

## 研究資料 (Research record)

# Destructive sampling method for estimating the biomasses of African oil palm (*Elaeis guineensis*) plantations on tropical peatland

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### Abstract

We aimed to determine methods to estimate African oil palm (*Elaeis guineensis*) biomass on tropical peatlands. In this study we established a study plot in a 12-year-old African oil palm plantation in Sarawak, Malaysia. After measuring the stem diameters, heights, etc., of the palms in the plot, an average-sized palm was selected and its aboveground and belowground parts were destructively sampled to measure its biomass. Consequently, a destructive sampling method for estimating African oil palm plantation biomass on tropical peatlands was developed, based on the results of the field study. In addition, we discuss the ecological traits of African oil palms grown on tropical peatlands.

**Key words :** aboveground biomass, belowground biomass, root-to-shoot ratio, diameter at breast height, tropical peatland, African oil palm plantation

### 1. Introduction

The African oil palm (*Elaeis guineensis*) (hereafter referred to as oil palm) is believed to have originated in Africa (Corley and Tinker 2003), but is now cultivated as a plantation or cash crop in the tropical regions of Asia, Africa, and America, because its nuts contain high levels of good-quality vegetable oil. Malaysian palm oil production accounted for 36% of the global palm oil production between 2011 and 2013, and together with Indonesian palm oil is projected to account for 84% of the global production in 2013 (FAO 2015). Oil palm plantations are usually established on mineral soils; however, due to lack of land, peat soils are being developed on the basis of Good Agricultural Practice (GAP) (FAO 2003), in accordance with the sustainability of peatland functions (Ministry of Agriculture of Indonesia 2009). In addition, land with peat soil is often close to ports and towns with better infrastructure which are important for exporting the heavy commodity palm oil. In Malaysia, oil palms have been successfully planted on peat soils for two generations, and are into their third generation (Melling et al. 2011).

Oil palm production has been alluded to cause substantial, and often irreversible, damage to the natural environment (Clay 2004), because large amounts of carbon dioxide are released into the atmosphere when

tropical peat swamp forests are converted into oil palm plantations. Carbon dioxide emissions from biomass have been estimated using biomass data from tropical rainforests and oil palm plantations on mineral soils (Fargione et al. 2008). However, those data may differ from the data of the biomasses of tropical peat swamp forests and oil palms cultivated on tropical peatlands. No data are available in the literature about biomass of oil palm on tropical peatland. To evaluate the effects of converting peat swamp forests to oil palm plantations, knowledge of the biomasses of peat swamp forests and oil palms cultivated on tropical peatlands is required.

Therefore, a method of estimating the biomasses of peat swamp forests was developed (Monda et al. 2015 in press). In this study, a destructive sampling method was developed that was based on a field study of a 12-year-old oil palm plantation in Sarawak, Malaysia.

### 2. Plot establishment and selection of sample individuals

#### 2.1 Plot establishment

A study plot was established to select palms for destructive biomass sampling, in order to estimate their dry mass per unit of land area. Oil production begins around 2.5 years after planting (Corley and Tinker 2003), and the

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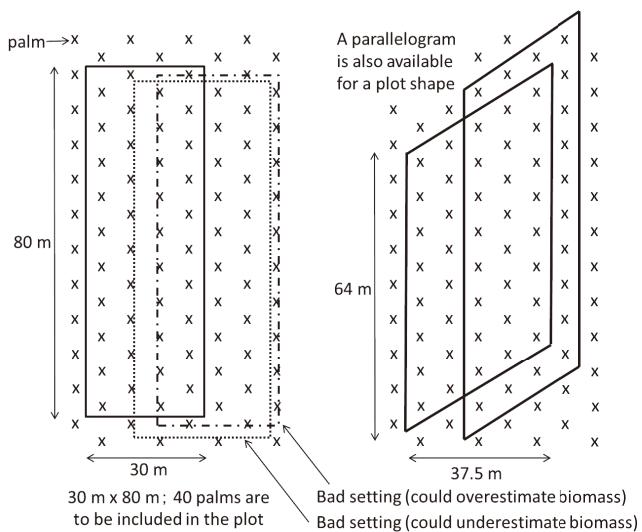
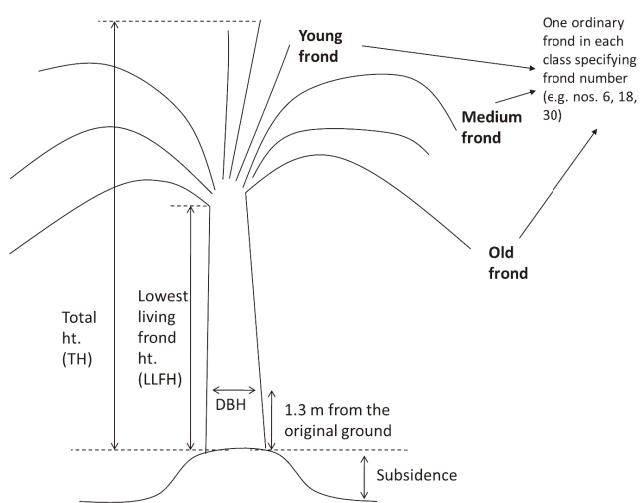


Fig. 1. Plot establishment

Fig. 2. Oil palm (*Elaeis guineensis*) measurements

economic life of a plantation is about 25 years. Oil palm biomass depends on plantation age. Although no statistical data are available, 12-year-old oil palms are considered to be the oldest age group in Sarawak, so we selected a 12-year-old plantation ( $2^{\circ}43'43.11''N - 111^{\circ}55'14.00''E$ ).

Even in the same plantation, the oil palm size usually differs among individuals; the required number of sample palms depends upon the variation in oil palm size in the plantation. From the perspective of revenue or yield, the optimal oil palm density is considered to be in the range 119–228 palms  $ha^{-1}$  (Corley and Tinker 2003), although it may depend on the cultivation period, soil conditions, etc. The study plot was 30 m in breadth and 80 m in length (Fig. 1, left), with a typical stand structure in spatial and girth at breast height (GBH) values. The average diameter at breast height (DBH, obtained by dividing GBH by  $\pi$ ; Fig. 2) and its coefficient of variation varied considerably when a small number of palms were measured (Fig. 3). However, the variation in the average DBH decreased after 20 palms had been measured, and the coefficient of variation was low after 30 had been measured. This indicated that at least 30, and preferably 40 or more palms, were required in the study plot, in order to obtain unbiased biomass data per unit of land area. In the study plot, the stand density was approximately 160 palms  $ha^{-1}$ ; therefore, the optimal plot area was approximately 0.25 ha (about 40 palms) or larger. The plot did not necessarily have to be rectangular (Fig. 1, left); parallelogram- (Fig. 1, right), square-, or hexagon-shaped plots are also acceptable. More importantly, the plot boundary should pass through the center between

the planting rows, to avoid an overestimation (Fig. 1 middle-left, alternating long and short dashed line) or an underestimation (Fig. 1 middle-left, dashed line) of biomass.

Oil palm biomass can be estimated using simple parameters that represent the shape of each oil palm and allometry equations or conversion factors that are appropriate for the characteristics of the palm. The parameter that is usually used in allometry equations for calculating palm biomass is stem height (Khalid et al. 1999a, Thenkabail et al. 2004, Goodman et al. 2013), which is combined with the total height (Fig. 2) or stem diameter (Yulianti 2010). Specific plant parts can also be used, such as fronds, for more accurate aboveground biomass estimation (Aholoukpè et al. 2013, Asari et al. 2013). In our study, stem height (height of the apex of the stem) was difficult to determine, because petioles obscured the apex. For the oil palm that was destructively investigated (see below), the stem height was visually estimated before destructive sampling was conducted based on the stem diameter that tapered to a point inside the petioles at 5.3 m. However, the actual stem height measured during the destructive sampling procedure was 4.4 m, which was 0.9 m shorter than the estimate. The accurate measurement of the oil palm stem height is difficult. The GBH, total height (TH), and the lowest living frond height (LLFH)\* were measured easily in all of the oil palms in the plot. A steel tape and a Vertex III clinometer (Haglof, Sweden) were used for the measurements.

\*The LLFH depends on TH and the number of living fronds from the top to the lowest living frond. The number of

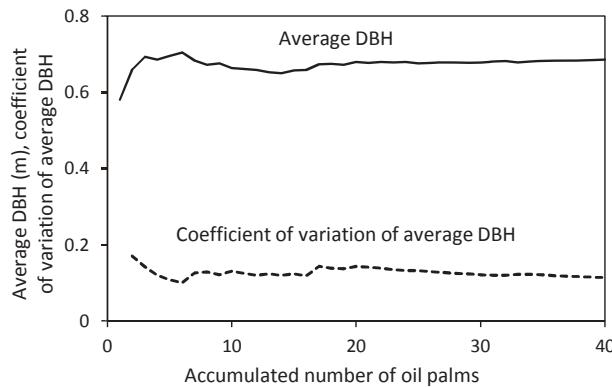


Fig. 3. Accumulated number of oil palms (*Elaeis guineensis*), average diameter at breast height (DBH), and coefficient of variation of the average DBH in the study plot

fronds is usually controlled in managed plantations (36 in the study plantation). Because frond biomass is dependent upon the number of fronds present, the inclusion of frond number, or the distance from TH to LLFH, as a parameter in allometry estimation may improve the accuracy of frond biomass estimates.

The ground just beneath the oil palm stems is often raised to a mound shape in plantations that are several years old because of ground subsidence. The GBH, TH, and LLFH from the mound (Fig. 2) were measured. Oil palms tend to lean over when they are planted in uncompacted peat (Mutert et al. 1999). For leaning or fallen palms (Fig. 4), the stem diameter at 1.3 m from the transition point between the stem and the root was measured in place of DBH. In the study plot, 12 palms (out of the 40 palms in the plot) were leaning.

In the study plot, the mean DBH was  $68.6 \pm 7.8$  cm (mean  $\pm$  standard deviation), the mean TH was  $9.9 \pm 1.0$  m, and the mean LLFH was  $3.3 \pm 1.0$  m. The stand's basal area at breast height was  $62.2 \text{ m}^2 \text{ ha}^{-1}$ .

Plants other than oil palms also grew in the oil palm plantation. However, weeding is usually quite intensive in oil palm plantations; therefore, the biomasses of plants other than oil palms were negligible, and were ignored in this study.

## 2.2 Selecting sample oil palms

There are two methods of estimating tree biomass per unit of land area from an individual tree's biomass: (1) the basal area ratio method (Satoo 1973), and (2) the allometry equation method (Henry et al. 2013). Both are suitable for estimating



Fig. 4. Measuring an oil palm (*Elaeis guineensis*) that is leaning

oil palm biomass. For the first method, biomass is estimated in the plot using the following equation: the sum of the stem basal areas of all of the palms in the plot/the sum of the stem basal areas of sampled palms  $\times$  the biomass of sampled palms; the result is converted from biomass per plot to biomass per unit of land area. If the sample is only one palm, a palm that has an area close to the average basal area is selected. If the sample contains several palms (this is more accurate than using only one palm), the sample should contain palms from the largest size group to the smallest size group. For the second method, an allometry equation is developed by obtaining the biomass data of palms sampled from the largest to the smallest size groups in the plot. The biomass of every palm in the plot is estimated by using the allometry equation. The palm biomass in the plot is summed and then converted to biomass per unit of land area.

No allometry equations exist for estimating the biomass of oil palms cultivated on peatlands that include belowground biomass. Therefore, in this study, the basal area ratio method was used, and a palm that had close to the average stem basal area (for the plot) was selected for destructive sampling. The selected palm was the 19<sup>th</sup> largest in the plot; the 20<sup>th</sup> and 21<sup>st</sup>-largest palms were not selected because both were leaning and not representative of the other palms in the plot. The selected palm had a DBH of 70.3 cm, a basal area of 0.393 m<sup>2</sup>, a TH of 10.14 m, a LLFH of 3.7 m, and a maximum crown diameter of 12.6 m. The number of fronds per palm had been maintained at around 36 in the study plot. This number can differ in other plantations under different managements and can influence the values of LLFH and maximum crown diameter.

### 3. Destructive sampling methods for aboveground and belowground organs

The destructive sampling procedure was as follows:

1. All of the fronds and inflorescences (flowers and fruit) were pruned, numbered, and weighed, including the remaining petiole bases (Fig. 5).
2. An ordinary frond from each of the young-, medium-, and old-frond groups, e.g., frond nos. 6, 18, and 30 in Fig. 2 were selected, and a subsample of petioles, rachises, and pinnae (Fig. 6, right) were obtained for each group and weighed (*frond sample sets*). The no. 20 frond was selected in this study because nos. 18 and 19 had lost a part of the pinnae and were not representative of the other fronds in the medium-frond group.
3. All of the inflorescences were weighed and samples were taken (*inflorescence samples*).
4. Snips of plant parts were collected and weighed to improve the accuracy of the biomass estimates (Fig. 7a).
5. The stem was felled and cut into logs (Fig. 7b, c, d). The total stem volumes (with frond base and without frond base) were calculated using the Smalian method, by multiplying the length by the cross-sectional areas of stem (with frond base and without frond base) of each log. The discs were cut, and their volumes and weights were measured (Fig. 7e, f) (*stem samples*). The required number of discs depended on the stem length. In this study, five discs at various heights (0.7, 1.2, 1.6, 2.5, and 3.4 m) were considered samples.
6. The lengths and weights of spears were recorded (Fig. 7g). For the biomass estimation, spears were included as fronds.

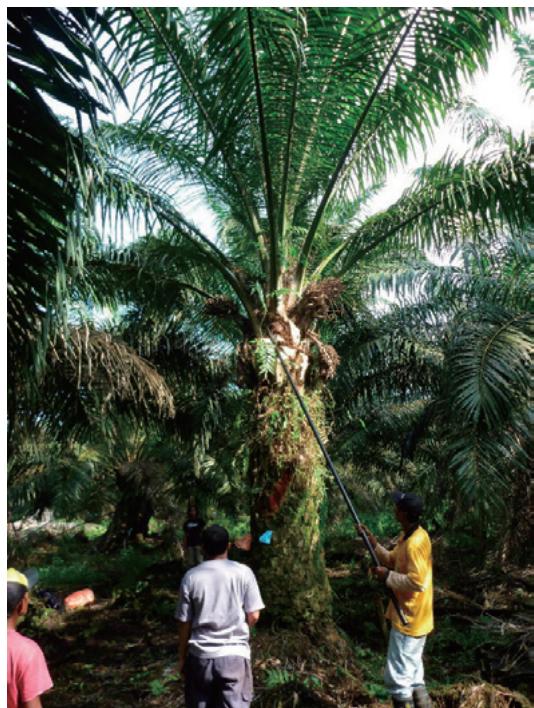


Fig. 5. Destructive sampling of oil palm (*Elaeis guineensis*) fronds and inflorescences

7. The belowground stem was dug up and cut into small pieces to weigh and to obtain samples (*belowground stem samples*) (Fig. 8a, b, c).
8. Two trenches that were 4 m long from the stem edge, 0.3 m wide, and 0.9 m deep, or deeper, were made using a chainsaw (Fig. 8d, e). A drainage pump was used when necessary. The alignments of the trenches are shown in Fig. 9.
9. The effects of different land uses (paths with possible soil compaction vs. frond piling) and the distance to neighboring oil palms (near to N1 and N2, far from F1 and F2) were considered; therefore, the trenches ran between N1 and F1 and between N2 and F2. N1 and N2 could be replaced by N3 and N4. Because oil palm roots do not penetrate below the level of a permanent water table (Corley and Tinker 2003), and the planned water-table depth was 0.5–0.75 m in the study plantation, soil sampling to a depth of 0.9 m appeared to be deep enough for collecting all of the roots. However, in reality, the roots penetrated to a depth of below 0.9 m; therefore, soil-sampling depth should be determined based on the actual root distribution.
10. Each sample block of soil was 1 m long, 0.3 m wide, and 0.3 m deep to a depth of 0.9 m, or deeper (Fig. 8d). The collected roots were weighed.
11. For roots under the belowground stem, a short trench that was as long as the stem diameter at ground level, 0.3 m wide, and 0.3 m deep to a depth of 0.9 m or deeper, was made using a chainsaw and an edged tool in order to collect and weigh roots every 0.3 m in depth (Fig. 8e).



Fig. 6. Measuring oil palm (*Elaeis guineensis*) fronds to obtain sub-samples of petioles, rachises, and pinnae

11. Sub-samples of the roots were taken, if required (Fig. 8f). The minimum fresh weight of a sub-sample should be 200 g (*root samples*).

12. All of the samples and sub-samples were taken to the laboratory to determine the dry/fresh weight ratios. The samples were oven-dried at 75°C to a constant weight.



Fig. 7. Destructive sampling of an oil palm (*Elaeis guineensis*) stem  
i : stem diameter with frond base, ii : stem diameter without frond base.



Fig. 8. Destructive sampling of oil palm (*Elaeis guineensis*) belowground organs

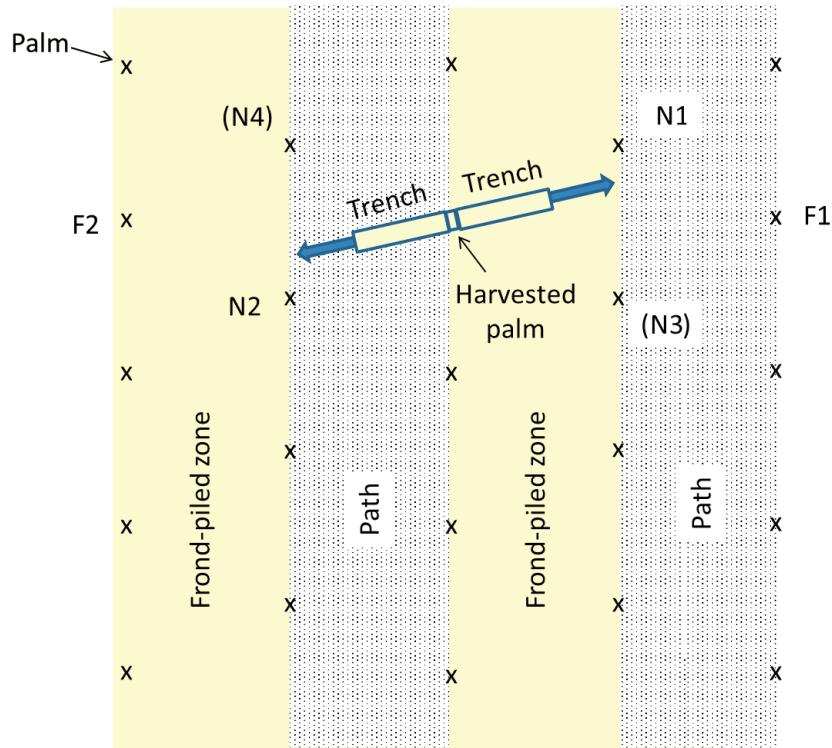


Fig. 9. Establishing trenches for the destructive sampling of oil palm (*Elaeis guineensis*) belowground organs

#### 4. A case study in measuring and estimating oil palm organs on peatland

##### 4.1 Root distribution

The roots were classified into three types (Fig. 10a), which corresponded to the primary, secondary, and tertiary roots (Corley and Tinker 2003): thick roots (5–7 mm in diameter) were primary roots, medium roots (2–3 mm in diameter) were secondary roots that sprouted from the primary roots, and tertiary roots (0.6–1.3 mm in diameter) sprouted from the secondary roots. Most of the primary roots were lignified. The root samples were collected at a depth of 0–0.3 m, just below the stem. Secondary roots accounted for the majority of the roots. This sample was obtained in soil far from the stem, both horizontally and vertically. Ratios of the projected root areas of the primary, secondary, and tertiary roots to the total were approximated when sampling (Fig. 10b, c).

The amount of root biomass per unit of soil volume was greatest near the stem and decreased with increasing distance from the stem, both horizontally and vertically (Table 1). The influence of land use (path or piled fronds) was unclear. Roots below the stem were considered deeper than 0.9 m from the surface. However, in dry land soil oil palm plantations, the root biomass is lower under the paths along the planting lines (Corley and Tinker 2003). The quantity of roots per palm is reduced when the rooting volume is reduced by a corresponding quantity of concretionary gravel (Tan 1979). On peatland, no clear difference was found in the root biomass between the path

and the frond-piled sites, in contrast to that found on dry land soils. Because peat soil is spongy, soil compaction is weak, even on paths, and any impact on root growth may have been small.

The water content of the roots tended to be low near the stem (Table 2, shown in italic). The primary roots were distributed in the soil near the stem, where the water content of the roots was low (Table 3a). The primary roots were also found in deeper soil, away from the stem (Table 3a). Secondary roots appeared to be distributed outside of the primary roots (Table 3b). Tertiary roots were mainly located at a depth of 0.6–0.9 m below the stem and in shallow peat away from the stem (Table 3c). Tertiary roots, which are important in nutrient and water absorption, appeared to be more prevalent under the frond-piled sites than under the paths. Although a clear difference was not found in root biomass in peat soils, root function appeared to differ between the paths and the frond-piled sites.

The root biomass of the sampled oil palm was estimated using the following procedure: the number of roots in the soil at a depth of 0–0.9 m per unit of land area decreased with increasing distance from the center of the stem (Fig. 11). This trend is similar to that observed in dry land soils (Khalid et al 1999a). However, compared to dry land soils, there were more roots near the stem and fewer at 2–4 m from the center of the stem.

The average root biomass per unit of land area ( $\text{kg} \cdot \text{m}^{-2}$ ) (at a depth of 0–0.9 m in this study) under the paths and frond-piled sites was then calculated for the following (Fig. 12): (a) a circle with a radius of  $r$  m (0.41 m in this study) that corresponded

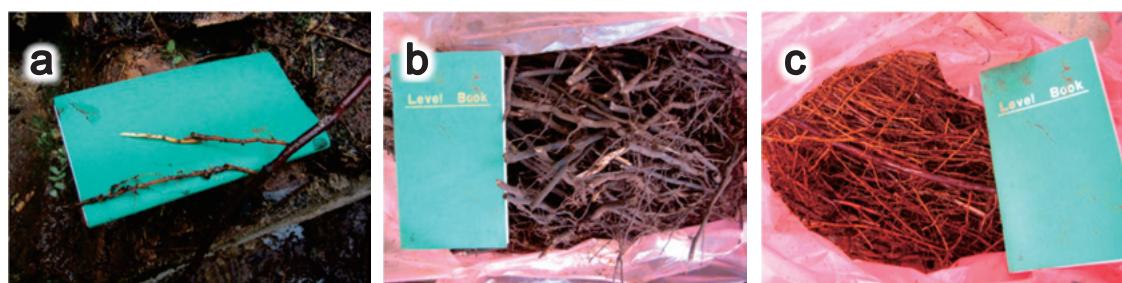


Fig. 10. Patterns of root growth and different root types of the oil palm (*Elaeis guineensis*)

Table 1. Oil palm (*Elaeis guineensis*) root biomass ( $\text{kg m}^{-3}$ )

Depth (m)	Distance from bole edge (m)				Bole	Distance from bole edge (m)			
	4	3	2	1		1	2	3	4
	Trench2 (frond piled)					Trench1 (path)			
0–0.3	0.1	0.2	0.5	1.3	6.4	1.4	0.1	0.1	0.0
0.3–0.6	0.0	0.1	0.5	1.1	5.2	1.0	0.2	0.1	0.0
0.6–0.9	0.1	0.0	0.0	0.7	2.3	0.4	0.2	0.1	0.1

Table 2. Oil palm (*Elaeis guineensis*) root water content ratio (0.0–1.0)

Depth (m)	Distance from bole edge (m)				Bole	Distance from bole edge (m)			
	4	3	2	1		1	2	3	4
	Trench2 (frond piled)					Trench1 (path)			
0–0.3	0.8	0.9	0.8	0.7	0.6	0.6	0.8	0.8	0.8
0.3–0.6	0.9	0.8	0.9	0.8	0.7	0.7	0.8	0.9	0.9
0.6–0.9	0.9	0.9	0.9	0.9	0.8	0.7	0.9	1.0	0.8

Table 3a. Oil palm (*Elaeis guineensis*) primary root volume ratio (0.0–1.0)

Depth (m)	Distance from bole edge (m)				Bole	Distance from bole edge (m)			
	4	3	2	1		1	2	3	4
	Trench2 (frond piled)					Trench1 (path)			
0–0.3	0.1	0.1	0.0	0.5	0.9	0.9	0.2	0.1	0.3
0.3–0.6	0.1	0.1	0.3	0.7	0.9	0.8	0.5	0.3	0.3
0.6–0.9	0.2	0.4	0.5	0.1	0.3	0.3	0.3	0.5	0.6

Table 3b. Oil palm (*Elaeis guineensis*) secondary root volume ratio (0.0–1.0)

Depth (m)	Distance from bole edge (m)				Bole	Distance from bole edge (m)			
	4	3	2	1		1	2	3	4
	Trench2 (frond piled)					Trench1 (path)			
0–0.3	0.1	0.1	0.2	0.2	0.0	0.1	0.0	0.5	0.3
0.3–0.6	0.1	0.1	0.4	0.2	0.0	0.1	0.6	0.4	0.3
0.6–0.9	0.7	0.2	0.3	0.3	0.2	0.1	0.6	0.4	0.3

Table 3c. Oil palm (*Elaeis guineensis*) tertiary root volume ratio (0.0–1.0)

Depth (m)	Distance from bole edge (m)				Bole	Distance from bole edge (m)			
	4	3	2	1		1	2	3	4
	Trench2 (frond piled)					Trench1 (path)			
0–0.3	0.8	0.9	0.8	0.3	0.1	0.0	0.8	0.4	0.5
0.3–0.6	0.8	0.8	0.3	0.1	0.1	0.2	0.3	0.2	0.3
0.6–0.9	0.1	0.4	0.2	0.6	0.5	0.6	0.1	0.1	0.1

to the area just below the stem; (b) concentric circles of  $r - 1 + r$  m (0.41–1.41 m), including the nearest 1-m trenches to the stem; (c) concentric circles of  $1 + r - 2 + r$  m (1.41–2.41 m), including the second-nearest 1-m trenches to the stem; (d) concentric circles of  $2 + r - 3 + r$  m (2.41–3.41 m), including the third-nearest 1-m trenches to the stem; and (e) concentric circles of  $3 + r - 4 + r$  m (3.41–4.41 m), including the fourth-nearest 1-m trenches to the stem. The relationship between the distance from the center of the stem ( $x$ , m) and the cumulative root biomass ( $y$ , kg) in the circle was approximated by a power equation:  $y = 95.0600 x^{0.4913}$  ( $R^2 = 0.9967$ ) (Eq. 1) (Fig. 13). The

relationship was statistically significant ( $P = 0.0001$ ).

By assuming that the sampled oil palm occupied the area corresponding to the stem basal area of the sampled palm divided by the sum of the stem basal areas per unit land area, and the root distribution of the oil palm occupied the same area of the circle, which was estimated to have a radius of 4.49 m. The root biomass at a radius of 4.49 m estimated using Eq. 1 was 198.8 kg. Because the root biomass in soil deeper than 0.9 m was ignored, the root biomass in this study was underestimated.

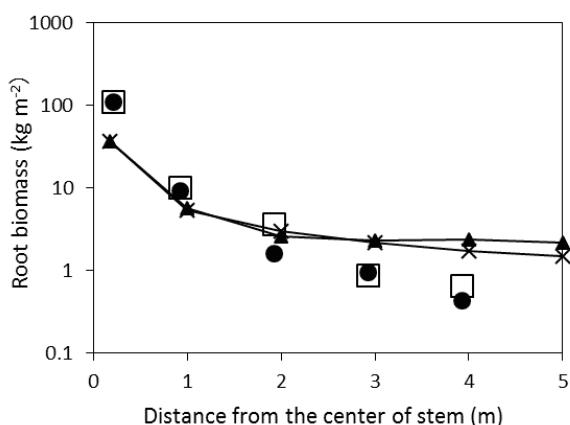


Fig. 11. Relationship between the distance from the center of the stem and the root biomass of an oil palm (*Elaeis guineensis*)

□, path; ●, frond pile (this study); x, dry land soil path; ▲, dry land soil frond pile (drawn by the authors, using original data from Khalid et al. 1999a, b).

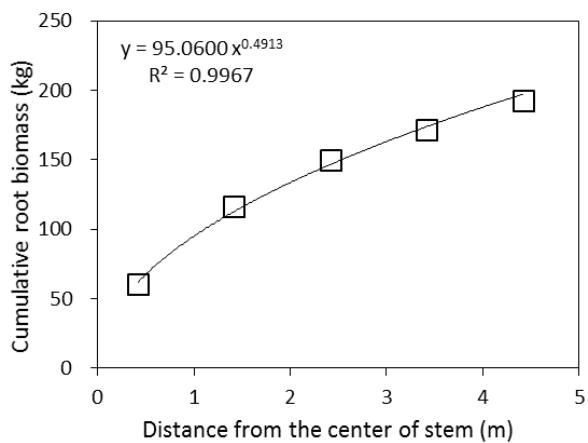


Fig. 13. Relationship between the distance from the center of the stem and the cumulative root biomass of an oil palm (*Elaeis guineensis*)

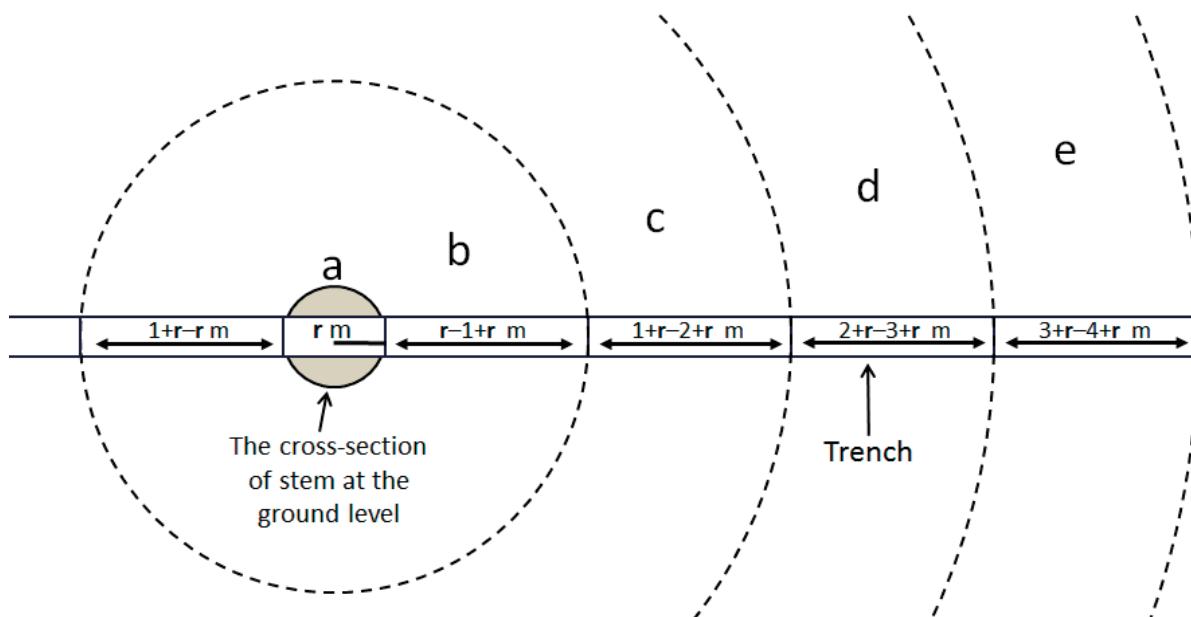


Fig. 12. Root samples used to estimate root biomass per unit of land area

(a) a circle with a radius of  $r$  m corresponding to the land just below the stem; (b) concentric circles of  $r - 1 + r$  m, including the nearest 1-m trenches to the stem; (c) concentric circles of  $1 + r - 2 + r$  m, including the second-nearest 1-m trenches to the stem; (d) concentric circles of  $2 + r - 3 + r$  m, including the third-nearest 1-m trenches to the stem; and (e) concentric circles of  $3 + r - 4 + r$  m, including the fourth-nearest 1-m trenches to the stem.

#### 4.2 Characteristics of aboveground and belowground organs of oil palms planted in peat soils

Table 4 presents the characteristics of each organ of the sampled palm. According to the basal area ratio method (the sum of the stem basal areas per unit of land area ( $62.2 \text{ m}^2 \text{ ha}^{-1}$ ) divided by the stem basal area of the sampled palm ( $0.393 \text{ m}^2$ )), was 158.1. The aboveground biomass of the study plantation was estimated to be  $69.1 \text{ Mg ha}^{-1}$ , and the belowground biomass was estimated to be  $33.8 \text{ Mg ha}^{-1}$ . The root-to-shoot ratio [belowground/aboveground biomass ratio for the vegetation type (IPCC 2003)] was 0.49, which is large compared to the values obtained in other studies (Fig. 14). The highest ratio has been found in the drier climate of the Ivory Coast, West Africa (0.67) (Dufrene and Saugier 1989). The value obtained in the present study was smaller, but was nearly double the values found for dry land soil stands with rainforest climates in Malaysia, Indonesia, and Nigeria (Corley et al. 1971, Khalid et al. 1999a, b, Lamade and Setiyo 1996, Ng et al. 1968, Rees and Tinker 1963). Oil palms cultivated on the tropical peatland appear to allocate a larger ratio of photosynthetic products to belowground organs (belowground/aboveground biomass ratio of 0.49) than those on dry land soils with tropical rainforest climates (0.11–0.32) (Corley et al. 1971, Khalid et al. 1999; Lamade and Setiyo 1996; Ng et al. 1968, Rees and Tinker 1963).

#### 5. Issues related to the biomass measurements and the estimation method

##### 5.1 Issues related to the biomass measurements

Stem height is the commonly used predictor variable for palm mass (Goodman et al. 2013). The inclusion of stem height as a predictor variable for oil palm biomass may improve the accuracy of biomass estimates. However, stem height (the height of the apex of the stem) of oil palm was difficult to determine non-destructively (2.1). Khalid et al. (1999a) defined stem height (palm height in the original paper) of oil palm as the distance from the ground to the base of no. 33 frond. Thenkabail et al. (2004) defined stem height as the distance from the ground to the point of the oil palm where the new rachis was developing within the protection of the established rachis. Because the definition of stem height of oil palm differed among the literatures, consistency of the definition is required when developing allometry equations using stem height as a parameter. Stem height (height of the apex of the stem) could be indirectly estimated by determining the relationship between stem height and other heights that were easily measurable (e.g., TH and LLFH). Using TH and LLFH instead of stem height as additional parameters to DBH will be a practical method of improving the accuracy of estimating oil palm biomass.

Soil sampling to a depth of 0.9 m was not deep enough for collecting all of the roots of the sampled oil palm. The roots

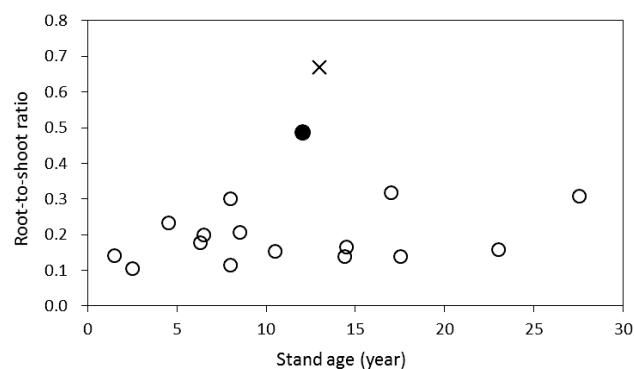


Fig. 14. Root-to-shoot ratios in oil palm (*Elaeis guineensis*) stands

○, Dry land soils with a tropical rainforest climate in Malaysia, Indonesia, and Nigeria (Corley et al. 1971; Khalid et al. 1999a, b; Lamade and Setiyo 1996; Ng et al. 1968; Rees and Tinker 1963); x, dry land soils with a tropical dry climate in the Ivory Coast, West Africa (Dufrene and Saugier 1989); ●, peat soils with a tropical rainforest climate (this study).

Table 4. General characteristics of a destructively sampled oil palm

Location	Block 105, Sibu, Sarawak. $2^\circ 8'43.11''\text{N}$ – $111^\circ 55'14.00''\text{E}$
Date	August 2012
Species	<i>Elaeis guineensis</i>
Age (y)	12
Stem density ( $\text{n ha}^{-1}$ )	166
DBH (cm)	70.8
Crown diameter (m)	12.6
Lowest living frond height (m)	3.7
Total height (m)	10.14
Biomass ( $\text{kg palm}^{-1}$ )	
Leaf	198.6
Pinnae	51.7
Rachis	36.3
Petiole	110.5
Inflorescence	75.0
Stem	163.7
Blowground stem	14.9
Root	198.8
Aboveground biomass (AGB)	437.3
Belowground biomass (BGB)	213.6
Total	650.9
BGB/AGB	0.49

below the stem were found to be deeper than 0.9 m, although the planned depth of the water table was 0.5–0.75 m. Root biomass is large at a depth of 0.2–0.6 m in dry land soils (Taillez 1971). However, root distribution depends on soil type (Chan 1977) and water-table management is important on peatland; therefore, to ascertain the root-distribution characteristics of peat soils, the roots should be collected from deeper than 0.9 m on the basis of the actual root distribution.

## 5.2 Issues related to the biomass estimation

At present, no published biomass data regarding allometry equations and root-to-shoot ratios are available for oil palms cultivated on tropical peatlands. The development of allometry equations and root-to-shoot ratios that are suitable for oil palms in peat soils is required because their growth may differ from those in dry land soils due to the larger belowground biomass/aboveground biomass ratio in peat soils (Fig. 14). The destructive sampling method of aboveground and belowground organs described in this study will help in the estimation of the biomasses of oil palm plantations on tropical peatlands.

Collecting data from palms older than the one sampled in this study (12 years old) would provide a fuller picture of oil palm biomass on peatlands. However, the history of oil palm cultivation in peat soils is short in Sarawak, and there are only a small number of plantations that are older than 12 years. Data collected from older palms would elucidate oil palm biomass characteristics throughout the entire range of the plants' economic life, particularly those that will be 20–25 years old in the future.

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