Carbon Flow and Budget in a Young Mature Oil Palm Agroecosystem on Deep Tropical Peat

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Abstract

An increasing area of deep tropical peat in Sarawak, which has been logged-over, is being cultivated with oil palm, generating revenue of about US 1 billion in 2006 for much needed socio-economic development. However, there is growing concern with this development in regard to greenhouse gas emissions and loss of carbon from the peat swamp. A study was therefore undertaken to investigate the C flow and budget in a 5 years old oil palm plantation on deep tropical peat, and to determine if this oil palm agroecosystem is a C sink or source. Results showed that the peat soil contained 3771 t C ha^{-1} while the other C pools together accounted for only 0.7 % of the total C in the agroecosystem. The net primary production (NPP) by the palms was 12.01 t C ha^{-1} y^{-1} while by-products increased soil organic C by 0.3 t C ha^{-1} y^{-1}. The measured soil respiration was 15.4 t C ha^{-1} y^{-1} with 60% loss through heterotrophic respiration resulting in a subsidence of about 1.6 cm y^{-1}. The oil palm was neither a net C sink nor source but the export of FFB without by-product utilization will cause a negative C balance of 2.01 t C ha^{-1} yr^{-1}.

Keywords: carbon sequestration, dynamics, pools

Introduction

The oil palm (*Elaeis guineensis*) is now grown widely on logged over tropical peat swamp forest in Sarawak, Malaysia. It brought much needed revenue of about US$ 1 billion in 2006 for socio-economic development of the State. Much concern has now been expressed, however, mainly by non-government organizations, on the impact of this new land development on greenhouse gas emissions and the loss of soil carbon. Globally, carbon dioxide comprises about 57% of greenhouse gases and 17% of it arises from converting forest to other land uses (Shukla & Chandel, 2006). Whether or not an agroecosystem is a net sink or source of carbon depends on the types of crop, soils, climate and cultivation practices.

Henson (1999) showed that the annual uptake of carbon dioxide by mature oil palm on coastal soil in Malaysia was 46.4 t ha^{-1} y^{-1} with a net fixation of 11.0 t ha^{-1} y^{-1} based on the eddy covariance technique. In this study, soil respiration was estimated to be only 28.5 t ha^{-1} y^{-1} which was about half of that reported by Melling *et al.* (2005) for peat soils under oil palm. The difference could be explained by the higher organic carbon content in the latter work. Neither of these articles discussed the net C balance in the oil palm agroecosystem and little is known about it to date. Thus, this paper discusses the C flow and budget in an oil palm agroecosystem on deep tropical peat and the net C balance.

Materials and Methods

The experimental site was located on five years old oil palms on deep peat in Mukah Division of Sarawak, Malaysia (Melling *et al.*, 2005). The peat was 5.55 m thick and classified as Typic Tropofibrist. It was acidic and contained 44.7 % carbon and 2 % nitrogen with a very high loss of ignition of about 99 %.

Total soil and excised-root respiration were measured at monthly intervals for a year using a closed-chamber method. Three stainless steel open ended cylinders, each 20cm in diameter and 25cm in height, were placed directly on the soil surface at each site. The soil along the edge of each cylinder was cut with a very sharp knife and the cylinder was pushed into the soil to a depth of 3 cm to prevent gas leakage from the bottom of the chamber. Excised-root respiration was determined using 20cm in diameter and 50cm long open-ended stainless steel cylinders driven into the soil profile with a very sharp knife, severing all roots about 2 months before measuring CO_2 gas. The CO_2 gas concentrations were determined in the laboratory within four hours using a CO_2 infrared gas analyzer (Fuji Electric ZFP-5).

The carbon uptake by the oil palm over a year and its partitioning to various components in the agroecosystem were estimated based on Teoh & Chew (1988), van Kraalingen (1989), Dufrene (1989) and Goh (1992). The carbon contents of the various components of oil palm biomass were taken from Henson (1999). In addition, the conversion factors for pruned fronds and dead roots to organic matter were based on our preliminary estimates of 0.029 and 0.017, respectively using re-computed data of Teoh & Chew (1988). About 10% of empty fruit bunches (EFB) and palm oil mill effluent (POME) was assumed to be converted to organic matter upon land application. The component of the carbon budget is shown in Figure 1. Using these values, net primary production (NPP), net ecosystem production (NEP) and net biome production (NBP) were estimated as follows:

NPP = Canopy + FFB + stem + root
NEP = NPP – microbial respiration – other respiration
NBP = NPP – microbial respiration – other respiration – FFB + organic C returns from roots and pruned fronds + partially decomposed pruned fronds

NEP is the C budget in oil palm ecosystems under natural conditions. NBP is the C budget associated with management in oil palm plantation and corresponds to soil C sequestration. Its formula is adjusted accordingly when part of its by-products e.g. EFB and POME are applied in the fields. Positive values of NEP and NBP indicate that the ecosystem gains C.

Results and Discussion

Carbon pool

The peat substrate contained the largest C pool in the oil palm agroecosystem, which was estimated at 3771 t ha^{-1} (Table 1). The other C pools made up only 0.7 % of the total C in the agroecosystem. In this study, the carbon content of the ground vegetation and logs from the previous logged-over jungle were not estimated. While the former may be small (Teoh & Chew, 1988), the latter could still be large five years after felling as their decomposition is relatively slow.

In the oil palms, most of the C was allocated to the canopy and stem. The fresh fruit bunches (FFB) contained about 5.4 t C ha^{-1} but the majority was exported from the plantation as thus, did not contribute to the C pool. However, the pruned fronds returned 5.3 t C ha^{-1} to the peat surface.

Table 1: Carbon pools (t C ha^{-1}) in a five years old oil palm agroecosystem on deep tropical peat in Sarawak, Malaysia

Component		t C ha^{-1}
Soil		3771
Palm	Canopy	8.46
	Stem	7.68
	Roots	2.94
	Sub-total	19.08
Palm by-products	Pruned fronds	5.29
	EFB	1.25
	POME	0.23
	Sub-total	6.77
Organic matter	Pruned fronds	0.39
	Dead roots	0.22
	EFB	0.49
	POME	0.09
	Sub-total	1.19
TOTAL		3798

Carbon flow

The net primary production (NPP) by oil palms on peat was 12.01 t C ha^{-1} y^{-1} (Figure 1) which was lower than the estimate provided by Henson (1999) for 9 to 10 years old palms on coastal soils. This might be attributed to the younger palm age and poorer soils in the current study. The decomposition of pruned fronds and by-products such as EFB and POME would increase the soil organic matter by 0.3 t C ha^{-1} y^{-1} only.

Melling *et al*. (2005) measured soil respiration at this site to be 15.4 t C ha^{-1} y^{-1}. This might be partitioned to microbial respiration, root respiration and decomposition of dead roots, which totalled 13.6 t C ha^{-1} y^{-1}. The difference might be ascribed to estimation errors in the model.

Carbon budget

The net primary production by oil palm at the experimental site was similar to microbial respiration (Table 2). In this study, the spatial scale is limited to the plantation and thus, the FFB which can be regarded as C sequestration off-site is not accounted for. Similarly, the use of fibre and shell to replace fossil fuel and the trapping of biogas from effluent ponds, which will reduce C emission to the atmosphere, are outside the scope of study. Thus, a large proportion of assimilated C was exported from the agroecosystem to the palm oil mill. This resulted in a negative C balance or a net C source of -2.01 t C ha^{-1} y^{-1} from the agro-ecosystem which is also known as NBP. If FFB by-products such as EFB and POME are applied to the fields as commonly done at the plantation, the NBP would increase to -0.98 t C ha^{-1} y^{-1}. The NEP was 1.06 kg C ha y^{-1}. This situation is most likely to reverse with increasing palm growth and production as it grows older. Since most of the assimilated C was allocated to the palm vegetative parts, the microbial respiration will cause a loss of C from the peat swamp resulting in an estimated shrinkage of 1.6 cm y^{-1}. This was similar to the average rate of peat shrinkage reported by Wosten *et al*. (1997).

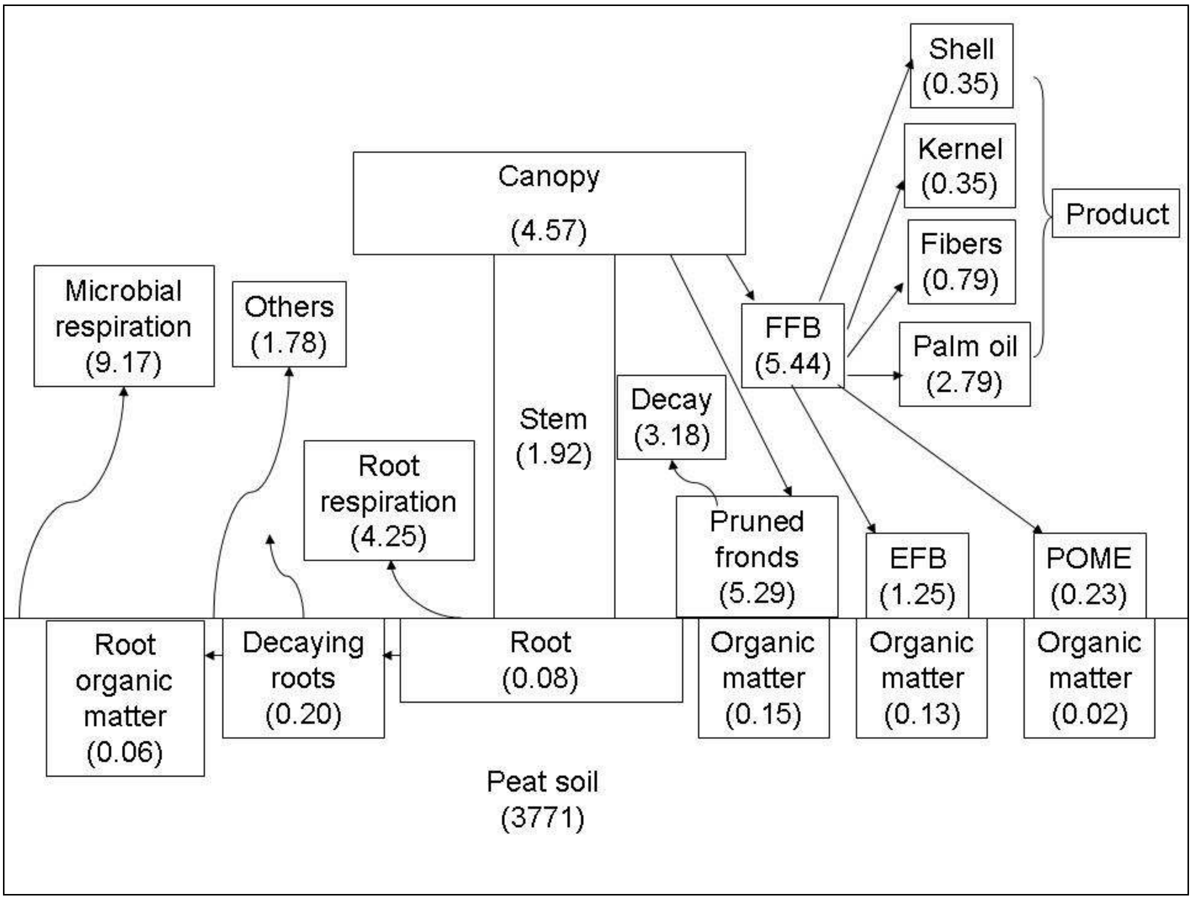

Figure 1: Net primary production by four to five years old palms on deep tropical peat and C flow within the agroecosystem (t C ha^{-1} y^{-1})

Table 2: C budget in a five years old oil palm agroecosystem on deep tropical peat

Component	t C/ha/yr
Net Primary Production (NPP)*	12.01
Microbial respiration	9.17
Other respiration	1.78
Net Ecosystem Production (NEP)**	1.06
Net Biome Production (NBP)***	-2.01

* NPP = Canopy + FFB + Stem + root
** NEP = NPP – microbial respiration – other respiration
***NB = NPP – microbial respiration – other respiration – FFB + organic C returned from roots and pruned fronds + undecomposed pruned fronds (See Figure 1)

Conclusion

On an annual basis, the four to five years old palms on deep tropical peat were neither a carbon sink nor source. However, most of the C was sequestered in the vegetative components of the palms or exported from the agroecosystem as FFB resulting in a negative NBP i.e. a C source. The returns of palm biomass such as pruned fronds, empty fruit bunches and palm oil mill effluent to the agroecosystem would increase the soil organic C by only 0.3 t ha^{-1} y^{-1}, which was lower than the oxidation rate of peat soils. In fact, the soil heterotropic respiration would cause the peat to subside by about 1.6 cm y^{-1}.

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