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Influence of Oil Palm Replanting, Age and Management Zones on Soil Carbon

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ABSTRACT

Oil palm (*Elaeis guineensis* Jacq.) cultivation is said to have caused losses of soil carbon due to deforestation. However, current oil palm cultivation is carried out either on previously rubber and cocoa plantation or replanted on first- or second-generation oil palm. The present study was conducted to assess whether there is a build-up of soil carbon throughout the growth of oil palm and will those amassed carbon (if any) be lost during replanting. The study was conducted at oil palm ages 5, 10, 15 years old, and newly replanted oil palm. At each age, soils were sampled at the frond heap pile (FH), the harvesting path (HP), and the inter-row (IR). Soil carbon content at all plots was not significantly different between ages with a mean of 2.24%. Between sections, soil carbon content at FH (3.10±1.42%) was significantly higher than the other sections. Our results showed that age of oil palm did not influence the accumulation of soil carbon. Replanting was also found not to have caused losses of soil carbon. As the different sections of the plantation yielded different results, future measurements of soil carbon should consider these different sections to properly represent the whole plantation.

Key words: **oil palm age, replanting, soil carbon, management zones**

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is an important oil seed crop in Malaysia and Indonesia, the world's two largest exporters. Malaysia and Indonesia supply 85% of the world's palm oil, and palm oil export earnings contribute immensely to the economy of both countries. As important as the oil palm industry may be to the two countries, large scale cultivation of oil palm has been drawing criticism from the international community, among other in regard to the losses of soil carbon from deforestation and land use change. This has led the European Union (EU) to pass a resolution in the European Parliament in 2018 to prohibit the importation of oil palm for biofuel into the EU by 2020. Adoption of the Roundtable on Sustainable Palm Oil (RSPO) certification by the majority of oil palm plantations have seen a slowing rate of deforestation across Malaysia and Indonesia (Carlson *et al.* 2018). The current practice for oil palm cultivation is either through replanting of palms more than 25 years old or planting on land that was previously planted with other commodity crops such as rubber and cocoa (Gaveau *et al.* 2016).

Like all chlorophyll containing plants, oil palm undergoes photosynthesis, taking up carbon dioxide (CO_2) from the atmosphere and transforming it into plant biomass. Carbon from plant biomass is either returned to soil through the decomposition of pruned fronds which are commonly left stacked on the soil surface, the decomposition of sloughed roots below ground and the decomposition of chipped oil palm trunks during replanting (Kho *et al.* 2019).

Therefore, the question that arises is whether the absorbed carbon throughout the 25 years of the oil palm's growth will be lost to the atmosphere during replanting or will there be an incremental increase in soil carbon with each successive replanting. The present study was carried out with the aim of determining the changes in soil carbon of oil palm over time and the effects of replanting on the fate of soil carbon.

MATERIALS AND METHODS

Study Site

The study was conducted at oil palm plots grown around the Universiti Putra Malaysia, Serdang campus. The soil at the site is mainly of the Munchong-Seremban soil series association (very-fine, kaolinitic, isohyperthermic, Typic Hapludox to clayey-skeletal, kaolinitic, isohyperthermic, Typic Hapludults). At both sites, dynamics of soil carbon was measured by taking soil samples from the 0-15 cm layer on oil palm ages 5, 10, 15 years old, and newly replanted oil palm. For each age, soils were sampled at the three distinct sections within an oil palm tree, which are the frond heap pile (FH), the harvesting path (HP), and the inter-row (IR). Five measurement replications were made at the three sections within each age.

Several assumptions were made at the onset of this study:

a) The management practices were the same i.e., fertilization was applied accordingly based on crop age and maintenance and upkeep of the pest and diseases was similar across ages.
b) The history of study plots i.e., the previous crops planted were ignored.
c) Micro relief effects are ignored.
d) Differences in the parameters measured were due to differences in oil palm age and management zones.
e) Loss of carbon from deforestation was disregarded.

Soil and Fine Root Sample Collection and Analysis

Soils were sampled from the top 15 cm layer at each of the three sections using an Edelman auger (Ø 7 cm) (Royal Eijkelkamp B.V., Giesbeek, Netherlands). The samples were air dried, crushed using a mortar and pestle, and sieved to pass through a 2-mm sieve. The soil samples were analyzed for total carbon content using the Dumas method (TruMac CNS Macro Analyzer, LECO Inc., Michigan, USA). Soil bulk density at each soil sampling point was determined by extracting an undisturbed core sample using a 100 cm^3 stainless steel ring. The undisturbed core samples were oven-dried at 105°C for 24 h and bulk density was determined as the water-free weight of the core sample over its volume. Using the soil carbon content (SC%) and the soil bulk density (BD), the soil carbon stock was determined as:

$$Soil\ C\ Stock\ = BD\,\frac{g}{cm^3} \times SC\% \times \frac{15\ cm}{sampling\ layer} \times \frac{1 \times 10^{-3} kg}{g} \times \frac{cm^2}{1 \times 10^{-8} ha}$$

Similar to the soil sample, the fine roots were sampled from the top 15 cm layer of the three sections by using a root auger (Ø 8 cm) (Royal Eijkelkamp B.V., Giesbeek, Netherlands). The core samples were air dried, and the roots were picked out using tweezers, cleaned from attached soil particles and oven-dried at 60°C until constant weight and the final weight was recorded.

Statistical Analysis

Measurements of soil carbon and fine root biomass were analyzed using one-way ANOVA with age and management zones as individual factors using R ver. 4.0.3. Means were separated using the least significant difference (LSD) test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Soil Carbon

The soil properties (i.e., total carbon content, bulk density, and carbon stock) are listed in Table 1. Soil total carbon content was not significantly different between oil palm ages. There were however variations of soil bulk density between oil palm ages with the replanted oil palm having the highest soil bulk density while the 15-year old oil palm had the lowest soil bulk density.

TABLE 1
Mean ± standard deviation of soil bulk density and carbon content across oil palm ages.

Age (years)	Bulk Density (g cm^{-3})	Soil carbon content (%)
5	$1.11{\pm}0.14^{ab}$	$2.40{\pm}0.87^{a}$
10	$1.18{\pm}0.18^{ab}$	$2.26{\pm}0.65^{a}$
15	$1.06{\pm}0.22^{b}$	$2.18{\pm}0.21^{a}$
Replanted	$1.22{\pm}0.15^{a}$	$2.11{\pm}0.22^{a}$

Note: Same superscript letters indicate means were not significantly different within the same columns at $p<0.05$.

Due to the differences in soil bulk density despite having the same soil carbon content across ages, there were variations of estimated soil carbon stock between the different oil palm ages (*Figure 1*). Nevertheless, the only contrasting difference was between oil palm ages 10 and 15, where the estimated soil carbon stock (mean ± standard deviation) were 40.95 ± 9.01 t C ha^{-1} and 32.25 ± 6.59 t C ha^{-1}, respectively.

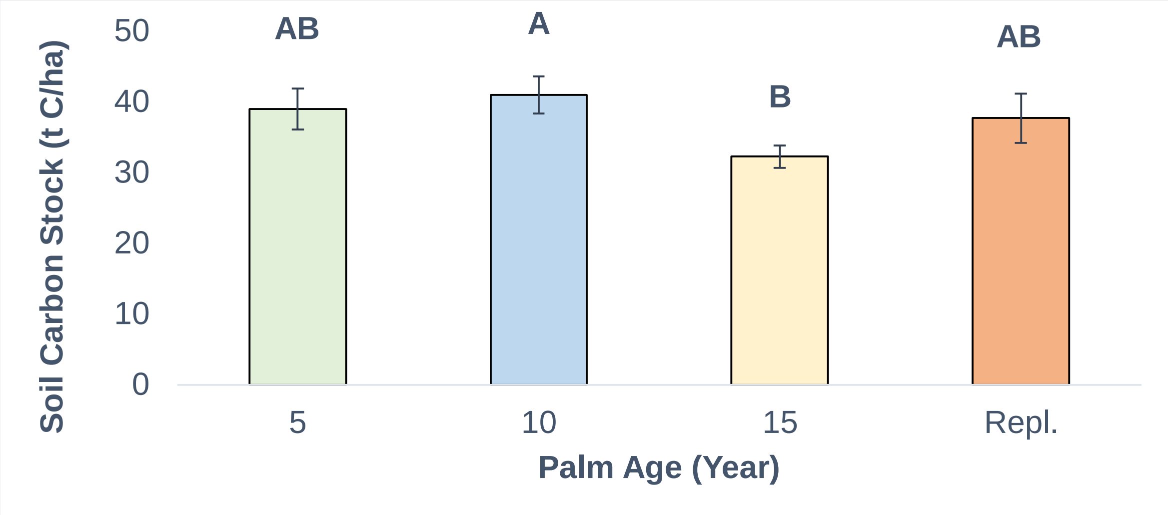

Figure 1: Mean carbon stock across oil palm ages.
Note: Bars indicate standard error. Same letters indicate means were not significantly different at p<0.05.

However, between the different management zones (*Figure 2*), soil carbon content (mean ± standard deviation) was found to be the highest at the frond heap (2.72 ± 0.92%) while soil carbon content at the inter-row (2.18 ± 0.81%) and harvesting path (1.91 ± 0.60%) were not significantly different from each other.

Figure 2: Mean soil carbon content of the different management zones.
Note: Bars indicate standard error. Same letters indicate means were not significantly different at p<0.05.

Fine Root Biomass

Figure 3 shows the fine root biomass across ages. There were significant differences in fine root biomass across the different oil palm ages. Fifteen-year-old palms showed the highest root biomass with a mean weight per volume of 8.87 mg cm^{-3} followed by the replanted palms (6.35 mg cm^{-3}) while palm aged 5 and 10 years were not significantly different from each other with means of 3.12 mg cm^{-3} and 2.12 mg cm^{-3}, respectively.

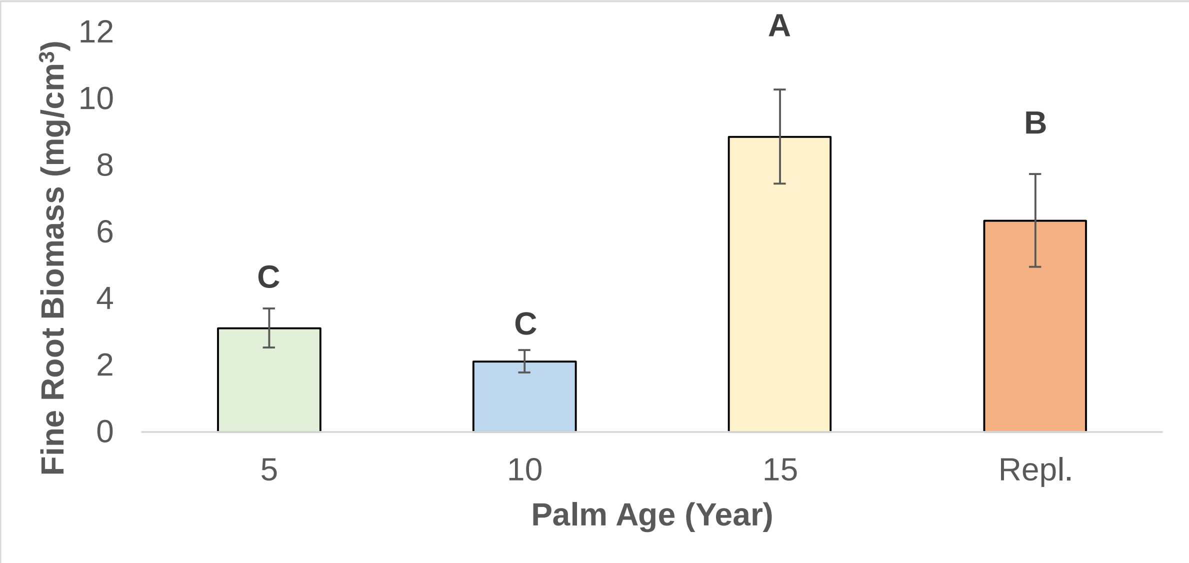

Figure 3: Mean fine root biomass across oil palm ages.
Note: Bars indicate standard error. Same letters indicate means were not significantly different at p<0.05.

Our findings of the fine root biomass contradicted with the findings of soil carbon stock across ages. Fine root biomass was highest in 15-year-old oil palms, but soil carbon stock was lowest in 15- year-old oil palms. However, between management zones, there were no significant differences between the frond heap and inter-row with the harvesting path (*Figure 4*). The harvesting path had the lowest fine root biomass with a mean of 3.17 mg cm^{-3} compared with mean fine root biomass of 7.44 mg cm^{-3} and 3.17 mg cm^{-3} for the frond heap and inter-row, respectively.

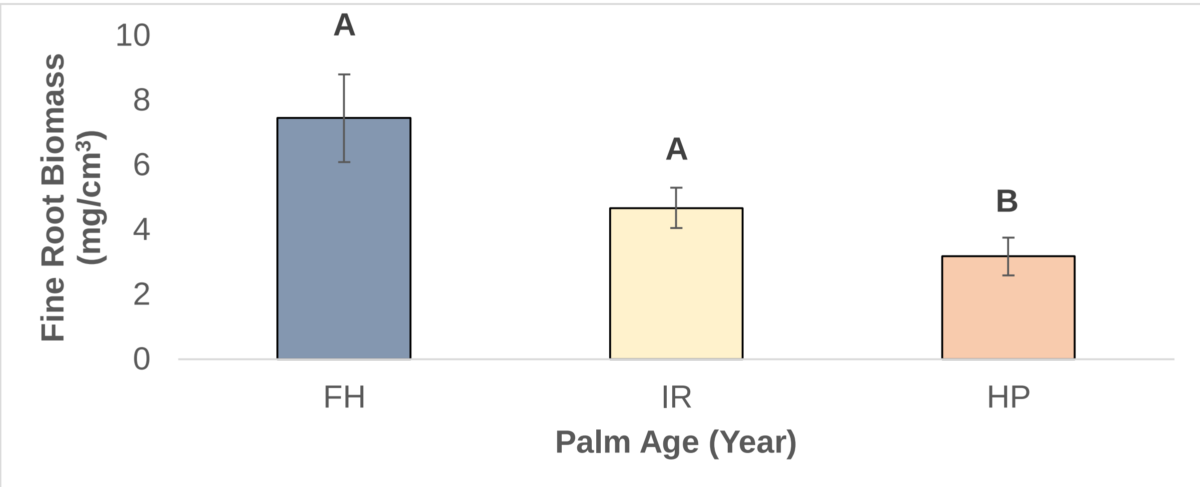

Figure 4: Mean fine root biomass of the different management zones.
Note: Bars indicate standard error. Same letters indicate means were not significantly different at p<0.05.

Influence of Replanting and Palm Age on Soil Carbon

Our findings do not show a clear trend of increasing soil carbon as the palm ages. This was in line with the findings of Khasanah *et al*. (2015) who found that soil carbon stock neither decreased nor increased in current oil palm plantations in Indonesia. They have also noted that historical activities of the site did not influence any carbon losses or build up.

Contrary to Khasanah *et. al.* (2015), a study by Rahman *et al.* (2018) on the changes in soil carbon from forest to oil palm in Sarawak, Malaysia observed an increase in soil carbon after replanting which was due to the incorporation of oil palm residues. The same effect was not observed in the present study perhaps due to the very recent clearing and replanting of the study plot when the research took place. The same effect was also not observed in the 5-year old plots as it was a newly established oil palm site and was not replanted oil palm.

Despite the differences in estimated soil carbon stock between oil palm ages 10 and 15 years, the main factor that led to the difference in estimated soil carbon stock was the soil bulk density rather than the soil carbon content. Our study found the replanted plot to have the highest bulk density. Soil bulk density decreased with age with the 15-year-old palms having the lowest bulk density.

Use of heavy machinery during replanting and land preparation may have been a factor for the higher soil bulk density at the replanted site. Zuraidah *et al.* (2010) in their study found that heavier machinery compacted soil even more in oil palm plantations which resulted in lesser root density.

Our findings of the fine root biomass, however, contradicted with the notion of the stagnant or non-evident trend of soil carbon increase. Fine root biomass showed an increasing trend from the fifth and tenth year of planting and peaked upon reaching 15 years, and declined as the oil palm was replanted. These contradictory findings may suggest that fine root turnover did not have a significant impact on the build-up of carbon in soil.

Influence of Management Zones on Soil Carbon

The different sections of the oil palm plantation i.e., the management zones demonstrated differences in soil carbon content and fine root biomass. The frond heap had the highest soil carbon content and highest fine root biomass while the harvesting path had the lowest values for both parameters.

Heavy foot and machinery traffic lead to compaction in the harvesting path (Zuraidah *et al*. 2010), causing lower root biomass in that zone. Although it has been demonstrated that fine root biomass is not a significant contributor to soil carbon stock, the frond heap receives a continuous input of biomass as fronds will be pruned twice a month to access the fruit bunch. The pruned fronds decompose, increasing soil carbon.

Due to the variation between management zones, future soil sampling strategies for carbon accounting in oil palm must take into account the differences of these management zones. Underestimation of soil carbon stocks may occur if soils are only sampled in the harvesting path. The same recommendation is also echoed by Rahman *et al.* (2018) who also found variations between management zones in oil palm.

CONCLUSION

Soil carbon content did not increase as the oil palm aged. Soil carbon stock differed with age but did not exhibit an increasing trend with oil palm age. The determining factor of the varying soil carbon stock was soil bulk density rather than soil carbon content. Fine root biomass was not a significant contributor to soil carbon stock as the 15-years-old oil palm had the highest fine root biomass, yet had the lowest soil carbon stock. Our findings indicate that oil palm cultivation and replanting of oil palm did not increase, nor did it decrease soil carbon. Soil carbon may stabilize and become neutral after successive cultivation of oil palm. Soil carbon content differed within an oil palm plantation in respect to the different management zones. Frond heap had the highest soil carbon content while harvesting path had the lowest. Future work on soil carbon stock accounting in an oil palm ecosystem should address the variation between the management zones to avoid biases.

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