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THE ESTIMATION OF FROND BASE BIOMASS (FBB) OF OIL PALM

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ABSTRACT

Increasing attention is being focused on the greenhouse gas (GHG) balance of crop production given the need to minimise emissions associated with global warming and climate change. Such emissions can be countered by growing crops such as oil palm that have a high capacity to sequester carbon. The ability to accurately determine carbon sequestration by the crop thus becomes increasingly important. In the case of oil palm, methods of estimating crop biomass are well developed. However, there are still improvements to be made to ensure a complete assessment of carbon stock. This article examines the role carbon sequestration played by frond bases of oil palm that remain attached to the trunk after frond pruning, and which are frequently ignored when assessing standing palm biomass and carbon stock. Data on frond base biomass (FBB) are reviewed, methods for its assessment are discussed, and its importance for calculating carbon sequestration and net carbon balance of oil palm plantations are examined. Carbon sequestration in the plantation for four mills in Papua New Guinea, with a mean crop rotation time of 21 years in their contributing estates was increased by an average of 11% after including FBB in the calculation of standing carbon.

Keywords: oil palm, frond bases, C sequestration, GHG balance.

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INTRODUCTION

In common with other agricultural activities, oil palm cultivation and processing has an impact on the atmospheric greenhouse gas (GHG) balance. This balance represents the difference between sequestration of carbon (C) and emission of GHG, generally expressed as either C or CO_2 equivalents (CO_2e.). If sequestration exceeds emission then palm oil production represents a C sink. Otherwise it is a source and contributes to global warming. Most sequestration occurs in the field with smaller amounts of C being stored in crop products and by-products at the palm oil mill and at other processing plants, and storage sites prior to consumption. Most C within the plantation is accumulated in the shoots and roots of the growing crop, with smaller amounts sequestered in ground vegetation and in litter, such as frond piles, shed frond bases and shed male inflorescences.

Both destructive and non-destructive methods have been developed to quantify frond, trunk and root biomass, which comprise the bulk of oil palm tissues. In some cases additional measurements are made to include minor components such as the undeveloped fronds in the crown and the developing fruit bunches. Annual measurements are required to take account of the non-linearity in the growth curve over time. The main impetus driving the development of such methodology has been the need to quantify biomass production. However, to evaluate C sequestration we need to assess the total standing biomass (SB) of the crop as it changes over time, and methods used for productivity assessment are not necessarily adequate for the purpose of obtaining SB. A significant case in point concerns the frond bases left attached to the trunk after cutting off the fronds, mainly during harvesting but also during seasonal pruning rounds. This frond base biomass (FBB)

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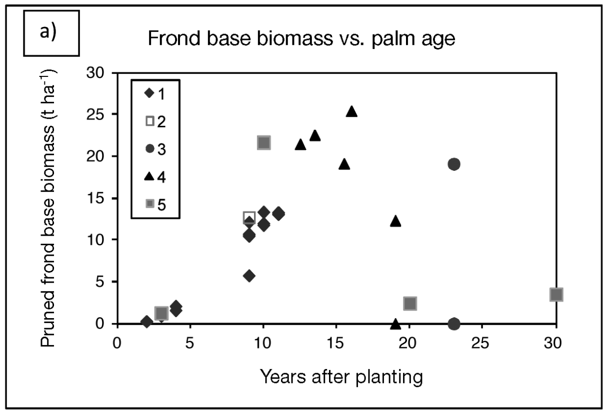
accumulates during the early and middle part of the crop life but as the palms age further, the bases are progressively shed so reducing FBB and in some cases, total SB. This article reviews existing data on FBB, presents some new data, discusses methods for FBB assessment and examines its impact on estimates of oil palm C sequestration and C balance.

PREVIOUS ESTIMATES OF FROND BASE BIOMASS

Documented studies that have included data on FBB are few in number when compared with other oil palm growth measurements. Those known to the authors are summarised in *Figure 1*. (Some additional sources were identified but lacked sufficient detail to define actual values of FBB and so were excluded.) Considered as a whole, the general trend is for FBB to increase with palm age before decreasing after 13 years or so, when the number of bases shed exceeds the number created due to frond pruning. Base abscission generally commences 11 to 15 years after planting (Corley and Gray, 1976) although in some cases palms as young as 19 years after planting have been found to have completely shed their bases.

Data from Study 1 were obtained partly non-destructively, using up to 100 palms per site, by counting bases on intact palms and taking base sub-samples to obtain representative dry weights. The data in Studies 2 to 5 were obtained by destructive sampling of palms in which all or a sample of bases were removed after felling, and oven dried, and the total FBB per palm obtained from the weights and numbers. The numbers of palms sampled destructively in these latter studies were generally small, being eight in Study 2, four (with bases) in Study 3, four per age in Study 4 and only one per age in Study 5. Both the limited sample numbers and the diversity of conditions at the various sites would have contributed to the scatter in the data. The fitted curve (*Figure 1b*) indicated that FBB reached a maximum at around 13 years after planting. Ignoring any palms lacking bases, such as were observed by Goh *et al*. (1994) for 19-year old palms and by Khalid *et al.* (1999) for 23-year old palms, led to an increase in the age at which FBB peaked as well as in the peak value itself (*Figure 1c*).



Note: Data for Study 1 are from Henson (1995 and unpublished results), for Study 2 from Caliman *et al*. (2005), for Study 3 from Khalid *et al*. (1999), for Study 4 from Goh *et al*. (1994), and for Study 5 from Syahrinudin (2005), and were adjusted where necessary for a planting density of 148 palms ha^{-1}. Modified from *Figure 2b* of Henson and Chang (2007).

Figure 1a. Attached frond base biomass measured in five studies plotted against age of palms.

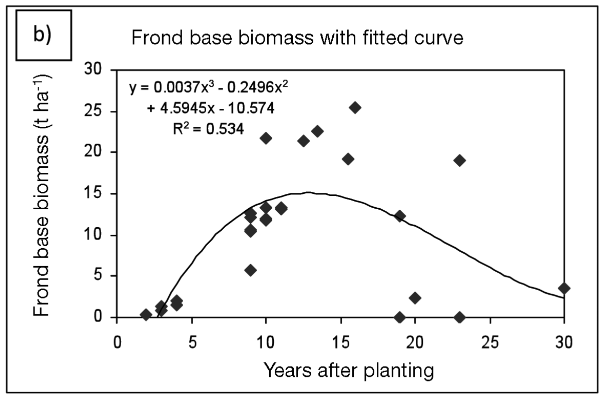


Figure 1b. Pooled data from Figure 1a *with fitted polynomial regression.*

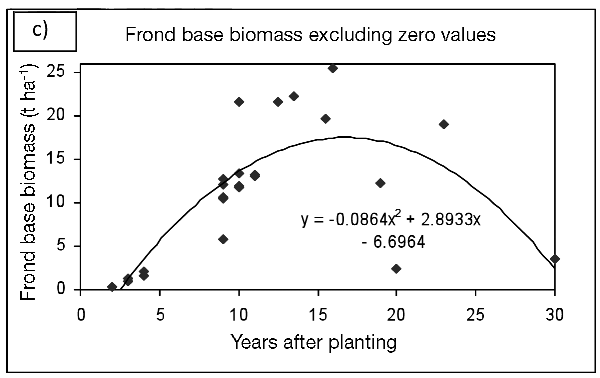
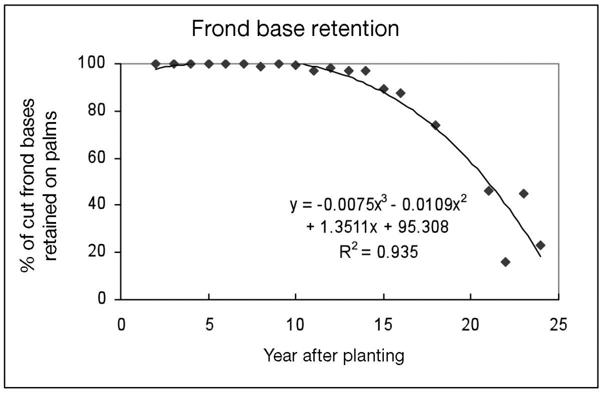


Figure 1c. As for Figure 1b *but with palms without pruned bases excluded.*

PRACTICAL ASPECTS OF MEASURING FROND BASE BIOMASS

To calculate the biomass present per hectare in attached pruned frond bases it is necessary to determine the average biomass (dry weight) per base, the number of cut bases present on each palm and the number of palms per hectare.

Ideally all bases should be measured but this involves much time and effort, especially as removing bases from the trunk can be slow and difficult. As a substitute, sampling a few 'representative' bases on a sub-sample of palms has



Note: For each age from 81 to 339 palms (mean = 165) were assessed visually and the results for all palms averaged.

Figure 2. The approximate percentage of cut frond bases retained on palms of various ages in Papua New Guinea.

generally been seen to suffice. Variation in base dry weight is likely to occur due to differences in the age of the palm when the frond is initiated; the position along the petiole where the frond is removed; and other factors such as nutrition, progeny and water supply that have an impact on palm growth.

As a practical approach, sampling one or two bases about half way up the trunk is suggested. The sampled material is then dried in an oven to constant dry weight.

To determine the number of attached frond bases per palm, a manual count of the total number can be made, although this may be difficult for tall palms, for palms that have shed some of their bases or where prolific growth of epiphytes obscures the bases. As fronds on the palm are arranged in eight spirals, then if no bases have been shed, assessing the number of bases in a single spiral and multiplying by eight will give a good approximation of the total per palm. Multiplying the mean biomass per base by the attached frond base number per palm will give the total attached FBB per palm which, multiplied by palm planting density gives the FBB per hectare. For palms that have partially shed bases, a more thorough counting is required. Usually, base shedding occurs progressively, starting part way up the trunk, which aids visual estimation of the percentage of bases retained on the palm (*e.g. Figure 2*).

MODELLING OF FROND BASE BIOMASS

An assessment of FBB is possible using simulation models. Two models have been produced that include data for FBB and show its contribution to standing oil palm biomass. The OPRODSIM model (Henson, 2005) calculates FBB using a single polynomial regression fitted to measured values such as those shown in *Figure 1a*. However, because this estimate of FBB depends solely on palm age and is unaffected by factors such as frond size or planting density, the FBB values obtained are only indicative.

A more mechanistic simulation of FBB is provided by the related model, OPCABSIM (Henson, 2009). In this model, FBB is calculated from single frond dry weights (SFDW) and pruned frond numbers. Frond dry weights are derived as in the OPRODSIM model and are based on standard growth curves that vary with site and growing conditions, there being four alternative options. The number of fronds pruned annually per palm (PFNP) is obtained from the following equation:

$$PFNP = (TFNPI + FPR) - TFNP$$

where TFNPI and TFNP are respectively the initial and final total frond numbers per palm present each year and FPR is the frond production rate (number of new fronds emerging per palm per year). The model assumes that no pruning is carried out in the first two years after planting so that cut FBB is zero in these years.

The frond bases left after pruning are taken to represent 20% of total frond biomass with the remainder of the frond being deposited in the frond piles. The pruned frond base biomass per hectare created annually on the palm (FBB) is thus given by:

$$FBB\ (t\ ha^{-1}\ yr^{-1}) = [PFNP * SFDW\ (kg\ frond^{-1}) * 0.2 * PD] / 1000$$

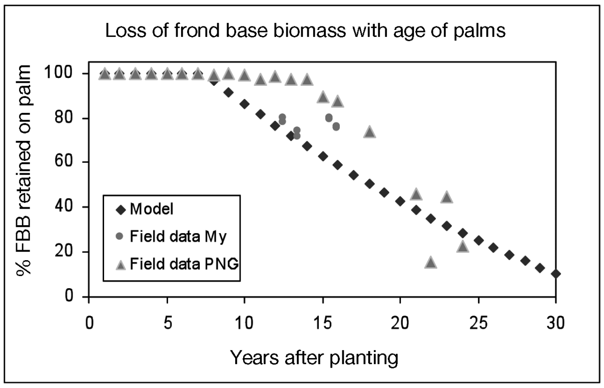
where PD is the number of palms per hectare.

The cut frond bases on the palm initially accumulate annually but at some point shedding commences, thus reducing the attached FBB. The rate of abscission is variable and it is this factor that renders prediction of FBB difficult. In OPCABSIM, it is assumed that no shedding occurs before the eighth year after planting (YAP), after which the % of the FBB formed and remaining attached to the trunk decreases in an approximately linear fashion (*Figure 3*), as described by the following equation:

$$\%\ attached\ FBB = 0.0537 \times YAP^2 - 5.9388 \times YAP + 140.07$$

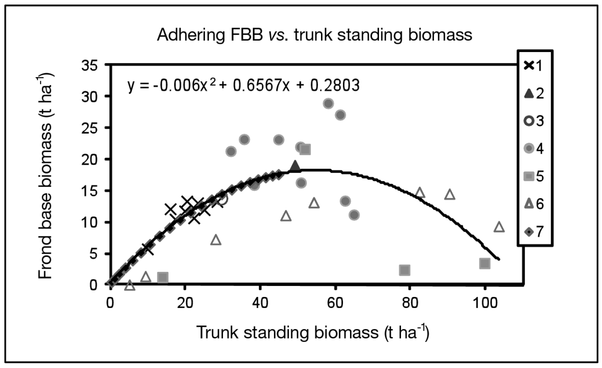
Figure 3 shows that this modelled trend differs somewhat from field observations. Thus, in Papua New Guinea there was little or no shedding of bases until palms exceeded 14 years of age. However, in Malaysia (Goh *et al*., 1994), loss of bases was observed in palms as early as 12.5 years after planting, in better agreement with the modelled values.

FBB can also be easily calculated on a spreadsheet without the use of complex models if the necessary supporting data are available. An example is given in the *Appendix 1*.



Note: A modelled curve is compared with changes in the field observed by Teoh and Chew (1988) in Malaysia (My) and by New Britain Palm Oil Ltd in Papua New Guinea (PNG). The latter data are taken from *Figure 2* and reproduced here for comparison. Modified from *Figure 2c* of Henson and Chang (2007).

Figure 3. Changes in the percentage of cut frond base biomass (FBB) retained on palms of different ages.



Note: Modified from *Figure 3* of Henson and Chang (2007).
Source: 1. Henson (1995 and unpublished observations).
2. Khalid *et al*. (1999).
3. Caliman *et al*. (2005).
4. Teoh and Chew (1988); Goh *et al.* (1994).
5. Syahrinudin (2005).
6. New Britain Palm Oil Ltd (unpublished).
7. OPRODSIM model, coastal site, medium frond size option.
Where necessary, data were adjusted to a planting density of 148 palms ha^{-1}.

Figure 4. Relationships between adhering frond base biomass (FBB) and trunk standing biomass for some oil palm stands, compared with data produced by OPRODSIM.

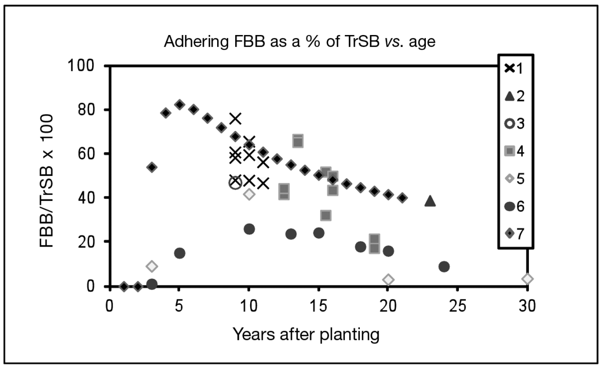
RELATIONSHIP BETWEEN FROND BASE BIOMASS AND TRUNK BIOMASS

Since growth of the trunk reflects the progressive addition of fronds to the palm, a possible alternative to deriving FBB from palm age is to relate it to trunk standing biomass (TrSB). However, as several characteristics of the trunk such as its diameter, tissue density and mean inter-node length can vary and so affect its biomass (Henson, 2006), the relationship between FBB and TrSB is likewise subject to variation (*Figure 4*), and so may not offer much improvement over the use of palm age as an independent variable from which to determine FBB.

It is apparent from data presented thus far that the contribution of FBB to total palm biomass can vary widely, being zero in some palms. It becomes most significant for palms around 10 to 15 years of age that have accumulated a high number of bases prior to the commencement of shedding. At this stage FBB can be more than half of the trunk biomass (*Figure 5*), indicating the importance of considering this component when estimating oil palm C stocks.

DECOMPOSITION OF FROND BASES AFTER SHEDDING

Shed bases add to the litter in the plantation and continue to be a source of stored C that needs to be accounted for to assess total C sequestration in the plantation. If the FBB attached to the palm is known, then the shed biomass can be easily calculated as being the difference between the total FBB that is formed and that remaining on the palm. The shed



Note: Data sources are as listed for *Figure 4*.

Figure 5. Relationships between the ratio of frond base biomass (FBB) to trunk standing biomass and palm age for some oil palm stands compared with data produced by OPRODSIM.

material then undergoes decomposition, releasing C as CO_2. The OPCABSIM model calculates the C remaining in the shed bases after allowing for decomposition using decay rates for petioles measured by Khalid *et al.* (2000), whereby:

FBSPB (frond base shed 'pile' biomass) =
[(0.5636 x FBBS n) + (0.1571 x FBBS n-1)] x 1.07

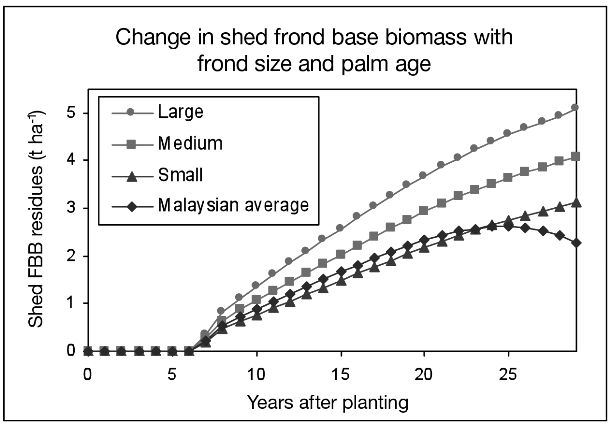
and n and n-1 refer to the present and previous years' pile biomass respectively, and 1.07 is an adjustment factor to account for any residues remaining from earlier years. The decomposition is relatively fast and quantities of base biomass, that accumulate over time (*Figure 6*), tend to be small.

There are still some uncertainties in the estimates of FBB present in plantation litter. The first is the variation caused by the initial size of the fronds. Data for four frond size options are shown in *Figure 6*. Another consideration is that no allowance is made for loss of dry weight of the bases prior to shedding. Finally, the proportion of the frond dry weight that remains on the palm after pruning, taken as 20%, could be in error. Despite these uncertainties the total weight of cut frond bases on the palm, directly determined for a number of palms, appear to broadly correspond with modelled values (*Figure 3*), suggesting that the FBB estimates are not too unrealistic.

Compared with other C stocks and litter sources in plantations, shed FBB is a relatively minor component (*Table 1*). Hence, precise assumptions regarding shedding and decomposition rates are not likely to be critical for the calculation of C storage.

FROND BASE BIOMASS AND CARBON SEQUESTRATION IN THE PLANTATION

The accuracy of calculating carbon sequestration and the carbon or GHG balance will be partly affected by how complete the data are in accounting for all plantation components. Presently, FBB is seldom included in most GHG budgets and its omission may lead to C sequestration being underestimated. The effects of this will, in some cases be rather small and any underestimate has to be weighed against the effort required to make FBB measurements. Including FBB will have a greater impact if short crop rotations are practised, since FBB tends to contribute more to total palm biomass in younger palms. For four mills in Papua New Guinea with a mean crop rotation time in contributing estates of 21 years, C sequestration in the plantation was increased by an average of 11%, after including FBB in the calculation of standing carbon (*Table 2*).



Note: The large, medium and small frond sizes were generated by the OPRODSIM model, and are compared with that attributed to the Malaysian national average oil palm (Henson, 2003). Modified from *Figure 7* of Henson (2009).

Figure 6. Relationship between shed frond base biomass residues (FBB in litter in the plantation) and palm age using four frond size options.

CONCLUSION

Relatively few records of FBB are found in published sources and none are sufficiently comprehensive to provide a good indication of trends with palm age at individual sites. Pooled data from different studies provide general relationships but the scatter is large and the precision poor. This is partly due to the confounding of palm age and site which can only be overcome by recording changes in palms at the same sites over time. In addition, in most studies that include FBB, relatively few palms have been sampled and these may not necessarily have been representative of the whole population, especially in the case of old palms that can vary considerably in the rate at which bases are shed. These shortcomings point to the need for more systematic and comprehensive data collection that takes account of the variability found due to

TABLE 2. EFFECT OF INCLUDING FROND BASE BIOMASS (FBB) AS A COMPONENT OF TOTAL OIL PALM STANDING BIOMASS ON PLANTATION C SEQUESTRATION (t CO_2 equivalent ha^{-1} yr^{-1})[a]

	Mill 1	Mill 2	Mill 3	Mill 4
FBB excluded	11.91	12.46	12.68	12.88
FBB included	13.93	14.15	13.81	13.44

Note: [a]Data were calculated for plantations served by four palm oil mills in Papua New Guinea using a modified version of the RSPO (Round Table for Sustainable Palm Oil) carbon calculator, PalmGHG [Chase and Bessou (2011)].

TABLE 1. MEAN STANDING BIOMASS (t ha^{-1}) OF VARIOUS PLANTATION COMPONENTS OVER 30 YEARS[a]

Frond size option[b]	Oil palm[c]	Ground cover	Frond piles	Shed frond bases	Shed male inflorescences
Small	70.49	4.73	5.44	1.40	0.51
Medium	75.76	3.51	7.27	1.89	0.51
Large	105.33	2.98	9.13	2.36	0.51

Note: [a]Modified from *Table 5* of Henson (2009). [b]Generated using the OPRODSIM model. [c]All biomass including adhering FBB.

differences between sites, planting materials and palm age.

Studies also need to be undertaken to improve measurement precision by resolving previously neglected issues such as the fraction of frond dry matter that is removed by pruning and the extent to which the dry weight of the attached bases changes prior to them being shed. The contribution of FBB to total standing palm biomass is certainly significant and needs to be taken into account if the total sequestration of C in oil palm plantations is to be fully accounted for.

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Appendix 1

CALCULATION OF ATTACHED FROND BASE NUMBER FROM PALM GROWTH COMPONENTS[a]

1	2	3	4	5	6	7	8
Age of palms (yr)	**Number of bases per spiral**	**Number of bases per palm[b]**	**% of bases retained on palm[c]**	**Number of bases per palm[d]**	**Mean dry weight (g) per base**	**Total FBB (kg) per palm[e]**	**Total FBB (t) per hectare[f]**
3	5.51	44.1	99.1	43.7	248	10.8	1.46
5	15.13	121.0	100	122.1	261	31.9	4.31
10	30.40	243.2	100	243.8	258	62.8	8.47
13	37.01	296.1	94.6	280.0	200	56.0	7.55
15	52.49	419.9	87.8	368.7	187	69.0	9.31
18	67.40	529.2	72.4	390.1	368	143.7	19.40
20	87.27	698.2	58.0	404.7	312	126.1	17.02
24	117.28	968.2	17.8	166.8	315	52.5	7.09

Note: [a]Initial data were collected on estates of New Britain Palm Oil Ltd in West New Britain, Papua New Guinea.
[b]Assumes each spiral contains same number of bases and fronds are arranged in eight spirals per palm.
[c]Calculated from polynomial regression of frond base retention on palm age (*Figure 2*).
[d]Maximum total number of bases per palm (column 3) x % retained (column 4)/100.
[e]Number of retained bases per palm (column 5) x mean dry weight per base (column 6)/1000.
[f]Total FBB per palm (column 7) x planting density (taken as 135 palms ha^{-1})/1000.