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KEY AGRO-ENVIRONMENTAL MANAGEMENT OF TROPICAL PEATLAND

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SUMMARY

Sarawak, like many peatland sites throughout Southeast Asia is currently faced by challenges because of the needs for agricultural development to meet its aspiration for socio-economic progress. But, with limited suitable agricultural land, the cultivation of peat swamp, which is abundant in the State, is inevitable. To do this, it necessitates the Government and the associated agencies to develop an environmental sensitive home grown holistic approach to balance the agricultural development in order to mitigate carbon emission problems associated with peat development. This approach takes into account soil processes and interaction between agro-management and environments. The key features of these agro-environmental management approaches, which are based on the principle of drainage, compaction and water management, attempts to integrate agriculture, nature and environment for humankind. The key agro-environmental management of tropical peatland in Sarawak, Malaysia is discussed in this paper. The study was conducted in oil palm plantation on peat (OPP) and undisturbed peat swamp forest (PSF). Compaction of peat is introduced primarily as a means to increase the bulk density and bearing capacity of the peat in order to reduce early palm leaning, decrease the rate of nutrient leaching and optimize the yield. Mechanical compaction has also brought unintended benefits such as decreased soil CO_2 emissions and reduced susceptibility of peat fire outbreaks because the lower soil porosity enhances the capillary rise of water in the soil, keeping the soil moist. The higher soil moisture content due to the higher soil bulk density was also found to decrease soil CO_2 fluxes in cultivated peat as evidenced by the comparisons of compacted and non-compacted peat in OPP as well as OPP versus PSF. Thus, the successful implementation of key agro-environmental management as good agricultural practices on peat lies heavily on good procedural synthesis based on scientific findings, knowledge and understanding of tropical peat.

Keywords: *drainage, compaction, water management, CO_2, oil palm yield*

INTRODUCTION

Hydrology is an important factor in the formation, functions and resilience of peat swamp ecosystems (Melling and Hatano, 2004; Wosten *et al*., 2008). Under natural conditions, the accumulation and long-term maintenance of peat carbon requires a continuous supply of organic matter and a decomposition rate lower than its supply. The latter is assumed to be met if water table is equal or near to the peatland surface throughout the year (Ritzema *et al*., 2002). Thus, most studies reported that the conversion of peatland for agriculture purposes, which involved lowering of water table, would result in the acceleration of peat oxidation and degradation, which release massive carbon dioxide (CO_2) (Hooijer *et al*., 2011; Page *et al*., 2011). Using this premise, it has become an entrenched notion that the ultimate solution towards the lowering of peat oxidation and release of CO_2 depends solely on the control of water table (Hooijer *et al*., 2010; Page *et al*., 2011; Hergoualch and Verchot, 2011). These authors generally ignored that the lowering of water table in tropical peatlands can occur naturally, especially in Borneo, where the peatlands are of ombrogenous type i.e. receiving water and nutrient through rainfall only. Under this condition, the fluctuation of water table is mainly dictated by the seasonal changes in rainfall pattern. The presumption that water table maintenance is an all cure for GHG issues to some extent reflects the lack of detailed understanding of the ecosystem and dynamics across the wide geographic variation of peatland sites throughout Southeast Asia.

Peat soils in their inherent state have high infiltration capacity and hydraulic conductivity, low soil bulk density and low capillary rise, resulting in lower plant available water (Melling *et al*., 2008). These peat soil characteristics make reliance on water table alone impractical in water management of peat where loss of water via evapotranspiration and outflow would create moisture deficits, particularly in the top layer of peat above the water table. In fact, effective mitigation of peat oxidation would require a permanent water table equal to or above the peat surface, which is deleterious to the growth and production of terrestrial agricultural crops because they require both sufficient oxygen and water to facilitate optimum metabolic pathways for growth and photosynthesis.

Sarawak has developed an environmental sensitive holistic approach to balance agricultural development and mitigation of carbon emission problems associated with peat development. It takes into account soil processes and interaction between agro-management and environments. This agro-environmental management approach, combining the principle of drainage, compaction and water management, attempts to integrate agriculture, nature and environment for humankind.

In oil palm plantation, drainage is carried out to lower the water table to between 50 and 75 cm below ground surface which is suitable for its deep rooting system (Henson and Chai, 1997). Upon the lowering of the water table, peat compaction is implemented to increase the bulk density and bearing capacity in order to reduce early palm leaning and decrease the rate of nutrient leaching and optimize the yield.

However, the introduction of peat compaction upon drainage in plantation has brought other unintended benefits such as decreased soil CO_2 emissions and reduced susceptibility of peat fire. Thus, this paper discusses the concepts, aim and importance of agro-environmental management of oil palm on peat.

MATERIALS AND METHODS

This study was conducted in an oil palm plantation (OPP) (02° 11' N, 111° 50' E) and a tropical peat swamp forest (PSF) (001°27‘N, 111°8‘E). Two different sites namely compacted and un-compacted OPP were selected to assess the physical properties, yield and soil CO_2 fluxes.

Monthly measurements of soil CO_2 fluxes since 2008 until 2013 were performed using open bottom cylindrical stainless steel chamber. Water table was measured on a monthly basis using a perforated PVC pipe dip well. Undisturbed core samples were also collected to determine soil bulk density and water-filled pore space (WFPS). Porosity is derived from soil bulk density and particle density (Brady and Weil, 1996). Bunch weight and bunch number were recorded weekly from both compacted and un-compacted OPP and tabulated into monthly data. The average fresh fruit bunch (FFB) at each site was then calculated.

Regression analysis was carried out using SAS 9.2 to determine the relationship between the FFB, soil CO_2 flux and WFPS.

RESULTS

Water table, bulk density, porosity and water-filled pore space (WFPS) of both OPP and PSF are shown in **Table 1**. The levels of mean water table in un-compacted, compacted OPP and PSF were -59.8 cm, -60.7 cm and -15.1, respectively. Bulk density at 5 cm, 10 cm, 25 cm, 45 cm and 60 cm depth for PSF were generally lower than OPP. Bulk density for compacted OPP were higher than un-compacted OPP as a result of drainage and mechanical compaction. The consequent of higher bulk density in compacted OPP were lower porosity at 5 cm, 10 cm, 25 cm, 45 cm and 60 cm depth. Soil moisture expressed as water-WFPS in compacted OPP was higher (83.3%) than in un-compacted OPP (71.3%) and forest (75.1%).

As shown in **Table 1**, FFB from compacted OPP (32.3 t ha^{-1} yr^{-1}) was higher than un-compacted OPP (16.8 t ha^{-1} yr^{-1}). At the same time, mean soil CO_2 flux from compacted OPP (9.5 t C ha^{-1} yr^{-1}) was lower than un-compacted OPP (11.2 t C ha^{-1} yr^{-1}). Highest mean soil CO_2 flux was recorded from the PSF (12.5 t C ha^{-1} yr^{-1}). Fresh fruit bunch increased with WFPS. There was a significantly positive linear relationship between FFB and WFPS (**Figure 1a**). However, a significantly negative linear relationship between soil CO_2 fluxes and WFPS (**Figure 1b**) was obtained indicating that soil CO_2 fluxes decreased with increasing WFPS.

DISCUSSION

The water table at the studied sites was controlled between 50 and 75 cm below the peat surface. This is deemed suitable for the oil palm rooting system as suggested by Henson and Chai (1997). Similar benefit was also observed by Lim et al. (2012) who found that the highest FFB yield was recorded at water table of 50-75 cm, followed by 25-50 cm, 75-100 cm, more than 100 cm and less than 25 cm below the peat surface.

Although the water table was similar for both sites, FFB yields differed by almost 50% between the two sites. FFB yield from compacted OPP (32.2 t ha^{-1} yr^{-1}) was higher than un-compacted OPP (16.8 t ha^{-1} yr^{-1}) (**Table 1**). In unmanaged peat, higher porosity of the peat leads to higher leaching rate of nutrients and lower capacity to retain soil moisture particularly in peat surface (Melling *et al*., 2008). This affects the availability and efficiency of nutrient uptake by the crop. However, with compaction, peat properties changed through improved bulk density and WFPS (Ball *et al*., 2008). Higher bulk density upon compaction decreased macropores (>600μm) and increased micropores (3–30 μm) (Kasimir-Klemedtsson *et al*., 1997). The consequences are higher soil mass per volume and reduced nutrient loss via leaching, resulting in better growth and yield of the crops (Laiho *et al*., 1999) including oil palm. Thus, FFB yield increased with increasing WFPS (**Figure 1a**).

In this study, soil CO_2 flux from compacted OPP was 15% and 24% lower than un-compacted OPP and PSF, respectively, which was due to the higher bulk density, lower porosity and higher soil moisture in compacted site (**Table 1** and **Figure 1b**) (Melling *et al*., 2005; Melling *et al*., 2012). This agrees with Ruser *et al*. (2006) who found that compaction significantly reduced soil CO_2 fluxes when soil moisture exceeded 70%. Higher moisture in the soil pore space reduced both underground biotic activity and soil gas diffusiveness resulting in lower soil CO_2 fluxes from compacted peat (Ball *et al*., 2008; Castellano *et al*., 2011).

In addition to proper drainage, compaction is one of the most important key for water management in sustaining peat moisture. Studies conducted in an oil palm plantation and natural peat swamp forest revealed that soil CO_2 flux was highest in the tropical peat swamp forest ecosystem even though its mean water table level was higher (Melling *et al*., 2005; Melling *et al*., 2012) (**Table 2**). This indicated that water table was not the dominant factor affecting soil CO_2 flux from oil palm plantation on tropical peatland, which contradicted the findings of Jaenicke *et al*. (2010) and Hergoualch and Verchot (2011). Bulk density and WFPS were observed to be higher in OPP compared with forest ecosystem (**Table 2**). Brigham *et al*. (2000) surmised that larger pore spaces in peat resulted in large losses of stored water while higher bulk density enabled greater water retention even under unsaturated conditions. This probably contributed to better capillary rise which allows water to move upwards to the surface and therefore, improves and sustains the moisture of peat along its vertical profile even in dry spells to meet plant water requirement, which is difficult to achieve through water table control only.

Table 1: Comparison of soil physical properties, oil palm yield and soil CO_2 fluxes between PSF, un-compacted OPP and compacted OPP

Variables	PSF	Un-compacted OPP	Compacted OPP
Mean water table (cm)	-15.1	-59.8	-60.7
WFPS* (%)	75.1	71.3	83.3
Bulk density (g cm^{-3}):			
5 cm	0.15	0.23	0.24
10 cm	0.14	0.11	0.18
25 cm	0.09	0.11	0.13
45 cm	0.08	0.09	0.13
60 cm	0.07	0.09	0.08
Porosity (%):			
5 cm	87.7	88.1	82.4
10 cm	88.3	94.3	87.0
25 cm	92.8	95.1	91.4
45 cm	93.8	97.2	91.7
60 cm	94.0	96.4	94.9
FFB (t ha^{-1} yr^{-1})	-	16.8	32.3
Soil CO_2 flux (t C ha^{-1} yr^{-1})	12.5	11.2	9.5

Table 2: Average water table, WFPS, bulk density, soil CO_2 fluxes of different ecosystems

Ecosystem	Mean water table (cm)	WFPS (%)	Bulk density (g cm^{-3})	Soil CO_2 flux (t C ha^{-1} yr^{-1})	Reference
Forest	-45.3	57.6	0.15	21.9	Melling et al., 2005
Sago	-27.4	78.1	0.16	12.0	
OPP	-60.2	60.4	0.20	16.6	
OPP	-67.6	70.1	0.23	9.0	Melling et al., 2012
SF	-14.7	66.5	0.11	11.2	
PSF	-3.9	70.0	0.11	12.3	

OPP= oil palm plantation; SF = Secondary peat swamp forest; PSF = Natural peat swamp

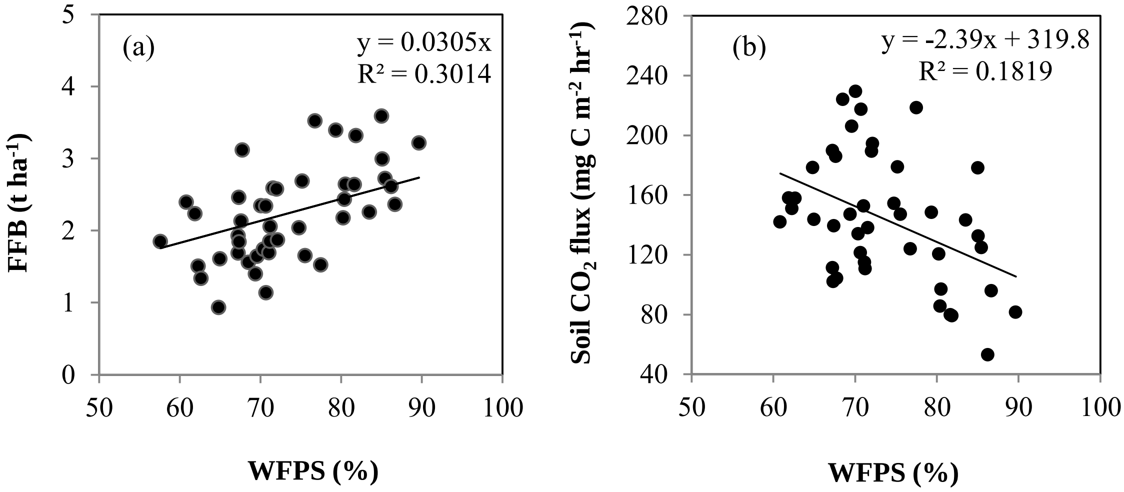

Figure 1: Relationships between (a) FFB, (b) soil CO_2 flux and WFPS

CONCLUSION

The agro-environmental management approach is based on the principle of compaction and water table management. Effective water management can be achieved by apposite compaction procedure and the control of water table. The agro-environmental management for oil palm on tropical peatland improved peat properties, which resulted in higher oil palm yield, reduced soil CO_2 emissions and lower susceptibility of peat fire outbreaks. However, the success of agro-environmental management lies heavily on good procedural synthesis of scientific findings, knowledge and understanding on tropical peat. The promotion and communication of this successful concept should be intensified, preferably with government incentives and incorporate into good agriculture practice certification for oil palm on peat.

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