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Soil amelioration using steel slag in drained peatland under oil palm plantation increases CO₂ emission

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Abstract. Increasing the productivity of tropical peatland can be achieved by soil ameliorations using steel slag and lateritic soil. However, the effect of such ameliorants on the peat decomposition is not well understood. This study was aimed to evaluate the influence of soil ameliorants of steel slag and lateritic soil to peat decomposition as reflected by CO₂ emission. A year study was conducted in smallholder oil palm plantation in Jambi Province, Indonesia to monitor CO₂ emission from treatments plots of control (T1), steel slag 600 kg ha⁻¹ (T2), lateritic soil 600 kg ha⁻¹ (T3) and a combination of T2 and T3 (T4), which each treatment had 5 replications. CO₂ emission was measured every three months by a closed chamber method. Results showed that CO₂ emission were followed the order of T4>T2>T1≥T3. CO₂ emission from T4 (49 ± 20 t ha⁻¹ year⁻¹) was 20% higher than T1 (40 ± 23 t ha⁻¹ year⁻¹), while T2 (44 ± 17 t ha⁻¹ year⁻¹) was 9% higher than T1. CO₂ emission from T3 (40 ± 14 t ha⁻¹ year⁻¹) was similar to T1. This study showed that steel slag accelerates peat organic matter decomposition which is indicated by higher CO₂ emission of steel slag treatments compare to other treatments.

1. Introduction

The oil palm plantation area in Indonesia was expanded over time on both mineral and peat soils, addressing the increased global demand of vegetable oil, fats, and biodiesel [1-3]. Although peatland was considered unsuitable for agricultural purposes, the limited areas of mineral soil caused the peatland conversion was unavoidable. The total peatland area in Indonesia is 13.4 million ha [4] which is mainly distributed over three big islands of Sumatra, Kalimantan, and Papua. Around 1.7 million ha of Indonesian peatland is used for oil palm plantation [5].

Oil palm cultivation in peatland always started with land clearing and subsequently followed by water drainage for providing convenient access to the land and favoring the root to grow well. However, drainage leads the increased organic matter, which releasing huge CO₂ gas into the atmosphere and worsening global warming [6].

Peatland had soil physicochemical problems, which caused the low productivity of crops cultivated there [7-9]. However, ameliorations together with fertilization have been applied to increase the productivity of peatland [10]. These inputs' quantity and quality depend on the capital, where estate companies are mostly having big access to these inputs while smallholders are lack. This situation explains why smallholders have lower productivity compare to companies. Steel slag and lateritic soils are ameliorants materials used to increase oil palm productivity in tropical peatland.

Steel slag is a metal material, which generated as a by-product of steel manufacturing [11]. Steel slag contains Si, Ca, Fe, Al and Mn [12,13], which are widely used as soil ameliorant to reduce soil acidity and improve crop productivity [14-16]. However, the effect of steel slag in agriculture soils to suppress



greenhouse gas emission is still in argument due to the widely variation of environmental factors [17,18]. Moreover, the published report regarding the greenhouse effect on steel slag used in tropical agriculture peatland is limited.

Lateritic soil is a highly weathered soil, which had low nutrient content, high clay mineral content, low cation exchange capacity and high Al and Fe oxides [19, 20]. Lateritic soils were distributed across Indonesian islands and commonly found as Ultisols and Alfisols in terms of soil taxonomy [21]. Lateritic soils have the potential to be used as soil ameliorant in peatland due to their function to stabilized organic acid [22]. However, the published report on greenhouse gas emission as the response of incorporation of lateritic soil with peat soil is difficult to find.

The used of steel slag and lateritic soil to increase oil palm productivity in tropical peatland is growing. However, the effect of steel slag and lateritic soils on CO₂ released from soils are not being fully understood. This issue should be recognized to address the sustainable management practices of peatland agriculture. This study was aimed to evaluate the effect of steel slag and lateritic soil used in peatland to on the peat decomposition as reflected by CO₂ emission.

2. Materials and methods

2.1. Site description

This field experiment was established in smallholder oil palm plantation in Sumber Agung Village, Sungai Gelam Sub District, Muaro Jambi District, Jambi Province, Indonesia, at the geographic coordinate of 103°52'E and 1°43'S in the period of July 2010 to July 2011. The detailed land characteristic including the land and crop management of this study site, at the time of this study, was already reported comprehensively in a published article [23].

2.2. Treatment design

Twenty study plots were established each located in the middle distance of trees, in frond pile rows, where human traffic along these rows was very limited. Four treatments of soil ameliorants were established i.e. T1: no soil ameliorant application; T2: steel slag 600 kg ha⁻¹; T3: lateritic soil 600 kg ha⁻¹; and T4: T2+T3. Each treatment had five replications, which all were distributed according to Randomized Block Design.

Before treatment application in early July 2010, composite peat samples from three depths of 0 to 15, 15 to 30 and 30 to 50 cm were collected each plot using a special peat auger (Eijkelpkamp, Netherland). Lateritic soil was collected from the nearest Ultisols, while steel slag was brought from the waste steel industry in Java Island. Peat samples together with soil ameliorants of steel slag and lateritic soil were then analyzed in a laboratory. Chemical properties of peat, steel slag, and lateritic soil were available in table 1.

Table 1. Chemical properties of peat, steel slag, and lateritic soil used in this study

Items	Units	Peat (cm depth)			Steel slag	Lateritic soil
		0-15	15-30	30-50		
P ₂ O ₅	%	31	22	10	0.01	nt
K ₂ O	%	0.03	0.03	0.03	nt	nt
CaO	%	0.33	0.23	0.13	27.8	0.08
MgO	%	0.11	0.13	0.11	0.05	0.08
Fe	%	0.02	0.02	0.01	13.5	6.5
Cu	ppm	23	15	18	60.7	53
Zn	ppm	22	18	18	718	64
B	ppm	nm	nm	nm	373	218
Mn	ppm	38	18	12	nm	nm

All the data are given on an oven-dried basis; nm=not measured; nt=not traceable.

Plots area of 3 m x 3 m was cleared from weed, roots, litter, remaining wood log and subsequently leveled. Perforated PVC pipes were installed in each plot for monitoring water table depth. About 3 cm depth of peat was removed and placed in the bucket then incorporated with ameliorants. The mixed peat and ameliorants were then returned on the plot.

2.3. *CO₂ measurement*

Once treatments already were applied, CO₂ emission from the middle of the plot was measured by a closed chamber method using an infrared gas analyzer (IRGA Li-820). PVC chamber with a diameter of 25 cm and height of 25 cm, which the cap equipped with a gas inlet, outlet, and glass thermometer, was used to trap and measure the CO₂ gas concentration inside the chamber. Gas chambers were installed on each plot 24 hours before CO₂ measurement to minimize the effects of soil disturbance on microbial activity. CO₂ measurement was conducted one day after treatments application in the morning and calculated based on of the following equation [24]:

$$fc = \frac{Ph}{RT} \times \frac{dC_c}{dt} \quad (1)$$

Where fc is CO₂ flux, P represents atmospheric pressure, h is the chamber height, R is a gas constant, and T is the temperature inside the chamber, dC_c/dt is the changes of CO₂ concentration by time.

2.4. *Environmental factors*

Environmental factors of soil temperature, air temperature, chamber temperature and water table level were selected based on their relationship with peat decomposition [6, 18, 23, 26]. During gas sampling, the temperature inside the chamber, 1 m above the chamber, and 5 cm inside the soil were recorded. Water table depth was also be monitored manually using a measuring stick.

2.5. *Data analysis*

The effect of soil amelioration to CO₂ emission was analyzed using ANOVA and the difference among treatments was analyzed using Duncan Multiple Range Test with a 5% significant degree. The relationship between the two variables was analyzed using Pearson's correlation method.

3. Results

3.1. *Averaged CO₂ emission*

Averaged CO₂ emission has followed the order of T4>T2>T1>T3 (figure 1). The highest CO₂ emission was T4 (49 ± 20 t ha⁻¹ year⁻¹), 20% higher than T1 significantly (40 ± 23 t ha⁻¹ year⁻¹). T2 was the second with 44±17 t ha⁻¹ year⁻¹ means 9% higher than T1 significantly. CO₂ emission from T3 (40 ± 14 t ha⁻¹ year⁻¹) was similar to T1.

3.2. *Temporal variation of CO₂ emission*

The average CO₂ emission at the beginning of this study was relatively similar among treatments, in the range of 37-42 t ha⁻¹ year⁻¹ (figure 2). The pattern of T1 during the period of October 2010 to April 2011 was different compare to T2, T3 and T4. CO₂ emission from the T1 plot was extremely increased in October 2010 then gradually decline. The rest of the treatments were also increased in October 2010 but not as high as T1. They increased consistently until April 2011 then decreased together with T1.

3.3. *Averaged environmental factor*

Correlation analysis was done between treatments and the environmental factors of soil temperature, air temperature, chamber temperature and water table level. Those environmental factors were selected based on their relationship with peat decomposition [6,18,23,26] and were collected coincident with CO₂ measurement in the field. This analysis already neglected the outliers, which were determined by the 5th and 95th percentiles. Table 2 shows no peat environmental factors had a significant correlation with CO₂ emission (5% p-level).

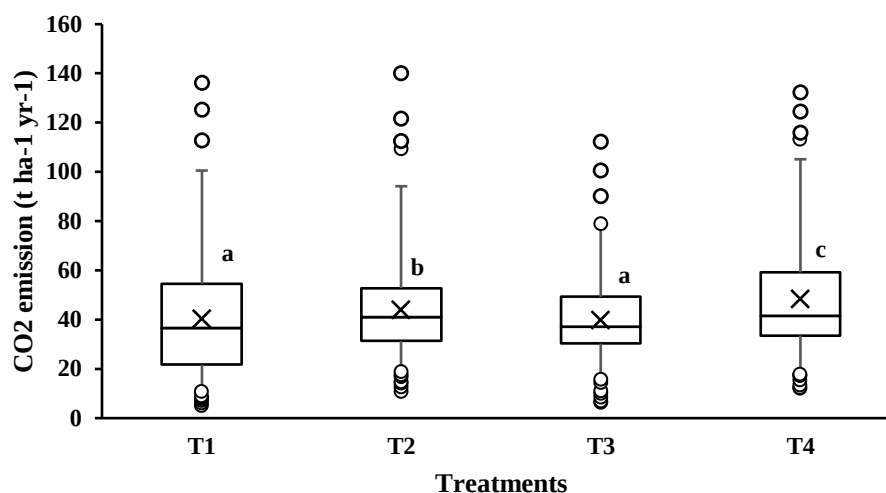


Figure 1. Box-whisker plot showing the distribution of peat CO₂ emission and their mean (X) for different treatments of ameliorants under oil palm plantation at the study site. Outliers (hollow dots) were determined by the 5th and 95th percentiles. Different alphabetical means were significantly different at 5% of DMRT.

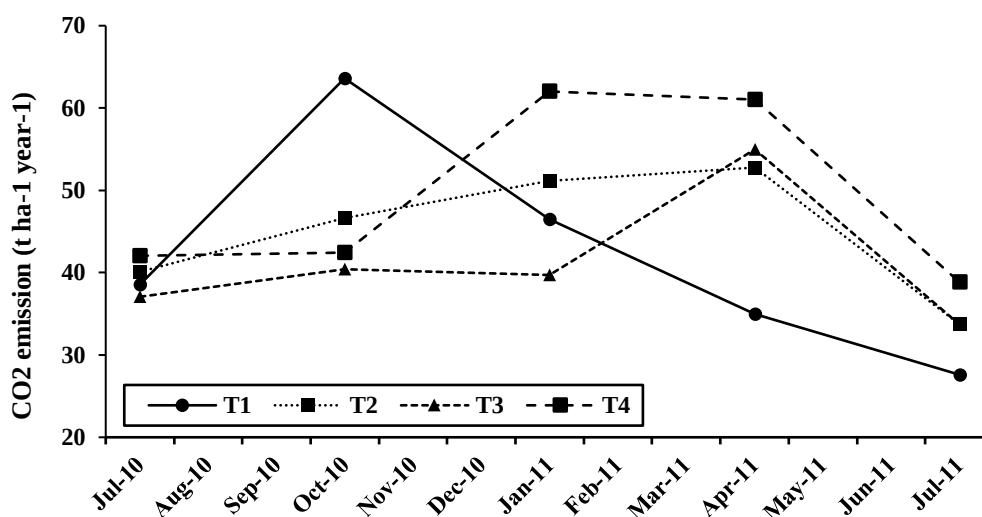


Figure 2. Temporal variation of averaged CO₂ emission from for different treatments of ameliorants under oil palm plantation at study site.

Table 2. Pearson's correlation between CO₂ emission and peat environmental factors

Environmental factors	CO ₂ emission (t ha ⁻¹ year ⁻¹)			
	T1	T2	T3	T4
Soil temperature (°C)	-0.47	-0.32	0.12	0.06
Air temperature (°C)	-0.43	-0.12	0.28	-0.02
Chamber temperature (°C)	-0.41	-0.14	0.22	-0.03
Water table depth (cm)	0.06	-0.29	-0.52	-0.32

4. Discussion

4.1. Effects of treatments to peat CO₂ emission

Steel slag increases organic matter decomposition in peat, reflected by the higher CO₂ emission of T2 than T1 (figure 1). Steel slag contain high CaO (table 1) which could increase the soil pH, favors the microbial activity to decompose peat then releasing CO₂ into the atmosphere. Moreover, nutrients were not available for crops such as phosphate (P) in the low pH circumstances of peat [22]. The transformation P into available form for roots, in the favorable soil pH, is very important to support the metabolism process in crop tissues. The high micronutrient content of Fe, Zn and Mn of steel slag (table 1) could also important for roots. The high activity of roots reflected in the high organic substrates production which those easily be consumed by microbes, lead to increased CO₂ production [25]. Furthermore, the autotrophic respiration of roots was also high due to the high root activity [26].

Steel slag with additional lateritic soil in T4 had the highest CO₂ emission, indicates the increasing microbial activity due to the additional micronutrient from lateritic soil. However, the number of nutrients in lateritic soils alone was insufficient to increase the microbial activity in peat, proven by the similar CO₂ emission between T1 and T3. The low nutrient content and low active clay of lateritic soils of T3 have no contribution to enhance microbial activities.

4.2. Temporal fluctuation of CO₂ emission

The result of the first CO₂ measurement has not reflected the effect of soil ameliorations because it was carried out once after soil amelioration applied. CO₂ emission is by-product of organic matter decomposition by microbes which the process needs time. The range CO₂ emission of 37 to 42 t ha⁻¹ year⁻¹ indicates the high micro variation of peat characteristic and environmental factors affected peat decomposition (figure 2).

In the second CO₂ measurement, 3 months after treatment application, T1 was extremely high indicates the effect of soil disturbance occurred during the preparation of the study plot. The peat disturbance possibly enhances peat aeration and the more oxidic condition of peat accelerates labile organic matter decomposition. However, CO₂ emission from T2, T3 and T4 was not dramatically increased, although peat aeration increased, which possibly due to the increased bonding between labile organic matter with soil ameliorants [14]. The lower CO₂ emission in the soil ameliorants treatment indicates that organic matter decomposition in the form of ligand occurs slower than labile organic matter decomposition.

In the third CO₂ measurement, 6 months after treatment application, T1 was decline continuously until the end of this study. It indicates the labile organic matter was decreased over time. Conversely, CO₂ emission tend to be increased on soil amelioration treatments, indicates the peat decomposition process increase simultaneously. This increased CO₂ emission occurred until the fourth measurement and subsequently decreased in the fifth measurement, which means 9 and 12 months after treatment application, respectively. Peat decomposition tends to be constant after one-year soil amelioration.

Temporal variation of CO₂ emission in this study revealed the importance of long-term measurement of soil amelioration study, at least one year, regarding its effect on peat decomposition. The long-term study showed the possibility, even without direct measurement, of the interconnection among organic matter quality, microbial activity, and soil ameliorant to CO₂ emission. However, in the short-term study below 3 months, which somehow using cash crop, soil amelioration may suppress CO₂ emission likewise this study.

5. Conclusions

Based on this year field study, we found that steel slag amelioration increases peat decomposition, which possibly because of the favoring effect of additional steel slag to soil microbe activities. Soil lateritic ameliorant is not affecting CO₂ emission possible due to the low CaO and nutrient content.

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