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Short Communication

Soil CO_2 flux from tropical peatland under different land clearing techniques

(Fluks CO_2 dari tanah gambut tropika dengan kaedah pembersihan tanah berbeza)

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Abstract

Measurement of CO_2 flux was carried out at five sites at MARDI Peat Research Station in Sessang, Sarawak. The sites represented four different types of land clearing technique namely felling and burning (FB), felling and stacking-outside the plot (FSO), felling, stacking and chipping (FSC), and selective clearing (SC). The CO_2 flux was measured using static chamber method connected to a portable CO_2 infrared gas analyser. Soil CO_2–C flux exhibited diurnal pattern with peak rates as high as 950 mg m^{-2} h^{-1} occurred during the mid afternoon (1100–1300). Emission of CO_2 was highly correlated with soil temperature (r^2 = 0.86) and water table (r^2 = 0.63). Annual CO_2 flux from the peat soil surface varies significantly among land clearing techniques. The highest estimated annual carbon loss as CO_2 emission was 48.3 t/ha/year under FB area. The FSO and FSC land clearing methods significantly reduced the emission of CO_2 with the estimated C loss around 33 t/ha/year. Annual emissions of CO_2 from SC are lower compared to other land clearing techniques. There were no significant differences between the annual CO_2 flux from SC and undisturbed forest.

Introduction

In Malaysia, there are about 2.4 million hectares of peatland of which 60.5% or 1.5 million hectares are found in Sarawak. This area is now being felled rapidly for agriculture especially for oil palm and sago plantation. Drainage of peatland for agriculture leads to a rapid change in the physical, chemical and biological properties of the soil. Drainage enhances peat decomposition (oxidation of peat) rates turning the peatland from a carbon dioxide (CO_2) sink into CO_2 emission (Silvola et al. 1996).

The development of peatland for agriculture involves land clearing, commonly undertaken by the ‘slash and burn’ technique. Peat, being organic in nature, is easily burnt, particularly during dry weather and with deep water table. Many of these so-called ‘managed’ fire spread out of control, burning not only the surface vegetation but also the underlying peat material and tree roots. The practice of open burning also contributes significantly to air pollution, which on a large scale can result in severe interstate haze problems. Burning methods contribute to the dense haze that blankets a large part of Southeast

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Asia and causing severe deterioration in air quality and health problems (Bowen et al. 2000).

In addition, burning of peat materials will release more than 80 gaseous compounds of which some are toxic. Volatile organic compounds such as aliphatic aromatic hydrocarbon, furfurals and organic acids are carcinogenic to human (Okazaki et al. 1999). To avoid these potential hazards, different approaches of land clearing have to be considered. The objective of the study was to investigate the effect of different land clearing technique on the CO_2 emission from the soil surface of peatland.

Materials and methods

Site description

The study was carried at MARDI Peat Research Station in Sessang, Sarawak. The station covered 387 ha of intensively logged over forest sitting on deep peat that ranged from 0.5 m to more than 5.0 m thick (MARDI 1996). Based on Von Post Scale, peat soil in Sessang falls under the amorphous/sapric peat (H7-H9), which is highly humified or decomposed soil. It was brown to brown black in colour and had a strong smell. The organic content was in the range of 93–98%, and fibre content was 2–7%.

Mean temperature ranges from 22.1–31.7 °C. The percentage sunshine hour ranges from 36 to 54 per month, with a mean of 45% calculated based on 12 hours daylight. The mean relative humidity ranges from 61–98% throughout the year. The mean annual rainfall is 3,540 mm which monthly distribution pattern exhibits a distinct lower rainfall in July (160 mm/month), and an intense wet period between October and January (more than 400 mm/month).

Measurement of CO_2 flux was carried out at five sites which represented four different types of land clearing and forest. The land clearing techniques employed in this study were felling and burning (FB), felling and stacking-outside the plot (FSO), felling, stacking and chipping (FSC), selective clearing (SC) and one undisturbed forest as a control.

Flux monitoring device

CO_2 emitted from the soil surface of the peat soil was trapped using a static chamber (Bekku et al. 1995). The chamber was built using PVC measuring 10 cm in diameter by 15 cm tall, with a total chamber volume of 4.7 litres. The concentration of CO_2 flux was measured using a flow-through portable infrared gas analyser (IQ 1000 INS) connected to the chamber with the pumping rate at 3 litres/m. Recording of CO_2 flux began in June 2002 and followed by one in October 2003. It was further repeated in March, July and November 2003. The last two CO_2 flux readings in 2004 were carried out in March and September. In each of the five study areas, three PVC rings were driven about 5 cm into the soil and the bottom outer ring of the chamber was covered with peat soil.

Flux calculation

Gas fluxes were calculated by the following equation (Widen and Lindroth 2003):

$$\text{Flux} = [d(CO_2)/(dt)] \times PV/ART$$

where:

$d(CO_2)/(dt)$ = Evolution rate of CO_2 (mol mol^{-1} s^{-1}) within the chamber headspace at a given time (s) after putting the chamber in place

P = Atmospheric pressure (atm)

V = Volume of the headspace gas within the chamber (m^3)

A = Area of soil enclosed by the chamber (m^2)

R = Gas constant (8.205746×10^{-5} atm K^{-1} mol^{-1})

T = The air temperature (K)

Flux measurements were made between 1,000 and 1,400 at each of the chamber site. The water table depth and temperature of soil (at 10 cm depth), ambient, and in the chamber were recorded. To determine differences in the CO_2 evolution among land clearing types, LSD test ($p = 0.05$) were carried out using SAS statistical program (SAS Inst. 2004).

Results and discussion

Factor controlling CO_2 flux

A common pattern of daily variation on CO_2 emission measured from various land clearing techniques at Sessang is shown in *Figure 1*. Emission of CO_2 from the soil surface exhibited diurnal variation. The CO_2 flux ranged from low (90 mg CO_2-C m^{-2} h^{-1}) to peak flux rates as high as 950 mg CO_2-C m^{-2} h^{-1} which normally occurred during mid afternoon (1000–1400). The emission of CO_2 from peat soil surface generally originated from biological processes, namely microbial respiration, root respiration and faunal respiration. Release of CO_2 from soil biological and microbial respiration is highest at moderately high soil temperatures with adequate soil moisture and substrate C (Kirschbaum 1995; Follett 1997). Daily variations of CO_2 flux in SC were smaller and similar pattern was observed in peat forest.

Several studies have shown that factors such as temperature, water table, moisture, available organic carbon of the soil influenced CO_2 production and emission from the peat soil. Temperature had a marked effect on CO_2 evolution from the soil. At higher temperatures partial inhibition of microbial respiration occurs, which is attributed to the inactivation of biological oxidation systems.

The emission of CO_2 in the study area was highly correlated ($r^2 = 0.86$) with soil temperature (*Figure 2*). Based on the equation derived from this correlation, any 2 °C rise in the soil temperature would result in the increased by 122 mg CO_2-C m^{-2} h^{-1}. Removal of trees during land clearing in FB, FSO and FSC had exposed the soil surface to direct sunlight which leads to an increase in soil temperature. Higher soil temperatures following tree removal had been associated with increased organic matter decomposition in histosols soil (Bridgham et al. 1998). Elevated soil temperature will also speed up the decomposition process of organic material in the peatland (Melillo et al. 2002).

Surface peat CO_2 emissions contributes considerably to total ecosystem respiration and it is greatly influenced by water table depth. Stability of hydrology, forest floor micro-topography and vegetation structure are other factors that influence peat CO_2 dynamics in undrained peatland. Significant linear increase in CO_2 flux was observed in this study as the water table dropped (*Figure 3*). This was mainly due to the increase in area where aerobic respiration could take place. Similar observations were also reported by Silvola et al. (1996) and Jarvis (1997). Knowles and Moore (1998) have demonstrated that by lowering the water table from 10 to 70 cm, the CO_2 flux

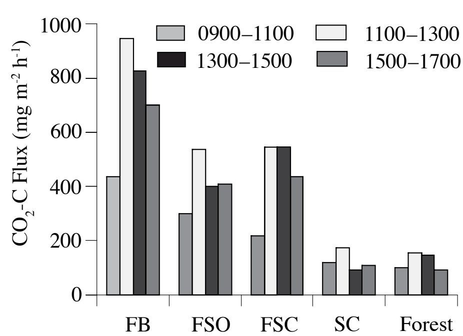

Figure 1. Daily variation of CO_2 emission measured from the study area

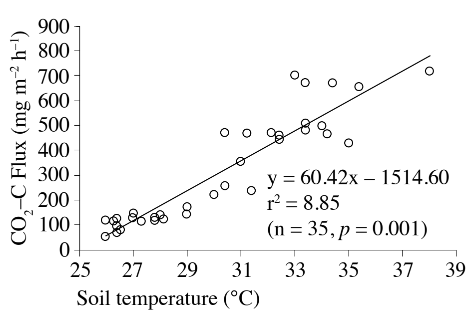

Figure 2. Relationship between soil temperature and soil CO_2 fluxes

significantly increased from 83.3 to 333.0 mg m^{-2} h^{-1}.

Effect of land clearing type on CO_2 flux

There were variations of CO_2 emission across the land clearing techniques. Changes in monthly CO_2 emission under different land clearing technique during the three-year measurement period was presented in *Figure 4*. Throughout the study period, the monthly CO_2 fluxes were highest in the FB followed by FSO and FSC. There was significant increase in the CO_2 flux in these three areas between June 2002 and March 2003. In FB the CO_2-C fluxes were 225, 356 and 700 mg m^{-2} h^{-1} for June 2002, October 2002 and March 2003, respectively. A two-fold increase in CO_2 emissions in FB was associated to a decrease in soil C pool caused by the burning processes during land clearing. There were no differences between monthly fluxes in FB from July 2003 to September 2004.

The emission of CO_2 in FSO and FSC was significantly lower compared to FB. The changes in monthly fluxes in FSO and FSC followed by similar pattern as in FB with the higher emission occurred about one year after land clearing (*Figure 4*). There was no significant difference in monthly fluxes of soil CO_2 between June 2002 and September 2004. In July 2003 higher fluxes were observed in FSO with the values of 507 mg m^{-2} h^{-1}.

Adopting FSO and FSC land clearing techniques were not the best option in reducing CO_2 emission since the loss of C still occurred through decomposition process of wood that have been chipped and stacked within the cleared area. The process is normally much faster under aerobic condition with the help of bacteria, fungi, actinomycetes and soil fauna (Craft 2001).

Among the four methods of land clearing, SC emitted the lowest CO_2

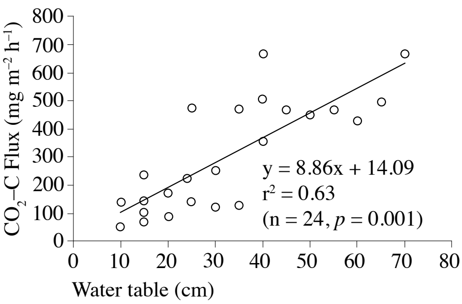

Figure 3. Relationship between water table depth and CO_2 fluxes

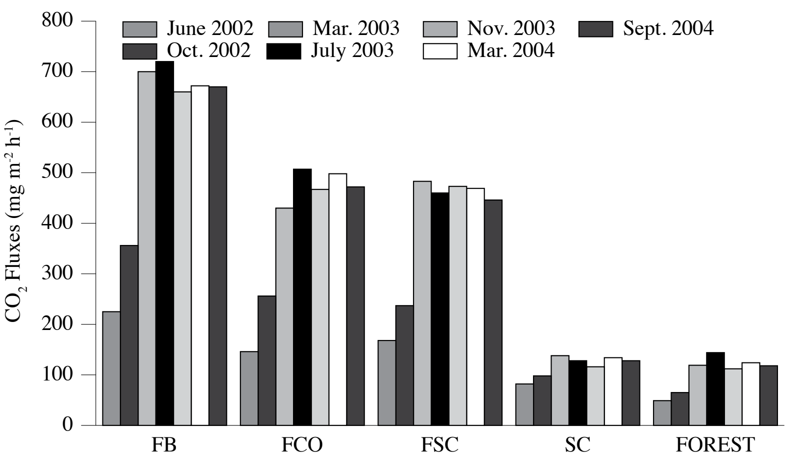

Figure 4. Changes in monthly CO_2-C emission under different land clearing techniques from 2002 to 2004
[Data represent means ± S.E (n = 3). Error bar indicate S.E. (standard error) of the mean]

Table 1. Estimated yearly CO_2 emission under different land clearing techniques

Land clearing technique	CO_2 Emission (mg C m^{-2} h^{-1})		
	2002 ± SE	2003 ± SE	2004 ± SE
FB	290a ± 29.54	693a ± 24.66	671a ± 33.92
FSO	201b ± 25.70	468b ± 18.84	485b ± 18.21
FSC	202b ± 16.35	472b ± 18.65	458b ± 23.06
SC	90c ± 10.09	127c ± 7.80	131c ± 10.74
Forest	57cd ± 8.47	123c ± 7.74	127c ± 5.20

Mean ± SE (Standard Error) with the same letters within column are not significantly different from each other at 5% level by LSD

Table 2. Estimated annual C loss under different land clearing techniques

Land clearing technique	Carbon loss (t/ha/year)
FB	48.3 ± 11.46
FSO	33.7 ± 8.06
FSC	33.0 ± 7.69
SC	10.2 ± 1.14
Forest	9.0 ± 1.98

emission. The CO_2-C fluxes ranged from 87 to 138 mg m^{-2} h^{-1}, which was comparable with the fluxes measured from the peat forest area. As expected, monthly emission of CO_2 from the forest soil surface was always lower than other land clearing technique throughout the monitoring period. In the forest, the fluxes ranged from 49 to 144 mg CO_2-C m^{-2} h^{-1}, with the lowest CO_2 flux was recorded in June 2002.

In the peatland ecosystems, forest hold large amount of C stocks in tree and organic material in the soil. Land clearing technique through burning would release C to the atmosphere as CO_2. Forest ecosystem also reacts as a C sink in which it absorbs CO_2 from the atmosphere and uses the C to produce plant tissue.

Annual patterns

Data in *Table 1* represents the estimated mean values of yearly emission calculated from monthly CO_2 flux. The mean of CO_2 fluxes were subjected to LSD test to test the significant effect of land clearing techniques on CO_2 emission. The yearly CO_2 emission in FB for 2002, 2003 and 2004 were significantly higher compared to other land clearing methods. The study showed that conventional methods of land clearing by burning contributed to the highest emission of CO_2 to the atmosphere. If the annual of C (9.0 t/ha/year) loss from the forest area is taken as a control *(Table 2)*, it was estimated that the C loss after land clearing in FB area was 39.3 t/ha/year. This contributed greatly to the largest increased in world atmospheric CO_2 in 1997 (Houghton 2001).

Land clearing methods using FSO and FSC significantly reduced the emission of CO_2. In FSO and FSC, the yearly flux ranged from 201 to 485 mg CO_2-C m^{-2} h^{-1} (*Table 1*) with the estimated annual C loss at 33.7 and 33.0 t/ha/year respectively. Yearly emissions of CO_2 from SC area are smaller compared to other land clearing methods. It ranged from 90 to 131 mg CO_2-C m^{-2} h^{-1}, or about 10.2 t/ha/year of C loss annually (*Table 2*). There were no significant differences between the yearly CO_2 flux at SC and forest.

The annual soil C loss of 9.0 t/ha/year for the forest ecosystem, was much lower to those observed by other researchers (Inubushi et al. 2003; Melling et al. 2005). CO_2 emission in drained and degraded peat swamp forest may range from 9–35 t/ha/year (Hadi et al. 2001; Jauhiainen et al. 2005). The different in the annual figure may reflect variation in hydrology and temperature regime of the given ecosystems.

Conclusion

The conventional methods of land clearing contributed to large amounts of C losses as CO_2. Land clearing techniques such as felling and stacking-outside the plot (FSO) and felling, stacking and chipping (FSC) reduced C loss, but the decomposition process of wood that have been chipped and stacked within the cleared area may have contributed to C loss. In felling and burning (FB), FSO and FSC, where there was no vegetation, CO_2 flux rates exhibited diurnal pattern that peaks at noon which mainly associated with the raise in soil temperate. Selective clearing technique seems to be the most appropriate method of land clearing which produces the lowest CO_2 flux compared to the other land clearing techniques.

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Abstrak

Pengukuran fluks CO_2 telah dijalankan di lima tempat di Stesen Penyelidikan Gambut MARDI, Sessang, Sarawak. Ia mewakili empat kaedah pembersihan tanah yang berbeza dikenali sebagai tebang dan bakar (FB), tebang dan kumpul luar plot (FSO), tebang, kumpul dan racik (FSC), dan pembersihan terpilih (SC). Pengukuran fluks CO_2 dilakukan dengan menggunakan keadah kebuk statik tertutup yang disambung terus kepada penganalisis mudah alih gas CO_2 infra merah. Fluks tanah CO_2 menunjukkan corak diurnal dengan kadar puncak pembebasan sehingga 950 mg CO_2 m^{-2} h^{-1} yang direkod pada waktu tengah hari. Pembebasan gas CO_2 mempunyai korelasi yang tinggi ($r^2 = 0.86$) dengan suhu tanah dan aras air ($r^2 = 0.63$). Fluks tahunan CO_2 yang dibebaskan dari tanah gambut berbeza mengikut kaedah pembersihan tanah. Anggaran tahunan tertinggi kehilangan karbon sebagai gas CO_2 ialah 48.3 t/ha/tahun dari kawasan FB. Kaedah pembersihan tanah secara FSO dan FSC dapat mengurangkan pelepasan gas CO_2 secara berkesan dengan anggaran tahunan dalam lingkungan 33 t/ha/tahun. Pelepasan tahunan dari kawasan SC adalah rendah berbanding dengan kaedah pembersihan tanah yang lain. Tidak ada perbezaan yang nyata antara kehilangan tahunan gas CO_2 dari kawasan SC dengan hutan.

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