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Root activity patterns of two coffee species (*Coffea liberica* and *Coffea robusta*) grown under different soil environments: a study using ^{32}P tracer technique*

[Corak aktiviti akar bagi dua spesies kopi (*Coffea liberica* dan *Coffea robusta*) dalam persekitaran tanah yang berlainan: satu kajian dengan teknik penyurih ^{32}P]

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Key words: *Coffea liberica, Coffea robusta,* root activity, ^{32}P tracer technique, distribution of root activity

Abstrak

Taburan aktiviti akar dua spesies kopi (*C. liberica* dan *C. robusta*) yang ditanam di empat lokasi iaitu Serdang, Kluang, Pontian dan Parit Botak, meliputi enam siri tanah: Bungor, Munchong, Rengam, Parit Botak, tanah gambut cetek dan tanah gambut sederhana dalam, dikaji dalam lapan ujikaji dengan menggunakan teknik penyurih ^{32}P.

Walaupun pokok kopi Liberica mempunyai hamparan akar penyerap permukaan aktif yang lebih luas daripada kopi Robusta, taburan akar aktif di dalam lingkungan silara adalah sama apabila diukur berhubungan dengan hampiran silara. Dalam kedua-dua spesies, aktiviti akar di kawasan yang berhampiran dengan pangkal pokok (dalam jejari 25–50 cm dari pangkal pokok) ialah 3–4 kali ganda lebih tinggi daripada aktiviti di hujung silara (dripline).

Akar penyerap permukaan bagi pokok kopi Liberica muda mempunyai aktiviti akar yang tinggi di kawasan jejari 50 cm dari pangkal pokok. Aktiviti ini, walau bagaimanapun menurun beransur-ansur dengan umur pokok, menghasilkan hamparan akar penyerap permukaan aktif yang bertambah luas. Corak aktiviti akar adalah sama bagi pokok yang ditanam di tanah gambut atau tanah pedalaman.

Saiz lilitan batang kopi Liberica tiada kesan ketara terhadap taburan akar penyerap permukaan (10 cm dalam) aktif.

Di tanah siri Munchong, hampir kesemua akar penyerap aktif bagi Robusta (95%) dan kopi Liberica (83%) terdapat dekat permukaan (5 cm) tanah. Kira-kira 15% daripada aktiviti akar kopi Liberica tertabur di kedalaman 50 cm.

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Di tanah asid sulfat iaitu siri Parit Botak, kesemua (96%) akar penyerap aktif bagi kopi Liberica berkumpul berdekatan dengan permukaan tanah (5 cm dalam). Di tanah gambut, taburan akar penyerap aktif yang lebih dalam ternyata.

Untuk mencapai penggunaan baja secara lebih cekap, baja haruslah diletak berhampiran dengan pangkal pokok di bawah silara.

Abstract

The root activity distribution of two coffee species viz. *C. liberica* and *C. robusta* grown in four locations viz. Serdang, Kluang, Pontian and Parit Botak covering six soil series viz. Bungor, Munchong, Rengam, Parit Botak, shallow and moderately deep peat was studied in eight experiments using radioactive ^{32}P soil injection tracer technique.

Although Liberica coffee trees have a wider spread of active surface feeder roots than Robusta coffee, their respective active root distribution within the crown area were similar when measured in relation to the spread of the tree crown. In both species, the average activity close to the trunk (25–50 cm radius from trunk) was 3–4 times higher than those at the dripline.

The surface feeder roots of young Liberica coffee trees had high root activity within the 50 cm radius from the trunk, which declined progressively with age resulting in a wider spread of active feeder roots. In spite of the decline, activity remained highest within the 50 cm radius irrespective of age. The results were similar on both the peat and inland soils.

Girth size of Liberica coffee had no significant effect on the active surface (10 cm depth) feeder root distribution.

On Munchong series, almost all the active feeder roots of Robusta (95%) and Liberica (83%) coffee were distributed near the soil surface (5 cm). About 15% of the root activity of Liberica coffee were distributed at the 50 cm depth.

On the acid sulphate soil viz. Parit Botak series, almost all (96%) the active feeder roots of Liberica coffee were confined to the soil surface (5 cm depth). On peat, a deeper distribution of the active feeder roots was observed.

To achieve greater fertilizer use efficiency, fertilizer should be applied closer to the trunk below the canopy.

Introduction

One of the major factors affecting crop yield is the supply of adequate plant nutrient. In theory, an increase in nutrient supply is most easily met by the addition of nutrient in the form of fertilizers. However, fertilizers are expensive and fertilizers not utilized by the crop may represent an environmental pollutant. Efficient fertilizer use can be achieved by applying the most suitable form of fertilizer and placing it in an area where it can be rapidly taken up at times when the plant's needs are most crucial.

Unlike an annual crop, it is not practical to harvest entire mature trees to measure nutrient uptake from fertilizers applied. As such, crop yields are commonly used as a criterion to estimate such responses. Unfortunately, yield is often a poor criterion to estimate fertilizer use efficiency due to the multiplicity of the factors affecting yields. Conventional yield trials of tree crops are often expensive to run as large experimental plots are usually involved and yield data have to be collected over several seasons. Thus, root activity studies are considered good preliminary approach in the case of tree crops as such studies provide basic information as to when and where fertilizers should be applied to ensure greater efficiency of fertilizer use. Isotope techniques make determination of active root distribution comparatively easy. Their application to tree crops has been demonstrated for coffee (Saiz del Rio et al. 1961; IAEA 1975), pepper (Sankar et al. 1988), guava (Purohit and Mukherjee 1966), cocoa (Cornwell 1957; IAEA 1975), mango (Bhajappa and Singh 1973), oil palm (Broeshart 1959) and rubber (Singh et al. 1972).

In Malaysia, the study of root systems, particularly of tree crops, has been somewhat neglected as it involved elaborate and painstaking evacuation of the roots. In many instances, the spread of the lateral branches is often taken as a rough guide in estimating the lateral root spread. Hence, dripline fertilizer placement and spreading fertilizer under the tree crown is often practised. While the use of this criterion may or may not adequately indicate the spread of the lateral roots, the overriding factor in optimizing fertilizer use lies in the ability of the root to take up the fertilizers applied. The use of soil injection technique with tracer viz. ^{32}P allows the most direct and non-destructive method in delineating the root activity pattern.

The objective of this study is to investigate the active root distribution of two coffee species (viz. *Coffea liberica* and *C. robusta*) grown under different environments using ^{32}P radioactive tracer technique.

Materials and methods

The basic concept and methodology of delineating active root distribution pattern of trees have been previously described (IAEA 1975). The concept is based on the assumptions that:

- for maximum efficiency of utilization, fertilizers should be applied in areas of highest root activity,
- the isotope content of the sampled leaf reflects the root activity in the area in which the isotope was applied,
- leaves of a defined leaf type (e.g. morphological position) will provide the same results, and
- the delineated root activity pattern with a given isotope would be the same for other nutrients.

The method involves soil injection with labelled ^{32}P solution at specific distance (lateral) from the tree at different depths and subsequent isotope assay in the leaf sample. Treatments were tested in a completely randomized design. All lateral placement x depth treatments were arranged in a factorial combination. Single trees were used as experimental units in all the experiments.

The root activity patterns of coffee trees grown in four locations viz. Serdang, Kluang, Pontian and Parit Botak, covering six soil viz. Bungor, Munchong, Rengam, Parit Botak, shallow and moderately deep peat (*Appendix 1*) were studied. Experimental details are summarized in *Table 1*.

The trees in each experiment were selected from existing plots which were grown from seeds as monocrop (except for experiment 8 which was intercropped with coconut). The trees were detopped at 3 years of age and regularly pruned to remove water shoots. Depending on the site, each tree received 0.8–1.0 kg of either 15 N:7 P_2O_5:18 K_2O:2 MgO or 12 N:12 P_2O_5:17 K_2O:2 MgO fertilizer mixture per annum in four equal split applications. The fertilizers were broadcasted under the crown. The trees were carefully selected to ensure uniformity in terms of biomass, girth size, crown size and plant vigour. Each tree received a known amount of ^{32}P (2–3 mCi), depending on the experiment (*Table 1*), distributed in eight equal aliquots containing 5 mL of 1 000 ppm P KH_2PO_4 carrier solution. The eight aliquots were applied around the tree at a fixed radius at equidistant from each other and at a given depth. The injection points were made 1–3 days in advance using an auger and plugged. The ^{32}P labelled solution was dispensed into the hole through a glass tube using an auto-pipette. The glass tube was then flushed with 20 mL of water. The holes were then covered with soil taken from the same area. All experiments were timed to coincide with the rainy season.

Twenty 10 cm length recently matured shoots (plus leaves) were sampled over the entire upper exposed canopy from each tree at various intervals (*Table 1*) after soil injection with ^{32}P. The samples were dried in a forced draught oven at 60 °C for 24 h and then crushed. Five gram sub-samples were then taken for ashing at 550 °C. The ash was dissolved in 20 mL of 2 M HCl before being filtered. Ten millilitres of the extract was then pipetted into plastic scintillation vial for Cerenkov counting using a liquid scintillation counter.

In all experiments, the combined results of harvest I and II were presented since none had shown any significant interaction between harvests and treatments.

Results

Lateral root spread

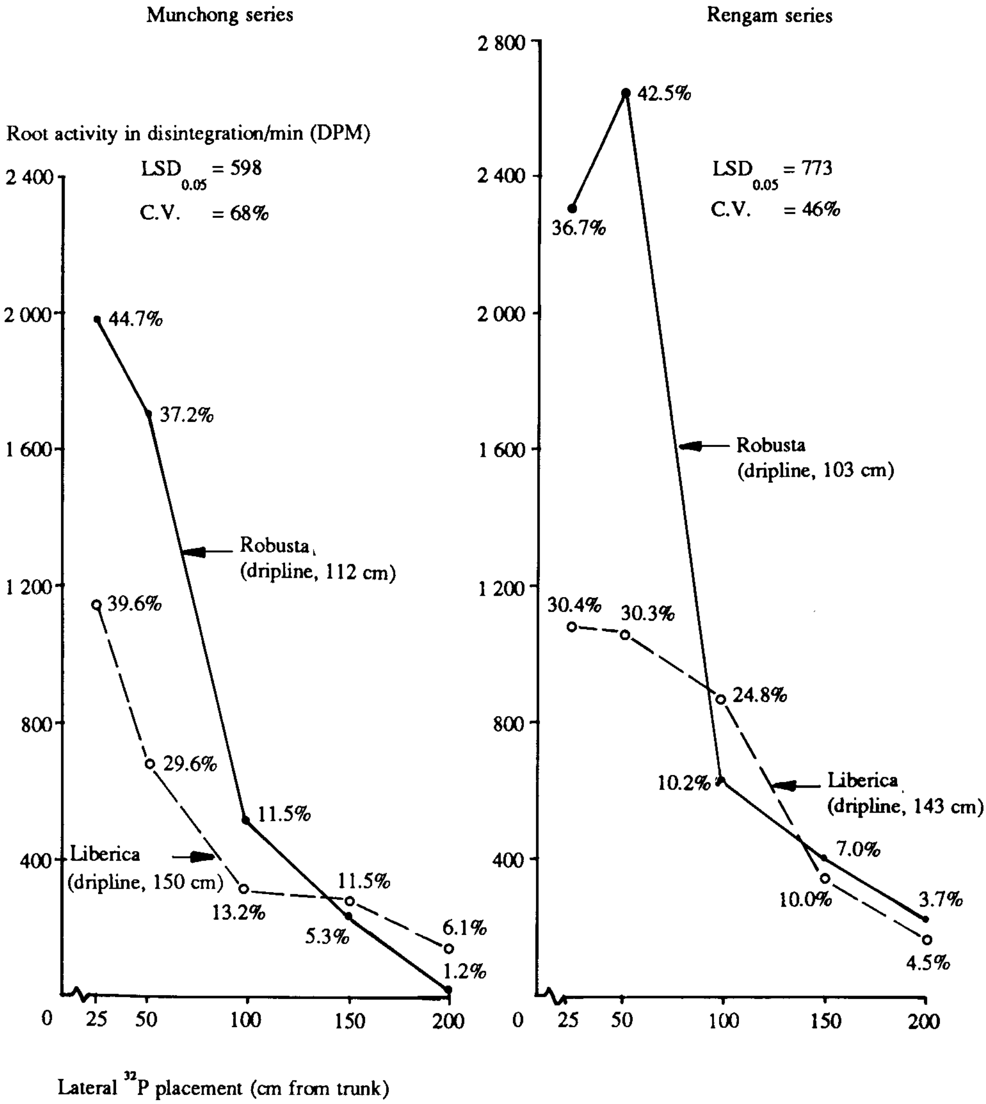
Species effect The active root distribution of surface lateral roots (10 cm depth) of Liberica and Robusta coffee grown on two soils viz. Rengam series and Munchong series soil is presented in *Figure 1*.

The interactions between species and placement were significant ($p = 0.05$) on both soils. Generally, both Liberica and Robusta species had the highest concentration of active roots located close to the trunk within the 50 cm radius and declined thereafter. The decline was less marked in Liberica coffee, indicating a wider spread of its lateral roots. The effects were similar on both soils.

Between 30% to 40% and 30% of the total root activity of Liberica coffee were observed at the 25 cm and 50 cm radius respectively, while 10–12% was observed at the 150 cm radius which is near the dripline (*Figure 1*). Only 5–6% of the total activity was located at the 200 cm radius. For Robusta coffee, the concentration of active

Table 1. Experimental detail

Expt. No.	Location/ Soil series	Treament					Plant age (years)	Planting distance (m)	^{32}P applied (mCi/plant)	Sampling for ^{32}P assay days after ^{32}P appl.	
		Species	Av. girth size (cm)	Lateral placement (cm)	Depth (cm)	Repl.				1st	2nd
	Serdang										
1	Bungor	*C. liberica*	22.4, 30.5	25,50,100,150,200	10	4	5	3 x 3	2.4	24	53
2	Munchong	*C. liberica*	31.2	25,50,100,150,200	10	5	13	3 x 3	2	29	49
		C. robusta	34.8				13	3 x 3			
3	Munchong	*C. liberica*	33.7	50,100,150	5,50,100	4	14	3 x 3	3	28	-
		C. robusta	44.1				14	3 x 3			
	Kluang										
4	Rengam	*C. liberica*	24.4	25,50,100,150,200	10	3	8	3 x 3	2	31	50
		C. robusta	38.9				8	3 x 3			
	Parit Botak										
5	Parit Botak	*C. liberica*	29.3	50,100,150	5,30,50	4	20	3 x 3	3	29	-
	Pontian										
6	Moderately deep peat	*C. liberica*	19.0,26.1	25,50,100,150,200	10	3	5	3 x 3	2	30	50
7	Shallow peat	*C. liberica*	25.0,40.6	25,50,100,150,200	10	3	8	3 x 3	2	30	50
8	Shallow peat	*C. liberica*	41.1	50,100,150	5,30,50	4	14	3.7 x 3.7	3	29	-



$$\% \text{ distribution of activity} = \frac{\text{DPM values of treatment}}{\text{Total DPM values of all treatments}} \times 100$$

Figure 1. Root activity and percentage distribution of surface (10 cm depth) lateral roots of Liberica and Robusta coffee on the Munchong and Rengam series

roots found near the trunk was higher, accounting for 37–45% of the total activity at the 25 cm radius and 38–43% at the 50 cm radius while only 10–12% was located at the 100 cm radius which is located near the dripline, 5–7% at the 150 cm and 1–5% at the 200 cm radius.

Age effect Generally, younger Liberica coffee trees grown on peat had higher concentrations of active roots located closer to the trunk than older trees as indicated by the sharp decline in the root activity beyond the radius of 50–100 cm. The decline was progressively less pronounced with age,

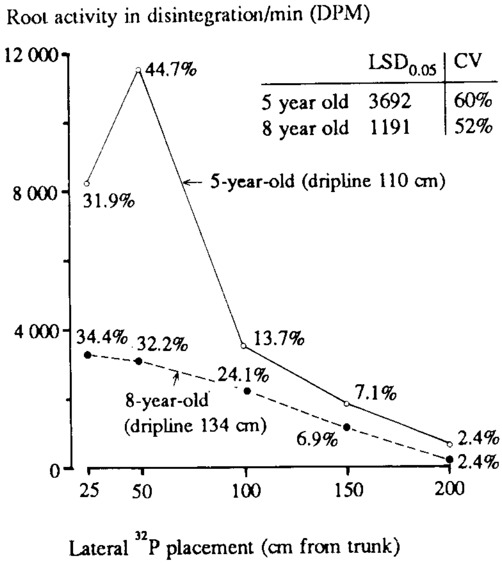


Figure 2. Root activity and percentage distribution of surface (10 cm depth) lateral roots of 5 and 8-year-old Liberica coffee grown on peat soil

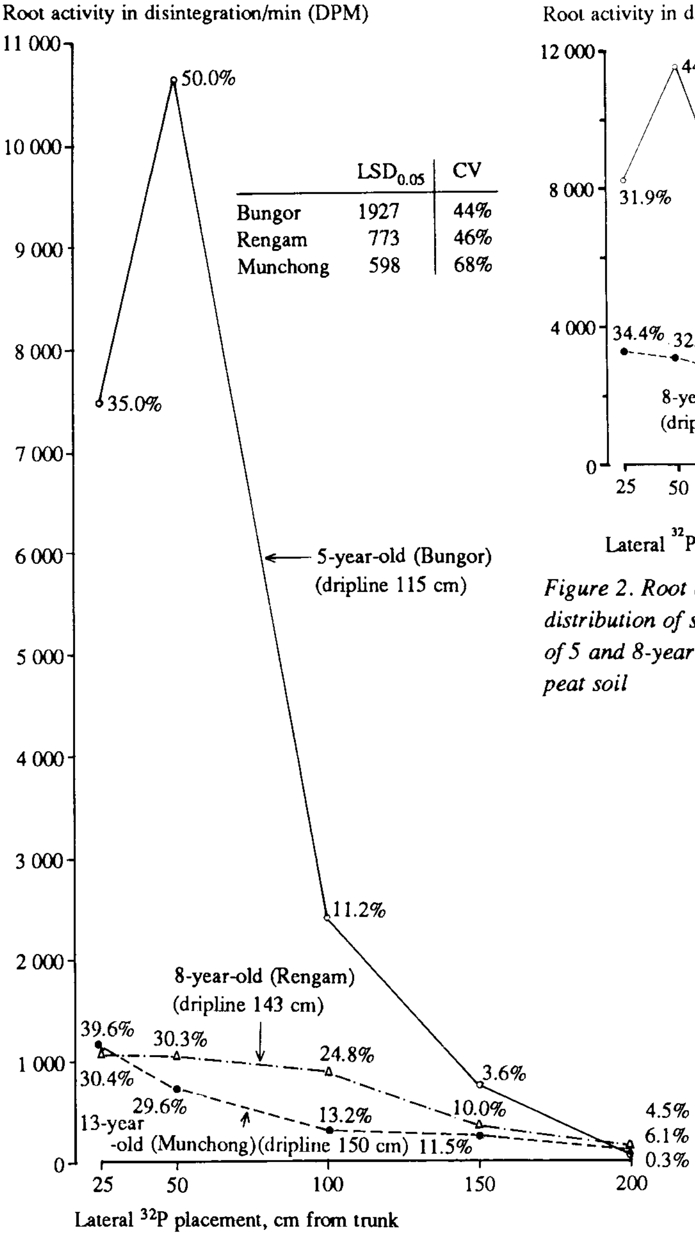


Figure 3. Root activity and percentage distribution of surface (10 cm depth) lateral roots of 5, 8 and 13-year-old Liberica coffee grown on three inland soils

indicating a wider spread of the active surface roots of older trees (*Figure* 2). Similar trends were observed on the inland soils (*Figure 3*) although the experiments were conducted on three different soil series (viz. Bungor, Rengam and Munchong series). It is, however, noteworthy that the three soil series have several similarities in terms of their physical (viz. texture and bulk density) and chemical (viz. pH and CEC) properties.

On both the peat and inland soils, the root activity of 5-year-old Liberica coffee trees increased marginally from 32–34% at

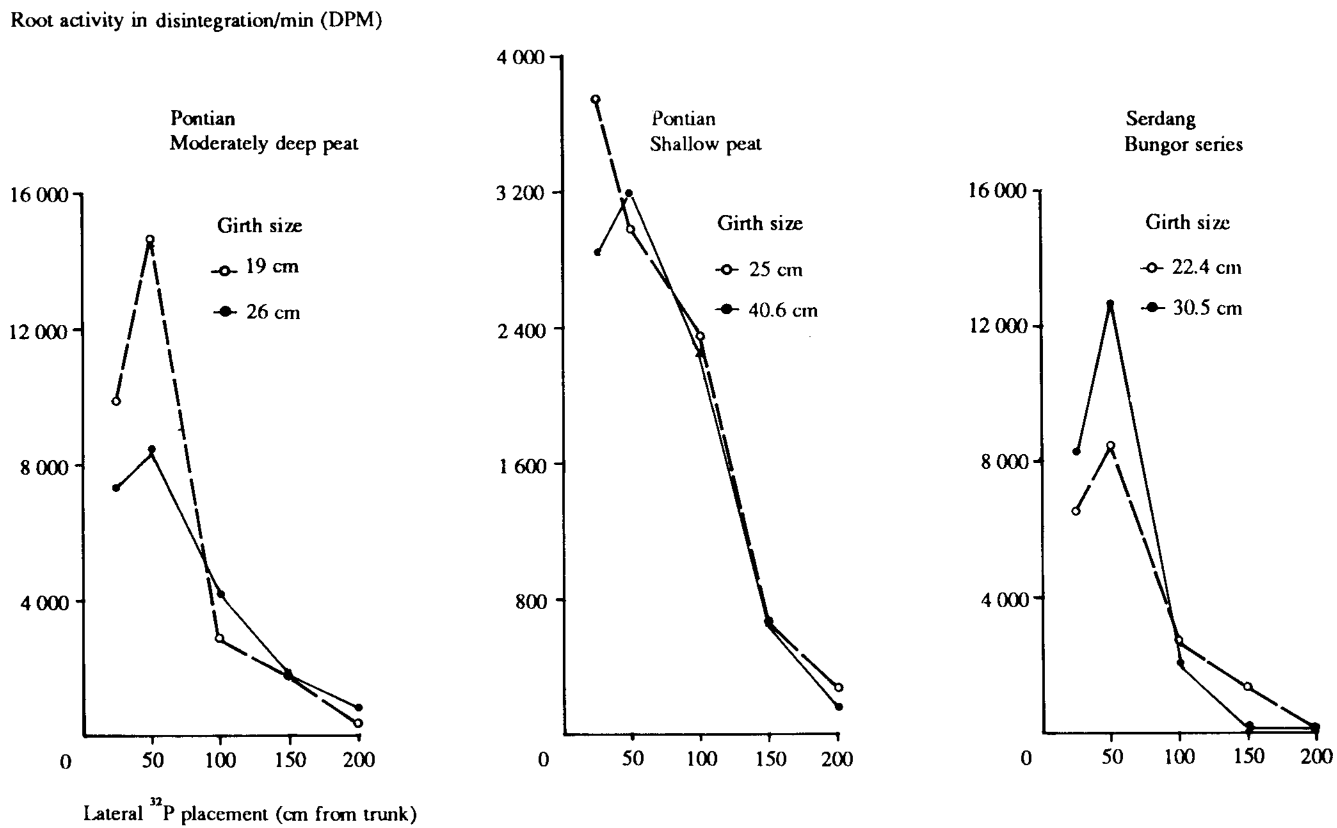


Figure 4. Effect of girth size on root activity distribution of surface (10 cm depth) lateral roots of Liberica coffee grown on different soils

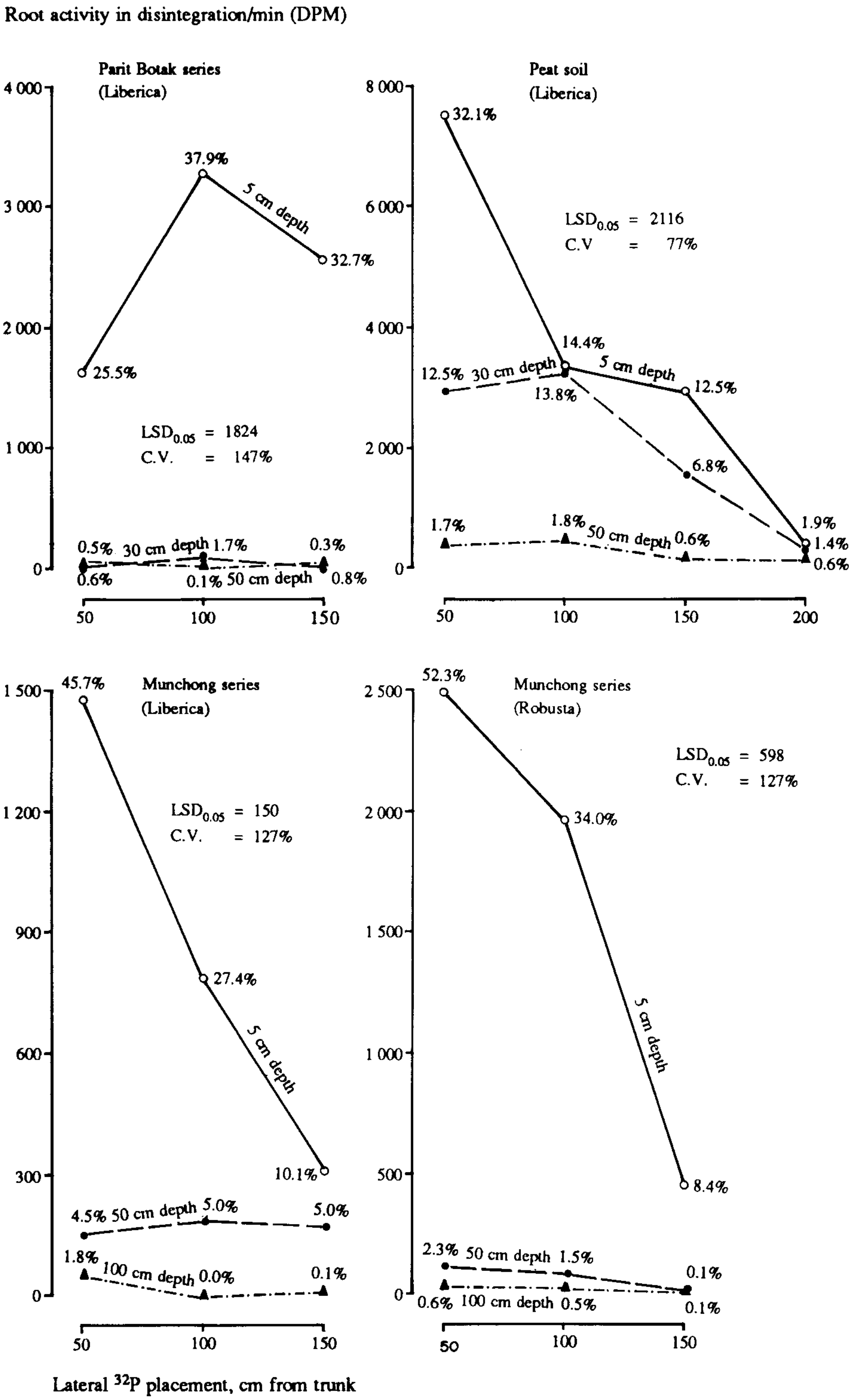


Figure 5. Root activity and percentage distribution of lateral and vertical roots of Liberica and Robusta coffee grown on 3 different soils.

the 25 cm radius to 45–50% at the 50 cm radius. Thereafter, the activity declined markedly to 11–14% at the 100 cm radius before tapering off at 4–7% and 0–2% at the 150 cm and 200 cm radius respectively. For the older 8-year-old trees, the activity showed a more gradual decline from a maximum of 30–34% at the 25 cm radius to about 25% at the 100 cm and 2–6% at the 200 cm radius. Except for a lower activity (13%) at the 100 cm radius, the active root distribution of the 13-year-old trees was similar to that of the 8-year-old trees.

In all cases, irrespective of age or soils, the root activity around the dripline was well below the area closer to the trunk.

Girth size effect The analysis of variance showed no significant interaction between girth size and placement. This indicated that girth size did not have any significant effect on lateral root spread in any of the three soils although on one site (shallow peat) the difference in girth size was as high as 62% (*Figure 4*).

Root depth and spread

The interaction between depth x lateral root spread was highly significant ($p = 0.01$), on two soils (viz. Munchong series and peat) while on the Parit Botak series, only the depth effect was significant ($p = 0.01$, *Figure 5*).

The significant interaction is essentially the result of a sharp decline in root activity of the surface lateral roots with distance from the trunk and a markedly less or absence of active sub-surface roots. On Munchong series, 83% of the total root activity of Liberica coffee were located at the 5 cm depth, 88% of which within the 100 cm radius. Almost all the remaining active roots (15%) were distributed at the 50 cm depth while activity at the 100 cm depth was negligible (2%). The trends were similar with Robusta coffee which has almost 95% of the active roots located at the 5 cm depth and confined mainly to the 100 cm radius.

On peat, almost all the active roots were located at the 5 cm (61%) and 30 cm (35%) depth, most of which within the 150 cm radius. Activity at the 50 cm depth was less than 5% of the total activity.

In contrast, Liberica coffee grown on acid sulphate soil (Parit Botak series) had virtually all (96%) the active roots confined to the surface (5 cm depth).

Discussion

Fertilizer placement poses unique problems in tree crops. Besides wide plant spacing, several other factors viz. variety and plant age (Rogers 1953), soil type (Rogers and Booth 1960), moisture (Beukes 1984) and plant nutrients (Gardner et al. 1952) can influence root distribution and consequently fertilizer placement. Purohit (1980), in his review on fertilizer placement in fruit trees, concluded that the spread of the crown serves only as a rough guide while the spread of the root system does not necessarily coincide with maximum feeding area.

From the present study, it can be summarized that both the coffee species viz. *C. liberica* and *C. robusta* grown under two different inland soils (viz. Munchong and Rengam soil series) and peat at different locations (viz. Serdang, Kluang and Pontian) have similar distribution of active surface feeder roots when measured in relation to the spread of the tree crown (*Figure 1*). The similarity is characterized by the high concentration of active feeder roots nearer to the trunk and low activity at the dripline (*Figure 1*). In both species, the activity at the 25–50 cm radius from the trunk was 3–4 times higher than those at the dripline. Similar trends were previously reported by Saiz del Rio et al. (1961) and Huxley et al. (1974) on Arabica coffee.

The effect of tree age on surface lateral root distribution of Liberica coffee showed similar trends in both the peat and inland soils although the latter were tested under different soils and environmental conditions (*Figure 2* and *Figure 3*). Generally, younger

Liberica coffee trees had higher activity of the surface feeder roots located at the 25–50 cm distance from the trunk. The activity, however, declined progressively with age resulting in a wider spread of the surface feeder roots. But in all cases, irrespective of age, activity was 2–4 folds higher at the 25–50 cm radius than at the dripline. It is, however, interesting to note that in experiments 1 and 6 (*Figure 2 and Figure 3*), a distintively lower activity in the area close to the trunk (25 cm radius) was observed, all of which were associated with younger 5-year-old trees.

In all the three experiments (1, 6 and 7), girth size did not have any significant effect on the distribution of surface feeder roots (*Figure 4*).

On Munchong series, almost all the active roots of Liberica and Robusta coffee were confined to the soil surface (*Figure 5*). However, Liberica coffee appeared to have a somewhat deeper rooting habit than Robusta coffee as shown by the higher activity (15%) at the 50 cm depth. In both species, however, root activity was negligible at the 100 cm depth. In contrast, Arabica coffee grown on well-drained Kikuyu red loam in Kenya has been shown to have deep active roots (IAEA 1975). However on the Munchong soil, the decline in root activity with depth may possibly be associated with the lower fertility and bulk density of the soil (*Appendix 1*). On the Parit Botak series where the root activity of Liberica coffee was confined to the 5 cm depth, the extremely low soil pH (3.4) and high levels of exchangeable aluminium (6–7 meq/100 g) at the 15–30 cm depth may have restricted the root growth.

In contrast, Liberica coffee grown on peat had deeper distribution of active roots where activity at the 5 cm and 30 cm depths accounted for 61% and 35% respectively of the total activity. Very low root activity was located at the 50 cm depth which is probably associated with the fluctuating high watertable.

It is noteworthy that although the area below the canopy received regular applications of fertilizers, root activity was higher in the area closer to the trunk. However, the presence of plant debris commonly observed around the trunk may have influenced the moisture and nutrient status of the soil and consequently the root activity in the area.

From this study, it can be concluded that *C. liberica* and *C. robusta* commonly grown in Peninsular Malaysia have higher activities located near the surface and closer to the trunk than the dripline. In view of this, current fertilizer management involving interrow application (Leong 1986) and broadcast application below the canopy (Abd. Rahman Azmil et al. 1989) should be amended. This study recommends that fertilizer application would be most effective when the fertilizer is placed closer to the trunk below the canopy.

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Appendix 1. Site details and chemical properties of composite samples from experimental sites

Location/ P. material	Soil series/ soil taxonomy	Depth (cm)	pH water 1:2.5	Base saturation (%)	CEC (meq/100g)	Texture	Organic matter (%)	Bulk density (g/cc)
Serdang	Bungor	0–15	4.7	35.0	7.9		0.88	1.15
Shade/	Typic Paleudult	15–30	4.7	18.0	7.0	Sandy clay	0.68	1.25
sandstone		30–45	4.6	10.0	3.5		0.55	1.36
Serdang	Munchong	0–15	4.5	6.1	13.8		1.83	1.15
Shale	Tropeptic Haplorthox	15–30	4.5	8.9	8.0	Clay	1.35	1.27
		30–45	4.5	5.0	8.0		0.98	1.28
Kluang	Rengam	0–15	4.6	49.1	8.0		2.74	1.25
Granite	Typic Paleudult	15–30	4.0	14.2	10.9	Sandy clay	1.72	1.30
		30–45	4.2	8.0	7.4		0.71	1.40
Parit Botak	Parit Botak	0–15	3.8	8.8	36.9		16.2	0.62
Marine	Typic Sulphaquept	15–30	3.4	12.1	32.3	Clay	7.7	0.65
alluvium		30–45	3.2	16.0	18.2		2.2	0.62
Pontian	Moderately shallow peat	0–15	3.2	3.5	133.3	-	-	0.17
Peat	Typic Tropohemist	15–30	3.2	5.1	119.2	-	-	0.13
		30–45	3.1	6.5	120.0	-	-	0.12
Pontian	Shallow peat	0-15	3.6	11.0	150.7	-	-	0.20
Peat	Ferric Tropohemist	15–30	3.6	10.7	148.2	-	-	0.18
		30–45	3.6	10.9	145.0	-	-	0.17