Temperature Effect Investigation toward Peat Surface CO₂ Emissions by Planting Leguminous Cover Crops in Oil Palm Plantations in West Kalimantan

Arifin¹, Suntoro Wongso Atmojo², Prabang Setyono³ and Widyatmani Sih Dewi⁴

1. Environmental Engineering Department, Tanjungpura University, Pontianak 78124, Indonesia

2. Agriculture Faculty, Sebelas Maret University, Surakarta 57126, Indonesia

3. Environmental Science Postgraduate Program, Sebelas Maret University, Surakarta 57126, Indonesia

4. Agriculture Postgraduate Program, Sebelas Maret University, Surakarta 57126, Indonesia

Abstract: The aim of this research was to know the impact of planting leguminous cover crops (LCCs) of *Mucuna bracteata* and *Calopogonium mucunoides* in oil palm plantation on peatland on reducing CO₂ emissions. Atmosphere temperature, peat surface temperature, in-closed chamber temperature and peat surface CO₂ fluxes were monitored on two adjacent experimental plots. The first experimental plot was on the newly opened peat surface (NOPS) and another was on the eight years planted oil palm land (EPOL). The closed chamber techniques adopted from International Atomic Energy Agency (IAEA) (1993) were implemented to trap CO₂ emissions emitted from 24 treatment plots at the 1st, 3rd and 6th months observations. Average CO₂ fluxes observed on no LCCs plots in the NOPS site were 61.25 ± 8.98 , 33.76 ± 2.92 and 33.75 ± 3.45 g/m²·h, while in the EPOL site were 55.38 ± 15.95 , 29.90 ± 5.32 and 27.70 ± 4.62 g/m²·h at the 1st, 3rd and 6th months monitoring, respectively. Average CO₂ fluxes observed on the planted *M. bracteata* plots in the NOPS site were 68.2 ± 24.5 , 12.88 ± 3.70 and 10.40 ± 1.28 g/m²·h, whereas in the EPOL site were 54.04 ± 6.70 , 11.45 ± 2.00 and 9.33 ± 3.49 g/m²·h at the 1st, 3rd and 6th months monitoring, respectively. Average CO₂ flux observed on the planted *C. mucunoides* plots in the NOPS site were 66.5 ± 23.7 , 15.41 ± 1.51 and 9.74 ± 2.55 g/m²·h, while in the EPOL site were 47.00 ± 5.00 , 9.34 ± 1.23 and 10.52 ± 4.80 g/m²·h at the 1st, 3rd and 6th months, respectively. *P*-value for the experimental sites was 0.008 (< 0.05), indicating the significant difference in the level of CO₂ fluxes between the sites. *P*-value for the treatments in the experimental plots was 0.000 (< 0.05), indicating markedly different level of CO₂ fluxes among treatments. *P*-value for the age of *M. bracteata* and *C. mucunoides* planted on the experimental plots was 0.000 (< 0.05), indicating the significant difference in the level of CO₂ fluxes due to the enhanced LCCs age performing at the increase of shading effects. The comparison of CO₂ fluxes among experimental plots shows that planting *M. bracteata* and *C. mucunoides* on the peatland could reduce CO₂ emission.

Key words: Temperature, peat surface CO₂ emissions, *Mucuna bracteata*, *Calopogonium mucunoides*.

1. Introduction

Lowland peatlands in Southeast Asia cover 24.8 million ha (Mha), which is 56% of the tropical area and 6% of the global peatland area. Their high carbon density gives rise to a large regional peat carbon store of 68.5 giga tons equivalent to 77% of the tropical and 11%-14% of the global peat carbon store [1]. Although peatlands cover only 6% of the terrestrial surface of the earth, they play a central role in the

global carbon (C) cycle. In their natural state, peatlands capture C as carbon dioxide (CO₂) with a long-term average uptake rate of 25 g C/m²/year [2]. Since 1990, 5.1 Mha of the total 15.5 Mha of peatland in Peninsular Malaysia and the islands of Kalimantan and Sumatra have been deforested, drained and burned, while most of the remaining peat swamp forest has been logged intensively [3, 4]. Over the same period, the area of unmanaged secondary peat swamp forest doubled to nearly one-quarter of all peatlands, whilst industrial oil palm and pulpwood (*Acacia*) plantations

Corresponding author: Arifin, M.Eng.Sc., research field: environmental science. E-mail: arifinghandi@yahoo.com.

expanded dramatically from 0.3 Mha to 2.3 Mha—an increase from 2% to 15% of the total peatland area [4] to cover over 3.1 Mha (20%) of the peatlands of Peninsular Malaysia, Sumatra and Borneo in 2010. The majority (62%) of these plantations were located on the island of Sumatra [5], but in West Kalimantan province (Indonesia Borneo), approximately 50% of peatlands have been converted to oil palm plantations with 1.7 Mha of peatlands under either current or future plantation use [6]. It is anticipated that the expansion of oil palm plantation in West Kalimantan province will be a major source of greenhouse gas emissions by 2020, if change in land use continues at current levels, with oil palm plantations predicted to one-third of the province's land by 2020. At the same time, the area of natural, intact forests will reduce from 15% in 2008 to 5% in 2020. The deforestation and drainage that accompany conversion of peat swamp forest to plantation result in the release of CO₂ into the atmosphere. If the expansion of oil palm plantations on peat lands continues without any restriction, then it is predicted that 90% of the greenhouse gas emissions associated with oil palm plantations will come from peat lands by year 2020 [7].

In a peatland plantation, CO₂ fluxes to the atmosphere are the product of both autotrophic (vegetation-derived) and heterotrophic (microbial-derived) respiration processes resulting from the decomposition of peat organic matter under the aerobic conditions. Until recently, most studies have invoked the groundwater table as the most important explanatory factor for the scale of heterotrophic emissions [8-12]. It is now becoming clear, however, that this is not the only factor and changes in peat surface temperature are also important, particularly on deforested peatlands where the peat surface is exposed to increased levels of solar radiation [13].

A recent study by Jauhainen et al. [13], for example, on the temperature dynamics and heterotrophic CO₂,

N₂O and CH₄ fluxes under different shading conditions on agricultural land and degraded peatland sites in Central Kalimantan, showed that shading of the peat surface and hence differences in peat temperatures had a marked influence on greenhouse gas (GHG) fluxes, with a 25% emissions increase for each 1 °C temperature change at 5 cm depth on agricultural land. The rate of decomposition of organic matter in peatlands increases positively with increase in temperature [14-16]. In the tropics, diurnal and annual temperature fluctuations are relatively modest compared to Northern peatlands. There is, however, a general temperature increase after deforestation and also an increase in diurnal temperature fluctuation in the surface peat and hence a likely increase in the rate of peat decomposition. A clear CO₂ emission and temperature relationship for tropical peat was found in the following four years of hourly automated monitoring of both variables in peat swamp forest, which was a doubling rate of instantaneous *in-situ* CO₂ emission over a 5 °C temperature range (from 24 °C to 29 °C) including autotrophic respiration emissions [17]. Moreover, long-term combined field and laboratory studies in the subtropical peatlands of the everglades (Florida) showed that peat oxidation expressing as peat surface subsidence doubled with a 10 °C increase in temperature [18]. Similarly, CO₂ emission rates from incubated surface samples of tropical peat from Sumatra were also found to double between 25 °C and 35 °C [19]. Hirano et al. [17] found that increase in temperature had a greater effect on CO₂ emission rate than soil moisture or water table depth.

In the study by Jauhainen et al. [13], soil surface shading was achieved using plastic shading nets, but given the extent of peatland under oil palm plantations, this would be costly and impractical to implement at a large scale. By contrast, soil shading by the use of cover crops could provide a much cheaper solution, with leguminous cover crops (LCCs) providing also some additional advantages for improved soil

condition and potential plantation productivity. Reducing peat temperatures could result in a marked reduction in peat carbon substrate loss, and hence not only a reduction in GHG to the atmosphere but also extended utilization of the peat substrate.

Two of the most widely used plantation cover crops in Southeast Asia are *C. mucunoides* and *M. bracteata*. *C. mucunoides* originated from the tropical Americas and West Indies. It then spread widely and is now found in most humid tropical areas (Africa, Asia, Australia). It was introduced into Indonesia and Malaysia as agricultural cover crop, as such is either grown alone or mixed with other legumes, especially in rubber, oil palm or young forest plantations. It provides soil protection against erosion, reduces soil temperature, improves soil fertility and controls weeds [14]. It grows optimally where daily temperature is in the range of 24-36 °C [14] and there is well-distributed or seasonal rainfall with annual values in the range of 1,000-1,500 mm [15]. It can grow on a wide range of soil types, but does best on acidic clay soils (pH 4.5-5). It is tolerant to high aluminium saturation but not with saline soils. It can tolerate with flooding, but has poor drought tolerance [14]. Fire also kills the plant, but seeds survive and regrow easily on ashes after a burn [16]. *C. mucunoides* is moderately tolerant to shade and can grow in plantations where light transmission is between 60% and 100%. It remains productive under coconut palms (at 60%-70% light transmission), but lower light transmission reduces yield and heavy shade can kill the plant [16]. *C. mucunoides* is a N-fixing legume that has no specific requirement for *Rhizobium* and nodulates readily. It is a valuable green manure in rice fields where it is tolerant to stagnant water conditions [15]; it has been used as a cover crop in plantations (banana, coffee, rubber, palms, black pepper), but should be prevented from overgrowing young trees by regular cutting [19].

M. bracteata is a native of India and adjacent countries. A thorough study was carried out on its

suitability to use as a cover crop in rubber plantations in India, where it was found to have all the desirable characters of an ideal cover crop. Later, it was introduced as a cover crop for *Hevea brasiliensis* (pararubber) and oil palm plantations in Malaysia and elsewhere. *M. bracteata* is a fast growing, deep rooted perennial creeping and climbing legume that was found to grow as a wild plant among road sides and forest boundaries in the Northeastern region of India. It grows fast with vine growths of 10-15 cm in a day. Fibrous roots develop from the nodes of vines growing on the ground, when the soil is wet. *M. bracteata* can be established in plantations either by seed or by rooted cuttings; the former is the most convenient and popular method in pararubber and oil palm plantations, where it can produce up to 5,620 kg biomass over a three years periods. Underneath, the green biomass—the dried mulch of about 30-40 cm thickness in a deep layer can develop at different stages of decay. These dried leaves slowly decompose and add nutrients to the soil, thus contributing nutrients to the main crop and higher yields. In addition, there is increased insulation of the soil surface, reduction in the loss of soil moisture and increase in soil moisture retention capacity. The other beneficial feature of *M. bracteata* is that it is a mycorrhiza species, which is also beneficial to the main crop through enhancing nutrient and water absorption. Finally, the growth of cover crops in plantations is also beneficial since they can smother the growth of weeds [20].

Oil palm plantations established on peatland is much less canopy cover than the original peat swamp forest. The surface peatland during the early stage of plantation growth receives a much higher level of solar radiation and thereby increases the peat surface temperature. In addition, the intensive drainage systems implemented in most oil palm plantation on peatlands maintain the groundwater level at ideally around 70 cm below the peat surface, but often at greater depths. Low water table combined with high

surface peat temperature drives a high heterotrophic CO₂ emission [21], with plantation on peatland recognized as a significant source of greenhouse gas emissions to the atmosphere in the Southeast Asian region [1, 5, 7, 22]. In order to investigate opportunities for emissions mitigation, this study investigated one approach to protecting the peat surface from solar radiation through the use of LCCs. Specifically, the roles of two widely utilized cover species—*C. mucunoides* and *M. bracteata*, were investigated. The study objective was to determine the use of LCCs in oil palm plantations toward the decrease of peat surface CO₂ emission.

2. Methodology

2.1 Sites

The field experiment was carried out in Arus Sungai Deras Estate of Mitra Aneka Rezeki oil palm

plantation, which administratively located in Teluk Pakedai Subdistrict, Kubu Raya District, West Kalimantan Province (Fig. 1). Geographically, the experiment site was located within the coordinate latitude of 109°18'14.53" East and longitude of 0°17'13.50" South with the height of 4-11 m above the sea surface. The experiment sites are categorized into the tropical climate of Afa climate type, which based on classification of average temperature on the coldest months above 18 °C, having no dry months with intensity lower than 60 mm/month and annual precipitation rate of over 2,500 mm/year. The peatland in Mitra Aneka Rezeki oil palm plantation classifies to S3 class or “marginal congruous” with the average daily air temperature marginal factors. Precipitation rate is recorded 2,611 mm/year with 153 rainy days, five wet months (precipitation > 200 mm/month) and five dry months.

Fig. 1 Study site (★) on Mitra Aneka Rezeki oil palm plantation (Teluk Pakedai Subdistrict, Kubu Raya Regency, West Kalimantan Province).

The average rainfall and rainy day in Kubu Raya Regency in 2013 were 281.8 mm and 19 d, respectively. The monthly rainfalls at the 1st (June), 3rd (September) and 6th (December) months CO₂ fluxes monitoring were 128, 231 and 445 mm, respectively [23]. The rainfall and rainy day in the Teluk Pakedai Subdistrict in 2013 were 146.42 mm and 12 d, respectively. The monthly rainfalls at the 1st, 3rd and 6th months CO₂ fluxes observation were 100, 166 and 302 mm, respectively [24].

The average, maximum and minimum atmosphere temperatures in Kubu Raya Regency in 2013 were 26.9, 32.4 and 23.5 °C, respectively. The average atmosphere temperatures at the 1st, 3rd and 6th months CO₂ fluxes monitoring were 27.3, 26.6 and 26.2 °C, respectively. The maximum atmosphere temperatures at the 1st, 3rd and 6th months CO₂ fluxes monitoring were 33, 31.9 and 30.8 °C, respectively. The minimum atmosphere temperatures at the 1st, 3rd and 6th months CO₂ fluxes monitoring were 22.5, 23.5 and 23.7 °C, respectively. The average relative atmosphere moisture in the Kubu Raya Regency in 2013 was 85%. The average relative atmosphere moistures at the 1st, 3rd and 6th months CO₂ fluxes monitoring were 83%, 86% and 90%, respectively [23].

The average C-organic, N-total and ratio of C-organic/N-total of peat in study site are 28.28%, 1.13% and 24.20, respectively. The average bulk density and water content of peat in study site are 0.24 g/cm³ and 400.10%, respectively. The average pH-H₂O, pH-KCl and redox potential in study site are about 2.96, 2.67 and 227.15 mV, respectively.

2.2 Experiment Site Setup

The two stage nested experiment design was conducted in this research and began in March 2013 by nursery of *M. bracteata* and *C. mucunoides* on the nursery area of Arus Sungai Deras Estate of Mitra Aneka Rezeki oil palm plantation for four weeks. The nursery of *M. bracteata* was done by cutting, whereas *C. mucunoides* was conducted by planting seeds in the

24 pieces polybags of 0.05 cm × 10 cm or 5 cm × 15 cm. *M. bracteata* and *C. mucunoides* were watered three times at 9:00 am, 12:00 pm and 3:00 pm a day during the nursery. Introducing manure/fertilizer into the polybags was avoided during the nursery. Two adjacent sites were selected for the experiment with different conditions and had 15 m apart from each other on the same peatland approximately 2 m depth. First site was not planted with oil palm—newly opened peat surface (NOPS), and ferns were the main vegetation in the area, such as species of *Lygodium*, *Polypodium*, *Pteris* and *Stenochlaena palustris*. The second was the eight years planted area by oil palm (EPOL). Both the sites were manually cleared from litter and vegetations including their roots before starting planting, so the first site became an opened surface area. Each 6 m × 8 m area was prepared in both the sites and divided into 12 plots of 2 m × 2 m. Each plot was marked by using small roundwood placed at the corner and given certain numbers. *M. bracteata* and *C. mucunoides* were planted in accordance with the specified plots randomly (Fig. 2). Especially for the opened area, the layers of plastic shading net were tightened on several wooden sticks for one month to reduce solar radiation, which could stub out the *M. bracteata* and *C. mucunoides* during the age. During the observation, *M. bracteata* and *C. mucunoides* on both the sites were watered at 9:00 am, 12:00 pm and 3:00 pm a day, except on the day which had been determined to collect air samples for CO₂ concentration determination.

2.3 Field Data Collection

The closed chamber techniques adopted from International Atomic Energy Agency (IAEA) [25] were implemented to collect air samples for CO₂ concentration determination in 24 experiment plots at the 1st, 3rd and 6th months observations. The dimension of the closed chambers was 50 cm × 50 cm × 30 cm made by acrylic and aluminum rod. The chambers were equipped with a 12 V fan and driven

Fig. 2 Field experiment site setup: *M. bracteata* (Mb), *C. mucunoides* (Cm) and no planted LCCs (No).

by a 12 V battery for performing the homogeneous CO₂ emission inside. The ASTM mercury thermometer was equipped on the upper side of the chambers through small hole and was sealed semi-permanently for monitoring the temperature inside the chambers. All 24 CO₂ flux monitoring plots at both the experiment sites were included in data collection, and 24 CO₂ flux readouts formed the database for the analysis. The Eq. (1) from IAEA [25] was applied to convert ppm into mg/m²·min and g/m²·h:

$$E = \frac{dc}{dt} \times \frac{Vch}{Ach} \times \frac{mW}{mV} \times \frac{273.2}{(273.2 + T)} \quad (1)$$

where,

E = flux CO₂ (mg/m²/d);

dc/dt = concentration difference (ppm/min);

Vch = closed chamber volume (m³);

Ach = closed chamber area (m²);

mW = CO₂ molecular weight (g);

mV = constant molecular volume (22.41 L);

T = average temperature (°C).

The labeled vacuumed vial bottles and Terumo syringes were prepared before CO₂ flux observations. The observations were performed in the highest

emission time of 12:00-15:00 pm [26] by installing the chambers on the each experiment plot to collect air samples. The day of collecting samples was determined with consideration of the same water table at ± 50 cm depth of the closest drainage and assuming to have the same underground water table. The lower chamber edging was placed in the peat at a depth of 2 cm during sampling. Each sample was transferred into 10 mL vacuumed vial bottles by using 10 mL Terumo syringe with interval 1, 5, 10, 15 and 20 min. Temperatures inside the chambers were monitored each before air sampling with interval 1, 5, 10, 15 and 20 min by mercury thermometer that was set and sealed on the top of chambers. The vacuumed vial bottles were then glued by silicon to ensure no leakage. The CO₂ samples were then analyzed in the Environmental Research Laboratory Center for Agriculture, in Jakenan-Pati, Central Java.

2.4 Laboratory Analysis

The Varian 450-GC (Middleburg, The Netherlands) was used to analyze CO₂ concentration in the Environmental Research Laboratory Center for Agriculture, in Jakenan-Pati, Central Java. H₂ was

used as carrier gas with inlet pressure of 300 kPa and maximum 650 kPa. The solid-phase microextraction (SPME) mode was applied to analyze the air samples to determine CO₂ concentration. In this mode, the CP-8410 auto injector based on the CP-8400 auto sampler was carried out. The 10 mL vials were manually positioned in tray consisting of five 10 mL vials each tray. The sampler was injected into both (either from the same sample vial or from adjacent vials) during the same analysis. The flame ionization detector (FID) with maximum temperature of 450 °C and the detectivity of 2 pg C/s was utilized.

2.5 Statistical Analyses

The CO₂ concentrations of each plot in mole ppm were analyzed for linearity based on consecutive air samples taken during interval sampling times (1, 5, 10, 15 and 20 min). Minitab 14 programme was used for statistical analyses. Throughout the estimation of peat properties, ambient temperature, peat temperature, relative peat moisture and peat CO₂ flux data were analyzed as mean and standard error (SE). Analysis of variance (ANOVA) was applied and then pair wise comparison (Tukey procedure) was tested among sites, treatments and monitoring months of LCCs and to compare CO₂ fluxes. All statistical analyses were run at the 95% confidence level.

3. Results

3.1 Peat Temperature

The average peat temperature between both experiment sites showed higher in NOPS site than in EPOL site. Generally, the widest and narrowest differences were found at the 6th and 1st months monitoring, respectively, due to the shade effect of LCCs foliage.

The average peat temperature on the no planted LCCs plots were 33.50, 32.15 and 32.14 °C in the 1st, 3rd and 6th months, respectively, for the NOPS site. The highest peat temperature was 33.60 °C occurring in the 1st month. The lowest peat temperature was

32.12 °C occurring in the 6th month. The difference of peat temperature during experiment was 1.46 °C for NOPS site. The widest and narrowest differences of peat temperature were 0.2 °C in the 1st month and 0.05 °C in the 6th month. The average peat temperature on the planted *M. bracteata* plots were 34.14, 29.63 and 29.62 °C in the 1st, 3rd and 6th months, respectively, for the NOPS site. The highest peat temperature was 34.17 °C occurring in the 1st month. The lowest peat temperature occurred in the 6th month of 29.50 °C. The difference of peat temperature was 4.67 °C in the NOPS site. The widest and narrowest differences of peat temperature were 0.26 °C and 0.06 °C in the 6th and 1st months, respectively. The average peat temperature on the planted *C. mucunoides* were 34.14, 29.64 and 29.49 °C in the 1st, 3rd and 6th months, respectively, for the NOPS site. The highest peat temperature was 34.17 °C occurring in the 1st month. The lowest peat temperature was 29.46 °C occurring in the 6th month. The difference of peat temperature was 4.71 °C in the NOPS site. The widest and narrowest differences of peat temperature were 0.22 °C and 0.06 °C in the 3rd and 1st months, respectively.

The average peat temperature on the no planted LCCs plots in the EPOL site were 33.36, 31.39 and 31.32 °C in the 1st, 3rd and 6th months, respectively. The highest peat temperature was 33.39 °C occurring in the 1st month. The lowest peat temperature was 31.25 °C taking place in the 6th month. The difference of peat temperature during experiment was 2.14 °C. The widest peat temperature occurred in the 3rd and 6th months of 0.14 °C. The narrowest peat temperature occurred in the 1st month of 0.08 °C. The average peat temperature on the planted *M. bracteata* plots in the EPOL site were 33.15, 29.56 and 29.55 °C in the 1st, 3rd and 6th months, respectively. The highest peat temperature occurred in the 1st month of 33.19 °C. The lowest peat temperature was 29.45 °C occurring in the 3rd month. The difference of peat temperature was 3.74 °C in the EPOL site. The widest

differences of peat temperature were 0.21 °C occurring in the 3rd and 6th months, while the narrowest difference occurred in the 1st month of 0.07 °C. The average peat temperatures on the planted *C. mucunoides* plots in the EPOL site were 33.09, 29.57 and 29.56 °C in the 1st, 3rd and 6th months, respectively. The highest peat temperature occurred in the 1st month of 33.13 °C. The lowest peat temperature was 29.45 °C occurring in the 6th month. The difference of peat temperature was 3.68 °C in the EPOL site. The widest difference of peat temperature was 0.23 °C occurring in the 3rd and 6th months, while the narrowest difference occurred in the 1st month of 0.1 °C (Table 1).

3.2 CO₂ Fluxes

Overall relationship between average CO₂ fluxes and sites, treatments, monitoring months showed strong correlation ($R^2 = 82.2\%$) during experiment. The differences of sites, treatments and monitoring months were significant based on the values of $P = 0.0008$, $P = 0.0000$ and $P = 0.0000$, respectively.

The CO₂ flux differences on the experiment plots corresponded to peat temperatures as a result of shading condition due to planting LCCs. No statistically significant correlations were investigated between the fluxes and peat characteristics. The average CO₂ fluxes on the no planted LCCs, planted *M. bracteata* and *C. mucunoides* plots in newly NOPS site at the 1st month monitoring were insignificant, however, they occurred at the 3rd and 6th months monitoring. The average CO₂ fluxes on the no planted LCCs, planted *M. bracteata* and *C. mucunoides* plots of NOPS site were 6.12 ± 8.98 , 6.82 ± 24.5 and 6.65 ± 23.7 g/m²·h, respectively, at the 1st month monitoring.

The average CO₂ fluxes on the no planted LCCs, planted *M. bracteata* and *C. mucunoides* plots were 3.38 ± 2.92 , 1.29 ± 3.70 and 1.54 ± 1.51 g/m²·h, successively, at the 3rd month monitoring. The average CO₂ fluxes on the no planted LCCs, planting *M. bracteata* and *C. mucunoides* plots were 3.37 ± 3.45 , 1.04 ± 1.28 and 0.97 ± 2.55 g/m²·h, severally, at the 6th month monitoring.

The average CO₂ fluxes on the no planted LCCs, planted *M. bracteata* and *C. mucunoides* plots of eight years planted oil palm land (EPOL) site were 5.54 ± 15.95 , 5.40 ± 6.70 and 4.70 ± 5.00 g/m²·h, respectively, at the 1st month monitoring. The average CO₂ fluxes on the no planted LCCs, planted *M. bracteata* and *C. mucunoides* plots were 2.99 ± 5.32 , 1.14 ± 2.00 and 0.93 ± 1.23 g/m²·h, successively, at the 3rd month monitoring. The average CO₂ flux on the no planted LCCs, planting *M. bracteata* and *C. mucunoides* plots were 2.77 ± 4.62 , 0.93 ± 3.49 and 1.05 ± 4.80 g/m²·h, severally, at the 6th month monitoring.

There were fluctuation differences of CO₂ fluxes in the NOPS site at the 1st, 3rd and 6th months monitoring. The CO₂ flux fluctuation was 5.61 g/m²·h at the 1st month monitoring; the highest and lowest CO₂ fluxes were 8.80 g/m²·h and 3.19 g/m²·h on the planted *C. mucunoides* and *M. bracteata* plots, respectively. The CO₂ flux fluctuation at the 3rd month monitoring was 2.17 g/m²·h; the highest and lowest CO₂ fluxes were 3.79 g/m²·h and 0.76 g/m²·h on the no planted LCCs and *M. bracteata* plots, respectively. The CO₂ flux fluctuation at the 6th month monitoring was 2.70 g/m²·h; the highest and lowest CO₂ fluxes were 3.89 g/m²·h and 0.71 g/m²·h on the no planted LCCs and planting *C. mucunoides* plots, respectively.

Table 1 The average peat temperature in different treatments, monitoring months and sites.

Sites	Average peat temperature $\pm$ deviation standard (°C)								
	No LCCs (monitoring months)			<i>M. bracteata</i> (monitoring months)			<i>C. mucunoides</i> (monitoring months)		
	1st	3rd	6th	1st	3rd	6th	1st	3rd	6th
NOPS	33.50	32.15	32.14	34.14	29.63	29.62	34.14	29.64	29.49
EPOL	33.36	31.39	31.32	33.15	29.56	29.55	33.09	29.57	29.56

No significant fluctuation differences of average CO₂ fluxes in the NOPS site were observed on the planted *M. bracteata* plots (0.69 g/m²·h and $P = 0.999$) and *C. mucunoides* plots (0.53 g/m²·h and $P = 1.000$), compared to the no planted LCCs in the NOPS site at the 1st month monitoring. The differences were marked on the *M. bracteata* plots (-4.84 g/m²·h and $P = 0.0001$; -50.85 g/m²·h and $P = 0.0001$, at the 3rd and 6th months monitoring, respectively) and on the *C. mucunoides* plots (-4.58 g/m²·h and $P = 0.0001$; -51.51 g/m²·h and $P = 0.0001$, respectively), compared to the no planted LCCs in the NOPS site at the 1st month monitoring.

The CO₂ flux fluctuation differences in the NOPS site were insignificant at the 3rd and 6th months monitoring on the planted *M. bracteata* plots (-2.09 g/m²·h and $P = 0.2195$; -2.34 g/m²·h and $P = 0.0982$, respectively) and on the *C. mucunoides* plots (-1.83 g/m²·h and $P = 0.4256$; -2.40 g/m²·h and $P = 0.0774$, respectively), compared to the no planted LCCs plots at the 3rd month monitoring. However, the significant differences in the NOPS site were observed on the planted *M. bracteata* plots (-5.53 g/m²·h and $P = 0.0001$; -5.78 g/m²·h and $P = 0.0001$, at the 3rd and 6th months monitoring, respectively), compared to on the planted *M. bracteata* plots at the 1st month monitoring. The significant differences also occurred on the planted *C. mucunoides* plots (-5.11 g/m²·h and $P = 0.0011$; -5.68 g/m²·h and $P = 0.0001$, at the 3rd and 6th months monitoring, respectively), compared to on the planted *C. mucunoides* plots at the 1st month monitoring.

The CO₂ flux differences during experiment in the EPOL site tended to increase. The CO₂ flux difference was 1.46 g/m²·h at the 1st month monitoring; the highest and lowest CO₂ fluxes occurred on the no planted LCCs plot of 6.69 g/m²·h and 3.32 g/m²·h, respectively, at the 1st month monitoring. The CO₂ flux difference at the 3rd month monitoring was 2.62 g/m²·h; the highest and lowest CO₂ fluxes were 3.44 g/m²·h and 0.81 g/m²·h on the no planted LCCs and *C.*

mucunoides plots, respectively. The CO₂ flux difference at the 6th month monitoring was 2.95 g/m²·h; the highest and lowest CO₂ fluxes were 3.41 g/m²·h and 0.46 g/m²·h on the no planted LCCs and *M. bracteata* plots, respectively.

There were insignificant differences of average CO₂ fluxes in the EPOL site on the planted *M. bracteata* plots (-0.13 g/m²·h and $P = 1.000$) and on the *C. mucunoides* plots (-0.84 g/m²·h and $P = 0.9987$), compared to the no planted LCCs in EPOL site at the 1st month monitoring. The differences were significant at the 3rd and 6th months monitoring on the *M. bracteata* plots (-4.39 g/m²·h and $P = 0.0001$; -4.60 g/m²·h and $P = 0.0001$, respectively) and on the *M. bracteata* plots (-4.60 g/m²·h and $P = 0.0001$; -4.48 g/m²·h and $P = 0.0001$, respectively), compared to the no planted LCCs in the EPOL site at the 1st month monitoring.

The CO₂ flux differences in the EPOL site were insignificant at the 3rd and 6th months monitoring on the planted *M. bracteata* plots (-1.84 g/m²·h and $P = 0.4151$; -2.06 g/m²·h and $P = 0.2406$, respectively) and on the *C. mucunoides* plots (-2.06 g/m²·h and $P = 0.2411$; -1.94 g/m²·h and $P = 0.3319$, respectively), compared to the no planted LCCs plots at the 3rd month monitoring. However, the significant differences of average CO₂ fluxes in the EPOL site were observed on the planted *M. bracteata* plots (-4.26 g/m²·h and $P = 0.0001$; -4.47 g/m²·h and $P = 0.0001$ at the 3rd and 6th months monitoring, respectively), compared to on the planted *M. bracteata* plots at the 1st month monitoring. The significant differences also occurred on the planted *C. mucunoides* plots (-3.77 g/m²·h and $P = 0.0002$; -3.65 g/m²·h and $P = 0.0003$ at the 3rd and 6th months monitoring, respectively), compared to on the planted *C. mucunoides* plots at the 1st month monitoring.

The average CO₂ flux differences in the EPOL site at the 1st month monitoring were insignificant on the no planted LCCs plots (-5.87 g/m²·h and $P = 1.000$), planted *M. bracteata* plots (-0.72 g/m²·h and $P =$

0.9998) and planted *C. mucunoides* plots ($-1.42 \text{ g/m}^2\cdot\text{h}$ and $P = 0.8194$), compared to no planted LCCs in NOPS site at the 1st month monitoring. However, the average CO₂ flux differences in the EPOL site were significant at the 3rd and 6th months monitoring both on the planted *M. bracteata* plots ($-4.98 \text{ g/m}^2\cdot\text{h}$ and $P = 0.0001$; $-5.19 \text{ g/m}^2\cdot\text{h}$ and $P = 0.0001$, respectively) and on the *C. mucunoides* plots ($-5.19 \text{ g/m}^2\cdot\text{h}$ and $P = 0.0001$; $-5.07 \text{ g/m}^2\cdot\text{h}$ and $P = 0.0001$, respectively), compared to no planted LCCs plots of NOPS site at the 1st month monitoring. The significant differences of average CO₂ flux in the EPOL site were observed at the 3rd and 6th months observation both on the planted *M. bracteata* plots ($-4.39 \text{ g/m}^2\cdot\text{h}$ and $P = 0.0001$; $-4.60 \text{ g/m}^2\cdot\text{h}$ and $P = 0.0001$, respectively) and *C. mucunoides* plots ($-4.60 \text{ g/m}^2\cdot\text{h}$ and $P = 0.0001$; $-4.48 \text{ g/m}^2\cdot\text{h}$ and $P = 0.0001$, respectively), compared to on the no planted LCCs plot of EPOL site at the 1st month monitoring. No significant differences of CO₂

fluxes were observed on the planted *C. mucunoides* plot ($-0.70 \text{ g/m}^2\cdot\text{h}$ and $P = 0.9999$) at the 1st month monitoring, compared to on the planted *M. bracteata* at the 1st month monitoring (Table 2, Fig. 3).

4. Discussion

The authors discovered that CO₂ flux responded to the treatments in both NOPS and EPOL sites and provided a clear trend. Peat in both sites can be characterized physically compacted as consequence of the solidification at the time of land clearing and preparation before planting of oil palm. The substrate losses due to drainage system and high temperature (equatorial area) also increase the occurrence of the solidification of the sites. Jauhiainen et al. [13] wrote physical compaction as an outcome of low organic matter inputs and substrate losses occurred in the increased anoxic conditions due to enhanced drainage, high temperature and fire impacts. However, there

Table 2 The average CO₂ fluxes in different treatments monitoring months and sites.

Sites	Average CO ₂ fluxes $\pm$ deviation standard ($\text{g/m}^2\cdot\text{h}$)								
	No LCCs (monitoring months)			<i>M. bracteata</i> (monitoring months)			<i>C. mucunoides</i> (monitoring months)		
	1st	3rd	6th	1st	3rd	6th	1st	3rd	6th
NOPS	$6.12 \pm 8.98^{\text{is}}$	$3.38 \pm 2.92^{\text{s}}$	$3.37 \pm 3.45^{\text{s}}$	$6.82 \pm 24.5^{\text{is}}$	$1.29 \pm 3.70^{\text{s}}$	$1.04 \pm 1.28^{\text{s}}$	$6.65 \pm 23.7^{\text{is}}$	$1.54 \pm 1.51^{\text{s}}$	$0.97 \pm 2.55^{\text{s}}$
EPOL	$5.54 \pm 15.95^{\text{is}}$	$2.99 \pm 5.32^{\text{s}}$	$2.77 \pm 4.62^{\text{s}}$	$5.40 \pm 6.70^{\text{is}}$	$1.14 \pm 2.00^{\text{s}}$	$0.93 \pm 3.49^{\text{s}}$	$4.70 \pm 5.00^{\text{is}}$	$0.90 \pm 1.23^{\text{s}}$	$1.05 \pm 4.80^{\text{s}}$

is: insignificant; s: significant.

Fig. 3 Average temperature and CO₂ fluxes at three differed above peat surface conditions on the NOPS and EPOL sites during experiment.

was no fire history at both sites since restriction by regulations either in practice of opening with burning peatland or controlled management fire in the plantation. Therefore, the authors suggested no fire impact toward peat microbial communities over time in the both sites.

The location was no far from Kapuas River and tidal water influenced the fluctuation of daily average water level of drainage system. The high tide generally happened in early morning and evening, whereas the peak ebb tide took place in daytime. The water table of drainage system, which was close to the peat surface in the experiment location, has consequence as the most dominant factor influencing peat microbial communities regardless of the role of LCCs. Peat water table position is typically the only factor used to explain GHG flux dynamics in tropical peat regardless of the vegetation cover of a particular land use type [21]. The differences of water table changed peat microbial communities over time, including in the monitoring months during experiment. Although at the daytime, the monitoring of CO₂ fluxes was conducted with the approximately same water level, the authors suggested that higher daily and monthly water level happened at the 3rd and 6th months than the 1st month monitoring due to the higher rainfall intensity influencing the lower CO₂ fluxes.

The average heterotrophic CO₂ flux differences occurred on the no planted LCCs plots in both sites, but it was found to be slightly higher in NOPS site at the 1st, 3rd and 6th monitoring months. Also the difference in average heterotrophic CO₂ fluxes occurred on the planted *M. bracteata* plots in the both sites; it was higher for NOPS site than EPOL site at the 1st monitoring months, however, the greatly narrow differences were found at the 3rd and 6th monitoring months. Similarly, the identical trend of CO₂ flux differences were also obtained on the planted *C. mucunoides* plots in both sites at the 1st, 3rd and 6th monitoring months. Astiani et al. [27] conducted a

research on the newly burnt fern cover, pineapple and corn sites; all sites with typical cropland condition had totally open canopy and thus tended to increase CO₂ fluxes. Jauhiainen et al. [13] noted that peat temperature (influenced by vegetation cover) is other physical factor to influencing GHG flux.

The decrease of CO₂ fluxes began at the 3rd month monitoring in both sites. The differences of CO₂ flux between the 1st and 3rd months monitoring were insignificant on the no planted LCCs plots of both sites. The reducing CO₂ fluxes on the planted *M. bracteata* plots in NOPS site at the 3rd and 6th months monitoring were slightly higher than in EPOL site. Similarly, the CO₂ fluxes on the planted *C. mucunoides* plots varied at the 3rd and 6th months monitoring for NOPS and EPOL site, indicating the ultimate effectiveness of reducing CO₂ emission at the three months age of the LCCs. The trend of CO₂ fluxes between the planted *M. bracteata* and *C. mucunoides* plots tended to be similar at the 1st, 3rd and 6th months monitoring, so it can be concluded that there was no significant difference of reducing CO₂ emission between the both LCCs.

The comparison of the decrease of CO₂ fluxes between the no planted LCCs and planted LCCs plots at the same months monitoring was done. The CO₂ fluxes were higher at the 1st month monitoring compared to the 3rd and 6th months monitoring. The CO₂ fluxes difference on the planted *M. bracteata* plots in NOPS site at the 3rd and 6th months monitoring were slightly higher than in EPOL site. In contrast, the CO₂ fluxes difference on the planted *C. mucunoides* plots were higher at the 3rd and 6th months monitoring in the NOPS site than in the EPOL site, showing insignificant differences of CO₂ fluxes between the both months monitoring.

The decrease of CO₂ fluxes at the 3rd and 6th months monitoring on the both site corresponded with the shading condition due to enhancing leaves density of the LCCs. The shading condition increased significantly after the 1st month age of LCCs and

reached the ultimate effect at the 3rd month age. The increase of shading effect of the LCCs could hold the solar radiation more effectively, thus making the lower peat temperature. Moore and Dalva [28] noted that in response to climatic change, an increase in CO₂ emission is predicted to occur in organic soils through both the elevated temperature and the lowered water table. An increase in temperature from 10 °C to 22.6 °C resulted in increase in CO₂ emission rates by an average of 2.4 times. Wang et al. [29] found an average increase of 21% in heterotrophic respiration by a 2 °C increase in soil temperature in a meta-analysis. Jauhiainen et al. [13] noted that the increased shading at the agricultural land site resulted in 1 °C lower temperature values close to the peat surface, but at deeper monitoring depths; the temperature changes remained much lower along the increasing shading gradient. A shading increase did not only reduce the diurnal temperature difference in the peat, but also the peat depth where the short-term (diurnal) changes reached. The average CO₂ fluxes of unfertilized peat at the agricultural land site were markedly higher on unshaded and 28% shaded plots, when compared to the average of 90% shaded plot. Hirano et al. [17], Kusin et al. [30], Jauhiainen et al. [31] and Husnain et al. [32] noted that diurnal surface peat temperature variations can also give rise to notable temporal difference in CO₂ emission, especially if there are oxic conditions and the surface peat to 5 cm depth (or even to 10 cm) is considered as the main source of heterotrophic CO₂ emissions. Also in this study, the effect of shading intensity of both LCCs species on peat temperature and heterotrophic CO₂ emissions was clear on the both sites.

5. Conclusions

The NOPS responded higher temperature and CO₂ fluxes to the atmosphere, while the oil palm was performed with vegetation canopy which could reduce solar radiation reaching to peat surface. The existence of the LCCs on peatland can reduce CO₂ fluxes. The

ultimate CO₂ emission reduction capability of the LCCs can reach at the 3rd month of planting age. Considering the vast size of oil palm plantation on the peatland in tropical lowlands, the implementation of *M. bracteata* and *C. mucunoides* are promising to reduce CO₂ emissions effectively and efficiently.

Acknowledgments

The authors are very thankful to the land owner of Mitra Aneka Rezeki oil palm plantation for renting its land for this research and much help for providing supporting data and site maintenance, and their students who are involved in this research but could not be mentioned singly. They also show their appreciation to soil laboratory staff of Tanjungpura University and Sebelas Maret University for assisting the peat samples analysis, and the Environmental Research Laboratory Center for Agriculture, in Jakenan-Pati for helping CO₂ gas analysis.

References

- [1] Page, S. E., Rieley, J. O., and Banks, C. J. 2011. "Global and Regional Importance of the Tropical Peatland Carbon Pool." *Glob. Change Biol.* 17 (2): 798-818.
- [2] Gorham, E., Lehman, C., Dyke, A., Clymo, D., and Janssens, J. 2012. "Long-Term Carbon Sequestration in North American Peatlands." *Quaternary Sci. Rev.* 58: 77-82.
- [3] Langner, A., and Siegert, F. 2009. "Spatiotemporal Fire Occurrence in Borneo over a Period of 10 Years." *Glob. Change Biol.* 15 (1): 48-62.
- [4] Miettinen, J., and Liew, S. C. 2010. "Degradation and Development of Peatlands in Peninsular Malaysia and in the Islands of Sumatra and Borneo Since 1990." *Land Degra. Dev.* 21 (3): 285-96.
- [5] Miettinen, J., Hooijer, A., Shi, C., Tollenaar, D., Vernimmen, R., Liew, S. C., Malins, C., and Page, S. E. 2012. "Extent of Industrial Plantations on Southeast Asian Peatlands in 2010 with Analysis of Historical Expansion and Future Projections." *GCB Bioenergy* 4 (6): 908-18.
- [6] World Wildlife Fund (WWF) of West Kalimantan. 2014. *Area of Oil Palm Plantations on Peatlands in Kalimantan*. WWF Annual Report, Pontianak City, West Kalimantan, Indonesia. (unpublished)
- [7] Carlson, K. M., Curan, L. M., Asner, G. P., Pittman, A.

- M., Trigg, S. N., and Adeney, J. M. 2012. "Carbon Emissions from Forest Conversion by Kalimantan Oil Palm Plantations." *Nature Climate Change* 3: 283-7.
- [8] Berglund, Ö., and Berglund, K. 2011. "Influence of Water Table Level and Soil Properties on Emissions of Greenhouse Gases from Cultivated Peat Soil." *Soil Biology and Biochemistry* 43 (5): 923-31.
- [9] Furukawa, Y., Inubushi, K., Ali, M., Itang, A. M., and Tsuruta, H. 2005. "Effect of Changing Groundwater Levels Caused by Land-Use Changes on Greenhouse Gas Emissions from Tropical Peatlands." *Nutr. Cycl. Agroeco.* 71 (1): 81-91.
- [10] Chen, C. P., and Aminah, A. 1997. "*Calopogonium mucunoides* Desv." In *Record from Proseabase*, edited by Faridah-Hanum, I., and Van der Maesen, L. J. G. Bogor, Indonesia: Plant Resources of South-East Asia (PROSEA) Foundation.
- [11] Jaatinen, K., Laiho, R., Vuorenmaa, A., Del Castillo, U., Minkinen, K., Pennanen, T., Penttilä, T., and Fritze, H. 2008. "Response of Anaerobic Microbial Communities and Soil Respiration to Water-Level Drawdown in a Northern Boreal Fen." *Environ. Microbiology* 10 (2): 339-53.
- [12] Manzoni, S., Schimel, J. P., and Porporato, A. 2013. "Response of Soil Microbial Communities to Water Stress: Results from a Met-Analysis." *Ecology* 93 (4): 930-8.
- [13] Jauhiainen, J., Kerojoki, O., Silvennoinen, H., Limin, S., and Vasander, H. 2014. "Heterotrophic Respiration in Drained Tropical Peat Is Greatly Affected by Temperature—A Passive Ecosystem Cooling Experiment." *Environmental Research Letters* 9: 18.
- [14] Cook, B. G., Pengelly, B. C., Brown, S. D., Donnelly, J. L., Eagles, D. A., Franco, M. A., Hanson, J., Mullen, B. F., Partridge, I. J., Peters, M., and Schultze-Kraft, R. 2005. *Tropical Forages: An Interactive Selection Tool*. CSIRO, DPI&F(Qld), CIAT and ILRI, Brisbane, Australia.
- [15] Kretschmer, A. E., and Pitman, W. D. 2001. "Germplasm Resources of Tropical Forage Legumes." In *Tropical Forage Plants: Development and Use*, edited by Sotomayor-Rios, A., and Pitman, W. D. Florida, USA: CRC Press.
- [16] FAO. 2011. "Grassland Index: A Searchable Catalogue of Grass and Forage Legumes." Accessed July 4, 2015. <http://www.fao.org/ag/AGP/AGPC/doc/GBASE/Default.htm>.
- [17] Hirano, T., Jauhiainen, J., Inoue, T., and Takahashi, H. 2009. "Controls on the Carbon Balance of Tropical Peatlands." *Ecosystems* 12 (6): 873-87.
- [18] Stephens, J. C., and Stewart, E. H. 1977. "Effect of Climate on Organic Soil Subsidence." In *Proceedings of the 2nd Symposium on Land Subsidence*, 647-55.
- [19] Parthasarathy, V. A. 2008. *Organic Spices*. New Delhi, India: New India Publishing.
- [20] Kothandaraman, R., Premakumari, D., and Panicker, S. 1987. "Studies on Growth, Nodulation and Nitrogen Fixation by *Mucuna bracteata*." In *Proceedings of the Sixth Symposium on Plantation Crops*, 283-8.
- [21] Intergovernmental Panel on Climate Change (IPCC). 2014. *2013 Supplement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories: Wetlands*, edited by Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., and Baasansuren, J. Switzerland: IPCC.
- [22] Carlson, K. M., Curan, L. M., Asner, G. P., Pittman, A. M., Trigg, S. N., and Adeney, J. M. 2012. "Carbon Emissions from Forest Conversion by Kalimantan Oil Palm Plantations." *Nature Climate Change* 3: 283-7.
- [23] Pontianak Meteorology, Climatology and Geophysics Agency. 2014. Kubu Raya Regency Climatology Data, West Kalimantan, Indonesia. (unpublished)
- [24] Pontianak Meteorology, Climatology and Geophysics Agency. 2014. Teluk Pakedai Subdistrict Rainfall and Rainday Data, West Kalimantan, Indonesia. (unpublished)
- [25] International Atomic Energy Agency (IAEA). 1993. *Manual on Measurement of Methane and Nitrous Oxide Emission from Agricultural*. Vienna, Austria: IAEA, 46-8.
- [26] Sunar. 1993. "Study Implementing Two Varieties of Paddy Rice Straw on Rice Field and Their Influences toward Methane Emissions." M.Sc. thesis, Bogor Agricultural Institute Postgraduate Program, Bogor, Indonesia.
- [27] Astiani, D., Mujiman, Hatta, M., Hanisah, and Fifian, F. 2014. "Soil CO₂ Respiration along Annual Crops or Land-Cover Type Gradients on West Kalimantan Degraded Peat Land Forest." *Procedia Environmental Sciences* 28: 132-41.
- [28] Moore, T. R., and Dalva, M. 1993. "The Influence of Temperature and Water Table Position on Carbon Dioxide and Methane Emissions from Laboratory Columns of Peatland Soils." *Journal of Soil Science* 44 (4): 651-64.
- [29] Wang, J. T., Lu, L., Piao, S., Janssens, I. A., Tang, J., Liu, W., Chi, Y., Wang, J., and Xu, S. 2014. "Soil Respiration under Climate Warming: Differential Response of Heterotrophic and Autotrophic Respiration." *Glob. Change Biol.* 20 (10): 3229-37.
- [30] Kusin, K., Hirano, T., Limin, S., and Osaki, M. 2014. "Carbon Dioxide Emissions through Oxidative Peat Decomposition on a Burnt Tropical Peatland." *Glob. Change Biol.* 20 (2): 555-65.
- [31] Jauhiainen, J., Hooijer, A., and Page, S. E. 2012. "Carbon Dioxide Emissions from an *Acacia* Plantation on Peatland in Sumatra Indonesia." *Biogeosciences* 9 (2): 617-30.

- [32] Husnain, H., Wigena, I. P., Dariah, A., Marwanto, S., Setyanto, P., and Agus, F. 2014. "CO₂ Emission from Tropical Drained Peat in Sumatra, Indonesia." *Mitig. Adap. Strateg. Glob. Change* 19 (6): 845-62.