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NUTRIENT ABSORPTION BY OIL PALM PRIMARY ROOTS AS AFFECTED BY EMPTY FRUIT BUNCH APPLICATION

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ABSTRACT

Various parts of the oil palm primary roots were tested to determine the part which absorbs nutrients. An understanding of this aspect of nutrient absorption by the oil palm will explain why the application of empty fruit bunches (EFB) is important. Applying EFB increases the amount of roots, thus increasing the palm's ability to absorb nutrients and hence, potentially making fertilizer applications more effective. To determine which part of the roots collects and absorbs nutrients, various locations on the primary roots, starting from the root tip, were treated with a solution of KH_2PO_4 containing 5 µg P ml^{-1} and 4 µCi of carrier-free ^{32}P. The various locations were identified based on their colour, i.e. *creamy white for the root tip, beige for that part of the root just after the creamy white portion, and dark brown for the oldest part of the root. After 24 hr of exposure, the amount of radioactivity emitted from each location was determined. Another experiment was conducted to determine the nutrient distribution pattern in the root after the nutrient was absorbed. In this experiment, the root tip and the part of the root that was dark brown in colour were treated with potassium chloride solution laced with ^{86}Rb for 24 hr. After that time period, about 1 cm of each treated root, starting from the root tip and moving towards the palm base was cut, and their radioactivity determined. Results show that the part of the root that was creamy white (root tip) was significantly more active ($P<0.05$) in absorbing the nutrient compared to the other parts of the root. The amount of nutrient absorbed at that part of the root increased over time and was significantly higher ($p<0.05$) at 72 hr compared to absorption at 24 hr. The nutrient distribution pattern in the root from the point of exposure towards the palm base was different when the nutrient was absorbed from the root tip compared to the older part of the root which was dark brown in colour. When the nutrient was absorbed at the root tip, the distribution pattern of the nutrient along the length of the root from the tip to the base of the palm showed a certain pattern. Nutrient concentration was highest at the tip of the root and gradually decreased along the root towards the palm base. However, the nutrient distribution in the treatment of the dark brown part of the root did not follow the same pattern. It is suggested that the nutrient collected within the spaces in the older brown part of the root and flowed towards the root tip before being absorbed. Application of EFB increased the mass of roots. The results imply that for fertilizer application to be more effective, the fertilizers should be applied to those places where most of the roots are formed,* i.e. *especially under the heaps of EFB.*

Keywords: oil palm roots, nutrient absorption, ^{32}P, ^{86}Rb, oil palm empty fruit bunches.

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INTRODUCTION

Over the years, much effort has been expended to increase the amount of oil that can be produced from 1 ha of oil palm. One such effort is the study of how nutrients are acquired by the oil palm roots. It was felt that a better understanding of how nutrients are acquired could lead to improved fertilizer application and increased oil yield.

There has been a number of opinions from Ruer (1967), Jourdan and Rey (1997) and Corley and Tinker (2003) on the structure of oil palm roots in relation to nutrient acquisition. Corley and Tinker (2003) believed that root length is more important than root mass or volume for effective diffusion of nutrients to occur. The water and nutrient uptake process was thought to be more effective with a longer root length. However, Ruer (1967) and Jourdan and Rey (1997) were of the view that nutrients are only absorbed at the distal end of the roots, particularly where the root tissues are creamy white in colour. Ruer's (1967) investigations of the oil palm root anatomy led him to believe that nutrients are absorbed at the distal end of the roots. From another approach, Jourdan and Rey's (1997) findings using video densitometry led to their view that nutrient absorption occurs at the distal end of the roots. It is obvious then that there are two different schools of thought about oil palm roots in relation to nutrient acquisition. This is not surprising as uptake of nutrients into the roots is a complicated process for most essential elements, and the process is compounded by the plant's nutrient demand. In addition, different nutrients are said to be absorbed at different locations on the roots (Corley and Tinker, 2003).

Whichever the view, many oil palm planters and agronomists in the industry have long observed that the application of empty fruit bunches (EFB) leads to increased yield (Loong, *et al.*, 1987; Lim and Chan, 1989; Lim, 1998; Lim and Zaharah, 2000; 2002). They suspect that improved soil-available K as a result of EFB application may have much to do with the better yields. What is not so obvious, however, is that the proliferation of roots under an improved soil condition is also an important contribution to the increased yield. Tailliez (1971) and Hamdan *et al.* (1998) had earlier suggested this idea. An article recently published by Liew and Zaharah (2007) provides further evidence to support the idea. Other than these observations, there is no other direct evidence available.

To determine which of the two points of view is correct, *i.e.* whether nutrients are absorbed at the apical part of the roots or along the entire length of roots, experiments were conducted. The effect of EFB on root proliferation was also investigated and ascertained. As such, the objectives of the studies were: (i) to determine amount of phosphate absorbed at various parts of a primary oil palm root, (ii) to determine the distribution pattern of potassium in the primary root after being treated with potassium solution, and (iii) to determine the effects of EFB application on root proliferation.

MATERIALS AND METHODS

Absorption Segment of the Primary Root

In these experiments, 3-year-old DxP palms were used. Primary roots were isolated, and the following parts of the roots were treated: a) the root tip which was creamy white in colour, b) the part of the roots which was beige in colour, and c) the part of the roots further back from the root tips where the colour was dark brown. The roots were all in a horizontal position in the soil. Care was taken to choose those primary roots that had no new emerging roots. Each treatment was replicated five times. For the treatment, a 50-ml solution of KH_2PO_4 containing 5 μg P ml^{-1} and 4 μCi of carrier-free ^{32}P was injected into a plastic bag, which had been wrapped around the different parts of the roots as categorized above. About 6-10 cm of the treated part of the root was wrapped with a plastic bag with both ends of the bag secured to the root with rubber bands.

The roots were exposed to the ^{32}P solution for 48 hr, after which they (roots) were cut off and placed in clean glass vials. The treated part was labelled P0. For beige or brown roots, sections of the roots about 3-4 cm long were progressively cut off before and after the treated part. The sections after the treated part and approaching the root tip were labelled P1, P2 and so forth. For the white part of the roots, there were no P1 and P2 sections because the root tip was already the end of the root. The sections before the treated portion were labelled P-1, P-2 and so forth (*Figure 1*). The root sections were then oven-dried at 72ºC until constant weight and the data recorded.

Each root section was in turn cut into shorter lengths of about 0.5 cm and placed in separate clean glass scintillation vials. A 10-ml solution of scintillation cocktail was then pipetted into each vial and placed in a Liquid Scintillation Counter (model Tri-Carb 3100TR by Packard-Packard BioScience Co.), and the exposure time was set at 5 min. The count per minute was then recorded. This count was then divided by the dry weight of the root to get the count per gram of root. The data were transformed using $\log_{10}$ and then subjected to Analysis of Variance.

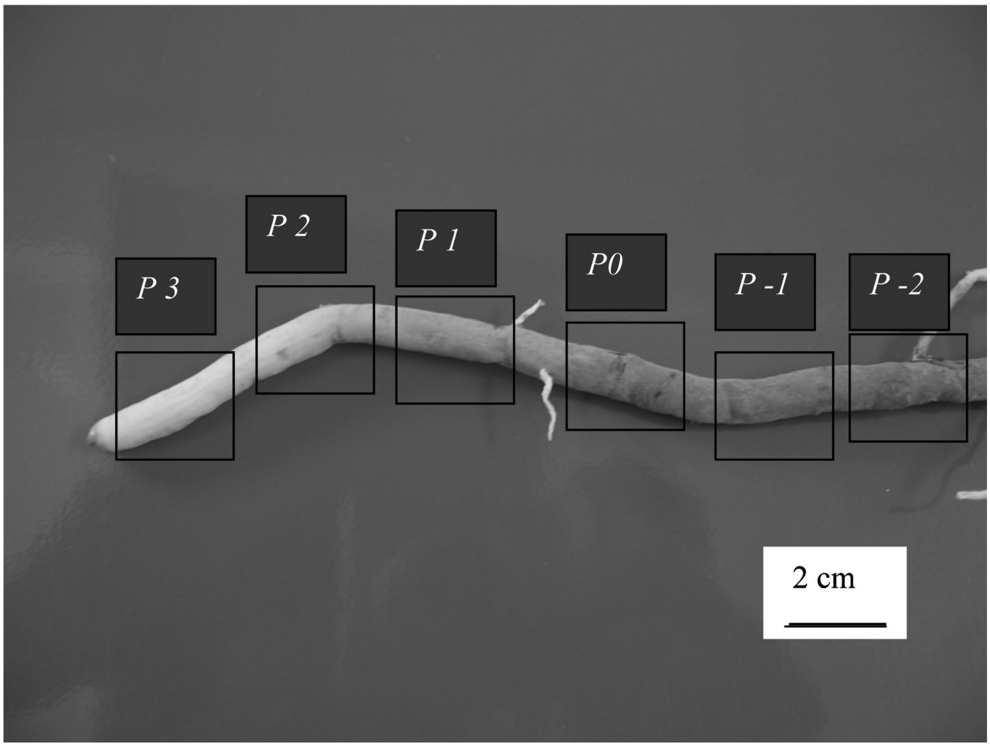

Figure 1. Order and labelling of primary root sections before and after the treated area (PO).

Uptake of Potassium in Primary Roots with Time

This experiment was carried out in a glasshouse at Universiti Putra Malaysia, using 12-month-old DxP oil palm seedlings. The seedlings were first labelled according to the treatments described below, and then arranged in a randomized complete block design (RCBD) with four replicates, using one palm per replicate.

To study the nutrient uptake pattern of an oil palm root, 1000 ml of a 0.05 M solution of potassium chloride labelled with 3 mCi of ^{86}Rb was first prepared. Fuchia dye was added to the KCl solution to monitor the movement of the solution in the root. This solution was used later after a root had been identified. Using jets of water, about 5-7 cm of primary roots together with their tips were first isolated and washed with distilled water. Then, about 2 cm of the root tip which was white in colour was inserted into a plastic tube. Using a syringe, 10 ml of the KCl solution were injected into the plastic tube (*Figure 2*).

The brown portion of the primary roots was treated in the following manner. A plastic tube measuring 10 cm length x 2 cm width was first obtained. As both ends of the plastic tube were open,

Figure 2. Feeding of brown roots with KCl solution labelled with ^{86}Rb. A few drops of Fucia dye gave the solution its red colour.

the plastic tube could be sleeved up the root and the lower end tied to form a cup. A 10 ml ^{86}Rb-labelled 0.05M KCl solution was injected into the tube.

The treatments were:

T1 - brown part of the root treated with ^{86}Rb-labelled 0.05 M KCl solution for 24 hr;
T2 - white part of the root treated with ^{86}Rb-labelled 0.05 M KCl solution for 24 hr;
T3 - white part of the root treated with ^{86}Rb-labelled 0.05 M KCl solution for 48 hr; and
T4 - white part of the root treated with ^{86}Rb-labelled 0.05 M KCl solution for 72 hr.

After the various treatment times, about 2 cm sections of the roots were cut starting from the treated portion and moving towards the palm base. The cut roots were then washed in distilled water, dried with a paper towel and placed in separate glass vials. The vials were then labelled and sent to Nuclear Malaysia (which is a centre for nuclear research) to determine the radiation count from each sample using a gamma counter.

Effect of Empty Fruit Bunches on Primary Root Proliferation

This experiment uses 3-year-old DxP palms was conducted at Field 2002A, Labu Estate, in Negeri Sembilan, where the palms were planted on Rengam series soil (Typic Kandiudult). The area has a gentle slope of about 7°. One layer of 110 kg EFB (+ EFB) was applied onto the soil surface covering an area of dimensions 1.3 m wide and 1 m long, placed at a distance of about 1 m from the palm base. On the opposite side of the same palm, an area of similar dimensions was marked out. No EFB was applied on this side and thus became the control treatment (-EFB). The arrangement of the two treatments is shown in *Figure 3*.

Also as can be seen in *Figure 3*, both treatments were applied in between palms of the same row so that the frond piles next to the treated palm would equally impact both the +EFB and -EFB treatments. The organic matter content of the top 15 cm of soil in the EFB-treated and non-treated areas was similar (1.56±0.63%).

Treatments were replicated five times and arranged in a complete randomized design (CRD). At three years old, the palms were fertilized every six months with 315 g N per palm from ammonium sulphate (21% N) and 750 g K per palm using muriate of potash (50% K). Ground magnesium limestone (1.5 kg per palm) and Jordan phosphate rock (13.2% P) at 340 g P per palm were applied separately once a year. A total of 2544, 2152 and 2424 mm of rainfall were recorded during the three years of palm growth.

To determine the effects of EFB or its absence on the proliferation of oil palm roots, three soil cores, each at 0-15, 15-30 and 30-45 cm soil depths, were collected in the centre of treated area using a specially designed soil auger (*Figure 4*) three months after treatment. The roots were manually separated from the soil, and later each root order was identified based on the criteria by Goh and Samsudin (1993). The sizes of the roots were classified according to their diameter, with the primary roots having diameters from 3.45-8.50 mm, secondary roots 0.85-3.30 mm, tertiary roots 0.30-1.05 mm and quaternary roots 0.2 mm. The weight of the soil mass, which was air-dried, and wet weight of the roots were determined. The root mass (which was oven-dried) when divided by the soil mass (which was air-dried) gave the root mass per unit soil mass. The data collected were analysed according to the paired T-test.

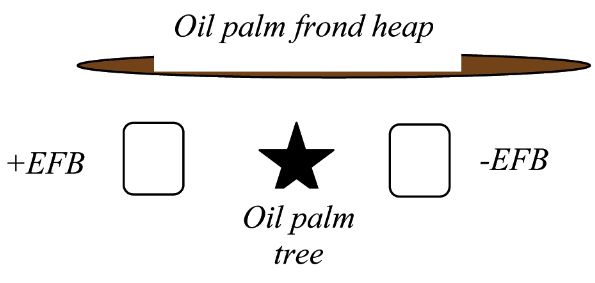

Figure 3. Positions of +EFB and –EFB treatments in relation to the oil palm tree and oil palm frond heap.

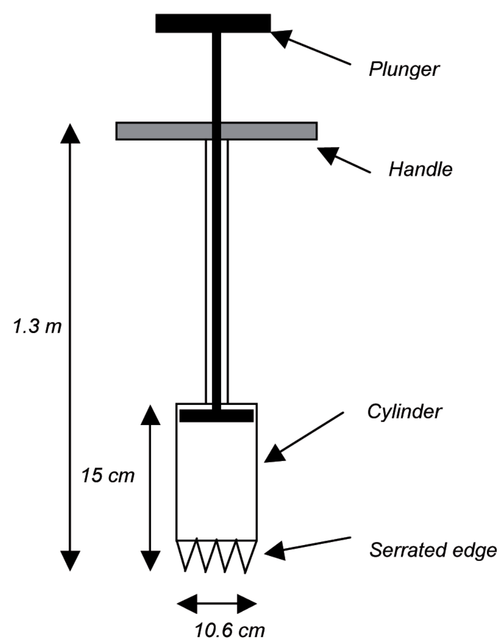

Figure 4. Soil auger used for root sampling in the experiment.

RESULTS

Absorption Segment of Primary Roots

At positions P1 and P2, the radioactive count at 48 hr was significantly higher for the beige root part compared to the brown root part (*Table 1*). P1 and P2 were also the white parts of the root. On the other side of P0, no difference in radiation count was observed among all three differently coloured root parts.

Uptake of Potassium in Primary Roots over Time

It was observed that the longer the white portion of the primary root was immersed in the ^{86}Rb laced potassium solution, the higher the amount of potassium absorbed. At 72 hr (T4) significantly more ($p < 0.05$) potassium was absorbed compared to treatments T1 and T2 (*Figure 5*).

By progressively tracing the radiation along the roots, starting from the root tip and moving towards the palm base, the distribution pattern of the potassium along the length of the root was determined. Potassium absorbed by the white portion of the root was observed to move towards the palm base. The amount of potassium, however, declined in the parts of the root progressively further away from the treated area (*Figure 6*).

When the white and brown portions of the primary roots were treated with the labelled potassium, the distribution pattern for the nutrient along a 10-cm length of the roots was observed (*Figure 7*). There appeared to be a distinct difference

TABLE 1. RADIOACTIVE COUNTS (X 10^5) OF ^{32}P AT VARIOUS POSITIONS FROM P0 AFTER 48 hr

Treatment (root colour)	P-2	P-1	P0	P1	P2
	---cpm/g root-------------------------				
White	20.0 ± 17.0a	96.0 ± 56.0a	-	No sample	No sample
Brown	1.3 ± 0.4a	7.0 ± 3.4a	-	1.9 ± 0.9a	1.4 ± 0.5a
Beige	2.6 ± 0.6a	8.5 ± 3.4a	-	57.0 ± 38.1b	18.0 ± 0.8b

Note: Means (+ S.E.) within a column with the same letter are not significantly different from one another at $\alpha = 0.05$ using paired T-test.

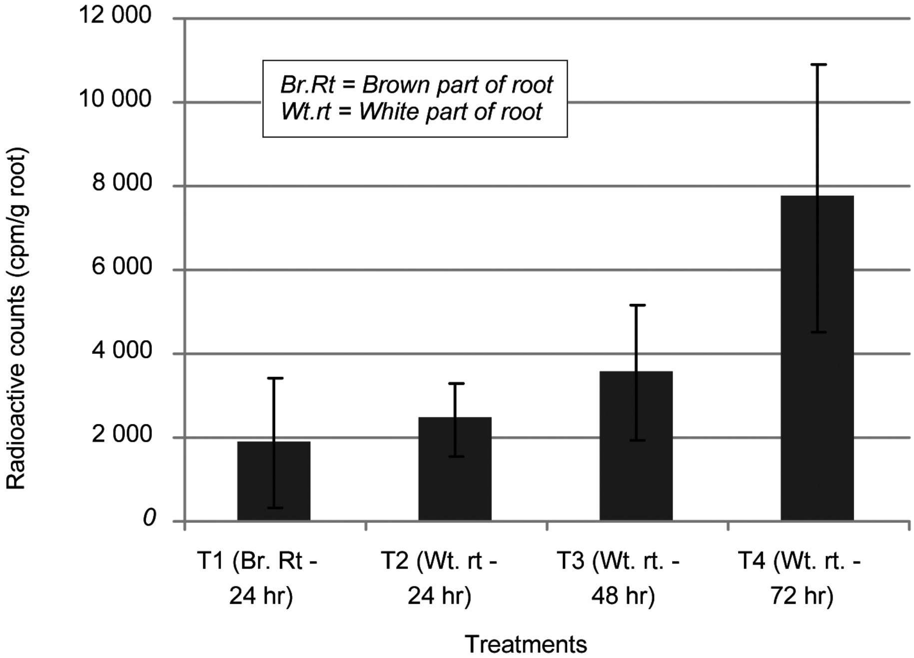

Figure 5. Pattern of potassium uptake when primary roots were treated with potassium solution labelled with ^{86}Rb.

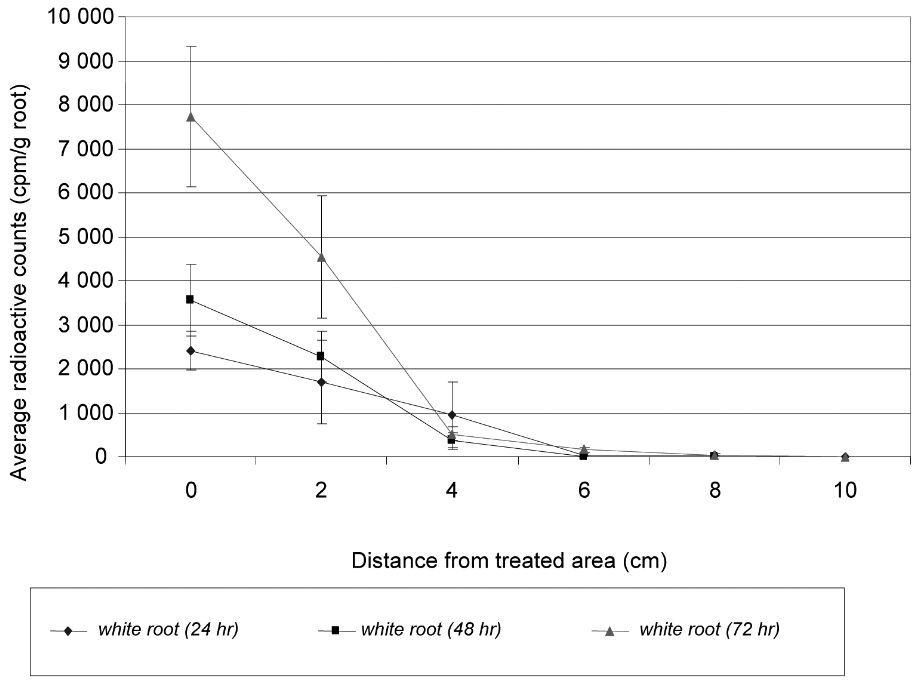

Figure 6. Radioactive counts from various parts of oil palm roots after soaking the white portion (root tip) for 24, 48 and 72 hr in KCl solution labelled with ^{86}Rb.

in the way the potassium was distributed within the root when the treatment was applied to the white or the brown parts of the roots. More potassium was observed within the brown compared to the white root parts, especially at the 6 and 8 cm portions of brown roots (*Figure 7*). No radiation was detected at the 10 cm part of the root, indicating that potassium did not reach there. The distribution pattern of potassium away from the treated area suggested that the way potassium entered the brown part of the root differed from that entering the white part of the root.

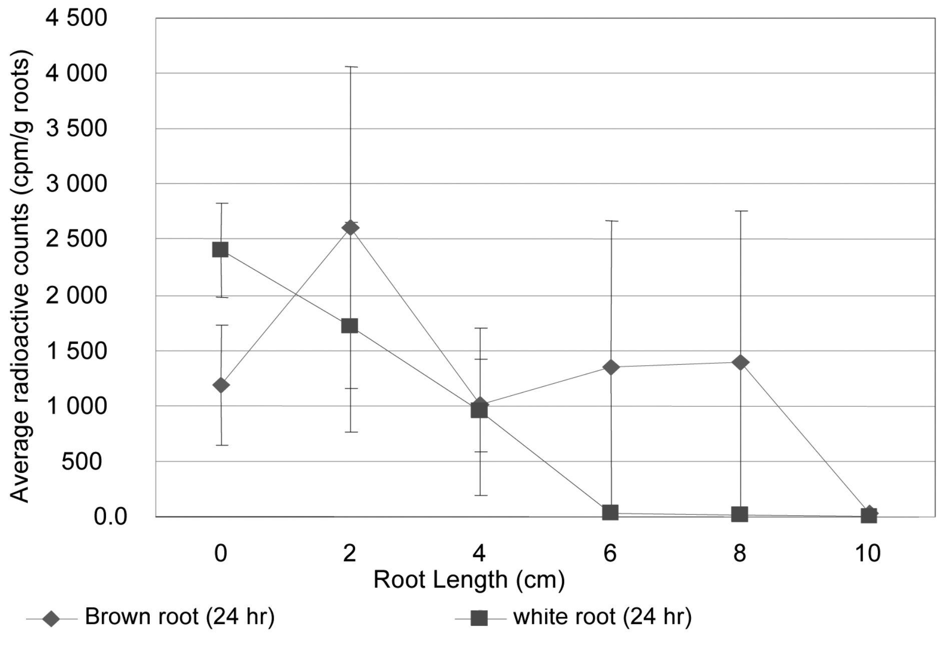

Figure 7. Movement of ^{86}Rb up the primary root towards the palm base from the white and brown portions of the roots within 24 hr.

Effect of Empty Fruit Bunches on Primary Root Proliferation

Application of EFB was observed to stimulate the development of roots of all orders, particularly at 30-45 cm depth (*Table 2*). There were significantly more roots at this depth for the EFB-treated area compared to the non-treated area. The roots at the EFB-treated area were a combination of all root orders, *i.e.* primary, secondary, tertiary and quaternary, with an average weight of 0.147 g/100 g soil.

A comparison of the mass of individual root orders showed no significant difference (α=0.05) in the weight of the various root orders between EFB and non-EFB treated soils (*Table 3*), probably brought on by the high variability observed.

DISCUSSION

The younger parts of the root, which are white to beige in colour, are more active in absorbing nutrients. Ruer (1967) and Jourdan and Rey (1997) were right when they suggested that the younger parts of the roots, usually the root tips, are the active sites of nutrient uptake. However, more importantly, our data also showed how nutrients were 'captured' and how they flowed within the root. The following descriptions attempt to describe how nutrients flow within a root and into the palm.

The morphology of the oil palm roots as described by Ruer (1967) shows that much of the oil palm roots are made up of aerenchyma cells. Such cells have empty spaces within them and as such can

TABLE 2. PROLIFERATION OF ROOTS (all orders) AT VARIOUS SOIL DEPTHS THREE MONTHS AFTER EMPTY FRUIT BUNCHES (EFB) APPLICATION TREATMENTS

Soil depth (cm)	Treatment	Mean root mass (g)/100 g soil
0-15	+EFB	0.055 ± 0.019a
	-EFB	0.083 ± 0.025a
15-30	+EFB	0.113 ± 0.004a
	-EFB	0.119 ± 0.027a
30-45	+EFB	0.147 ± 0.024a
	-EFB	0.072 ± 0.017b

Note: Means (± S.E.) of treatments at various soil depths followed by the same letter are not significantly different from one another at α=0.05 using paired T-test.

TABLE 3. PROLIFERATION OF THREE ROOT ORDERS AT VARIOUS SOIL DEPTHS THREE MONTHS AFTER APPLICATION OF TREATMENTS

Depth (cm)	Treatment	1^o roots	2^o roots	3^o (+ 4^o) roots
		---------Mean root mass/100 g soil---------		
0-15	+EFB	0	0.03 ± 0.01a	0.027 ± 0.007a
	-EFB	0	0.04 ± 0.01a	0.042 ± 0.017a
15-30	+EFB	0.06 ± 0.03a	0.04 ± 0.01a	0.009 ± 0.004a
	-EFB	0.08 ± 0.02a	0.03 ± 0.01a	0.005 ± 0.001a
30-45	+EFB	0.08 ± 0.03a	0.05 ± 0.04a	0.006 ± 0.002a
	-EFB	0.04 ± 0.01a	0.03 ± 0.01a	0.005 ± 0.002a

Note: Means (± S.E.) of treatments at various soil depths for each root order followed by the same letter are not significantly different from one another at α=0.05 using paired T-test. EFB – empty fruit bunches.

hold air, water and nutrients. In addition, there are also 'empty spaces' within the root structure. These spaces are larger than those found within the aerenchyma cells and are possibly formed when the aerenchyma cells die off and decay. Hence, when a nutrient solution enters the brown or beige parts of the roots, it (the solution) probably collects within these empty spaces. This explains the presence of a large amount of potassium within the length of the brown portions of the roots as shown in *Figure 7*.

It is likely that these spaces are interconnected, forming tunnels within the root. The tunnels would extend from the oldest parts of the root (which are dark brown colour) to the younger (beige) parts of the root. If the roots were inclined downwards, the nutrient solution would flow downwards, pulled by gravity, along these tunnels until it came in contact with the active white root cells where the nutrient was then absorbed.

That nutrients collected within the beige part of the root is shown in *Table 1*. The significantly higher amount of phosphate at positions P1 and P2 for the treatment at the beige part of the root compared to the treatment of the brown portion could only have come from P0, the part of the root exposed to the radioactive solution. Much of the radioactive solution at P0 had flowed into the 'spaces' within the beige portion of the root and into the white part of the root where the nutrient was absorbed.

The importance of this observation can be better understood when the root system is viewed as a whole. Scattered along the length of a primary root, emerging new active roots are often observed. These new roots could either develop into another primary root or a secondary root. If there are large numbers of these new roots, chances are that the nutrient solution that has collected within the 'empty spaces' would get into contact with the new roots. As the present data show, nutrients are absorbed into the palms when the nutrients come into contact with a white part of the root.

A situation could occur when the empty spaces within the roots are filled with water and nutrients. The soil nutrient solution would follow the apoplast pathway and when it is in close proximity to the active part of the root, the nutrients are absorbed. A concentration gradient is created, causing the nutrients that have collected in these empty spaces to flow towards the active sites. In a sense, these active sites could be called nutrient 'sinks'. If there is active uptake of the nutrient solution, then more nutrients would be drawn not only from within the root itself but also from the soil surrounding the roots, provided that the roots are still bathed in soil solution. An effective concentration gradient would have been set up drawing more nutrients into the roots. Kolek and Kozenka (1992) provided some insights into this mechanism in their review on roots and water uptake. Drew and Fourcy (1986) also gave further insights into this mechanism in *Zea mays*. The most important point to be made with respect to this concentration gradient is that it is probably happening over the entire length of the oil palm root system where new roots are emerging. With a total root length of about 51 to 71 km per palm (Tinker, 1976) for palms at ages 4.5 to 6.5 years, the palm is capable of acquiring a lot of nutrients. There does not seem to be any example of this mechanism occurring in other plant species, and this may be the first observation in oil palm. The implication of this result thus suggests that under the variable tropical climate, the chances of improving nutrient uptake would be better if fertilizers are applied to where most of the roots are located.

In addition to the above suggestion, the study could provide an explanation to some observations made by Khairuman (1998), and possibly also further explain the results obtained by Zaharah *et al.* (1989). Khairuman (1998) observed that root activities were higher under frond piles compared to the harvester's path located between the palm rows. This is because a higher mass of roots proliferates under the organic matter, possibly with much of these roots being new and active. The active state of the new roots draws nutrients into themselves, resulting in the high radioactivity observed by Khairuman (1998).

Zaharah *et al.* (1989) published results of a trial on phosphate fertilizer placement using 18-year-old DxP palms planted on Munchong series soil (Typic Haplorthox). In that trial, they placed ^{32}P into the soil of a frond heap and into the soil within a palm circle. They then monitored the surrounding palms for radioactivity. They found that the radiation count for palms with ^{32}P applied to the soil in the frond heap was much higher compared to palms with ^{32}P applied in the palm circles. Also, radiation was detected from palms further away (36 m) when ^{32}P was applied onto the frond heap compared to the palm circle. The following conclusions are, however, made with much caution because both trials were not conducted simultaneously. It was felt that the afore-mentioned ^{32}P distribution may not be just a coincidence but a reflection of the way the nutrient was absorbed and distributed by the larger mass of new primary and possibly other roots that had proliferated under the frond piles. This conclusion is suggested because the implications could be profound, leading to a more efficient fertilizer application method that can result in a reduction in the cost of production.

There are arguments that suggest that the total length of roots is important for effective nutrient uptake (Corley and Tinker, 2003). This argument is correct to some extent. As the present observation suggests, the soil nutrient solution could enter the roots via an apoplastic pathway and collect in the empty spaces within the root structure. As the data in *Table 1* suggest, the phosphorus in the solution is then 'pulled' towards the parts of the roots, P1 and P2, that are creamy white in colour and actively absorbing the nutrient. As such, if the total length of the roots is long then more nutrients are 'captured' within them and drawn towards the active parts.

This study, however, cannot disregard the possibility that nutrient absorption could have occurred at the older brown parts of the roots. Another study would need to be initiated to determine whether this is so.

In this study, the application of EFB resulted in a significant proliferation ($p < 0.05$) of roots, particularly at the 30-45 cm depth. This result implies that there may be more new 'creamy white' roots that are active. This is a positive development in terms of nutrient uptake, although the implication of this development is not clearly seen at this moment.

CONCLUSION

Phosphate is absorbed at the apical part of the root which is creamy white in colour. It is suggested that the soil nutrient diffuses into the older part of the root and then accumulates within the empty spaces there. If the nutrient solution is near the white creamy part of the root or root tips, then the nutrient (which in this case is phosphorus) would be absorbed into the root's xylem vessels. Application of EFB increases the mass of roots at the 30-45 cm soil depth. This appears to be a positive development for nutrient uptake, especially for easily mobile nutrients such as K.

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Announcement

In response to the numerous requests from the scientific community, academicians, students and readers, MPOB is pleased to announce that the Journal of Oil Palm Research (JOPR) will be published THREE times a year beginning 2010.

From 2010, JOPR will be published in April, August and December. The Journal will continue to publish full-length original research papers and scientific review papers on various aspects of oil palm, palm oil and other palms.

As part of our continuous effort to improve the quality and to offer value-added benefits to our valued readers, two new columns have been introduced in JOPR, *i.e.* Letters to Editor and Short Communications.

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