absorbing roots near to the trunk in Boskoop and Goldparmane apple trees. Root distribution studies in three apple varieties (Zerebeov, 1966) showed that root penetration depended on the soil depth at which the impermeable layer occurred and its mechanical composition. In irrigated plots of Azerbajdzau at an elevation of 600 to 700 m, most of the roots of apple trees were distributed in the 20 to 75 cm soil layer (Babaev, 1968). Studies of Babuk (1971) indicated that most of the roots of young transplants were confined to 0 to 40 cm layer and that of older trees in the 80 to 100 cm soil layer.

Studies near Catania in Sicily on the roots of Sour orange by Baldini (1957) revealed that most of the roots were found between 10 to 20 cm laterally at a depth of 40 to 70 cm. Montenegro (1960) reported that drought sensitivity in citrus was dependent on feeder root distribution but was probably related to the lack of xeromorphic features in roots and leaves. Ten year-old Hamlin orange on trifoliate orange had 90 per cent of the root system within 90 cm of the surface. Cahoon et al. (1961) concluded that 0 to 10 cm depth of the soil contained majority of the roots and that irrigation had a pronounced effect on the percentage of roots in each soil depth. Under the soil and climatic conditions existing in Coorg, the root system of one and a half year-old healthy Coorg Mandarins were found to extend 10.2 cm vertically and 160 cm horizontally (Aiyappa and Srivastava, 1965). The experiment conducted on a Rumona sandy loam with fair to good internal drainage led Cahoon and Stolzy (1966) to conclude that by increasing the interval between irrigation or by reducing water infiltration the root density can be increased in the soil profile. Aiyappa and Srivastava (1968) studied the root system of healthy and chlorotic trees of two and a half year-old mandarin orange in Coorg. The roots were found to penetrate 224 cm vertically and 351 cm laterally in healthy ones as against 199 and 179 cm in severely chlorotic trees. The heaviest concentration of feeder roots in a three and a half year-old mandarin was found in the top 60 cm soil column, a greater part of the root system being constituted by laterals (Aiyappa et al., 1968).

Burns and Kulkarni (1920) from a study of guava roots opined that the average spread of roots was to 110 cm with a vertical distribution upto 20 cm below the soil surface.

Goff (1897) isolated the root system of nine year-old grape vine in Wisconcin and found that very few roots are shallower than 20 cm and that the roots descended 2.4 m in a sandy soil below light clay loam. Root excavation of 'Concord' vine in a terraced vine yard in Iowa (Doll, 1958) showed that on fertile soil, the vines had a maximum root extension of 6.6 m with vertical spread of 5.9 m as against its lateral and vertical spread of 7.25 and 2.85 m respectively in a less fertile soil. The concentration of roots was maximum in the surface 30 cm. Mihacea and Puri (1968) reported that in the vine growing centre of Teremia, the root system of Riparia Glorie vine extended 1.5 to 2 m laterally and to a depth of over 4 m vertically with most of the lateral roots situated at about 30 to 60 cm from the surface. Stoev and Rangelev (1969) from their observations on the root system of Muscat Rouge vines grown on their own roots and on other root stocks found that on its own roots, the vines developed the fewest feeding roots reaching to a depth of 60 cm whereas on other root stocks they penetrated to 75 cm. Excavation studies conducted by Chelam (1974) at the Agricultural College, Coimbatore, on the root system of eleven year old grape vine varieties indicated that many of the growing roots were located at a depth of 90 cm of which a greater part was in 20 to 40 cm depth. The root growth varied among different cultivars depending upon the vigour.

Bojappa and Singh (1975) studied the feeder root distribution patterns of young and old mango trees by the soil auger sampling technique at the Indian Agricultural Research Institute, New Delhi. They found the highest concentration of feeder roots in the zone close to the tree (60 cm) at the top 15 cm layer of soil. About 89 to 90 per cent of feeder roots were within the peripheral 180 cm.

In pear trees, the greatest root concentration was found between 60 and 240 cm from the trunk (Aldrich, 1935). According to Bini (1963), the roots of peach trees in soil cultivated to a depth of 20 cm were concentrated below that zone and showed little branching. Cockroft and Wallbrink (1966) reported that the root distribution of peach and pear trees in shallow soil was confined to the top 90 cm of soil. Root length was maximum in surface soil.

The studies on chlorosis - susceptible and resistant plum trees revealed that the susceptible ones had most of their roots in the 25 to 60 cm layer of soil while the roots of the resistant ones were found initially in the top 20 cm layer of soil and later in the 10 to 50 cm layer (Molcanov, 1966).

Lupescu (1961) observed that the vertical roots of apricot var. Paviot grafted on different root stocks reached to a depth of 2.85 to 3.9 m with most of the roots lying in the superficial layers between 0 to 20 cm.

In one to 5 year-old trees, most of the roots were in the 11 to 40 cm layer (Tamasi, 1970) and the root spread in one year-old apricot trees on wild apricot root stock planted in a clayey soil was in an area of 1.91 m^2.

In 24 year-old Walnut trees, 60 per cent of the roots were seen at a depth between 40 to 60 cm (Maliga and Tamasi, 1957). Chernobai (1971) reported that most of the roots of walnut trees spread horizontally in the 30 to 80 cm deep soil layer and occupied an area of 2.8 to 6.7 times larger than the crown.

2.1.2. Plantation crops

The investigation by Bavappa and Murthy (1961) revealed that in arecanut, the roots were concentrated within 60 to 90 cm round the base of the palm. Bhat and Leela (1969) pointed out that in 8 year-old arecanut palms, 61 to 67 per cent of all types of roots and 51.3 to 6c.6 per cent of fine roots were concentrated within a circle of 50 cm radius around the palm. More than 80 per cent of all root types were within 1 to 1.25 m from the trunk, the greatest rooting depth being 2.6 m.

Both healthy and cadang-cadang affected coconut palms growing on a sandy loam soil had most of the primary and secondary roots at 30 to 90 cm from the tree base to a depth of 60 to 90 cm (Magnaye, 1969). Root studies in coconut carried out at Veppankulam (Anon, 1970) showed that a great majority of roots were confined to 16 to 60 cm layer of soil. Kushwah et al. (1973) from their studies on the coconut rooting pattern opined that palms receiving regular cultivation and manuring produced the highest number of roots. About 74 per cent of the roots produced did not have lateral spread beyond 2 m from the trunk and most of the roots were confined to 120 cm soil depth.

Excavation of the root system of coffee in Puerto Rico revealed that nearly 95 per cent of the root system by weight was present in the upper 30 cm of the soil. Trees having heaviest tops were found to have the heaviest roots and the extent of root system was best indicated by the trunk diameter (Arrillaga and Gomez, 1940). According to Hatert (1958), in Robusta coffee the tap root reached a length of 90 cm while the superficial laterals and other secondary roots formed a large mass around the tree over an area of 7 - 8 m^2. The root distribution pattern was more irregular with age due to local necrosis. Root system of one-year-old coffee plants in nursery in Salvador loamy sand indicated nearly all roots being concentrated in the top 30 cm soil layer (De Castro, 1960).

Mc Creary *et al.* (1943) studied the root distribution of cacao growing on different soils of Trinidad by excavation method. The main laterals were numerous and evenly disposed around the tap root. All the stout laterals were found in the top 30 cm layer but numerous laterals came off at 30 to 35 cm depth. Hardy (1944) reported that in nutrient deficient compact acid clays or in sands having high water table, the root system of cacao was characterised by a lengthy tap root, a sparse but widely distributed superficial roots and a well marked fibrous surface root mat.

In tea, the density of absorbing roots decreased with depth and reached a minimum in the 50 to 60 cm soil layer. The greatest number of conducting roots was at a depth of 10 to 30 cm and the absorbing roots increased with distance from the stem (Patarava, 1968).

Trerada and Chiba (1971) recorded the root development of black pepper vines in Brasil and found that 85 to 90 per cent of the feeder roots were confined to upper 30 cm.

2.2. Root activity patterns of tree crops

The traditional methods are suitable only for investigating a few plants because of the labour involved in digging profiles, tracing and mapping the roots etc.

Such techniques apart from being laborious can only provide a picture of total root distribution without distinguishing active, dormant and dead roots. Isotope techniques, in contrast, offer a quick and reliable means of determining the distribution pattern of roots. Two methodologies have been adopted. One is plant injection technique (Racz *et al.*, 1967) and the other, soil injection technique (Hall *et al.*, 1953). The former is applicable only in small plants for studying the root distribution pattern while the latter is suitable with any plant for studying the distribution of active roots which are directly responsible for water and nutrient absorption from soil. The soil injection technique has been extensively used for studying the root activity patterns of tree crops. The method involves soil injection of tracer at various depths and radial distances from the plant followed by determination of the absorbed radioactivity by the plant. Generally, ^{32}P, a hard beta emitter is used for this purpose as tracer because of its convenient half life (14.3 days) and ease of measurement, eventhough many others including stable isotope of N(^{15}N), ^{86}Rb and non radioactive Sr (IAEA, 1975; Ellis and Barnes, 1973; Fox and Lipps, 1960) were sometimes used. The radioactivity recovered in the plant from a particular soil zone depends on the proportion of active roots in that zone. In small plants such as cereals, total radioactivity absorbed by the plant can be determined. However, when the bulk of the plant is too large as in tree crops, the determination of total radioactivity absorbed by the plant will be a difficult proposition. In such cases, IAEA (1975) recommended the radioassay of a suitable plant part to evaluate the uptake of the applied label from various root zones.

2.2.1. Fruit trees

Ulrich *et al.* (1947) from a study on the root activity of grape vine in a red loam, California, employing radiophosphorus reported an irregular distribution of roots about the vine. Ninety per cent of the roots were observed within a radius of 60 cm from the base though some laterals were found at a distance of only 2.5 cm from the vines. Dev *et al.* (1971) on studying the proliferation of roots occurring at different depths in three varieties of grapes by soil injection technique found that roots occurring at different depths from 31 to 56 cm absorbed more ^{32}P and hence had more activity in the roots at that region.

Using ^{32}P-labelled superphosphate, Bojappa and Singh (1973) found that the maximum root activity of mango was upto 2.4 m laterally and 30 cm vertically in the soil. About 77 per cent of root activity was observed upto 60 cm in one trial and it was 85 per cent upto 30 cm depth in another trial. Absorption from the peripheral zone of 3 m was 88 per cent in both experiments.

By selective placement of ^{32}P within rooting volume, Atkinson (1974) studied the distribution of root activity in apple trees and concluded that in 2 year-old trees of cultivar Cox/M9, maximum absorption of the radio-label was from 30 cm depth as against 90 cm depth in 25 year-old trees of cultivar Fortune/M9.

Experiments carried out in 30 year-old orange trees to study the root activity pattern in summer and spring in a fine sandy clay loam of Spain (IAEA, 1975) revealed that during summer months, the highest activity was at 2 to 3 m distance from the tree and at 30 cm depth. Early in spring, high root activity was observed near the tree (50 cm distance) at 60 and 30 cm depths. In mature 30 year-old trees, the zone of highest root activity was farther away from the tree than in younger trees of 14 years (IAEA, 1975). From an experiment with 8 and 12 year-old citrus trees in Taiwan, IAEA (1975) reported that in the former, the highest root activity was seen at 100 cm lateral distance/10 cm depth in spring season and for the latter in the winter season, the activity was higher near the soil surface within the 100 to 200 cm lateral distance.

2.2.2. Plantation crops

Wet and dry season experiments in fruiting coffee trees in Columbia (IAEA, 1975) indicated that in wet season root activity at 30 cm distance/15 cm depth was significantly higher than at any other soil zones tested. In dry season, no indication was obtained of the zones of high and low root activities. Uptake was low in dry season. Experiments at Kenya on the root activity pattern of coffee (IAEA, 1975) revealed two zones viz., near the soil surface upto a distance of 82.5 cm from the tree base and in the 45 to 75 cm depth at a distance of 30 cm from the tree. Experiments with one year-old coffee plants growing on Salvador loamy sand, (IAEA, 1975) pointed out that nearly all roots were concentrated in the top layer of 30 cm. In 2 year-old plants, the lateral spread of the roots was upto 80 cm and for adult trees, it was 130 cm.

Wet and dry season experiments carried out on cacao at Ghana using tracer technique (IAEA, 1975) revealed highest root activity in the upper 2.5 cm soil layer. In both wet and dry seasons, the effect of distance on root activity was not significant, but there was an indication of high root activity near the soil surface at a distance of 90 to 150 cm.

From a study on the root activity pattern of coconut employing ^{32}P, Balakrishnamurthy (1971) suggested that maximum uptake occurred from 1 m distance from the palm at a depth of 12 cm. The greatest root activity was observed in the upper 0 to 30 cm layer of soil close to the palm (within 150 cm) and intensity was more in wet season.

Studies conducted in Sri Lanka using radiotracer on the efficiency of fertilizer utilisation by coconut palms (IAEA, 1975) showed that nutrient uptake was maximum at a lateral distance of 50 cm and a decrease was observed with increase in radial distance. Activity was very high within a radius of 2 m within a depth of 10 to 45 cm. Results of the experiments on the root activity patterns of 15 and 60 year-old coconut trees (tall var. Laguna typica) in the Philippines in wet and dry seasons were reported by IAEA (1975). The highest zone of root activity was at 1 to 2 m distance and upto 15 cm depth. Results of experiments carried out in wet and dry seasons in 50 year-old coconut palms in sandy loam soil in Sri Lanka (IAEA, 1975) indicated that root activity in wet season was highest at 1 m distance and 10 cm depth. In dry season, root activity was highest at 0.5 m distance at 10 cm depth. Activity at lower depths and greater distances was high in the dry season.

Phosphorus-32 injection experiments were carried out to study the root activity pattern of young, 7 year-old and bearing oil palms in wet and dry seasons in Malaysia and Ivory coast (IAEA, 1975). In Malaysia during the wet season, the highest root activity was found at the soil surface at a distance of 3 m from the tree. About 70 to 80 per cent of active roots were within 0 to 20 cm depth. In Ivory coast, highest root activity was observed at 0 to 20 cm depth. Wet season activity was more intense and confined to the surface unlike in dry season where the activity showed a steep decline with depth.

Soong *et al.* (1971) studied the P uptake of *Hevea brasiliensis* seedlings by ^{32}P soil injection technique and subsequent analysis of the leaves and latex. Maximum root activity was found in a lateral distance of 3.6 m from the trees. Phosphorus uptake by mature rubber trees from the soil by using ^{32}P soil injection technique was investigated by Silva *et al.* (1979). Radioactivity in the latex, a reliable assay for determining distribution of active roots, was higher when ^{32}P application was done at a lateral distance of 0.75 m from the tree and at 15 cm soil depth.

MATERIALS AND METHODS

MATERIALS AND METHODS

All the experiments were conducted at the College of Horticulture, Vellanikkara which is situated at an altitude of 22.25 m above MSL at latitude 10°32'N and longitude 76°10'E and enjoys typical humid warm tropical climate.

3.1. Soil and experimental material

The Physico-chemical characteristics of the soil at the experimental site are furnished in Table 1. The soil is acidic laterite fairly rich in organic matter with high content of available P and K. Black pepper var. Panniyur-1 was invariably used for all the experiments. These plants belonged to an existing field experiment on the effect of spacing, variety and type of standard on the growth and yield of black pepper vines. The trial was established in 1979 under the Kerala Agricultural Development Project and the vines were four years old when they were made use of for the present study.

3.2. Root activity patterns of black pepper vine and erythrina standard

3.2.1. Absorption of soil-applied ^{32}P by the vine

In order to examine how fast the applied radio-activity was absorbed by the vine, ^{32}P solution was injected into soil holes at a depth of 10 cm. along the circumference of a semicircle (Fig.3) of 15 cm. radius facing the vine and the radioactivity recovered in the leaves at a canopy height of 1.5 m was determined at intervals of 5, 15, 30, 60 and 120 min after ^{32}P placement. There were two replications for each treatment.

3.2.2. Standardisation of leaf sampling procedure for radioactivity measurement in black pepper

Two soil treatments of radioactivity at 15 and 30 cm radial distances away from the vine and at a depth of 10 cm were compared in this experiment. The vines spaced at 3 m and trailed on dead wood supports (teak poles) were selected for the study. The lay out of this experiment is similar to the Replication III as shown in Fig. 1. The radioactivity was applied on 15th June, 1983 into 8 soil holes taken on the circumference of the semicircle facing the vine (Fig.3) to give 2.5 mCi/plant/treatment (9.25×10^7 Bq). There were six replications for each treatment. Leaf samples were collected from each vine separately from three canopy positions namely top, middle and bottom after dividing the total canopy height into three equal parts. Three separate samples from canopy sides facing ^{32}P applied area, opposite side of the applied area and from all around the plant were collected from each of the canopy positions. Thus the number of samples collected from each vine was nine (ie., 3 positions on the canopy x 3 methods of sampling). The samples were collected 10 and 24 days after ^{32}P application for radioassay.

Table 1. Physico-chemical characteristics of the soil basins of the vine at the experimental field.

Soil characteristic	Pepper on teak pole			Pepper on erythrina		
	Soil depth (cm)			Soil depth (cm)		
	0-10	10-20	20-40	0-10	10-20	20-40
Organic Carbon (%)	1.42	1.31	1.23	1.21	1.26	1.10
pH	5.8	5.6	5.5	6.0	5.8	5.9
Available P (ppm)	390	200	235	210	229	136
Available K (ppm)	380	440	460	340	140	450
Exchangeable Ca (me/100 g)	5.8	4.1	2.1	4.2	5.9	3.9
Exchangeable Mg (me/100 g)	0.73	0.42	0.30	0.40	1.2	0.49
Mechanical analysis of 0-40 cm soil layer (%)	Sand - 57.5 : Silt - 16.5 : Clay - 26.0					

3.2.3. Root activity studies

The quantitative estimation of root activity was based on the absorption of applied ^{32}P at different depths and lateral distances from the plant. The radioactivity recovered in the leaves as a result of absorption from different root zones were compared to arrive at the root zone of maximum absorption of the applied label (IAEA, 1975). The experiment consisted of 12 treatments (3 depths x 4 lateral distances). The lateral distances were 15, 30, 60 and 120 cm from the vine and the depths were 10, 20 and 40 cm. Each treatment was replicated thrice. Single trees were used as experimental units. The pattern of root activity was studied with pepper vines trailed on both live (erythrina) and dead (teak pole) standards selected from an existing field trial which was laid out with two varities of black pepper (Karimunda and Panniyur-1), three spacings (2 m x 2 m; 2.5 m x 2.5 m and 3 m x 3 m) and three standards (Teak pole-dead standard, _Erythrina indica_ and _Garuga pinnata_ - live standards) in factorial RBD with four replications. For the present study on the root activity of black pepper, only the plants of var. Panniyur-1 trailed on erythrina (live) and teak pole (dead) supports were made use of. The three spacings of the ongoing field trial formed the the three replications of the present study (Fig.1).

For studying the root activity of erythrina (live standard), no separate experiment was conducted. Instead, the leaf samples were collected from these plants also at each time when the leaves of pepper vines were sampled. Therefore, the lateral distances of ^{32}P application referred to in the text were all in relation to the vine. Since the pepper vine was planted 30 cm away from the standard, in effect; the lateral distances from the vine viz., 15, 30, 60 and 120 cm do not correspond to similar distances from the standard.

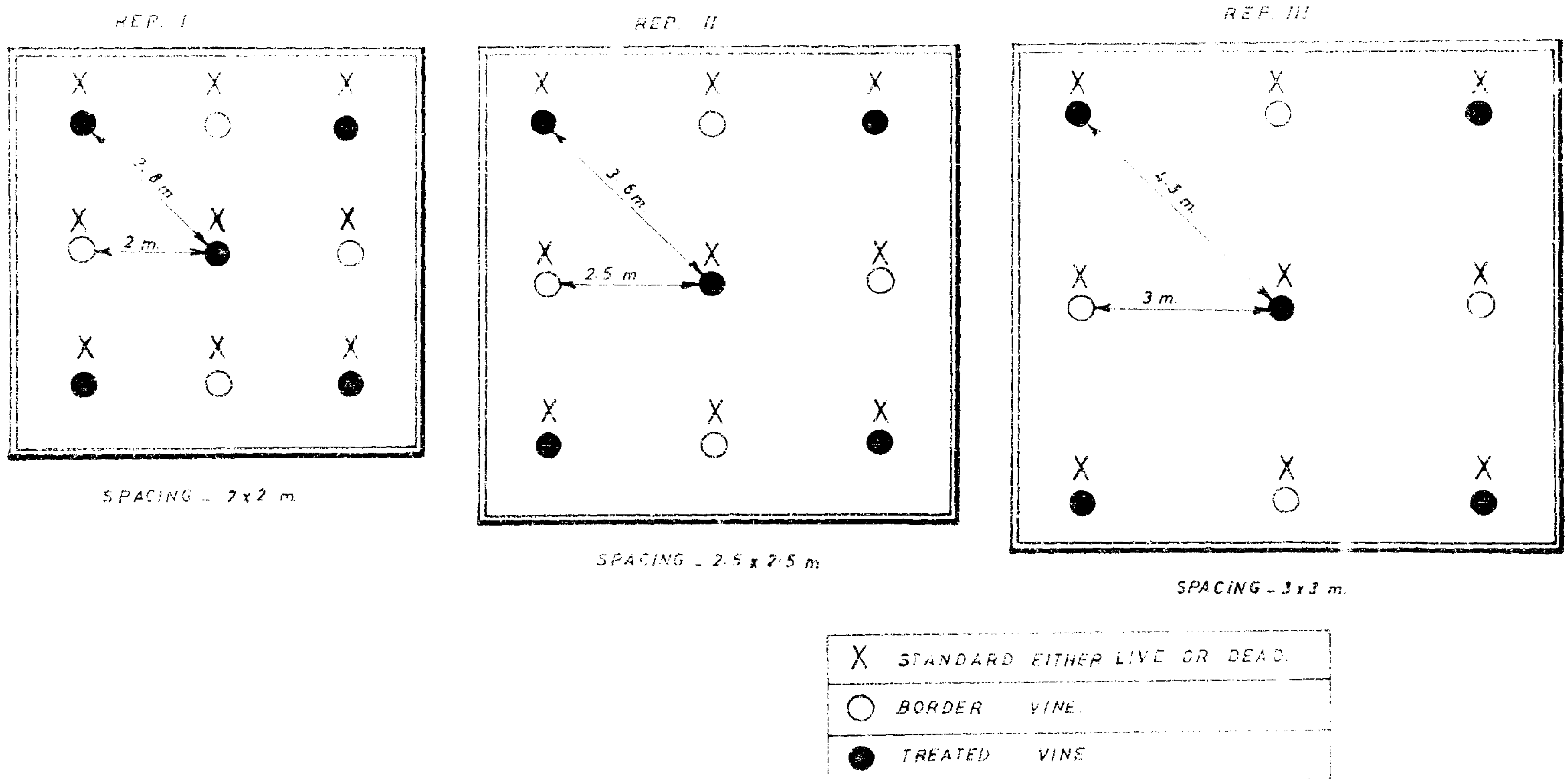
3.2.4. Soil injection of ^{32}P solution

An injection device developed for the purpose of applying desired volume of ^{32}P solution at a given depth is diagramatically presented in Fig. 2. It consists of a Lumac Dispensette fitted to a 1 l glass reservoir bottle of 3 mm thickness embedded in paraffin wax in a suitable plastic bucket (20 cm dia x 19 cm ht).

Molten paraffin wax was poured into an empty plastic bucket to give a wax layer of 2.5 cm thickness. Upon cooling, the reservoir bottle was filled with cold water and placed centrally on the wax layer in the bucket. The bottle was kept in such a way that the end position of the grooves at the mouth of the bottle (when dispenser is fixed) was at right angles to the bucket handle. In this position, when the dispenser was attached, the bucket handle was free to move when lifted, without touching the delivery tube of the dispenser. Molten wax was again poured into the vacant space between the reservoir bottle and the bucket until the bottle was completely immersed upto the neck. It was then allowed to stand overnight for the solidification of the wax. The water from the bottle was removed and the radioactivity in the supplied stock vial was transferred into the reservoir bottle through a funnel. The vial was washed five to six times with 1000 ppm carrier P solution (KH_2PO_4) and the washings were poured into the bottle. Finally enough carrier solution was added into the bottle to give 78 uCi (2.886 x 10^6Bq) of ^{32}P/ml of the solution. Finally a 'Lumao Dispensette' (calibrated plunger for repeated delivery of desired volume of the solution upto 5 ml) with 30 cm long polythene delivery tube was attached to the reservoir bottle.

The soil application of ^{32}P solution was done in a semicircle facing the vine as shown in Fig. 3. Equally spaced 8 holes to the required depth along the circumference of the semicircle of a particular radius (radial distance from the vine) were prepared a day in advance of ^{32}P application using a soil auger of 2 cm dia. The holes were plugged with wooden rods to prevent filling up during the rains. At the time of ^{32}P application, the wooden rod was removed from the hole and an access tube made of glass (8 mm dia) was introduced into the hole. The delivery tube of the dispenser was then introduced into the access tube.

FIG. 1. LAY OUT OF VINES IN RELATION TO ^{32}P TREATMENT.



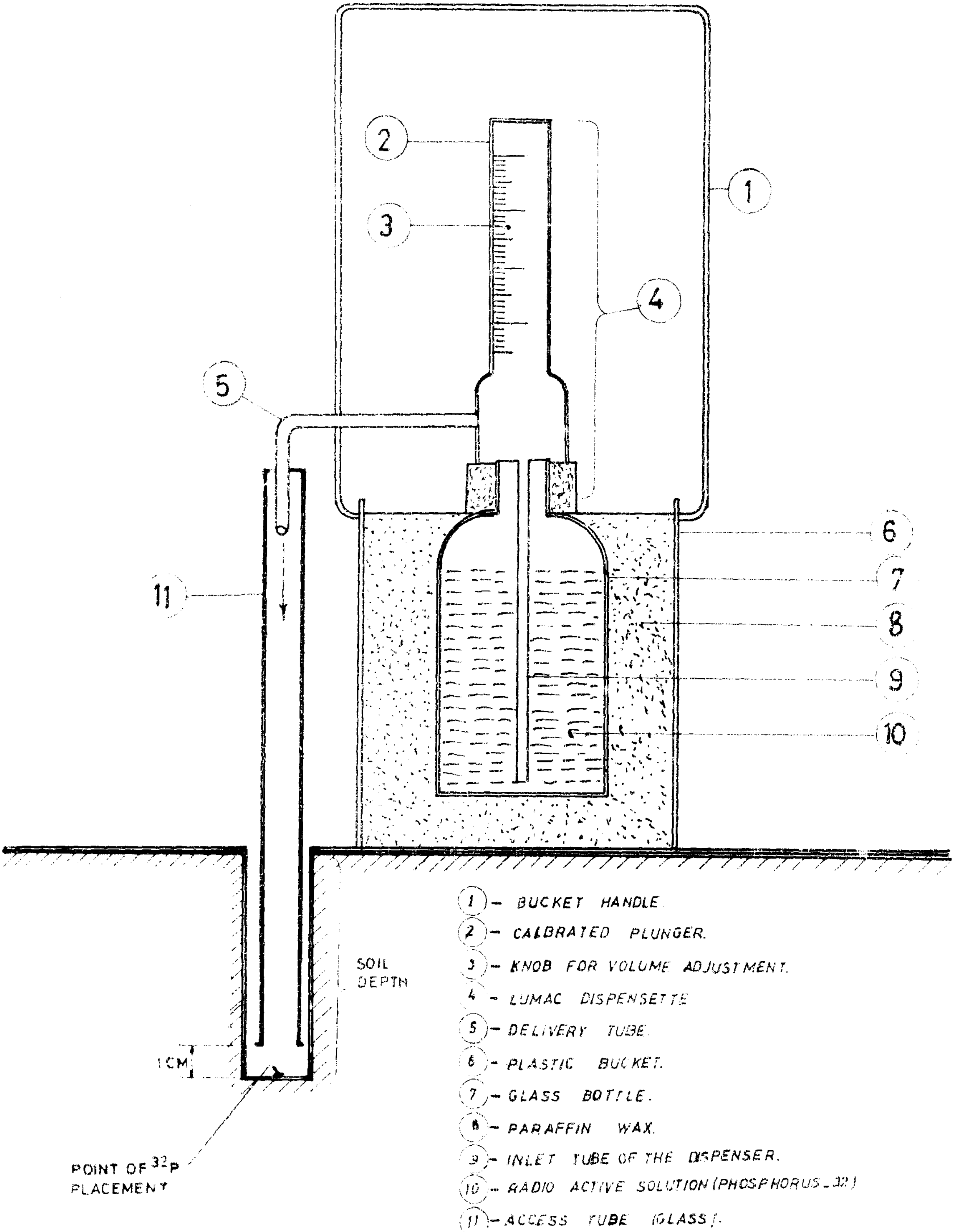


FIG. 2 DEVICE FOR SOIL INJECTION OF ^{32}P SOLUTION

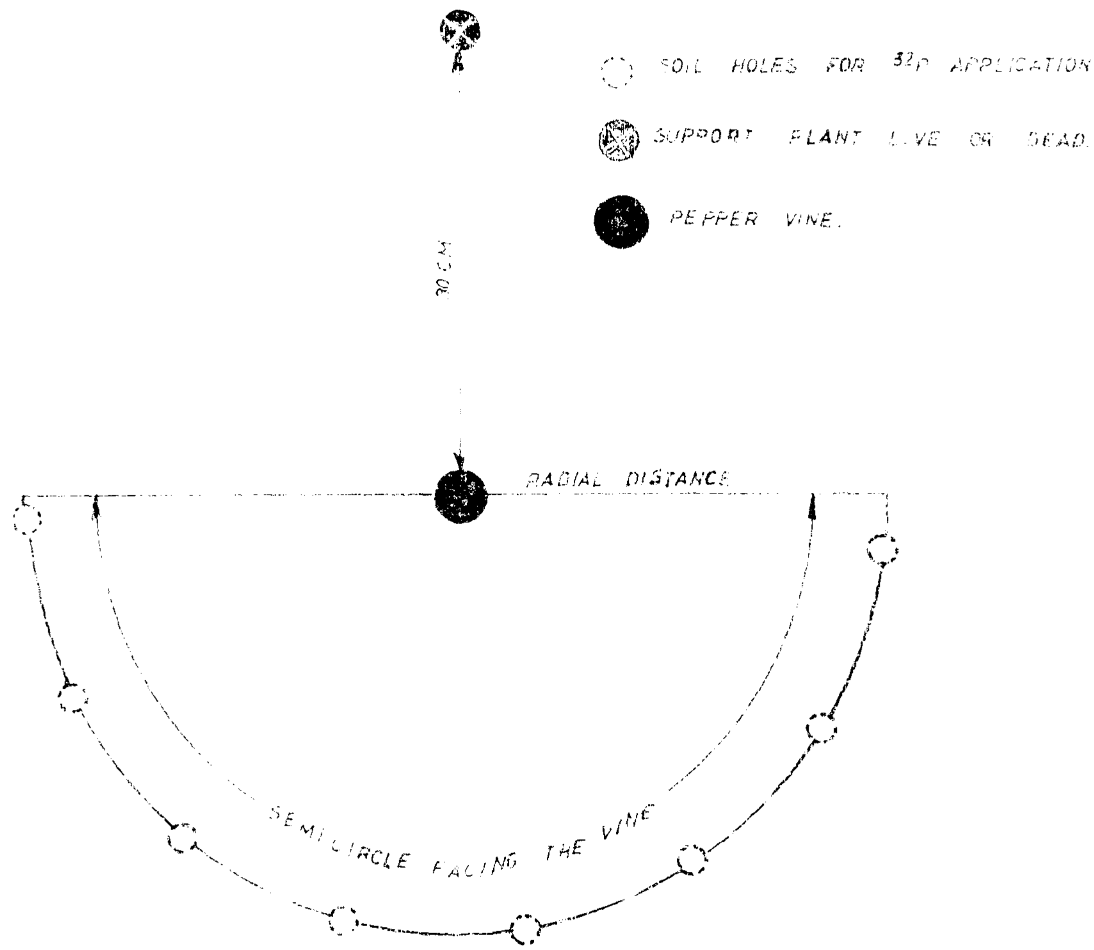


FIG.3 METHOD OF ^{32}P APPLICATION IN SEMICIRCLE FACING THE VINE.

The accoso tube was raised to give a clearance of 1 cm at the bottom of the hole and 4 ml of the radioactive solution was dispensed into each hole. The radioactivity remaining on the sides of the access tube was washed down with a jot of about 5 ml distilled water using a wash bottle. The total activity thus correspond to 2.5 mCi (9.25×10^7 Bq)/ plant. Soon after the application of radioactive solution, the holes were filled back with the soil removed from it.

3.3. Absorption of ^{32}P by the vine and erythrina standard as influenced by the method of application.

In order to study the uptake of ^{32}P in relation to the method of application, an experiment was conducted with pepper vines trailed on teak pole and on erythrina. Three methods of application were tried in this experiment (Fig. 4). They were:-

a. Application of the tracer in semicircle facing the vine.

b. Application of the tracer in semicircle opposite the vine and

c. Application of the tracer in full circle around the vine.

The radial distance from the vine was kept constant at 30 cm for ^{32}P application while two depths namely 20 and 40 cm were included as treatments. Thus the total number of treatments compared in this study was six (all combinations of two depths and three methods of application). Each treatment was replicated thrice with one plant/treatment/replication.

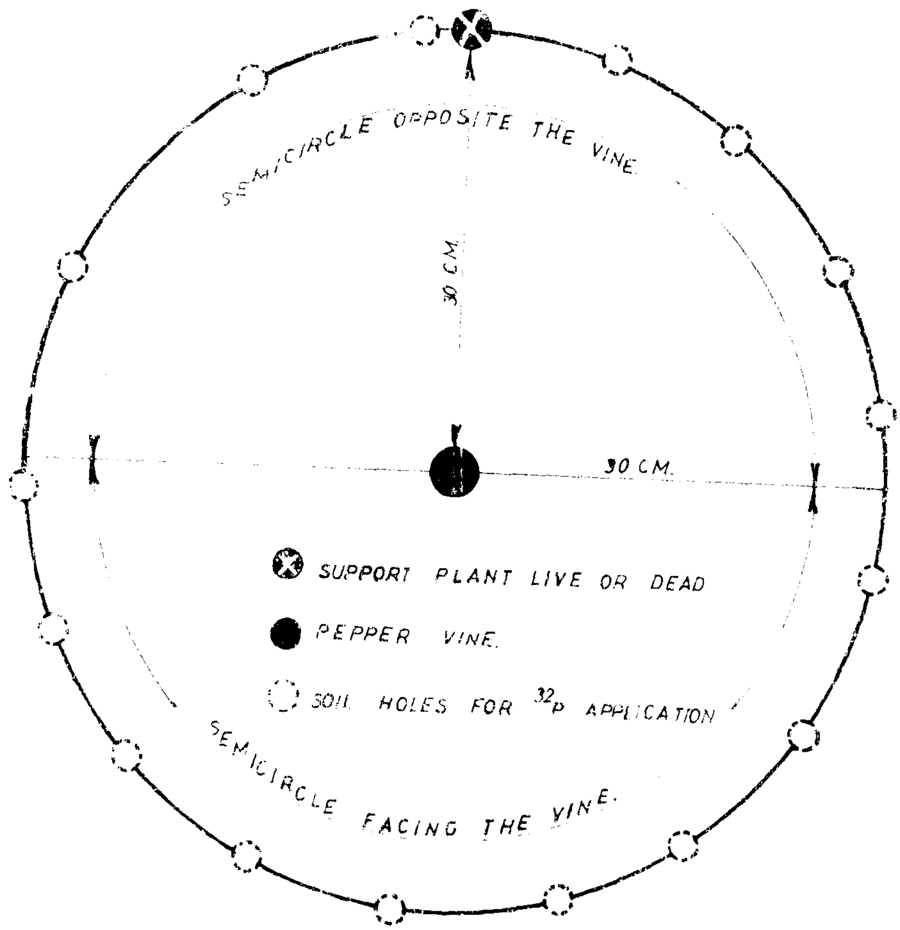


FIG. 4 DIAGRAMATIC REPRESENTATION OF ^{32}P APPLICATION IN SEMICIRCLES FACING AND OPPOSITE THE VINE AND ALSO IN FULL CIRCLE.

In the case of application of radioactivity in semicircles, the method already described under Section 3.2.4. was followed. However, for the application of radioactivity in full circle, the total amount of applied label 2.5 mCi (9.25×10^7 Bq), was dispensed into 16 equally spaced holes around the plant at the rate of 2 ml ^{32}P solution (in 1000 ppm carrier P)/hole. Therefore, the amount of radioactivity dispensed per hole is half the amount received by a soil hole in semicircular application. The radioactivity was applied on 4th August, 1984. Leaves were sampled for radioassay and total P determination at 15, 30, 45, 60 and 75 days after application.

3.4. <u>Leaf sampling</u>

The standardisation of leaf sampling procedure for radioactivity measurement forms a part of the present work (Section 3.2.2.) as there is no published report available on this aspect. First fully mature leaves from fruiting branches of the lower two third canopy were collected from all sides around the vine. From each vine 6 leaves were collected to form a sample. This procedure of leaf sampling was based on the results obtained from studies conducted as given under section 3.2.2. (see also Sections 4.3 and 5.2). The method was followed in all the experiments.

In the case of erythrina, recently matured trifoliate leaves were considered for sampling. After collection of the leaves, the petioles were removed and only the leaf laminae were used for radioassay and total P determination.

3.5. Radioassay of leaf samples

For the determination of ^{32}P activity in the leaf samples, the method developed by Wahid et al (1985) was followed. The method is based on the determination of ^{32}P activity by Cerenkov counting technique. Briefly, the procedure involves wet digestion of oven dried (75°C) and finely cut leaves with 1:1 perchloric-nitric acid mixture and determination of radioactivity in the digest. One gram leaf sample was weighed into a 250 ml conical flask followed by addition of 15 ml diacid mixture. The flask with its contents were then heated on a hot plate at a low temperature until the initial frothing subsided. The digestion was continued at increased temperature until the digest became clear and its volume reduced to 2 to 3 ml. The flask with its contents was then cooled and the colourless digest was quantitatively transferred into a 20 ml glass scintillation counting vial with glass distilled water upto a final volume of 20 ml by repeated washings of the flask. The radioactivity was determined after 4 h in a microprocessor controlled liquid scintillation system (Rackbeta of LKB Wallac, Finland) adopting channel settings and the programme recommended for tritium counting by liquid scintillation technique.

3.6. Specific activity determination

Specific activity of ^{32}P in the leaf samples was estimated as follows. After the radioassay of the sample, an aliquot (2 ml) of the leaf digest was removed from scintillation vial for the determination of total P by the vanadomolybdate method (Jackson, 1958). The specific activity of the ^{32}P sample was then calculated as the ratio of ^{32}P content per unit weight of P and expressed as cpm/mg P.

3.7. Percentage root activity

The percentage root activity was computed independently for the pepper vines trailed on teak pole, on erythrina and for the live standard employing the following equation.

$$\text{Percentage root activity} = \frac{\text{Radioactivity recovered in the leaf for a particular distance and depth (cpm)}}{\text{Total radioactivity recovered from all the distances and depths (cpm)}} \times 100$$

3.8. Root competition for applied ^{32}P

In order to examine the magnitude of root competition for applied ^{32}P between the vine and the live support-erythrina, specific activity ratios were compared. For this purpose, the mean specific activities obtained at different intervals of sampling for the leaf samples collected in experiment 3.3. were made use of. The specific activity ratio is given by the equation:

Specific activity (cpm/mg P) of the leaves of pepper vine trailed on erythrina

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Specific activity (cpm/mg P) of the leaves of pepper vine trailed on teak pole.

3.9. <u>Radioassay of berry and rachis</u>

Eighteen ^{32}P-treated pepper vines of the root activity experiment (Section 3.2.3.) selected at random were harvested in January, 1984. The berries and their rachis were separated for each vine. Subsamples of each were dried in an oven at 75°C. After drying, they were separately radioassayed following the same method as described for the determination of radioactivity in the leaf (Section 3.5).

3.10. <u>Phosphorus-32 absorbing power of climbing roots</u>

Another experiment was conducted to examine whether the climbing roots are capable of nutrient absorption. For this purpose, pepper cuttings of var. Panniyur-1 were grown in pots for six months. Coir ropes arranged vertically to a height of 2 m were used as supports. The branches of the vine were cut at about 10 cm from the growing point to give one nodal point at the centre with fresh climbing roots and one fully opened leaf. The vine cutting was placed on a beaker containing ^{32}P solution in such a way that about three-fourth of the length of the climbing roots were immersed in the solution. Care was taken to see that the stem portion of the cutting, the leaf and the growing point were not contaminated. The absorption of ^{32}P by the climbing roots in this manner was studied at two concentrations namely 20 (0.74MBq) and 100 uCI (3.7 MBq). The cuttings were allowed to absorb ^{32}P for one h. At the end of this period, the leaf at the node as well as the immature leaves at the growing point were removed and radioassayed separately.

3.11. Nutrient removal by pepper vine and erythrina standard

3.11.1. Collection of plant samples and processing

Three erythrina trees with the pepper vines (var. Panniyur-1) at the harvest stage, were cut down at ground level. The vines were separated from the support plants for the determination of dry matter and nutrient removal.

The total dry matter and nutrient removal by pepper vine trailed on erythrina tree were worked out as follows. The vine was divided into four parts namely berry, rachis, leaf and stem. Erythrina plant was divided into leaf, petiole and stem. Fresh weight was taken for each part after chopping into small pieces. A known quantity of samples collected from each of the samples was used for determination of dry weight and nutrient concentration.

The plant samples were oven dried at 75°C, powdered in a mill with stainless steel blades and stored in polythene bottles for chemical analysis.

3.11.2. Chemical analysis of plant samples

The plant samples were analysed for major and micronutrients. Total nitrogen was determined by micro Kjeldahl method (Jackson, 1958). In this method all forms of nitrogen in the sample were converted into sulphate of ammonia by digestion with sulfuric and salicylic acids in the presence of sodium sulfate as an electrolyte and selenium as catalyst. The digest was made upto a known volume with distilled water. An aliquot of the resulting solution was distilled with excess of alkali and the distillate was collected in 4% boric acid-indicator mixture. The amount of ammonia evolved was determined by titration with standard sulfuric acid.

The analysis of other nutrients viz., P, K, Ca, Mg, S, Fe, Mn, Zn and Cu was done after diacid digestion of the samples as described under Section 3.6 and transferring the digest to 100 ml volumetric flask. The digestion flask was washed 3 to 4 times with glass distilled water and volume was made upto 100 ml. Aliquots from this solution were taken for the analysis of the nutrient elements.

Phosphorus was estimated colorimetrically by the vanadomolybdo-phosphoric yellow colour method (Jackson, 1958). Potassium was determined in a flame photometer (EEL make). Calcium, Mg, Fe, Mn, Zn, and Cu were determined using an atomic absorption spectrophotometer (Instrumentation Limited, USA). For the determination of Ca and Mg, $SrCl_2$

(1000 ppm Sr final concentration) was used as the releasing agent.

Sulfur in the plant digest was determined turbidimetrially following barium chloride method (Jackson, 1958)

3.12. Soil Analysis

For the determination of physico-chemical characteristics of the soil at the experimental site, soils were collected from the basins of three randomly selected pepper vines representing both live and dead standards. From each basin, soil cores were removed at three points 30 cm away from the plant from depths 0 to 10, 10 to 20 and 20 to 40 cm. The soil samples collected from each depth from the 3 points of each basin were pooled to give a sample for particular depth. The soil sampling was done in February, 1984.

Soil moisture was determined immediately after sample collection. A portion of each sample was transported to the laboratory in tared aluminium can for fresh weight determination. It was then kept in an oven at 105°C until a constant weight was obtained. The loss in weight of the soil before and after oven drying was expressed as moisture percentage.

Another lot was air dried and sieved through 2 mm mesh for physico-chemical analysis. Soil pH was determined using a pH meter (1:2.5 soil-water ratio). Organic carbon was estimated by Walkley and Black method described by Piper (1942). Available phosphorus was determined in the Bray No.1 extract of soil by the chloro-stannous reduced molybdo-phosphoric blue colour method in hydrochloric acid medium (Jackson, 1958). Available K, exchangeable Ca and Mg (N NH_4OAc, pH 7) were also determined following the methods suggested by Jackson (1958). Mechanical analysis was carried out following International Pipette Method (Piper, 1942).

3.13. Biometric observations

At the time of harvest, the plant height, girth and yield/plant were recorded separately for the 36 plants each on teak pole and erythrina standards which were used for root activity studies.

3.14. Statistical analysis

The data relating to the absorption of ^{32}P by the pepper vine and erythrina were analysed by applying the analysis of variance technique, suggested by Panse and Sukhatme (1967) for factorial experiments in Randomised Block Design.

RESULTS

RESULTS

4.1. Soil injection of ^{32}P solution

A method of injecting desired volume of ^{32}P solution into the root zone of crop plants was developed. This method makes use of a device fabricated for field operation. It consisted of a 'Lumac Dispensette' connected to a reservoir bottle which in turn was embedded in paraffin wax contained in a plastic bucket (Fig.2). A detailed account of the device was given under 'Materials and Methods' (Section 3.2.4). The field operation of this soil injection device is shown in Plate 1. The reservoir bottle of the apparatus can hold 1 l of the radioactive solution. The radioactivity requirement/plant in all the experiments was 2.5 MCi which has to be equally distributed into either 16 or 8 soil holes. The radioactivity/ml solution used in these experiments was 78 uCi (2.886×10^9 Bq) which would necessitate dispensing of 2 or 4 ml solution/soil hole corresponding to 16 and 8 soil hole applications to give the required radioactivity/plant. To dispense 4 ml of radioactive solution containing 312 uCi ^{32}P (1.54×10^7 Bq), the volume adjusting knob was loosened and its pointer brought to the 4 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. At an injection dose of 2.5 mCi (9.25×10^7 Bq)/plant, the requirement of radioactivity for 16 plants is 40 mCi (14.8×10^9 Bq) in 512 ml of carrier solution (1000 ppm P).

Plate - 1

Soil injection of ^{32}P solution

Plate - 1

The radiation dose of this solution at the outer surface of the bucket was found to be less than 10 mR/h. The variations in the successively dispensed volumes of the solution was found to be less than 5 per cent.

4.2. <u>Absorption of soil-applied ^{32}P by the vine</u>

The pattern of ^{32}P absorption by the vine as a function of time is depicted in Fig.5. In this preliminary experiment, ^{32}P was placed at 15 cm radial distance from the vine at a soil depth of 10 cm. Detectable amounts of radioactivity were obtained in the leaves as early as 5 min after application. During a period of 2 h, the absorption of ^{32}P was found to be nearly linear. The radioactivity recovered in the leaf increased from about 5 at 5 min to 85 cpm/g at 2 h.

4.3. <u>Standardisation of leaf sampling procedure for ^{32}P assay</u>

The data pertaining to the radioactivity recovered in the leaves following soil injection of ^{32}P in relation to leaf position on the canopy and method of sample collection are presented in Table 2. The statistical analyses of the data are presented in Appendices I and II. The results showed that the radioactivity recovered in the leaves was not influenced by their relative position on the canopy as evidenced from the lack of statistical significance in the variation of ^{32}P content of leaves sampled from various canopy heights <u>viz</u>., top, middle and lower one-thirds. Radioassay of the leaves was conducted 10 and 24 days after ^{32}P placement. On

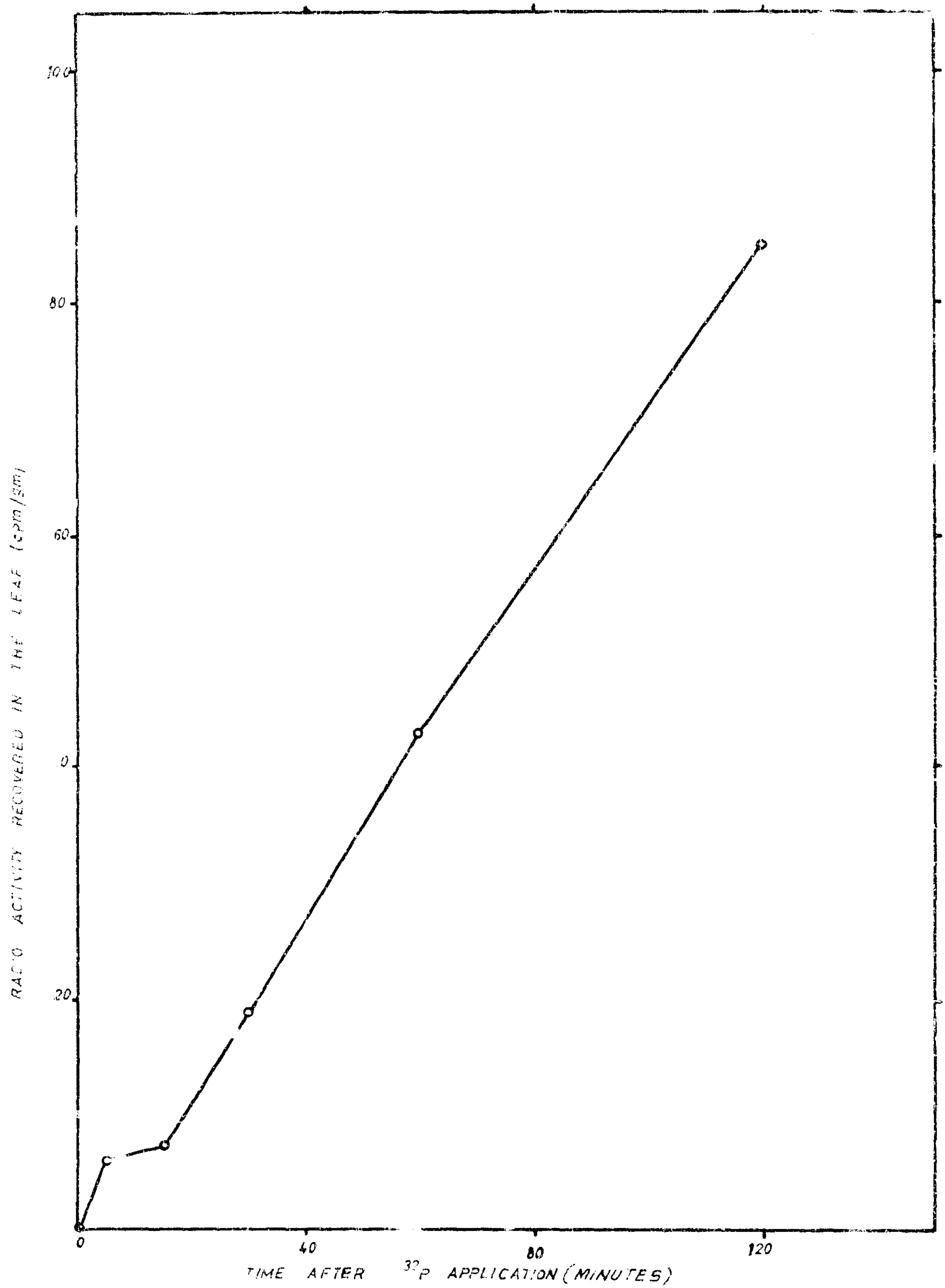


FIG. 5. ABSORPTION OF SOIL-APPLIED RADIOPHOSPHORUS BY BLACK PEPPER VINE AS A FUNCTION OF TIME.

both sampling dates, identical results were obtained. Much similar to this observation, the absorption of the label was also not affected by the method of sampling. Thus, the difference in ^{32}P count rates among leaf samples collected from canopy sides facing the applied area, opposite side of the applied area and from all around the vine were not statistically significant.

4.4. <u>Root activity pattern of black pepper</u>

4.4.1. Pepper vine trailed on teak pole

The absorption pattern of ^{32}P by the vine from various soil depths and radial distances are presented in Tables 3 to 6. In view of the large variation observed in the uptake of ^{32}P, the statistical analysis was carried out after logarithmic transformation of the data. The analyses of variance are given in Appendix III. The absorption of the radiolabel varied significantly with radial distance from the vine. It was found that the amount of radioactivity taken up by the plant from 15 and 30 cm radial distances was appreciably higher than that from farther distances, 60 and 120 cm. This trend was observed at all sampling intervals. Nevertheless, the absorption of ^{32}P was found to be higher from 15 cm lateral distance than from 30 cm at 30 days.

Uptake of ^{32}P was found to be more from 40 cm than from 10 cm soil depth at 30 and 60 days of ^{32}P application while the differences in ^{32}P recovery from these depths were not statistically significant at 15 and 45 days sampling intervals. The interaction between depth and distance was absent.

The distribution pattern of active roots in various soil zones expressed as percentage of the total root activity is given in Table 7. The data revealed that more than 50 per cent of the active roots were located within 15 cm from the vine. The percentage root activity increased from 51.6 at 15 days to 68.5 at 30 days after ^{32}P application. Not much differences were observed in the percentage root activity beyond this period upto 60 days. About 20 to 30 per cent of the functional roots were found to reside at 30 cm from the vine. The variation in percentage root activity at this distance was not much at various sampling intervals. At distances beyond 30 cm from the vine, the root activity decreased to less than 5 per cent.

The vertical distribution of active roots in soil varied with sampling interval. Initially (at 15 days after ^{32}P application) 45.2 per cent of the total feeding roots were found to concentrate within 10 cm soil depth. However, the root activity at this soil zone declined to 22.3 per cent 60 days after ^{32}P placement. Similarly at 20 cm soil depth, a decrease from 31.8 to 15.6 per cent was observed during the same period. On the contrary, there was a gradual increase in root activity at the lowest depth tried (40 cm) from 22.9 to 61.2 per cent.

Table 2. Radioactivity recovered in the vine leaf (cpm/g) as influenced by its position on the canopy.

Days after ^{32}P placement	Canopy side in relation to ^{32}P applied area	Radial distance from the vine	Leaf position on the canopy		
			Top	Middle	Bottom
10	Facing the applied area	15	1567	1140	1957
		30	1126	1743	2948
	Opposite to applied area	15	1303	1151	2193
		30	3739	5559	572
	All around the vine	15	1346	921	1378
		30	1198	572	1545
24	Facing the applied area	15	8932	34988	22643
		30	4026	10883	10100
	Opposite to applied area	15	11393	12412.	32409
		30	4554	7178	4729
	All around the vine	15	15787	31631	27212
		30	6671	11241	8822

Note: Differences in ^{32}P counts among various leaf positions in the canopy are not statistically significant.

Table 3. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of the vines trailed on teak pole after 15 days of application (log-transformed values)

Depth (cm)	Lateral distance (cm)				Mean
	15	30	60	120	
10	3.523 (3336.7)	2.449 (281.0)	1.766 (58.3)	2.505 (319.8)	2.561 (363.6)
20	3.043 (1103.4)	3.432 (2703.9)	1.226 (16.8)	1.972 (93.7)	2.418 (261.8)
40	3.292 (1958.2)	2.963 (918.5)	2.275 (188.3)	2.136 (136.7)	2.666 (463.9)
Mean	3.286 (1931.9)	2.948 (887.0)	1.755 (56.9)	2.204 (160.0)	

SEM ± for lateral distances : 0.205 SEM ± for depths : 0.178

$CD_{(0.05)}$ for comparison of :-

Lateral distance : 0.602

Depth : Not significant

Lateral distance x depth : Not significant

Parentheses denote retransformed values.

Table 4. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of the vines trailed on teak pole after 30 days of application (log-transformed values)

Depth (cm)	Lateral distance (cm)				Mean
	15	30	60	120	
10	4.167 (14683.1)	3.089 (1228.6)	2.490 (309.0)	1.905 (80.4)	2.913 (818.1)
20	3.463 (2902.6)	3.656 (4527.5)	2.051 (112.4)	2.392 (246.8)	2.890 (777.[illegible])
40	4.101 (12604.6)	3.749 (5612.5)	2.989 (973.9)	2.725 (531.4)	3.391 (2459.9)
Mean	3.910 (8129.1)	3.498 (3148.8)	2.510 (323.4)	2.341 (219.3)	

SEM ± for lateral distances : 0.140 SEM ± for depths : 0.121

$CD_{(0.05)}$ for comparison of :-

Lateral distance : 0.410

Depth x Lateral distance : Not significant

Depth : 0.355

Parentheses denote retransformed values.

Table 5. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of the vines trailed on teak pole after 45 days of application (log-transformed values)

Depth (cm)	Lateral distance (cm)				Mean
	15	30	60	120	
10	4.232 (17077.3)	3.359 (2283.5)	2.998 (994.6)	2.473 (297.4)	3.266 (1842.9)
20	3.653 (4500.1)	4.063 (11554.8)	2.197 (157.5)	2.353 (225.7)	3.067 (1165.9)
40	4.278 (18987.3)	3.637 (4333.5)	2.950 (891.0)	3.111 (1290.1)	3.494 (3118.6)
Mean	4.055 (11342.3)	3.686 (4853.7)	2.715 (518.7)	2.646 (442.4)	

SEM ± for lateral distance : 0.195 SEM ± for depths : 0.169

$CD_{(0.05)}$ for comparison of :-

Lateral distance : 0.572

Depth : Not significant

Lateral distance x depth : Not significant

Parentheses denote retransformed values.

Table 6. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of the vines trailed on teak pole after 60 days of application (log-transformed values)

Depth (cm)	Lateral distance (cm)				Mean
	15	30	60	120	
10	4.129 (13454.8)	3.619 (4157.2)	3.056 (1137.8)	2.743 (553.2)	3.387 (2435.9)
20	3.641 (4374.3)	3.893 (7821.1)	2.292 (195.9)	2.478 (300.4)	3.076 (1191.2)
40	4.504 (31949.3)	3.973 (9392.3)	3.128 (1341.7)	3.177 (1502.3)	3.695 (4959.3)
Mean	4.091 (12342.8)	3.828 (6734.1)	2.825 (668.7)	2.799 (629.7)	

SEM ± for lateral distances : 0.146 SEM ± for depths : 0.126

$CD_{(0.05)}$ for comparison of :-

Lateral distance : 0.427

Depth : 0.370

Lateral distance x depth : Not significant

Parentheses denote retransformed values.

Table 7. Percentage root activity of black pepper trailed on teak pole

Days after ^{32}P application	Lateral distance (cm)				Depth (cm)		
	15	30	60	120	10	20	40
15	51.6	27.0	1.7	19.8	45.2	31.8	22.9
30	68.5	24.5	4.8	2.1	31.4	19.4	49.3
45	77.3	16.8	3.2	2.6	15.6	21.7	62.7
60	64.5	28.7	3.9	2.9	23.3	15.6	61.2

4.4.2. Pepper vine trailed on erythrina

The log-transformed ^{32}P absorption data and their analyses of variance are furnished in Tables 8 to 11 and Appendix IV respectively. As in the previous case, the absorption of radiolabel was found to be the highest from the immediate vicinity of the vine ie., within 15 and 30 cms distance from the vine. The least absorption of ^{32}P occurred at 120 cm from the vine. As regards soil depth, the difference in the recovery of ^{32}P were not found to be statistically significant. Interaction between distance and depth was not significant.

Distribution of active roots in various soil zones expressed as percentage of the total activity is given in Table 12. It was seen that there was a marginal decrease in the root activity from 15 to 30 cm lateral distance beyond which there was a sharp decline. Less than 5 per cent of the feeder roots were found to be located beyond 60 cm from the vine. In general, the preponderance of active roots at different soil depths upto 40 cm was found to be more or less the same.

4.5. Root activity pattern of erythrina

The absorption pattern of ^{32}P by the live standard (*Erythrina indica*) from the soil zones corresponding to the radial distances from the pepper vine has also been studied.

Table 8. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of the vines trailed on erythrina after 15 days of application (log-transformed values)

Depth (cm)	Lateral distance (cm)				
	15	30	60	120	Mean
10	3.713 (5160.2)	2.896 (787.6)	1.854 (71.4)	0.708 (5.1)	2.292 (196.1)
20	2.667 (464.1)	2.989 (975.6)	1.905 (80.3)	1.477 (30.0)	2.259 (181.7)
40	2.927 (845.9)	2.632 (428.8)	2.604 (401.4)	0.989 (9.7)	2.288 (194.1)
Mean	3.102 (1265.3)	2.839 (690.7)	2.121 (132.0)	1.058 (11.4)	

SEM ± for lateral distances : 0.304 SEM ± for depths : 0.263

$CD_{(0.05)}$ for comparison of :-

Lateral distance : 0.[illegible]2

Depth : Not significant

Lateral distance x depth : Not significant

Parentheses denote retransformed values.

Table 9. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of the vines trailed on erythrina after 30 days of application (log-transformed values)

Depth (cm)	Lateral distance (cm)				Mean
	15	30	60	120	
10	4.306 (20210.1)	3.581 (3811.5)	2.458 (286.8)	2.076 (119.1)	3.105 (1273.5)
20	2.988 (972.3)	3.584 (3834,0	2.783 (606.1)	1.988 (97.2)	2.835 (684.5)
40	3.806 (6402.8)	3.552 (3566.0)	3.282 (1913.6)	1.848 (70.5)	3.122 (1324.7)
Mean	3.700 (5010.9)	3.572 (3735.2)	2.841 (692.9)	1.970 (93.4)	

SEM ± for lateral distances : 0.205 SEM ± for depths : 0.177

CD (0.05) for comparison of :-

Lateral distance : 0.601

Depth : Not significant

Lateral distance x depth : Not significant

Parentheses denote retransformed values.

Table 10. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of the vines trailed on erythrina after 45 days of application (log-transformed values)

Depth (cm)	Lateral distance (cm)				Mean
	15	30	60	120	
10	4.199 (15801.9)	3.661 (4579.2)	2.534 (341.8)	2.161 (144.9)	3.139 (1376.1)
20	3.180 (1513.2)	3.776 (5975.7)	3.120 (1319.0)	2.051 (112.5)	3.032 (1076.3)
40	4.005 (10113.3)	3.723 (5279.6)	3.659 (4558.0)	1.934 (85.8)	3.330 (2137.7)
Mean	3.794 (6230.2)	3.720 (5247.2)	3.104 (1271.3)	2.049 (111.9)	

SEM ± for lateral distances : 0.233   SEM ± for depths : 0.202

CD (0.05) for comparison of :-

Lateral distance : 0.684

Depth : Not significant

Lateral distance x depth : Not significant

Parentheses denote retransformed values.

Table 11. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of the vines trailed on erythrina after 60 days of application (log-transformed values)

Depth (cm)	Lateral distance (cm)				Mean
	15	30	60	120	
10	4.206 (16071.2)	3.598 (3966.2)	2.689 (488.7)	2.336 (216.8)	3.207 (1612.1)
20	3.376 (2378.[illegible])	3.751 (5638.6)	2.877 (752.6)	2.250 (177.8)	3.063 (1157.4)
40	4.059 (11453.2)	3.584 (3836.0)	3.450 (2816.5)	1.128 (13.4)	3.055 (1135.6)
Mean	3.880 (7595.3)	3.644 (4410.4)	3.005 (1011.9)	1.905 (80.3)	

SEM ± for lateral distances : 0.243   SEM ± for depths : 0.211

$CD_{(0.05)}$ for comparison of :-

Lateral distance : 0.713

Depth : Not significant

Lateral distance x depth : Not significant

Parentheses denote retransformed values.

Table 12. Percentage root activity of black pepper trailed on erythrina

Days after ^{32}P application	Lateral distance (cm)				Depth (cm)		
	15	30	60	120	10	20	40
15	41.6	52.3	5.8	0.21	27.3	55.0	17.7
30	58.7	35.2	5.6	0.54	37.3	31.0	31.7
45	78.5	17.6	3.7	0.20	10.5	76.5	13.0
60	50.1	41.8	5.8	1.6	28.6	46.3	25.0

Statistical analysis of the data (Tables 13 to 16 and Appendix V) revealed that absorption of ^{32}P by the live support was almost similar upto a lateral distance of 60 cm away from the vine. However, the uptake of ^{32}P by the support plant from a distance of 120 cm from the vine was much smaller. Initially the absorption of ^{32}P by the support plant was not influenced by the depth of placement of the radiolabel. But there was a considerable reduction in the uptake of ^{32}P from soil depth lower than 20 cm after 30 days of application. It was also observed that during this period there was a significant distance x depth interaction influencing the absorption of the applied label, the absorption being maximum from 20 cm depth at 30 and 60 cm away from the vine.

The data relating to the percentage root activity of erythrina in various soil zones are given in Table 17. Approximately 97 per cent of the erythrina roots were confined to 60 cm from the vine. As regards soil depth, about 90 per cent of the roots were found within a depth of 20 cm from the surface.

The mean count rate/g leaf as well as the specific activity (cpm/mg leaf P) for black pepper on teak pole and erythrina and for the live standard (erythrina) are presented as a function of time in Figs. 6 and 7. The results indicated that the radioactivity recovered in erythrina leaf expressed

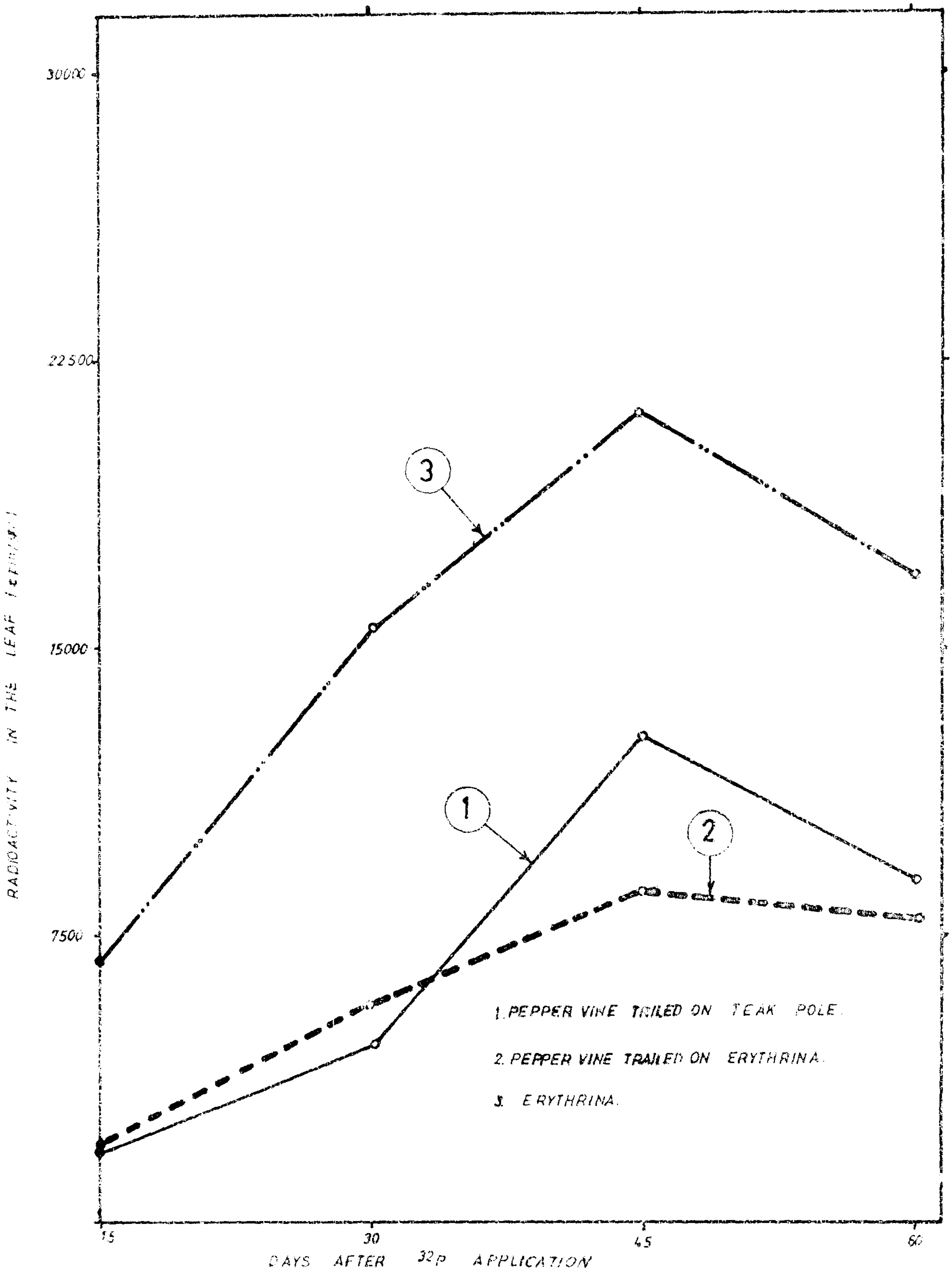


FIG.6 TOTAL RADIOACTIVITY RECOVERED IN THE LEAF AT DIFFERENT INTERVALS AFTER ^{32}P APPLICATION

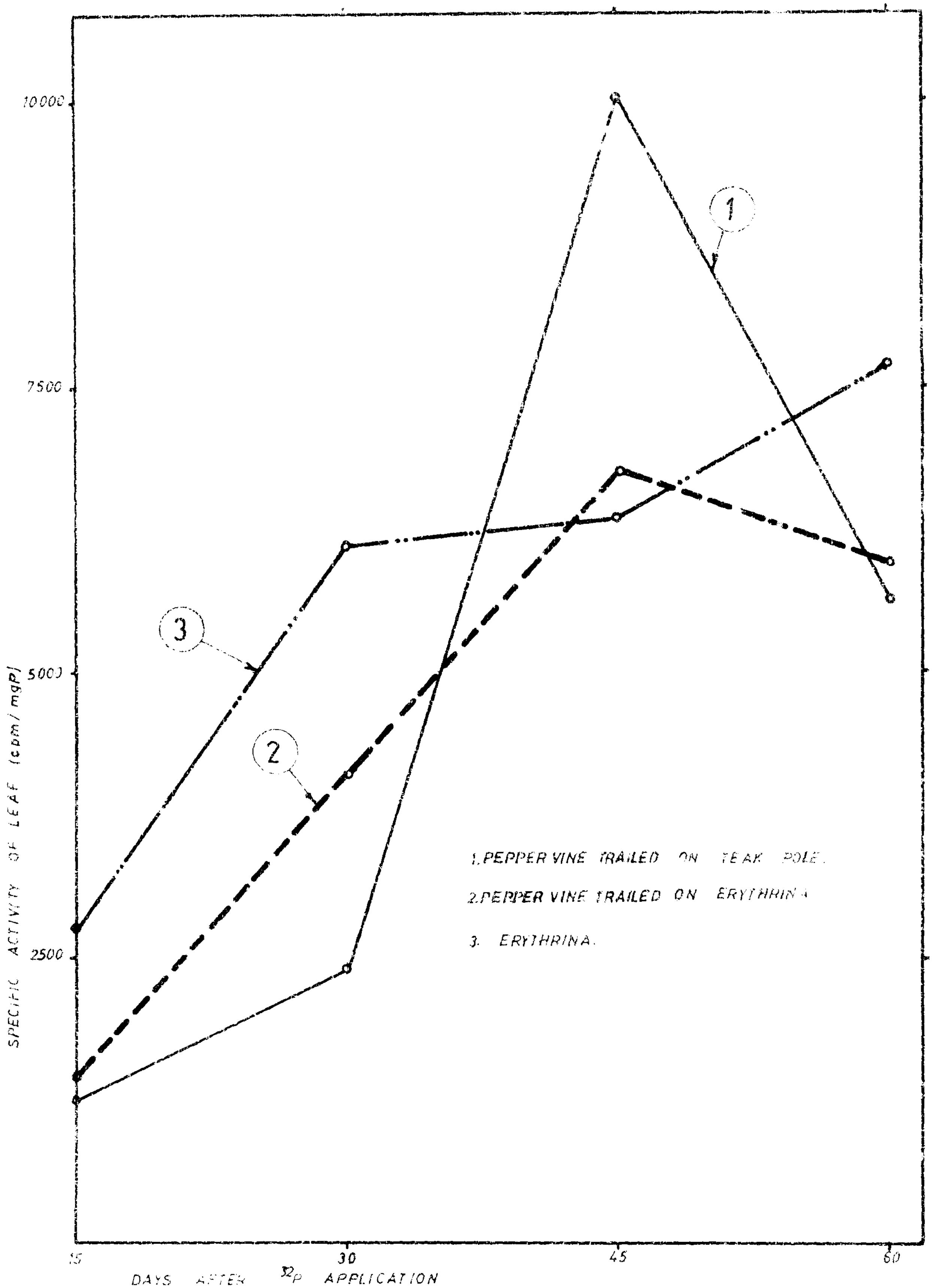


FIG. 7 MEAN SPECIFIC ACTIVITY OF LEAVES AT DIFFERENT INTERVALS AFTER ^{32}P APPLICATION

on dry matter basis was considerably more than that found for the pepper vine trailed on either teak pole or erythrina (Fig. 6). Generally speaking, radioactivity recovered in the vine on erythrina increased upto 45 days after application and declined thereafter. At 45 days, the pepper vine trailed on teak pole was found to contain a higher amount of ^{32}P than the vine trailed on erythrina. When the specific activities were compared, the pattern of ^{32}P uptake presented a different picture (Fig. 7). In this case, the pepper vine on teak pole had the highest specific activity compared to the vine trailed on erythrina or the erythrina standard. There was a gradual increase in the specific activity of the vine leaves upto 45 days which decreased thereafter irrespective of the type of standard on which they were trailed.

4.6. Absorption of ^{32}P by the vine and live standard in relation to method of application

The data presented in Tables 18 to 22 and Appendix VI indicated that the recovery of radioactivity in the leaf was not influenced by ^{32}P application in semicircle either facing the vine or opposite the vine, and depth of placement (Fig. 4). However in the case of plants trailed on erythrina, a significant decrease in the recovery of ^{32}P was observed when the radioactivity was applied in full circle as compared to semicircular application, at three sampling dates viz., 15, 45 and 75 days after application (Tables 23 to 27 and

Appendix VII). Differences in the absorption of ^{32}P from 20 to 40 cm soil depths were, however, not found to be significant. The data given in Tables 28 to 32 and Appendix VIII showed that absorption of soil-applied ^{32}P by erythrina was influenced neither by the depth of placement nor by the method of application.

When the radioactivity was expressed on dry matter basis, the absorption of ^{32}P was found to be the highest in erythrina standard followed by pepper on teak pole and the least by pepper trailed on erythrina (Figs. 8 to 10). This trend was observed irrespective of the method of application. Nevertheless, when specific activities were compared, the highest activity in the leaf was found in plants trailed on teak pole (Figs. 11 to 13), while there was not much difference in the specific activities between the vines trailed on erythrina and the erythrina plant itself. Eventhough it may be observed that there was a considerable decrease in the total radioactivity absorbed by the three plants when the application of ^{32}P was made in full circle compared to semicircle application, statistical significance was obtained only in case of pepper vines trailed on erythrina as already described above (Appendix VII).

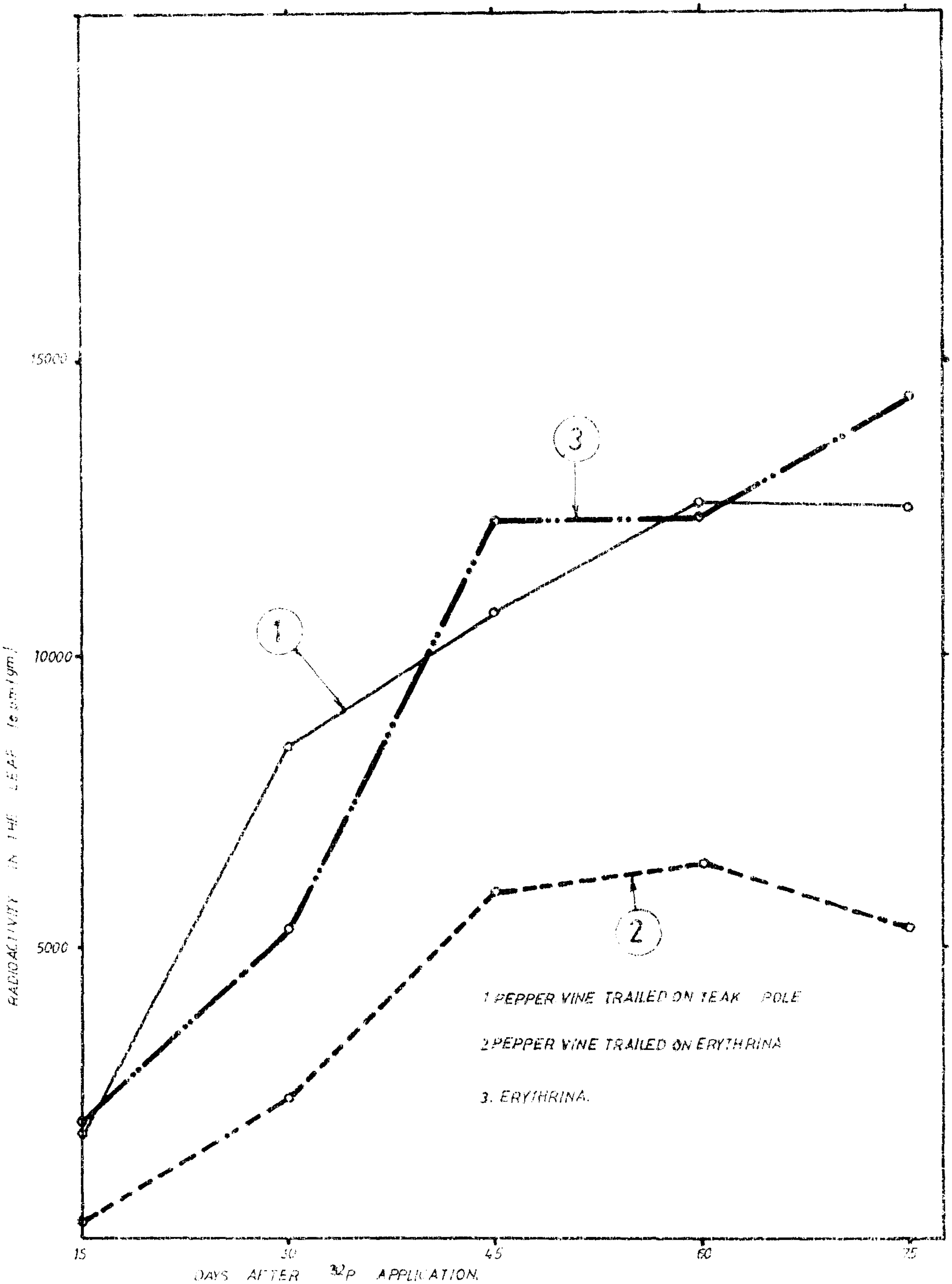


FIG.8 RECOVERY OF RADIOACTIVITY IN THE VINE AND ERYTHRINA LEAVES FOLLOWING SOIL APPLICATION OF ^{32}P IN SEMICIRCLE FACING THE VINE.

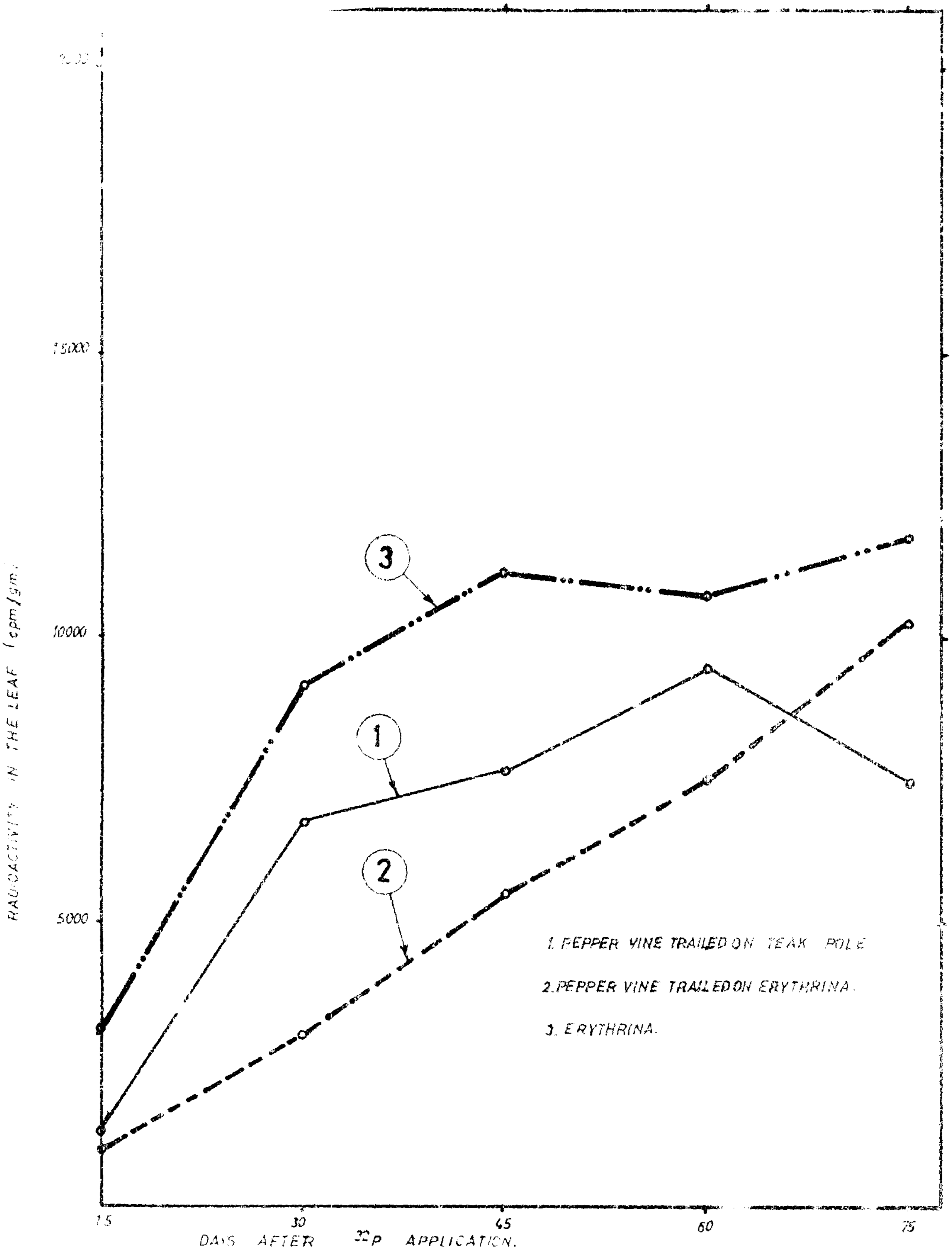


FIG. 9 RECOVERY OF RADIOACTIVITY IN THE VINE AND ERYTHRINA LEAVES FOLLOWING SOIL APPLICATION OF ^{32}P IN SEMICIRCLE OPPOSITE THE VINE.

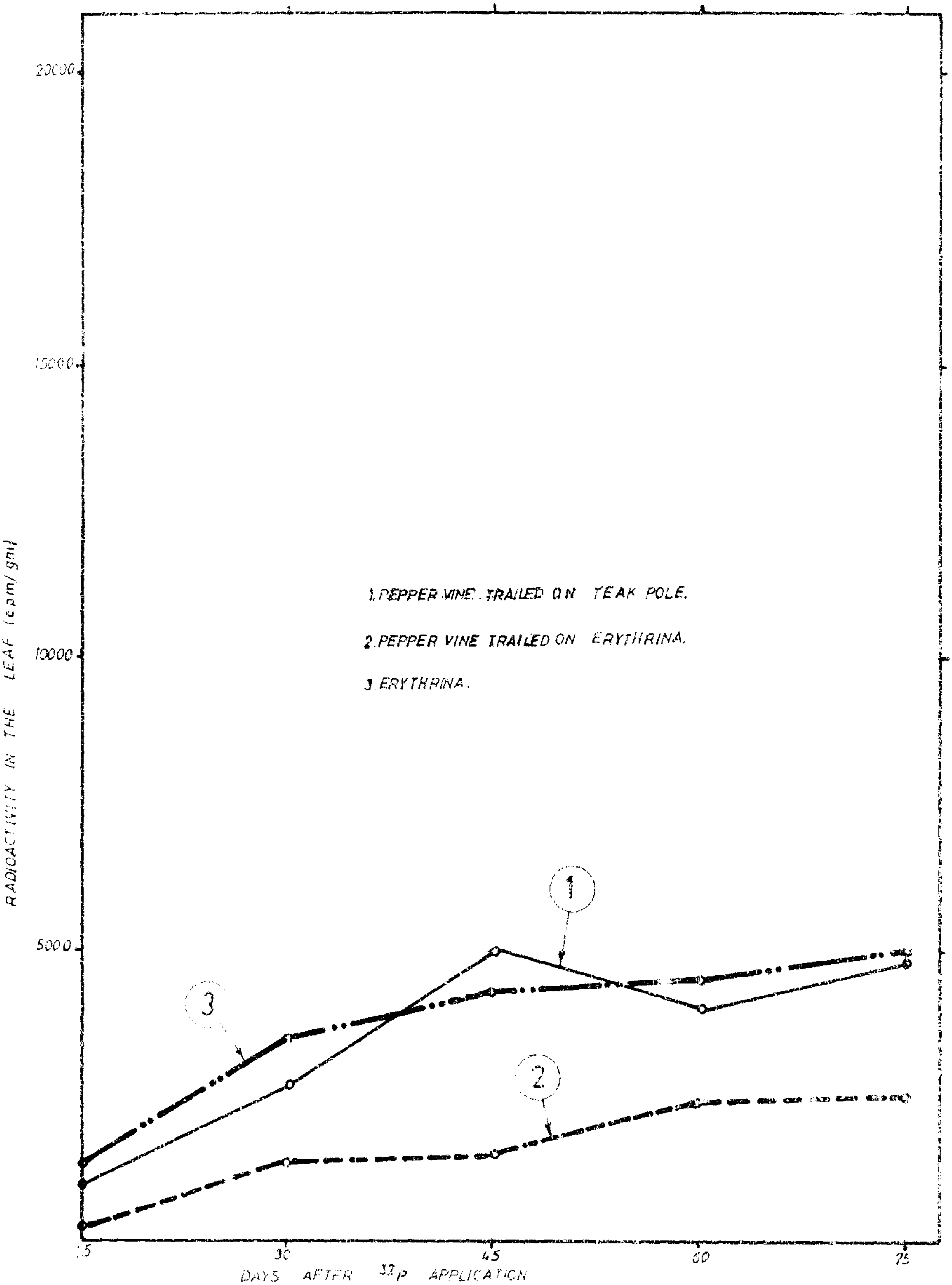


FIG. 10 RECOVERY OF RADIOACTIVITY IN THE VINE AND ERYTHRINA LEAVES FOLLOWING SOIL APPLICATION OF ^{32}P IN FULL CIRCLE.

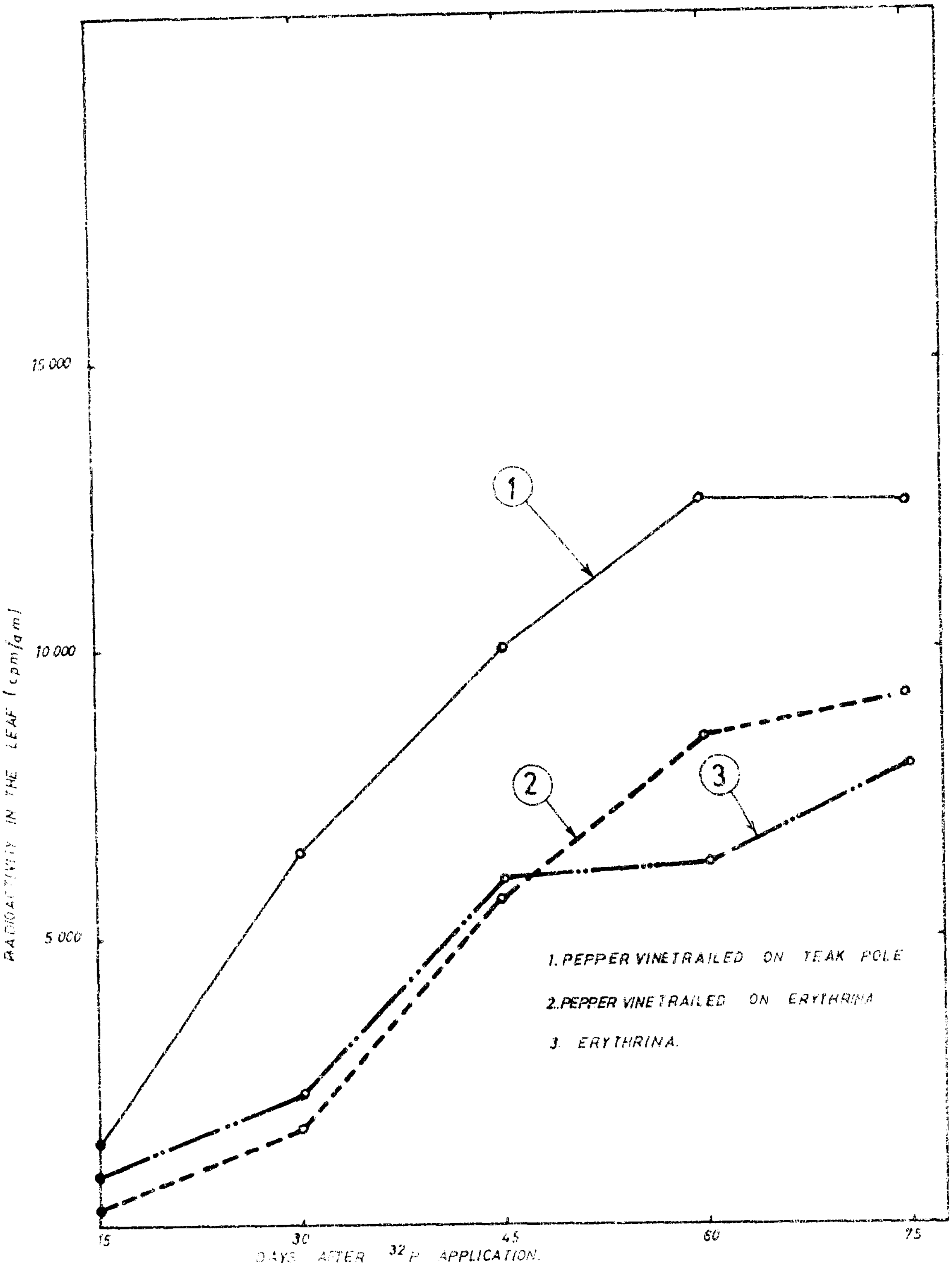


FIG. 11 SPECIFIC ACTIVITY OF VINE AND ERYTHRINA LEAVES FOLLOWING SOIL APPLICATION OF ^{32}P IN SEMICIRCLE FACING THE VINE.

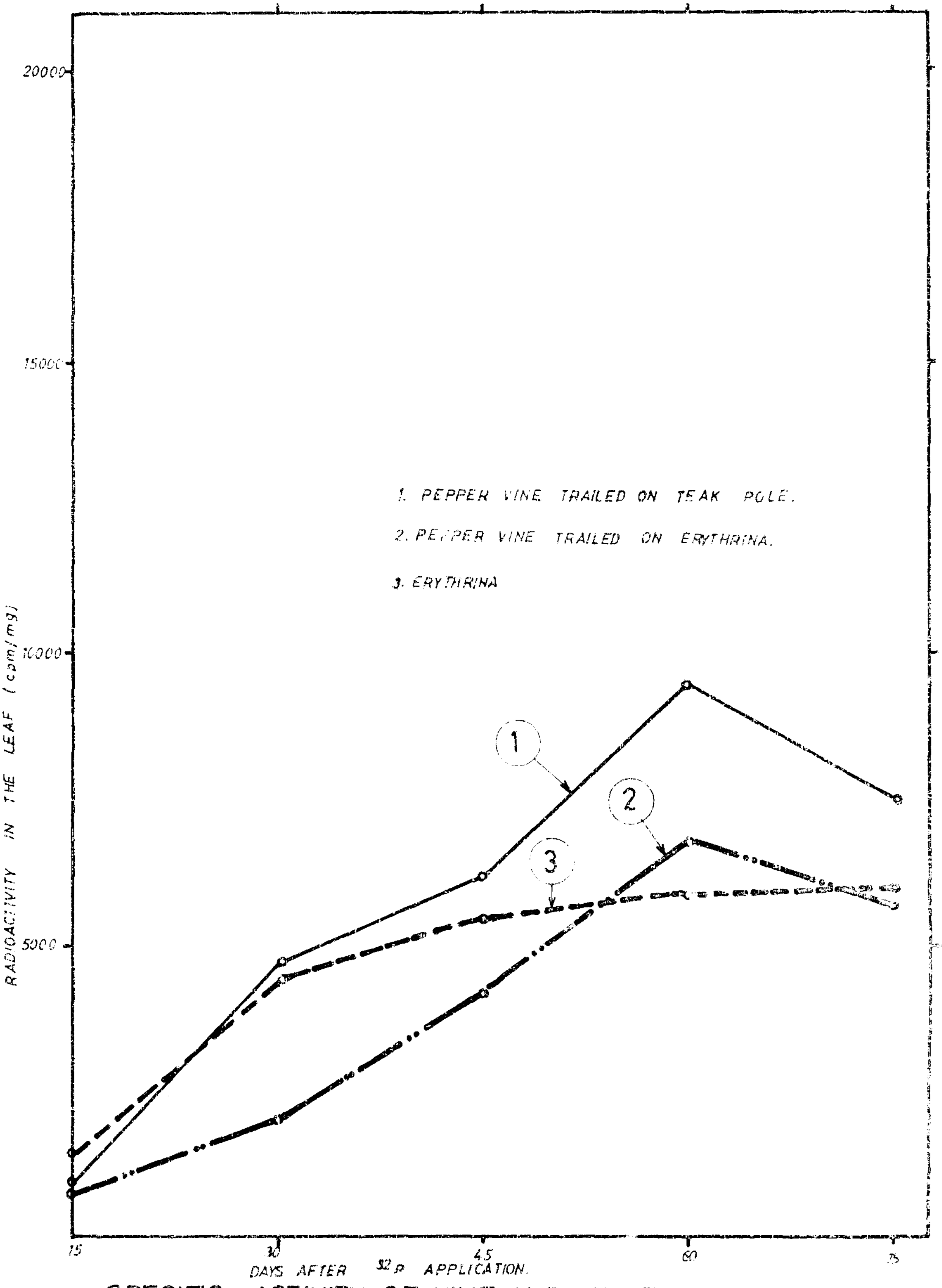


FIG. 12 SPECIFIC ACTIVITY OF VINE AND ERYTHRINA LEAVES FOLLOWING SOIL APPLICATION OF ^{32}P IN SEMICIRCLE OPPOSITE THE VINE.

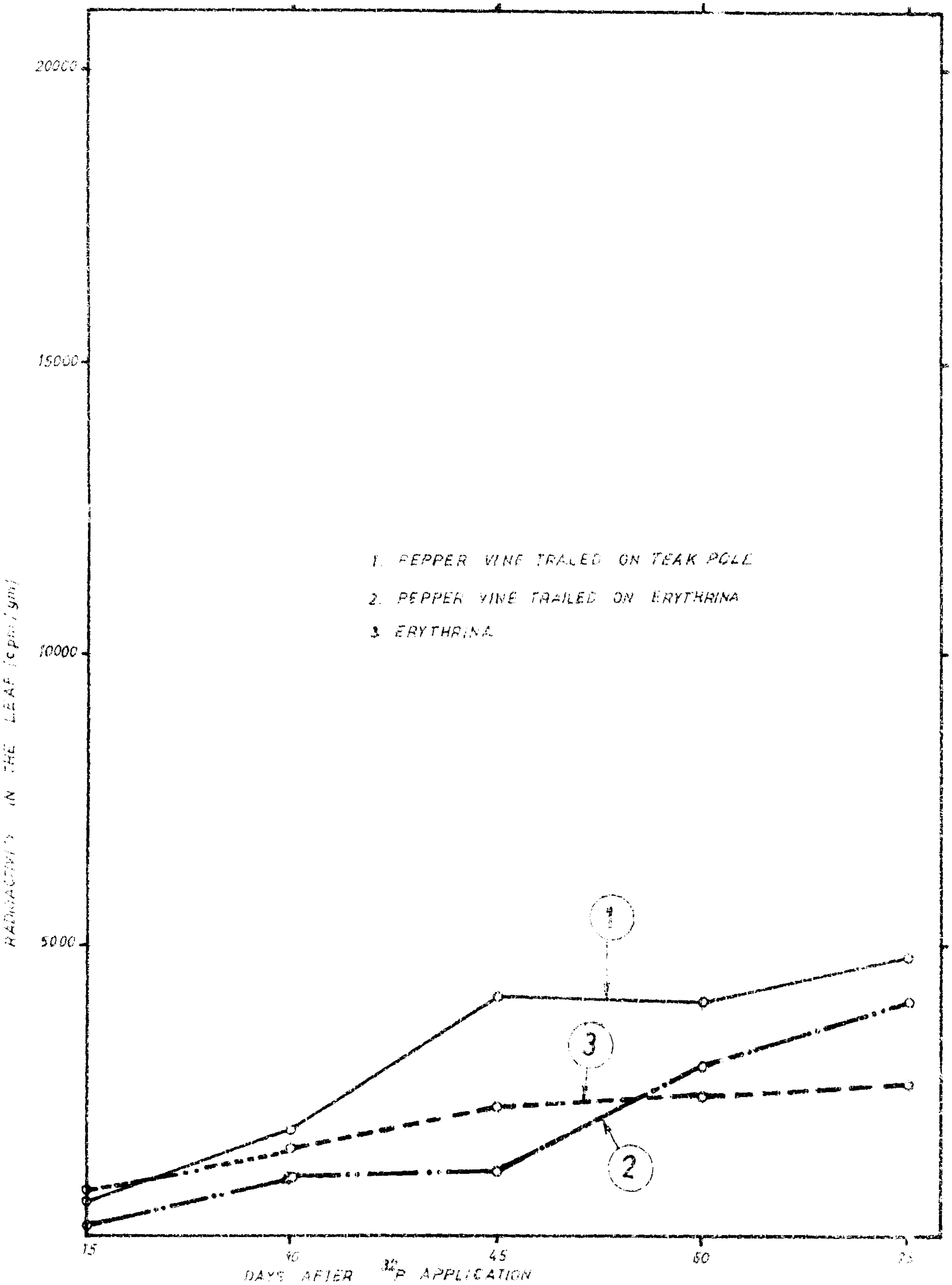


FIG: 13 SPECIFIC ACTIVITY OF VINE AND ERYTHRINA LEAVES FOLLOWING SOIL APPLICATION OF ^{32}P IN FULL CIRCLE.

Table 13. Absorption of ^{32}P by erythrina (cpm/g) from the soil basins of black pepper vine after 15 days of application (log-transformed values)

Depth (cm)	Lateral distances in relation to black pepper vine (cm)				
	15	30	60	120	Mean
10	3.500 (3162.1)	4.002 (10038.4)	2.792 (619.7)	1.960 (91.2)	3.063 (1157.2)
20	3.072 (1180.3)	3.835 (6835.6)	4.268 (18526.9)	1.119 (13.1)	3.073 (1183.9)
40	2.984 (963.4)	2.225 (167.8)	2.354 (225.8)	1.438 (27.4)	2.250 (177.9)
Mean	3.185 (1532.0)	3.354 (2258.3)	3.138 (1373.8)	1.506 (32.0)	

SEM ± for lateral distances : 0.318 SEM ± for depths : 0.276

$CD_{(0.05)}$ for comparison of :-

Lateral distance : 0.934

Depth : Not significant

Lateral distance x depth : Not significant

Parentheses denote retransformed values.

Table 14. Absorption of ^{32}P by erythrina (cpm/g) from the soil basins of black pepper vine after 30 days of application (log-transformed values)

Depth (cm)	Lateral distances in relation to black pepper vine (cm)				
	15	30	60	120	Mean
10	4.185 (15307.1)	4.187 (15385.4)	3.061 (1150.8)	3.301 (1999.6)	3.683 (4824.9)
20	3.755 (5689.4)	4.441 (27575.7)	4.533 (34111.8)	1.930 (85.1)	3.663 (4619.7)
40	3.983 (9619.6)	3.401 (2520.3)	3.051 (1123.5)	2.050 (112.3)	3.121 (1322.4)
Mean	3.974 (9426.9)	4.010 (10225.7)	3.548 (3533.2)	2.427 (267.3)	

SEM ± for lateral distances : 0.240 SEM ± for depths : 0.208

$CD_{(0.05)}$ for comparison of :-

Lateral distance : 0.703

Depth : Not significant

Lateral distance x depth : Not significant

Parentheses denote betransformed values.

Table 15. Absorption of ^{32}P by erythrina (cpm/g) from the soil basins of black pepper vine after 45 days of application (log-transformed values)

Depth (cm)	Lateral distances in relation to black pepper vine (cm)				
	15	30	60	120	Mean
10	4.261 (18254.8)	3.997 (9942.4)	3.387 (2439.7)	7.739 (5478.2)	3.846 (7017.9)
20	4.344 (22061.5)	4.493 (31126.4)	4.794 (62299.1)	2.299 (199.1)	3.983 (9607.8)
40	4.062 (11525.7)	3.463 (2903.2)	3.313 (2057.7)	2.239 (173.3)	3.269 (1858.6)
Mean	4.222 (16681.2)	3.984 (9649.3)	3.832 (6787.8)	2.759 (573.9)	

SEM ± for lateral distances : 0.213 SEM ± for depths : 0.185

$CD_{(0.05)}$ for comparison of :-

Lateral distances : 0.626

Depth : 0.542

Lateral distance x depth : 1.084

Parentheses denote retransformed values.

Table 16. Absorption of ^{32}P by erythrina (cpm/g) from the soil basins of black pepper vine after 60 days of application (log-transformed values)

Depth (cm)	Lateral distances in relation to black pepper vine (cm)				
	15	30	60	120	Mean
10	4.005 (10113.4)	3.865 (7328.4)	3.269 (1859.5)	3.595 (3939.8)	3.684 (4827.2)
20	4.160 (14443.4)	4.568 (36949.7)	4.687 (48671.4)	2.093 (123.9)	3.877 (7532.5)
40	4.121 (13217.0)	3.419 (2626.1)	2.822 (663.9)	2.441 (276.0)	3.201 (1588.1)
Mean	4.095 (12451.8)	3.951 (8925.7)	3.593 (3916.8)	2.710 (512.7)	

SEM ± for lateral distances: 0.188 SEM ± for depths : 0.163

CD $_{(0.05)}$ for comparison of :-

Lateral distances : 0.551

Depth : 0.477

Lateral distance x Depth : 0.954

Parentheses denote retransformed values.

Table 17. Percentage root activity of the support plant, erythrina

Days after ^{32}P application	Lateral distances in relation to black pepper vine (cm)				Depth (cm)		
	15	30	60	120	10	20	40
15	17,2	53.5	29.2	0.26	30.4	63.0	6.6
30	28.5	45.7	25.9	2.1	23.1	65.0	11.9
45	24.0	37.3	36.2	2.4	23.3	64.4	12.2
60	25.9	43.5	28.4	2.3	17.1	68.5	14.4

Table 18. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on teak pole as influenced by method of application (log-transformed data for the 15th day after application)

Depth (cm)	Methods of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	3.063 (1154.9)	2.748 (559.3)	2.897 (789.7)	2.903 (799.0)
40	3.107 (1278.6)	2.657 (454.4)	2.738 (547.2)	2.834 (682.5)
Mean	3.085 (1215.2)	2.703 (504.1)	2.818 (657.4)	

SEM ± for method of application : 0.245 SEM ± for depth: 0.200

CD(0.05) for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x Depth : Not significant

Parentheses denote retransformed values.

Table 19. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on teak pole as influenced by method of application (log-transformed data for the 30th day after application)

Depth (cm)	Methods of application			
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	Mean
20	3.479 (3016.3)	3.533 (3410.0)	3.410 (2570.0)	3.474 (2978.9)
40	3.479 (3013.9)	3.373 (2360.8)	3.264 (1838.5)	3.372 (2356.2)
Mean	3.479 (3015.1)	3.453 (2837.3)	3.337 (2173.7)	

SEM ± for method of application : 0.220 SEM ± for depth : 0.179

CD (0.05) for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 20. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on teak pole as influenced by method of application (log-transformed data for the 45th day after application)

Depth (cm)	Method of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	3.602 (4001.9)	3.371 (2347.3)	3.587 (3859.4)	3.520 (3309.7)
40	3.771 (5905.4)	3.605 (4025.5)	3.626 (4223.5)	3.667 (4647.8)
Mean	3.687 (4861.4)	3.488 (3073.9)	3.606 (4037.4)	

SEM ± for method of application : 0.226   SEM ± for depths : 0.184

$CD_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 21. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on teak pole as influenced by method of application (log-transformed data for the 60th day after application)

Depth (cm)	Methods of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	3.820 (6602.4)	3.590 (3887.2)	3.627 (4240.6)	3.679 (4774.5)
40	3.821 (6628.6)	4.040 (10962.9)	3.453 (2836.4)	3.771 (5907.1)
Mean	3.821 (6615.5).	3.815 (6528.1)	3.540 (3468.2)	

SEM ± for method of application : 0.197 SEM ± for depth : 0.161

$CD_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 22. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on teak pole as influenced by method of application (log-transformed data for the 75th day after application)

Depth (cm)	Method of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	3.694 (4346.1)	3.710 (5126.6)	3.561 (3642.9)	3.655 (4521.0)
40	3.842 (6956.3)	3.539 (3460.5)	3.704 (5054.6)	3.695 (4955.3)
Mean	3.768 (5865.7)	3.625 (4212.8)	3.633 (4291.1)	

SEM ± for method of application: 0.183 SEM ± for depth : 0.149

$CD_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransferred values.

Table 23. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on erythrina as influenced by method of application (log-transformed data for the 15th day after application)

Depth (cm)	Methods of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	2.704 (506.1)	3.071 (1177.1)	2.018 (104.3)	2.598 (396.1)
40	2.176 (150.1)	2.503 (318.3)	1.799 (62.9)	2.159 (144.3)
Mean	2.440 (275.6)	2.787 (612.1)	1.908 (80.9)	

SEM ± for method of application: 0.208 SEM ± for depth : 0.170

$CD_{(0.05)}$ for comparison of :-

Method of application : 0.655

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 24. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on erythrina as influenced by method of application (log-transformed data for the 30th day after application)

Depth (cm)	Methods of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	3.361 (2295.6)	3.508 (3222.3)	3.289 (1947.4)	3.386 (2433.1)
40	3.132 (1355.5)	3.193 (1557.8)	2.344 (220.7)	2.889 (775.3)
Mean	3.246 (1763.9)	3.350 (2240.4)	2.817 (655.6)	

SEM ± for method of applications 0.172 SEM ± for depth : 0.141

$CD_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : 0.443

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 25. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on erythrina as influenced by method of application (log-transformed data for the 45th day after application)

Depth (cm)	Method of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	3.720 (5242.3)	3.853 (7131.1)	2.896 (787.0)	3.490 (3087.2)
40	3.496 (3132.6)	3.487 (3067.9)	2.817 (655.8)	3.267 (1847.1)
Mean	3.608 (4052.4)	3.670 (4677.4)	2.856 (718.4)	

SEM ± for method of application : 0.209 SEM ± for depth : 0.171

$CD_{(0.05)}$ for comparison of : -

Method of application : 0.659

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 26. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on erythrina as influenced by method of application (log-transformed data for the 60th day after application)

Depth (cm)	Method of application			
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	Mean
20	3.715 (5191.5)	3.949 (8894.1)	3.508 (3219.9)	3.724 (5297.6)
40	3.498 (3147.5)	3.604 (4018.8)	3.017 (1038.8)	3.373 (2359.8)
Mean	3.607 (4042.3)	3.777 (5978.6)	3.262 (1828.9)	

SEM ± for method of application : 0.139 SEM ± for depth : 0.114

CD$_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 27. Recovery of soil-applied ^{32}P in the leaves (cpm/g) of pepper vine trailed on erythrina as influenced by method of application (log-transformed data for the 75th day after application)

Depth (cm)	Methods of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	3.432 (2704.5)	4.047 (11132.4)	3.215 (1638.7)	3.564 (3667.7)
40	3.676 (4744.5)	3.842 (6957.8)	3.118 (1310.9)	3.545 (3510.8)
Mean	3.554 (3582.1)	3.945 (8800.9)	3.166 (1465.6)	

SEM $\pm$ for method of application : 0.173 SEM $\pm$ for depth : 0.141

$CD_{(0.05)}$ for comparison of :-

Method of application : 0.545

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 28. Absorption of ^{32}P by erythrina (cpm/g) from soil basins of the vine as influenced by method of application (log-transformed data for the 15th day after application)

Depth (cm)	Methods of application: Semicircle facing the vine	Semicircle opposite the vine	Full circle	Mean
20	3.334 (2156.5)	3.059 (1144.3)	2.452 (283.1)	2.948 (887.3)
40	2.171 (148.3)	3.345 (2212.8)	2.956 (904.3)	2.824 (667.0)
Mean	2.752 (565.5)	3.202 (1591.3)	2.704 (505.9)	

SEM ± for method of application : 0.316 SEM ± for depth : 0.258

$CD_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 29. Absorption of ^{32}P by erythrina (cpm/g) from soil basins of the vine as influenced by method of application

(log-transformed data for the 30th day after application)

Depth (cm)	Method of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	3.630 (4269.9)	3.825 (6684.1)	3.295 (1972.5)	3.583 (3832.6)
40	2.766 (583.2)	3.863 (7300.6)	3.379 (2393.4)	3.336 (2167.9)
Mean	3.198 (1577.9)	3.844 (6985.5)	3.337 (2172.8)	

SEM $\pm$ for method of application: 0.226   SEM $\pm$ for depth : 0.185

$CD_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 30. Absorption of ^{32}P by erythrina (cpm/g) from soil basins of the vine as influenced by method of application (log-transformed data for the 45th day after application)

Depth (cm)	Methods of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	4.087 (12204.5)	3.834 (6823.5)	3.329 (2132.9)	3.750 (5621.2)
40	2.948 (887.9)	3.890 (7755.9)	3.676 (4741.1)	3.505 (3196.1)
Mean	3.517 (3291.8)	3.862 (7274.8)	3.502 (3179.9)	

SEM ± for method of application : 0.292 SEM ± for depth : 0.238

$CD_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

Table 31. Absorption of ^{32}P by erythrina (cpm/g) from soil basins of the vine as influenced by method of application (log-transformed data for the 60th day after application)

Depth (cm)	Method of application			Mean
	Semicircle facing the vine	Semicircle opposite the vine	Full circle	
20	4.053 (11310.8)	3.809 (6437.9)	3.589 (3878.2)	3.817 (6560.8)
40	3.548 (3529.9)	3 .855 (7157.1)	3.652 (4486.5)	3.685 (4839.5)
Mean	3.801 (6318.7)	3.832 (6788.0)	3.620 (4171.3)	

SEM ± for method of application : 0.248   SEM ± for depth : 0.202

CD$_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denot retransformed values.

Table 32. Absorption of ^{32}P by erythrina (cpm/g) from soil basins of the vine as influenced by method of application (log-transformed data for the 75th day after application)

Depth (cm)	Method of application: Semicircle facing the vine	Semicircle opposite the vine	Full circle	Mean
20	4.265 (18402.3)	4.117 (13097.7)	3.595 (3920.7)	3.992 (9813.2)
40	3.521 (3317.3)	3.697 (4978.8)	3.552 (3568.5)	3.590 (3891.6)
Mean	3.893 (7813.2)	3.907 (8075.3)	3.573 (3740.3)	

SEM ± for method of application: 0.252 SEM ± for depth : 0.206

$CD_{(0.05)}$ for comparison of :-

Method of application : Not significant

Depth : Not significant

Method of application x depth : Not significant

Parentheses denote retransformed values.

4.7. **Absorbing power of climbing roots**

The radioassay of the samples collected from the pepper cuttings which were allowed to feed through climbing roots from ^{32}P solution did not reveal a significant uptake of ^{32}P through climbing roots. The count rates observed in leaf samples from these vine cuttings was less than 10 cpm/g during 1 h absorption period.

4.8. **Relative uptake of applied ^{32}P by the vine trailed on erythrina**

The relative uptake of ^{32}P based on the equation given under Section 3.8 was worked out to assess the root competition between the pepper vine and the live support, erythrina (Table 33). The data revealed that when ^{32}P application was made in the semicircle facing the vine, (Fig.4) there was a gradual increase in the specific activity ratios upto 45 days beyond which the difference was only marginal. At the end of 75 days of ^{32}P absorption by the vine, the specific activity ratio obtained was 0.74. In the case of application of ^{32}P in semicircle opposite the vine, the initial specific activity ratio at 15 days was 0.92 which declined to 0.43 at 30 days and then increased to 0.67 at 45 days. The variation in specific activity ratio beyond 45 days of ^{32}P absorption was little. At 75 days, the ratio was 0.77. When the application of ^{32}P was done in full circle, the specific activity ratio increased from 0.22 at 15 days to 0.82 at 75 days.

Table 33. Specific activity ratios of black pepper leaves*

Methods of application	Sampling interval (days)				
	15	30	45	60	75
Semicircle facing the vine	0.22	0.26	0.57	0.68	0.74
Semicircle opposite the vine	0.92	0.43	0.67	0.71	0.77
Full circle	0.22	0.55	0.27	0.71	0.82

* Computed by dividing the mean specific activity of leaf of the vine on erythrina by that on teak pole.

4.9. Relationships among ^{32}P contents of various plant parts

A comparison of the relative concentration of ^{32}P in leaf, berry and rachis (Table 34) indicated that the accumulation of absorbed ^{32}P was more in leaf as compared to spike. On dry matter basis, berry contained more ^{32}P than its rachis. However when specific activities were compared, a reverse trend was observed. The count rates (cpm/g dry matter) observed in berry, leaf and rachis were highly correlated (Table 34). The correlation coefficients were much higher when the specific activities of the respective parts were considered. An 'r' value of 0.83** was obtained between the specific activities of berry and leaf while the corresponding correlation between rachis and leaf was 0.79**.

4.10. Nutrient removal by the pepper vine and live standard

Biomass produced (roots excluded) by bearing pepper vine and the partitioning of total dry matter into various parts are given in Table 35. The values were the means for three plants with an average yield of 4.65 kg green pepper. The dry matter content of the whole plant was 6.16 kg of which 60 per cent was accounted for by the stem. The spike (berry and rachis) contributed about 24 per cent while, 16 per cent of the total dry matter was due to leaf production.

The distribution of nutrients in various parts of the plant as well as the total nutrients removed by the whole plant are given in Table 36. Berry was found to be the major accumulator of N and P in terms of nutrient content per g dry matter (2.66 and 0.15 per cent respectively). However, when the whole plant was considered, about 30 per cent of the total N and P removed by the plant were recovered in the stem. Potassium absorbed by the plant was concentrated mainly in the rachis (4.2 per cent) followed by leaf (2.9 per cent) while Ca, S and Mn were accumulated more in the leaf (2.25 per cent, 0.11 per cent and 711 ppm respectively). In the case of Mg, stem was found to be the major accumulator. Calcium content of rachis was the highest among the four plant parts studied. Zinc was distributed almost evenly in the stem and rachis but its concentration was comparatively less in leaf and berry. As in the case of N and P, major portion of absorbed K, Ca, Mg, S, Fe, Zn and Cu were recovered in the stem when the total dry matter production was considered.

Dry matter production of the support plant, erythrina, and its nutrient removal are presented in Tables 37 and 38 respectively. About 96 per cent of the total dry matter produced (18.5 kg) was accounted for by the stem while only 4 per cent was due to leaf production. The leaf was found to contain the highest concentration of all major and micronutrients in erythrina. Despite this, the total quantities of the various nutrients recovered in the stem were much higher than in other plant parts.

Table 34. Correlations (r) among ^{32}P contents of plant parts

Plant part	cpm/g dry matter	cpm/mg P
Berry and Leaf	0.53**	0.83**
Rachis and Leaf	0.73**	0.79**
Berry and Rachis	0.71**	0.92**

**Significant at 1% level

df = 16

Table 35. Partitioning of dry matter in black pepper vine trailed on erythrina

Plant part	Dry matter (Kg)	Percentage of the total
Rachis	0.188	3.04
Berry	1.284	20.85
Stem	3.683	59.74
Leaf	1.005	16.32
Total	6.160	100.00

Table 36. Nutrient removal by black pepper vine trailed on erythrina

Nutrient	Plant part				Total
	Berry	Rachis	Leaf	Stem	
-g-					
N	34.60 (2.66)	3.97 (2.10)	23.07 (1.61)	60.69 (1.08)	122.33
P	2.07 (0.15)	0.13 (0.07)	1.32 (0.12)	3.40 (0.08)	6.92
K	28.50 (6.10)	8.20 (4.20)	30.30 (2.90	90.40 (2.20)	157.40
Ca	12.85 (0.88)	2.04 (1.10)	22.26 (2.25)	45.88 (1.30)	83.03
Mg	12.48 (0.52)	1.26 (4.43)	10.03 (0.64)	33.41 (1.27)	57.18
S	1.24 (0.09)	0.13 (0.06)	1.20 (0.11)	1.97 (0.05)	4.54
-mg-					
Fe	123.50 (96.20)	95.01 (506.90)	280.52 (279.10)	692.84 (188.10)	1191.87
Mn	137.00 (106.70)	27.98 (149.30)	714.62 (711.00)	605.18 (164.30)	1484.78
Zn	22.08 (17.20)	6.12 (32.70)	22.40 (22.30)	134.40 (36.50)	185.00
Cu	35.80 (27.90)	11.34 (60.50)	37.28 (37.10)	113.40 (30.80)	197.82

Note: Values are means of three plants.

Parentheses denote nutrient concentrations expressed as percentage dry matter for major nutrients and as ppm for micronutrients.

Table 37. Partitioning of dry matter in the support plant, erythrina

Plant part	Dry matter (Kg)	Percentage of the total
Leaf	0.476	2.57
Petiole	0.191	1.04
Stem	17.828	96.39
Total	18.495	100.00

Table 38. Nutrient removal by the support plant, erythrina

Nutrient	Plant part: Leaf	Petiole	Stem	Total
-g-				
N	21.40 (4.15)	4.35 (2.30)	354.50 (2.00)	380.25
P	0.82 (0.17)	0.12 (0.07)	10.32 (0.05)	11.26
K	4.54 (1.11)	1.98 (1.07)	150.56 (0.83)	157.08
Ca	14.20 (2.80)	5.90 (3.10)	290.20 (1.60)	310.30
Mg	17.47 (1.59)	2.72 (0.59)	194.93 (0.53)	215.12
S	0.726 (0.16)	0.07 (0.06)	5.35 (0.03)	6.143
-mg-				
Fe	118.25 (248.30)	13.15 (68.80)	6625.10 (371.60)	6756.50
Mn	649.70 (1364.30)	359.13 (1878.70)	2816.90 (158.00)	3825.73
Zn	10.23 (21.50)	2.73 (14.30)	240.70 (13.50)	253.66
Cu	12.57 (26.40)	1.62 (8.50)	174.70 (9.80)	188.89

Note: Values are means of three plants.

Parentheses denote nutrient concentrations expressed as percentage dry matter for major nutrients and as ppm for micronutrients.

4.11. Biometric observation

Significant differences were seen in plant height, girth and yield of black pepper between the vines trailed on dead and live standards. The mean values for these three characters were higher for the vine trailed on dead wood support than that trailed on live standard (Table 39 and Plate 2).

Table 39. Comparison of vegetative characters and yield between the vine trailed on teak pole and on erythrina

Character	Pepper on teak pole	Pepper on erythrina	t (0.05)
Height (cm)	4.44 (18.40)	2.90 (29.20)	Sig.
Girth (cm)	1.54 (27.90)	1.33 (34.30)	Sig.
Yield of green pepper	5.33 (63.20)	1.96 (110.00)	Sig.
Phosphorus content } %	0.1536 (27.20)	0.1388 (25.00)	NS.

Note: Values are means of 36 plants

Parentheses denote Coefficient of variation (%)

Sig. Significant

NS. Not significant

Plate - II

Black pepper vines (var. Panniyur-1) trailed on dead (teak pole) and live (*Erythrina indica*) standards.

Plate - II

DISCUSSION

DISCUSSION

5.1. Soil injection of ^{32}P solution

In studies of root activity patterns of tree crops, the requirement of radioactivity is enormous primarily due to the greater dilution of the absorbed and translocated label in such crops. In order to get countable radioactivity in the plant part sampled (generally, leaf), a higher amount of applied radioactivity is required. The results of the studies on root activity patterns of tree crops conducted by the IAEA (IAEA, 1975) showed that application of 5 mCi (1.85×10^8 Bq) of ^{32}P/plant was necessary for obtaining countable radioactivity in plant samples. In the present study, however, 2.5 mCi/vine was found to yield countable radioactivity in leaf samples. Depending on the number of treatments involved in an experiment, the total radioactivity required could be very large to the extent of causing health hazard to the handling personnel. To overcome this, the IAEA recommended application of ^{32}P in sealed glass vials by dropping them (one vial/hole) into the desired soil depth and crushing the vial with a metallic 'crusher' to release the radioactivity into the soil. As the facilities for preparing sealed glass vials containing radioactive solution are not generally available in an ordinary radiotracer laboratory, a procedure for soil injection of radioactivity using an applicator (Fig.2 and Plate 1) was developed. A detailed account of the device and the method of ^{32}P application were presented in Sections 3.2.4. and 4.1. It was observed that the radiation dose rate at the outer surface of the plastic bucket was less than 10 mR/h for 40 mCi ^{32}P in 512 ml aqueous solution of 1000 ppm carrier P. Obviously, the shielding of the radiation by the quantity of water, the glass bottle, paraffin wax and the plastic bucket was effective. These shielding materials were chosen because they do not produce Bremsstrahlung, non-characteristic X-rays produced when high energy beta particles such as that emitted by ^{32}P (E_{max} = 1.71 MeV) strike a heavy metal. The initial surface dose rate (10 mR/h) was found to decrease gradually with decrease in the volume of the solution contained in the bottle as the soil injection progresses. Normally, a single operator can complete the soil injection of ^{32}P solution into 120 soil holes of 15 plants with 8 soil holes/plant provided, all the preparations in the field including installation of access tubes were made in advance. The reproducibility of the dispensed volume of the solution was also satisfactory as evidenced from the very low coefficient of variation of the order of less than 5 per cent observed for six successive deliveries in a preliminary standardisation work. Washing the access tube with a jet of distilled water (about 5 ml) was suggested to drain off any radioactivity sticking on the inside of the access tube into the soil depth as far as possible. Moreover, as the applications were made to 8 or 16 soil holes/plant, the total radioactivity received by a plant may be reasonably constant.

Extension of the delivery tube of the 'Lumac Dispensette' to more than 50 cm was found to cause problems during operation. It may be noted that the delivery tube will remain filled with the solution between successive operations. If the delivery tube is longer than 50 cm, the quantity of the solution remaining in the delivery tube was found to cause a downward pull to make the outlet valve of the dispenser open resulting in the dripping of the solution even after the downward stroke of the plunger had been completed. For this reason, a delivery tube of less than 50 cm length is recommended. In the present study, a delivery tube of 30 cm length was invariably used. Inclusion of the carrier (1000 ppm P) in the solution is important to reduce the fixation of ^{32}P by the soil especially of high phosphate fixing power such as laterite through isotopic exchange. It may be expected that the fixation of ^{32}P atoms will be negligible compared to that of ^{31}P atoms (carrier) due to the predominance of ^{31}P atoms over ^{32}P atoms in the solution (IAEA, 1975). Therefore, the soil availability of the applied radiolabel will be little affected.

5.2. Leaf sampling technique for ^{32}P assay

The soil injection technique for studying the root activity patterns of plants was first introduced by Hall *et al.* (1953). Consequent on this, several reports have appeared in the literature on the root activity patterns of especially short duration field crops such as grasses (Lipps *et al.*, 1957), sorghum (Mc Clure and Harvey, 1962), tomatoes (Dejong and Otinkrang, 1969) etc. In these crops the determination of root activity can be made based on the uptake of the radiolabel by the whole plant. However, in perennial tree crops, this method of assessing root activity is not feasible owing to the very bulk of the plant itself. A more convenient method suggested by the IAEA (IAEA 1975) involves comparison of radioactivity recovered in a plant part generally, leaf following soil injection of a suitable radioisotope into various soil zones. The reliability of this approach has been tested in many perennial tree crops such as oil palm, coconut, cocoa and citrus. The adoption of this technique in the study of active root distribution in black pepper necessitates prior standardisation of the plant part for sampling and subsequent radioassay, as no work has been conducted so far in this crop on these aspects.

The results of preliminary studies conducted for standardising leaf sampling procedure for ^{32}P assay (Table 2) revealed that the differences in the radioactivity content of the leaves sampled either from various canopy positions or from different sides of the plant (canopy sides facing the applied area, opposite side of the applied area and from all around the plant) were not statistically significant. This would mean that the uptake and distfibution of ^{32}P was fairly rapid throughout the canopy. In fact, the applied radiolabel was detected in the leaf as early as 5 min after its application in soil (Fig.5). In many crops, however, this is not the case. For example, studies conducted with citrus in Taiwan showed higher ^{32}P content in the leaves of lower part of the canopy than in the leaves of upper part of the canopy (IAEA, 1975). Besides, in certain crops, leaf type x root position interaction was found to be significant indicating specific pathways during transport of the absorbed ^{32}P from root to top. The leaf type here means the leaves sampled from canopy sides facing the applied area, opposite side of the applied area and from all around the plant. Plants such as apple and citrus were found to have such a type of interaction while in cocoa and and citrus, this phenomenon was absent (IAEA, 1975). Eventhough it is difficult to ascertain the exact position of the leaf on the vine in relation to ^{32}P treated/opposite soil area because of the very climbing nature of the plant around the support, a test was, nevertheless, made in the present study to examine the presence of such an interaction. The radioactivity recovered in the leaf samples collected from canopy sides facing the applied area and opposite side of the applied area were practically the same and the variations in count rates were statistically not significant (Appendices 1 and 2) indicating thereby the translocation of ^{32}P was uniform and not influenced by the position of the leaf in relation to ^{32}P applied soil area. Similarly, ^{32}P content of the leaves collected from all around the plant was also not at variance. From these results, it may be concluded that leaf samples collected from any side of the vine and from any height of the canopy will be suitable for radioassay. However, sampling of the leaves from lower two-third portion of the canopy is recommended here for convenience and this has been the procedure followed in all the subsequent experiments reported herein. The results also indicate that the method of leaf sampling adopted for nutrient analysis (de Waard, 1969) is equally applicable for ^{32}P assay in black pepper.

5.3. Root activity pattern of black pepper

The active roots of black pepper vine trailed on teak pole (dead support) were found to reside mostly within 30 cm soil area (Table 7). Over 90 per cent of the absorbing roots are found in this region. Initially, absorption from surface layers upto 20 cm accounted for a significant portion of the total radioactivity recovered in the leaf. However, with time there was a perceptible decrease in the absorption of ^{32}P from surface soil layers with a concomitant increase in the absorption from lower layers (40 cm). Such a trend could be expected with an increase in moisture content in deeper soil layers during the later half of the experiment. The soil moisture data collected in December coinciding with the last sampling date (Table 40), however, did not indicate variations in the soil moisture with depth. It may be pointed out that the soil at the experimental site is a gravelly laterite and therefore, the determination of soil moisture by gravimetric method may not yield reliable results. For this reason, the rainfall data for the experimental period (Table 41) may be considered a better index of moisture availability in the soil. It was seen that the rainfall during the experimental period (from 4th October to 5th December) decreased from 149.8 in the month of October to 60.2 mm in the month of November. Evidently, the availability of moisture in the soil would be more during the initial stages of the experiment than during the later periods. Consequently, the variation in the soil moisture content of the surface and lower layers may be expected to be marginal. Hence, the absorption pattern of radioactivity from various soil zones during the initial period of the

Table 40. Soil moisture conent (%) in the vine basins at the time of harvest

Lateral distance (cm)	Depth (cm)	Pepper trailed on teak pole	Pepper trailed on erythrina
15	10	7.2	7.1
	20	7.0	6.8
	40	8.5	7.5
30	10	6.7	7.0
	20	7.6	5.8
	40	7.6	6.4
60	10	5.9	6.0
	20	5.5	5.5
	40	6.1	6.0
120	10	5.7	6.6
	20	4.8	5.5
	40	5.8	6.1

Note: Values are means of three replicates.

Table 41. Amount of rainfall (mm) received during the experimental period

Month	1983	1984
June	387.2	853.1
July	580.6	730.4
August	754.7	260.2
September	494.6	158.6
October	149.8	323.7
November	60.2	7.8
December	24.4	16.4

Table 40. Soil moisture conent (%) in the vine basins at the time of harvest

Lateral distance (cm)	Depth (cm)	Pepper trailed on teak pole	Pepper trailed on erythrina
15	10	7.2	7.1
	20	7.0	6.8
	40	8.5	7.5
30	10	6.7	7.0
	20	7.6	5.8
	40	7.6	6.4
60	10	5.9	6.0
	20	5.5	5.5
	40	6.1	6.0
120	10	5.7	6.6
	20	4.8	5.5
	40	5.8	6.1

Note: Values are means of three replicates.

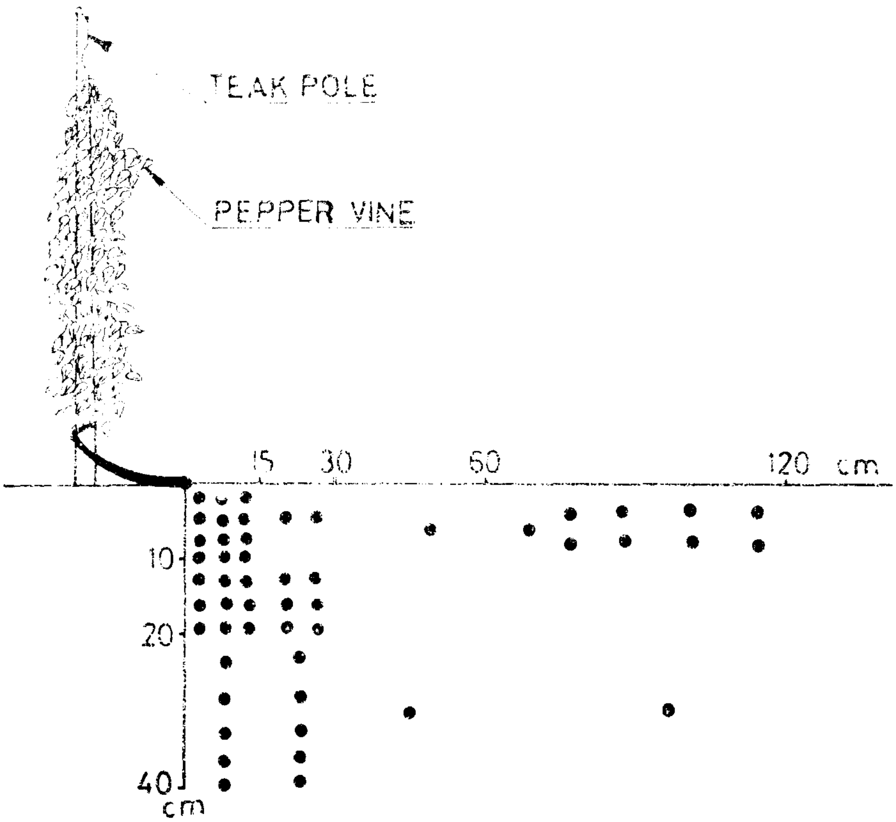
Table 41. Amount of rainfall (mm) received during the experimental period

Month	1983	1984
June	387.2	653.1
July	980.6	730.4
August	754.7	260.2
September	494.6	158.6
October	149.8	323.7
November	60.2	7.8
December	24.4	16.4

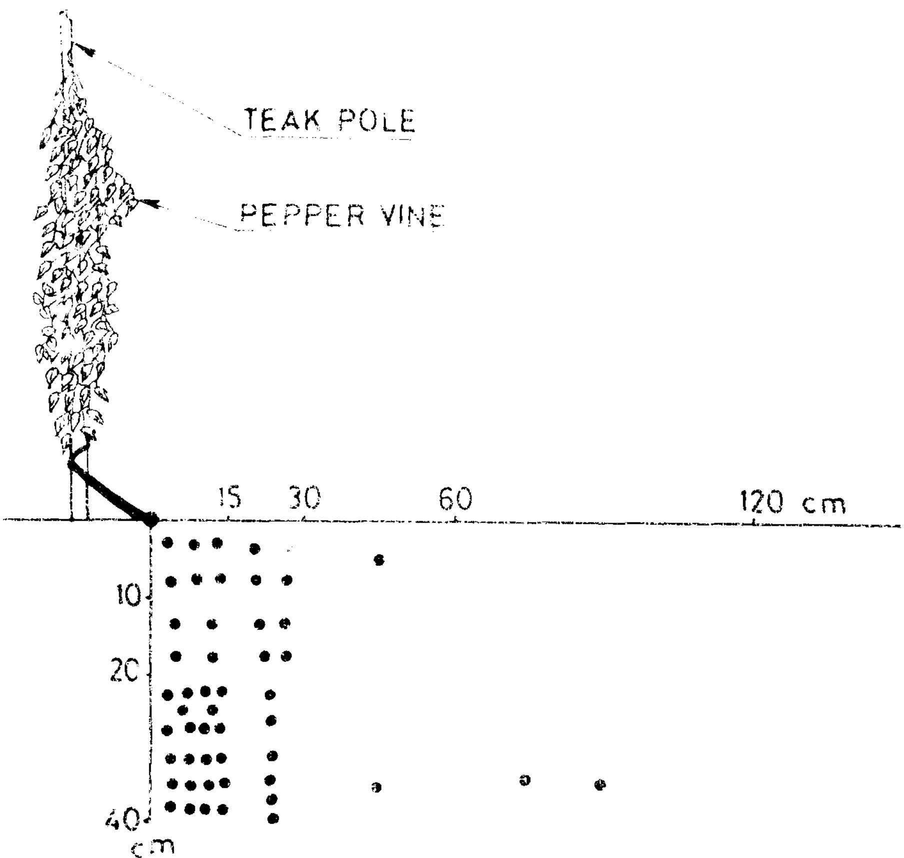
experiment truly reflects the preponderance of the feeder roots in these soil zones. With the recession of the monsoon season by the end of the experiment, moisture loss due to evapotranspiration from the surface layers may be drastic especially when the rate of replinishment of water into soil through rains diminishes. Such a situation will lead to the development of a distinct moisture gradient in the soil profile with more moisture in the deeper layers. This could have been, perhaps, responsible for the higher uptake of ^{32}P by the vine from deeper layers than from the surface layers during the latter part of the experimental period. Therefore, the pattern of ^{32}P absorption observed at later intervals need not necessarily indicate the proportion of feeder roots in various soil layers, instead it is a measure of the root activity as influenced by the moisture regimes prevalent in various soil layers. These results imply that the vine is capable of exploiting deeper soil layers with the cessation of rains. In several crops such as apple (Atkinson, 1974) and coconut (Balakrishnamurthy, 1971) similar trends in root activities with change in soil moisture level were observed.

The pattern of root activity of pepper vine trailed on erythrina was found to be almost identical to that trailed on deadwood support with respect to lateral distance (Table 12). In this case also, over 90 per cent of the roots were found within 30 cm from the vine. In the case of erythrina, the roots were found to traverse upto a distance of 60 cm from the vine (Table 17). If an estimate is made of the proportion of active roots of the live standard within 30 cm away from the vine which is the most active root zone of the pepper vine, it will be seen that 80 per cent of the feeder roots of erythrina are lying in this region indicating thereby that erythrina has a more extensive root system than the vine. As compared to the vine on teak pole, the active roots of the vine on erythrina were more or less evenly distributed along the soil profile. Further, the results do not indicate an increase in the root activity of the vine in deeper layers with time as observed in the case of the vines trailed on teak pole. Comparison of the active root distribution of the live standard with that of the pepper vine trailed on it suggests that the support plant and the vine explore to almost same extent the various soil layers as evidenced from the similar percentage of root activity of the two plant species at various soil depths. When the two crop systems viz., pepper on erythrina and pepper on teak pole are evaluated in terms of moisture depletion from the soil column, it will be apparent that the loss of water in the former is the result of combined evapotranspiration from both plants as against the loss of water due to evapotranspiration from the vine alone in the latter. In so far as the root aotivity patterns of the two plant species are almost similar along the rhizosphere profile, there would be less chance of a sharp moisture gradient with depth. Perhaps, this would explain the failure to obtain greater recovery of ^{32}P from deeper layers (below 20 cm) during the end of the monsoon season. Considering all these aspects, the root activity pattern of black pepper vine may be diagramatically shown as in Fig.14. There was no evidence to show the avoidance of feeding zone of erythrina by the vine as reported for other mixed culture situations (Willey, 1979). The root exploratory area of the vine when grown in association with erythrina was found to be confined to 30 cm lateral distance while the roots of support plant were found to traverse upto 60 cm from the vine. The relatively unexplored area by the support plant in the feeding zone of the vine is at about 15 cm from the vine where the concentration of vine roots is more. On the contrary, the vine was found to explore deeper soil layers (below 20 cm) efficiently when it was trailed on dead wood. The data collected from these studies are, however, not adequate to explain the differential pattern of root activities of the vine in these two situations.

From the foregoing discussion, it is clear that the maximum absorption of the applied nutrient takes place



A1 - OCTOBER



A1 - DECEMBER

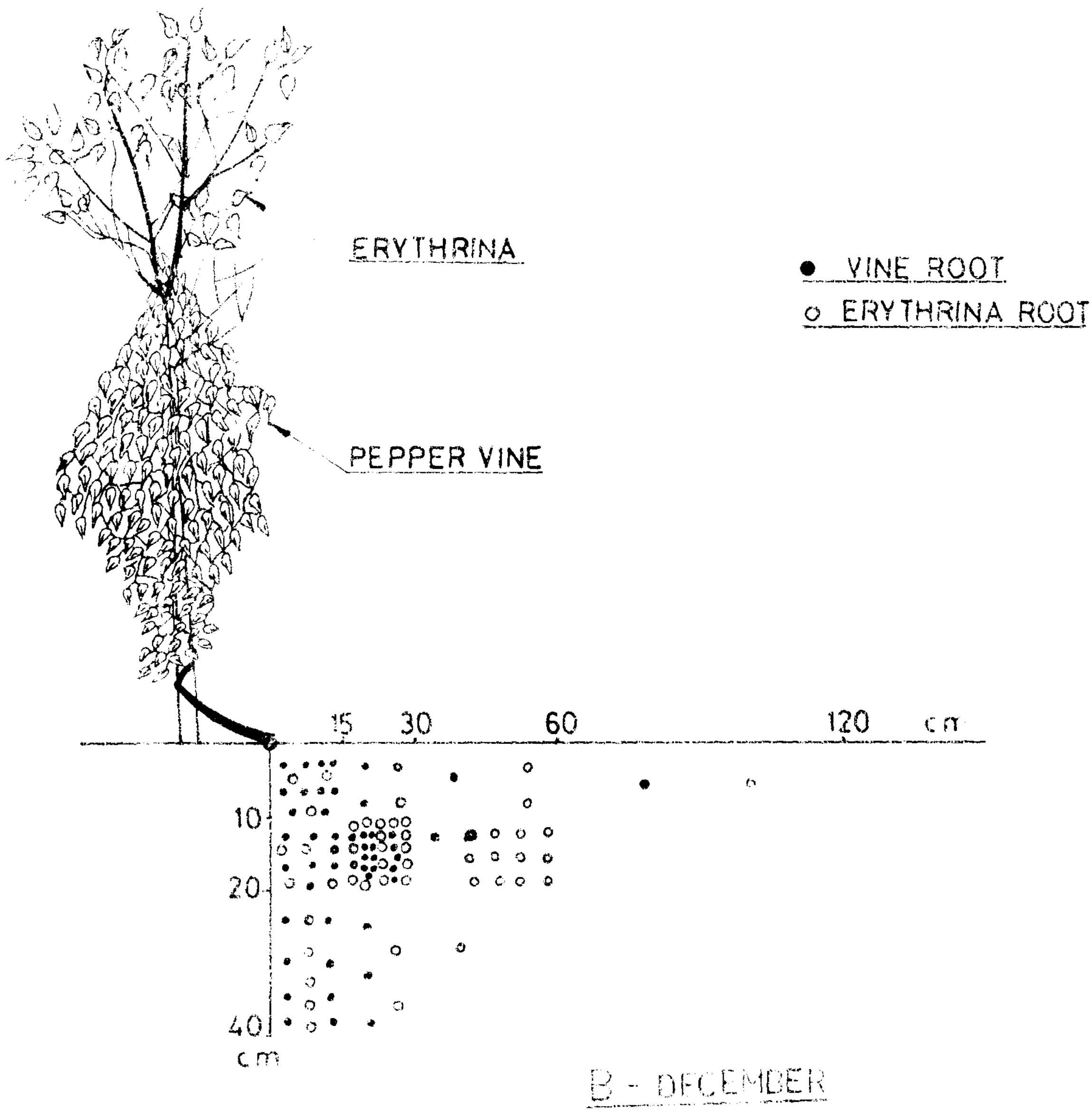


Fig. 14. DIAGRAMATIC REPRESENTATION OF ROOT ACTIVITY PATTERN OF BLACK PEPPER VINE TRAILED ON
A1 & A2 - TEAK POLE
B - ERYTHRINA

within a soil column of 30 cm. radius from the vine. In view of the relative abundance of the feeder roots (20 to 30 per cent) within 10 cm soil depth, there is every chance of root pruning if the fertiliser application is done in opened basins. It is suggested, therefore, that broadcasting of the fertilisers and subsequent incorporation into the soil by raking may be preferred to basin application as the former would avoid excessive root damage.

The results of the present study also indicate the possibility of adoption of still closer planting than the recommended spacing of 3m x 3m. A closer spacing down to 1m between plants does not seem to cause overlapping of the exploratory area of the roots between adjacent vines. Moreover, the root activity of the live standard, erythrina, beyond 60 cm from the vine is also negligible. No information is presently available as to the effect of high density cropping on the growth and yields of pepper vines. Investigations on these aspects are worth taking up.

Conventionally, in studies on root activity patterns of crop plants, application of radioactivity is done into equally spaced holes around the plants. The method followed for the present study was to inject radioactivity into soil holes taken in a semicircle facing the vine (Fig. 3). This method was followed because the vine was trailed on a support. When the support is another plant, erythrina in this case, it is likely that the root activity on either side of the vine may not be the same because of the probable interference of the support plant in the semicircle opposite the vine owing to its closer proximity to the standard (Fig.4). It is for this reason, a separate experiment was conducted to examine whether there is any difference in the proportion of active roots between the two opposing semicircles. In this experiment, however, not all the treatments already discussed (4 radial distances x 3 depths) were compared. The comparison was confined to only the most active root zone namely 20 and 40 cm depths at a radial distance of 30 cm. The recovery of ^{32}P in the leaves in relation to its placement at three soil zones along the circumference of the semicircle facing the vine, opposite the vine and also full circle around the vine (Fig. 4) was evaluated (Table 18 to 32). The concentration of active roots was found to be similar in both semicircles on either side of the vine, irrespective of the type of standard on which the vine was trailed. This indicates that roots emanating from the vine are uniformly distributed radially around the vine. However, in the case of pepper vine trailed on erythrina there was a marked decrease in the absorption of ^{32}P when the same amount of radioactivity was applied in full circle. Such a trend was not observed in the case of vines trailed on teak wood

(Tables 18 to 22). Despite the lack of statistical significance, the mean values of count rates expressed on dry matter basis as well as specific activity revealed that there was a general decrease in the absorbed radioactivity by these plants irrespective of the type of standard (Figs. 8 to 13). Perhaps the failure to achieve statistical significance in the case of vines trailed on teak pole could be due to large plant to plant variation in the uptake of ^{32}P as evidenced from the significant block effect (Appendix VI). Existence of such large variability in root activity between plants was reported in tree crops (IAEA, 1975). Under relatively uniform soil and other environmental conditions, the error component due to variation between individual trees was attributed to (a) difference in vegetative characters such as girth, height, foliage and fruiting capacity and (b) difference in probability of injected ^{32}P striking the roots. The large variability in ^{32}P uptake among individual plants trailed on teak pole as observed in the present study may be explained by the difference in the probability of injected ^{32}P striking the roots rather than the differences in vegetative characters of the plant because variation in the growth characters of these plants were not marked (Table 39). Eventhough increasing the number of replications may seem the only logical solution for reducing such variability, studies with birch trees had shown that even with fear replications the coefficient of variation among the replicates was more than 100 per cent. Therefore, it may be considered as the intrinsic variability of the plant itself rather than the limitation of the technique (IAEA, 1975). The decrease in absorption of ^{32}P by the vine when the radioactivity was applied in full circle as compared to semicircle application implies that the nutrient concentration available per root is more important in enhancing the absorption. From these considerations, it may be suggested that in the case of pepper vine trailed on erythrina the restriction of fertilizer application to a semicircle will be more effective for the better utilisation of the added nutrients. For convenience, the semicircle (30 cm radius) facing the vine may be preferred for fertilizer application. The same method of fertilizer application is equally applicable to vines trailed on teak pole also.

The absorption of ^{32}P by the vine was found to increase initially and then decrease (Figs. 6, 7 and 8 to 13). It was observed that the decline occurred after 45 days of ^{32}P application. Such a trend in absorption of the radiolabel may be due to the extension of roots beyond the ^{32}P-applied zone resulting in a reduced rate of uptake (IAEA 1975).

5.4. Relative absorption of ^{32}P by pepper vines trailed on teak pole, erythrina and by the live standard, erythrina

So far, the discussion has been centered around the root activity pattern of individual cases namely, pepper vine on teak pole, on erythrina and the standard, erythrina. Comparison of the effects of dead and live standards on ^{32}P uptake was not made statistically since the error mean squares for ^{32}P data were not homogeneous for experiments using erythrina and teak pole. Therefore, a different methodology based on the relative uptake of applied ^{32}P was followed for ascertaining whether there is any advantage or disadvantage due to the use of erythrina as support plant. In other words, it measures the degree of interference/competition between the two plant species for the applied radiolabel when grown side by side with each other.

The two situations viz. trailing the vine on teak pole and on erythrina may be considered as monoculture and mixed culture respectively with respect to the vine. According to de Wit (1960), any two plant species growing in the same space would divide a constant environment leading to either beneficial (complimentary) or harmful (competitive) interaction between each other. In order to arrive at the magnitude of such interaction, a simple mathematical expression involving comparison of the relative uptake of ^{32}P was derived:

Relative uptake of the applied label (RUA) by the vine trailed on erythrina may be expressed as

$$\frac{Q_b}{Q_a} \qquad (1)$$

Where Q_a and Q_b denote the total amount of ^{32}P absorbed by the vine trailed on erythrina (b) and that on teak pole (a) respectively. If this ratio is unity, it means that there is no competition between the two plant species while values less than or greater than unity indicate competitive and beneficial interactions respectively.

The total quantity of ^{32}P taken up by the plant can be determined if ^{32}P content/g plant dry matter or specific activity of the plant is known. By multiplying these quantities by total dry matter or total P uptake in g respectively, Q can be found out. That is

$$Q = (\text{cpm/g dry matter}) \times \text{TDM} \qquad (2)$$

or

$$Q = \text{SAP} \times \text{TP} \qquad (3)$$

Where TDM is the total dry matter content of the plant, TP is the total P uptake by the plant and SAP is the specific activity of the plant (cpm/g P). In the present study, neither the ^{32}P concentration/g dry matter nor the specific activity of the plant is available. However, radioassay of various parts of the plant revealed that the count rates/g dry matter of various plant parts as well as their respective specific activities were highly correlated. Thus ^{32}P contents of leaf and spike which form the major P-accumulating organs of the vine were linearly correlated (Table 34). Out of these, highest correlations were obtained among the specific activities of the plant parts which indicates that specific activity of leaf may be considered as a good index of the specific activity of the plant. Therefore, specific activity of the leaf was considered for computing an estimate of total ^{32}P uptake by the plant. Equation (3) may be, therefore, modified as:

$$Q' = SAL \times TP \qquad (4)$$

Where Q' is the estimate of total ^{32}P uptake by the plant and SAL is the specific activity of the leaf. Substituting these quantities in equation (1), an index of the relative uptake of the applied label (RUA') may be worked out as follows:

$$RUA' = \frac{Q'_b}{Q'_a} = \frac{(SAL \times TP)_b}{(SAL \times TP)_a} \qquad (5)$$

Since the ratio $\frac{(TP)_b}{(TP)_a}$ may be assumed to be constant, it follows that:

$$\frac{Q'_b}{Q'_a} \propto \frac{(SAL)_b}{(SAL)_a} \qquad (6)$$

The ratio of the specific activities of the leaves of the vines trailed on erythrina and on teak pole would thus provide a measure of the relative uptake of ^{32}P by the vine when grown in association with erythrina as compared to pure crop or monoculture.

The value of the constant $\frac{(TP)_b}{(TP)_a}$ in the present experiment should be less than 1 as could be inferred from the higher dry matter production and almost similar leaf P content of the vines trailed on teak pole as compared to the vines on erythrina (Table 39). Therefore, the RUA' value computed from the specific activity ratios of the leaves (eqn.5) should indicate the minimum competition (negative interaction) between the vine and the live standard if the value is less than unity. A perusal of the RUA' data presented in Table 33 revealed that the uptake of ^{32}P by the vine was adversely affected when it was grown in assocation with erythrina. The magnitude of this effect was to reduce ^{32}P uptake by the vine by more than 20 per cent as evidenced from the activity ratio of about 0.8 observed during the second half of the experimental period. The degree of competition between the vine and erythrina remained unaltered irrespective of the method of ^{32}P application either in semicircle or in full circle.

Comparison of biomass produced by the two plant species revealed that the dry matter produced by the vine trailed on erythrina was about one-third of that produced by its support plant. The vine produced on an average 6.16 kg of dry matter as against 18.5 kg produced by erythrina. When partitioning of the dry matter was made, it was seen that over 96 per cent of the total dry matter produced by the support plant was utilised for the production of stem while about 50 per cent of the total dry matter produced was accounted for by the stem in the case of pepper vine. The quantities of nutrients removed by the pepper vine was found to be less than that removed by erythrina. The comparison is more glaring in the case of N, P, Ca, Mg, Fe, Mn, and Zn. Among those nutrients, perhaps the competition for nitrogen between the two plants may not be crucial as the support plant, erythrina being a leguminous plant, is capable of fixing N_2 in their roots. It is important to note that because of defoliation of the support plant during summer months, there is an annual recycling of about 0.7 kg dry matter which to some extent compensates for the nutrient removed by the plant. The annual input of nutrients into the soil through leaf fall thus amounts to 25.7 g N, 0.94 g P, 6.5 g K, 20 g each of Ca and Mg, 0.8 g S, 131.4 mg Fe, 1008 mg Mn, 13 mg Zn and 14.2 mg Cu/plant.

The antagonistic effect of erythrina on the growth and yield of pepper vine (Table 39; Anon., 1984., Menon _et_ _al_., 1982) may not be viewed purely as a result of root competition between the two plants for soil nutrients. The soil analysis indicated that the concentrations of available nutrients are more than adequate to meet the requirements of both vine and live standard at a time. The high soil concentrations especially of P and K may be due to the regular application of P and K fertilizers to the vine basins. Root competition for a nutrient may be expected when its supply in the soil is not adequate to meet the demands of the two plants. Perhaps qualitative and quantitative differences in the chemical and micro-biological composition of the rhizosphere of the vine when grown as pure crop (on dead wood) and in association with erythrina (on live standard) may be responsible for the observed trends in vine growth and consequent uptake of ^{32}P in these two situations.

If an attempt is made to compute the annual exhaust of nutrients through harvest of 1.284 kg dry pepper, it may be be seen that the total quantities of the nutrients removed annually from the system follows the decreasing order N (38.5 g) = K (36.7 g) > Ca (14.9 g) > Mg (13.7 g) > P (2.2 g) > S (1.37 g). The quantities of N and P removed by the vine agree well with that reported by Pillai and Sasikumaran (1976) for the variety, Panniyur-1 with an average yield of 1 Kg black pepper. However, the annual removal of K was found to be higher than that reported by these authors. In view of the high build-up of P in the soil following annual application of P fertilizers and the very low requirement of this nutrient by the vine, it seems possible that P application can be skipped once a good build-up of soil P has been attained. Such an approach has been found applicable in coconut (Wahid et al., 1975; Wahid et al., 1977; Khan et al., 1983).

SUMMARY

SUMMARY

An investigation on the root activity pattern of black pepper vine (*Piper nigrum* L.) and allied aspects was conducted during 1983-84 in the College of Horticulture, Vellanikkara. The major objectives of the experiments were to determine the soil, zone of maximum nutrient absorption by the vines trailed on erythrina and teak pole, to assess the root density of erythrina in the rhizosphere of black pepper, to evaluate the root competition between the vine and the live standard for applied P, to compare the nutrient removal by the vine and erythrina and also to examine whether the climbing roots of the vine are capable of nutrient absorption.

In studies with black pepper, var. Panniyur-1 was invariably used. For root activity studies, radiophosphorous was employed as the tracer and radioassay of plant samples was done based on Cerenkov counting technique. For the chemical analyses of soil and leaf samples spectrophotometric, flame photometric and atomic absorption methods were adopted. The salient findings from these studies are summarised below.

A method of soil injection of desired volume of ^{32}P solution especially suitable for root activity studies with perennial crop plants was developed. The method makes use of a "Lumac Dispensette" (or any other suitable automatic dispenser) connected to a reservoir bottle containing ^{32}P solution which in turn is embedded in paraffin wax in a suitable plastic bucket. The method is rapid and the radiation hazard to the

operating personnel is minimal at the level of radio-activity generally required in root activity experiments.

A leaf sampling technique for ^{32}P assay in black pepper was developed. Sampling of the leaves from lower two-third position of the canopy was recommended for this purpose.

The absorption of applied P by the vine was found to be very fast. Detectable amounts of soil applied radio-activity was recovered in the leaf at a height of 1.5 m within 5 min of application.

For the vines trailed on either erythrina or on teak pole, the zone of maximum absorption of applied ^{32}P was found to be within 30 cm from vine. Absorption of ^{32}P was found to be higher when it was applied in semicircle rather than in full circle.

The vines trailed on teak pole were found to have the capacity to explore deeper layers than the vines trailed on erythrina. This trend was noticed with the recession of mansoon season.

The active root system of erythrina was found to be more extensive than the vine. High density of active roots of erythrina was observed upto 60 cm from the vine. However, it is relatively more of a surface feeder compared to the vine.

Relative absorption of applied ^{32}P by the vines trailed on erythrina as compared to the vines trailed on teak pole indicates that the absorption of the applied nutrient was less when the vine is trailed on erythrina. Eventhough it would appear to be due to root competition between the two plant species for the nutrient, the effect of alterations in the chemical and microbiological make up of the vine rhizosphere when grown in association with erythrina cannot be ruled out.

In general, at least 20 per cent reduction in the absorption of phosphorus by the vine could be expected if it is trailed on the live standard.

The total nutrient contents of the whole vine with an annual yield of 1.284 kg black pepper were much less than that of its support plant, erythrina. The differences were more marked with respect to total content of N, P, K, Ca, Mg, Fe, Mn and Zn.

Computation of annual exhaust of nutrients through harvest of 1.284 kg dry pepper indicated that 38.5 g N, 36.7 g K, 14.9 g Ca, 13.7 g Mg, 2.2 g P, 1.37 g S, 218 mg Fe, 155 mg Mn, 28 mg Zn and 47 mg Cu were annually removed from the plant system.

Annual recycling of about 0.7 kg dry matter containing 25.7 g N, 0.94 g P, 6.5 g K, 20 g each of Ca and Mg, 0.8 g S, 131.4 mg Fe, 1008 mg Mn, 13 mg Zn and 14.2 mg Cu could be expected from the defoliation of erythrina plant during summer months.

The absorption of ^{32}P by the climbing roots of the vine was found to be insignificant.

The results obtained from the studies reported herein help to formulate the following recommendations and suggestions.

(i) Fertilizer application in black pepper gardens should be restricted to a semicircle of radius 30 cm facing the vine irrespective of the type of standard for the maximum utilisation of the added inputs.

(ii) In view of the preponderance of feeder roots of the vine within 10 cm from the soil surface, application of fertilizer in basins is likely to damage the feeder roots. Therefore, it is suggested that broadcasting the fertilizer and raking in for their incorporation into the soil would be a more meaningful approach.

(iii) Presently 3 m x 3 m spacing is followed in planting of the vines. Since the active root system of the vine is limited to an area of 30 cm from the vine the likelihood of overlapping of the roots of the adjacent vines is very less even if spaced 1 m apart. Experiments on the effect of closer planting on the growth and yield of the pepper vines are worth taking up.

ABBREVIATIONS USED

Bq	:	Bequerel
cm	:	centimeter
cpm	:	counts per minute
dia	:	diameter
E_{max}	:	maximum energy of beta particle
g	:	gram
h	:	hour
ha	:	hectare
ht	:	height
ie.,	:	that is
IAEA	:	International Atomic Energy Agency
kg	:	kilogram
l	:	litre
m	:	meter
M Bq	:	mega Bequerel
m Ci	:	milli Curie
mg	:	milligram
MeV	:	million electron volts
min	:	minutes
ml	:	milli litre
mR	:	milli Roentgen
MSL	:	mean sea level
ppm	:	parts per million
Q	:	total amount of ^{32}P absorbed by the plant

Q'	:	an estimate of total ^{32}P uptake
RBD	:	randomised block design
RUA	:	relative uptake of the applied label
SAL	:	specific activity of leaf
SAP	:	specific activity of plant
TDM	:	total dry matter
TP	:	total P uptake
uCi	:	micro Curie
var	:	variety
viz.,	:	namely

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* Originals not seen.

APPENDICES

APPENDIX - I

Analysis of variance of leaf ^{32}P - recovery data after ten days of ^{32}P application

Source	Degrees of freedom	Mean sum of squares	
		15 cm lateral distance	30 cm lateral distance
Block	5	42247812.20*	7619042.60*
Leaf position on the canopy	2	2696597 .90	4094087.90
Area of application	2	582019 .50	3426529.40
Interaction	4	297098 .90	10289708.8
Error	40	955638 .80	11891101.9

*Significant at 5% level.

APPENDIX - II

Analysis of variance of leaf ^{32}P - recovery data after 24 days of ^{32}P application

Source	15 cm lateral distance		30 cm lateral distance	
	Degrees of freedom	Mean sum of squares	Degrees of freedom	Mean sum of squares
Block	4	10725737413.1**	5	226244263.0*
Leaf position on the canopy	2	95138621.6	2	99970728 .0
Area of application	2	54065939.3	2	60535643 .1
Interaction	4	382550362.9	4	14413467 .8
Error	32	380494963.6	40	40823152 .6

** Significant at 1% level

* Significant at 5% level

APPENDIX - III

Analysis of variance of log-transformed leaf cpm values for the experiment on distribution of root activity of black pepper trailed on dead wood.

Source	Degrees of freedom	Mean sum of squares			
		Sampling interval (days)			
		15	30	45	60
Block	2	1.7551*	0.2775	2.5902**	0.7762*
Distance	3	4.3530**	5.2028**	4.4593**	4.0563**
Depth	2	0.1864	0.9591*	0.5485	1.1512**
Interaction	6	0.5874	0.3493	0.4315	0.1773
Error	22	0.3791	0.1760	0.3417	0.1909

** Significant at 1% level

* Significant at 5% level

APPENDIX - IV

Analysis of variance of log-transformed leaf cpm values for the experiment on distribution of root activity of black pepper trailed on live standard.

Source	Degrees of freedom	Mean sum of squares			
		Sampling interval (days)			
		15	30	45	60
Block	2	0.2561	0.2649	0.5962	0.8622
Distance	3	7.5245**	5.7030**	5.8623**	7.0282**
Depth	2	0.0039	0.3104	0.2736	0.0878
Interaction	6	0.6568	0.5250	0.5344	0.7862
Error	22	0.8315	0.3779	0.4898	0.5318

** Significant at 1% level

* Significant at 5% level

APPENDIX - V

Analysis of variance of log-transformed leaf cpm values for the support plant, erythrina

Source	Degrees of freedom	Mean sum of squares			
		Sampling interval (days)			
		15	30	45	60
Block	2	0.5021	1.2976	2.2036	0.5994
Distance	3	6.7342**	4.9136**	3.7701**	3.4797**
Depth	2	2.6781	1.2229	1.7212*	1.4549*
Interaction	6	1.3321	1.2356	1.1302*	1.4233**
Error	22	0.9117	0.5172	0.4095	0.3171

** Significant at 1% level

* Significant at 5% level

APPENDIX - VI

Analysis of variance of log-transformed leaf cpm values for pepper vine trailed on teak pole in relation to method of application

Source	Degrees of freedom	Mean sum of squares				
		Sampling interval (days)				
		15	30	45	60	75
Block	2	0.7429	1.2666*	1.4634*	0.3160	1.1268*
Depth	1	0.0211	0.0467	0.0979	0.0585	0.0071
Method of application	2	0.2305	0.0343	0.0602	0.1541	0.0591
Interaction	2	0.0160	0.0117	0.0148	0.1557	0.0500
Error	10	0.3594	0.2895	0.3051	0.2326	0.2001

* Significant at 5% level

APPENDIX - VII

Analysis of variance of log-transformed leaf cpm values for pepper vine trailed on erythrina in relation to method of application

Source	Degrees of freedom	Mean sum of squares				
		Sampling interval (days)				
		15	30	45	60	75
Block	2	0.3114	0.4411	0.6338	0.4686	0.2782
Depth	1	0.8655	1.1102*	0.2239	0.5551	0.0016
Method of application	2	1.1745*	0.4804	1.2304*	0.4121	0.9091*
Interaction	2	0.0544	0.2296	0.0309	0.0282	0.0822
Error	10	0.2595	0.1778	0.2621	0.1165	0.1796

*Significant at 5% level

APPENDIX - VIII

Analysis of variance of log-transformed leaf cpm values for the support plant, erythrina as influenced by method of application

Source	Degrees of freedom	Mean sum of squares				
		Sampling interval (days)				
		15	30	45	60	75
Block	2	0.8925	0.8607	0.6591	0.4896	0.1730
Depth	1	0.0691	0.2755	0.2706	0.0786	0.7260
Method of application	2	0.4519	0.6939	0.2480	0.0782	0.2142
Interaction	2	1.2315	0.4293	0.9288	0.1571	0.1858
Error	10	0.5989	0.3067	0.5110	0.3689	0.3805

STUDIES ON THE ROOT ACTIVITY PATTERN OF BLACK PEPPER (*Piper nigrum* L.) EMPLOYING RADIOTRACER TECHNIQUE

By

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ABSTRACT OF A THESIS

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ABSTRACT

An investigation on the root activity pattern of black pepper vine and allied aspects was conducted employing Phosphorus-32. The results indicated that the active root zone of black pepper vine trailed either on erythrina or on teak pole is in a soil column of 30 cm radius around the vine. It is suggested that fertilizer application to pepper vines may be done in a semicircle of 30 cm radius facing the vine for the most effective utilisation of the added nutrients. Growing the vine in association with erythrina as support was found to reduce the uptake of ^{32}P by at least 20 per cent as compared to that grown on teak pole. The active root system of erythrina was found to be more extensive than the vine reaching upto 60 cm from the pepper plant. The absorption of ^{32}P by the climbing roots of the vine was found to be insignificant.

A method of leaf sampling for ^{32}P assay in black pepper vine as well as a method of soil injection of ^{32}P solution into root zone of crop plants was developed.

Annual exhaust of nutrients by way of harvest of 1.284 kg dry pepper was found to be 38.5 g N, 36.7 g K, 14.9 g Ca, 13.7 g Mg, 2.2 g P, 1.37 g S, 218 mg Fe, 155 mg Mn, 28 mg Zn and 47 mg of Cu.

From the defoliation of erythrina, an annual

recycling of 0.7 kg dry matter containing 25.7 g N, 0.94 g P, 6.5 g K, 20 g each of Ca and Mg, 0.8 g S, 131.4 mg Fe, 1008 mg Mn, 13 mg Zn and 14.2 mg Cu may be expected.