Int.J.Curr.Res.Aca.Rev.2015; 3(6):88-96

International Journal of Current Research and Academic Review

ISSN: 2347-3215 Volume 3 Number 6 (June-2015) pp. 88-96

www.ijcrar.com

Carbon dioxide gas flux in inland peatland of Kalampangan, Sebangau District, Central Kalimantan, Indonesia

Herry Redin[1,2], Zaenal Kusuma[3], Roedy Sulistiyono[3] and Hakimah Halim[4]

[1]Postgraduate student, Faculty of Agriculture, Brawijaya University, Malang, Indonesia
[2]Faculty of Agriculture, Palangkaraya University, Indonesia
[3]Faculty of Agriculture, Brawijaya University, Malang, Indonesia
[4]Faculty of Agriculture, Lambung Mangkurat University, Banjarbaru, South Kalimantan, Indonesia

Corresponding author

KEYWORDS

Carbondioxide (CO_2) Gas flow, Inland peatland, Chamber method

A B S T R A C T

Living environmental problem recently considered by international world is climate change phenomenon, i.e. change in physical condition of earth atmosphere, such as temperature and rainfall distribution bringing extensive effect on various human life sectors. Findings of Intergovernmental Panel on Climate Change (IPCC) ensure that global climate change occurs since earth atmosphere isfilled green house gases, such as carbondioxide (CO_2), dinitrogen oxide (N_2O),methane (CH_4) and hydrocarbons, such as CFC. Gas can pass low temperature short wave radiation, but hold the hot long wave radiation. Consequently, earth atmosphere gets warmer with the rate equivalent to the increment rate of green house gaseous concentration in the atmosphere. According to IPPC (2001) report, during the 20th century, mean increment of earth surface temperature was 0.6±0.2^{o}C (Jauhiainen *et al.*, 2004). This study was aimed at (i) measuring CO_2 flux of the peatland in several types of Sebangau peatland usages, Central Kalimantan, and (ii) knowing the relationship between groundwater level and temperature with CO_2 emission release. Measurements of CO_2 flux was carried out in 4 types of petland usages, forest, shrub, plantationand agricultural area. CO_2 gas sampling inthe field used closed chamber method for soil surface. The gas samples were analyzed in the laboratory using an infrared CO_2 analyzer, and the measurement data were converted following Takakai *et al.* (2004). Observations were also conducted on water depth fluctuation, humidity, soil temperature as supporting data, and peatland description (depth and decomposition rate). Results showed that CO_2 flux of rubber plantation peatland surfacein Sebangau district was higher than other land usages. CO_2 flux of the peatland use ranged from 266.95 to 258.28 mg C $m^{-2}d^{-1}$ for corn, 225.15 to 210.42 mg C $m^{-2}d^{-1}$ for rectangular planting distance palm tree, 271.23 to 265.19 mg C $m^{-2}d^{-1}$ for palm tree and LCC, 234.29 to 215.10 mg C $m^{-2}d^{-1}$ for triangular planting distance palm tree, 255.37 to 233.76 mg C $m^{-2}d^{-1}$ for ferns, 435.33 to 422.37 mg C $m^{-2}d^{-1}$ for cajuputi, 483.15 to 455.38 mg C $m^{-2}d^{-1}$ for rubber, 268.95 to 256.28 mg C $m^{-2}d^{-1}$ for kale, 256.37 to 234.76 mg C $m^{-2}d^{-1}$ for long beans, 268.85 to 256.48 mg C $m^{-2}d^{-1}$ for green onion, and 265.95 to 254.38 mg C $m^{-2}d^{-1}$. The order of CO_2flux from the highest to the lowest wasas follows: rubber>cajuputi>palm treeand LCC>kale>green onion>corn>tomato>longbeans>ferns>triangular planting distance palm tree>rectangular planting distance palm tree.

Introduction

In connection with climate change issues, one of the human activities assumed to highly involve in green house gas supply is peatland clearance. Peatland is a highly valuable natural ecosystem since it holds living biodiversity and works as climate regulator and life reliance location of millions of people. Peatland clearance, excessive drainage, and frequent fires are assessed as green house gas emission contributors, such as CO_2, CH_4, and N_2O.

Hooijer *et al.* (2006) estimate that Indonesia peatland contributed 2000 Mega ton (Mt) of CO_2 per year of total CO_2 emission, 3000 Mt per year, that put Indonesia as the country of the thrid highest green house gas producer in the world after United States and China. Emission from non-peatland is estimated only about 500 Mt and from oil and gas burning about 500 Mt.

In natural condition, peat forest is net sink of carbon, but if the peats is cleared most carbon in the plant biomass will be oxidized to CO_2, especially if it is followed with combustion. Following the biomass combustion above the soil surface, several centimeters of peat layer will also be burnt. It the area is drained, the peatdehydration will increase CO_2 emission.

Various agricultural techniques like shrub burning above the peat in traditional agricultural activity and various soil management practice will be able to raise the emission rate of CO_2. Indonesia contribution to green house gas is either global problem or national problem that highly affects all orders of life.

Carbon emission data of peatland highly vary depending upon the peat characteristics and the environmental conditions. Thus, carbon emission measurements of various types of peatland utilization and different peat characteristics need to do in order to describe the carbon emission condition of the peatland. This study was aimed to (i) measure CO_2 flux of the peatland for several types of peatland utilization of Sebangau, Central Kalimantan, and (ii) know the relationship between the level of ground water and soil temperature and CO_2 emission.

Research method

The study was carried out in Juli–August, 2014, in Kalampangan, Sebangau District, Palangka Raya, Central Kalimantan. Carbondioxide analysis was done in the Laboratory of CIMTROP UNPARand soil analysis in Analytical Laboratory UNPAR. Field study was done in 3 types of peatland use, forest, shrub and agricultural area.

Materials used were those for soil and carbondioxide analyses. Equipment used were Chamber of 18.5, 19.5, 20.5, and 21 cm diameter, pipe, soil humidity measurer, syringe, standard CO_2 maker, CO_2 emission measurer, vacuum plastic, camera, stationary and other needs for field study.

Location selection was conducted in 3 types of peatland uses,forest, gardening, shrub, and agricultural area. It is located in Sebangau District, Palangka Raya, Central Kalimantan.

In 4 types of peatland uses, 3 plots of 1 x 1 m^2were firstly made to place the chamberand installed pipe with holes on the side part to measure the fluctuation of groundwater level.

Field sampling of CO_2gas sample used closed chamber method for CO_2gas collection above the soil. The CO_2gas samples removed from the chamber were coded. The sample collected was immediately analyzed in less than 24 hours after the gas sampling.

The gas samples were then taken to the laboratory for analysis using an infrared CO_2 analyzer (Fuji ZFP9GC11). Before measurements of CO_2 emission flux, standard CO_2 was firstly made for callibration and for the dillution of CO_2 gas taken from the pipe. The measurements were then converted using the calculation of Takakai *et al.*(2006) as follows:

$$F = \rho \times V/A \times \Delta c/\Delta t \times 273/(273 + T) \times \alpha$$

where:

F = CO_2 gas flux value (mg C m^{-2} d^{-1})
V = chamber volume (m^3)
A = bottom area of inner chamber (m^2)
ρ = CO_2 gas density (1.977x106 mg m^{-3})
$\Delta c/\Delta t$ = intermediate ratio per gas conssesion material in the chamber along collection time (m^3 m^{-3} d^{-1})
T = absolute temperature in the chamber (°C)
A = coversion factor of CO_2 to C (12/44)

Variable observed was CO_2gas flux from soil surface. In each observation, measurements of ground water level fluctuation, humidity, and soil temperature were also done. Data were then analyzed and presented in Tables and graphs.

Results and Discussion

General condition of peatland in the study site

The study site is located in Kalampangan, at the geographic position of $20^0$16’ 00” - $20^0$19’ 20” S and 113^0 58’ 20” - $114^0$03’ 50” E. This village administratively belongs to Sabangau district, Palangkaraya, Central Kalimantan Province. The distance of Kalampangan to the district capital is 3 km and to the provincial capital 17 km. Kalampangan has an area of 5,000 ha with flat topography (slantness of 0 – 3 %) and the altitude of 14 – 18 m above sea level.

The peatland in the study site is characterized with quartz layer. The thickness of peat layer is categorized as deep to very deep (organic layer thickness> 250 cm) with C-organic range between 39.26 – 66.43 %.Based on the findings of Bogor Agriculture Institute Team (1986), the peatland in Kalampangan area was classified as Tropohemist, with minerals under the peat as quartz sand. But based on the peat thickness criteria of Widjaja-Adhi (1988), the peat of Kalampangan is categorized as deep to very deep (>300 cm). Major peat material of Berengbengkel is dominated by wooden vegetation residues, but lower layer consist of herbaceous vegetation residues such as pandan and other aquatic grass (Morley, 1981).

The peatland of the study sites generally has relatively high acidity (pH 3-4). This acidity levfel is closely related with organic acid content, i.e. humic acid and fulvic acid (Andriesse, 1974; Miller and Donahue, 1990). The decomposed organic matters have carboxyl reactive group and phenol of weak acid.

Peatland in the study site generally possesses varied alkaline content of Calcium (Ca) and Potassium (K). Ca and K content ranged from 1.56 to 5.38 me Ca/100 g and 0.07 to 0.59 me K/100 g, respectively.

Organic carbon ranged from 2.58 to 38.15 %. The highest organic C was recorded in the peatland of cajuputi natural forest, while the lowest was in the peatland of corn plantation.

Total N content of the peatland of all study sites ranged from 0.18 to 0.61 %. As a whole, total N of kale plantation peatland is the highest and cajuputi natural peatland is the lowest. In peatland, total N content is classified as low to high followed with high N availability for plants.

This availability is affected by some factors, one of which is high C/N ratio (C/N > 30) causing N produced from mineralization process be mobilized by microorganisms for their living needs. C/N content in the peatland varied with location (14–69). As awhole, the highest C/N content in the peatland occurred in the peatland of palm plantation with triangular planting distancesand the lowest in the peatland of cajuputi natural forest. Organic matters in the peatland ranged from 4.46 to 66.00 %. The highest organic matter was found in the peatland of corn plantation and the lowest in cajuputi natural forest.

CO_2 flux of peatland surface in various types of land usages

Based on peatland surface CO_2 gas measurements of various land usages (Table 1), it was found that CO_2 flux in natural forest peatland was higher than that in other peatland usages (Fig. 1). CO_2 flux in corn plantation ranged from 186.89 to 261.13 mg C $m^{-2}d^{-1}$, 165.48 to 230.95 mg C $m^{-2}d^{-1}$ for intercropping plantation, in natural forest 408.63 to 520.32 mg C $m^{-2}d^{-1}$, and for shrub from 214.32 to 257.54 mg C $m^{-2}d^{-1}$.

Therefore, in general, the order of CO_2 flux from the highest to the lowest is natural forest peatland> shrub>corn>intercropping. It could result from that there are many fresh litters being decomposed in natural forest peats and addition of CO_2 from forest vegetation roots.

Table 1 and figure 1 show that CO_2flux measurements in various types of peatland surface utilizations of Sebangau district rubber plantation are higher than other land usages, while the lowest is found in the palm tree plantation of rectangular planting distance. CO_2 flux measurements ranged from 266.95 – 258.28 mg C $m^{-2}d^{-1}$ for corn, 225.15 – 210.42 mg C $m^{-2}d^{-1}$, palm tree of rectangular planting distance, 271.23 – 265.19 mg C $m^{-2}d^{-1}$ for palm tree and LCC, 234.29 – 215.10 mg C m^{-2} hr^{-1} for palm tree of triangular planting distance, 255.37 – 233.76 mg C $m^{-2}d^{-1}$ for ferns, 435.33 – 422.37 mg C m^{-2} hr^{-1} for cajuputi, 483.15 – 455.38 mg C $m^{-2}d^{-1}$ for rubber, 268.95 – 256.28 mg C m^{-2} hr^{-1} for kale, 256.37 – 234.76 mg C $m^{-2}d^{-1}$ for long beans, 268.85 – 256.48 mg C $m^{-2}d^{-1}$ for green onion, and 265.95–254.38 mg C $m^{-2}d^{-1}$.

The order of CO_2flux from the highest to the lowest isrubber>Cajuputi>palm treeand LCC >kale>green onion>corn>tomato>long beans>Ferns>palm tree of triangular planting distance>palm tree of rectangular planting distance.

Positive correlation is shown as follows

1) Between air temperature and 4 cm-soil temperature, 10 cm-soil temperature, soil humidity and flux
2) Temperature of 4 cm-soil and 10 cm-soil temperature, soil humidity, groundwater level and flux
3) Temperature of 10 cm-soil temperature and soil humidity, groundwater level and flux
4) Soil humidity and groundwater level and flux
5) Groundwater level and sunlight and flux

Negative correlation is shown between

1) Air temperature and groundwater level and sunlight
2) Temperature of 4 cm-soil, 10 cm-soil and soil humidity with sunlight
3) Sunlight and flux

The palm tree of rectangular planting distance is highly influenced by air temperature positively correlated with 4 cm-soil temperature, 10 cm-soil temperature, soil humidity, groundwater level, sunlight, and eventually affects the flux (Table 2). Rumbang *et al.* (2009) stated that the amount of CO2 emission released by the peatland was influenced by environmental factors, such as groundwater level, air temperature and soil temperature. It is affected by peat characteristics as well, such as peat pH, KPK and organic C content.

In palm tree of rectangular planting distance, air temperature is negatively correlated with the groundwater level and sunlight, in which increased air temperature will reduce the groundwater level, even though air temperature could also be positively correlated with sunlight, but because of other factors, such as wind, the correlation becomes negative (Table 2). Moreover, soil temperature will influence the flux if data measurements are continuously done. Hirano *et al.* (2009) uttered that length of solar radiation and canopy condition will affect soil temperature. Correlation between carbon flow and temperature was found in tropical peats using 4 years of monitoring data in an open area and forest at the temperature of 24^{o}C to 29°C. Brady (1997) also found that CO_2 emission level of Sumatera tropical peatland surface incubation was two times higher at the temperature between 25 ^{o}C and 35 ^{o}C.

This study found that mean emission ± standard deviation (SD) released was 218.12 ± 7.39 mg $Cm^{-1}y^{-1}$ from rectangular palm tree plantation with emission range (max ± min) of 225.15 ± 210.42 mg $Cm^{-1}y^{-1}$ (Table 1 and Fig. 1). Based on Rumbang *et al.* (2009), carbondioxide emission released from the palm tree plantation was 97 mg $Cm^{-2}h^{-1}$.

CO_2 emission released by the peatland also has correlation with environmental factors, particularly air temperature and soil temperature. The effect of air temperature on CO_2 emission could result from the different canopy size affecting the air temperature under the canopy. Increase in CO_2 emisiion could also come from root respiration. On the other hand, plant type and age influence the amount of root respiration. Jauhiainen *et al.* (2004) demonstrated that the contribution of root respiration reached 21% of total CO_2 emission acacia plantation grown in the peatland in Jambi.

Rubber

Positive correlation is shown between

1) air temperature and 4 cm-soil temperature, 10 cm-soil temperature, soil humidity and groundwater level.
2) Temperature of 4 cm-soil and 10 cm-soil, soil humidity and groundwater level.
3) Temperature of 10 cm-soil and soil humidity and groundwater level
4) Soil humidity and grounwater level
5) Sunlight and flux

While negative correlation is shown between

1) Air temperature and sunlight and flux

2) Temperature of 4 cm-soil, 10 cm-soil temperature, soil humidity, grounwater level and sunlight and flux.

In rubber plantation, the canopy factor was highly dominant, so that it will inhibit the sunlight, but air temperature will positively correlate with 4 cm-soil temperature, 10 cm-soil temperature, soil humidity, groundwater level and sunlight which eventuallyraise the flux due to increased microorganism activity in the soil (Table 3).

In this study, it was found that mean emission ± standard deviation (SD) released was the highest from the rubber plantation area, 467.75 ± 14.14 $mgCm^{-1}y^{-1}$, while the releasable emission range emisi (max ± min) was 483.15 ± 455.36 $mgCm^{-1}y^{-1}$(Table 1 and Fig. 1). Based on Rumbang *et al.* (2009), carbondioxide emission released from the rubberplantation was122 $mgCm^{-2}h^{-1}$.

Rumbang *et al.* (2009) elucidated that the extent of CO_2 emission released by the peatland was affected byenvironmental factors, such as depth of groundwater level, air temperature, and soil temperature. CO_2 emssion released by the peatland has correlation with environmental factors as well, especially air and soil temperature. Moreover, difference in either canopy numbers or size influences the air temperature under the canopy and affect the soil temperature. Also, soil temperature of the rubber plant is lower than that of food plant area. In spite of low soil temperature in rubber plant area, the CO_2 emission is higher, because CO_2 emission from the peatland does not only come from the microorganism activity in decomposition process, but from root respiration as well.Plant type and age affect the amount of root respiration. It is assumed that CO_2 emission originated from the root respiration in rubber area sufficiently contributes to the amount of CO_2 emission released by the peatland.

Air temperature is negatively correlated with sunlight and flux in rubber plantation, and could result from canopy/areal shade factor. Low light reaching the soil surface causes 4 cm-soil temperature is negatively correlated with 10 cm-soil temperature, soil humidity, groundwater level and sunlight that eventually reduces the flux (Table 3).

Soil temperature will affect the flux rate if data measurements are continuously done. Hirano *et al.* (2009) uttered that duration of solar radiation and canopy condition will influence the soil temperature. The relationship of carbon flow and temperature is obvious for tropical peats using 4 years of data monitoring in the open area and forest at temperature range of 24^oC–29°C. It was also supported by Brady (1997) that CO_2 emission rate of Sumatera tropical peat surface incubation samples in was also found twice higher at the temperature between 25^oC and 35^oC.

Conclusion

1. CO_2 gas flux from the peatland surface of Sebangau district used for rubber cultivation was higher than other land usages. CO_2 flux measurements in the peatland uses ranged from 266.95 to 258.28 mg C $m^{-2}d^{-1}$ for corn, 225.15 to 210.42 mg C $m^{-2}d^{-1}$ for rectangular planting distance of palm tree, and 271.23 to 265.19 mg C $m^{-2}d^{-1}$ for LCC, 234.29 to 215.10 mg C $m^{-2}d^{-1}$ for triangular planting distance of palm tree, 255.37 to 233.76 mg C $m^{-2}d^{-1}$ for ferns, 435.33 to 422.37 mg C $m^{-2}d^{-1}$ for cajuputi, 483.15 to 455.38 mg C $m^{-2}d^{-1}$ for rubber, 268.95 to 256.28 mg C $m^{-2}d^{-1}$ for kale, 256.37 to 234.76 mg C $m^{-2}d^{-1}$ for long beans,

268.85 to 256.48 mg C $m^{-2}d^{-1}$ for green onion, and 265.95 to 254.38 mg C $m^{-2}d^{-1}$ for tomato, respectively. The order of CO_2 flux from the highest to the lowest was as follows: rubber>cajuputi>palm treeand LCC >kale>green onion>corn>tomato>long beans>fern>triangular planting distance palm tree>rectangular planting distance palm tree.

2. CO_2 flux released from various types of peatland usage was highly influenced by planting distance, canopy and other environmental factors, such as air temperature, soil temperature, humidity, ground water level, and sunlight. It was also affected by nutrient enrichment (fertilizer) to plants.

3. Type and age of plants will also affect CO_2 flux. Perennial crops certainly have strong rooting system and many roots, so that carbondioxide emission will go out through root respiration.

Recommendation

Based on these findings, this study suggests further studies on CO_2 contribution from root respiration of several vegetation types above.

Table.1 Soil chemical analytical data

	corn	Rectangular palm tree	palm and LCC	Triangular palm tree	Ferns	Cajuputi	rubber	kale	Long beans	Green onion	tomato
Organic C (%)	9.24	2.58	38.15	3.67	31.33	9.01	8.82	31.74	31.62	30.23	32.09
Total N (%)	0.24	0.18	0.55	0.24	0.47	0.48	0.34	0.61	0.55	0.53	0.58
C/N	38	14	69	16	66	19	26	52	58	57	55
Organic matter(%)	15.99	4.46	66.00	6.35	54.20	15.59	15.25	54.91	54.70	52.29	55.51
K (me/100g)	0.26	0.13	0.59	0.24	0.19	0.15	0.15	0.55	0.14	0.07	0.47
Ca (me/100g)	5.38	2.88	1.68	4.88	1.89	2.35	2.44	2.06	1.56	2.63	2.88

Table.2 CO_2 flux of various types of land utilization

	corn*)	Rectangular palm tree*)	Palm and LCC*)	Triangular palm tree*)	Ferns*)	Cajuputi*)	rubber*)	kale*)	Long beans*)	Green pnopn*)	tomato*)
rata-rata	261.20	218.12	267.44	227.13	247.33	428.17	467.75	261.54	248.66	263.15	258.87
SD	4.97	7.39	3.30	10.48	11.82	6.59	14.14	6.60	12.06	6.25	6.20
Min	258.28	210.42	265.19	215.10	233.76	422.37	455.36	256.28	234.76	256.46	254.38
Max	266.95	225.15	271.23	234.29	255.37	435.33	483.15	268.95	256.37	268.85	265.95

)carbondioxide emission unit(mgCm^{-2}y^{-1})

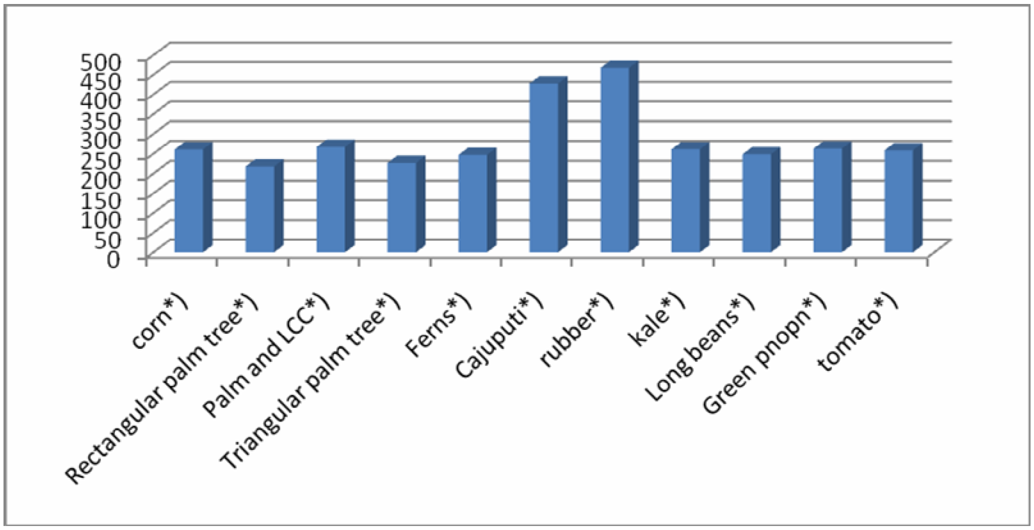
Table.3 Correlation test among research variables in rectangular plants

	Air temperature	4 cm-Soil temperature	10 cm-Soil temperature	pH H2O	C/N	Soil humidity	ground water level	sunlight	Bacterial microbe	Fungi microber	rate (flux)
Air temperature	-										
4cm-soil temperature	0,841	-									
10 cm-soil temperature	0,614	0,944	-								
pH H2O	-	-	-	-							
C/N	-	-	-	-	-						
Soil humidity	0,489	0,883	0,989	-	-	-					
Groundwater level	-0,249	0,315	0,611	-	-	0,723	-				
Sunlight	-0,978	-0,935	-0,766	-	-	-0,661	0,041	-			
Bacterial microbe	-	-	-	-	-	-	-	-	-		
Fungi microbe	-	-	-	-	-	-	-	-	-	-	
rate (flux)	0,382	0,822	0,964	-	-	0,993	0,800	-0,567	-	-	-

Table.4 Correlation test among research variables in rubber plant

	Airtempe-rature	Soil tempera-ture 4cm	Soil temperature 10 cm	pH H2O	C/N	Soil humidity	Groundwater level	Sunlight	Bacterial microbes	Fungi microbes	rate (flux)
Air temperature	-										
4 cm-Soil temperature	0,776	-									
10 cm-Soil temperature	0,679	0,064	-								
pH H2O	-	-	-	-							
C/N	-	-	-	-	-						
Soil humidity	0,767	1,000	0,049	-	-	-					
Groundwater level	0,864	0,988	0,217	-	-	0,986	-				
Sunlight	-0,992	-0,688	-0,768	-	-	-0,678	-0,792	-			
Bacterial microbe	-	-	-	-	-	-	-	-	-		
Fungi microbe	-	-	-	-	-	-	-	-	-	-	
rate (flux)	-0,993	-0,698	-0,759	-	-	-0,688	-0,800	1,000	-	-	-

Figure.1 Carbondioxide emission from various types of land usage



References

Andriesse, J.P. 1974. Tropical peats in South East Asia. Dept.of Agric. Res of the Royal Trop. Inst. Comm., 63. Amsterdam. 63 Pp.

Brady, M. 1997. Organic matter dynamics of coastal peat deposits in Sumatra, Indonesia PhD-Thesis. 258 Pp.

Brady, M.A. 1997. Effects of vegetation changes on organic matter dynamics in three coastal peat deposits in Sumatra, Indonesia. In: J. O. Rieley and S. E. Page (Eds). Biodiversity and Sustainability of Tropical Peatlands. Samara Publishing Limitted, Cardigan, UK.

Hirano, T., Jauhiainen, J., Inoue, T., Takahashi, H. 2009. Controls on carbon balance of tropical peatlans. *Ecosystem*, 12: 873–887.

Hirano, T., Jauhiainen, J., Inoue, T., Takahashi, H. 2009. Controls on the carbon balance of tropical peatlands. *Ecosystem*, 12: 873–887.

Jauhiainen, J., Vasander, H., Jaya, A., Inoue, T., Heikkinen, J., Martikainen, P. 2004. Carbon balance in managed tropical peat in Central Kalimantan, Indonesia. Dalam: Päivänen, J. (Ed.). Wise use of peatlands. Proceeding of the 12th International Peat Congress. Tampere, Finland. Publisher International Peat Society, Vapaudenkatu, Jyväskylä, Finland. Pp. 653–658.

Miller, M.H., Donahue, R.L. 1990. Soils. An introduction to soils and plant growth. Prentice Hall Englewood Cliffs, New Jersey. 768 Pp.

Morley, R.J. 1981. Development and vegetation dynamics of a lowland ombrogenous peat swamp in Kalimantan Tengah, Indonesia. *J. Biogeogr.*, 8: 383–404.

Takakai, F., Morishita, T., Hashidoko, Y., Darung, U., Kuramochi, K., Dohong, S., Limin, S.H., Hatano, R. 2006. Effects of agricultural land-use change and forest fire on N_2O emission from tropical peatlands, Central Kalimantan, Indonesia. *Soil Sci. Plant Nutr.*, 52: 662–674.

Widjaja-Adhi, IP. G. 1988. Physical and chemical characteristic of peat soil of Indonesia. *IARD J.*, 10: 59 – 64.