CO₂ emissions from acacia plantation on peatland in Sumatra, Indonesia

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Extended Abstract

Lowland peatlands in Southeast Asia cover 24.78 Million hectares (Mha), which is 56% of the tropical and 6% of the global peatland area (Page et al. 2011). Their high peat carbon density, however, gives rise to the large regional peat carbon store of 68.5 Gt, equivalent to 77% of the tropical and 11% of the global carbon store (Page et al., 2011). Since 1990, 5.1 Mha of the total 15.5 Mha of peatland in Peninsular Malaysia and the islands of Borneo and Sumatra has been deforested, drained and burned while most of the remainder has been logged intensively (Miettinen and Liew 2010). Over the same period, the area of unmanaged secondary peat swamp forest has doubled to nearly a quarter of all peatlands and industrial plantations have expanded dramatically from 0.3 Mha to 2.3 Mha, an increase from 2 to 15% of the total peatland area. When deforestation of tropical peat swamp forest is not followed by managed economic use it becomes subject to fire, delayed vegetation recovery and rapid degradation resulting in transfer of large amounts of CO₂ to the environment (atmosphere and drainage water) (Aldhous, 2004; Rieley et al., 2008; Langner and Siegert, 2009; Page et al., 2009).

By 2008 only 10% of the peatlands of Peninsular Malaysia, Borneo and Sumatra remained in an intact or slightly degraded condition (Miettinen and Liew, 2010). The implications of this high rate of land use change, and the increasing frequency and extent of fires, for losses of peat carbon have received increasing attention in recent years (e.g. Hooijer, 2006, 2010; Couwenberg et al., 2010; Miettinen and Liew 2010; Murdiyarso et al., 2010; Koh et al., 2011). Unfortunately, data on carbon losses from tropical peatland are confusing and contradictory. Most studies have focussed only on gaseous CO₂ and CH₄ emissions from the surface of peat and have not accounted for the contribution of CO₂ released in root respiration in the total emission measured. Methods used are poorly described and results are not strictly comparable. Measurements have not been made continuously throughout the day (day and
night) or for long periods (weeks, months, years). For example, Melling \textit{et al.} (2005 a,b) drew conclusions about the CO$_2$ and CH$_4$ fluxes at the surface of a drained peat swamp forest and oil palm and sago plantations on peat, based on means and standard errors of only three replicates at each site, measured between 10.00 and 13.00 hrs on one day a month for a year. Carbon dynamics of tropical peatlands involve: the vegetation carbon dioxide (CO$_2$) flux balance between sequestration in photosynthesis and emissions in plant respiration, CO$_2$ emissions from soil animals and microorganisms in aerobic peat decomposition processes, CO$_2$ and other C-gas losses in fires, fluvial exports of dissolved and particulate organic carbon (DOC and POC), and net methane (CH$_4$) emissions from microorganisms in anaerobic peat decomposition processes. Aerobic decomposition processes by methanotrophs may consume some or all produced CH$_4$ and convert it to CO$_2$. In addition, nitrous oxide (N$_2$O), a non carbon greenhouse gas, is released as a result of soil nitrogen mineralization. The quantities of CH$_4$ and N$_2$O jointly involved in peat-atmosphere exchanges are small, however, and their effect on climate change processes is much less than concurrent CO$_2$ emissions (Hadi \textit{et al.}, 2005; Jauhiainen \textit{et al.}, 2005, 2008, in prep; Melling \textit{et al.}, 2005a, 2005b, 2007).

A few studies have quantified peat carbon store losses, determined from changes in peat surface levels (subsidence) over long time periods (years), combined with information on peat carbon concentration and bulk density (see paper by Hooijer \textit{et al.}, this conference). This approach has been hampered by incomplete data sets (inadequacy and inconsistency of monitoring) and a lack of reference data that would allow adequate definition of carbon loss rates before, during and after land use change (Wösten \textit{et al.}, 1997; Couwenberg \textit{et al.}, 2010).

The largest number of peat CO$_2$ emission rate measurements has been obtained using the closed-chamber method, which measures momentary gaseous carbon transfer between the peat surface and the atmosphere (inside the chamber). Even for this method, however, there are fewer than ten peer-reviewed publications presenting CO$_2$ flux data under monitored hydrological conditions (e.g. Inubushi \textit{et al.}, 2003; Furukawa \textit{et al.}, 2005; Hadi \textit{et al.}, 2005; Jauhiainen \textit{et al.}, 2005, 2009; Melling \textit{et al.}, 2005a; Ali \textit{et al.}, 2006; Hirano \textit{et al.}, 2009), with some additional data from incomplete studies described in unpublished reports and conference proceedings. In these studies it is impossible to separate heterotrophic CO$_2$ emissions from peat oxidation (decomposition) and autotrophic CO$_2$ emissions from root respiration (on vegetation growing areas) owing usually to inadequately applied methodology and data collection procedures for peat decomposition rate quantification. Moreover, the
closed chamber method involves gas monitoring only, and cannot detect losses of particulate and dissolved carbon (DOC and POC) in drainage water.

This paper focuses on the impact of land use change on CO₂ emissions from tropical peatland. We monitored CO₂ emissions and water depth for nearly 3 years in an Acacia pulp tree plantation, in Riau, Sumatra, on peat that had not been affected by fire either during or after peatland conversion. The locations were representative of the various Acacia crop growth cycle stages, including post-harvest, and the water table was controlled at an average of about 0.8m below the surface. Acacia was planted in rows at an average distance of 3.5m between trees. Root systems were confined to within one metre from the tree base, although on some occasions a few longer roots extended further away. Over 2300 CO₂ emissions measurements were obtained from 144 monitoring positions established along eight transects, located across one large peat dome; this provides the largest and longest CO₂ emissions database from co-located, multiple locations in a single tropical peat-covered landscape. In order to quantify the emissions arising only from peat decomposition, three procedures were applied to separate autotrophic from heterotrophic respiration; a) CO₂ emissions were measured from several positions both near (≤90 cm) and far (≥134cm) from Acacia trees, i.e. within and beyond the tree rooting zone; b) CO₂ emissions were measured at a number of monitoring locations where the peat and plant roots were cut using a saw (trenching) to exclude root respiration emissions, c) CO₂ emissions were measured both before and after tree harvesting conditions, to further exclude root respiration emissions.

Our results show; (i) mean CO₂ flux rates differ from 14% up to 80% between the monitoring positions next to and those furthest away from trees in mature tree stands (aged 24 to 60 months), (ii) a no dependence between momentary water table depths and CO₂ emissions arising from peat decomposition on a given day, (iii) a stronger correlation (R² = 0.47) between the means of long-term peat CO₂ emissions and long-term (average) water table depths on the monitoring transects. The mean CO₂ emission (±SE) from sites where root respiration was excluded (i.e. the heterotrophic flux) was 1053±88 mg m⁻² h⁻¹ at 0.78 m average water table depth. Data for long-term means indicate that CO₂ emissions increase under deeper drainage conditions.

The mean heterotrophic peat CO₂ emission rates provide annual estimates of 92 t CO₂ ha⁻¹y⁻¹ at 0.78 m water table, which is over 20 tonnes higher than the 70 t CO₂e ha⁻¹ y⁻¹ suggested by two previously published meta-analysis studies of peat CO₂ emissions under comparable drainage conditions (Hooijer et al., 2006, 2010; Couwenberg et al., 2010), and almost three
times higher than the estimate of 34.1 t CO$_2$ ha$^{-1}$ y$^{-1}$ used in recent peat carbon loss upscaling studies by Murdiyarso et al. (2010) and Koh et al. (2011).

The direction and slope of the regression between long-term CO$_2$ emissions and water table depths in our study and the two meta-analyses (op. cit.) are similar while our estimate of total peat carbon losses are close to those obtained from peat subsidence measurements and related determinations of peat carbon concentration and bulk density made at the same locations (Hooijer et al., this conference).

Our study is the largest and longest CO$_2$ emissions investigation undertaken in plantations on tropical peatland. More importantly, it is the first study of any magnitude to separate autotrophic and heterotrophic CO$_2$ emissions and therefore to show the true magnitude of peat decomposition emissions from an industrial plantation on tropical peatland and to link the magnitude of these to water table depth. More studies of this magnitude are required for comparison and confirmation of the extent of the carbon losses from drained peat.

There is also an urgent need for a detailed appraisal of the methods used to measure both CO$_2$ and CH$_4$ in both closed chambers and on towers open to the atmosphere. Guidance is needed on the amount of sample replication needed to ensure statistical reliability of results and also on the time periods (diurnal, weekly, monthly) and scale required in order to provide reliable data for upscaling to an annual basis. Neither is there sufficient information on the impact of fire and time since drainage on losses from both developed and undeveloped areas (our study covers only 3 years with a maximum of 8 years since deforestation and original drainage while some plantations of oil palm and pineapple on peat in Peninsular Malaysia were established more than 50 years ago).

There is a positive correlation between peat water table depth and peat CO$_2$ emissions and therefore it is also important to monitor the former regularly and following a strict protocol. The importance of long-term hydrology on carbon dynamics in drained peat has not received sufficient attention in some data collections or data selections for meta-analyses.

Finally, caution should be exercised in meta-analyses, in which the use of too much data from one individual study can lead to pseudo-replication which may result in bias in the data. Carbon emission evaluations and projections based on literature values should be restricted to data describing comparable peat characteristics and land management histories.

References