Abstract No: A-043

GREENHOUSE GAS (GHG) EMISSIONS IN RELATION TO WATER TABLE AND SOIL AMELIORATION FROM TROPICAL PEAT SOILS

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SUMMARY

Tropical peatlands could be a source of greenhouse gases (GHG) as they contain large amounts of soil carbon (C). In order to be suitable for cultivation, peatlands must be drained, limed and fertilised due to the excess water, acidic soil properties and low soil fertility. On the other hand, drainage and soil amelioration may influence GHG emissions. This study was conducted with the aim to understand the effect of water table depth and soil amelioration on GHG emissions on tropical peat soils. Peat soil columns from Central Kalimantan, Indonesia were used to estimate GHG emissions under different water tables and soil amelioration treatments. Twenty seven peat columns were arranged using a randomized block design with two factors; water table position at 15 cm, 35 cm and 55 cm from the soil surface, and secondly 3 different ameliorants: without ameliorant/control, biochar (2.5 tonnes ha^{-1}) + compost (2.5 t ha^{-1}); steel slag (2.5 t ha^{-1}) + compost (2.5 t ha^{-1}). Each of the treatments was replicated three times. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions from the peat soil columns were measured at weekly intervals for 92 days and analysed using gas chromatography in the Indonesian Agricultural Environment Research Institute (IAERI). Results showed that soil ameliorations influenced CO_2 and N_2O emissions from the peat soil. As application of soil ameliorants tended to stimulate GHG emissions, amelioration of peat soils to enhance soil fertility should be more wisely considered due to the effect on GHG emissions. Estimated GHG emissions from the treatments were between 0.12-0.32 kg CO_2-C column^{-1} 92 days^{-1}. Water tables affected the C-stock and net CO_2-C exchange in peat soil columns.

***Keywords**: biochar, columns, compost, steel slag, water table depths*

INTRODUCTION

Tropical peatlands in Indonesia are mostly distributed in Sumatra, Kalimantan and Papua and cover an estimated 14.9 million ha and account for about 47% of the total tropical peatland area which contain an estimated 33-55 Gt of carbon (C) (Wahyunto *et al.*, 2004 and 2005; Ritung *et al*., 2011; Page *et al.*, 2011). However, tropical forest peatlands are susceptible to large-scale C losses, due to their large C store and rapid rates of deforestation (Langner *et al.*, 2007). Large areas of tropical forest peatland in Indonesia have been converted into agricultural and non-agricultural sectors because of human population growth and economic development. In the agricultural sector, the C-stock in soil is affected by changes in land-use or management practices

Both natural and converted tropical peat soils are important contributors to the global C cycle as they could be a source of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Inubushi *et al.*, 2003). Natural peatlands that are used for agricultural activities need to be drained, limed and fertilized due to excess water, low nutrient content and high soil acidity. Drainage and soil management of peat soils influence greenhouse gas (GHG) emissions. Lowering the water table increases C mineralization and CO_2 and N_2O emissions but decreases CH_4 emissions (Moore and Dalva 1993; Regina *et al.*, 1996; Berglund and Berglund 2011). Soil ameliorants are applied not only to enhance the nutrient status of the soil and to improve crop yield but also to reduce GHG emissions (ICCTF 2011; Susilawati *et al.*, 2016). Most studies on soil ameliorations/amendments have been conducted in mineral soils; however, a few publications on the effects of soil amelioration in peat soil have also been reported (Subiksa *et al.*, 2009)

Most GHG studies in tropical peatlands are based on remote sensing data as direct measurements of gas fluxes are expensive, complicated and have technical constraints (Jaenicke *et al.*, 2008; Page *et al*., 2011). While in the field, daily GHG emissions can vary depending on the climate and hydrologic regime. Therefore, we conducted this study to investigate the influence of water table depth and soil amelioration treatment on peat soil columns adjusted to the same conditions.

MATERIALS AND METHODS

The soil sampling site was located at Jabiren, Pulang Pisau district, in Central Kalimantan province, Indonesia (02°30´52.5´´S, 114°10´11.6´´E). Polyvinyl chloride (PVC) pipes, with length of 100 cm and diameter of 21 cm were used to collect the peat soil.

A randomized block design with two factors was used to establish 3 different water tables depths (15 cm, 35 cm and 55 cm from the soil surface) and 3 different ameliorants (without ameliorant/control, biochar (2.5 tonnes ha^{-1}) + compost (2.5 t ha^{-1}); steel slag (2.5 t ha^{-1}) + compost (2.5 t ha^{-1})). There were three soil columns replicates for each treatment and a total of 27 soil columns were manipulated. Each soil column was placed into a large bucket in the greenhouse and the water table of each bucket was checked using a transparent tube (diameter 10 mm) that was installed on the outside wall of each the bucket. The water tables were checked daily to ensure they remained at a constant level. Rain water was used to set the water depths.

Gas samples for CO_2, CH_4 and N_2O from the soil columns were measured simultaneously once a week for 92 days. Gas samples were measured with the closed chamber method (Sapkota *et al.*, 2014). Gas samples from the chamber were taken once a week using 10-cm^3 syringes and the sampling was repeated 5 times during chamber closure (at 5, 10, 15, 20 and 25 minutes). Gas sampling commenced at 06:00 in the morning on each sampling day. Gas samples were determined by a gas chromatograph (GC) which was equipped with a thermal conductivity detector (TCD) for CO_2 analysis, a flame ionization detector (FID) for CH_4 analysis and an electron capture detector (ECD) for N_2O analysis.

According IPCC (2007), GHG emissions was calculated as CO_2 + (25 x CH_4) + (298 x N_2O). Soil carbon stocks (per unit area) was estimated as the product of C concentration (%C), bulk density (g cm^{-3}), and soil volume (m^{-3}) (Warren *et al.*, 2012).

A two-way analysis of variance (water tables and ameliorations) followed the Least Significant Difference (LSD) test were used to compare the mean values of GHG emissions, soil C-stock and net CO_2-C exchange. Soil C-stock changes were measured using C content of the peat soil after treatments. Statistical analyses were conducted using SAS University Edition.

RESULTS AND DISCUSSION

There was no interaction between water tables and ameliorations on GHG emissions (Figure 1). There was no significant effect of water tables on GHG emissions, however, there was a significantly ($P < 0.01$) effect of amelioration on GHG emissions from the peat soil columns. The GHG emissions from all treatments ranged from 0.12-0.32 kg CO_2-C columns^{-1} 92 days^{-1}. The GHG emissions from the control treatment were approximately 0.14 kg CO_2-C columns^{-1} 92 days^{-1} and those from the biochar+compost and steel slag+compost treatments were approximately 0.29 and 0.20 kg CO_2-C columns^{-1} 92 days^{-1}, respectively. The application of biochar+compost and slag+compost to the peat soil columns significantly increased GHG emissions compared to the control treatment by approximately 51% and 29%, respectively.

The high GHG emissions from the biochar+compost treatment are likely due to the increased availability of the microbial substrates following biochar+compost application and subsequent increased microbial decomposition and mineralization of the organic matter (Smith *et al.* 2010; Jones *et al.* 2011).The application of compost in this treatment increased the availability of the nitrogenous substrates and the easily degradable organic matter for denitrification (Linn and Doran 1984; Dobbie *et al.*, 1999). GHG emissions from the soil amended with biochar depend on the characteristics of the biochar, the addition of exogenous nitrogen and soil properties (Zhang *et al.*, 2010).

The application of steel slag+compost most likely stimulated GHG emissions as the electron acceptor activity associated with steel slag was not sufficient to accept all of the electrons released from the reduction process due to the high organic matter content (Lee *et al.*, 2012). Compost and peat soils have high soil organic matter (SOM) contents and that the application of steel slag+compost caused lower GHG emissions compared to the biochar+compost treatment. In this study, both soil ameliorants increased soil pH. According to Ali *et al.* (2009), the alkaline pH of steel slag contributes to an increase in soil pH. In addition, soil pH increases in tropical acid soils supplied with composts derived from organic products (van der Watt *et al.*, 1991). Although the mechanism of increasing soil pH through the application of organic matter is not fully understood it likely occurs because of the specific adsorption of organic anions and the corresponding release of hydroxyl ions (Hue, 1992). This study showed that the biochar+compost and steel slag+compost treatments increased GHG emissions as both soil ameliorants increased the soil pH.

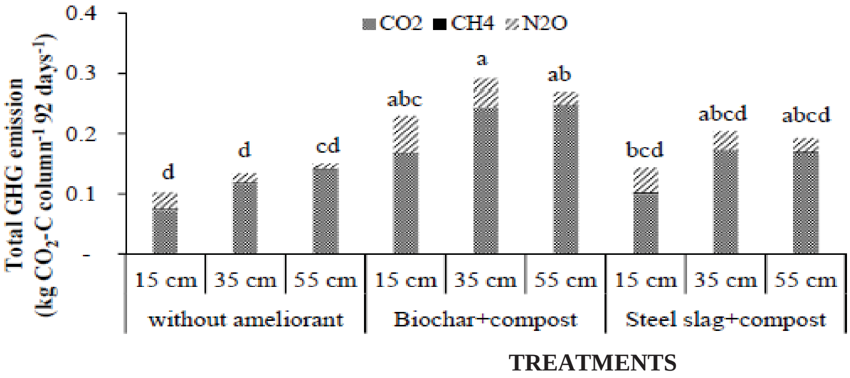

Figure 1: GHG emissions from the different water table depths (15, 35 and 55cm) and soil amelioration treatments in the peat soil columns.

There was no interaction between water table and soil amelioration on the C-stock in the peat soil columns. This study indicates that the water table depth had a major impact on the C-stock, while soil ameliorant was relatively unimportant (Figure 2). The C-stock ranged from approximately 0.96-1.41 kg C column^{-1}. In the different water table treatments, the highest C stock (1.39 kg C column^{-1}) was found when the water table was -35 cm below the soil surface followed by -15 cm (1.30 kg C column^{-1}) and -55 cm (1.00 kg C column^{-1}).

The carbon stock in agricultural soils is an important indication of CO_2 sequestration from the atmosphere (Paustian *et al.* 1998). According to Mazzoleni *et al.* (2012), C-stock in agro-ecosystems depends on C-inputs as well as on its outflows, as regulated by the organic matter decay rates. The C losses in the peat soil columns recorded over the short term may be a transient phenomenon. Therefore, longer-term experiments should be developed to monitor changes that occur over time in response to amelioration at various water table depths. In this study, CO_2 emissions contributed the highest emissions compared to CH_4 and N_2O emissions. The contribution of CO_2 emissions was approximately 81%, followed by N_2O (17.6%) and CH_4 (1.33%) emissions (Figure 1). Deeper water tables tend to lead to more intensified oxidation rates, faster soil decomposition and lower C-stocks in peat soil column (Moore *et al.* 1993).

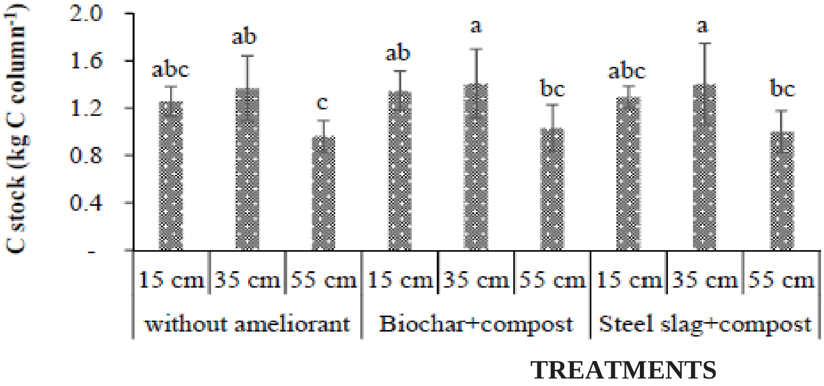

Figure 2: Carbon (C) stock under different water tables depths (15, 35 and 55cm) and soil ameliorations in peat soil columns.

The CO_2-C exchange between the atmosphere and terrestrial systems represents the balance between C inputs by autotrophic fixation and outputs by autotrophic respiration and heterotrophic oxidation of organic material. In this study, net CO_2-C exchange was determined from changes in the topsoil organic C and total CO_2-C fluxes. The net CO_2-C exchange between the atmosphere and terrestrial were approximately 0.75-1.22 kg CO_2-C column^{-1} 92 days^{-1} (Figure 3). There was no interaction between the treatments but there was a significant effect of water table on net CO_2-C exchange in the soil. The lowest values were found at 55 cm below the soil surface. According to Hirano *et al.* (2009) hydrology is one of the most important abiotic factors influencing the net CO_2-C exchange in tropical peatlands. Drawdown of the water table increases oxygen content in the soil, thereby stimulating aerobic decomposition

In this study there was a linear correlation between CO_2 emission and water table. This likely occurred because oxygen diffusion into the soil increases when the water table is lowered; therefore the soil becomes aerated stimulating aerobic decomposition (Silvola *et al.* 1996; Nykanen *et al.* 1998).

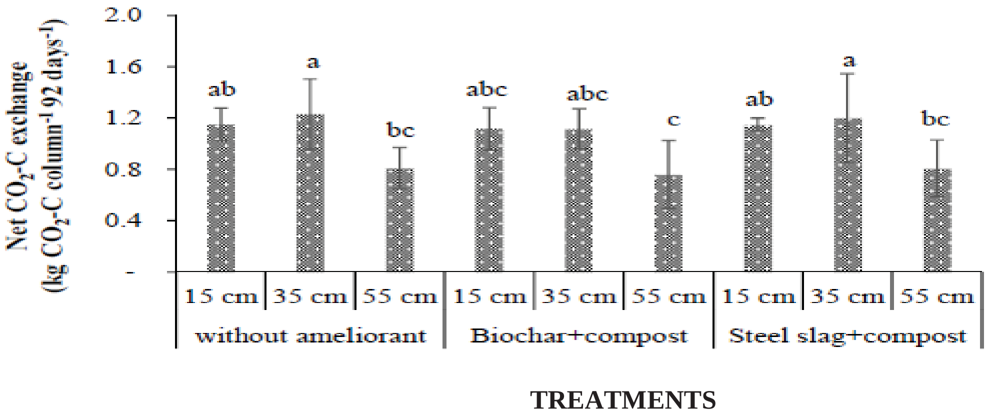

Figure 3: Net carbon dioxide (CO_2-C) exchange under different water tables depths (15, 35 and 55cm) and soil ameliorations in peat soil columns.

CONCLUSIONS

The biochar+compost and steel slag+compost treatments increased GHG emissions from the peat soil columns. Water table drawdown resulted in lower C-stocks and net CO_2-C exchange. Long-term experiments should be developed to monitor changes that occur over time in response to amelioration at various water tables.

ACKNOWLEDGEMENTS

This study was financially supported by Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture.

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