

GREENHOUSE GAS EMISSIONS FROM A PLANTATION ON THICK TROPICAL PEAT

Jyrki Jauhiainen

University of Helsinki, Department of Forest Sciences, P.O. Box 27, 00014 University of Helsinki, Finland. Tel. +358 09 19158148, jyrki.jauhiainen@helsinki.fi.

Aljosja Hooijer (Deltares, The Netherlands), Susan Elisabeth Page (Department of Geography, University of Leicester)

SUMMARY

Peat surface CO₂, CH₄ and N₂O emissions, groundwater table depth and peat temperature were monitored along transects in an *Acacia* tree plantation on thick tropical peat in Sumatra, Indonesia. The autotrophic root respiration was separated from heterotrophic CO₂ emissions resulting from organic matter decomposition. There was a positive correlation between mean long-term water table depth and heterotrophic CO₂ emission. On average, the contribution of autotrophic respiration to daytime CO₂ emission was 21% in mature *Acacia* stands. At locations 0.5 m from trees this was up to 80% of the total emissions, but it was negligible at locations more than 1.3 m away. Mean cumulative daytime heterotrophic CO₂ emission was 94 t ha⁻¹ y⁻¹ at a mean water table depth of 0.8 m, with a minimum emission of 80 t ha⁻¹ y⁻¹ after correction for the effect of diurnal temperature fluctuations. CO₂ formed 90%, CH₄ 0.3% and N₂O 9.7% of the total emission GWP impact of these gases along all transects combined.

KEY WORDS: CO₂, CH₄, N₂O, drainage, land use change

INTRODUCTION

Lowland peatlands in Southeast Asia cover 24.8 Mha, which is 56% of the tropical and 6% of the global peatland area (Page *et al.*, 2011). Their high carbon density gives rise to a large regional peat carbon store of 68.5 Gt, equivalent to 77% of the tropical and 11–14% of the global peat carbon store. By 2007, some 60% of peat swamps in Peninsular Malaysia and the islands of Sumatra and Borneo were partly or completely deforested and usually influenced by some form of drainage and only 10% remained in pristine condition (Miettinen and Liew, 2010).

The focus of this paper is on the greenhouse gas emissions arising from peat decomposition following conversion of peat swamp forest to industrial plantation of *Acacia* pulp wood trees. Our aim is to quantify heterotrophic CO₂ emissions across a range of conditions and improve understanding of the drivers of peat oxidation. Based on daytime gas flux monitoring we assessed the effects on emissions of (i) land cover type and plantation tree growth stage and (ii) water table depth on both heterotrophic plus autotrophic (total) and on heterotrophic emissions. Peat surface – atmosphere flux levels for the other two important greenhouse gases (GHG) in peat, namely CH₄ and N₂O, were compared to CO₂ emissions.

MATERIAL AND METHODS

The study area is in an *Acacia crassicarpa* pulp wood plantation on peatland in the Riau Province, Sumatra, Indonesia. CO₂ data (n >2300) were collected along 8 transects (A–H) located on one large peat dome on which peat thickness ranged from 4–9 m (average 6 m). The plantation area is drained by a rectangular system of canals at 800 m intervals. Monitoring included recently harvested sites with bare peat through immature growth stages to closed canopy sites with mature trees up to 5 year old (Table 1). Each gas flux monitoring transect consisted from 2 to 4 sub-transects along which seven CO₂ monitoring locations were situated in line between tree rows of ~3.5 m distance. A lesser amount of air samples for CH₄ (n=47) and N₂O (n=56) analyses was collected from locations in the middle of each of the sub-transects (A, B, C, D and F transects).

Soil CO₂ emission was partitioned into autotrophic root respiration and heterotrophic peat oxidation components by using several methods. First, the presence of autotrophic CO₂ emission sources was determined through pit observations. Very few roots were found at monitoring locations in the middle of sub-transects, and it could therefore be assumed that at such locations (i.e. ≥ 1.3 m from trees on average) respiration from tree roots was negligible. Secondly, monitoring locations were kept free from any herbaceous vegetation. Thirdly, during the last 6 months of monitoring the contribution of root respiration to total CO₂ emission was tested experimentally by regular trenching (sawing) of the peat surface down to a depth of 0.5 m around the three central monitoring locations on each sub-transect. Finally, trees were felled along several transects, which allowed measurements also under conditions where live tree roots were guaranteed to be excluded (Table 1).

The depth of the water table below the peat surface and peat temperatures were monitored at the same locations and times as CO₂ emissions. Surface peat CO₂ emissions were measured by using a portable infrared gas analyzer EGM-4 connected to a respiration chamber unit. Air sampling for CH₄ and N₂O analyses was made from closed chambers, and the gases were analyzed by gas chromatography. The main statistical test was one-way ANOVA run at the 95% confidence level.

RESULTS

The average water table depth along all transects was about 0.8 m but there were considerable variations in time and space during the two-year monitoring period (Table 1, Jauhiainen *et al.*, 2012). The average daytime air temperature close to the peat surface was 33.6°C along transects in the open and young immature *Acacia* stages and 30.0°C in closed canopy *Acacia* (Table 1). At a depth of 5 cm below the peat surface, mean daytime temperatures were between 29.3°C and 33.0°C (mean 31.5°C) in the open and young immature tree stands and between 28.2°C and 29.2°C (mean 28.7°C) in closed canopy tree stands (Jauhiainen *et al.*, 2012). Diurnal mean (24 h) and mean daytime peat temperatures at a depth of 5 cm differed by 1.3°C to 1.6°C along the closed canopy and the open canopy, respectively.

Since no significant differences ($p > 0.05$) in CO₂ emission were identified before and after trenching, at the ‘furthest from trees’ measurement locations along the B, D, G and H transects that varied from ‘mature’ to ‘open’ during trenching operations, all data from the ‘furthest from trees’ monitoring locations were combined for subsequent analyses. This

Table 1. Tree stand age characteristics (months) and average water table characteristics (m from the peat surface) at the GHG monitoring transects during monitoring period.

	Tree stand age (months)							Water table depth (m)								
	A	B	C	D	E	F	G, H	A	B	C	D	E	F	G	H	
Mean	31.2	32.6	46.2	1.3	6.0	7.1	12.2	0.93	0.77	1.06	0.71	0.72	0.84	0.43	0.92	
SD	6.1	4.4	6.0	2.4	0.8	3.4	2.7	0.28	0.16	0.33	0.25	0.22	0.14	0.12	0.16	
Range	17	17	20	13	2	12	8	1.28	0.90	1.55	1.26	0.94	0.67	0.55	0.60	
Min.	24	26	40	0	5	-2	8	0.30	0.31	0.41	0.07	0.26	0.55	0.17	0.60	
Max.	41	43	60	13	7	10	16	1.58	1.21	1.96	1.20	1.20	1.22	0.72	1.20	
%ile 25	26	29	41	0	5	6	10	0.72	0.67	0.83	0.58	0.59	0.73	0.34	0.81	
%ile 50	28	33	43	0	6	9	13	0.90	0.76	1.04	0.69	0.73	0.83	0.43	0.97	
%ile 75	38	35	52	2	7	9	14	1.13	0.87	1.26	0.90	0.86	0.94	0.52	1.04	
Cycle	1st	1st	1st	2nd	2nd	2nd	2nd									
Stage	Mature			Open and Immature												

confirmed that the tree roots were relatively localised around the bases of the trees. Based on the measures taken in data collection outlined above and in subsequent data analysis, CO₂ emission data obtained from the ‘furthest from trees’ monitoring locations were defined as ‘heterotrophic emissions’. The data from the ‘nearest to trees’ locations include emissions from both roots and organic matter decomposition and hence ‘total soil respiration’ is used for this emission in this presentation.

The highest values for total soil respiration emissions were obtained along transects A, B, C, F and H, three of which (A, B, C) were ‘mature’ plantations with average tree stand ages over 31 months. The lowest total emissions were obtained along the recently replanted and open transects (D, E, G), with average tree stand ages below 13 months (Table 1, Fig. 1). In two of the mature tree stand transects (A, B), mean total emissions were significantly higher than the heterotrophic emissions, at 56% and 21% respectively. Along the other transects in the open and immature trees stands, the differences were in general smaller (Fig. 1). Mean daytime autotrophic respiration for the closed canopy *Acacia* transects varied between 115 and 630 mg CO₂ m⁻² h⁻¹. The highest average daytime autotrophic respiration at transect A was 36% of the total CO₂ emission. For transects B and C, the average autotrophic respiration emissions were about 17% and 9%. The overall mean autotrophic respiration for these transects was 320 mg CO₂ m⁻² h⁻¹, which was 21% of the total CO₂ emission.

There was a trend of reducing CO₂ emission when the mean water table was closer to the peat surface (Fig. 1). Correlation (R²) between mean heterotrophic CO₂ emission and mean water table depth for all transects was 0.47, and for total CO₂ emission it was 0.34 (Fig. 1). The overall daytime mean (±SE) heterotrophic respiration emission derived by regression was 93.9 ± 17.2 t CO₂ ha⁻¹ y⁻¹ (1072 ± 197 mg m⁻² h⁻¹) at 0.8 m water table depth (Fig. 1).

Several studies suggest temperature differences in peat impact on organic matter oxidation rates by ratio Q₁₀ = 2 (see Discussion for details). An average difference between daytime and diurnal peat temperature at 5 cm depth of 1.45°C was found across the *Acacia* plantation growth stages. By applying temperature correction, based on diurnal surface peat temperature fluctuation and a Q₁₀ = 2, daytime CO₂ emissions were subject to a 14.5% reduction. Temperature corrected emission values as scaled-up units (t ha⁻¹ y⁻¹), the regressions for all transects are presented in Fig. 1. The overall temperature corrected mean (±SE) heterotrophic respiration emission derived by regression was 80.3 ± 17.2 t CO₂ ha⁻¹ y⁻¹ at 0.8 m water table depth (Fig. 1).

No clear relation was found between CH₄ and N₂O emissions and water table depth. A relation between mean CH₄ flux and tree growth stage was not evident, but mean N₂O fluxes were somewhat higher for the open and immature transects (D, F) in comparison to the mature transects. Mean CH₄ flux (\pm SE) for all transects (values from -0.094 to 0.861 mg m⁻² h⁻¹) was 0.134 ± 0.027 mg m⁻² h⁻¹. Mean N₂O flux (\pm SE) for all transects (values from 0.009 to 53.645 mg m⁻² d⁻¹) was 0.372 ± 0.061 mg m⁻² h⁻¹. On an annual basis, the mean emissions for all transects would be 0.0124 ± 0.0029 t ha⁻¹ y⁻¹ for CH₄ and 0.0340 ± 0.0085 t ha⁻¹ y⁻¹ for N₂O.

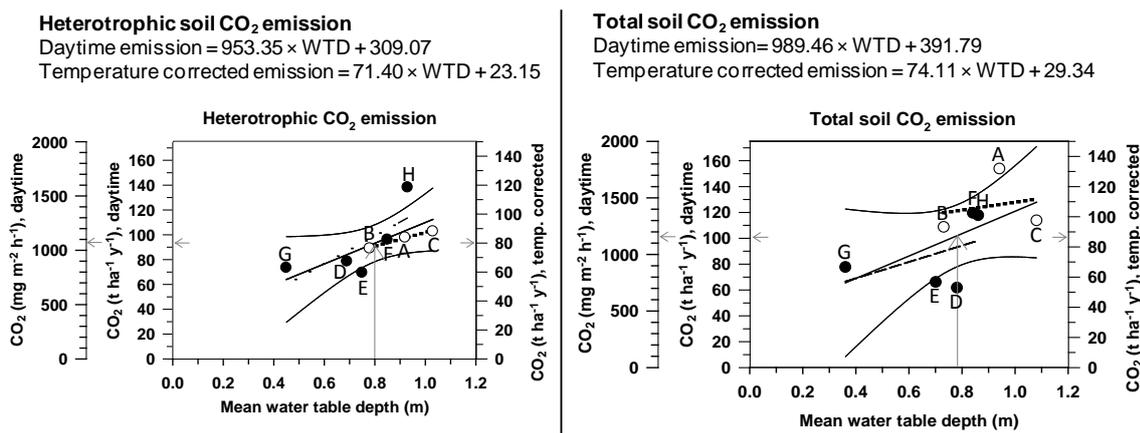


Fig. 1. Regression of mean peat surface CO₂ emission from heterotrophic respiration at furthest from trees locations (left) and mean total soil CO₂ emission at nearest to trees locations (right) at mean water table depths at the monitoring transects (A–H). Emission values provided in multiple units; daytime emission values (mg m⁻² h⁻¹, t ha⁻¹ y⁻¹) on the left axis, and temperature corrected emissions (t ha⁻¹ y⁻¹) on the right axis. Linear regression lines for ≤ 16 months old trees (\circ -symbol, dotted line), ≥ 24 months old *Acacia* (\bullet -symbol, dashed line), average (solid line), and 95% confidence limits (solid curves) for the combined data from 8 transects are provided. Linear regressions for daytime (mg m⁻² h⁻¹) emissions and temperature corrected emissions (t ha⁻¹ y⁻¹) for all transects are above the graphs. Arrows indicate regression mean emissions and water table depths

DISCUSSION

The autotrophic respiration contribution of 21% to the total CO₂ emission in mature tree stands in our study is much lower than the previous values suggested for oil palm plantations on peatland, which range from 46% (Melling *et al.*, 2007) to 29% (Hergoualc'h and Verchot, 2011). This difference may be caused by the fact that these earlier studies and reviews were based on very small numbers of measurements that were not specifically set up to separate autotrophic from heterotrophic CO₂ emissions. The relationship between heterotrophic emissions from peat and water table depth has been found to be non-linear at undrained sites and those with unregulated drainage, especially during periods when water table is close to the peat surface (e.g. Jauhiainen *et al.*, 2008; Hirano *et al.*, 2009). In peatlands with low water tables and controlled permanent drainage such as *Acacia* plantations, however, this relation is far weaker.

The means of the water table depths along each transect throughout the entire study period (i.e. long-term water table depth) showed a strong relationship with long-term mean heterotrophic respiration CO₂ emissions (Fig. 1). The highest regression R²-value (0.99) was for the mature tree growth stage, which represented comparatively constant environmental conditions after several years had elapsed following harvesting. Longer-term emission values

based on uncorrected daytime CO₂ flux measurements may result in an overestimate because peat temperatures vary diurnally. This emission value can therefore be considered a maximum, which should be moderated for daytime temperature and emission both being above the daily average.

In a previous study, however, a clear CO₂ emission/temperature relationship for tropical peat was found in situ measurements in forest floor (Hirano *et al.*, 2009) and in laboratory incubation (Brady, 1997), of a resulting in both relation of $Q_{10} = 2$, i.e. a difference in peat temperature of 1°C results in a 10% difference in emission. The average difference between daytime and diurnal temperatures was 1.45°C across the *Acacia* plantations. The daytime CO₂ emission value may therefore be reduced by up to 14.5% to account for diurnal temperature fluctuation in peat. The resulted temperature corrected emission value of 80 CO₂ ha⁻¹ y⁻¹, at an average water depth of 0.8m, is close to the value of 76 t CO_{2e} ha⁻¹ y⁻¹ resulting from subsidence and bulk density measurements conducted partly in the same landscape at the same water table depth (Hooijer *et al.*, 2011). The high sensitivity of CO₂ emissions to peat temperature, and the resulting relative insensitivity to water table depth, implies that bringing up water tables in plantations will not reduce carbon losses by as much as would be expected on the basis of peat surface emissions in forest systems (e.g. Jauhiainen *et al.*, 2008). Based on day time measurements and global warming potential on a 100 year time horizon, contributions of the three GHGs from heterotrophic respiration to the total were 93.3% by CO₂, 6.4% by N₂O and 0.3% by CH₄. CO₂ was by the far most important form of carbon emitted, but N₂O may also make a notable contribution to the total GHG emissions from peat decomposition.

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