Use of Ameliorant to Reduce Methane and Carbon Dioxide Emissions from Rice Paddy at Peat Soils of Central Kalimantan

Pemanfaatan Bahan Amelioran untuk Mengurangi Emisi Metan dan CO_2 dari Sawah Lahan Gambut di Kalimantan Tengah

M.D. Mario[1]

ABSTRACT

Peat forests emit methane and carbon dioxide naturally. Rate of the emissions may increase if the forest is converted for other uses such as rice field. The use of mineral soil, enriched with electric furnace slag containing high level of cationic irons, as ameliorant is expected to give several benefits. Firstly, it can reduce the harmful effects of phenolic acids in the soils thereby increasing yield of rice. Secondly, it will form complex bonding that improves peat stability and reduces methane (CH_4) and carbon dioxide (CO_2) emissions. This study evaluated the impact of using ameliorant in three peat soils of Central Kalimantan, i.e. inland peat at Berengbengkel, transitional peat at Sampit, and coastal peat at Samuda. The ameliorant was a combination of Fe-rich mineral soil (Fe_2O_3 =22.06%) and electric furnace slag (Fe_2O_3 =42.60%). The amount of ameliorant was determined based on 5% maximum adsorption of Fe^{3+}. It was found that inland peat soils emit more CH_4 and CO_2 than transitional and coastal peat soils. The use of ameliorant reduced the rate of the emission significantly. Without amelioration, total amount of carbon losses through CH_4 and CO_2 emission were about 2.086, 1.986, and 1.967 t $ha^{-1}yr^{-1}$ for inland, transitional, and coastal peats, respectively. Ameliorant application reduced total carbon losses in these three peat soils by about 0.597, 0.609, and 0.628 t $ha^{-1}yr^{-1}$, respectively, and also significantly the yield of rice. Based on the findings and if there was no ameliorant application, it is estimated to require 660, 1247, and 2820 years to decompose all organic carbon of inland, transitional, and coastal peat soils, respectively. Meanwhile, with ameliorant application, the time required will be about 980,1789, and 3950 years, respectively.

Key Words : *Peat soil, Ameliorant, Methane, Carbon dioxide, Rice*

ABSTRAK

Secara alami, hutan-hutan di lahan gambut mengeluarkan gas metan (CH_4) dan hidrat arang (CO_2) ke udara. Laju emisi gas-gas tersebut akan meningkat apabila hutan-hutan gambut dikonversi ke penggunaan lain, seperti lahan sawah. Penggunaan bahan tanah mineral, yang diperkaya dengan *electric furnace slag* berkadar besi tinggi, sebagai pembenah tanah (amelioran) diharapkan akan memberikan beberapa keuntungkan. Pertama, bahan amelioran tersebut akan megurangi pengaruh buruk dari asam-asam fenolik pada tanah sambil meningkatkan hasil padi. Kedua, amelioran akan membentuk senyawa kompleks yang dapat memperbaiki stabilitas gambut dan mengurangi emisi gas metan dan CO_2. Penelitian ini mencoba mengevaluasi dampak penggunaan bahan amelioran pada tiga macam tanah gambut dari Kalimantan Tengah, yakni gambut pedalaman di Berengbengkel, gambut peralihan di Sampit, dan gambut pantai di Samuda. Bahan amelioran yang digunakan adalah kombinasi antara tanah mineral kaya besi (22,06% Fe_2O_3) dan *electric furnace slag* (42,60% Fe_2O_3). Takaran bahan amelioran ditentukan berdasarkan 5% dari serapan maksimum dari besi bebas (Fe^{3+}). Hasil penelitian menunjukkan bahwa gambut pedalaman melepaskan lebih banyak gas metan dan CO_2 daripada gambut peralihan dan pantai. Bahan amelioran secara nyata menurunkan laju emisi. Tanpa ameliorasi, jumlah kehilangan karbon melalui metan dan CO_2 sebesar 2,086; 1,986; dan 1,967 t $ha^{-1}th^{-1}$ masing-masing dari lahan gambut pedalaman, peralihan, dan pantai. Pemberian bahan amelioran dapat menekan kehilangan karbon pada ketiga jenis tanah gambut tersebut masing-masing sebesar 0,597; 0,609; dan 0,628 t $ha^{-1}th^{-1}$, serta meningkatkan hasil padi. Dari hasil penelitian terlihat bahwa tanpa pemberian bahan amelioran maka perkiraan waktu yang diperlukan untuk dekomposisi seluruh karbon organik pada masing-masing lahan gambut tersebut adalah 660; 1.247; dan 2.820 tahun. Sementara itu, dengan pemberian bahan amelioran maka waktu yang diperlukan untuk dekomposisi adalah 980; 1.789; dan 3.950 tahun masing-masing untuk gambut pedalaman, peralihan dan gambut pantai.

Kata Kunci : *Tanah gambut, Bahan amelioran, Metan, Karbon dioksida, Padi*

INTRODUCTION

Indonesia has peat land of about 21.9 million ha that spread over Sumatra, Kalimantan and Irian Jaya. In the last three decades, this land has been used intensively for agricultural activities, in particular for annual crops and plantation. Conversion of the peat forest for agriculture reduces peat stability and accelerates the decomposition process. The decomposition process will be accelerated under aerobic condition and this leads to higher methane and carbon dioxide emissions. Boer *et al.* (1996) reported that methane emission from peat forest in Central Kalimantan was about 5.71 mg $m^{-2}h^{-1}$ while from rice field was about 9.40 mg $m^{-2}h^{-1}$. The use of Fe^{3+} cation in peat soil can reduce the rate of carbon loss. Sabiham and Sulistyono

1. Central Sulawesi AIAT (BPTP Sulteng)

(2000) reported that adding Fe, in the form of $FeCl_3.6H_2O$ at a rate of equivalent to 5% maximum adsorption of Fe^{3+}, could reduce CH_4 and CO_2 emission rates of Jambi peat soils by about 23.01% and 29.94%, respectively, while those of Kalimantan peat soils by about 32.97% and 27.67%, respectively. Furthermore Salampak (1999) found that the use of mineral soil (with high Fe content) as ameliorant at a rate of 10 t ha^{-1} in Sampit transitional peat, reduced concentration of fenolat acid by about 30% and increased rice yield by about 380%.

At present, some of peat forests in Cental Kalimantan have been used for agricultural activities mainly for rice. The rice growing areas are found in inland, transitional, and coastal peat soils. Productivity of these soils, particularly inland peat soils, is very low. This study evaluated the impact of using ameliorant on CH_4 and CO_2 emissions as well as rice productivity in these three peat soils.

MATERIALS AND METHOD

The study was conducted in Central Kalimantan at Berengbengkel (inland peat), Sampit (transitional peat), and Samuda (coastal peat). The treatments were arranged using Randomized Complete Block Design, namely :

1. A0 = without ameliorant
2. A1 = 100% mineral soils
3. A2 = 10% slag + 90% mineral soils
4. A3 = 20% slag + 80% mineral soils
5. A4 = 30% slag + 70% mineral soils
6. A5 = 40% slag + 60% mineral soils
7. A6 = 50% slag + 50% mineral soils
8. A7 = 100% slag

Amount of ameliorant used in each treatment is presented in Table 1 and it was calculated based on 5% maximum adsorption of Fe^{3+} .

Methane and carbon dioxide emissions were measured using chamber made from flexi glass with dimension of 1 x 0.5 x 0.5 m^3. Thermometer and small wind fan were placed in the chamber. The wind fan is to ensure the homogeneity of air in the chamber before sampling. The air samples from the chamber were taken at 0, 4, and 8 weeks after transplanting (WAP) using syringe. Air sampling was replicated four times with sampling interval at about 5 minutes, i.e. at 0',5',10', and 15'.

RESULT AND DISCUSSIONS

Methane and carbon dioxide emissions. It was indicated that the rate of CH_4 and CO_2 emissions from paddy field of inland peat soils is the highest, followed by transitional and coastal peat soils (Table 2). Relative rates of CH_4 emissions from transitional and coastal peat soils to those from inland peat soils were 97% and 96%, respectively, while for difference in humification level, fiber and water content between the three peat soils. Humification level of inland peat soils is the lowest among others. Peat soils with low humification level will be

Table 1. Amount of ameliorant used in each treatment at the three locations

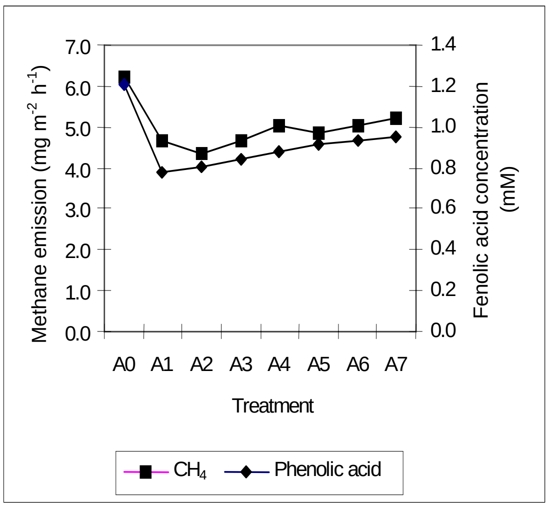
Location	Maximum adsorption	Amount of mineral soil (MS) and slag (S) used											
		A1	A2		A3		A4		A5		A6		A7
		MS	MS	EFS	MS	EFS	MS	EFS	MS	EFS	MS	EFS	EFS
	$\mu g\ g^{-1}$	……………… t ha^{-1} ………………											
Samuda	20227	7.86	7.08	0.58	6.29	1.17	5.51	1.75	4.72	2.34	3.93	2.92	5.48
Sampit	16842	6.55	5.89	0.49	5.24	0.97	4.58	1.46	3.98	1.95	3.27	2.43	4.87
Berengbengkel	10351	4.45	4.00	0.33	3.56	0.66	3.11	0.99	2.67	1.32	2.22	1.65	3.30

Note : Calculated based on Fe^{3+} solubility from mineral soil (23.3%) and slag (16.2%) and slag F_2O_3 content in mineral soil (22.1%) and slag (42.6%). EFS= electric furnace slag.

Table 2. Means and standard deviation of CH_4 and CO_2 emission rates from inland, transitional, and coastal peat soils in Central Kalimantan

Gases	Age of crops	Berengbengkel (inland)		Sampit (transitional)		Samuda (coastal)	
		Mean	Stdev	Mean	Stdev	Mean	Stdev
		………………………………… mg m^{-2} h^{-1} …………………………………					
CH_4	0 WAP	6.38	0.32	6.20	0.61	6.14	0.23
	4 WAP	7.38	0.51	6.77	0.11	6.90	0.57
	8 WAP	7.04	0.12	-	-	8.27	0.35
CO_2	0 WAP	66.61	0.87	61.98	3.74	57.21	3.57
	4 WAP	74.60	3.48	72.82	4.32	60.49	3.57
	8 WAP	68.68	2.24	-	-	76.96	4.63

Note : WAP = Week After Planting; Stdev = standard deviation



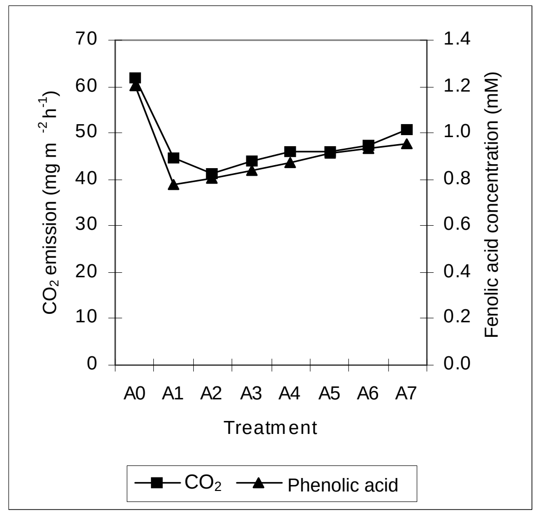


Figure 1. Effect of ameliorant on (a) CH_4 emission rated and (b) CO_2 emission rates

decomposed faster as this peat soil contains high organic matter that makes it easy to be decayed. In addition, water content of inland peat soils is also higher than those of the other two peat soils.

Rates of CH_4 and CO_2 emissions from the paddy field also increased with age (Table 2). Rates of CH_4 and CO_2 emissions at 4 WAP in comparison with those at 0 WAP increased by about 14% and 9%, respectively. This increase related to role of rice plant as media for releasing the gases from the soils into the atmosphere. Methane produced by the soil micro-organisms in the sub-surface layers of soils was dispersed to the root zone and then transported by the plant aerenchyma to the leaves and released to the atmosphere. Denier Van der Gon (1996) stated that about 90% of the total methane emissions from rice field were released to the atmosphere through the crops. According to Neue *et al*. (1992) the maximum emission occurred at panicle initiation stage.

Effect of ameliorant on rates of CH_4 and CO_2 emissions. Application of ameliorant into peat soils could increase the stability of the soils through the reduction of CH_4 and CO_2 emissions. It was found that by adding only mineral soils as ameliorant, the rate of methane emission droped from 6 to about 4 mg $m^{-2}h^{-1}$ and then increase gradually up to about 5.5 mg $m^{-2}h^{-1}$ when the composition of mineral soils in the ameliorant was reduced (Figure 1). Similarly, rate of CO_2 emission also decreased significantly when the mineral soil was added into peat soils as ameliorant, i.e. from 60 to about 45 mg $m^{-2}h^{-1}$, and then it increased again up to 50 mg $m^{-2}h^{-1}$ if slag was aplied as ameliorant.

In comparison with previous study, the rate of CH_4 emission from this study was a bit higher. Boer *et al.* (1996) found that the rate of CH_4 emission from shallow peat soils (70 cm depth) was only 3.2 mg $m^{-2}h^{-1}$ while in this study was about 6 mg $m^{-2}h^{-1}$. This indicates that the thickness of peat determines the rate of the emission as this study was conduced at peat soil with 1-5 m depth. This fact is in line with Buttler *et al.* (1994) finding where the CH_4 emission tended to increase with peat thickness. On the other hand, the rate of CO_2 emission from this study was lower than that of previous study conducted at subtropical peat soils (Buttler *et al*., 1994). The difference was about 20 mg $m^{-2}h^{-1}$. This is because the organic matter in subtropical peat soils was composed of spaghnum matters that are easy to be decomposed, while tropical peat soils were derived from hardwood (high lignin content) that are more difficult to be decomposed.

Furthermore, Figure 1 indicates that the pattern of CH_4 and CO_2 emission rates is similar to that of phenolic acid concentration. This phenomenon relates to the polimerization of phenolic acid with Fe from ameliorant as a cation bridge which leads to the deceleration of decomposition process.

At present, total area of peat lands that have been used for agricultural activities (rice in particular) is about 3.95 million ha (19.7%). Based on this findings, total CH_4 and CO_2 emissions from the agricultural peat land would be about 10.13 and 107.88 t $ha^{-1}yr^{-1}$, respectively or equivalent to about 1.18 and 0.06% of total national emissions from agricultural sector. If ameliorants were applied, the total CH_4 and CO_2 emissions from these agricultural peat soils can be reduced by about 25.1 and 27.3% respectively.

Estimation of carbon loss. Based from these findings, it can be estimated that the carbon loss from rice field in the peat lands as a result of CH_4 and CO_2 emissions was about 2.07 t C $ha^{-1}yr^{-1}$ for inland peat, 1.99 t C $ha^{-1}yr^{-1}$ for transitional peat and 1.97 t C $ha^{-1}yr^{-1}$ for coastal peat (Table 3). By adding ameliorant, the rate of carbon loss would decrease to about 1.49 t C $ha^{-1}yr^{-1}$ for inland peat, 1.38 t C $ha^{-1}yr^{-1}$ for transitional peat, and 1.34 t C $ha^{-1}yr^{-1}$ for coastal peat. These estimates were lower than those reported by Maltby (1997), i.e. 5-42 t C ha^{-1} yr^{-1}.

Table 3. Estimated carbon loss from peat soils with and without ameliorant addition

Treatment	Estimated of C loss		
	……………. t $ha^{-1}yr^{-1}$ …………….		
Without ameliorant	2.07	1.99	1.97
With ameliorant	1.49	1.38	1.34

If we assumed total organic carbon of coastal peat was 1312 t ha^{-1} (C-organic 57.0%, bulk density 0.2 g cm^{-3}, and thickness 115 cm), transitional peat 2475 t ha^{-1} (C-organic 57.3%, bulk density 0.2 g cm^{-3}, and thickness 220 cm), and coastal peat 5882 t ha^{-1} (C-organic 57.7%, bulk density 0.2 g cm^{-3}, and thickness 510 cm), the time required for decomposition would be lengthened to about 980, 1789, and 3950 years, respectively.

Productivity of peat soils. From observation, most of rice crop planted in inland peat soils of Berengbengkel stoped growing at age of 42 days after planting (DAP). Team IPB (1986) reported that the rice crop would stop growing at 30 DAP. This is because the concentration of phenolic acids in the inland peat soils is too high. Tadano *et al.* (1992) stated that the phenolic acids such as *p*-hydroxybenzoic, p-coumaric, ferulic, vanilic, syringic, and sinapic acids can poison the crop in particular at the early stage of growing. By applying only mineral soils as ameliorant, this condition could not be restored (Table 4). However, if slag were used as ameliorant, the rice crop could grow with yield of about 1.56 t ha^{-1}. This might be because the slag contain nutrients that are required by the crops such as Ca, Mg, and Si. Suwarno and Goto (1997) stated that the slag contained about 209-226 g CaO kg^{-1}, 98-122 g MgO kg^{-1}, and 121-160 g SiO_2 kg^{-1}. It was reported that natural fertility of inland peat soils is very low since it was formed under rainfall regime and very thick *(ombrogen peat).* In addition, below these soils it is found sand layer which contains very low nutrient.

Table 4. Yield of IR 64 at different ameliorant application

No.	Treatment	Inland	Transitional	Coastal
		…………………… $t\ ha^{-1}$	……………………	
1.	A0	0^{a}	2.11^{a}	4.08^{a}
2.	A1	0^{a}	2.27^{a}	4.18^{a}
3.	A2	0.61^{b}	2.35^{ab}	4.37^{ab}
4.	A3	0.78^{c}	2.51^{ab}	4.78^{ab}
5.	A4	0.3^{d}	3.09^{abc}	5.00^{ab}
6.	A5	1.11^{e}	4.15^{abc}	5.07^{ab}
7.	A6	1.14^{e}	4.78^{bc}	5.17^{ab}
8.	A7	1.56^{f}	5.08^{c}	5.62^{b}

Application of ameliorant could significantly increase the yield of rice crop planted in transitional peat soils. By adding mineral soils and slag (50%: 50%) to the peat soils, the yield of crop increased from 2.1 to 4.8 $t\ ha^{-1}$ (Table 4). By increasing slag composition in the ameliorant (>50%), the rice yield did not increase further. On the other hand, rice crop planted at coastal peat soils could reach 4.1 ton rice ha^{-1}. However, with ameliorant application (50% slag) the yield could increase up to 5.2 $t\ ha^{-1}$. Crop performances grown under the three peat soils were different due to the difference in fertility. Naturally, coastal peat soils are more fertile than transitional and inland peat soils. Base saturations of these three soils were about 8.1, 6.6, and 3.8%, respectively.

CONCLUSION

Methane and carbon dioxide emissions from inland peat are the highest and followed by transitional and coastal peat soils. Ameliorant application reduced the rate of emission between 25 and 27% thereby reducing the rate of carbon loss. The estimated carbon loss reduction due to ameliorant application was about 0.60 $t\ C\ ha^{-1}yr^{-1}$ for inland peat soils, 0.61 $t\ C\ ha^{-1}yr^{-1}$ for transitional peat soils and 0.63 $t\ C\ ha^{-1}yr^{-1}$ for coastal peat soils.

Productivity of coastal peat soils can be increased just by adding mineral soils at a rate of 7.9 $t\ ha^{-1}$, while transitional peat soils needs slag with composition of 4.6 t mineral soil ha^{-1} and 1.5 t slag ha^{-1}. Productivity of inland peat soils can not be restored eventhough 100% of slag was used as ameliorant.

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