

# QUANTIFYING TOTAL CARBON STOCK OF MATURE OIL PALM

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## ABSTRACT

The carbon stock of oil palm is an important indicator of environmental and agronomical impact of oil palm. Measuring variations in oil palm biomass with age, geographical region, and plantation management are necessary to accurately predict carbon stock across ecosystems. However, quantification of total carbon stock for mature oil palms is not well described. Here, we determined above- and below-ground biomass of mature palms planted on mineral soil in Sarawak, Malaysia using both destructive and non-destructive methods. Based on allometric equations, older palms constitute a greater total carbon stock, with the largest contributions from trunks and roots. Total carbon stocks assessed per the non-destructive method were 50.7 Mg C ha<sup>-1</sup>, 44.4 Mg C ha<sup>-1</sup>, and 72.1 Mg C ha<sup>-1</sup> in 11-year old, 21-year old, and 29-year old palms, respectively. Our results show that trunk biomass increases with the age of palms. Root biomass was substantially higher in older palms. Using the destructive method, total carbon stock of the 21-year old palms was approximately 51.3 Mg C ha<sup>-1</sup>. Differences between the two methods may be attributed to unaccounted palm components using the non-destructive method. The inclusion of unaccounted palm components, such as spears, cabbage and trunk bole would increase total carbon stock of 21-year old palms to approximately 48.0 Mg C ha<sup>-1</sup>. This suggests that the non-destructive method may effectively estimate carbon stock, given specific corrections and assumptions. This study demonstrates a field applicable approach for quantifying the total carbon stock of oil palm to assess the impact of oil palm plantation on the ecosystem carbon balance.

**Keyword:** carbon stock, oil palm, biomass.

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## INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is a major economic crop that continues to expand rapidly across landscapes, covering the whole process chain while ensuring the oil palm industry meets sustainable goals (Kushairi *et al.*, 2017; 2018). All palm oil and its products produced in Malaysia will come from sustainable sources and practices by 1 January 2020, reinforce Malaysia's commitment to responsible farming practices (Kushairi *et al.*, 2017).

Comprehensive plantation carbon measurements are imperative to assess the long-term effects of plantation carbon balance on greenhouse gases in the atmosphere. There is currently unprecedented interest to explore the contribution of oil palm as a potential carbon sink (Henson, 1999; Germer and Sauerborn, 2007; Kho *et al.*, 2011). The oil palm stores approximately 90%-96% of total annual dry production in the above-ground biomass as trunk, fronds, and bunches (Corley and Tinker, 2003; Kotowska *et al.*, 2015). As such, the above-ground biomass is an important indicator of carbon budget of oil palm plantation. The management of oil palm plantation affects the carbon cycle mainly through the contribution of above-ground biomass

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components. Maintenance pruning of palms and continuous recycling of fronds contribute to annual dry matter production at approximately 10 Mg ha<sup>-1</sup> yr<sup>-1</sup> in the Ivory Coast (Hartmann, 1991). The standing stock of palms provides a semi-permanent carbon pool, which, depending on the alternative land uses, would otherwise enter the atmosphere.

Despite the importance of above-ground biomass, data is limited and the applicability of allometric equations remains to be tested. Destructive sampling by felling palm is another method to estimate palm biomass but involves financial losses and is usually targeted at mature old palms to be replanted. In Malaysia, biomass estimation has been done using both non-destructive allometric equations and destructive methods to determine above- and below-ground biomass of 23-year old palms (Khalid *et al.*, 1999a, b). The aim of this study is to quantify above- and below-ground biomass of mature palms on mineral soil. We will explore both destructive method and allometric equations to compare both methods to estimate total standing carbon stock of oil palm on mineral soil across a range of different-aged palms.

## MATERIAL AND METHOD

### Study Site

This study was carried out at an oil palm plantation, the Lambir Estate of Sarawak Oil Palms Berhad, in Lambir, Miri, Sarawak in Malaysia (4°6'N, 113°59'E) in 2013 (Figure 1). The total area of planted oil palm in Lambir Estate was approximately 4200 ha. The Lambir Estate is divided into Lambir 1

(2028.5 ha) and Lambir 2 (2192.02 ha), with oil palms planted between 1985 and 2002. The planting density was 136 palms ha<sup>-1</sup>. Three 1 ha plots (100 x 100 m) were established, one each on the area of oil palm planted in 1985 (LAMOP85), 1992 (LAMOP92), and 2002 (LAMOP02). The oil palm estate planted in 1992 was assessed using both non-destructive and destructive sampling, while the other two sites (1985 and 2002) were mainly assessed following non-destructive sampling. The mean annual rainfall was approximately 2630 mm between 2000 and 2010. The mean annual temperature in Lambir estate for the period 2000-2010 was 25.9°C with little seasonal variation (temperature and precipitation recorded from an 80 m tall canopy crane approximately 15 km away from Lambir Estate).

The soils in the Lambir Estate consist of sandstone and shale. The shale-derived soils are clay-rich adult Ultisols (Soil Survey Staff, 2006), with typically 40% sand and high water-holding capacity (Davies *et al.*, 1998). The sandstone-derived soils are humult Ultisols (Soil Survey Staff, 2006), with high sand content (typically 68% sand) and low water-holding capacity (Ashton and Hall, 1992; Davies *et al.*, 1998). The topography of Lambir Estate ranges from hill ridges and terraces to low-lying alluvial areas or low basins. Hills covered approximately 60% of Lambir Estate (Wall, 1964). The soils and geomorphology of Lambir Estate have previously been described in detail (Wilford, 1961; Wall, 1964).

### Non-destructive Method

All palms within the 1 ha sampling plot were tagged and numbered. The main components of oil palm were measured following the non-destructive

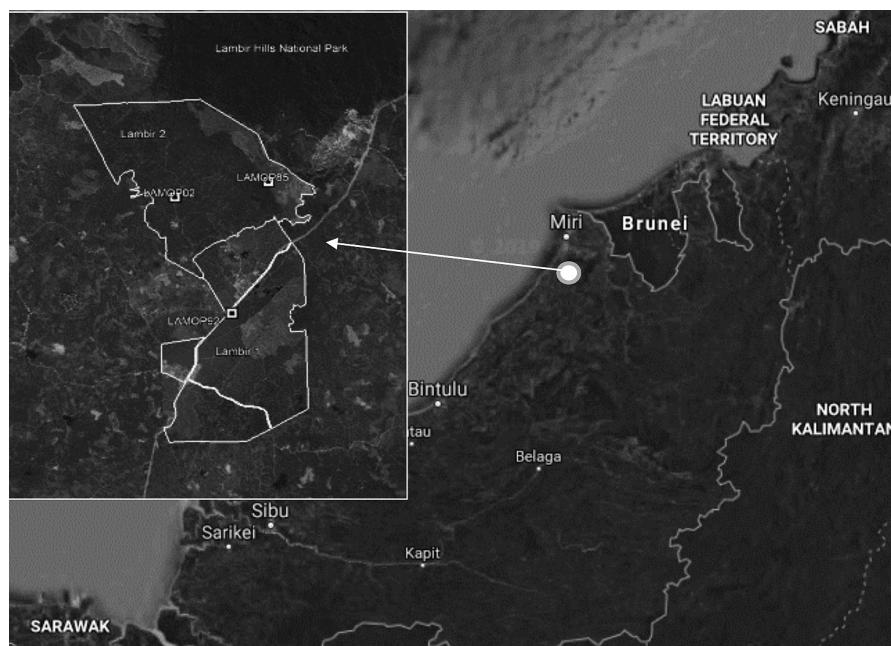


Figure 1. The study site in Lambir 1 Estate and Lambir 2 Estate near Miri, Sarawak.

sampling method successfully employed and tested in previous studies (Corley *et al.*, 1971; Corley and Tinker, 2003; Aholoukpè *et al.*, 2013) dry weight of leaflets, dry weight of a fragment (length = 0.30 m). Measurements were conducted mainly to determine the main oil palm biomass components, particularly trunk, frond, frond base, and root. In addition, epiphytes grown on frond bases of palms were measured. In this study, non-destructive sampling method refers to sampling of palm components without the need to destructively fell the whole palm.

**Trunk.** All palms were measured for diameter and height. Diameter was measured at 1.3 m from ground level using a large caliper. Using the laser rangefinder (Forestry Pro, Nikon Inc., USA), the height was measured at frond 41 or the 6<sup>th</sup> frond in the first spiral (Zuraidah *et al.*, 2017). Trunk biomass was estimated based on the allometric equation given by Corley and Tinker (2003):

$$T = VS = (\pi r^2 h) S \quad (\text{Equation 1})$$

where  $T$  is the trunk dry weight (kg),  $V$  is the volume increment of the trunk (l/yr),  $h$  is the annual height increment,  $r$  is the trunk radius, and  $S$  is the density of dry trunk (kg litre<sup>-1</sup>):

$$S = 0.0076t + 0.083 \quad (\text{Equation 2})$$

where  $t$  is the age of palm in years from transplanting.

**Frond.** Frond biomass includes leaflets, rachis and petiole. Three mature fronds of 17, 21 and 25, following the phyllotaxis arrangement of fronds around the palm axis, were sampled from each palm. The length of rachis was measured, and a 30-cm fragment was sampled mid-way along the rachis. Rachis fragment was dried in the oven at 80°C to constant weight. The mean biomass of an individual mature frond is estimated by the following equation given by Aholoukpè *et al.* (2013):

$$MDW_{\text{mature frond}} = 1.147 + 2.135 \times [1/3 \times (DW_{\text{rachis17}} + DW_{\text{rachis21}} + DW_{\text{rachis25}})] \quad (\text{Equation 3})$$

where  $DW_{\text{rachis17}}$ ,  $DW_{\text{rachis21}}$ , and  $DW_{\text{rachis25}}$  is the dry weight of rachis 17, 21, and 25 respectively. The dry weight of rachis was estimated based on the following equation given by Aholoukpè *et al.* (2013):

$$DW_{\text{rachis}} = 1.133 \times \frac{DW_{\text{frag}}}{L_{\text{frag}}} \times L_{\text{rachis}} \quad (\text{Equation 4})$$

where  $DW_{\text{frag}}$  is the dry weight of 30 cm fragment ( $L_{\text{frag}}$ ) of the rachis length ( $L_{\text{rachis}}$ ).

**Frond base.** Quantity of frond bases were calculated for each palm in the 1 ha plot. Frond bases were sampled within 0.5 m length around the palm at 1.3 m above-ground. The frond bases were separated into the following: i) complete frond base; and ii) fragments of frond base. Sub-samples were collected from each component, weighed, and dried to constant weight. The average frond base from these seven palms was extrapolated across all palms in 1 ha.

**Root.** Three triangular subplots were established among seven palms in the middle of each 1 ha plot following the design by Syahrinudin (2005) (Figure 2). Soil cores (11 cm diameter, 60 cm length) were extracted to a depth of 60 cm from 16 systematic sampling points in each triangular subplot. All roots were extracted and separated from the 60 cm soil cores, washed, oven dried at 80°C, and weighed.

Given that the extracted roots were estimated between 0 and 60 cm from the soil surface, we corrected the estimation up to 100 cm depth to reduce the discrepancies of root measured from different soil depths. The correction factor was calculated using the depth distribution of root biomass of a mature palm at the MPOB Research Station, Kluang, Johor (Khalid *et al.*, 1999b). Root biomass was extrapolated up to 100 cm based on the following equation:

$$W_R = 0.4408e^{-0.016x} \quad (\text{Equation 5})$$

where  $W_R$  is the dry mass of roots in kg, and  $x$  is the soil depth in cm. Hence, the correction factor for soil depth between 0 cm and 100 cm was 1.298.

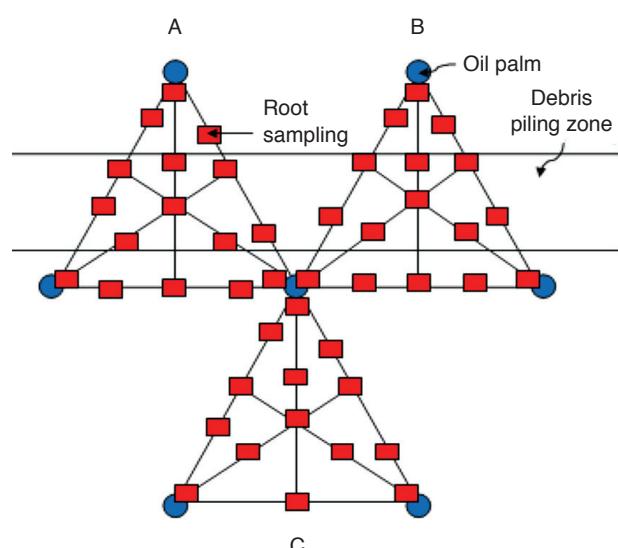


Figure 2. Triangular subplots established among seven palms in the middle of 1 ha plot following Syahrinudin (2005). Red square represents root sampling point, and blue circle denotes oil palm stand.

**Epiphytes.** Epiphytes or climbers were sampled within 1 m around the palm at 1.3 m above-ground. Samples were dried in the oven at 80°C to constants weight. The average dry weight of epiphytes within 1 m was corrected following the height of each palm across 1 ha.

### Destructive Sampling

Ten palms were randomly selected from the 21-year old plantation and felled (*Figure 3*). Each palm was carefully dissected and separated into the following components: i) trunk; ii) leaflets; iii) rachis; iv) petiole; v) frond base; vi) inflorescence; vii) spears; viii) cabbage; ix) trunk bole; x) root; xi) epiphytes; and xii) fruit bunch.

The fresh components were weighed in the field and sub samples of each component were weighed and dried to determine dry weights. Dried components were determined for C content for conversion factor from biomass to carbon. Specifically, the components of palms were treated following the procedure as follows:

1. Trunk – the trunk was divided equally into four sections. A sub sample of trunk (0.5 m fragment) was extracted from a randomly selected section, and further divided into eight parts. One-fourth was collected and dried to constant weight.



Figure 3. Each palm was randomly selected and felled, carefully dissected and separated in LAMOP92.

2. Leaflets / rachis / petiole / frond base / spears / cabbage / inflorescence / fruit bunch / epiphytes / trunk bole – all samples were collected and fresh weights were recorded. Sub samples (one-eighth of the total fresh weight) were collected and oven dried to constant weight.
3. Root – a soil pit measuring 1 x 1 m and up to a depth of 1 m was established for each palm. The extracted soils were sieved and separated for roots. All roots extracted were weighed and dried to constant weight.

### RESULT

#### Total Standing Biomass following Non-destructive Method

In the 1 ha plot, the total number of palms assessed were 117, 112, and 130 in the 29-year old plantation, 21-year old plantation, and 11-year old plantation, respectively. However, we estimated total standing biomass based on the recommended planting density of 136 palms  $\text{ha}^{-1}$ . The average recorded diameter was  $47.2 \pm 5.8 \text{ cm}$  in the 29-year old plantation,  $51.2 \pm 5.5 \text{ cm}$  in the 21-year old plantation, and  $59.5 \pm 6.7 \text{ cm}$  in the 11-year old plantation. The tallest palms averaged approximately  $11.0 \pm 1.1 \text{ m}$  in 29-year old plantation, followed by 21-year old plantation with average height of  $7.7 \pm 1.1 \text{ m}$ , and the lowest palms was in 11-year old plantation with an average height of  $4.7 \pm 0.7 \text{ m}$ .

The total standing biomass was approximately  $72.1 \text{ Mg C ha}^{-1}$ ,  $44.4 \text{ Mg C ha}^{-1}$ , and  $50.7 \text{ Mg C ha}^{-1}$  in LAMOP85, LAMOP92, and LAMOP02 respectively. The highest standing biomass for 29-year old palms was largely due to trunk and root biomass. Our current data is similar to that reported in previous studies (Rees and Tinker, 1963; Corley *et al.*, 1971; Syahrinudin, 2005) suggesting that trunk biomass increases with palm age and maybe more as a function of height, as observed in our study. The root biomass may not show any trend among the mature palms assessed, however we found a much greater root biomass in 29-year old and 11-year old palms. This can be attributed to sampling techniques employed that may have included other roots (vegetative undergrowth) from various sampling points. Hence, the root biomass reported in this study should be treated and interpreted cautiously and the sampling technique requires further investigation or refinement. However, the root biomass reported for 21-year old palms is quite consistent to that reported previously in Malaysia (Corley *et al.*, 1971).

As expected, the trunk biomass is relatively high in older palms in LAMOP92 and LAMOP85 than younger palms in LAMOP02 (11-year old). Both trunk and roots contributed equally large

carbon for the 29-year old palms, suggesting that carbon is still allocated to these components in older palms (Corley *et al.*, 1971). However, we found substantially lower root biomass for 21-year old palms both using destructive and non-destructive methods. This may be attributed to the health and conditions of the palms or to a smaller extend the progenies of palms planted.

#### Total Carbon Stock of Oil Palm Following Destructive Method

The average height of palms was approximately 8.3 m, and ranged between 7.3 and 10.1 m. The diameter of palms ranged between 39 and 64 cm. Using the destructive method to weigh all components of oil palm, the total standing biomass of 21-year old palms was 51.3 Mg C ha<sup>-1</sup> (*Table 1*). This is approximately 16% higher than those assessed using the non-destructive method in the same plot (LAMOP92) and age group. The disparity was explicitly due to unaccounted components including cabbage, spears, trunk bole and the larger amount of epiphytes found growing on the trunks of oil palms. The epiphytes were 0.2 Mg C ha<sup>-1</sup> based on non-destructive method but were relatively higher with estimate of 2.1 Mg C ha<sup>-1</sup> using the destructive method. This is mainly attributed to the abundance and the species of epiphytes. The average mass of epiphytes from the palms selected for non-destructive method was approximately 26.8 ± 2.9 kg, while those selected for destructive method was about 38.4±25.4 kg. Hence, there is a large variation of biomass of epiphytes between palms.

It is inevitable that some components were not assessed following inaccessibility to conduct measurements, particularly cabbage, spears and trunk bole. These components could only be measured when the palms were harvested. Based on destructive method, however, these components constitute approximately 3.5 Mg C ha<sup>-1</sup>. If these

missing components were included and assessed, the total standing biomass of palm following non-destructive method may add up to approximately 48.0 Mg C ha<sup>-1</sup>. The non-destructive method was 7% lower than destructive method. However, both methods yielded comparable results following careful assumptions and estimation.

#### Comparing Total Carbon Stock of Oil Palm

This study provided essential information on the standing biomass and total carbon stock of mature oil palm in Sarawak, Borneo region. In this study, we have assessed all components of oil palm to determine the total carbon stock of mature standing oil palm. However, certain components of oil palm are harvested and taken out from the oil palm system, or often not measured. These components, for example fruit bunch and epiphytes, are typically not included in estimations of total carbon stocks. Hence, considering the components typically assessed using destructive methods, our estimation is relatively higher than earlier studies conducted in Johor, Malaysia, but considerably lower than a recent study conducted in Sumatra, Indonesia (*Table 2*). The substantial differences are mainly attributed to the biomass of trunk and trunk bole. Larger trunk and trunk bole can be explained by the different progenies, soils, agronomic treatments, and environmental factors. Despite these differences, we believe that our results add to the knowledge on oil palm carbon stocks and the distribution of carbon in various oil palm components, including soil.

#### RECOMMENDATION

Regardless of the components measured and included in the estimation of total carbon stock, our results agree with previous studies (Kho and Jepsen, 2015). In addition, our results using both the non-

**TABLE 1. TOTAL STANDING CARBON STOCK (Mg C ha<sup>-1</sup>) OF VARIOUS OIL PALM COMPONENTS AT DIFFERENT AGES BASED ON NON-DESTRUCTIVE AND DESTRUCTIVE SAMPLINGS CONDUCTED IN 2013**

Sampling method	Non-destructive		Destructive	
	2002 (11 yr)	1992 (21 yr)	1985 (29 yr)	1992 (21 yr)
Year planted (age)				
Trunk	14.3	23.8	30.7	25.6
Frond	7.7	5.6	6.3	5.8
Frond base	4.2	2.3	0.6	2.6
Cabbage/spears	-	-	-	1.4
Inflorescence	0.1*	0.1*	0.1*	0.1
Trunk bole	-	-	-	2.1
Root	22.5	11.0	31.9	10.0
Climber/epiphyte	0.6	0.2	1.2	2.1
Fruit bunch	1.3*	1.3*	1.3*	1.3
Others	-	-	-	0.3
Total	50.7	44.4	72.1	51.3

Note: \* Estimated based on destructive sampling, assuming that inflorescence and fruit bunch are invariant to the age of palm.

**TABLE 2. COMPARISON OF TOTAL CARBON STOCK (Mg C ha<sup>-1</sup>) OF MATURE OIL PALM USING THE DESTRUCTIVE METHOD**

Source	Syahrinudin (2005)	This study	Khalid <i>et al.</i> (1999a,b)
Location	Sumatra, Indonesia	Lambir, Miri, Sarawak	Kluang, Johor
Planting density	-	136	136
Age (yr)	20	21	23
Trunk	31.5	25.6	17.5
Frond	8.4	5.8	10.1
Frond base	1.0	2.6	7.5
Others*	0.7	1.5	1.2
Trunk bole	5.5	2.1	2.7
Root	11.1	10.0	2.6
Total	58.2	47.6	41.6

Note: \* Others include spears, inflorescence and cabbage.

destructive and destructive methods have shown comparable total carbon stocks with appropriate corrections and assumptions particularly above-ground biomass. The root biomass using the non-destructive sampling techniques may require careful sampling protocol to avoid accounting for non-palm roots. We suggest using the non-destructive method to assess total carbon stocks of oil palm, in line with previous recommendations, e.g. perennial crops (Hardon *et al.*, 1969; Corley *et al.*, 1971). Such simple measurements and analyses, if widely conducted by the oil palm industries, could provide essential and accurate information on total carbon stocks or annual dry matter production of oil palm across various sites, soils, progenies and environment. From that point of view, it is imperative to obtain more quantitative data in order to estimate carbon balances more effectively and understand the contribution of oil palm as a carbon sink or source. In addition, comparative studies on changes in biomass and carbon stocks provide plausible answers to the impacts and implications of forest conversion to oil palm plantations.

## CONCLUSION

Our study provides a detailed description of total standing carbon stock of mature oil palm. We find that the total carbon stock of older mature palms is the highest and that considerable biomass is allocated in the trunk and roots. The non-destructive and destructive methods are relatively consistent, however, corrections for unaccounted components of palms, sampling procedures, and careful assumptions are needed. The non-destructive method demonstrates a field applicable approach for quantifying total carbon stock of oil

palm to assess the impact of oil palm plantation on the ecosystem carbon balance.

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