Selection of land clearing technique and crop type as preliminary steps in restoring carbon reserve in tropical peatland under agriculture

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Summary
Replacement of natural forest by agricultural crops is generally expected to change the role of tropical peatland from that of carbon sink to carbon loss ecosystem. Preliminary studies in Malaysia, however, indicate that CO_2 emission from agriculture on peatland can be minimised through farm management. Land clearing by burying the forest debris added more than 100 t C ha^{-1} into the peatland; otherwise it would have been immediately lost by burning. Newly cleared plots were colonized by fast growing *Macaranga triloba* that absorbed 25 t C ha^{-1}yr^{-1} from the air. It was estimated that the agriculture systems experienced minor net-carbon-loss with major emission from decomposition of peat and large amounts of biomass waste.

Key index words: peatland, forest clearing, agriculture, carbon emission

Introduction
Tropical peatland plays an important role in the global carbon (C) cycle. Diemont *et al.* (1997) estimated that 5 m thickness of tropical peatland stores up to 2,500 tons C per ha. It was estimated that more than 70 billion tonnes, or up to 20% of soil C is stored in tropical peatland. In addition, about 34 million tonnes of C is sequestered annually by tropical peatland. The replacement of natural forest by agricultural crops, however, is expected to reduce its C sink capacity. Immirzi and Maltby (1992) estimated C loss of 5-42 t ha^{-1}yr^{-1} from peatland under agriculture and Wosten *et al.* (1997) estimated the release of 7.2 t C ha^{-1}yr^{-1} from 2 cm yr^{-1} surface subsidence of peatland under agriculture. This paper presents results of initial efforts undertaken by the Malaysian Agricultural Research and Development Institute (MARDI) to quantify C balance from agricultural development on peatland and its implications for farm management.

Carbon loss during clearing of tropical peatland
Three months after forest felling in the MARDI Peat Research Station at Sessang, Sarawak, the volume and weight of forest debris, with diameters larger than 15 cm, were recorded as 169 m^3 ha^{-1} and 123 t ha^{-1}, respectively (Mohammad and Ismail, 2007). More than half of the debris was less than 15 cm in size and decomposed naturally within three years. Assuming that the debris contained 10% moisture and 50% C of its dry weight, total C content of the debris can be estimated at about 60 t ha^{-1}. The same amount of C was expected in the smaller sized debris and leaves. The burning technique of land clearing immediately released all C in the debris into the atmosphere. Meanwhile, zero burning techniques released similar amounts of C within three years. The most environmental-friendly method was the one that involved burying of the debris, which added more than 100 t C ha^{-1} reserves into the peatland. The technique, however, costs three times more than the commonly practiced burning or twice the currently recommended zero burning (Ismail and Jamaludin, 2007).

It was reported that the land clearing operations contributing to surface subsidence were drainage (6 cm), human activities (6 cm), machine activities (12-22 cm), removal of underground biomass of 50 cm depth (8 cm) and burning (11 cm) (Ismail and Jamaludin, 2007). Assuming that the bulk density of the peatland surface was 0.1 g cm^{-3} and dry peat material contained 50% C, the burning of 11 cm could result in an immediate release of 50 t C ha^{-1} into the atmosphere. Immediately after land clearing, peat soil CO_2 fluxes exhibited diurnal variations, peaked during mid afternoon and increased with the extent of disturbance caused by the forest clearing (Zulkefli *et al.*, 2007). Highest soil CO_2 flux recorded at noon was from the plot cleared by the burning method (700 mg CO_2 m^{-2} hr^{-1}) and followed by zero burning (450 mg CO_2 m^{-2} hr^{-1}). In all cases, the fluxes remained at these levels for more than thee years. This may explain the constantly high CO_2 level detected over Sumatra and Kalimantan after extensive peat fires in 1997/8 and 2001.

Ten months after land clearing, 92 plant species belonging to 72 genera and 47 families regenerated (Salma *et al.*, 2007). The most dominant tree species regenerated was *Macaranga triloba*. Six years later, this species had grown to a height of about 20 m, with average stand density of about 2,000 ha^{-1} and 20-60 cm girth size. With estimated fresh weight of 0.3 t per tree, 40% moisture content and

40% C of the dry biomass, the total C sink in the regenerated trees was estimated to be 150 t C ha^{-1}, equivalent to about 25 t C ha^{-1} yr^{-1}. Considering soil CO_2 flux of 10 t C $ha^{-1}yr^{-1}$, the species regeneration had resulted in net C-sink of about 15 t C $ha^{-1}yr^{-1}$.

Carbon balance from agricultural activity on tropical peatland

Water table depth under various agro-systems, measured weekly in 2006, is shown in Table 1. Generally, it fluctuated within the intended depths. There was occasional under-drainage and but no occurrence of over-drainage. Table 2 showed that the highest soil CO_2 flux was recorded under oil palm (150-200 mg C m^{-2} hr^{-1}), followed by pineapple (120-150 mg C m^{-2} hr^{-1}), jackfruit (100-120 mg C m^{-2} hr^{-1}) and sweet potato (80-110 mg C m^{-2} hr^{-1}). There was no clear indication on the effect of water table depth as commonly perceived. Other than the crop type and its agronomic practices, the high soil CO_2 flux under oil palm could also be influenced by a higher degree of peat decomposition, as the plot was planted almost 10 years earlier. It is important to note that the figures represent highest possible fluxes as these were measured at noon.

The number of weed species recorded under various agro-systems is presented in Table 3 and their occurrence in Table 4. Weeds infestation is a major problem for agriculture on tropical peatland and is generally controlled by chemicals on a regular basis. Rough estimations of the quantity and C content of agricultural biomass indicated net-C-loss in oil palm and pineapple agro-systems (Table 5). Other than soil CO_2 flux, a significant portion of C emission is expected from degradation of large quantities of biomass waste. Only a small portion of the biomass is currently utilized, e.g. for making compost, animal feed, 'bio-mat', etc. It is expected that the C balance in these agro-systems can be improved significantly by increased utilization of the biomass waste.

Conclusion

The changing role of developed peatland from that of C sink to C loss, to some extent, can be minimised. Our initial studies indicate that land clearing by burying the forest

Table 1. Intended and measured water table under various agro-systems on tropical peatland

Crop type	Year started	Water table depth (cm)	
		Intended	Measured (weekly in 2006)
Pineapple	2004	30-50	10–50
Jackfruit	2004	50-80	30–70
Oil palm	1995	50-80	35–80

Table 2. Soil CO_2 flux in various agro-systems measured at noon on tropical peatland

Crop Types	CO_2 flux (mg C m^{-2} hr^{-1})					
	February 2006	March 2006	June 2006	August 2006	December 2006	March 2007
Pineapple	120	148	130	119	115	125
Jackfruit	100	105	110	99	120	97
Sweet potato	80	100	90	110	81	96
Oil palm	146	178	160	150	150	192

Table 3. Weed species regenerated under various agro-systems on tropical peatland

Sampling time	No. of weed species			
	Papaya	Sweet-Potato	Jackfruit	Oil Palm
October 2005	25	31	30	38
April 2006	29	41	34	39
September 2006	31	48	45	45

Table 4. Dominant weed species in various agro-systems on tropical peatland

Weed species	Sweet potato	Papaya	Jackfruit	Oil palm
Fimbristylis pauciflora	x	x	-	-
Cyperus rotundus	x	x	x	
Melastoma malabathricum	x	-	x	x
Pityrogramma calomelanos	x	-	-	-
Hedyotis corymbosa	-	x	-	-
Lindernia crustacean	-	x	-	-
Asystasia intrusa	-	-	x	x
Ageratum conyzoides	-	-	x	-
Nephrolepis biserrata	-	-	-	x
Dianella ensifolisa	-	-	-	x

Table 5. Estimated carbon balance from oil palm and pineapple agro-systems on tropical peatland

	Estimated biomass (t $ha^{-1}yr^{-1}$)	Estimated moisture content (%)	Estimated C sink (50% of dry biomass (t $ha^{-1}yr^{-1}$)	Estimated C emission (70% of discard C) (t $ha^{-1}yr^{-1}$)
Oil palm (150 palm/ha, 25-year cycle)				
Peat soil	-	-	-	10
Fresh fruit bunch (80% discard - fresh)	20	70	6	3
Discard frond (dry)	10	0	5	3
At replanting (frond, trunk, root - dry)	(5)	0	3	(2)
Weed (fresh)	4	80	1	1
Total		-	15	18
C balance (sink–emission)			- 3	
Pineapple (40,000 plant/ha, 2-year cycle)				
Peat soil	-	-		8
Fresh fruit (50% discard - fresh)	30	80	6	1
Planting material (300 g/sucker - fresh)	6	50	1	-
At replanting (1.5 kg/plant – fresh)	(30)	50	7	(6)
Weed	4	80	1	1
Total	68	-	15	16
C balance (sink–emission)			-1	

Note: In parenthesis – the actual effect is on total value at replanting

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debris should be encouraged as a large quantity of additional C reserve will be stored in peatland. Newly cleared peatland, if not immediately used for crop cultivation, should not be disturbed but allowed to be colonized by the fast growing *Macaranga triloba* that can utilize large amounts of C from the air, resulting in a net C-sink environment. Current peatland agro-systems are estimated to be minor net C-emitters, which can be improved by proper utilization and management of biomass waste. A more damaging effect is probably the continuous depletion of C reserves from peat decomposition under aerobic conditions.

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