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Decomposition of Tropical Peat Soils

1. Decomposition kinetics of organic matter of peat soils

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Abstract

Malaysian tropical peat soils were examined for their microbial decomposability by incubation under aerobic conditions at 35°C. Incubation data fitted well info the one compartment exponential decay model. Decomposition rate constants ranged from 0.0000241 to 0.000388 day^{-1}, equivalent to a half-life time of 78.6 and 4.89 years. No promotive effect of pre-air-drying on the decomposition rate was detected. The decomposition rate tended to increase with the increase of the soil pH and/or ash content of soil. The promotive effect of pH amendment of strong soil acidity by liming on the decomposition rate was confirmed, while no effect of NPK fertilizer application on the decomposition rate was observed. The inhibitory effect of sulfate salts of Cu, Zn and a highly polymerized hydroxyaluminium chloride solution on the microbial decomposition was observed.

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

Introduction

More than 20 million ha of lowland peat soil occur in tropical Southeast Asia of which about 2.4 million ha are located in Malaysia. Despite their many limitations and constraints on crop growth, there has been an increasing demand to develop peat soil swamps for agriculture[1,4,7].

Peat soil has peculiar properties; strong acidity/deficiency in both macro- and micro-nutrients/low bulk density/large shrinkage by desiccation, etc.[2,4]. More than 98% of the original peat consists of organic matter, a mixture of semi-decomposed plant biomass gradually accumulated under water saturation conditions, revealing the intrinsic nature of biomass, i.e. decomposition by microorganisms.

The decomposition of organic matter of peat soil leads to an irreversible loss of soil resources, resulting in surface subsidence of peatland. The subsidence is undoubtedly the most detrimental and hard-to-overcome constraint for sustainable agriculture of peatland. The surface subsidence of Malaysian peatland after the initial stage of large subsidence ranges from 2 to 4 cm per year[7].

Another aspect of the decomposition of peat soil is related to the emission of greenhouse effect gases, CO_2 and CH_3, since peatland constitutes a large reservoir of carbon.

Only a very small number of papers on the decomposition of peat soil organic matter, particularly on the tropical one have been published. Studies on the characteristics of microbial decomposition of tropical peat soils and methods to suppress the decomposition may contribute to the development of a new technology to reduce the decomposition loss of peat materials in agricultural fields.

In the first of a series of 2 papers, we report on the decomposition kinetics of peat soil organic matter. *In situ* decomposition rate obtained by the measurement of CO_2 flux from the soil surface will be reported in the next paper[13].

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Materials and methods

Peat soil samples examined were taken from both cultivated agricultural fields and peat soil swamp forests in Malaysia (Fig. 1, Table 1). Wet samples were air-dried under the shade to a certain level of moisture content, and passed through a 2 mm mesh sieve. Typical Malaysian non-peaty soils were also used in the incubation experiment for comparison with the peat soils (Table 2).

Samples that were never completely air-dried were inoculated with a filtrate solution of the original wet sample and adjusted to 75% moisture content and incubated aerobically at 35°C for until about 100 days. CO_2 evolved was adsorbed by a dilute NaOH solution and the amount was measured periodically by titration of excess alkali with a dilute HCl solution after addition of an excess amount of $BaCl_2$ solution. The decomposition values were fitted into a 2-compartment exponential decay model[8,9], consisting of a readily decomposable 'labile' fraction C_1 (decomposition rate constant k_1) and a non-readily decomposable 'non-labile' fraction C_2 (k_2):

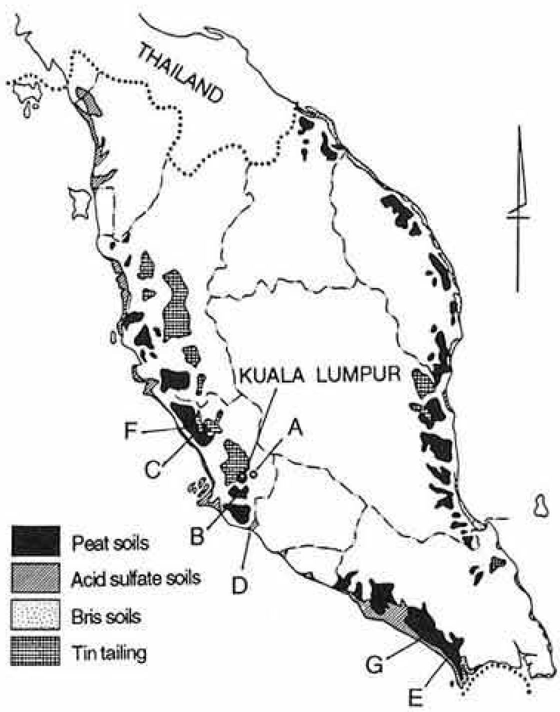

Fig. 1. Distribution of peat soils in Peninsular Malaysia and sampling sites for the present studies
A: MARDI H. Q. Serdang, B: MARDI Jalan Kebun, C: MARDI Tanjong Karang, D: MARDI Kuala Lingi, E: MARDI Pontian, F: Tanjong Karang, G: Ulu Air Baloi, Pontian.

$$Y_t = C_1\exp(-k_1t) + C_2\exp(-k_2t) \quad \text{.......... (1)}$$

where, Y_t is the residual amount expressed as the proportion of the initial amount after t time (day), and Y_t equals 1 at time 0. The formula for the single compartment model was modified from the model (1), provided that the C_1 value was 0 as follows:

$$Y_t = C_2\exp(-k_2t) = \mathrm{Exp}(-kt) \quad \text{............ (2).}$$

Results and discussion

1) Decomposition rate

The promotive effect of pre-air-drying on the decomposition of soil organic matter, which commonly occurs in mineral soils, was not detected in Malaysian tropical peat soils[10], and all the current incubation experiments were carried out using non-air-dried samples.

Decomposition time course of organic matter of tropical mineral soils was similar to that of Japanese mineral soils in that the decomposition followed the 2-compartment exponential decay model (Table 2). In contrast to the mineral soils, however, the decomposition data of tropical peat soils better fitted into a 1-compartment exponential decay model, indicating that a proportion of the readily decomposable fraction (C_1) was negligibly small (Fig. 2, Table 3). The decomposition rates ranged from 0.0000241 to 0.000388 day^{-1} for all the samples examined (Tables 3–6), equivalent to a half-life time of 78.6 and 4.89 years, respectively.

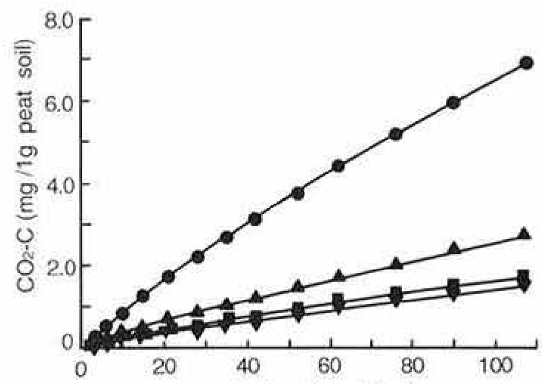

Fig. 2. Decomposition of peat soil by incubation under aerobic conditions at 35°C (primary forest, Tanjong Karang)
● 1st layer, ▲ 2nd layer, ▼ 3rd layer, ■ 4th layer.

Table 1. Some physical and chemical properties of Malaysian peat soils (105°C oven-dry basis)

Sample number[a)]	Layer depth (cm)	Moisture content[b)] (%)	pH[c)]	EC[c)] (mS cm^{-1})	Bulk density (g cm^{-3})	PR[d)]	Ash content (%)	Total-C content (%)	Total-N content (%)	C/N ratio
MARDI Jalan Kebun (E7, maize (baby-corn) field)										
1	0–14	60.2	3.68	0.39	0.29	0.95	6.0	56.5	1.44	39.3
2	14–33	85.5	3.19	0.25	0.14	1.1	1.3	58.8	1.35	43.4
3	33–53	88.4	3.65	0.10	0.099	0.97	1.5	58.8	1.29	45.7
4	53–75	91.0	4.21	0.060	0.080	0.75	1.8	59.0	1.36	43.4
5	75–102	92.0	5.01	0.050	0.076	0.40	3.0	59.1	1.30	45.4
Tanjong Karang (primary forest reserve)										
6	0–15	76.2	3.37	0.20	0.16	0.03	8.2	51.3	2.05	25.1
7	15–35	78.8	3.33	0.14	0.15	0.20	4.0	54.7	1.66	33.0
8	35–55	82.2	3.40	0.11	0.13	0.65	3.0	56.5	1.34	42.2
9	55–80	85.9	3.53	0.090	0.12	0.20	3.0	57.2	1.22	46.9
Ulu Air Baloi, Pontian (primary forest)										
10	0–15	81.9	3.53	0.30	0.13	0.65	1.1	55.6	2.01	27.7
11	15–35	83.8	3.58	0.22	0.14	0.32	0.42	58.0	1.63	35.6
12	35–55	88.6	3.72	0.10	0.088	0.04	0.43	58.2	1.40	41.6
13	55–80	90.8	3.90	0.06	0.069	0.08	0.68	58.7	1.32	44.4
Ulu Air Baloi, Pontian (oil palm plantation)										
14	0–5	73.7	3.71	0.39	0.20	0.15	5.3	53.9	2.52	21.4
15	5–20	83.7	3.65	0.24	0.12	0.62	4.8	56.5	1.99	28.4
16	20–50	87.5	3.60	0.20	0.080	0.69	2.4	57.0	1.58	36.2
17	50–70	87.7	3.66	0.13	0.090	0.30	0.93	58.2	1.40	41.6
MARDI Jalan Kebun (plowed layer samples collected for incubation experiments)										
18	0–13	74.0	3.26	0.13	0.24	3.6	3.1	58.0	1.33	43.7
19	0–15	-	6.42	0.29	-	-	15.0	50.6	1.60	31.5
20	0–10	-	5.04	0.17	-	-	11.5	53.8	1.41	38.0
21	1–10	-	3.60	0.15	-	-	7.2	56.4	1.41	40.0
22	0–10	79.4	3.60	0.13	0.19	1.7	2.6	59.2	1.26	46.9
MARDI Pontian (vegetable field and secondary forest)										
23	0–18	52.8	6.34	0.35	0.26	0.002	15.4	51.9	1.38	37.6
24	0–15	70.9	3.58	0.47	0.14	0.15	3.4	56.7	1.87	30.4

a): 18; Field E10 (newly developed), 19; Field F4 (fallow), 20; Field F13 (asparagus), 21; Field 13 (pineapple), 22; Field K4 (coffee garden), 23; Field No. 26 (vegetable field), 24; secondary forest.
b): At sampling time.
c): pH and EC (electric conductivity): 1 : 2.5 H_2O suspension.
d): Penetration resistance (soil hardness at the location (kg cm^{-2})).

Except for only one soil profile of E7 field of MARDI Jalan Kubun Station, surface layer samples were decomposed at a larger rate than subsurface layer samples (Table 3). The exceptionally high decomposition rate of the 5th layer of the E7 profile could be ascribed to its high soil pH (Table 1), since microbial activity examined by the decomposition of glucose was not particularly high in this layer[10)].

The primary forest and oil palm plantation field of Ulu Air Baloi indicated in Table 1 were closely located at about 1 km distance, and showed a similar origin of peat accumulation. Compared to the former soil profile, the latter tended to be decomposed at a higher rate than the former (Table 3), presumably due to the higher ash content in the oil palm plantation than in the primary forest (Table 1).

Except for the surface layer of the primary forest of Tanjong Karang which showed a particularly small C/N ratio, in general, the peat soil samples from the cultivated field were decomposed at a higher rate than those from the forest and/or non-cultivated field, indicating that agricultural use stimulates microbial decomposition (Table 3).

The decomposition rate tended to be higher for the sample with a higher soil pH (Fig. 3). For the utilization of peat soil for crop production strong acidity must be corrected because crops cannot grow properly on such strongly acidic media with a pH of 3–4. Samples taken from the field subjected to NPK application experiments with different levels of

Table 2. Rate constant for the decomposition of organic matter of mineral soils (105°C oven-dry basis)

$Y_t = C_1\exp(-k_1t) + C_2\exp(-k_2t)$

Sample name	pH (1:2.5) (water)	Total-C (%)	C/N (ratio)	C_1 [a)] k_1 $k_2(10^{-4})$	$\sigma(10^{-3})$ [b)] $\sigma(10^{-1})$ $\sigma(10^{-5})$	$T_{1/2}$ [c)]	A.D.R. [d)] (%)	SD [e)] (10^{-3})
MARDI Kuala Lingi, acid sulfate soil, primary forest								
1st layer (0–5 cm)	3.1	6.42	19.5	C_1 0.00821	0.253			0.221
				k_1 0.196	0.126	3.53(D)	–	
				k_2 2.43	0.651	7.82(Y)	8.48	
2nd layer (5–25 cm)	2.9	3.66	48.9	C_1 0.00389	0.448			0.171
				k_1 0.0993	0.159	6.98(D)	–	
				k_2 0.569	0.912	33.4 (Y)	2.15	
MARDI Kuala Lingi, acid sulfate soil, soybean field								
1st layer (0–15 cm)	3.5	3.87	25.6	C_1 0.0053	0.0025			0.209
				k_1 0.189	0.180	3.67(D)	–	
				k_2 1.777	0.629	10.7 (Y)	6.28	
MARDI Serdang, lateritic soil, groundnut field								
1st layer (0–15 cm)	6.3	1.66	15.9	C_1 0.0129	0.463			0.522
				k_1 0.275	0.241	2.52(D)	–	
				k_2 1.697	1.298	11.2 (Y)	6.01	
MARDI Tanjong Karang, marine alluvial clay soil, paddy field								
1st layer (0–10 cm)	6.7	2.21	9.8	C_1 0.0188	0.595			0.594
				k_1 0.232	0.166	2.99(D)	–	
				k_2 3.333	1.618	5.70(Y)	11.4	

a): $Y_t = C_1 + C_2 = 1$ (at time $t = 0$). b): Standard deviation for C_1, k_1, k_2. c): Half-life time, day (D) or year (Y). d): Annual decomposition rate. e): Standard deviation of the whole fitness.

Table 3. Rate constant for the decomposition of Malaysian peat soils

$Y_t = \mathrm{Exp}(-kt)$

Sample number	Depth (cm)	$k(10^{-4})$	$\sigma(10^{-5})$	$SD(10^{-3})$	$T_{1/2}$ (year)	A.D.R. (%)
MARDI Jalan Kebun (E7, maize (baby-corn))						
1	(0–14)	0.742	0.278	0.494	25.6	2.67
2	(14–33)	0.614	0.170	0.303	30.9	2.22
3	(33–53)	0.803	0.221	0.392	23.6	2.89
4	(53–75)	0.859	0.332	0.590	22.1	3.09
5	(75–102)	1.44	0.601	1.06	13.2	5.13
Tanjong Karang (primary forest reserve)						
6	(0–15)	1.020	0.350	0.042	18.7	3.91
7	(15–35)	0.490	0.084	0.160	38.7	1.77
8	(35–55)	0.267	0.026	0.049	71.2	0.97
9	(55–80)	0.289	0.025	0.048	65.8	1.05
Ulu Air Baloi, Pontian (primary forest)						
10	(0–15)	0.741	0.222	0.380	25.6	2.67
11	(15–35)	0.325	0.026	0.044	58.5	1.18
12	(35–55)	0.345	0.067	0.114	55.0	1.25
13	(55–80)	0.298	0.040	0.689	63.6	1.08
Ulu Air Baloi, Pontian (oil palm plantation)						
14	(0–5)	0.947	0.179	0.305	20.1	3.40
15	(5–20)	0.444	0.094	0.162	42.7	1.61
16	(20–50)	0.473	0.114	0.196	40.1	1.71
17	(50–70)	0.572	0.116	0.198	33.2	2.07
MARDI Jalan Kebun (surface layer of upland cultivated field)						
18	(0–13)	0.479	0.100	0.165	39.6	1.73
19	(0–15)	1.52	0.555	0.909	12.5	5.40
20	(0–10)	0.878	0.574	0.095	21.6	3.16
21	(1–10)	0.743	0.219	0.362	25.6	2.68
22	(0–10)	0.241	0.077	0.013	78.6	0.88
MARDI Pontian (No. 26, vegetable field)						
23	(0–18)	3.50	0.227	0.380	5.43	12.0
MARDI Pontian (secondary forest)						
24	(0–15)	0.878	0.670	1.27	21.6	3.16

Table 4. Effect of pH amendment by GML and NPK fertilizer on the decomposition rate of peat soil (MARDI Jalan Kebun, E7 maize-growing field)

$Y_t = Exp(-kt)$

Treatment[a)]	Soil pH (H_2O)	k(10^{-4})	$\sigma(10^{-5})$	$T_{1/2}$ (year)
L0 − NPK	3.94	0.639	0.179	29.7
L0 − N(+PK)	4.03	0.550	0.146	34.5
L0 − P(+NK)	3.92	0.549	0.100	34.6
L0 − K(+NP)	4.14	0.601	0.152	31.6
L0 + NPK	4.01	0.544	0.142	34.9
L1 − NPK	4.68	0.982	0.366	19.3
L1 + NPK	4.65	0.830	0.327	22.9
L2 − NPK	5.98	3.17	0.867	5.99
L2 + NPK	5.76	3.10	0.878	6.13
L3 − NPK	6.13	3.79	1.11	5.01
L3 + NPK	6.19	3.88	1.28	4.89

a): Lime treatment consists of 4 levels 0(L0), 12.5(L1), 25.0(L2), 50(L3) t/ha of ground magnesium limestone (GML). N: 150 kg N/ha (urea), P: 60 kg P_2O_5 (triple superphosphate), K: 100 kg K_2O (muriate of potash).

GML (ground magnesium limestone) to analyze the growth performance of maize (*masmadu*)[11)] were examined, and the results indicated that the increase of pH promoted the decomposition of peat soils (Table 4). The effect of the pH amendment on the decomposition rate was confirmed by other incubation experiments on pH amendment with the addition of calcium carbonate[10)]. The results were consistent with the observation of Farrell and McDonnell (1986) showing that the addition of lime and/or subpeat mineral soils to peat increased the rate of decomposition[3)].

On the other hand, NPK fertilization did not affect the decomposition rate of peat soil organic matter (Table 4). The scattering diagram of the relationship between the C/N ratio and the decomposition rate constant of all the samples analyzed in the present study indicated that there was no correlation between both parameters.

Among other soil properties, the ash content was also well correlated with the decomposition rate; samples with a higher ash content tended to decompose at a higher rate constant (Fig. 4).

In comparison with the Japanese grassy peat soil of Bibai, the decomposition rate of Malaysian woody peat soil was smaller presumably due to the lower ash content, larger C/N ratio and lower carbohydrate content than in the Bibai grassy peat soil[10)].

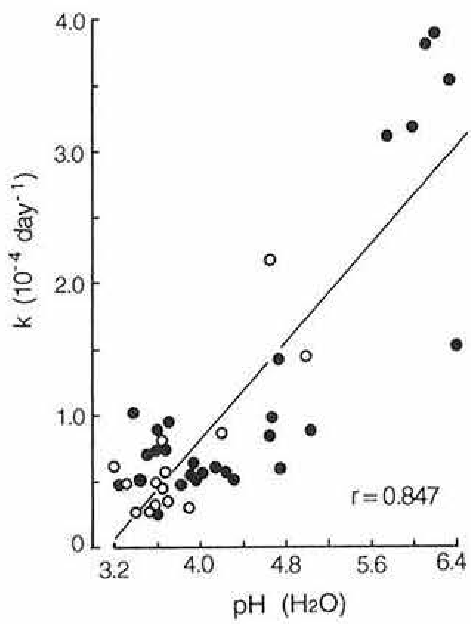

Fig. 3. Relationship between soil acidity (pH) and rate constant (k) of the decomposition of peat soil
● Surface year peat soil,
○ Subsurface layer peat soil.

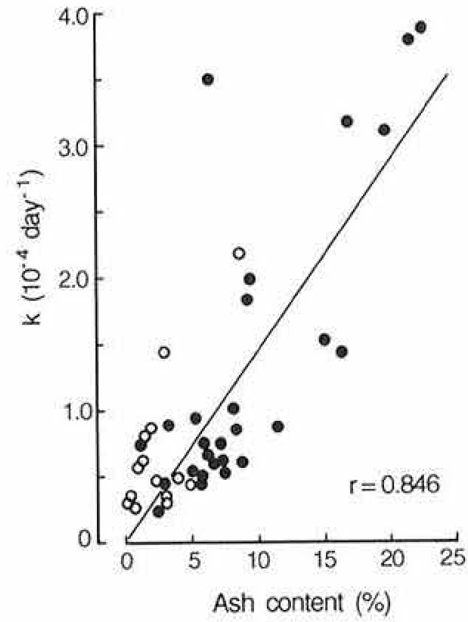

Fig. 4. Relationship between ash content and rate constant (k) of the decomposition of peat soil
● Surface layer peat soil,
○ Subsurface layer peat soil.

2) Effects of heavy metals on the decomposition rate of peat soil organic matter

Micro-nutrients such as Cu, Zn are commonly added to peat soils for agricultural use, because of their deficiency in peat soil, and the metal salts, $CuSO_4$, $ZnSO_4$ and a highly polymerized hydroxy-aluminium chloride solution (Hydroral C50-B, Taki-Kagaku)[5] were found to suppress the decomposition (Table 5). The mitigating effect of Cu on the microbial decomposition of peat soil had been suggested by Mathur & Sanderson[3], Farrell & McDonnell[6] and Yonebayashi et al.[14]. Among the 3 metals examined, the high molecular Al compound was most effective. The suppressive effect of the metals could be attributed tentatively to their chelating interaction which may result in the resistance of peat soil organic matter to microbial decomposition, since the formation of metal-organic matter complexes was inferred based on the observation of coagulation-precipitation of organic matter of the incubated samples in water suspension[12]. Another cause could be the inactivation of certain soil enzymes by metals, as suggested by Mathur & Sanderson[6].

Table 5. Effects of $CuSO_4$, $ZnSO_4$ and hydroxyaluminium on the decomposition rate of peat soil from MARDI Jalan Kebun, E10 (newly developed and prepared field)

$Y_t = \mathrm{Exp}(-kt)$

Treatment[a]	$k(10^{-4})$	$\sigma(10^{-5})$	$T_{1/2}$ (year)	A.D.R. (%)
No amendment	0.601	0.246	31.6	2.17
Cu (L1)	0.567	0.226	33.5	2.05
Cu (L2)	0.553	0.174	34.2	2.01
Cu (L3)	0.575	0.174	33.0	2.08
Zn (L1)	0.575	0.240	33.0	2.08
Zn (L2)	0.576	0.191	34.8	1.97
Zn (L3)	0.556	0.183	34.1	2.01
Al (L1)	0.539	0.175	35.3	1.95
Al (L2)	0.542	0.158	35.0	1.96
Al (L3)	0.545	0.152	34.8	1.97

a): Cu; L1 273, L2 1386, L3 5556 ppm Cu addition as $CuSO_45H_2O$, Zn; L1 279, L2 1384, L3 5552 ppm Zn addition as $ZnSO_47H_2O$, Al; L1 1161, L2 2322, L3 4644 ppm Al addition as hydroxyaluminium chloride (Hydroral-C50B).

Table 6. Effect of hydroxyaluminium on the decomposition rate of peat soil samples taken from the maize-growing field (E10)

$Y_t = \mathrm{Exp}(-kt)$

Treatment[a]	$k(10^{-4})$	$\sigma(10^{-5})$	$T_{1/2}$ (year)	A.D.R. (%)
− Al(L2, NPK)	0.842	0.443	22.5	3.03
+ Al(L2, NPK)	0.599	0.205	31.7	2.16

a): − Al; Without hydroxyaluminium chloride, + Al; With hydroxyaluminium chloride. L2; GML 15 t/ha for the previous maize cropping, NPK and micronutrients were applied for the current experiment.

In our field experiment the hydroxyaluminium polymer did not affect adversely the growth of maize (*masmadu*)[12], and the incubation experiment of the soil sample of this field revealed the suppressive effect of the Al-polymer on the decomposition rate (Table 6). These results indicated that this material could be utilized for the reduction of the rate of decomposition loss of peat soil materials, though further studies on the effects of the Al-polymer on both the growth performance of various crops and long-term environmental implications for ecosystems are necessary.

Conclusion

The present studies on the decomposition of tropical peat soils indicated that the utilization of peatland for agriculture promotes the decomposition of peat soil organic matter, particularly through the neutralization of the soil acidity and enrichment of ash content, both of which are associated with agricultural activities.

The suppressive effect of sulfate salts of Cu, Zn which are commonly added to peat soil for agriculture as micro-nutrients on the microbial decomposition was observed. A highly polymerized hydroxyaluminium was found to show a mitigating effect on the decomposition of peat soil organic matter.

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