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Oil Palm (*Elaeis guineensis*) Roots Response to Mechanization in Bernam Series Soil

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Abstract: Problem statement: Field practices involving the use of mechanization in oil palm plantations could result in soil compaction which alters the soil physical properties. The gradual deterioration of soil physical conditions could restrict the growth and function of roots. This study was carried out to evaluate the response of oil palm roots to changes in soil physical properties due to mechanization in Bernam series soil belonging to the clay texture class. **Approach:** Compaction treatments were imposed for 6 consecutive years and a comparison was done on the effects of different trailer weights on oil palm roots growth. Roots and soil were sampled using root and soil augers at 0-30 cm depth from the harvesting and frond pile paths. **Results:** The results showed that the oil palm roots were affected by the mechanization treatments. Growth of oil palm roots was significantly affected by the 4T trailer weight. Palms in compacted soil produced less primary and secondary roots but this was compensated for by the production of longer and thicker tertiary and quaternary roots. **Conclusion:** The compaction treatments affect the soil physical properties, which in turn affect the growth and distribution of oil palm roots.

Key words: Soil compaction, oil palm roots, trailer weight, soil physical properties

INTRODUCTION

Mechanization practices in oil palm plantations such as the use of machines for harvesting and cultural practices could contribute to the gradual deterioration of soil physical conditions that restrict the growth and function of roots. The ability of roots to grow and explore the soil for water and nutrients is an important factor affecting the growth and yield of oil palm. Adverse soil physical conditions such as poor drainage or compaction are detrimental to crops resulting in reduced yield. The study of roots is an important research aspect to determine the interaction of plants with changes in soil conditions. However, such studies are very tedious and time consuming.

The oil palm has an adventitious root system; with primary roots generally about 6-10 mm in diameter, originating from the base of the trunk and either spreading horizontally or descending at varying angles into the soil. The primary roots bear secondary roots, of about 2-4 mm in diameter. Tertiary roots, about 0.7-1.2 mm in diameter, branch out from the secondary roots, which in turn bear the quaternary roots. Quaternary roots are unlignified, about 0.1-0.3 mm in diameter and 1-4 mm long and are often assumed to be the main absorbing roots (Corley *et al*., 1976). The total length of tertiary and quaternary roots in the soil is the most important root characteristic as they are the absorbing roots that affect fertilizer use efficiency. Most of the root biomass is found within 1m of the soil

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surface, but tertiary and quaternary roots are found mostly in the upper 30 cm from the soil surface. Primary roots can grow up to 20 m away from the base of the palm and some primary roots could penetrate below the water table at 90 cm from the surface (Ng *et al*., 2003). The distribution of roots depends largely on the nature of the soil. Oil palm being a monocot needs a friable soil for root branching because the roots cannot expand laterally, forcing their way through impermeable material. The extent of the root system may also be limited by the occurrence of a water table. Root elongation as well as proliferation is strongly affected by many physical and chemical properties of the soil.

Excessive soil compaction impedes root growth and the roots tend to grow horizontally. Therefore it limits the amount of soil explored by roots, preventing access to the water and nutrients stored deep in the soil. It also causes stress to roots and they subsequently become more susceptible to other crop stresses such as heat, insects and diseases (Davis, 1998; Duiker, 2004). Research has also shown that root systems are generally very elastic in their response to adverse soil physical conditions. For example, inhibition of root elongation due to mechanical impedance may be compensated by an increase in root diameter or branching of the root system. A study by Mosena and Dillenburg (2004) on Brazilian pine found that higher soil Bulk Density (BD) values were associated with a shorter and thicker tap root although the growth of lateral roots and shoots remained unaffected at earlier stages. It is possible that the relationship between root elongation rate and soil strength is similar for most crop species. Mechanically impeded roots are shorter, thicker and more irregularly shaped than the thinner fibrous roots that develop under low-compaction conditions (Bennie, 1996). In soils with good physical properties, the entire topsoil is well permeated with roots from the early stage of development in a plantation (Corley *et al*., 1976).

Many researches have been done to study the effect of mechanization on soil BD and porosity, yet relatively few have related their results to root growth. The objective of this study was to evaluate the response of oil palm roots to different trailer weight treatments in a plantation.

MATERIALS AND METHODS

Study site: The study was conducted on a 22 hectares oil palm plantation at Melentang Estate, Bagan Datok, Perak, Malaysia. The area is a flat coastal terrain with Bernam series soil (Paramananthan, 2000) which is clay textured (50% clay, 32% silt and 18% sand). The soil BD, particle density and porosity were 0.8 and 2.45 g cm^{-3} and 67% respectively. The average rainfall of the area was 1400 mm a year. The trial area was planted in 1996 with GH300 DxP materials with a planting density of 148 palms ha^{-1} and the compaction trial was started in 2002 when the palms were about 7 years old. All field operations at the trial site, such as fertilizer applications, FFB evacuation and weeding were carried out manually using standard estate practices.

Treatments: The treatments were a combination of three trailer weights with 3 travels per month. The three trailer weights were 0T (tractor without trailer), 2T (tractor with 2 tonnes trailer weight) and 4T (tractor with 4 tonnes trailer weight). There was no tractor traffic on the control plots. Each treatment was replicated five times (the replicates represented as the blocks).

Soil analysis: Soil BD, porosity and moisture characteristics were determined in the laboratory using undisturbed soil samples which were taken based on the core method (Blake and Hartge, 1986). A split tube sampler with sampling rings of 5 cm height and diameter were used. The sampling depths were 0-10, 10-20 and 20-30 cm. Soil BD was determined using the core method and soil porosity was derived mathematically from bulk density and particle density. The soil moisture properties were determined using ceramic plates (Townend *et al*., 2001).

Root analysis: Destructive root sampling was done to study the oil palm roots density and distribution. Root samples were taken from the harvesting and frond pile paths of selected plots that were treated with three rounds of transportation frequency per month for compaction. After six years of compaction treatments, roots were sampled according to the triangle method developed by Tailliez (1971). The triangular area between three neighboring palms was subdivided into 16 sub-triangles with each side about 2 m long (Fig. 1). Roots samples were extracted from 0-30 cm soil depth from the centre of each sub-triangle using a root auger with a diameter of 10 cm and a height of 15 cm, to minimize damage to the plants. The roots samples were first separated from the soil before transport to the laboratory for analysis.

Roots were washed with water to remove any remaining soil and separated into 3 root classes i.e., primary, secondary and tertiary roots with the latter bearing the quaternary roots. The quaternary roots were not separated from the tertiaries due to their very small size. The measurements recorded were the number,

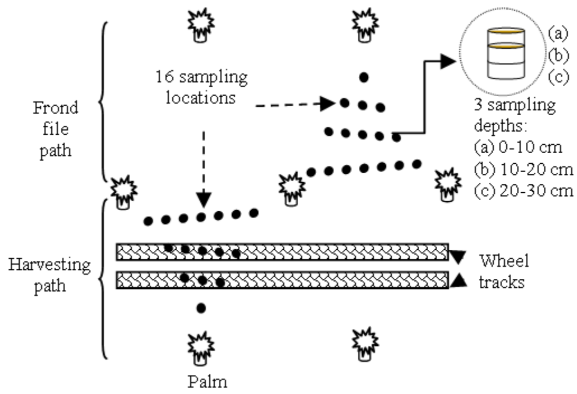

Fig. 1: Schematic diagram of root sampling

length and diameter of the roots. Root diameters were measured using a digital caliper. Root lengths were measured indirectly by using the 'intersection method' (Tennant, 1975). The length was obtained by counting the intersections between the roots and the vertical and horizontal lines of 1-cm grid square and then multiplied by a conversion factor 0.786.

The root length and the root diameter data were used for the determination of root surface area. The root samples were then dried in an oven at 70-80°C until constant weight was achieved, which was then recorded.

RESULTS

Total root biomass: A bigger root biomass was observed in the control and 0T plots, however 2T and 4T plots showed a decreasing trend with increasing trailer weight. The root biomass was significantly reduced in the 4T plots by about 28% compared to the control (Fig. 2).

Root length density and diameter: The primary root length density and root diameter were unaffected by increasing trailer weights for the control, 0T and 2T plots. However, the 4T trailer weight significantly reduced root length density, with a corresponding increase in the diameter of the primary roots (Table 1).

As with the case of the primary roots, the root length density of secondary roots was significantly affected by the 4T treatment. The secondary roots in control plots were found to be significantly thinner, but there was no significant difference in the diameter of the secondary roots in the other treatment plots. The diameter of secondary roots tended to increase with minimal increase in soil compaction although the root length density was only affected by the heaviest trailer weight.

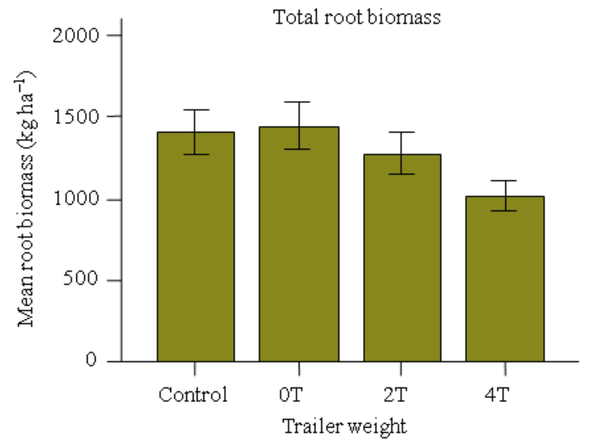

Fig. 2: Total oil palm root biomass for different trailer weights

Table 1: Root length density and diameter of oil palm roots for different trailer weights

Root class	Trailer weight	Root length density (mm cm^{-3})	Root diameter (mm)
Primary	Control	0.2239a	5.778a
	0T	0.2258a	5.878a
	2T	0.2760a	6.000a
	4T	0.1724b	6.424b
Secondary	Control	0.4222a	2.007a
	0T	0.4345a	2.234b
	2T	0.4525a	2.238b
	4T	0.3422b	2.217b
Tertiary and quaternary	Control	0.2843a	0.5518a
	0T	0.3296ab	0.5391a
	2T	0.3753ab	0.5855b
	4T	0.4083b	0.5828b

Note: Means with the same letter in a column for each root class are not significantly different at 5% probability

In contrast, increase in soil compactness resulted in a corresponding increase in root length density as well as the diameter of tertiary and quaternary roots (Table 1).

Root surface area: The root surface area increased significantly with increasing trailer weight and for the 4T treatment root surface area was significantly increased by about 54% compared to the control (Fig. 3).

Soil bulk density and porosity: The compaction treatment resulted in significant changes to the soil SBD and porosity of the Bernam Series soil. The annual mean soil BD increased and porosity decreased with increasing trailer weight (Fig. 4). The mean soil BD increased significantly by about 30% while the soil porosity reduced significantly by about 15%.

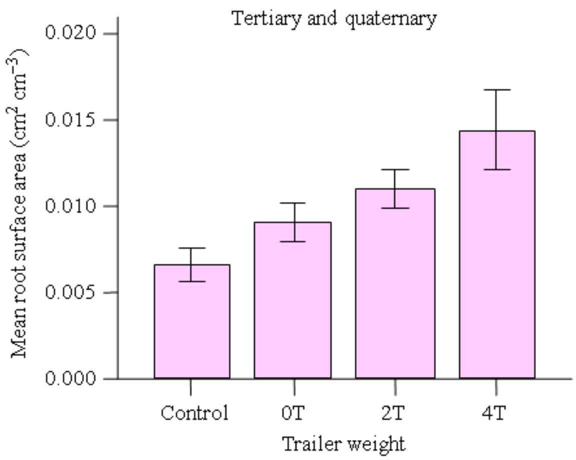

Fig. 3: Oil palm tertiary and quaternary root surface area for different trailer weights

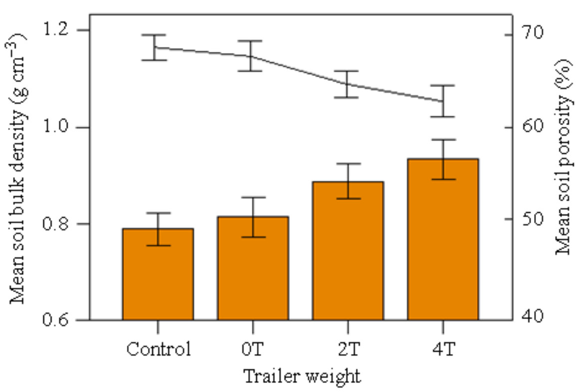

Fig. 4: Soil bulk density (▬) and porosity (⟋) of Bernam Series soil for the different trailer weights

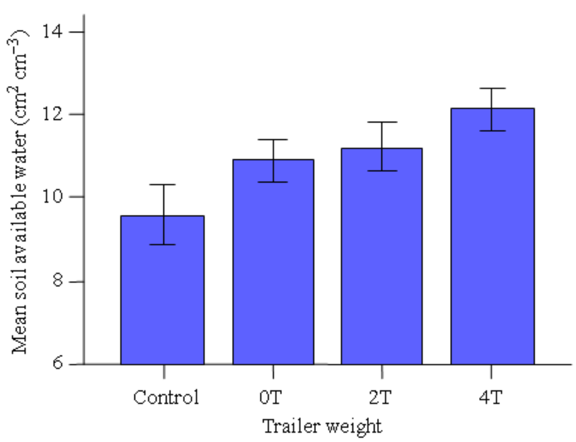

Fig. 5: Soil available water of Bernam series soil for the different trailer weights

Soil available water: Figure 5 shows that mean soil Available Water (AW) increased with increasing trailer weight. The mean soil AW of the treated plots was significantly higher by about 19% compared to the control.

DISCUSSION

Both environmental and cultural conditions were expected to modify the development of oil palm roots. Root elongation and proliferation are strongly affected by many soil physical and chemical properties. In soils with good physical properties, the root system will be highly dynamic. They are usually well distributed in the soil to absorb moisture and nutrients, for continual supply of these vital resources to the plant. When soils are compacted, soil BD increases and the number of larger pores decreases, leading to increased resistance to root growth

The reduction in root growth could be a direct consequence of increased soil mechanical impedance due to significantly high soil BD and low porosity of compacted soil caused by the trailer weights (Fig. 4). Since the oil palm has a relatively shallow root system; development is retarded in compacted soils. Compacted soils are less favorable to root elongation as it limits the amount of soil explored by roots compared to roots in non-compacted soil.

The most useful root parameter is root length density distribution around the palm. The theory of diffusion has shown that root length is more important than either root mass or volume in the uptake process for most ions and water, because of the restriction imposed by the soil on ion diffusion and water capillary movement (Corley and Tinker, 2003). Roots growing into compacted soil must displace soil particles and as such the rate of elongation decreases as soil strength increases.

Root length density of primary roots was significantly reduced in the 4T plots suggesting that the primary roots proliferate less in compacted soils. The inhibition of root elongation due to higher soil BD in the 4T plots was compensated for by an increase in root diameter, probably due to ease of root penetrating in the soil. As soil strength increases, root elongation rate decreases due to the increasing resistance of the soil particles to displacement. Researchers have found that the root elongation rate or root length is inversely proportional to mechanical impedance whereas root diameter is directly proportional to mechanical impedance (Bennie, 1996; Jungk, 1996).

Similar to the primary roots, the root length density of secondary roots was significantly affected only by the 4T trailer weight because of the compacted soil that resulted in restrictions to root extension. The secondary roots in control plots were found to be significantly thinner so that they could easily explore the non-compacted soil. There was no significant difference in the diameter of the secondary roots in the other treatment plots (Table 1). The diameter of secondary roots tends to increase with minimal increase in soil compaction although the root length density was only affected by the heaviest trailer weight. This indicates that the secondary roots are able to penetrate the soil better compared to the primary roots.

When a soil is compacted, soil porosity is decreased and the pore space diameters become smaller. Once soil pore diameters are less than the diameter of the main root tips, root morphological changes may occur. The thickening of roots grown in compacted soil indicates the absence of pores with diameters equal or larger than the roots. The roots become thicker to exert more force to squeeze into the diminished pore size. As roots thicken, growth slows and there is a production of more laterals of various diameters that are small enough to fit into the reduced pore sizes of the compacted soil (Lipiec *et al*., 2003).

Theoretically, the root length density of tertiary and quaternary roots should also be reduced with increasing trailer weight due to higher soil BD. On the contrary, increase in soil compactness resulted in a corresponding increased in the length density and diameter of tertiary and quaternary roots. Palms in compacted soils produced less primary and secondary roots but was compensated for by producing longer and thicker tertiary and quaternary roots with increasing trailer weight (Table 1) for better uptake of water and nutrients. The shorter root length density suggest that the primary and secondary roots have to maintain a higher than normal uptake rate of nutrients and water per unit root length. In order to meet the demand for water and nutrients, they produce longer tertiary and quaternary roots. Greater root length in compacted soils could also be in response to better soil AW (Fig. 5) and nutrients as roots tend to proliferate more in these conditions. As soil BD increases, porosity decreased as a result of reduction in the size of macropores. This would then increase the amount of micropores that will retain more water in the compacted soil.

The root surface area was computed using the measurements of root length and root diameter, assuming the roots were cylindrical. Water and nutrients uptake by plants has been shown to be a direct function of root surface area (Goh and Samsudin, 1993). Soil compaction increased the root length and diameter, therefore resulting in increased surface area of the tertiary and quaternary roots that could improve water and nutrient uptake.

CONCLUSION

The oil palm roots could be affected by mechanization practices in the plantation. The growth of oil palm roots was greatly affected by the 4T trailer weight. Palms in compacted soil produced less primary and secondary roots but was compensated for by producing longer and thicker tertiary and quaternary roots that improve uptake of water and nutrients. This is an indication that compaction treatments affected the soil physical properties, which in turn influenced the root growth in the oil palm plantation in Bernam series soil.

Good management of soil physical characteristics will improve root proliferation and uptake of water and nutrients. This will result in improved crop yield and better fertilizer use efficiency. Further research is required on the factors determining oil palm root penetration and proliferation.

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