The Planter, Kuala Lumpur, ***98*** *(1155): 405-420 (2022)*

Root Distribution of Mature Oil Palms in Mineral and Peat Soils and Its Implication on Fertiliser Placement

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The correct placement of fertilisers is critical, as losses can be very significant especially in regions of high and frequent rainfall, non-terraced slopes, sandy textured soils and peat. To maximise uptake efficiency, fertilisers should be evenly broadcast over the soil surface area that contains the highest density of feeder roots. In order to determine the latter, an investigation was undertaken to ascertain the biomass and distribution of roots of various ages of mature oil palms planted in both mineral and second generation peat soils.

Results of the study indicate that if site factors are not limiting, palm age and past fertiliser placement history are two major factors influencing oil palm root development and distribution.

In mature well decomposed peat, although roots could be found growing 4 m from palm bole, actual root biomass per unit volume of soil was low. Only 21 per cent of the feeder roots of 8-year-old palms were found growing outside the weeded palm circles (WPC). Even within the latter, approximately 50 per cent were concentrated within a radius of 1 m from the palm bole. The low bulk density and high porosity of peat appears to discourage roots from growing beyond this distance.

In mineral soils, there was a consistent and gradual increase in root spread beyond the WPC, with palm age. Feeder root distribution beyond a 2 m radius ranged from as low as 26 per cent in 6-year-old palms planted on terraces to 41 per cent for 8-year-old palms established in non-terraced soils. Only palms older than 10 years of age had root biomass greater than 50 per cent beyond this radius.

In all sites, there was an increase in primary and secondary root biomass with soil depth and a linear decrease in feeder root biomass down the soil profile. Soil chemical analysis indicated that apart from palm age, the horizontal and vertical distribution of feeder roots was strongly influenced by soil fertility gradients created by past fertiliser placement history. As fertilisers were previously applied entirely in the WPC for younger palms (<8 years), there was a significant decline in soil fertility with increasing distance from the palm bole and increasing soil depth. The majority of feeder roots were concentrated within the 2 m radius from the palm bole and in the top 20 cm of soil, where nutrient levels were the highest. In older palms (>10 years) where fertilisers had been broadcast over frond heaps in the interpalm spaces and interrows, feeder root biomass was higher outside the WPC, as soil fertility gradients were less apparent.

Taking into account the root distribution patterns of oil palm in relation to palm age, specific recommendations on fertiliser placement for oil palm grown on mineral and peat soils are made, so as to improve fertiliser uptake and utilisation.

Keywords*: Fertiliser placement, oil palm, mineral soils, peat soil, root distribution.*

Being a monocotyledon, the oil palm has an adventitious root system that can be categorised into four main classes (Corley & Tinker, 2003). The primary roots measuring 6-10 mm in diameter originate from the base of the trunk and spread either horizontally or descend at various angles down the soil profile. From these emerge secondary roots 2-4 mm in diameter, which branch out into smaller tertiary roots (0.7-1.2 mm diameter), that in turn bear fine quaternary roots (0.1 - 0.3 mm diameter). The length and total biomass of the latter two categories of roots is highly important, as their major role involves absorption of nutrients and water, although the non-lignified tips of primary and secondary roots are also thought to assist in this function (Hartley, 1967; Corley & Tinker, 2003).

The amount of oil palm root biomass and its spread or distribution is highly dependent on a number of site factors, such as soil texture, structure, fertility, organic matter, moisture content, groundwater table, presence or absence of impermeable layers and existing vegetation. As the roots are the primary organs for nutrient and water absorption, an understanding of their growth and distribution in the soil is highly important, as they affect uptake efficiency of the applied fertilisers (Zuraidah *et al*., 2010).

Like most plantation companies, Asian Agri gives due consideration to the latter when developing its standard operating procedures (SOP) for fertiliser application and placement. In newly planted seedlings, the fertilisers are broadcast close to the seedling, commencing 15 cm from the palm bole to the edge of frond extension. As the palms grow older and their root systems spreads out, fertilisers are broadcast from a distance of 30 to 50 cm from the bole to the edge of the weeded palm circle. This practice continues until the palms are 8 years of age. At this age, palm canopies would be closing up and a significant amount of roots would have extended beyond the weeded circles and into the interpalm and interrow spaces. If both of the latter are weed free or only have light growth of vegetation, macro nutrient fertilisers are broadcast over the pruned fronds heaps which have been arranged in a u-shaped configuration, whenever fronds are removed during the process of harvesting and pruning. If the latter spaces are dense with vegetation, the fertilisers are still applied in the palm circles until weed control is implemented. Due to low dosages that are applied and to facilitate monitoring, micro nutrient fertilisers are broadcast close to the palm bole in the weeded circles, irrespective of palm age.

The correct placement of fertilisers is critical as losses can be very significant, especially in regions of high and frequent rainfall, non-terraced slopes, sandy textured soils and peat (Foong, 1993; Kee & Chew, 1996; Goh *et al*., 1999). Investigations carried out by Meane *et al.* (1979) showed that losses were higher when fertilisers were applied in weeded palm circles and harvesters paths, as compared to broadcasting fertilisers over frond heaps. Research trials on fertiliser placement have often recorded an increase in fresh fruit bunch (FFB) yield when fertilisers were generally broadcast over the entire area, as compared to application confined to weeded palm circles (Teoh & Chew, 1985; Foster & Tayeb, 1986).

In order to validate Asian Agri's current SOP on fertiliser placement in relation to palm age, a research project was initiated to investigate and document the distribution and spread of the root system of 8, 11 and 14-year-old palms planted on mineral soils and 8-year-old palms on peat soils. The study was later extended to include 6-year-old palms on non-terraced and terraced mineral soils in order to ascertain whether broadcasting of fertilisers over pruned frond heaps in the interrow and interpalm spaces could be implemented at an earlier palm age, in order to minimise fertiliser loss and enhance fertiliser uptake efficiency.

The results of this investigation are presented in this paper.

TRIAL DETAILS AND METHODOLOGY

Details on age of palms, planting density and spacing, soil type, soil texture and topography of sites in the investigation are summarised in *Table 1*. For each category, a total of 12 palms were selected for root inspection. In sites with flat to undulating topography, one palm was selected every tenth row in a repeated sequence (example: row 10: seventh palm, row 20: fourteenth palm, row 30: twenty-first palm, row 40: twenty-eighth palm, row 50: seventh palm, row 60: fourteenth palm, row 70: twenty-first palm, row 80: twenty-eighth palm etc.). On terraced sites, the twelve palms were selected from six terraces, with two palms per terrace, spaced ten palms apart. Care was taken to ensure that only normal palms with average palm height and size were selected. Abnormal palms plus those growing in depressions, along road and drain sides were omitted from the study.

For each selected palm on non-terraced sites 1, 2 and 3, soil-root sampling was conducted in three different directions i.e., parallel to the palm row (interpalm space), perpendicular to the interrow and perpendicular to the harvesters path and at eight predetermined distances from the palm bole (50 cm, 100 cm, 150 cm, 200 cm, 250 cm, 300 cm, 350 cm, 400 cm) and at three soil depths (0-20 cm, 20-40 cm, 40-60 cm). In sites 5 and 6, sampling was confined to the interrow and interpalm spaces and at a single soil depth (0-20 cm). This variation in sampling was introduced mainly due to cost and logistics constraints, since results of earlier investigations in sites 1, 2 and 3 had shown that a significantly lower biomass of feeder roots were found growing towards the harvesters paths or below a soil depth of 20 cm. It was assumed that a similar pattern of feeder root distribution would also be found in the older palms in sites 5 and 6. On terraced sites (site 4), soil-root sampling was carried out in only one direction i.e. parallel to the palm row (interpalm space) and at the same eight distances from the palm bole and at the same three soil depths.

For soil-root sampling, the trenching method as described by Sinuraya (2010) and Filliers *et al.* (2018) was adopted, with the dimensions of each trench being 1.0 m width x 1.0 m depth x 4.5 m length. A specially built scope measuring 20 cm x 15 cm x 15 cm (4,500 cm^3) was used to excavate the soil samples. Ring sampling to determine bulk density and porosity was carried out and an additional soil sample at each sampling point was also collected for chemical analysis (Sinuraya, 2010). The soil samples for root biomass determination were washed clean with water to separate roots from soil and the roots were then oven dried at 105°C for 14 hours. After drying, the roots were cut and separated into primary, secondary and tertiary/quaternary roots based on root diameter measurements, as given by Hartley (1967) and Corley and Tinker (2003). Due to the small size of the latter, tertiary and quaternary roots were placed into one category. On separation, all root categories were weighed to determine their respective dry weights, which was used as a direct estimation of their root biomass per given volume of soil (4,500 cm^3).

Soil samples for chemical analysis were analysed for pH, organic carbon, total nitrogen, total and available phosphorus and exchangeable potassium, calcium and magnesium. The ring samples were analysed for bulk density and percentage porosity. Duncan's multiple range test (DMRT) was

TABLE 1
DETAILS OF ROOT DISTRIBUTION STUDY SITES

Site	*Palm age (years)*	*Planting density (palms/ha)*	*Planting distance (m)*	*Soil type*	*Soil texture*	*Site topography*	*Sampling depth (cm)*	*Sampling direction from palm bole*
1	8	160	8.50 x 7.36	Deep peat (>3.0 m), Typic Haplosaprist	Sapric peat	Flat	0-20, 20-40, 40-60	Interrow, interpalm, harvesters path
2	8	143	9.02 x 7.81	Mineral, Typic Dystrudept	Sandy loam	Undulating to gently rolling, non-terraced	0-20, 20-40, 40-60	Interrow, interpalm, harvesters path
3	6	148	8.83 x 7.65	Mineral, Typic Kandiudult	Sandy clay loam to sandy loam	Undulating to gently rolling, non-terraced	0-20, 20-40, 40-60	Interrow, interpalm, harvesters path
4	6	148	8.83 x 7.65	Mineral, Typic Kandiudult	Sandy clay to clay	Hilly, terraced	0-20, 20-40, 40-60	Interpalm
5	11	143	9.02 x 7.81	Mineral, Typic Dystrudept	Sandy loam	Undulating to gently rolling, non-terraced	0-20	Interrow, interpalm
6	14	136	9.21 x 7.98	Mineral, Typic Dystrudept	Loam	Flat to undulating, non-terraced	0-20	Interrow, interpalm

carried out to determine statistical differences between different categories of root biomass and correlation analysis was undertaken to determine statistical relationships, if any, between root biomass and soil chemical and physical parameters.

RESULTS AND DISCUSSION

Root biomass x root size

The total root biomass of the various root size categories in the four sites at all soil depths and distance from the palm bole are summarised in *Table 2*.

For 8-year-old palms planted in deep peat (site 1), tertiary and quaternary feeder roots formed the largest portion (42%) of the root biomass, followed by secondary (34%) and primary roots (24%). This trend was reversed in similar aged palms planted on non-terraced sandy loam mineral soils (site 2). At the latter site, feeder roots only constituted 18 per cent of the total root composition, whilst primary and secondary roots constituted 54 and 28 per cent, respectively.

The root size composition of younger 6- year-old palms planted in heavier textured mineral soils in site 3 (non-terraced) and site 4 (terraced) followed the same pattern as their older counterparts in site 2. Primary, secondary and the finer feeder roots constituted 64 to 71 per cent, 17 to 19 per cent and 11 to 17 per cent of the root biomass, respectively.

The reasons for the disparity in root size composition between peat and mineral soils could be linked to bulk density and porosity characteristics of the soils. Peat soils generally have very low bulk density (<0.3 g/cm^3) and high porosity (>80%) as seen in *Table 3*. Consequently, primary root growth and spread may be curtailed, which may be compensated by a profusion of tertiary and quaternary root formation in order to fully exploit moisture and nutrients, under such limiting conditions. In contrast, the bulk density (1.0 - 1.6 g/cm^3) and porosity (30 - 50 per cent) of mineral soils, facilitates the development and spread of primary roots at the expense of the finer feeder roots, with the latter being sufficient in numbers to fully exploit moisture and nutrients within its rhizosphere.

TABLE 2
ROOT TYPES BIOMASS DISTRIBUTION AT VARIOUS SITES

Site	*Root dry weight (%)*		
	Primary roots	*Secondary roots*	*Tertiary and quaternary roots*
1 (8-year-old palms, deep peat)	24	34	42
2 (8-year-old palms, mineral soil, non - terraced)	54	28	18
3 (6-year-old palms, mineral soil, non - terraced)	64	19	17
4 (6-year-old palms, mineral soil, terraced)	71	17	11

* Total root biomass in bulked soil depth of 0-60 cm

TABLE 3
SOIL PROPERTIES OF SIX SAMPLING SITES

Soil texture and physical parameters	Soil depth (cm)													
	Site 1			Site 2			Site 3			Site 4			Site 5	Site 6
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	0-20
Coarse sand (%)	-	-	-	52	52	50	18	17	16	16	14	12	55	37
Fine sand (%)	-	-	-	16	15	16	34	33	33	30	27	26	16	7
Silt (%)	-	-	-	17	17	17	13	15	15	15	13	15	11	31
Clay (%)	-	-	-	15	16	17	35	35	36	39	46	47	18	25
Texture classification[1]	Peat	Peat	Peat	SL	SL	SL	SCL	SCL	SC	SC	C	C	SL	L
Bulk density (g/cm^3)	0.22	0.17	0.20	1.32	1.46	1.55	1.44	1.46	1.46	1.49	1.47	1.50	1.35	1.29
Porosity (%)	84	87	85	50	45	41	41	41	41	39	40	37	43	42

[1] Texture classification : SL = sandy loam, SC = sandy clay, SCL = sandy clay loam, C = clay, L = loam

Root types x soil depth

In most soils, the vertical distribution of the root system down the soil profile, depends primarily on the depth of the water table, the presence or absence of impediments, soil physical characteristics such as texture, structure, bulk density, porosity and fertility status (Corley & Tinker, 2003). In free draining soils, primary and secondary roots may descend to great depths. In Nigeria, roots were found at 3 m (Hartley, 1967) whilst Jourdan and Rey (1997) observed roots to a depth of 6 m in the Ivory Coast. However, Lambourne (1935) found very few roots below a water table at 0.9 m.

A similar pattern was found in this study. In peat (site1), there was a linear increase in the biomass of primary and secondary roots with peat depth. The largest proportion of primary (62%) and secondary roots (36%) were found at 40 to 60 cm depth, a reflection of their primary functions of water absorption and anchorage. In contrast, tertiary and quaternary roots showed a linear decrease with soil depth, with the highest concentration (45%) occurring in the top 20 cm of soil *(Table 4)*.

In all three mineral soil sites (sites 2, 3 and 4), the trend was similar to that observed in peat. The biomass of primary and secondary roots increased from 22 to 52 per cent at 20 to 40 cm soil depth and then decreased to as low as 17 per cent from 40 to 60 cm depth. On the other hand, tertiary and quaternary roots significantly decreased down the soil profile from 46 to 51 per cent in the top 0 to 20 cm, to only 19 to 22 per cent at 40 to 60 cm depth (*Table 4*).

The linear decline of feeder root biomass with soil depth in all the four sites is closely correlated with a fertility gradient down the soil profile (*Table 5*). Very strong negative

TABLE 4
ROOT TYPES BIOMASS DISTRIBUTION IN VARIOUS SOIL DEPTHS AT DIFFERENT SITES

Soil depth (cm)	*Root dry weight (%)*											
	Site 1 8-year-old palms, deep peat			*Site 2* 8-year-old palms, mineral soil, non - terraced			*Site 3* 6-year-old palms, mineral soil, non - terraced			*Site 4* 6-year-old palms, mineral soil, terraced		
	*IR**	*2R*	*3&4R*	*IR*	*2R*	*3&4R*	*IR*	*2R*	*3&4R*	*IR*	*2R*	*3&4R*
0 - 20	12	29	45	22	33	46	29	34	49	31	41	51
20 - 40	26	35	29	43	36	32	49	38	31	52	33	30
40 - 60	62	36	26	35	31	22	22	28	20	17	26	19

*IR = Primary roots , 2R = Secondary roots, 3&4R = Tertiary and quaternary roots

correlations were obtained between soil depth x root dry weight (r values > - 0.900) and between soil depth x soil nutrient levels (r values: -0.888 to -0.999) whilst a strong positive correlation (r values: 0.800 to 1.000) was recorded for root dry weight and soil nutrient levels (N, P, K, Mg, Ca) and soil organic carbon and pH. In peat, a moderate positive correlation (r values: 0.698) was also recorded with increasing bulk density and as expected, a strong negative correlation (r values: -0.930 to -0.999) between bulk density and decreasing root dry weight in two of the mineral soil sites (sites 2 and 3).

The strong negative fertility gradient down the soil profile is likely to be a result of past fertiliser applications and the decomposition of palm fronds and vegetation on the soil surface. In peat, more rapid mineralisation in the upper organic layers, would have further contributed to the development of higher fertility status at the upper soil layers.

Root biomass x horizontal distribution

The horizontal distribution of combined root sizes at various distances from the palm bole in all the six sites is summarised in *Table 6*.

In general, there was a significant decline (r values: -0.723 to -0.962) in root mass with increasing distance from the palm bole. In peat (site 1), 77 per cent of the root biomass was recorded within the weeded palm circle (0 - 2 m radius) and only 23 per cent found growing outside the latter (2 - 4 m radius) while 60 per cent of the roots were found concentrated within a radius of 1 m from the palm bole. Sinuraya (2010) recorded similar findings of root distribution of 16-year-old palms planted on first generation deep peat in the same locality. Eighty-nine per cent of the total root biomass was found within a radius of 1.5 m

TABLE 5
CORRELATIONS BETWEEN TERTIARY AND QUATERNARY FEEDER ROOTS IN RELATION TO SOIL DEPTH AND SOIL PHYSICAL AND FERTILITY PARAMETERS

Soil parameters	Coefficient of correlation (r)											
	Site 1			Site 2			Site 3			Site 4		
	SD[1] x RDW[2]	SD x SP[3]	RDW x SP	SD x RDW	SD x SP	RDW x SP	SD x RDW	SD x SP	RDW x SP	SD x RDW	SD x SP	RDW x SP
	-0.934	-	-	-0.996	-	-	-0.989	-	-	-0.988	-	-
pH (units)	-	-0.886	0.993	-	-0.822	0.867	-	-0.999	0.993	-	-0.983	1.000
Organic carbon (%)	-	-0.838	0.589	-	-0.964	0.983	-	-0.952	0.987	-	-0.978	0.999
Nitrogen (%)	-	-0.937	1.000	-	-0.971	0.987	-	-0.971	0.996	-	-0.993	0.999
Available phosphorus (ppm)	-	-0.868	0.988	-	-0.943	0.968	-	-0.919	0.967	-	-0.932	0.977
Exchangeable potassium (cmol/kg)	-	-0.851	0.982	-	-0.912	0.943	-	-0.903	0.956	-	-0.811	0.893
Exchangeable magnesium (cmol/kg)	-	-0.853	0.983	-	-0.866	0.905	-	-0.915	0.964	-	-0.959	0.991
Exchangeable calcium (cmol/kg)	-	-0.973	0.991	-	-0.910	0.942	-	-0.906	0.959	-	-0.943	0.983
Bulk density (g/cm^3)	-	-0.397	0.698	-	0.992	-0.999	-	0.866	-0.930	-	0.327	-0.175
Porosity (%)	-	-0.327	-0.643	-	-0.998	1.000	-	-	-	-	-0.327	0.175

[1] SD = Soil depth, [2] RDW = Root dry weight, [3] SP = Soil parameters

TABLE 6
HORIZONTAL DISTRIBUTION OF TOTAL BIOMASS IN 0 - 60 CM[1] SOIL DEPTH AT VARIOUS SITES

Site	*Root dry weight (%)*									
	Distance from palm bole (cm)								*Inside WPC*[2]	*Outside WPC*
	50	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*(0-200 cm)*	*(200-400 cm)*
1 (8-year-old palms, deep peat)	35	25	14	9	6	5	3	3	77	23
2 (8-year-old palms, mineral soil, non - terraced)	15	14	16	13	11	14	9	8	58	42
3 (6-year-old palms, mineral soil, non - terraced)	17	16	16	14	10	9	9	9	63	37
4 (6-year-old palms, mineral soil, terraced)	21	21	17	14	6	7	6	6	73	27
5 (11-year-old palms, mineral soil, non-terraced)	14	14	11	11	11	12	12	15	50	50
6 (14-year-old palms, mineral soil, non-terraced)	10	10	10	13	15	15	13	14	43	57

[1] For sites 5 and 6, soil depth 0-20 cm, [2] WPC = Weeded palm circle

from the palm bole and only 11 per cent occurred between 1.5 to 4.5 m. The low bulk density (<0.22 g/cm^3) and high porosity (>85%) inhibited roots from venturing too far out. In an earlier smaller scale investigation on deep peat, Cheong (pers. comm., 2009) observed that roots growing beyond a certain distance from the palm bole often died, probably due to the highly porous nature of the peat.

Horizontal root distribution in mineral soils of sites 2, 3 and 4 also resembled the trend observed in peat soil, with root biomass decreasing with increasing distance from the palm bole. Nevertheless, there were some distinct differences between the ratio of root biomass occurring within and outside the weeded palm circles (WPC) on all the four sites.

Unlike the 8-year-old palms on peat, the palms of similar age planted in mineral soils (site 2) had a greater proportion of root biomass (42%) growing outside the weeded circles. In the younger 6-year-old palms (sites 3 and 4), total root biomass recorded outside the weeded circles was much lower, being only 37 and 27 per cent in non-terraced soils (site 3) and terraced soils (site 4), respectively. Although the three mineral soil sites differed in soil texture, there were no significant differences in their bulk density and porosity values (*Table 3*). As such, the differences in root biomass recorded within and outside the weeded circles between site 2 (8-year-old palms) and sites 3 and 4 (6-year-old palms) are likely to be attributed to their age differences rather than physical structure of the soil, although other micro-site factors cannot be discounted. In the younger 6-year-old palms, although their roots had reached the interrows and interpalm spaces, total root biomass still remained low and would be expected to increase with age. The latter case was confirmed as older palms of 8, 11 and 14 years of age, had much higher root biomass (42 to 57%), outside the WPC. An increase in root biomass beyond the WPC in older palms, was also recorded by Fairhurst (1996) in a detailed study on 10-year-old palms in West Sumatra, Indonesia. He found no differences in root length density under soils in weeded palm circles and those under frond stacks. In a root distribution study carried out in a sandy loam textured soil in Colombia, Tailliez (1971) found the highest concentration of roots (56 per cent) occurring outside the weeded circles and in the interrow spaces. He attributed this to the higher fertility, organic matter and moisture expected to be found beneath the pruned fronds, stacked in the interrows. However, as Tailiez (1971) made no mention of palm age, it remains uncertain whether the higher biomass of roots in the interrows, was due to the palms being older or due to more favourable growth conditions as cited by the researcher.

As nutrient and water uptake are the primary functions of tertiary and quaternary feeder roots, their horizontal distribution in the top 20 cm of soil where they are most abundant, is of major importance. In sites 1 to 4, feeder roots in the top soil also displayed a similar horizontal distribution pattern as the total root mass, declining with increasing distance from the palm bole, with almost similar root dry mass ratios, within and outside weeded palm circles *(Table 7)*.

At all the four sites, significant negative correlations were recorded between the concentration of P, K, Mg, Ca in the top 20 cm of soil and the distance from the palm bole (*Table 8*). This decline in nutrient concentration with distance from the palm bole, can be attributed to historical fertiliser placement practices. As the fertiliser was only applied in the palm circles and not beyond, repeated

TABLE 7
HORIZONTAL DISTRIBUTION OF TERTIARY AND QUATERNARY FEEDER ROOTS IN 0-20 CM SOIL DEPTH AT VARIOUS SITES

Site	*Root dry weight (%)*									
	Distance from palm bole (cm)								*Inside WPC*[1] *(0-200 cm)*	*Outside WPC (200-400 cm)*
	50	*100*	*150*	*200*	*250*	*300*	*350*	*400*		
1 (8-year-old palms, deep peat)	24	24	19	12	8	5	4	4	79	21
2 (8-year-old palms, mineral soil, non - terraced)	12	15	17	15	12	10	9	1	59	41
3 (6-year-old palms, mineral soil, non - terraced)	17	17	17	13	10	8	10	8	64	36
4 (6-year-old palms, mineral soil, terraced)	23	20	17	14	7	7	6	6	74	26
5 (11-year-old palms, mineral soil, non-terraced)	14	12	12	10	11	13	13	15	48	52
6 (14-year-old palms, mineral soil, non-terraced)	9	6	7	9	15	17	18	19	31	69

[1] WPC = Weeded palm circle

TABLE 8

CORRELATIONS BETWEEN TERTIARY AND QUATERNARY FEEDER ROOTS IN RELATION TO SOIL PARAMETERS OCCURING AT VARIOUS DISTANCE FROM PALM BOLE IN 0-20 CM SOIL DEPTH

Soil parameters	*Coefficient of correlation (r)*																	
	Site 1			*Site 2*			*Site 3*			*Site 4*			*Site 5*			*Site 6*		
	RDW[1] x DFPB[2]	*SP[3] x DFPB*	*SP x RDW*	*RDW x DFPB*	*SP x DFPB*	*SP x RDW*	*RDW x DFPB*	*SP x DFPB*	*SP x RDW*	*RDW x DFPB*	*SP x DFPB*	*SP x RDW*	*RDW x DFPB*	*SP x DFPB*	*SP x RDW*	*RDW x DFPB*	*SP x DFPB*	*SP x RDW*
Root dry weight (g/4,500 cm^3 soil)	-0.962	-	-	-0.723	-	-	-0.929	-	-	-0.960	-	-	0.444			0.931		
pH (units)	-	0.197	-0.140	-	0.099	-0.545	-	0.357	-0.558	-	-0.001	0.071	-	-0.585	-0.433	-	0.523	0.761
Organic carbon (%)	-	0.211	-0.351	-	0.446	-0.773	-	0.112	-0.123	-	-0.348	0.423	-	0.756	0.337	-	0.688	0.621
Nitrogen (%)	-	-0.407	0.392	-	0.357	-0.850	-	0.077	0.111	-	-0.022	-0.130	-	0.656	0.219	-	0.767	0.805
Available phosphorus (ppm)	-	-0.533	0.650	-	-0.865	0.651	-	-0.739	0.850	-	-0.518	0.533	-	-0.157	-0.042	-	0.218	-0.024
Exchangeable potassium (cmol/kg)	-	-0.781	0.881	-	-0.713	0.752	-	-0.669	0.822	-	-0.598	0.701	-	0.581	0.207	-	0.689	0.887
Exchangeable magnesium (cmol/kg)	-	-0.788	0.810	-	0.455	-0.913	-	-0.591	0.510	-	-0.571	0.605	-	-0.614	-0.154	-	0.696	0.847
Exchangeable calcium (cmol/kg)	-	-0.877	0.844	-	-0.303	-0.272	-	-0.154	0.160	-	-0.830	0.837	-	0.820	0.138	-	0.755	0.738
Bulk density (g/cm^3)	-	-0.400	0.098	-	-0.923	0.630	-	-0.286	-0.535	-	-0.176	0.012	-	-0.838	-0.456	-	-0.855	-0.866
Porosity (%)	-	-0.076	0.063	-	0.939	-0.682	-	-0.632	0.841	-	0.434	-0.337	-	0.879	0.514	-	0.753	0.723

[1] RDW = Root dry weight, [2] DFPB = Distance from palm bole, [3] SP = Soil parameters

application over a 6 to 8-year period, resulted in the development of a fertility gradient, with significantly higher nutrient concentrations within the WPCs. As oil palm feeder roots are known to congregate towards a nutrient and moisture source, as expected, a higher biomass of feeder roots was recorded within the more fertile WPCs, as compared to the less fertile soil extending beyond the latter (*Table 7*). This was reflected in a statistically significant positive correlation between nutrient concentration and root biomass (*Table 8*).

The scenario was slightly different for the older 11 and 14-year-old palms growing in mineral soils in sites 5 and 6 respectively. Feeder root composition outside the WPC ranged from 52 to 69 per cent and was 29 to 92 per cent higher than their younger 6-year-old counterparts *(Table 7)*. In the latter two sites, fertility gradients were less well defined, as fertilisers had been broadcast over palm frond heaps in the interrows and interpalm spaces over the last few years. As such, soil fertility outside the WPC was equal or even higher than in their respective WPCs. The higher soil fertility coupled with older palm age could be major factors contributing to higher root biomass occurring outside the WPC in sites 5 and 6.

Root distribution x growth direction

The distribution of feeder roots growing in the interrows, interpalm spaces and harvesters paths is summarised in *Table 9*.

For 8-year-old oil palms grown on peat, although total biomass of feeder roots found outside of the WPC was low, a significantly higher amount was found in the interpalm spaces (45%), when compared to either the interrows (24%) or harvesters paths (31%). As the pruned fronds were mainly stacked in the interpalm spaces, the feeder roots may have grown preferentially towards higher moisture and nutrient levels. In addition, the dense growth of ferns in the interrows could have checked the growth of oil palm roots expanding into that zone.

For 6 and 8-year-old palms grown on mineral soils located on non-terraced landform (sites 2 and 3), feeder root growth was generally evenly distributed between the interrows (39 - 40%) and interpalm spaces (37 - 38%), but higher than that found in the harvester path (22 - 24%) region. As the pruned fronds on mineral soils are arranged in a U-shaped configuration (covering interrows and interpalm spaces), their mulching effect and decomposition could have provided higher moisture and fertility levels for root growth, as well as suppressing growth of competitive vegetation in the latter two zones. Soil chemical analysis in this study found a higher concentration of N, K, Mg, Ca and organic matter in the interrow or interpalm spaces, when compared to the harvesters paths (*Table 10*).

No significant differences were recorded in the much older 11 and 14-year-old palms in sites 5 and 6. Feeder root biomass was high outside the WPC and evenly distributed between interrows and interpalm spaces, probably as a result of broadcasting macro nutrient fertilisers outside the WPC and onto the pruned frond heaps. Although micro-nutrient fertiliser (boron) was applied in the WPC, its low dosage (0.10 - 0.15 kg/palm) and non-regular annual application, would have had little impact on palm root distribution.

Recommendations for fertiliser placement

Based on the results from this study and earlier findings from various researchers, the following fertiliser placement SOP for oil palms planted in mineral and peat soils is proposed and summarised in *Table 11*.

TABLE 9
COMPARATIVE DISTRIBUTION OF TERTIARY AND QUATERNARY FEEDER ROOTS AT 0-20 CM SOIL DEPTH AT VARIOUS SAMPLING LOCATIONS

Site	*Root dry weight (%)*		
	Interrow	*Interpalm*	*Harvesters path*
1 (8-year-old palms, deep peat)	24	45	31
2 (8-year-old palms, mineral soil, non - terraced)	40	38	22
3 (6-year-old palms, mineral soil, non - terraced)	39	37	24
4* (6-year-old palms, mineral soil, terraced)	-	-	-
5 (11-year-old palms, mineral soil, non-terraced)	46	54	-
6 (14-year-old palms, mineral soil, non-terraced)	55	45	-

* Site 4 which was on terraces was only sampled in the interpalm space as there were no interrows nor harvesters paths on terraces
* Sites 5 and 6 were only sampled in the interrow and interpalm spaces

TABLE 10
SOIL NUTRIENT CONTENTS AT THREE SAMPLING LOCATIONS*

Site	*Location*	*Nutrient contents at 0-20 cm soil depth*						
		pH (units)	*C(%)*	*N(%)*	*Av. P (ppm)*	*K (cmol/kg)*	*Mg (cmol/kg)*	*C (cmol/kg)*
1	Interrow	3.57	36.73	1.54	29	0.44	0.84	4.32
8year-old palms	Interpalm	3.81	34.83	1.21	16	1.99	1.31	1.60
Deep peat	Harvesters path	3.68	34.26	1.37	27	0.92	0.73	1.73
2								
8-year-old palms	Interrow	4.54	1.73	0.15	1.44	0.15	0.27	0.33
Mineral soil	Interpalm	4.92	1.55	0.14	3.27	0.12	0.29	0.47
Non - terraced	Harvesters path	4.72	1.35	0.12	5.57	0.08	0.06	0.20
3								
6-year-old palms	Interrow	4.65	1.67	0.15	3.57	0.10	0.43	1.13
Mineral soil	Interpalm	4.77	1.19	0.13	1.53	0.12	0.18	0.40
Non - terraced	Harvesters path	4.57	1.09	0.11	1.53	0.07	0.18	0.50
5								
11-year-old palms	Interrow	4.59	2.85	0.21	39.57	0.11	0.21	0.88
Mineral soil	Interpalm	4.60	2.47	0.20	10.20	0.25	0.21	0.88
Non-terraced	Harvesters path	-	-	-	-	-	-	-
6								
14-year-old palms	Interrow	5.92	1.47	0.19	49.65	0.90	1.12	2.60
Mineral soil	Interpalm	5.89	1.46	0.19	8.42	1.11	1.32	2.49
Non-terraced	Harvesters path	-	-	-	-	-	-	-

* Site 4 is not included as root sampling was only carried out in interpalm spaces
For sites 5 and 6, no root sampling was carried out in harvesters paths

TABLE 11
PROPOSED FERTILISER SOP FOR MINERAL AND PEAT SOILS

Soil type	*Fertiliser type*	*Palm age (years)*	*Location of fertiliser placement*	*Application method*
Mineral soils (non - terraced and terraced)	Macro	3-5	100 % dosage Weeded palm circle	To be evenly broadcast commencing ±50 cm radius from palm bole to edge of weeded circle
	Macro	6 and 7	50 % dosage Weeded palm circle	To be evenly broadcast commencing ±50 cm radius from palm bole to edge of weeded circle
			50 % dosage Interpalm space	To be evenly broadcast over pruned fronds
	Macro	≥8	100 % dosage Interpalm space	To be evenly broadcast over pruned fronds
	Micro	All palm ages	100 % dosage Weeded palm circle	To be evenly broadcast within ±50 cm – 100 cm radius from palm bole
Peat soil	Macro	All palm ages	100 % dosage Weeded palm circle	To be evenly broadcast commencing ±50 cm radius from palm bole to edge of weeded circle
	Micro	All palm ages	100 % dosage Weeded palm circle	To be evenly broadcast within ±50 cm – 100 cm radius from palm bole

In peat, irrespective of palm age, the biomass of roots growing beyond the WPC is low. As such, all fertilisers should continue to be broadcast evenly within the WPC in order to maximise fertiliser uptake efficiency. Applying fertilisers beyond a 2 m radius from the palm bole, could result in high fertiliser losses.

To encourage feeder roots to grow beyond the 2 m radius, all newly pruned fronds should be stacked in the interpalm spaces, as close as possible to the edge of the WPC. The stacked fronds will improve soil moisture status through their mulching effect and on decomposition, improve soil fertility. Over time, as root growth expands, fertilisers can be broadcast over a larger surface area.

In mineral soils, the proposed SOP is a gradual transition from WPC application to full broadcasting of fertilisers over pruned frond heaps. The latter will minimise the creation of distinct spatial soil fertility zones, reduce acidification of WPC and fertiliser loss through leaching, surface run-off and in erosion of soil sediments (Goh *et al*., 1995).

This transition should commence when palms have reached 6 years of age and have developed significant feeder root biomass beyond the WPC. However, as the feeder root biomass at this age is still less than 40 per cent, losses can be high if the full fertiliser dosage is applied outside of the WPC. To mitigate this, half of the fertiliser should continue to be applied in the WPC and the remaining half broadcast over the frond heaps. As feeder roots normally grow towards moisture, organic matter and nutrients, the application of 50 per cent of the fertiliser beyond the WPC and placement of pruned fronds in the interpalm spaces will encourage feeder roots to grow towards these zones. After a 2-year transition period (palm aged 6 and 7 years), the feeder root biomass should now be higher outside the WPC and the full fertiliser dosage can be applied, to maximise fertiliser uptake efficiency.

CONCLUSION

Goh *et al.* (2003) suggested that fertiliser placement strategies for mature palms must take into account the characteristics of each fertiliser type, oil palm root development and palm age, soil properties, weed management policies and rainfall. They proposed that for palms up to 10 years of age, all fertilisers should be applied in and around the WPCs and outside the latter (broadcast onto frondstacks), for palms older than 10 years.

The results from this study confirm that if site factors are not limiting, root biomass and distribution are highly influenced by the age of the palms and past history of fertiliser placement. Taking these two major factors into account, recommendations on fertiliser placement for oil palms grown on mineral and peat soils, which can maximise fertiliser uptake and utilisation are proposed.

ACKNOWLEDGEMENT

The authors wish to thank the Senior Management of AA Group for their support and kind permission to publish this paper. Support provided by Estate Management of KBL, KNS, KAN, KGD and R&D field supervisors during the duration of the project is gratefully acknowledged.

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