

Carbon mineralization dynamics of tropical peats in relation to peat characteristics

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Manuscript received: 15 November 2018. Revision accepted: 30 June 2018.

Abstract. Saidy AR, Mariana ZT, Adji FA, Nusantara RW, Fitria I, Syahrudin. 2018. Carbon mineralization dynamics of tropical peats in relation to peat characteristics. *Biodiversitas* 19: 1413-1421. Understanding the dynamics of carbon mineralization of peats in the tropical areas is of essential significance in controlling carbon dioxide (CO₂) gas emission rates. An incubation study of tropical peats sampled from 3 different sites of the Barito Basin on the Borneo Island, Indonesia (uncultivated, used for paddy cultivation for ≤ 5 years and 5-10 years) was carried out to investigate a relationship between CO₂ production and peat characteristics. Results of study revealed that land use change from uncultivated peats to paddy fields resulted in significant changes in the chemical structure of peat organic carbon. Carbohydrate contents of the peat decreased significantly as a consequence of the conversion of natural peats to paddy fields. However, the paddy peats contained higher lignin than uncultivated peats. Changes in the chemical structure of the tropical peats resulted in changes in carbon mineralization. Carbon mineralization of uncultivated peats ranged from 2925–5310 mg CO₂-C kg⁻¹ peat, while carbon mineralization of 1065–2678 mg CO₂-C kg⁻¹ C peat was observed for paddy peats. Moreover, carbon mineralization data obtained from the experiment fitted properly to a two-pool C mineralization model. The developed carbon mineralization model showed that slowly and rapidly decomposable pools have a close relation with rubbed fiber and carbohydrate content data. Thus, results of this study suggested that carbon mineralization of peats could be estimated appropriately using rubbed fiber and carbohydrate content data.

Keywords: Carbohydrate, carbon structure, greenhouse gas fluxes, lignin, peat characteristics

INTRODUCTION

Carbon mineralization results in emission of carbon dioxide (CO₂) to the atmosphere that finally influence the process of global climate change which is receiving substantial attention recently due to its significant effect on agriculture, health, and infrastructure. Data of the World Bank (2007) showed that Indonesia, with the total emission of 3,014 Gt CO₂e per year, is the third largest emitter of carbon dioxide after the United States and the People's Republic of China. Out of the total CO₂ emission, 772 Mt CO₂e or 38% originated from peat decomposition, and this represents 58% of the total CO₂ emissions from world' peatland (Indonesian National Council on Climate Change 2010).

Extent of tropical peatlands in Indonesia, which cover approximately 10% of the wetlands on the islands of Sumatra and Borneo, is estimated to be ranging from 16.8 to 27.0 million hectares (Page and Banks 2007). Carbon stored in these peatlands is approximately 55 Gt (Jaenicke et al. 2008). National action for the reduction of greenhouse gas emissions (GHG) in Indonesia, as outlined in the Presidential Regulation No. 61 of Year 2011, stated

that Indonesia requires to reduce GHG emissions by 0.672 Gt CO₂e from peat and forest decomposition to achieve the target of 26% reduction or by 1,049 Gt CO₂e to achieve the reduction target of 41%. Therefore, methods of measuring carbon mineralization or models to estimate carbon dioxide emissions from peatlands are required for monitoring and evaluation of this GHG emission reduction.

The amounts of CO₂ produced during carbon mineralization from peatlands are generally calculated by direct field measurements (i.e., Wright et al. 2011; Hadi et al. 2012; Hatala et al. 2012). However, this method is very time consuming and the results obtained varied widely for different sites. Potential carbon mineralization of peats is also estimated from the amount of peat mass (carbon stock) (Page et al. 2002; Chapman et al. 2009; Holden and Connolly 2011). This method generally resulted in an overestimate of carbon mineralization because it is based on an unrealistic assumption that all organic carbon present in the peats decomposed completely. Another method that is more acceptable to the researchers and environmentalists is the use of carbon mineralization model to estimate carbon emission using inputs of peat characteristics such as hydrology, temperature and chemical composition of peat

(van Huissteden et al. 2006; Humphreys and Arora 2010; Jaenicke et al. 2010). However, most existing models are developed using non-tropical peats, thus validating these models for tropical peat is incomprehensible because of the unavailability of input parameters from tropical peats and also the complexity of tropical peatland ecosystems. Therefore, the study aimed to develop a carbon mineralization model to estimate carbon dioxide production using characteristics of tropical peats with different land-uses was undertaken.

MATERIALS AND METHODS

Peat sampling and analysis

Peats were sampled from sites within the Barito Basin on the Borneo Island, Indonesia. Eleven peat samples were collected from different sites, namely Marabahan, Pulau Damar, Bayur, and Gambut. These sites were selected based on the presence of extensive areas of tropical peatlands in the South Kalimantan Province, and they also covered peats with different land-uses ranging from uncultivated peats to peats cultivated with rice for 15 years (Abdullah, 1997). Peat soils at the Marabahan site were used for rice field for ≤ 5 years, while peat soils at the Gambut site were used for rice cultivation for 10-15 years. All peats sampled from Pulau Damar sites have not been used for any cultivation. Peats from Bayur site were sampled from different land-uses: uncultivated peats, rice field for varied years (≤ 5 years and 10-15 years). The peat soils within the Barito Basin were characterized by an irregular complex of poorly decomposed woody and grass materials to a depth of at least 2 m (Hadi and Inusbushi 2000).

A composite peat sample was collected from the 0-20 cm layer at each site, using a cylindrical core (10 cm diameter). Living plant material was selectively removed from the collected samples by hand, and the samples were thoroughly homogenized and stored in polyethylene containers at 5°C. To minimize the effect of physical factors on decomposition, the peats samples were dried at 30°C in the oven and then cut and ground to < 0.25 mm size before characterization and incubation. The peat samples were analyzed for bulk and particle density (Blake and Hartge 1986), ash content (Karam 1993), and the degree of decomposition by the von Post index, pyrophosphate index and rubbed fiber content (Parent and Caron 1993). Peat pH was determined in soil solution (volume of soil: volume of water = 3 : 50) using a glass electrode (Parent and Caron 1993). Total carbon and nitrogen were determined on a LECO CN2000 analyzer. Carbohydrate and lignin contents of the peats were measured using the method of Grandy et al. (2000) and Chesson (1991), respectively.

Incubation experiment

Carbon mineralization of peats experiencing different physicochemical characteristics was tested by determining the amount of carbon produced by microbial decomposition of organic carbon contained in the peats during the course of a 110-day long incubation experiment.

An appropriate mass of each peat sample (5.90 to 11.60 g fresh peat, depending on the bulk density (BD) of peats) was placed into a PVC tube of radius 1.95 cm covered with a mesh at the bottom, to give a depth of 20 mm after compacting the peats to a bulk density similar to that observed in the field. Distilled water was added to each PVC tube to reach 70% water-filled pore space (WFPS). The PVC tubes were then moved into 1 L Mason jars having 5 mL deionized water in a 20 mL plastic vial to maintain humidity. The jars were sealed with air-tight lids with rubber septa to allow sampling of gas from the jars and incubated in the dark for 110 days. For each peat, three replicate samples were prepared and incubated.

Carbon mineralization was measured by drawing 10 mL of headspace gas from each jar using a 10 mL syringe through the septum in the middle of the lid, the collected gas was transferred to a 10 mL air-tight glass vial, and then injected onto a gas chromatograph (Shimadzu GC-14A). Carbon mineralization was determined repeatedly for each sample at different time intervals during the entire incubation period. The initial measurement was conducted on the third day after the beginning of the incubation and subsequent measurements were carried out on a weekly basis. Every time, two measurements were conducted for each peat sample. The first measurement of CO₂ concentration in the jar was done immediately after closing the jars and the second measurement was performed after the completion of the specified incubation time. All jars were opened for three hours to allow the replacement of the CO₂-enriched air inside the jars with fresh air after each measurement. The concentration of CO₂ produced from each sample for each measurement was determined by calculating the difference between initial and final CO₂ concentrations. The total carbon dioxide produced from each sample during the entire incubation period of 110 days was given by the sum of carbon dioxide released from each sample for each measurement and it is expressed as the cumulative carbon mineralization.

Model fitting and statistical analysis

Data of cumulative carbon mineralization was then fitted to a two-pool C mineralization model, consisting of rapidly and slowly decomposing pools (equation 1):

$$C_t = C_s(1 - e^{-st}) + C_f(1 - e^{-ft}) \quad [1]$$

where: C_t is the sum of amount of C mineralization (mg CO₂-C kg⁻¹ of peat) by time t ; C_s and C_f are the sizes of slow and fast pools of mineralizable C (mg CO₂-C kg⁻¹ of peat), respectively; and s and f are the corresponding mineralization rate constants for the slow and fast pools (day⁻¹). The amount of CO₂-C production data were fitted to the model using the least-square non-linear curve fitting procedure in Microsoft Excel® (de Levie 2001). The values of C_s , C_f , s , and f that produced the smallest residual sums of squares (RSS) were retained.

Analysis of variance (ANOVA) was performed to determine differences in the carbohydrate content, lignin content and cumulative carbon mineralization of each peat, after the normality and the homogeneity was checked using

the Shapiro-Wilk and Bartlett tests, respectively. In the case of significance in the ANOVAs, the effect of treatments was compared by the Least Significant Difference (LSD) multiple comparison procedure at $P < 0.05$. Correlation and regression analysis between the carbon mineralization of peat and the variables of peat characteristics was performed to examine relationship between the carbon mineralization and the peat characteristics. All statistical procedures were conducted using the GenStat 11th Edition (Payne 2008).

Development of carbon mineralization model based on the peat characteristics

After fitting the data of carbon mineralization with a two-pool C mineralization model (equation 1), a simple regression analysis was conducted to establish the equations to estimate the size of rapidly and slowly mineralizable pools based on the chemical composition of the peats:

$$C_s = f(\text{chemical composition of peats}_{(\text{slow})}) \quad [2]$$

$$C_f = f(\text{chemical composition of peats}_{(\text{rapidly})}) \quad [3]$$

Equation (2) and (3) were then combined to establish an equation to predict the amount of carbon mineralized (C_t) based the two-pool C mineralization model as a function of changes in the chemical composition of the peats.

$$C_t = f(\text{chemical composition of peats}_{(\text{slow})}) (1 - e^{-st}) + f(\text{chemical composition of peats}_{(\text{rapidly})}) (1 - e^{-ft}) \quad [4]$$

The amount of carbon mineralized during the incubation period was then calculated using the equation (4) and then the results were compared with those obtained from the conducted-incubation study in the laboratory.

RESULTS AND DISCUSSION

Characterization and chemical composition of tropical peats

As shown in Table 1, the peats used in this experiment represented different degree of decomposition (low, moderate and high) based on the von Post's index and

rubbed fiber content (McKinzie 1974; Parent and Caron 1993). Bulk density of the peats ranged from 0.14 to 0.26 Mg m^{-3} , in which increase in the degree of peat decomposition led to increase in bulk density (Table 1). Reaction (pH) of peats is also likely to change with changes in the degree of peat decomposition. Peat representing low degree of decomposition had higher pH compared to the peats representing moderate and high degree of decomposition (Table 1).

Organic carbon (OC) content of the peats used in this study ranged from 287 to 774 g C kg^{-1} peat (Table 1), in which increase in the degree of peat decomposition reduced the OC content. Peat with a high degree of decomposition would have longer microbial decomposition process than the peats with a low degree of decomposition. As a result, the OC content of peats decreased with increasing the degree of peat decomposition. Results of this study are in agreement with Lampela et al. (2014) who reported that C content of peats sampled from tropical peat swamp forest of the Central Borneo has a significant correlation with the von Post degree of decomposition and the unrubbed fiber content. Similar to the OC content, total nitrogen (N) content of the peat also varied with the degree of peat decomposition. Nitrogen content of all peats varied from 9.2 to 37.7 g N kg^{-1} peat (Table 1). The combination of changes in OC and N content of peats with shift in the degree of peat decomposition resulted in lower C/N ratio in peats with high degree of decomposition than those with low degree of decomposition (Table 1).

Land use change from uncultivated peats to paddy fields resulted in significant changes in the chemical structure of carbon in the peats. Carbohydrate content of uncultivated peats (B-01, PD-01, PD-08, and PD-12) ranged from 25% to 33%. It decreased significantly to 18-22% in the peats cultivated with rice for over 5 years (B-03, B-12, M-02 and M-07), and further decreased to 16-20% in the peats cultivated with rice for 10-15 years (B-05, G-03, G-07) (Figure 1). In contrast to carbohydrate contents, land-use changes from uncultivated peats to cultivated peats for agriculture increased lignin contents. Lignin contents increased from 14-20% in uncultivated peats to 19-22% in the peats cultivated with rice for 5 years, and increased consequently to 24-34% in the peats cultivated with rice for 10-15 years (Figure 2).

Table 1. Properties of tropical peats used for study

Peat sample	Peat land-uses	Degree of decomposition			pH (H ₂ O)	BD (Mg m ⁻³)	Organic C (g C kg ⁻¹)	Total N (g N kg ⁻¹)	C/N Ratio	Ash content (g ash kg ⁻¹)
		von Post	Rubbed (%)	Index P (%)						
B-01	Uncultivated	H7	44	29.89	5.33	0.30	286.7	17.4	16.48	440
PD-01	Uncultivated	H7	32	34.87	4.14	0.18	774.2	34.5	22.47	150
PD-08	Uncultivated	H6	44	24.32	5.34	0.14	572.9	32.3	17.71	33
PD-12	Uncultivated	H2	57	21.45	5.42	0.16	749.9	37.7	19.91	194
B-03	Rice field (≤ 5 years)	H6	26	69.87	3.37	0.26	614.9	17.6	35.02	93
B-12	Rice field (≤ 5 years)	H6	27	65.78	3.65	0.29	409.8	19.9	20.59	253
M-02	Rice field (≤ 5 years)	H8	28	66.78	3.52	0.19	605.1	17.7	26.80	338
M-07	Rice field (≤ 5 years)	H2	28	45.66	3.67	0.15	667.5	25.5	26.18	211
B-05	Rice field (5-10 years)	H4	24	72.54	3.44	0.21	586.0	17.4	33.68	387
G-03	Rice field (5-10 years)	H3	18	78.23	3.34	0.16	565.0	14.6	38.80	47
G-07	Rice field (5-10 years)	H5	10	95.18	4.25	0.16	473.0	9.2	51.25	479

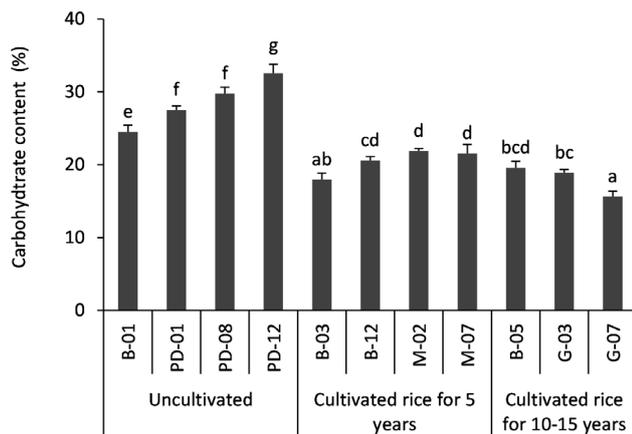


Figure 1. Carbohydrate contents of tropical peats. The vertical bars indicate standard deviation of mean ($n=3$) and similar letters above columns indicate no statistical difference between peats based on the LSD test at $P<0.05$.

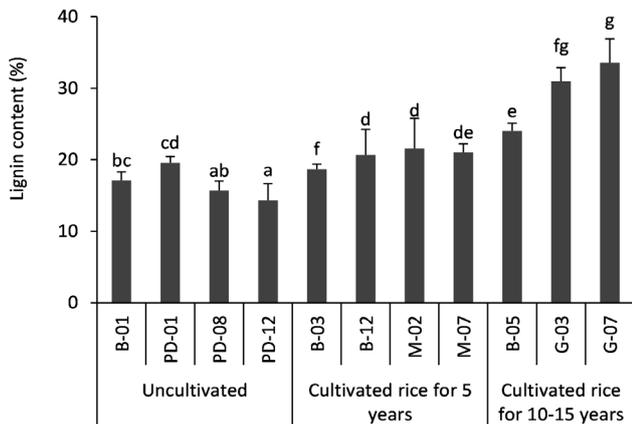


Figure 2. Lignin contents of tropical peats. The vertical bars indicate standard deviation of mean ($n=3$) and similar letters above columns indicate no statistical difference between peats based on the LSD test at $P<0.05$.

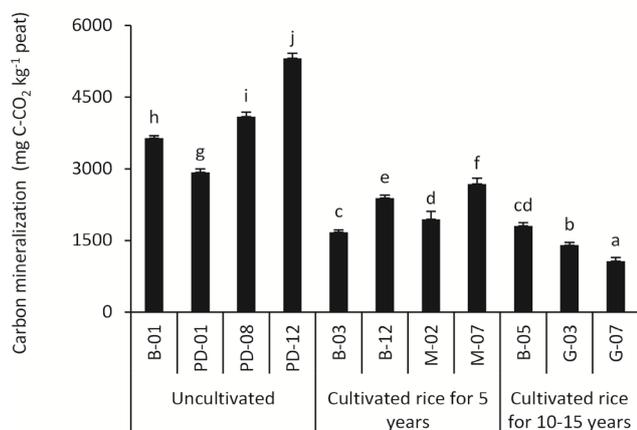


Figure 3. Cumulative carbon mineralization of tropical peats during a 110-day incubation period. The vertical bars indicate standard deviation of mean ($n=3$) and similar letters above columns indicate no statistical difference between peats based on the LSD test at $P<0.05$.

Changes in the chemical composition of peats with changes in land-use are attributed to faster oxidation process of cultivated-peats than that of uncultivated-peats. Drainage system of cultivated-peats resulted in lowering water table within peat profile with the consequence of a faster aerobic decomposition of organic carbon with O-alkyl C structure (carbohydrate) and the accumulation of the compounds with alkyl C structure (lignin) (Saidy et al. 2005). This is in agreement with the concept of decomposition proposed by Baldock et al. (1992) who suggested that decomposition of organic matter starts by utilizing the easily decomposable substrates such as carbohydrate by soil microorganisms. Decrease in carbohydrate content during the initial phase of organic matter decomposition is also in agreement with (Derrien et al. 2007) who observed that that carbohydrate decomposed rapidly during the initial biodegradation.

Decreases in the proportion of organic carbon in the form of carbohydrates (O-alkyl C structures) and increased lignin (alkyl C structures) result in increased O-alkyl C to alkyl C ratio, with change in land use from the uncultivated peats to rice cultivated-peats. Changes in the ratio of O-alkyl C to alkyl C has been suggested to be useful as an indicator of the degree of peat decomposition (Baldock et al., 1997; Baldock et al., 1992), in which increase in the ratio of O-alkyl C to alkyl C indicates increase in the degree of peat decomposition. In this experiment, increase in the ratio of O-alkyl C to alkyl C of the peats is consistent with the data of fiber content and pyrophosphate index which states that the degree of peat decomposition increased with changes in land use from the uncultivated peats to the rice cultivated-peats (Table 1).

Carbon mineralization of peats

Land-use changes in peatlands from uncultivated peats to reclaimed-peats for paddy fields also caused changes in the carbon mineralization of peats (Figure 3). Carbon mineralization decreased from 2925–5310 mg CO₂-C kg⁻¹ of uncultivated peats to 1672–2678 mg CO₂-C kg⁻¹ and 1065–1802 mg CO₂-C kg⁻¹ of peats cultivated with rice for over 5 years and 10-15 years, respectively (Figure 3). Changes in the carbon mineralization of the peats are related to changes in the chemical structure of carbon of the peats. Pyrophosphate index is higher in the cultivated-peats than in the uncultivated peats, indicating that cultivated peats contained higher lignin than that in the uncultivated peats. Figure 1 and Figure 2 showed that the cultivated peats had higher contents of lignin and lower contents of carbohydrates than those in the uncultivated peats. The results of this study are consistent with previous experiments which stated that the ratio of O-alkyl C (carbohydrate) and alkyl C (lignin) is an index of organic carbon quality as a source of energy for microorganisms (Baldock et al., 1997; Webster et al. 2000).

Dynamics of peat carbon mineralization in relation to peat characteristics

Figure 4 and Table 2 shows that C mineralization data for all peats fitted well to a two-pool C mineralization

model, which is indicated by the values of $R^2 \geq 0.99$ for all peats. This result is consistent with the previous laboratory incubation studies that found the two-pool model to be superior for fitting the C mineralization of added organic matter (Wang et al. 2004; Bowen et al. 2009; Ribeiro et al. 2010; Saidy et al. 2012). Results of fitting cumulative data of carbon mineralization of peats to a two-pool C mineralization model also show that the rapidly mineralizable C pool (C_f) was larger than slowly mineralizable C pools (C_s). The size of rapidly mineralizable C pool for all peats ranged between 892–4220 mg C kg⁻¹ peat, while the size of slowly mineralizable C pool was in the range of 324–2841 mg C kg⁻¹ peat (Table 2). Similar to the size of mineralizable C pools, mineralization rate of rapidly mineralizable C pool (0.0173–0.0298 day⁻¹) was higher than that of slowly mineralizable C pool (0.0105–0.0205 day⁻¹) (Table 2).

Simple regression analysis was performed between peat characteristics and the size of mineralizable C pools to establish relationship between the size of both slowly and rapidly mineralizable C pools and peat characteristics. It indicated that the size of C_s was positively correlated with rubbed fiber content, peat pH, nitrogen content, carbohydrate content, and negatively correlated with pyrophosphate index, C/N ratio and lignin content (Table 3). Results of simple linear regression analysis revealed that, based on the four highest R^2 values, the size of C_s could be predicted by the following equations:

$$C_s = -444.61 + 50.13 (\text{rubbed fibre content}); \quad (R^2 = 0.71; P < 0.01) \quad [5]$$

$$C_s = 2498.45 - 25.52 (\text{pyrophosphate index}); \quad (R^2 = 0.63; P < 0.01) \quad [6]$$

$$C_s = 3149.55 - 90.91 (\text{lignin content}); \quad (R^2 = 0.55; P < 0.01) \quad [7]$$

$$C_s = -1755.12 - 125.26 (\text{carbohydrate content}); \quad (R^2 = 0.72; P < 0.01) \quad [8]$$

Table 2. Results of the two-pool model fit C mineralization data of peats.

Samples	C_s^a (mg C kg ⁻¹ peat)	s^b (day ⁻¹)	C_f^c (mg C kg ⁻¹ peat)	f^d (day ⁻¹)	R^2
B-01	1594.4	0.0199	2485.5	0.0265	0.99
B-03	652.4	0.0187	1302.2	0.0210	0.99
B-05	687.4	0.0205	1311.9	0.0298	0.99
B-12	1095.9	0.0147	1763.2	0.0202	0.99
M-02	797.8	0.0141	1545.3	0.0221	0.99
M-07	1437.9	0.0157	1779.1	0.0233	0.99
PD-01	1364.1	0.0143	2236.7	0.0201	0.99
PD-08	1118.5	0.0184	3583.5	0.0225	0.99
PD-12	2841.3	0.0105	4220.8	0.0173	0.99
G-03	396.9	0.0202	1177.2	0.0268	0.99
G-07	323.9	0.0185	892.4	0.0260	0.99

Note: ^a The amount of slowly mineralizable C pool calculated using the two-pool C mineralization model. ^b Mineralisation rate of the slowly mineralizable C pool calculated using the two-pool C mineralization model. ^c The amount of rapidly mineralizable C pool calculated using the two-pool C mineralization model. ^d Mineralisation rate of the rapidly mineralizable C pool calculated using the two-pool C mineralization model.

Table 3. Coefficient correlation (r) between peat characteristics and slowly mineralizable C pool (C_s), and rapidly mineralizable C pool (C_f)

Peat characteristics	Slowly mineralizable C pool (C_s)	Rapidly mineralizable C pool (C_f)
Rubbed fiber contents	0.94**	0.84**
Pyrophosphate Index	-0.91**	-0.79**
Peat pH (H ₂ O)	0.81**	0.67**
Bulk density	0.06 ns	-0.18 ns
Organic carbon	0.13 ns	0.42*
Nitrogen content	0.76**	0.84**
C/N ratio	-0.75**	-0.64**
Ash content	-0.09 ns	-0.25 ns
Carbohydrate content	0.89**	0.84**
Lignin content	-0.85**	-0.79**

Note: ** = significant correlation at $P < 0.01$. * = significant correlation at $P < 0.05$. ns = non-significant correlation ($P > 0.05$)

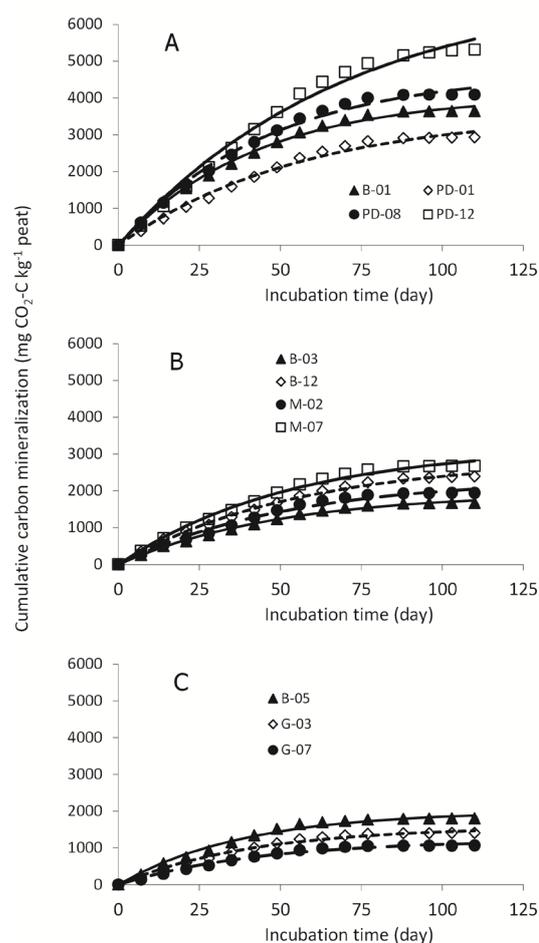


Figure 4. Carbon mineralization of uncultivated-tropical peats (A), tropical peats cultivated with rice for 5 years (B), and tropical peats cultivated with rice for 10–15 years during a 110-day incubation period. The lines indicated are curves fitted to the two-pool decomposition model: $C_t = C_a(1 - e^{-kt}) + C_s(1 - e^{-ht})$; $R^2 > 0.99$ and $P < 0.001$ for all curves

Relationship between the C_s values calculated using the experimental data and those estimated using equations (5)–(8) is described in Figure 5. Based on the two highest coefficient determination values (R^2), equations (5) and (8) are chosen to estimate the size of slowly mineralizable C pools.

Results of simple regression analysis for the size of rapidly mineralizable C pools showed that the C_f value was positively correlated with rubbed fibre content, peat pH, organic C content, carbohydrate content and negatively correlated with pyrophosphate index, C/N ratio, lignin content. Based on the four highest R^2 values resulting from simple linear regression analysis, C_f values for all peats could be estimated using the following equations:

$$C_f = -3.6 + 67.00 (\text{rubbed fibre content}); \quad [9]$$

$$(R^2 = 0.89; P < 0.01)$$

$$C_f = 230.21 + 81.97 (\text{nitrogen content}); \quad [10]$$

$$(R^2 = 0.59; P < 0.01)$$

$$C_f = 4879.73 - 125.01 (\text{lignin content}); \quad [11]$$

$$(R^2 = 0.73; P < 0.01)$$

$$C_f = -1545.37 + 158.21 (\text{carbohydrate content}); \quad [12]$$

$$(R^2 = 0.80; P < 0.01)$$

Relationship between the size of rapidly mineralizable C pool calculated using experimental data and estimated using equations (9)–(12) is illustrated in Figure 6. Based on the highest coefficient determination (R^2), equations (9) and (12) are selected to estimate the C_f value for all peats.

Estimation of carbon mineralization of peats using peat characteristics

The equations selected to estimate the size of slowly and rapidly mineralizable C pools, as explained above, were integrated into the two pool C mineralization model (equation 1) to establish an equation which would be useful to estimate carbon mineralization of peats. Integration of equations (8) and (9) into the two-pool C mineralization model resulted in equation (13), and incorporation of equations (5) and (12) resulted in equation (14).

Cumulative carbon mineralization was then calculated using carbohydrate and rubbed fiber content data from Table 1, values of s and f from Table 3 and the length of incubation (110 days). Relationship between cumulative carbon mineralization for all peats was estimated using equations (13) and (14), and from the experimental data is described in Figure 7. Results of correlation analysis revealed that equations (13) and (14) resulted in comparable accuracy for estimating the amount of carbon dioxide produced during the 110 days of peat decomposition. Correlation between cumulative carbon mineralization of peats estimated using equation (13) and that from experimental data resulted in r value of 0.925 ($P \leq 0.01$), while correlation between cumulative carbon mineralization calculated using

equation (14) and that of experimental data produced r value of 0.930 ($P \leq 0.01$). These findings indicate that the amount of carbon from peat mineralization may be estimated using carbohydrate and rubbed fiber content data.

Relationships between carbon mineralization of peatland, and rubbed fiber content (degree of peat decomposition) and carbohydrate content obtained in this study are in agreement with some of the previously reported studies. For example, Scanlon and Moore (2000) reported that the degree of peat decomposition significantly related to the CO_2 production from the peats. Dissolved organic carbon (DOC) concentration, a fraction of organic matter that easily decomposed, was dependent on the degree of peat decomposition. The less decomposed peats had higher DOC content than higher decomposed peat (Kalbitz and Geyer 2002). Control of the degree of peat decomposition on carbon mineralization was also reported by Kalbitz et al. (2003) who reported that DOC extracted from less humified organic materials decomposed rapidly (61-93% of DOC being mineralized), while more humified DOC decomposed slowly (mineralization of 4-9% of DOC). In another study, Ye et al. (2012) reported that peats with lower rubbed fiber content generally exhibited a greater degree of decomposition and hence a lower quality of carbon for microbial decomposition of peats. Results of all these previous studies indicate that the degree of peat decomposition is an important substrate property which controls the rate of carbon mineralization of peats.

A study conducted by Adesodun et al. (2001), which applied different organic matters to soils, showed that carbohydrate content is not effective in controlling soil structural stability due to fast decomposition of carbohydrate compounds in soil. In a study of the effect of sugars, amino acids and organic acids on peat mineralization, Hamer and Marcschner (2002) found that the addition of carbohydrate compounds, such as glucose and fructose, increased the carbon mineralization of the peats. Wright et al. (2011) reported that the amounts of carbon dioxide produced from peat decomposition was related to the quantity of carbohydrate compounds of the peats and was partly controlled by the degree of peat decomposition. Carbohydrate content was also reported to be used as a substantial energy source for microbial decomposition during the initial stage of decomposition (Lin et al. 2014). As a result, there was a 50% decrease of carbohydrate content from the surface to the deep peats. Organic carbon with the structure of O-alkyl carbon such as carbohydrate compounds in the peats has been reported to be an excellent predictor for peat decomposition (Tfaily et al. 2014). These results from the previous studies support the result of this study which also indicates that the carbohydrate compounds present in the peats play an important role in the carbon mineralization of the peats.

$$C_{\text{mineralization of peats}} = \{-1755.12 - [125.26 \times (\text{carbohydrate content})] \times (1 - e^{-st})\} + \{-3.6 + [67.00 \times (\text{rubbed fibre content})] \times (1 - e^{-ft})\} \quad [13]$$

$$C_{\text{mineralization of peats}} = \{-444.61 + [50.13 \times (\text{rubbed fibre content})] \times (1 - e^{-st})\} + \{-1545.37 + [158.21 \times (\text{carbohydrate content})] \times (1 - e^{-ft})\} \quad [14]$$

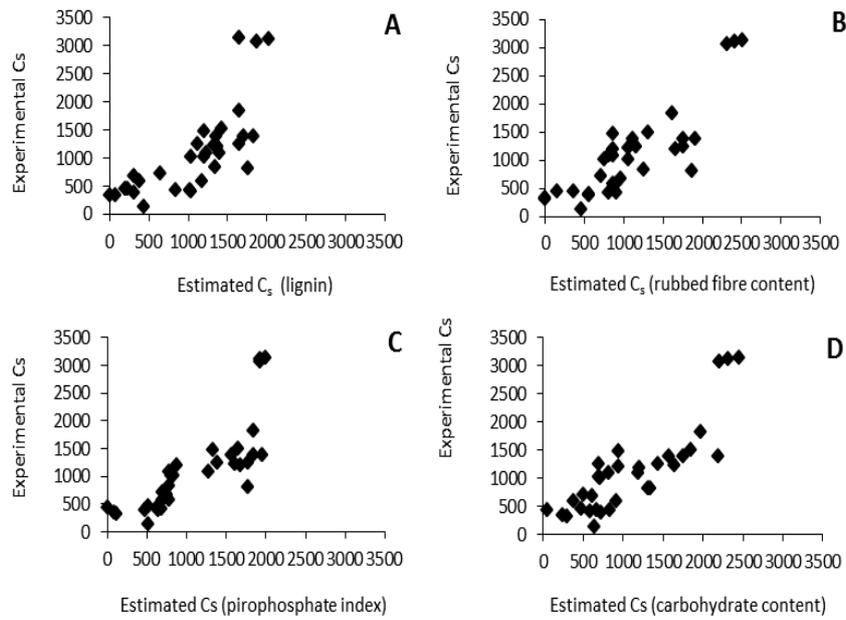


Figure 5. Relationship between the size of slowly mineralizable C pool (C_s -mg C kg^{-1} peat) calculated using experimental data and estimated using lignin content (A), rubbed-fiber content (B), pyrophosphate index (C), and carbohydrate content (D).

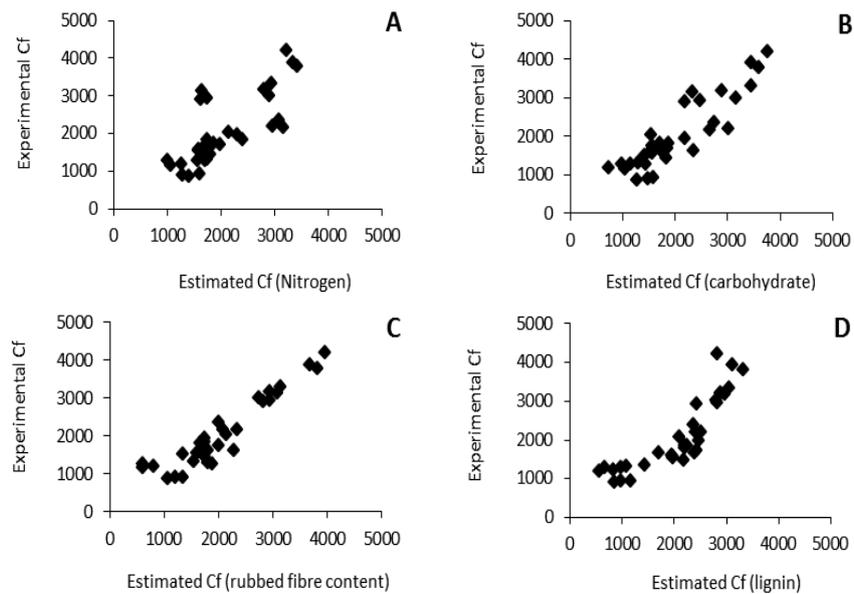


Figure 6. Relationship between fast-decomposable carbon pool (C_f -mg C kg^{-1} peat) determined by experiment and estimated using nitrogen content (A), carbohydrate content (B), rubbed-fiber content (C), and lignin content (D).

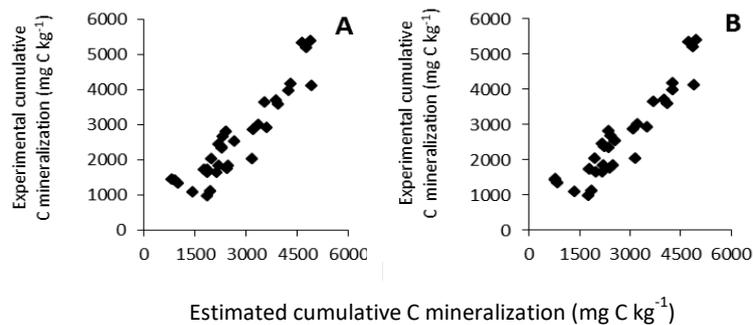


Figure 7. Relationship (scatter plot) between experimental cumulative C mineralization and estimated cumulative C mineralization using equation (13) (A) and equation (14) (B)

Although Grover and Baldock (2012) stated that substrate quality of peats had maximum influence on the size of the mineralizable carbon pool of the peats, environmental factors such temperature, moisture content and pH also determine the rate of peat mineralization (Updegraff et al., 1995; Walter and Heimann 2000; Petrescu et al. 2008; Wang et al. 2010). However, in the model developed in this study to estimate the carbon mineralization of peats, these environmental variables are not included. Contrary to the non-tropical areas, temperature is relatively constant across a variety of peatlands of tropical areas. Thus, the exclusion of the temperature in the carbon mineralization model does not result in serious problem. On the other hand, moisture content of tropical peats varied greatly because they are generally flooded in the rainy session and very dry during the dry season. Thus, the tropical peats are naturally influenced by moisture content variations. Observation of peat pH also exhibits a strong spatial variation between peatland sites, which may result from different peat management practices such as application of amelioration materials and peat tillage. Therefore, exclusion of moisture content and pH of peats from the model of carbon mineralization limits the application of this model for estimating CO₂ production reliably on either large or small spatial scales. However, the carbon mineralization model developed in this study is suitable for the estimation of CO₂ production for peats with different botanical origin but with relatively constant moisture content and pH. Further, linking of these factors to the model developed, should allow for better quantification of potential CO₂ produced during carbon mineralization of peats under different scenarios of land-use types and environmental factors.

Results of the physico-chemical properties of the peats showed that conversion of natural peatlands to paddy-cultivated peats changes the chemical structure of organic carbon in peat. The use of peatlands for agriculture decreases the amount of organic carbon with carbohydrate structure and increases the amount of organic carbon with lignin structure. The results also showed that carbon mineralization in the peats varies significantly with the changing use of peatlands from natural peats to paddy-cultivated peats. Changes in the carbon mineralization are thought to be related to changes in the chemical structure of organic carbon in the peats due to peat conversion for agriculture. The developed carbon mineralization model indicated that slowly and rapidly decomposable pools have a close relationship with rubbed fiber and carbohydrate content data. Results of this study also suggested that carbon mineralization of peats could be estimated suitably using rubbed fiber and carbohydrate content data.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Directorate General of Higher Education, Ministry of Research, Technology and Higher Education, the Republic of

Indonesia for funding this study through the Fundamental Research Grant.

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