SOIL PHYSICAL PROPERTIES AND OIL PALM GROWTH PERFORMANCE AS INFLUENCED BY CONTINUOUS TRACTOR TRAFFIC COMPACTIONS

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Changes in soil physical properties due to compaction have always been underestimated in their effects on oil palm growth. Hence, an extensive 90-month period trial was carried out to quantify the influence of various compaction intensities on soil physical properties, nutrient uptake, as well as oil palm growth responses, and yield. This research was carried out at the Malaysian Palm Oil Board (MPOB) Keratong Research Station, Pahang, where oil palm was planted on the inland sandy clay loam type of soil. In 2013, the experimental site was planted with the DxP AVROS variety at a density of 148 palms per hectare. The compaction treatments, comprising a tractor towing a trailer weighing 2 tons (T1), 4 tons (T2), and 8 tons (T3), and a control plot (no vehicle traffic), were commenced in 2014, at the palm age of 18 months. The vehicle traffic treatments were operated three times per month. The soil physical analyses and vegetative measurements were done twice, at 6-month intervals per year, whereas the yield components were recorded monthly when the oil palm trees reached 3 years old. From this study, it was found that the soil bulk density was significantly impacted by the weighing treatments after 90 months of compaction. Apparently, the mean soil bulk density in compacted plots, under wheel track area, and at 0–10 cm depth was higher by approximately 2.9%, 2.0%, and 0.7 to 1.5%, respectively, as compared to the control plots, frond pile area, and 10–20 cm and 20–30 cm soil depths. In contrast, the mean total porosity was significantly decreased by 3.9% in the compacted plots, lowest at the under-wheel tracks area by 47.2%, and significantly higher by 0.5 to 1.5% at the 0–10 cm depths. The soil compaction was further indicated by an increment of available water in compacted soil up to 120%. The soil hydraulic conductivity and infiltration rate were significantly reduced in compacted plots by 6.5 to 14.9% and 9.9 to 20.8%, respectively. It was found that the frond pile area recorded 17.0% and 14.8% higher soil hydraulic conductivity and infiltration rate, respectively, as compared to the wheel track area. Notably, there were no significant differences in nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg) concentrations in the control and all compacted plots, indicating that the nutrient availability was not affected by the compacted soil due to the heavy vehicle traffic. The fresh fruit bunch (FFB), bunch numbers, and weight were significantly higher in compacted plots as compared to the control. Nonetheless, the oil palm standing biomass in control plots was 3.52% significantly higher as compared to the compacted plots. The findings also demonstrate that there were insignificant differences between trunk heights in all treatments. However, the palm in compacted plots exhibited a significant reduction in trunk diameter, trunk dry weight, and petiole-cross section. The total leaf area and LAI value of palms in compacted plots were significantly higher by 1.0 to 8.0% as compared to the control. Evidently, the current findings indicate that, regardless of weight, the 90-month compaction treatments had impacted soil properties but did not become a limiting factor to palm production because a positive association between these treatments and oil palm yield was observed, supported by no significant difference in foliar nutrient content between treatments in this study.

Keywords: Oil palm, Mechanization, Soil bulk density, Soil compaction, Soil total porosity

SDG: GOAL 1: No poverty, GOAL 2: Zero hunger, GOAL 15: Life on land

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SIFAT FIZIKAL TANAH DAN PRESTASI PERTUMBUHAN KELAPA SAWIT YANG DIPENGARUHI OLEH PEMADATAN TRAKTOR SECARA BERTERUSAN

Oleh

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Perubahan pada sifat fizikal tanah akibat pemadatan tanah seringkali dipandang remeh dari segi kesannya terhadap pertumbuhan kelapa sawit. Maka, kajian selama 90 bulan telah dijalankan untuk mengukur kesan pelbagai keamatan pemadatan ke atas sifat fizikal tanah, kadar pengambilan nutrien, tumbesaran pokok dan juga hasil tanaman. Penyelidikan ini dijalankan di Stesen Penyelidikan Lembaga Minyak Sawit Malaysia (MPOB) Keratong, Pahang di mana kelapa sawit ditanam di kawasan tanah liat berpasir. Pada tahun 2013, tapak kajian telah ditanam dengan varieti DxP AVROS dengan kepadatan 148 pokok sawit sehektar. Rawatan pemadatan tanah, melibatkan traktor menunda treler seberat 2 tan (T1), 4 tan (T2), dan 8 tan (T3), serta plot kawalan (tiada trafik kenderaan) bermula pada tahun 2014, iaitu pokok berumur 18 bulan. Rawatan trafik dijalankan sebanyak tiga kali sebulan. Analisis fizikal tanah dan pengukuran vegetatif dilakukan dua kali setahun iaitu selang 6 bulan, manakala komponen hasil direkodkan setiap bulan apabila pokok menjelang usia 3 tahun. Daripada kajian ini, didapati ketumpatan pukal tanah telah terjejas dengan ketara oleh rawatan kajian selepas 90 bulan pemadatan. Perbezaan ketumpatan pukal tanah adalah sangat ketara antara rawatan. Purata ketumpatan pukal tanah dalam plot padat, di kawasan laluan tayar, dan pada kedalaman 0-10 cm, masing-masing lebih tinggi sebanyak 2.9%, 2.0%, dan 0.7 hingga 1.5% berbanding plot kawalan, kawasan timbunan pelepah, dan pada kedalaman 10-20 cm dan 20-30 cm. Sebaliknya, purata jumlah keliangan telah menurun sebanyak 3.9% dalam plot yang dipadatkan, dan ketara lebih tinggi sebanyak 0.5 hingga 1.5% pada kedalaman 0-10 cm. Pemadatan tanah juga ditunjukkan dengan pertambahan jumlah air yang ada dalam tanah yang dipadatkan sehingga 120%. Kekonduksian hidraulik tanah dan kadar penyusupan telah berkurangan dengan ketara dalam plot yang dipadatkan masing-masing dengan julat 6.5 hingga 14.9% dan 9.9 hingga 20.8%. Turut didapati bahawa kawasan timbunan pelepah mencatatkan sebanyak 17% dan 14.8% lebih tinggi kekonduksian hidraulik tanah dan kadar penyusupan jika dibandingkan dengan kawasan laluan tayar. Secara ketara, tiada perbezaan ketara dalam kepekatan Nitrogen (N), Fosforus (P), Kalium (K), dan Magnesium (Mg) hasil analisa daun di plot kawalan dan semua plot yang dipadatkan, menunjukkan bahawa ketersediaan nutrien adalah tidak terjejas disebabkan oleh tanah yang padat kesan lalu lintas kenderaan berat. Buah tandan segar (BTS), bilangan dan berat tandan adalah lebih tinggi dengan ketara di plot padat berbanding kawalan. Namun begitu, biojisim berdiri kelapa sawit dalam plot kawalan adalah 3.52%, jauh lebih tinggi berbanding plot yang dipadatkan. Penemuan juga menunjukkan bahawa terdapat perbezaan yang tidak ketara dalam ketinggian batang dalam semua rawatan. Walaubagaimanapun, pokok di plot yang dipadatkan menunjukkan pengurangan ketara pada dalam diameter batang, berat kering batang, dan keratan rentas tangkai daun. Jumlah luas daun dan nilai indeks kawasan daun (LAI) pokok sawit dalam plot padat adalah lebih tinggi dengan ketara sebanyak 1.0 hingga 8.0% berbanding pokok di plot kawalan. Jelas sekali, tanpa mengira berat, penemuan semasa menunjukkan bahawa rawatan pemadatan selama 90 bulan telah memberi kesan kepada sifat fizikal tanah, namun tetap tidak menjadi faktor pengehad kepada pengeluaran sawit kerana perkaitan positif antara rawatan ini dan hasil kelapa sawit diperhatikan dan disokong oleh penemuan bahawa tiada perbezaan kandungan nutrien dalam daun antara rawatan ditemui dalam kajian ini.

Kata kunci: Jumlah keliangan tanah, Kelapa sawit, Ketumpatan pukal tanah, Mekanisasi, Pemadatan tanah

SDG: MATLAMAT 1: Tiada kemiskinan, MATLAMAT 2: Kelaparan sifar, MATLAMAT 15: Kehidupan di darat

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"My life is so blessed with some of the most amazing people. Thank you for being part of my journey."

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LIST OF ABBREVIATIONS

2T	Tractor With 2 Tons Trailer Weight
4T	Tractor With 4 Tons Trailer Weight
8T	Tractor With 8 Tons Trailer Weight
ANOVA	Analysis of Variance
CTF	Controlled Traffic Farming
EFB	Empty Fruit Bunch
FFB	Fresh Fruit Bunch
GIS	Geographic Information System
LAI	Leaf Area Index
LCC	Leguminous Cover Crop
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council
pF	Potential Failure
R&D	Research and Development
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis Software
SDG	Sustainable Development Goals
USDA	United States Department of Agriculture
WD	Wheel Drive
WS	Wheel Steering

CHAPTER 1

INTRODUCTION

1.1 Background

The Malaysian oil palm industry serves as a backbone of the national economy, employing roughly around 382,000 workers in 2022, especially in the oil palm plantations. Out of the total workforce, 73.9% have been hired as field workers, fruit harvesters, and collectors (Ismail et al., 2016). This industry is very much dependent on labour to carry out harvesting and collecting fresh fruit bunches (FFB), weeding, manuring, and other plantation maintenance work. However, there is no argument for the fact that the plantation industry is suffering from a severe labour shortage (Murphy et al., 2021; Crowley, 2020). To overcome the problem, one of the ways is to ensure consistent palm oil production via continuous research and development (R&D) on labour-saving technologies by robust automation and adopting mechanization (Crowley, 2020).

Mechanization has become a buzzword in the oil palm industry of Malaysia over the recent years. It was introduced to the plantation in the early 1980s and has proven to overcome the acute shortage of labour, improve production efficiency, and enhance labour productivity since the major requirement for oil palm plantations is manpower. The introduction and adoption of the various agricultural mechanization particularly in FFB harvesting and collection as well as in-field collection significantly reduce the labour to land ratio from 1:8 ha to 1:10 ha (Abdullah et al., 2011) and increase labour productivity (Ismail et al., 2016). The development of mechanization in various field operations could lead to a greater potential for soil to be compacted as heavier modern equipment was used (Shuib et al., 2016). Unfortunately, the extensive usage of heavier equipment or machinery could contribute to the deterioration of soil's physical properties due to the compaction and eventually affect the yield potential (Nawaz et al., 2013). The main concern in oil palm plantations is repeated traffic of various machinery on the harvest path. Soil compaction mainly occurs because of the movement of trailer weights and transportation frequencies of the FFB in the plantation. Any traffic that passes through a field would potentially compact the soil. Thus, the more tractors pass over the field in a certain location, the more compacted the soil becomes (Wang et al., 2022). Shallow compaction could be corrected to some extent, but deep compaction would be challenging to correct. Severe soil compaction destroyed soil structure, promoted erosion, lost organic matter and fertility, and disrupted water, organic carbon, and plant nutrient cycles, thus reducing soil health due to the affected soil's physical properties (Vanderhasselt et al., 2023; Gregory et al., 2015). Soil physical properties including soil texture, structure, porosity, bulk density, hydraulic properties, and moisture characteristics have an important effect on plant growth as they influence the function of the root system which is closely related to water availability, pore space, and gaseous in soil. Continuous soil compaction may also lead to the restriction of root growth and proliferation as the soil might have poor aeration, lack available water in the root zone, nutrients accessibility, and soil permeability (Abisuwa et al., 2023; Jamali et al., 2021; Pandey et al., 2021; Lucas et al., 2019).

The suitability of different soil types found in oil palm agriculture areas for palm development varies greatly. Palms grow best in regions where the land is level or moderately undulating, where the soil is deep and well-drained, with no compacted or impermeable horizon close to the surface, and where the soil can retain sufficient moisture and nutrients. Thus, ongoing soil management is crucial. During all field operations in the plantation, the soil should be protected from any methods of degradation. Compaction caused by machinery can be reduced by monitoring the traffic system and avoided by keeping heavy equipment off damp soil. To reduce soil compaction, the machinery used should be of proper size and weight. Thus, proper control of soil physical characteristics is critical for increasing oil palm productivity.

1.2 Problem Statement

The altering of soil physical properties is the most significant impact of soil compaction caused by mechanization, although the importance of soil physical properties to crop growth is generally overlooked. This would have an impact on the soil long-term viability, and inevitably oil palm growth and yield. Many studies have inclined to investigate the impacts of soil compaction induced by mechanization on crop yield and growth performances correlated to the declining of soil physical characteristics (Liu et al., 2022; Botta et al., 2022; Shaheb et al., 2021; Shaheb et al., 2020; Millington, 2019; Shaheb et al., 2018; Sivarajan et al., 2018; Shah et al., 2017; Galambošová et al., 2017; Nawaz et al., 2013; Gregorich et al., 2011). According to Shaheb et al. (2021), the soil compaction induced by the heavy machinery could result in a significant crop yield reduction up to 50% or even more, depending on the intensity of the soil compactness. The soil bulk density was reported to be higher in the compacted soil (Botta et al., 2022; Shaheb et al., 2021; Gursoy, 2021; Osanyinpeju and Dada, 2018; Shah et al., 2017; Ji et al., 2013; Hamza et al., 2011; Blanco-Canqui et al., 2010) which subsequently caused a lower infiltration rate and led to water logging and flood (Alaoui et al., 2018). The prolonged waterlogging will provide a conducive environment for certain dangerous microbes that thrive in low oxygen, subsequently promoting the growth of root infections and other soil-borne pathogens that harm plants. Furthermore, the ability to access water and the efficiency of nutrient uptake by plant roots were compromised in waterlogged conditions. Consequently, the fertilizer applied to the soil may not be adequately absorbed by the plants, resulting in nutrient waste and inefficiency. The reduced capacity of the compacted soil to absorb water tends to run off the surface rather than infiltrating the soil, increasing the risk of erosion, and leading to soil loss and nutrient depletion (Napoli et al., 2017).

Detailed information on the severity and extent of soil compaction, as well as their interactions with the oil palm, is nonetheless still lacking. Hence, the field trial was executed in a commercial Malaysian Palm Oil Board (MPOB) oil palm plantation to allow natural process such as variable rainfall and wet and dry seasons to alter soil conditions throughout the study. The palms received actual plantation conditions, environment, and management. This study used the appropriate technique to link soil compaction caused by certain mechanized activities to oil palm development. The goal of this study was to determine the extent of soil deterioration induced by mechanical activities, its impact on oil palm growth performance, as well as their interactions through foliar nutrient content analysis. It is believed that the research would aid in a better understanding of the degree of soil compaction generated by the weight of the machines, which has an impact on palm growth and production.

1.3 Research Objectives

The objectives of the study were:

a) To evaluate the effect of different trailer weights on soil physical properties.
b) To evaluate the effect of soil compaction on oil palm nutrient uptake through foliar nutrient content analysis.
c) To determine the oil palm growth performance and yield in correlation to soil physical properties and foliar nutrient content.

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