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OIL PALM ADAPTATION TO COMPACTED ALLUVIAL SOIL (*Typic Endoaquepts*) IN MALAYSIA

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ABSTRACT

A study was carried out to evaluate the ability of oil palm to adapt to compacted Bernam series soil (Typic Endoaquepts). *After six years of soil compaction treatments, the mean soil bulk density, available water as well as the percentages of mesopores and micropores increased, whereas total porosity, hydraulic conductivity, infiltration rate and percentage of macropores decreased. Fresh fruit bunch (FFB) yield increased significantly with increased mean soil bulk density. On the other hand, the treatments resulted in significant reductions in oil palm standing biomass, root biomass as well as frond dry weight. Total green frond number, total leaf area and leaf area index were not affected by the treatments. The growth of oil palm roots was significantly affected by the compacted soil, resulting in lower primary and secondary root production, but compensated for by the production of longer and thicker tertiary and quaternary roots. The treatments caused changes in the soil physical properties and resulted in soil compaction, which then affected oil palm performance. The palms showed adaptation to these changes and responded positively by producing better yield following the compaction treatments. This shows that compacted soil may not be a problem to oil palm planted in the Bernam series soil.*

Keywords: Bernam series soil, oil palm adaptation ability, soil physical properties, compacted soil.

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INTRODUCTION

Mechanisation as a means of increasing labour efficiency and productivity has been successfully implemented in the Malaysian oil palm industry. Various mechanised systems have been introduced since the 1980s to improve production efficiency and to reduce production costs and labour dependence. Mechanisation is now widely accepted and adopted, especially for the collection and evacuation of fresh fruit bunches and in the application of fertiliser, pesticide and herbicide. Yusof and Ahmad (1998) reported that the adoption of mechanisation by an oil palm plantation showed a decrease by about 30% in labour requirement and an increase in productivity by 30% as well. However, the rapid increase in mechanisation of various oil palm field operations can contribute to deterioration in soil physical properties, and can be a major factor causing soil compaction which is often shown to be a problem in agricultural soil systems.

Alteration of the physical properties of a soil due to compaction includes changes to its structure, bulk density, soil strength, mechanical impedance, porosity and hydraulic properties such as infiltration rate and hydraulic conductivity. Soil aggregates and aeration pore spaces are critical to healthy soil and root systems, and their destruction is irreversible. Furthermore, compaction causes aerobic sites to concentrate closer to the soil surface, making them less available for root development. The main concern about soil compaction is its impact on crop productivity and sustainability, which has been recognised as a yield-limiting factor in crop production. Soil physical

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properties have an important influence on plant growth and development because they determine root penetration, water availability and gaseous exchange in the soil. Reduction in yield has often been attributed to adverse soil physical conditions that restrict the growth and function of roots (Chan *et al*., 2005; Hamza and Anderson, 2005).

Although much research had been done on soil compaction and its effect on crop yield, it is difficult to predict the effect of machinery compaction on crop growth as this depends on the soil type, type of crop grown, weight of the machine used, weather and the soil-water conditions at the time of the operation. Soil compaction can influence plant growth in many ways, and plant response depends on its stage of development and the severity of soil compaction. It is difficult to predict the effect of compaction on crop yield. It may even be beneficial to some plants, but most are detrimental to plant growth. It disrupts the respiration processes which relate to every function of the plant, leading to physiological dysfunction. This results in the inefficient use of essential resources and hormonal imbalance, causing abnormalities in tissue reactions. Defence mechanisms will be weakened and incomplete responses result in plant stress (Godefroid and Koedam, 2004).

Undoubtedly, soil physical properties have an important influence on plant growth. However, the importance of soil physical properties is often underestimated by researchers. The effect of mechanisation on soil bulk density and porosity has been studied, yet relatively few of the studies have related these properties to palm growth. Information on the severity and extent of soil degradation due to mechanisation in oil palm plantations or their impact on the oil palm growth is not available. Both environmental and cultural conditions are expected to modify the growth and yield of oil palm. Although soil amendments such as mulching using empty fruit bunches and fertiliser application could counter nutrient deficiencies, soil physical limitations such as a compacted layer and poor water-holding capacity are difficult to rectify. Oil palm responses to compaction are related to the alterations to the soil's physical properties.

As research on the management of soil physical properties planted with oil palm has been lacking, this study was conducted to determine the extent of degradation of Bernam series soil resulting from mechanisation activities, and its subsequent influence on oil palm performance. Therefore, results of this study can be of considerable value in determining the severity of soil degradation, and such information might be useful in selecting suitable machines to minimise environmental deterioration.

MATERIALS AND METHODS

Compaction Treatments

The study was carried out at Melentang Estate, Bagan Datok, Perak, which is located at 4° 00'20.96268"N and 100° 50'18.66199"E. The trial area was a flat coastal terrain of clayey Bernam series soil (*Typic Endoaquepts*). The area had been planted in 1996 with GH300 D x P materials at a planting density of 148 palms ha^{-1}. The compaction trial was started in 2002, with treatments comprising combinations of three trailer weights and three transportation frequencies. The trailer weights were 0T (tractor without trailer), 2T (tractor with a 2-t trailer weight, *i.e*. a normal trailer load) and 4T (tractor with 4-t trailer weight). The transportation frequencies were one, two and three rounds per month. There was no vehicle traffic in the control plots. Each treatment block consisting of 12 plots was replicated five times, which in total covered about 4.4 ha. The total of 60 experimental plots therefore covered about 22 ha of the plantation area.

Soil Physical Properties

Undisturbed soil samplings were done twice a year using a split tube sampler at the soil depths from 0 to 30 cm. Soil bulk density was determined using the core method while particle density was determined using a pycnometer (Blake and Hartge, 1986). Soil total porosity was then derived mathematically from bulk density and particle density. Soil moisture properties were determined using ceramic plates (Townend *et al*., 2001), while soil hydraulic conductivity and infiltration rate were measured using a mini disk infiltrometer (Decagon Devices, 2006). The micro-morphological characteristics of the soil samples were determined based on image analysis of impregnated thin soil sections (Drees, 1997). These sections were examined using a Leica DFC 290 microscope at 40X magnification and analysed using the associated Leica software for determination of the diameter and area occupied by the micro and mesopores (< 60 μm) and macropores (> 60 μm).

Oil Palm Fresh Fruit Bunches Yield

FFB yields were recorded at each harvesting round of every 10 to 12 days. The number and weight of FFB were recorded in the field from the 16 sample palms per treatment plot. These values were then extrapolated to yields in tonnes of FFB per hectare per year.

Oil Palm Vegetative Measurements

Oil palm above-ground growth was assessed every six months from the 16 sample palms per treatment plot. Measurements were made using conventional techniques to monitor the vegetative growth of oil palm in terms of leaf production, leaf area, petiole cross-section, trunk growth and total dry matter production (Fairhurst and Hardter, 2003).

Oil Palm Roots

Roots were sampled according to the triangle method developed by Tailliez (1971), with sampling points of 16 sub-triangles. Root samples were extracted from the 0 to 30 cm soil depth from the centre of each sub-triangle using a root auger. The primary, secondary and tertiary together with quaternary roots were separated from one another. Measurements include root count, weight, length and diameter. Root diameter was measured using callipers, while root length was measured using the 'intersection method' (Tennant, 1975). Assuming the roots to be cylindrical, surface area was computed using data on root length and diameter (Goh and Samsudin, 1993).

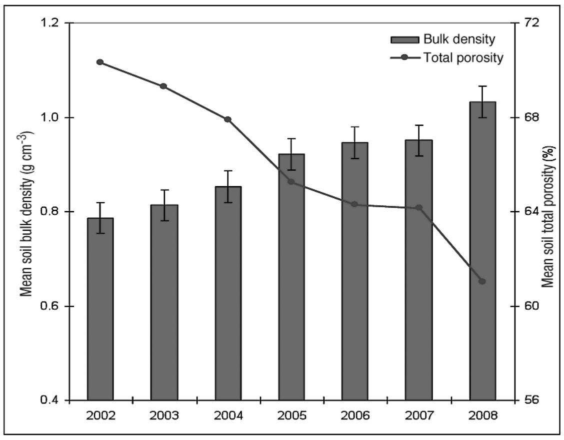

Figure 1. Soil bulk density and total porosity by year.

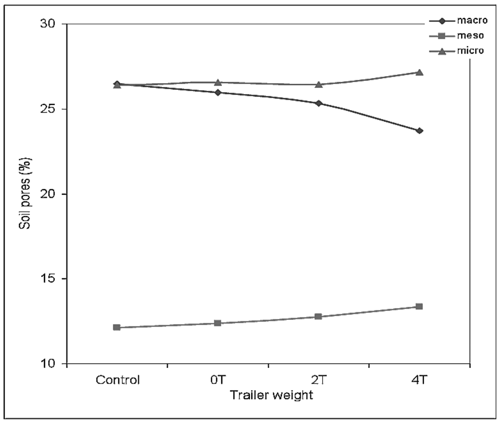

Figure 2. Soil pores as affected by trailer weight.

RESULTS AND DISCUSSION

Changes in Soil Physical Properties

The most notable changes observed in this study were in soil bulk density, porosity, available water, hydraulic conductivity and infiltration rate. These changes affected water and air movement through the soil profile, which is critical for providing a healthy environment for the plant root system. This study shows that the physical properties of Bernam series soil had changed due to the compaction treatments applied. The compaction treatments implemented at the study site increased the mean soil bulk density (BD) and reduced total porosity (TP). Annual mean BD increased by about 30% and TP decreased by about 15% after six years of compaction treatments (*Figure 1*). Both were significantly affected by the compaction treatments of 2T and 4T trailer weights. However, the compaction effect seemed to be more pronounced only at the surface layer, *i.e.* within the first 0-10 cm depth of the harvesting path, as compared with that of the frond pile area. Soil deeper down the profile (below the top 10 cm) was not affected by the treatments. The highest BD was exhibited in the 4T plots with three rounds per month of transportation frequency (TF), whereas the highest TP was observed in the control plots (Zuraidah *et al*., 2009). Thus, the combined effect of heavier weight and higher transportation frequency resulted in greater damage to the soil, but this was still well below the root-limiting critical range in the soil (USDA, 1999).

Compaction was also indicated by a significant reduction by 10% of the macropores and increments of mesopores and micropores by 10% and 3%, respectively, as compared with the control (*Figure 2*). The heavier trailer weight caused the larger pores to collapse and resulted in the production of more smaller pores during compression. Therefore, the reduction in pore space not only affected total porosity but also pore size.

Further evidence of soil compaction was apparent from the measurements of soil moisture characteristics. As bulk density increased, TP decreased as a result of a reduction in macropore size. This would then increase the amount of meso- and micropores leading to higher available water in the soil. Mean soil available water content (AWC) was significantly increased by 19% with increasing trailer weight. Higher AWC was observed in the harvesting path of the compacted plots and increased with increasing trailer weight (Zuraidah *et al*., 2009). The forces of compaction reduced the macropores, thereby increasing the meso- and micropores which retained water in the soil. A compacted soil holds more water than an uncompacted soil due to the loss of macropores, and water is confined in the meso- and micropore spaces, thus increasing AWC (Ares *et al*., 2005).

However, mean soil hydraulic conductivity and mean infiltration rate measured in the field showed a decreasing trend with increasing trailer weight (*Table 1*). Reduction in both hydraulic conductivity and infiltration rate by 51% and 31%, respectively, could be due to increased soil BD, reduced TP and pore deformation associated with compaction. Soil compaction causes a decrease in macropores, resulting in a much lower water infiltration rate into the soil (Al-Ghazal, 2002; Lipiec *et al*., 2006), as well as a decrease in saturated hydraulic conductivity (Blanco-Canqui and Lal, 2008; Zhou *et al*., 2008). Compacted soil reduces water infiltration rate and increases the potential for surface runoff, leading eventually to flooding and soil erosion. Conversely, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion (Duiker, 2004).

Oil Palm Adaptation to Compacted Soil

Although soil compaction was expected to reduce oil palm yield, the results show that the increment in mean soil BD and reduction in TP were beneficial to the oil palm in this study. There was a positive relationship between FFB yields and increasing BD (*Figure 3*). Mean FFB yield, bunch number and bunch weight were significantly increased by about 9%, 8% and 2%, respectively, in the compacted plots as compared with those in the control (*Table 2*). Higher soil bulk density in the treatment plots enhanced the soil's ability to retain water due to increases in meso- and micropores. The positive response in yield performance could be attributed to improved nutrient uptake associated with higher available water in the compacted plots. This condition increases the nutrient mobility rates to roots by diffusion and mass flow in the transpiration stream (Russell, 1982). Zuraidah *et al*. (2010a) have reported that FFB yield, bunch number and bunch weight were also increased with increasing TF. For growing plants, pore size is more important than total pore space because a larger void space can lead to poor root contact with the surrounding soil. Therefore, some degree of compaction is desirable to provide a suitable soil density for plant growth in low bulk density soils. Increased soil bulk density and reduced porosity could provide for better root contact with the surrounding soil and enhance nutrient uptake which would result in better oil palm yield.

The term 'standing biomass' describes the estimation of total dry weight of an oil palm

TABLE 1. MEAN SOIL HYDRAULIC CONDUCTIVITY AND INFILTRATION RATE AS AFFECTED BY TRAILER WEIGHT

Trailer weight	Infiltration rate ($cm\ min^{-1}$)	Hydraulic conductivity ($cm\ hr^{-1}$)
Control	0.2370±0.04a	0.1591±0.02a
0T	0.1711±0.05b	0.1573±0.03a
2T	0.1543±0.04b	0.1385±0.04a
4T	0.1646±0.05b	0.0780±0.01b

Note: Means in a column with the same letter are not significantly different at p<0.05.

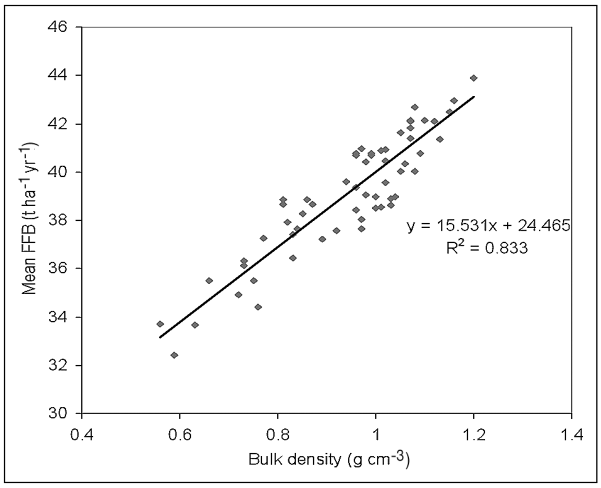

Figure 3. Fresh fruit bunches (FFB) yield in relation to soil bulk density.

TABLE 2. OIL PALM YIELD AS AFFECTED BY COMPACTION TREATMENTS

Trailer weight	Fresh fruit bunches ($t\ ha^{-1}\ yr^{-1}$)	Oil palm yield bunch No. ($No.\ palm^{-1}\ yr^{-1}$)	Bunch wt. ($kg\ bunch^{-1}$)
Control	36.13±3.0a	13.90±1.0a	17.57±0.5a
0T	38.59±2.0b	14.89±1.0b	17.84±0.2ab
2T	39.16±2.0b	14.69±1.0b	17.83±0.2ab
4T	40.25±3.0b	15.38±1.5b	18.01±0.3b

Note: Means in a column with the same letter are not significantly different at p<0.05.

stand in the field, and comprises fronds and trunks. However, the main above-ground biomass accumulation occurs in the trunk. The oil palm mean standing biomass of the control plots was significantly higher by about 12% as compared with those of the compacted plots. The compaction treatments affected the palms and resulted in significant reductions of standing biomass (*Figure 4*). However, the effects of the three different trailer weights and TF on the mean oil palm standing biomass did not differ significantly among one another.

The compaction treatments affected the growth of oil palm trunks and fronds (*Table 3*). Compared to the control, the palms in the compacted plots exhibited significantly smaller trunk diameter, lower mean trunk dry weight and a significant reduction in the frond dry weight by about 9%, 8% and 6%, respectively. Even though the difference in trunk height was not significant, the palms were taller in the 4T plots. There were no significant differences in trunk dry weight, trunk diameter and frond dry weight among the treated plots. The successful growth of plants depends on maintaining a balance in growth and function between the roots and the shoots.

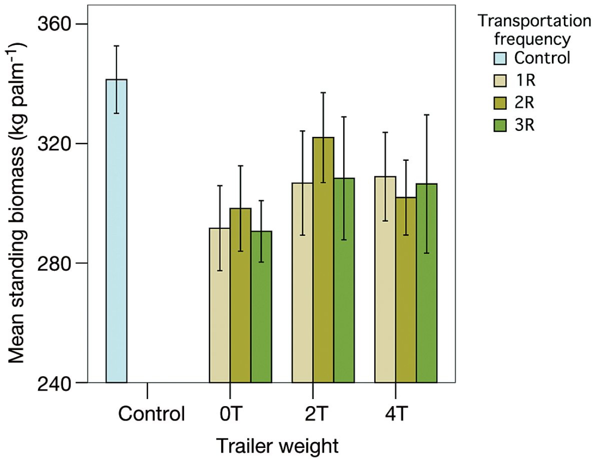

Figure 4. Mean standing biomass as affected by trailer weight and transportation frequency.

The higher yield in the treated plots could be attributed to the higher partitioning of dry matter to FFB and lower partitioning to the vegetative components, *i.e.* fronds, trunks and roots. The vegetative dry matter production per palm at a given palm age is more or less constant under non-limiting conditions, with FFB yield depending on the excess assimilates available, once vegetative requirements are satisfied (*e.g.* for new tissue growth and maintenance respiration). As the total dry matter production per palm increases, bunch yield increases almost in direct proportion, while vegetative dry matter production shows only a slight upward trend (Corley and Tinker, 2003a).

Total green frond number, total leaf area and leaf area index (LAI) were not significantly different among the treatments (*Table 4*). Total green frond number per palm was slightly less than the recommended total of 35 to 40 fronds per palm (Ng *et al*., 2003). However, total leaf area per palm was not affected by the compaction treatments, and this was reflected in the LAI value that was greater than 5. The optimum LAI for yield of oil palm is site-specific and varies from 5 to 7, depending on the environmental factors (sunshine, temperature and moisture) and planting material (von Uexkull *et al*., 2003). This implies that the frond canopy of the treated palms was able to intercept sufficient solar radiation and carry out the photosynthetic process without any impairment.

Although very tedious and time-consuming, a root study is an important aspect of productivity research to determine the interaction of plants with changes in soil conditions. Oil palm total root biomass was affected by the compaction treatments. Likewise, a greater root biomass was observed in the control and 0T plots; however, the 2T and 4T plots showed a decreasing trend in root biomass with increasing trailer weight. Root biomass was significantly reduced by about 28% in the 4T plots as compared with the control (Zuraidah *et al*., 2010b). Root biomass was directly related to the growth of the above-ground vegetative components. Therefore, in relation to standing biomass, a lower root biomass could be partly a product of a lower above-ground standing biomass in the compacted

TABLE 3. OIL PALM VEGETATIVE COMPONENTS AS AFFECTED BY COMPACTION TREATMENTS

Treatment	Oil palm vegetative components			
	Trunk dry wt (kg palm^{-1})	Trunk height (m)	Trunk diameter (m)	Total frond dry wt (kg palm^{-1})
Control	224.39±20a	3.95±0.2a	0.67±0.03a	125.89±10a
0T	202.10±30b	3.94±0.4a	0.61±0.02b	118.05±10b
2T	210.16±25b	3.92±0.3a	0.62±0.02b	120.92±10b
4T	209.78±25b	4.04±0.3a	0.61±0.02b	117.23±15b

Note: Means in a column with the same letter are not significantly different at $p<0.05$.

TABLE 4. FROND PARAMETERS FROM CONTROL AND COMPACTION PLOTS AFTER SIX YEARS OF TREATMENT

Trailer weight	Frequency	Total frond No. palm^{-1}	Total leaf area palm^{-1} (m^2)	Leaf area index (LAI)
Control		34.51±0.26aA	359.41±4.77aA	5.32±0.07aA
0T	1R	34.30±0.57aA	351.62±6.71aA	5.20±0.10aA
	2R	34.07±0.41aA	346.73±5.86aA	5.13±0.09aA
	3R	35.06±0.34aA	358.62±4.69aA	5.31±0.07aA
2T	1R	34.20±0.41aA	368.53±5.99aA	5.45±0.09aA
	2R	33.70±0.37aA	360.22±6.51aA	5.33±0.10aA
	3R	33.85±0.41aA	350.03±4.06aA	5.18±0.06aA
4T	1R	34.55±0.44aA	361.86±5.98aA	5.36±0.09aA
	2R	34.21±0.34aA	355.72±6.79aA	5.26±0.10aA
	3R	33.93±0.56aA	352.51±8.94aA	5.22±0.13aA

Note: Column means with the same small letter are not significant at $p<0.05$ for trailer weight; column means with the same capital letter are not significant at $p<0.05$ for transportation frequency.

plots. As the above-ground vegetative components (*i.e.* fronds) supply photosynthates to the roots, a reduced above-ground biomass could reduce this supply for root growth and result in the production of a lower root biomass. Another explanation may be that the lower root biomass under the compaction treatments implied that less energy was spent on root respiration; also, less shoot growth served to balance the root-shoot relationship (functional equilibrium). If the environment is constant, a logarithmic linear relationship is usually found between the weights of shoots and roots during vegetative growth (Russell, 1982). Hence, excess energy is used for the reproductive structures associated with FFB production in the compacted plots.

Consequently, an inverse relationship between soil bulk density and total root biomass was observed (*Figure 5*), as bulk density is one of the physical factors that could influence root growth. The reduction in root growth was a direct consequence of increased soil mechanical impedance due to significantly higher bulk density and lower porosity of the compacted soil caused by trailer weight. Oil palm has a relatively shallow root system; thus, the roots tend to develop less in compacted than in non-compacted fields. Compacted soils are less favourable for root elongation as they could limit the amount of soil explored by the roots as compared with that in the non-compacted soil (Zuraidah *et al.*, 2010b).

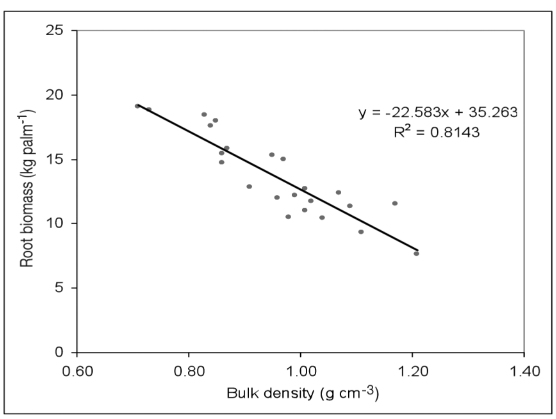

Figure 5. Root biomass in relation to soil bulk density.

On a per palm basis, the control and 0T compaction treatment did not affect the growth of all root classes. The 2T and 4T compaction treatments did not affect the primary and secondary roots, but the tertiary and quaternary roots were significantly increased by about 23% and 33%, respectively, compared with the control. Although not significantly so, the growth of primary and secondary roots was also reduced in the 4T plots (*Table 5*). In the more compacted soil, the growth of these roots was restricted due to higher soil bulk density and reduction of macropores. Root growth declined as the roots had to exert greater force to penetrate through the soil in search of water and nutrients. Subsequently, more lateral roots were generated in order to fit into the smaller pores.

The most useful root parameter is root length density distribution around the palm. It reflects the ability of the roots to absorb nutrients and water, and is related to the total length of root per unit volume of soil (Corley and Tinker, 2003a). Roots growing into compacted soil must displace soil particles; hence, the rate of elongation decreases as soil strength increases. Primary root length density was unaffected by the 0T and 2T compaction treatments. However, the 4T trailer weight significantly reduced root length density of the primary and secondary roots by about 23% and 19%, respectively, compared with the control. By contrast, increased soil compactness resulted in a corresponding increase in the length density of the tertiary and quaternary roots (*Table 5*). Thus, with increasing trailer weight, palms in the compacted soils produced less primary and secondary roots but compensated by producing longer tertiary and quaternary roots for better uptake of water and nutrients. The results suggest that a shorter root

TABLE 5. OIL PALM ROOTS AS AFFECTED BY COMPACTION TREATMENTS

Treatment	Oil palm roots		
	Biomass (kg palm^{-1})		
	1^0	2^0	3^0 & 4^0
Control	13.91±5.77a	3.43±1.15a	1.03±0.23a
0T	13.25±6.73a	3.63±0.77a	1.00±0.19a
2T	13.57±6.15a	3.54±1.00a	1.28±0.35b
4T	10.64±4.61a	2.92±1.15a	1.53±0.35b
	Length density (cm cm^{-3})		
	1^0	2^0	3^0 & 4^0
Control	0.022±0.005a	0.042±0.010a	0.028±0.010a
0T	0.023±0.006a	0.043±0.009a	0.033±0.010ab
2T	0.028±0.006a	0.045±0.007a	0.038±0.007b
4T	0.017±0.005b	0.034±0.007b	0.041±0.014b
	Diameter (mm)		
	1^0	2^0	3^0 & 4^0
Control	5.78±0.43a	1.93±0.09a	0.51±0.05a
0T	5.88±0.54a	2.31±0.09b	0.51±0.04a
2T	6.00±0.34a	2.24±0.14b	0.58±0.04b
4T	6.42±0.54b	2.19±0.18b	0.59±0.07b
	Specific root length (m g^{-1})		
	1^0	2^0	3^0 & 4^0
Control	0.114±0.035a	0.839±0.156a	1.846±0.583a
0T	0.090±0.020ab	0.867±0.100a	1.526±0.417a
2T	0.091±0.022ab	0.804±0.200a	1.643±0.417a
4T	0.079±0.020b	0.699±0.156b	2.862±0.917b

Note: Means in a column within a trait group which bear the same letter are not significantly different at $p<0.05$.

length density required the primary and secondary roots to maintain a higher than normal uptake rate of nutrients and water per unit root length in order to keep pace with demand, and this is done by producing longer tertiary and quaternary roots. Greater root length in compacted soils could also be in response to better soil available water as roots tend to proliferate more in soil regions with high water content. As reported by McMichael and Quisenberry (1993), when moisture is adequate, higher amounts of nutrients are available; hence, this will result in greater root elongation.

The primary root diameter were unaffected by the 0T and 2T compaction treatments. However, the 4T trailer weight significantly increased the root diameter of the primaries by about 10% compared with the control (*Table 5*). The inhibition of root elongation due to higher bulk density in the 4T plots was thus compensated for by an increase in root diameter in order to generate more energy to penetrate the soil. Root length density was greater and root diameter was smaller in the other plots, suggesting that the primary roots proliferated better in the less compacted soils. The diameter of secondary roots was also significantly increased by about 11% in the compacted plots. On the other hand, the secondary roots in the control plots were found to be significantly the thinnest as they could easily explore the non-compacted soil. There was no significant difference in the diameter of the secondary roots among the treated plots (*Table 5*). The diameter of secondary roots tended to increase with even a slight increase in soil compactness although their length density was only affected by the heaviest trailer weight. This indicates that the secondary roots could generate more energy to penetrate the soil farther compared with the primaries. Increased soil compactness of the 2T and 4T plots resulted in a corresponding increase in the diameter of the tertiary and quaternary roots by 16% compared with the control (*Table 5*). Although not significant so, generally more roots of all the classes were produced in the frond pile path area as compared with those in the harvesting path for all the compaction treatments. The lower bulk density, higher porosity and organic matter present at the frond pile path area provided better conditions for root growth. Roots show preferential growth towards better conditions of water and nutrient supply, and towards the rotting heaps of pruned palm fronds (Corley and Tinker, 2003b). On the other hand, the quantity of roots is reduced at the harvesting path area.

Research has shown that root systems are generally very elastic in their response to adverse physical conditions. The roots are able to respond to changes in soil properties to some extent. 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. Root elongation and proliferation are strongly affected by the physical properties of the soil. Soil compaction increased the root length and diameter, thereby resulting in an increased surface area of the tertiary and quaternary roots (feeder roots), which enhanced water and nutrient uptake. The root surface area was increased significantly with increasing trailer weight and the 4T treatment increased root surface by 54% as compared with the control (Zuraidah *et al*., 2010b). The increase in root absorption surface could have contributed to the significantly higher FFB yield from the compacted plots.

CONCLUSION

The compaction treatments applied in this study significantly altered the physical properties that cause soil compaction which subsequently influenced oil palm growth. The changes in soil physical properties were considered non-limiting to palm growth as the palms adapted well and in fact benefited from the compaction treatments. They adapted to soil compaction under field conditions through both morphological and distributional changes in the root system as well as the vegetative components. The palms responded positively in terms of increased FFB yield, bunch number and bunch weight. On the other hand, the compaction treatments resulted in significant reductions in oil palm standing vegetative biomass, root biomass, frond and trunk biomass. However, total green frond number, leaf area and LAI were not affected by the compaction treatments. Even though it has been widely reported that soil compaction caused undesirable effects on plant growth, this study shows that compaction may not be detrimental to oil palm productivity in the Bernam series soil. Hence, similar studies should be carried out on other soil series commonly used for planting oil palm to determine any differences in response.

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