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Decomposition of Tropical Peat Soils

2. Estimation of in situ decomposition by measurement of CO_2 flux

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Abstract

In situ decomposition of Malaysian peat soil organic matter in the field was estimated by the measurement of the CO_2 flux from the soil surface. The CO_2 flux ranged from 5.8 to 30.3 mmol $h^{-1}m^{-2}$, equivalent to 0.7 to 3.6 kg carbon per hour per ha. The CO_2 flux was correlated with the soil acidity and ash content: the higher the soil pH and/or ash content, the greater the CO_2 flux. Annual surface subsidence of arable peatland caused by the microbial decomposition of peat soil was estimated by the CO_2 flux measurement to be 50-70% of the whole annual surface subsidence. Annual amount of CO_2 emission from arable peatland in Peninsular Malaysia was estimated to be 2.23×10^6 t of carbon.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: agricultural development, carbon cycle, greenhouse effect gas, soil organic matter

Introduction

Decomposition characteristics of organic matter of Malaysian tropical peat soils obtained by the measurement of the decomposition rate under aerobic incubation at a constant temperature were reported in our previous paper[9]. The decomposition rate coincided with the soil acidity (pH) and ash content: the higher the soil pH and/or the higher the ash content, the higher the rate. In the present study the actual decomposition of peat soil organic matter in the field was determined to examine the relationship between the soil properties and the decomposition rate.

Surface subsidence of peatland is one of the major constraints in agricultural land for sustainable agriculture. The surface subsidence of Malaysian peatland after the initial stage of large subsidence ranges from 2 to 4 cm per year[6]. Major factors involved in the surface subsidence of peatland after clearance/reclamation of native forest include: (1) shrinkage of volume by desiccation resulting from lowering of the ground water level, (2) reduction of volume by extraction of stumps, roots, buried logs from land, (3) reduction of volume by compaction caused by loading of heavy machines and loss of the buoyant force of water by lowering of the ground water level, (4) loss of mass by erosion and solubilization and run-off into river/sea, and (5) loss of mass by microbial decomposition.

According to Schothorst, more than half of the surface subsidence of low moor peatland in the western Netherlands was due to microbial decomposition[13]. A greater proportion, 70% of the surface subsidence of arable tropical peatland, was ascribed to microbial decomposition[4]. These observations suggest that the decomposition loss could be the most substantial factor of the surface subsidence of peatland.

Another aspect of the decomposition of peat soil is related to the production of greenhouse effect gases, CO_2 and CH_3, since peatland constitutes a large reservoir of carbon. It has been considered that the decomposition and/or oxidation of peat soil organic matter, and even the destruction of peatland, will not

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substantially affect the global carbon turnover[2,14]. However, CO_2 emission from tropical peatland, particularly from agricultural fields is poorly documented.

Materials and methods

Distribution of peat soils in Peninsular Malaysia was described in the previous paper[9]. Measurement of CO_2 flux from the soil surface was carried out in various locations differing in land utilization, mostly in central Selangor (Jalan Kebun) and western Johor (Pontian and Ulu Air Baloi) (Table 1). For a comparison, CO_2 flux in lateritic soil at MARDI Cameron Highland Station, northwestern Pahan was also measured[12].

Another measurement of CO_2 flux was performed during our field tests related to NPK fertilizer application and use of several levels of ground magnesium limestone (GML) to modify the soil pH in order to analyze the growth performance of maize (*masmadu*) (MARDI Jalan Kebun, E7)[8]. CO_2 flux was also measured in a field experiment to study the effect of a highly polymerized hydroxyaluminium chloride solution (Hydroral C50-B, Taki Kagaku, 300 ml m^{-2}) on the growth performance of *masmadu* (MARDI Jalan Kebun, E10)[9].

Amount of CO_2 emission from the soil surface was measured by using the modified method of chamber-collection[7], and by gas-chromatographic analysis of the gas sample. At the same time the soil temperature at 5 cm depth and air temperature were measured, and surface soil (0 – 10 cm) was sampled for analyses of the moisture content, soil pH and some other soil properties.

Results and discussion

1) Estimation of in situ *decomposition by measurement of CO_2 flux*

Table 1. CO_2 flux from soil surface of peatland

Location & vegetation	Air-temp. (°C)	Soil-temp. (°C)	Soil moist. (%)[a]	Soil pH[b]	Soil EC[b] (mS/cm)	Ash content (%)	C/N (ratio)	CO_2 (mmol/ h/m^2)	CO_2-C (kg/h/ha)
Ulu Air Baloi, Pontian									
Primary forest	28.9	24.5	78.0	3.36	0.19	4.76	22.6	10.1	1.22
Oil palm	29.0	26.1	76.3	3.72	0.12	3.24	23.3	14.1	1.69
Ginger-oil palm	31.1	26.7	68.9	3.94	0.11	3.26	28.7	12.7	1.52
Pineapple	33.5	26.7	71.3	3.41	0.14	2.53	26.5	7.84	0.94
MARDI Pontian									
Maize	28.1	26.5	66.1	6.58	0.32	15.8	35.1	19.6	2.35
Okra	29.9	27.0	56.2	5.44	0.47	10.0	31.6	26.1	3.14
MARDI Jalan Kebun									
Fallow	31.3	29.9	49.1	3.48	0.13	3.09	43.7	5.82	0.70
Maize	35.1	31.1	54.0	3.48	0.42	3.09	43.7	7.43	0.89
Oil palm	29.4	26.9	71.7	3.40	0.12	8.20	46.3	9.47	1.14

a): After 105°C dry, b): Water suspension (1 : 2.5).

Table 2. CO_2 flux from soil surface of non-peat soil of MARDI Cameron Highland Station (lateritic soil)

Treatments	Air-temp. (°C)	Soil-temp. (°C)	Soil moist. (%)	Soil pH	Soil EC (mS/cm)	Carbon content (%)	C/N (ratio)	CO_2 (mmol/ h/m^2	CO_2-C (kg/h/ha)
Field plot for organic matter application experiment									
NPK only	25.1	21.5	23.8	6.60	0.22	2.45	9.42	6.7	0.80
NPK + 5CD[a]	25.1	22.2	25.9	6.80	0.55	–	–	30.3	3.63
NPK + 15CD	22.5	23.4	27.9	7.25	1.98	–	–	113.7	13.6
NPK + 25CD	22.5	23.5	28.0	7.02	2.04	3.72	7.50	180.4	21.6
Farmer's field[b]									
NPK + 5CD[c]	21.0	22.0	28.5	5.96	0.88	3.91	10.3	9.3	1.1

a): Application of chicken dung (CD), 5CD; 5 t, 15CD; 15 t, 25CD; 25 t/ha.
b): Neighboring MARDI Station. c): For the previous 4 seasons' cropping.

CO_2 flux ranged from 5.82 to 26.1 mmol $h^{-1}m^{-2}$, which is equivalent to 0.70-3.14 kg carbon per hour per ha (Table 1). CO_2 flux was the largest for the okra field of Pontian and the smallest for the fallow field of MARDI Jalan Kebun.

The CO_2 flux determined in the present study was comparable to that determined for another Malaysian arable peatland by Kyuma et al.[4], in which the annual fluctuations of the flux ranged between 11.6-32.5 mmol $h^{-1}m^{-2}$, for a Malaysian non-peat soil (Table 2), and for a low organic sandy loam soil of Japan (9.3 mmol $h^{-1}m^{-2}$, without organic matter amendment)[10]. Though tropical peat soil consists of a pile of organic matter, the labile fraction is usually very small and the decomposition process is slow as shown in the incubation experiments[9]. As a result, the CO_2 flux from tropical peat soil may not be particularly large. However, the soil CO_2 flux was larger than that of Canadian peat soil, where a flux of 1.4-4.5 mmol $h^{-1}m^{-2}$ was observed in summer time[5], and of Russian peat soil with various land uses, 0.76-1.2 mmol $h^{-1}m^{-2}$ during the period April-September[3].

The CO_2 flux tended to be positively correlated with the soil acidity and ash content: the higher the soil pH and/or the higher the ash content, the greater the CO_2 flux (Figs. 1 & 2). However, there was no relationship between the C/N ratio of soil and the flux (Fig. 3). These relationships agreed well with the results obtained during the incubation-decomposition experiments reported in our previous paper[9].

In situ decomposition measurements also confirmed the results of the incubation and kinetic analyses, i.e. no effect of NPK fertilizer application, but a significant promotive effect of soil pH amendment on the decomposition[8,9]: the higher the soil pH, the greater the CO_2 flux (Table 3).

The suppressing effect of a highly polymerized

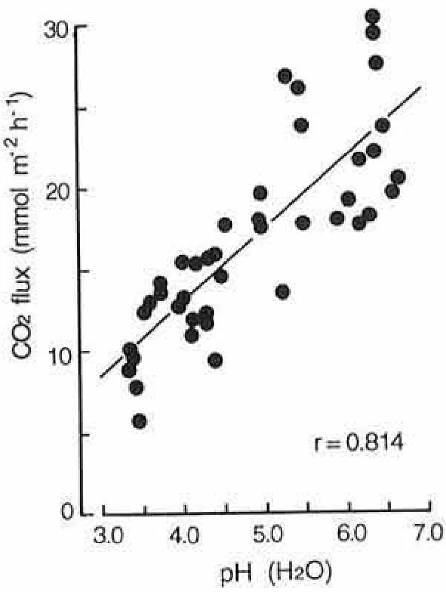

Fig. 1. Relationship between soil acidity (pH) and CO_2 flux from soil surface of peatland

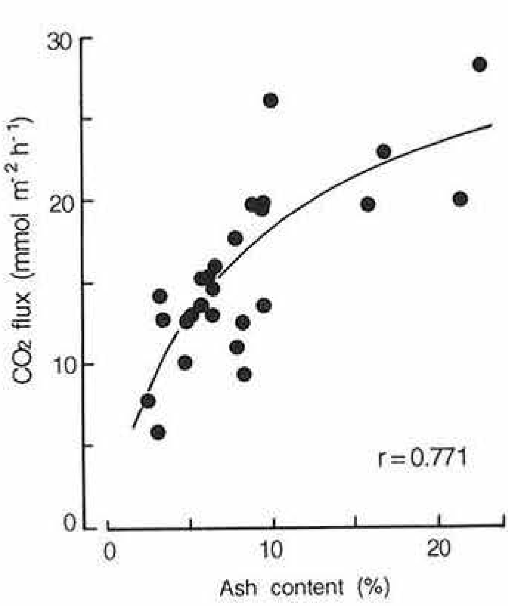

Fig. 2. Relationship between ash content and CO_2 flux from soil surface of peatland

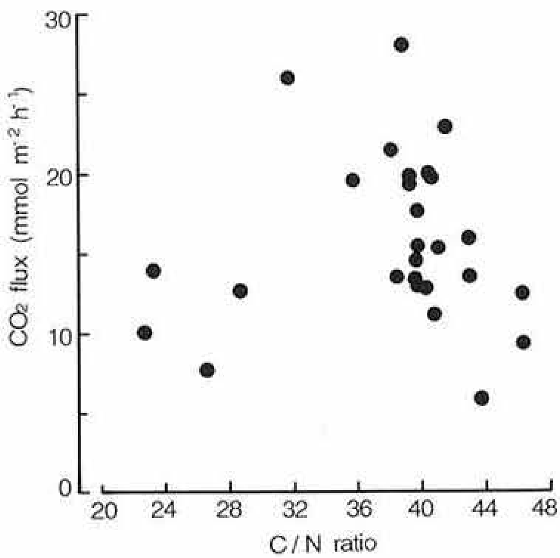

Fig. 3. Relationship between carbon-nitrogen ratio of soil and CO_2 flux from soil surface of peatland

Table 3. Effect of pH amendment by GML and NPK fertilization on the CO_2 emissions from the soil surface of maize field after harvest (MARDI Jalan Kebun, E7)

Treatment[a)]	Date (M/D)	Soil temp. (°C)	Soil pH (H_2O)	CO_2 (mmol/ h/m^2)
L0 + NPK	8/29	33.1	4.3	11.6
	9/4	31.9	4.3	12.3
	1/13[b)]	30.1	4.4	9.5
L0 − NPK	8/28	31.5	4.1	11.9
	9/4	32.2	4.1	11.0
	1/13[b)]	32.2	4.3	15.7
L1 + NPK	8/29	33.9	4.9	17.8
	9/30	31.7	4.9	17.7
	1/15[b)]	33.2	5.3	26.8
L1 − NPK	8/28	30.3	5.5	17.7
	9/4	31.4	5.5	23.8
	1/13[b)]	27.3	5.9	18.0
L2 + NPK	8/29	30.8	6.0	19.2
	1/15[b)]	31.3	6.5	23.7
L2 − NPK	9/4	30.6	6.4	27.8
	1/15[b)]	33.5	6.3	18.2
L3 + NPK	8/29	30.0	6.7	22.1
	9/30	30.6	6.7	29.3
	1/13[b)]	33.2	6.3	30.3
L3 − NPK	9/4	28.4	6.2	21.6
	9/30	31.4	6.2	17.6
	1/15[b)]	30.7	6.6	20.4

a): GML: 0(L0), 12.5(L1), 25(L2), 50(L3) t/ha, N(150 kg N as urea), P(60 kg P_2O_5 as triple superphosphate), K(100 kg K_2O as muriate of potash).
b): 1992, others 1991. Maize was harvested on May 28, 1991.

hydroxyaluminium chloride solution (Hydroral C50-B) on the decomposition of peat soil observed by the incubation method[9)] was confirmed by the measurement of the CO_2 flux in the same experimental field as that shown in Table 4.

Under temperate climatic conditions, Naganawa et al. indicated that the CO_2 emission from the soil surface was greater at a higher soil temperature than at a lower temperature for Japanese mineral soils[10)]. Kyuma et al. attributed the larger soil CO_2 flux in a cultivated field plot than in a forest plot with Malaysian peat soil to the higher soil temperature in the former[4)]. However, data on the measurements of the CO_2 flux and soil temperature presented in Tables 1, 3 & 4 indicated that there was no correlation between both parameters in such a narrow range of soil temperatures as 21.5–33.5°C.

2) Relationship between the decomposition of peat soil and surface subsidence

Table 4. Effect of hydroxyaluminium chloride (Hydroral C50-B) application on CO_2 emission from maize-growing field (MARDI Jalan Kebun, E10)

Treatment[a)]	Date (M/D)	Soil temp. (°C)	Soil pH (H_2O)	CO_2 (mmol/ h/m^2)
− Al(L2)	10/22	30.8	4.8	29.0
	11/23	27.0	4.8	11.8
	11/23[b)]	28.7	4.8	12.0
+ Al(L2)	10/22	30.8	4.3	24.4
	11/23	27.2	4.3	11.2
	11/23[b)]	28.7	4.3	9.5
Control plot				
R	10/22	31.5	3.5	7.4
	11/23	30.1	3.5	12.4
N	11/23	30.2	3.4	8.9

a): − Al(L2); without hydroxyaluminium. + Al(L2); with hydroxyaluminium. Both plots were amended with NPKMg, micro-nutrients and GML 15 t/ha (only for previous cropping). R; No maize, − GML, + NPKMg, + Micro-nutrients. N; No maize, No amendment.
b): Measurement in area without maize standing crop (at least 1 week after maize sampling for analysis).

Annual surface subsidence (h cm) of arable peatland caused by the decomposition of peat soil organic matter was calculated by using a mathematical model[8)]:

$$h = 105.12 \times \alpha \ d^{-1}\theta^{-1} \quad \text{......................... (1)}$$

where α is the CO_2 flux (mmol h^{-1}cm^{-2}), d is the bulk density (g cm^{-3}), θ is the carbon content of peat soil. The relationships between α, d and θ are illustrated in Fig. 4. For the Malaysian peat soil, α ranged from 0.0006 to 0.0030, d from 0.080 to 0.35 and θ from 0.45 to 0.60. More than half of the surface subsidence of arable peatland was ascribed to the microbial decomposition of peat soil organic matter. The annual surface subsidence (h) associated with the decomposition in the maize field at MARDI Jalan Kebun amounted to 1.55 cm when α was 0.00203, θ, 0.551 and d, 0.250, which accounted for 52% of the whole annual subsidence of 3 cm at this site. The corresponding values for a vegetable field at MARDI Pontian were found to be 1.64 cm (h) and 65.6%, a close value compared to 71.6% for the same location reported by Kyuma et al.[4)].

We can not predict easily and consistently whether an older field with a large CO_2 flux and a low carbon content may show a larger subsidence rate due to the decomposition, since the older field soil

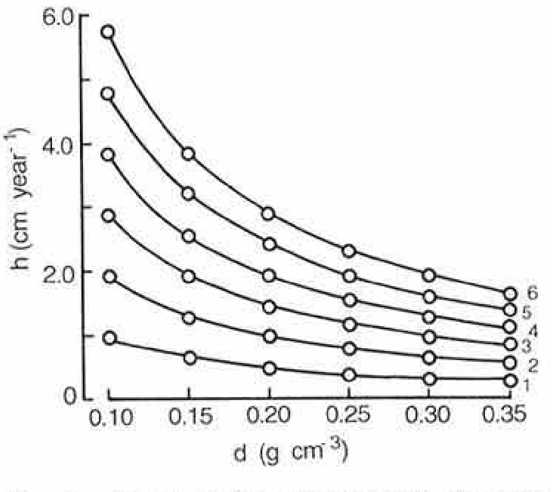

Fig. 4. Annual surface subsidence (h) of arable peatland in relation to CO_2 emission from soil surface (α) and bulk density of peat (d)
α: 1; 0.0005, 2; 0.0010, 3; 0.0015, 4; 0.0020, 5; 0.0025, 6; 0.0030 mmol $h^{-1}cm^{-2}$.
Carbon content of peat (θ); 0.550.

usually exhibits a larger bulk density than the younger field soil, and vice versa.

3) Estimation of annual amount of CO_2 emission from arable peatland

By postulating that the annual average CO_2 flux from the soil surface of an oil palm plantation on peatland is 0.0010 mmol $h^{-1}cm^{-2}$ with an acreage of 150,000 ha[1], and that the flux is 0.0015 for other dry land crops (24,000 ha), and 0.00020 (no CO_2 measurement was carried out in the present study for paddy, rubber, coconut fields but the flux was assumed to be one-fifth of that of oil palm field) for the fields with paddy, rubber and coconuts which grow under submerged or very wet conditions (130,000 ha), the total annual CO_2 emission from the arable peatland of Peninsular Malaysia should amount to 2.23×10^6 t of carbon. The carbon emission is estimated to amount to 0.0022% of 100×10^9 t of annual turnover of carbon in the ecosystems[14], and to 0.0033% of 68×10^9 t of annual global CO_2 flux from soil[11].

Conclusion

The present studies on the decomposition of tropical peat soil organic matter indicated that the utilization of peatland for agriculture actively stimulates the decomposition of peat soil organic matter, particularly through the neutralization of the soil acidity and enrichment of ash content, both of which result from agricultural practices.

Microbial decomposition of peat soil organic matter was considered to account for 50–70% of the surface subsidence of agricultural peatland in the tropics. The decomposition of peat soil organic matter and/or CO_2 emission are invisible processes and the decomposition will be recognized only after long term utilization through surface subsidence of the land.

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