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CARBON LOSS ASSOCIATED WITH LAND-USE CHANGE AND WILDFIRES IN TROPICAL PEAT SWAMP FORESTS

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SUMMARY

We estimated C loss from several land-use change types, including wildfires, in tropical peatlands. For this both 'stock-difference' and 'gain-loss' approaches were used and combined. Phytomass C loss from peat swamp forest (PSF) conversion to logged forest, fire-damaged forest, mixed croplands and shrublands, rice fields, oil palm and *Acacia* plantations were in the range 117- 215 Mg C ha^{-1}. C loss from both vegetation and peat associated with wildfires occurring in virgin PSF amounted to 436 Mg C ha^{-1}. Conversion of PSF to oil palm and *Acacia* plantations represented a C loss from both biomass and peat over the conversion period (25 and 6 years for oil palm and *Acacia* plantations, respectively) of 427 and 280 Mg C ha^{-1}. Peat C loss from wildfires or land-use change contributed substantially total C loss, demonstrating the urgent need in terms of global warming to protect tropical PSF.

KEY WORDS: *Acacia*, CO_2, CH_4, Oil palm

INTRODUCTION

Tropical peat swamp forests (PSF) are among the largest carbon (C) pools on earth and their increasing degradation and conversion to other land uses (LU) in Southeast Asia may contribute greatly to climate change (Frolking *et al.*, 2011). Although quantifying C loss from biomass changes may not present major difficulties, losses from the peat are much more complex to assess. The so-called 'stock-difference' approach may be suitable for estimating peat C loss from fires however the 'gain-loss' approach seems more appropriate when considering PSF conversion to another LU (Hergoualc'h and Verchot, 2011). Using data from the literature we assessed C loss in the phytomass from PSF conversion and C loss in both phytomass and peat from wildfires and from PSF conversion to oil palm and *Acacia* plantations by using the previously mentioned methods.

MATERIAL AND METHODS

We reviewed studies of C stocks in the five C pools recommended by IPCC (above ground and below ground biomass, dead wood, litter and soil) of seven land use (LU) types prevalent in

Southeast Asia: virgin peat swamp forest, logged forest, fire-damaged forest, mixed croplands and shrublands, rice fields, oil palm and *Acacia* plantations. From this compilation we quantified C stock changes in the phytomass resulting from virgin peat swamp forest conversion to the other LUs using the 'stock-difference' approach. With the same method, we assessed C stock changes in both phytomass and peat resulting from uncontrolled fires, using average peat C stock loss from fires.

C loss in both phytomass and peat from virgin peat swamp forest conversion was assessed combining the 'stock-difference' and 'gain-loss' approaches. C loss from the peat was calculated as the difference between the balance of peat C inputs (or gains) and outputs (or losses) in the virgin peat swamp forest and that after conversion. We calculated C inputs to the soil from litterfall and root mortality. The main soil C outputs are: mineralization (also called heterotrophic respiration), methanogenesis, leaching, runoff, erosion and land-clearing fires. C loss from vegetation cover change included loss from aboveground C stocks in trees only, since C flux from litter and roots was already taken into account in the soil 'gain-loss' method. An assessment of C loss combining the 'stock-difference' and 'gain-loss' approaches could be achieved only for the conversion of virgin peat swamp forest to oil palm and *Acacia* plantations due to lack of data on peat C fluxes in other LU treatments.

Methods and reference of the data sources used for calculating C stock values in the phytomass, and C fluxes from litterfall, root mortality, heterotrophic soil respiration and land-clearing fire are available in the paper of Hergoualc'h and Verchot (2011). An additional reference included here is the study of Jauhiainen *et al.* (2012) from which the assessment of soil heterotrophic respiration in *Acacia* plantations on peat was used.

RESULTS

C Stocks and stock changes

From the estimates of phytomass C stocks (Table 1), greatest C loss from phytomass is associated with conversion of virgin peat swamp forests into rice fields and mixed croplands and shrublands; the least loss is associated with selective logging. Conversion to oil palm and *Acacia* plantations lead to intermediate C loss from phytomass.

Total C losses in both peat and phytomass arising from uncontrolled fires are presented in Table 2 for virgin and logged peat swamp forests, mixed croplands and shrublands, rice fields, oil palm and *Acacia* plantations. Uncontrolled fires in virgin peat swamp forest lead to large C losses from both vegetation and peat. The contribution of C loss from the peat to total C losses is the lowest when the fire occurs in virgin peat swamp forest and highest when the fire occurs in mixed croplands and shrublands, and rice fields. These C losses from fire take place in a few days and additional subsequent losses from peat decomposition are to be expected in the burnt lands. Moreover, the risk of recurrent fires is increased in burnt lands (van der Werf *et al.*, 2008); thus further CO_2 emissions from peat combustion may also be expected.

Table 1. Time-Average C Stocks in the phytomass for different land use treatments and phytomass C losses associated with virgin peat swamp forest conversion[a]

Land Use	Rotation Time (years)	Time-Averaged C Storage (Mg C ha^{-1} over rotation time)	C Loss from forest conversion (Mg C ha^{-1} over rotation time)	C Loss from forest conversion (% C stock in the forest)
F	-	219.7 ± 28.4 (25)	-	-
LF	-	102.8 ± 27.8 (27)	116.9 ± 39.8 (27)	53.2 ± 19.4 (27)
FF	-	68.2 ± 22.0 (30)	151.6 ± 36.0 (30)	69.0 ± 18.7 (30)
C&S	-	15.7 ± 2.8 (55)	204.1 ± 28.6 (80)	92.9 ± 17.7 (80)
R	1	4.8 ± 0.3 (6)	214.9 ± 28.4 (31)	97.8 ± 18.1 (31)
OP	25	31.6 ± 8.8 (1)	188.1 ± 29.8 (26)	85.6 ± 17.5 (26)
A	6	28.0 ± 2.1 (66)	191.7 ± 28.5 (91)	87.3 ± 17.2 (91)

[a]F, virgin peat swamp forest; LF, logged forest; FF, Fire-damaged forest; C&S, mixed croplands and shrublands; R, rice field; OP, oil palm plantation; A, Acacia plantation. Phytomass C losses associated with virgin peat swamp forest conversion are expressed as a difference of C stocks between the forest and the converted land and as a percentage of the stock in the forest. Values are mean ± standard error (n).

Table 2. C Loss from the peat, vegetation, and in total following uncontrolled fires in virgin peat swamp Forests (F-FF), Logged Forests (LF-FF), Mixed Croplands and Shrublands (Burnt C&S), Rice fields (Burnt R), Oil Palm plantations (Burnt OP), and *Acacia* plantations (Burnt A) and following the conversion of virgin peat swamp Forests to Oil Palm (F-OP) and *Acacia* (F-A) plantations on peatland[a]

LUC Type	Length Time of C Loss (years)	C Loss (Mg C ha^{-1})			Contribution Peat to Total (%)
		Peat	Vegetation	Total	
F-FF	<1	284.7 ± 68.1[c]	151.6 ± 36.0	436.2 ± 77.0	65 ± 19
LF-FF	<1	284.7 ± 68.1[c]	34.6 ± 35.5	319.3 ± 76.8	89 ± 30
Burnt C&S	<1	284.7 ± 68.1 [c]	15.7 ± 2.8	300.3 ± 68.2	95 ± 31
Burnt R	<1	284.7 ± 68.1 [c]	4.8 ± 0.3	289.5 ± 68.1	98 ± 33
Burnt OP	<1	284.7 ± 68.1 [c]	31.6 ± 8.8	316.3 ± 68.7	90 ± 29
Burnt A	<1	284.7 ± 68.1 [c]	28.0 ± 2.1	312.7 ± 68.2	90 ± 29
F-OP	25	269.5 ± 86.6	157.7 ± 26.8	427.2 ± 90.7	63 ± 24
F-A	6	118.6 ± 30.8	161.0 ± 25.6	279.6 ± 40.1	42 ± 13

[a]The last column indicates the contribution of peat C loss to total C loss. Values are mean ± standard error.

[b]LUC, land use change.
[c]Corresponding to an average burnt peat depth of 40.0 ± 7.9 cm (n = 4)

Combination of the 'stock-difference' and 'gain-loss' approaches for assessing C loss in both phytomass and peat from virgin peat swamp forest conversion

Soil C inputs and outputs for the seven LU types in Table 3 are from the literature review of Hergoualc'h and Verchot (2011). Soil heterotrophic respiration in *Acacia* plantations on peat is from the study of Jauhiainen *et al.* (2012).

In the virgin peat swamp forest, the balance between soil C inputs and outputs gives a net peat accumulation rate (Table 3), which is similar to the current accumulation rate of 0.94 Mg C ha^{-1} y^{-1} measured by Page *et al.* (2004) at a site in Kalimantan. The differences between the balance of peat C inputs and outputs in the virgin peat swamp forest and that in the oil palm and *Acacia* plantations represent a net total loss from the soil of 10.8 ± 3.5 Mg C ha^{-1} y^{-1} and 19.8 ± 5.1 Mg C ha^{-1} y^{-1}, respectively. Total C loss from the peat and vegetation cover change over the conversion period (25 and 6 years for oil palm and *Acacia* plantations, respectively) is presented in Table 2. The rate of C loss is then estimated at 17.1 ± 3.6 Mg C ha^{-1} y^{-1} during 25 years for the conversion to oil palm plantations and 46.6 ± 6.7 Mg C ha^{-1} y^{-1} during 6 years for the conversion to Acacia plantations. Additional subsequent losses from peat decomposition (at the rates indicated in Table 3) are to be expected during the following rotations of the oil palm and *Acacia* plantations.

Table 3. Soil C inputs and outputs in a virgin peat swamp forest (F); an oil palm plantation (OP); and an *Acacia* plantation (A) on peat[a].

		Land use		
		F	OP	A
WT		−12 ± 7 (7)	−60 ± 5 (1)	-80 ± 7 (1)
Soil C inputs	Litterfall	7.4 ± 0.7 (24)	1.5 ± 0.1 (4)	5.1 ± 0.3 (7)
	Roots	1.5 ± 0.8 (9)	3.6 ± 1.1 (4)	6.0 ± 0.3 (1)
	Total	8.9 ± 1.4 (33)	5.0 ± 1.1 (8)	11.1 ± 1.0 (8)
Soil C outputs	$CO_{2\ Hetero}$	6.9 ± 1.3 (11)	9.3 ± 2.7 (5)	21.8 ± 4.7 (1)
	CH_4	0.028 ± 0.010 (8)	−0.0002 ± 0.000 (1)	n.a.
	Fires	-	4.5 ± 0.03 (14)	7.1 ± 0.08 (14)
	S&PR	1 ± 0.5 (1)	1 ± 0.5 (1)	1 ± 0.5 (1)
	Total	7.9 ± 1.4 (20)	14.8 ± 2.8 (21)	29.9 ± 4.7 (16)
Balance[b]		**1.0 ± 1.7 (53)**	**−9.8 ± 3.0 (29)**	**-18.8 ± 4.7 (24)**

[a]Soil C inputs are from litterfall and root mortality and C outputs are from heterotrophic respiration ($CO_{2\ Hetero}$), CH_4 fluxes, land-clearing fires, and soluble and physical removal (S&PR). Values are mean ± standard error (n), expressed in Mg C ha^{-1} y^{-1}. Water table (WT) depth is indicated in cm; n.a., not available.
[b]The balance represents the net peat C accumulation (in the virgin peat swamp forest) and loss (in the oil palm and *Acacia* plantations) rates.

DISCUSSION AND CONCLUSION

One of the major concerns regarding LUC in tropical peatlands is the estimation of C loss from the peat. If for wildfires the ‘stock-difference’ approach may be suitable, the ‘gain-loss’ approach seems more appropriate for other land-use change types. This method requires knowledge of the main C inputs (litterfall and root mortality) and the major outputs (soil heterotrophic respiration rates and loss associated with land-clearing fires). Soil respiration may be a useful indicator of peat C loss (Wösten *et al.*, 1997; Couwenberg *et al.*, 2010). However, the heterotrophic component must be estimated and outputs have to be balanced against inputs in order to evaluate how much C the peat is losing or sequestering. Then the balance between inputs and outputs before and after LUC must be compared (IPCC, 2006) in order to assess peat C loss associated with LUC.

Hydrology, soil temperature but also vegetation cover changes are critical in driving C cycle changes. The effect of nutrient additions through fertilization in tropical peats has not been systematically studied, but is likely also a factor in the assessment of overall LUC effects.
An element that needs improvement is our understanding of the nature of the relationship between drainage and organic C loss. Several authors have used a linear relationship between water table depth and C loss from peat (Uryu et *al.*, 2008; Couwenberg *et al.*, 2010; Hooijer *et al.*, 2010), yet we know that soil heterotrophic respiration does not decrease linearly with increasing water content in saturated conditions (Linn and Doran, 1984; Cook and Orchard, 2008). Thus, these relationships likely overestimate CO_2 emissions from peat decomposition.
The fate of tropical peat swamp forests is a major concern within the framework of climate change because of the high amount of C they currently store and could carry on storing, and the consequences of LUC for CO_2 release into the atmosphere. These ecosystems are therefore an important issue for climate change mitigation mechanisms, such as REDD (Reducing Emissions from Deforestation and forest Degradation). If the assessment on CO_2 release following LUC in tropical peatlands is overestimated, the expected climate change mitigation by the implementation of REDD will not be achieved. Many gaps still remain in our understanding of the C cycle in tropical peatlands. Among the main gaps are those related to belowground processes, particularly the heterotrophic and autotrophic components of soil respiration. Many studies generally misunderstand the process of soil respiration and consider it as a direct measurement of soil C losses when, in fact, only a fraction of this flux (the heterotrophicone) is involved in peat C loss and this fraction has to be balanced with main C inputs to the soil to assess peat C loss.

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REFERENCES

Cook, F. J., and V. A. Orchard (2008), Relationships between soil respiration and soil moisture, Soil Biol. Biochem., 40, 1013–1018, doi:10.1016/ j.soilbio.2007.12.012.

Couwenberg, J., Dommain, R. and Joosten, H. (2010). Greenhouse gas fluxes from tropical peatlands in Southeast Asia. *Global Change Biol.* **16**, 1715–1732.

Frolking, S., Talbot, J., Jones, M.C., Treat, C.C., Kauffman, J.B., Tuittila, E.-S. and Roulet, N. (2011). Peatlands in the Earth's 21st century climate system. *Environ. Rev.* **19**, 371–396.

Hergoualc'h, K. and Verchot, L.V. (2011). Stocks and fluxes of carbon associated with land-use change in Southeast Asian tropical peatlands: a review. *Global Biochem. Cy.* **25**, GB2001, doi:2010.1029/2009GB003718.

Hooijer, A., Page, S., Canadell, J.G., Silvius, M., Kwadijk, J., Wösten, H. and Jauhiainen, J. (2010). Current and future CO_2 emissions from drained peatlands in Southeast Asia. *Biogeosciences* **7**, 1505–1514.

IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Institute for Global Environmental Strategies, IGES, Hayama, Japan.

Jauhiainen, J., Hooijer, A. and Page, S.E. (2012). Carbon dioxide emissions from an *Acacia* plantation on peatland in Sumatra, Indonesia. *Biogeosciences* **9**, 617-630.

Linn, D. and Doran, J. W. (1984). Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. *Soil Sci. Soc. Am.* **48**, 1267–1272.

Page, S.E., Wust, R.A.J., Weiss, D., Rieley, J.O., Shotyk, W. and Limin, S.H. (2004). A record of late Pleistocene and Holocene carbon accumulation and climate change from an equatorial peat bog (Kalimantan, Indonesia): Implications for past, present and future carbon dynamics. *J. Quat. Sci.* **19**, 625–635.

Uryu, Y., *et al.* (2008). Deforestation, forest degradation, biodiversity loss and CO_2 emissions in Riau, Sumatra, Indonesia, WWF Indonesia technical report, 74 pp., Jakarta.

van der Werf, G. R., *et al.* (2008). Climate regulation of fire emissions and deforestation in equatorial Asia. *Proc. Natl. Acad. Sci. U.S.A.* **105**, 350–355.

Wösten, J.M.H., Ismail, A.B. and van Wijk, A.L.M. (1997). Peat subsidence and its practical implications: A case study in Malaysia. *Geoderma* **78**, 25–36.