The potential of ameliorants to mitigate carbon dioxide emission from oil palm plantation on peat soil

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Abstract. The development of oil palm plantations on peatlands leads to the release of greenhouse gases (GHG) into the atmosphere. Soil amelioration can improve the fertility of peat soil because consists of polyvalent cations that overcome the negative effect of high-level organic acid as well as reduce GHG emissions. This study aimed to observe the effectiveness of soil amelioration for reducing carbon dioxide ($CO_2$) emission from oil palm plantations on peat soil. The study was carried out on smallholder oil palm at Kumpeh, Muara Jambi District, Jambi Province. The study was arranged with six treatments and four replications of a Randomized Completely Block Design (RCBD). The treatments were control, manure, compost of empty fruit bunch, lateritic soil, pugam (peat fertilizer) type A and type T. The results showed that ameliorants could reduce $CO_2$ emission by approximately 1.7 – 34.4% compare to control except program T. The lowest $CO_2$ emission was produced during 5-7 weeks after the first application of ameliorants. The soil ameliorants should be added every 4 months to control the $CO_2$ emissions from peat soil. Long term observation is needed to more explore the potential of ameliorants to reduce $CO_2$ emission from oil palm plantation in peat soil.

1. Introduction

Nowadays, palm oil production meets up around 61% of vegetable oil produced worldwide [1][2]. Oil palm development to increase production is estimated to grow significantly over the coming years [3]. Palm oil production has a significant contribution as a driver of socio-economic development, improving livelihoods, and reducing poverty [4]. The intensification on a global scale and land-use change to increase production is necessary in order to meet the demand due to the increasing world population. On the other hand, it raises environmental concerns, in terms of deforestation and usage of marginal soil i.e., peat soil. Since 1990, oil palm plantation is one of the contributors of 2.5 Gt C losses in carbon stock in tropical peatlands [5]. However, there is limited data on how rapidly carbon is lost during the conversion process of oil palm plantation in peatland.

Peat soil covers an area of 14.9 million ha in Indonesia and it is spreading out in Sumatra, Kalimantan, Papua, and Sulawesi and other islands approximately around 35%, 32%, 30%, and 3%, respectively [6][7]. There is approximately 25 million ha of global peatland distribution in oil palm growing countries and only around 200,000 to 300,000 ha of oil palm plantation on peatland can be found in Sumatra and Kalimantan [8]. Deforestation and drainage of natural peat forest for conversion to oil palm plantations
highly affect greenhouse gas (GHG) emission and carbon accumulation that contributing to global warming [9][10][11]. Peat and forest degradation contribute around 45% of total GHG emissions from Indonesia [12]. Peat management is the potential target to reduce GHG emissions from Indonesia [13].

Although the ecosystem of peat soil is fragile, peat soil has important biological and hydrological functions. Cultivation management is needed for agricultural use of peatland including lowering of the water table, soil conservation practices i.e., soil amelioration, and other soil-crop management. These treatments hold promise for achieving GHG mitigation and adaptation [14]. The GHG emission of oil palm plantations on tropical peat soils is needed to be documented to explain conservation practices in oil palm development on production and environmental problem. Therefore, the aim of this study was performed to investigate the effectiveness of soil amelioration to mitigate carbon dioxide (CO₂) emission from oil palm plantations on peat soil.

2. Materials and methods

2.1. Study site
The field experiment was laid out at Arang-Arang oil palm smallholders, in Kumpeh Sub-District, Muaro Jambi Regency, Jambi Province, Indonesia that is located between 1°38'00.2"-1°38'58.3"S and 103°47'50.3"-103°49'58.4"E (Figure 1). This study had been carrying out as a part of a global study on peatland management under the coordination of the Indonesian Center for Agricultural Land Resources Research and Development.

![Figure 1. Map of Arang-arang village, Jambi Province.](image)

2.2. Experimental design and cultivation method
Each plot was cultivated by 48 plants with 8 m x 9 m planting size of oil palm. Each plot was 64 m x 54 m and the plots were arranged by a randomized complete block design with six treatments; namely control (without ameliorant/A0), empty fruit bunch compost of oil palm (A1), manure (A2), lateritic soil (A3), pugam (peat fertilizer) type A (A4) and type T (A5). Each of the treatments was replicated four times. The ameliorants and fertilizers were broadcast on a circle 200 cm from the center of the oil palm every 6 months.
2.3. CO₂ measurement

CO₂ fluxes at the soil surface were measured using a closed chamber method. Gas samples were collected 2 times a day (in the morning and the afternoon) by 10 ml syringes with 6, 12, 18, and 24 min after closure. CO₂ concentrations were determined on the day of sampling and analyzed using micro gas chromatography (GC) equipped with a thermal capture detector (TCD). The CO₂ fluxes were calculated using linear regression between gas concentration and sampling time.

3. Results and discussions

3.1. CO₂ emission

The CO₂ fluxes for the various treatments are shown in Table 1. The maximum and the minimum CO₂ fluxes were found from the compost of empty fruit bunches (A1) and control (A0), respectively. The highest CO₂ reduction was resulted by application of manure (A2) around 34.4% and followed by lateritic soil (A3), compost of empty fruit bunches (A1), and type A peat fertilizer (A4) around 26.5, 9.8 and 1.7%, respectively. The application of manure and compost of empty fruit bunches influence soil carbon (C) cycling, affect plant growth, and change the microbial community structure [15]. Lateritic soil reduced CO₂ emission most likely because it contains high iron and aluminum oxide that can be used as an oxidizing agent. Lateritic soils are formed in the tropics through weathering processes that favor the formation of iron, aluminum, manganese, and titanium oxides [16]. Moreover, an ameliorant that contains active polyvalent cations has the potential ability to reduce CO₂ emission from intensively managed peatland [17].

Table 1. Minimal, maximal, and average CO₂ fluxes from 6 treatments of soil ameliorants application at oil palm plantation on peat soil.

| Treatments | Min       | Max       | Average  | % reduction |
|------------|-----------|-----------|----------|-------------|
| A0         | 0.31      | 19.81     | 3.4      |             |
| A1         | 0.44      | 23.07     | 3.1      | 9.8         |
| A2         | 0.51      | 12.01     | 2.4      | 34.4        |
| A3         | 0.90      | 16.82     | 2.8      | 26.5        |
| A4         | 0.60      | 16.17     | 3.6      | 1.7         |
| A5         | 1.04      | 22.02     | 3.9      | -10.9       |

3.2 Effectiveness of soil amelioration

The effective utilization of empty fruit bunch compost of oil palm, manure, lateritic soil, pugam (peat fertilizer) type A and type T is shown in Figure 2. Linear regression of CO₂ fluxes and time of gas sampling was found at control (without application of soil ameliorant), while application of empty fruit bunch compost of oil palm, manure, lateritic soil, pugam (peat fertilizer) type A and type T show polynomial trend. The lowest CO₂ emission was produced during 5-7 weeks after the first application of ameliorants. The soil ameliorants should be added every 4 months to control the CO₂ emissions from peat soil Table 2. The lowest CO₂ emission was resulted by manure approximately 73.76 mg m⁻² hour⁻¹.

Adding of ameliorant on peatland is expected would have a positive impact on soil fertility, and reduction of oil palm CO₂ emission. The effective utilization of organic amendment, i.e., compost and manure, requires this material for enhancing soil fertility and it can be broadcasted around the circle of the oil palm tree. Compost or mature organic material is a better source of quality nutrients and results in lower GHG emissions than fresh organic material. Generally, empty fruit bunch is being used as a source of soil nutrients for the nearby oil palm plantations and as a result, increases the organic matter content of soil [18]. Intensifying the existing production of oil palm through soil conservation management on peatland can both satisfy demands of the crop production and reduce greenhouse gas emissions.
Synergistic options to meet multiple objectives should be done to achieve not only food security and sustainability but also environmental friendly [19].

Figure 2. The effectiveness of soil ameliorants application at oil palm plantation on peat soil.

Table 2. Correlations between soil ameliorants application and time for gas sampling at oil palm plantation on peat soil.

| Treatments | R²   | Regression (y = ax²+bx+c) | The effectivity of ameliorants (week) | Lowest CO₂ fluxes (mg m⁻² hour⁻¹) |
|------------|------|---------------------------|---------------------------------------|-----------------------------------|
|            |      | a            | b          | c          | Begin | End   |                          |
| A0         | 0.662 | -0.1        | -32.3     | 418.0     | 7     | 13    | 106.00                   |
| A1         | 0.680 | 12.1        | -169.7    | 701.0     | 7     | 13    | 73.76                    |
| A2         | 0.734 | 9.6         | -126.7    | 489.9     | 5     | 13    | 82.29                    |
| A3         | 0.668 | 9.5         | -129.1    | 520.2     | 5     | 13    | 105.74                   |
| A4         | 0.745 | 16.2        | -219.8    | 851.3     | 5     | 13    |                          |
| A5         | 0.371 | 11.3        | -153.1    | 700.5     |       |       |                          |

4. Conclusions
In summary, soil ameliorants are needed to meet up the demands of crop production and reduce CO₂ emissions. Therefore, ameliorants should be added every 4 months to control the CO₂ emissions from peat soil. However, long term observation is needed to more explore the potential of ameliorants to not only reduce CO₂ emission but also to gain the production of oil palm plantation in peat soil.

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