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Abstract. Peatlands with very high C contents are generally considered a source of greenhouse gas (GHG) emissions. This research aimed to quantify the changes in peatland characteristics and GHG emission from the conversion of peatlands to agricultural areas. Height of water table, pH, electrical conductivity (EC), redox potential (E_h), organic carbon (OC), hot water-soluble C, total-N, the concentrations of NH_4^+, and NO_3^-, soluble-Al, soluble-Fe, and the emission of CH_4, CO_2 and N_2O were quantified before and after land clearing of peats for agriculture. Results of study showed that pH, EC, OC contents, hot water-soluble-C, and total-N did not change after peatland clearing for agriculture. On the other hand, the concentrations of NH_4^+, NO_3^-, soluble-Al, soluble-Fe, redox potential and height of water table increased significantly after the peatland land clearing. Methane emissions from peatlands before peatland clearing were in the range of 0.13-0.22 mg C m^{-2} h^{-1} increased significantly to 0.14-0.31 mg C m^{-2} h^{-1} after the peatland clearing. The land clearing of peatlands for agricultural practices also caused increases in CO_2 and NO_x emissions by 85% and 76%, respectively. Changes in GGH emissions were not related to the changes in substrates quality of peats (OC contents, total-N and hot water- soluble-C). Results of the study indicate that increases in the GHG emission following the use of peatlands for agricultural areas are attributed to the changes in the peat characteristics.

1. Introduction

Peatlands in Indonesia, which are commonly found in Kalimantan, Sumatra, and Papua, are part of world's tropical peatlands and estimated to range from 16.8 to 27.0 million ha [1]. Peatlands with high rates of organic matter accumulation and low rate of decomposition are considered as sink of C. The amount of C stored in Indonesian peatlands is estimated to reach 55 Gt [2]. Peatlands are also capable of depositing water up to 10 times their mass [3,4]; therefore, peatlands are able to store large amounts of water during the rainy season and will then release slowly during the dry season [5,6]. Results of these studies indicate that peatlands in Indonesia play an important role in environments.

Some of Indonesia's peatlands have been reclaimed and used for agricultural lands in the last two decades, especially for large-scale oil palm plantation [7]. Conversion of peatlands to agricultural

lands causes an increase in GHG emissions from reclaimed peatlands [8,9]. The use of 416,000 ha of deep peatlands for oil palm plantations in the Ex Mega Rice Project of Central Kalimantan, Indonesia is projected for the next 25 years to emit 93–217 Mt CO_2 equivalent [10]. The conversion of peatlands into agricultural lands may cause Indonesia to be a contributor country to GHG emissions in the world.

Information on the mechanism of increasing GHG emissions due to the conversion of peatlands to agricultural areas is very crucial for the GHG emission mitigation of reclaimed-peatlands. Results of previous studies showed that long-term conversion of peatlands for agriculture results in changes in substrate quality of peats [11,12], which eventually results in changes in the GRG emission of peatlands. The use of tropical peatlands for paddy cultivation for 15 years results in a decrease in carbohydrate content and an increase in lignin content [13]. Peat with O-alkyl-C structures decrease significantly, while peat alkyl-C structures show a significant increase after a-20-year agricultural practices in tropical peatlands [14]. Results of these studies imply that changes in the GHG emission due to long-term use of peatlands for agricultural is related changes in the substrate quality of peats. However, comprehensive information on factors controlling changes in the GHG emission due to short-term conversion of peatlands to agricultural areas is unavailable. Therefore, the objective of this study was to quantify the immediate changes in the emissions of CH_4, CO_2, and N_2O following the use of peatlands for agricultural areas.

2. Materials and Methods

2.1. Experimental site and the measurement of gases

The study site is administratively situated in the Desa Landasan Ulin Utara (3°09'56.6"−3°10'41.0" S; 114°37'58.3"−114°39'51.4"E), Sub-District of Liang Anggang, Kota Banjarbaru, Province of South Kalimantan. The average temperature in the areas was 27-28 ^oC, and the annual precipitation was 2,600 mm. Dominant vegetation in this peatlands were *Melaleuca cajuputi* Roxb, *Melastoma malabathricum* L., and *Stenochlaena palustris* (Burm.F) Bedd.

Sampling and measurements of greenhouse gas emissions and peat characteristics were carried out at 15 different sampling points twice, before the land clearing (last week of November 2017) and after land clearing (second week of December 2017). Gas sampling was carried out using a static chamber method. The gas was collected at interval of 4, 8, 12 and 15 minutes after the closure of chamber using a 10 mL syringe through the septum in the middle of the chamber, then the collected gas was transferred to a 10 mL air-tight glass vial. The gas was then injected onto the Shimadzu GC-14A equipped with electron capture detector for N_2O measurement, flame ionization detector for CH_4 measurement, and thermal conductivity detector for CO_2 measurement. The calculation of gas fluxes were carried out using linear regressions of the change in gas concentration, the volume of chamber, and soil surface area and corrected for the field measured air temperature and atmospheric pressure [15].

2.2. Peat sampling and characterization

Peat samples were collected from each sampling point at a depth of 30 cm. Soil pH, electrical conductivity, height of water level, and redox potential were measured directly in the field. After removing plant debris, the samples were stored at 4 ^oC until the determination of peat chemical characteristics. Ammonium and NO_3 were extracted from peats using KCl 1 N (1:10=weight:volume), and the concentrations of NH_4 and NO_3 in the extract were measured using a hydrazine reduction method for NO_3-N and an indophenol blue method for NH_4-N [16]. The amount of organic-C in the peat was determined using the wet oxidation method of Walkley-Black [17], and total-N in the peats was measured using the Kjelhdahl method [18]. Hot water soluble-C was extracted from the peat using warm water (60 ^oC), and the concentration of organic-C in the extract was quantified using the anthrone-sulfuric acid method [19]. Soluble-Al and -Fe were extracted from the peat using NH_4OAc 1 N pH 4.8, and the concentrations of Al and Fe in the extract were quantified using aluminon and o-penanthroline methods, respectively [20,21].

2.3. Statistical analysis

Comparison of mean using t-test was conducted to assess if there are differences in the means of variables before and after land clearing of peats for agriculture. Relationship between the emission of CH_4, CO_2, N_2O and soil characteristics of peats was measured using correlation-regression analyses. All statistical analyses were performed using GENSTAT 12th Edition [22].

3. Results and Discussion

The conversion of peatlands to agriculture areas resulted in an immediate increases in the emissions of CH_4, CO_2, and N_2O (Figure 1). Methane emission before peat land clearing for agriculture was higher than that before land clearing (P<0.05). Methane emission before land clearing ranged from 0.13 to 0.22 mg C m^{-2} h^{-1} (average 0.17 mg C m^{-2} h^{-1}), while range of 0.13–0.31 mg C m^{-2} h^{-1} (average 0.23 mg C m^{-2} h^{-1}) CH_4 emission was observed after land clearing (Figure 1). Land clearing of peatlands for agriculture also resulted significant increases in CO_2 and N_2O emission by 85.48% and 76.34%, respectively (P<0.05).

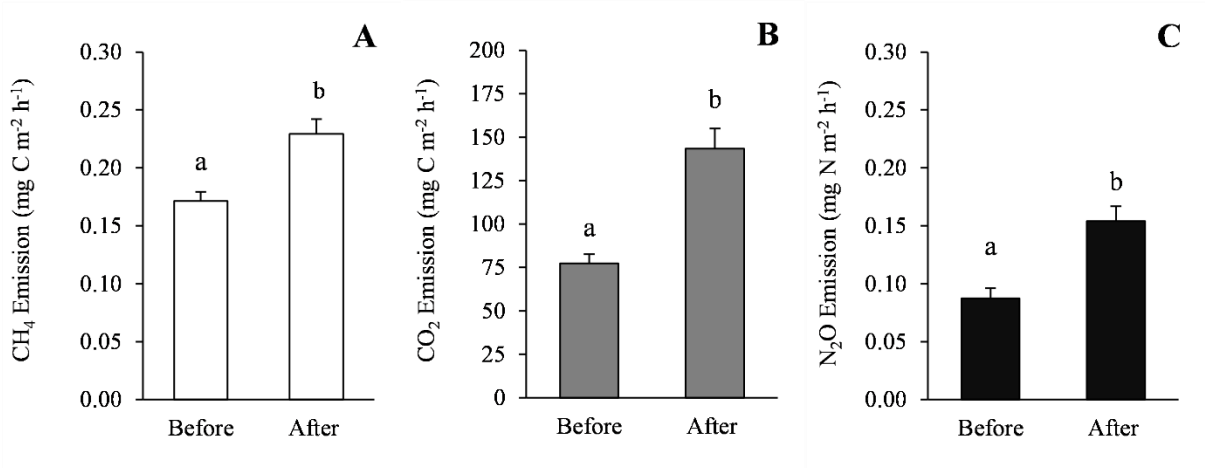

Figure 1: Emissions of CH_4 (A), CO_2 (B), and N_2O (C) before and after land clearing of peats for agriculture. The vertical bars represent standard errors of mean (n=15). Similar letters above columns indicate no statistical differences in GHG emissions between before and after land clearing of peats for agriculture based on the mean difference test at P<0.05.

It well known that the GHG emission are significantly influenced by environmental factors such as soil pH, redox potential, temperature [23,24] and changes in substrate quality of organic-C (peats) [25,26]. Peat characteristics before and after land clearing of peatlands were quantified to determine the relationship between changes in the GHG emissions and changes in peat characteristics before and after land clearing. Several peat characteristics such as peat pH, EC, organic-C and total-N contents, and hot water-soluble-C content were not significantly different between before and after land clearing (P>0.05; Table 1). On the other hand, land clearing of peatlands for agriculture led to considerable increases in the height of water table, redox potential, the concentrations of NH_4 and NO_3, and the concentration of soluble -Al and -Fe (P<0.05; Table 1).

No.	Peat Characteristics	Before	After
1.	Peat pH (H_2O, 1:5)	3.49 ± 0.05* *a***	3.52 ± 0.05 *a*
2.	Electrical Conductivity (mS)	391.99 ± 9.07 *a*	368.18 ± 6.25 *a*
3.	NH_4^+ (mg N kg^{-1})	9.76 ± 0.94 *a*	20.10 ± 2.14 *b*
4.	NO_3^- (mg N kg^{-1})	9.94 ± 1.94 *a*	22.16 ± 1.37 *b*
5.	Height of water table (cm)	2.11 ± 3.89 *a*	-8.56 ± 2.24 *b*
6.	Redox potential – E_h (mV)	-7.29 ± 6.81 *a*	-71.47 ± 9.87 *b*
7.	Organic C (g C kg^{-1})	189.59 ± 6.59 *a*	192.56 ± 6.48 *a*
8.	Total N (g N kg^{-1})	12.84 ± 0.92 *a*	12.55 ± 0.92 *a*
9.	Hot water soluble C (mg C kg^{-1})	32.43 ± 5.29 *a*	31.18 ± 5.30 *a*
10.	Soluble Al (mg Al kg^{-1})	11.38 ± 1.05 *a*	22.64 ± 1.90 *b*
11.	Soluble Fe (mg Fe kg^{-1})	15.37 ±1.62 *a*	32.93 ± 2.73 *b*

* Standard error of mean (n=15). ** Different small case indicate statistically differences between peat characteristics before and after land clearing of peats for agriculture based on the mean difference test at $P<0.05$.

Table 1: Changes in peat characteristics before and after the use of peatlands for agriculture.

Results of the previous studies stated that changes in the emission of GHG due to land changes are attributed the changes in the substrate quality [27,28]. However, the parameters of peat substrate quality in this study such as organic-C, total-N, and hot water soluble-C were not significantly different between before and after land clearing of peatland for agriculture ($P>0.01$; Table 1) and were not related to the changes in the GHG emission (data not shown). No significant changes in the parameters of peat substrate quality and no significant relation between substrate quality of peats and the GHG emission are probably due to short period before after land clearing (only three weeks) was not able to change the substrate quality of peats. Therefore, changes in the GHG emission in this study was likely to be attributed to the changes in the chemical characteristics of peats before and after land clearing. Results of the analyses of correlation and regression showed that the emission of CH_4 was related significantly to the changes in the height of water table and redox potential (Figure 2A and 2B), the emission of CO_2 was negatively correlated with the concentration of soluble-Al and -Fe (Figure 2C and 2D), and the emission of N_2O have significant correlation with the concentration of NO_3 and NH_4 (Figure 2E and 2F).

It was reported in the previous study that water table level control the emission of CH_4 from peatlands in China, in which the water level surface of peatlands drawdown from 0 to 50 cm below soil surface lead to 82% reduction in the CH_4 emission [29]. Results of study of tropical peat swamp forest also showed that increasing ground water level led to the development of anaerobic conditions, which is eventually stimulated CH_4 production [30]. Redox potential (Eh) is commonly used to determine the methanogenic activity. The methanogenic activity is negatively correlated with the Eh values, in which Eh of below +240 mV are reported to be threshold levels for methanogenic activity [31]. Relationship between redox potential and the emission of CH_4 in this study was in agreement with previous studies in the tropical peatlands [32,33].

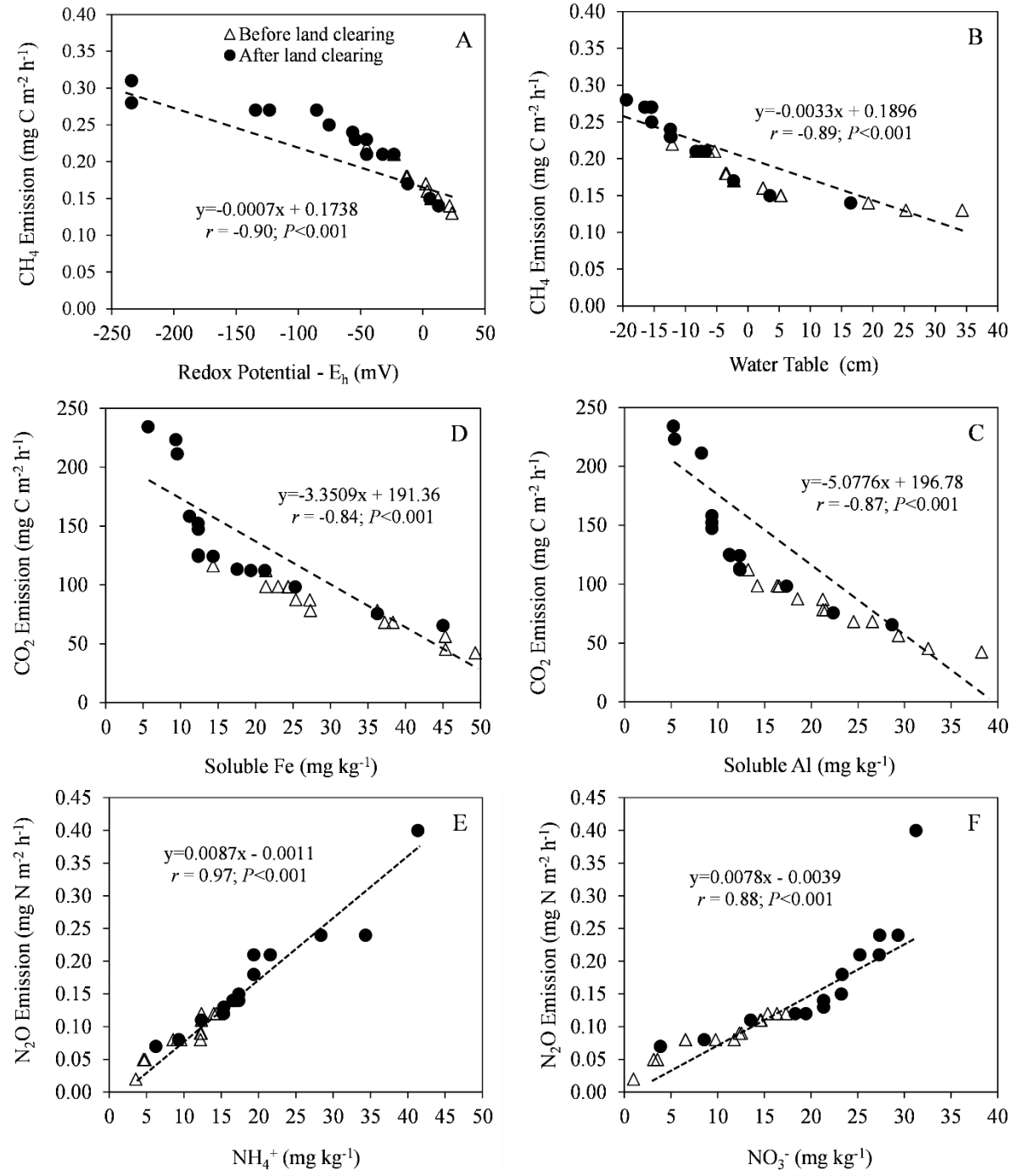

Figure 2. Relationship between CH_4 emissions and redox potential (A), CH_4 emissions and height of water table (B), CO_2 emissions and soluble-Al (C), CO_2 emissions and soluble-Fe (D), N_2O emissions and NH (E), and N_2O emissions and NO_3 (F).

Carbon dioxide emission of peatlands was in the range of 42.35–112.35 mg C m^{-2} h^{-1} before land clearing increased to 98.45–234.40 mg C m^{-2} h^{-1} after land clearing (Figure 2). The presence of Fe and Al in soils reduces C mineralization due the stabilization of organic-C through cation bridging and ligand exchange of organic-C by Al and Fe, which is eventually increasing the amount of organic-C protected from microbial decomposition [34,35]. Results of this study showed that the emission of

CO_2 was significantly and negatively correlated with soluble-Al and -Fe (Figure 2), indicating important roles of soluble Al and Fe in reducing C mineralization of peats. Results of this study are consistent with the previous studies stated that the presence Al and Fe decreases C mineralization [36,37].

The amounts of NH_4 and NO_3 are often considered to be the factors controlling the rate of N_2O emission through nitrification and denitrification processes [38,39]. The concentration of NH_4 and NO_3 increased from 3.56–15.25 mg N kg^{-1} before land clearing to 12.35–41.32 mg N kg^{-1} after land clearing and from 0.98–21.35 mg N kg^{-1} before land clearing to 14.56–31.24 mg N kg^{-1} after land clearing, respectively (Table 1 and Figure 2). Increasing the amounts of NH_4 and NO_3 following land clearing of peats for agriculture results in increasing the emission of N_2O. This was supported the significant and positive correlation between the emission of N_2O and the concentration of NH_4 and NO_3 (Figure 2).

4. Conclusion

The emissions of CH_4, CO_2, and N_2O increase significantly following land clearing of peatlands for agriculture. Land clearing of peatland for agriculture also result in significant changes in chemical characteristics peats, i.e. height of water table, redox potential (Eh), the concentration of NH_4 and NO_3, and the concentration of soluble-Al and -Fe However, peat pH, electrical conductivity and the parameters of peat substrate quality such as organic-C, total-N, and hot water-soluble-C did not change following land clearing of peatlands for agriculture. Short period of peatland conversion for agriculture (three weeks) was thought to be unable to changes the substrate quality of peats. Results obtained in this study demonstrate that changes in the emission of CH_4, CO_2, and N_2O as a results of a short period of peatland conversion for agriculture were attributed to the changes in the chemical characteristics of peats.

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