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Characteristics of Tropical Drained Peatlands and CO_2 Emission under Several Land Use Types

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ABSTRACT

Converting of tropical rain forest into plantation and agriculture land uses has been claimed as a main factor that affects to global warming and climate change. In order to provide a comprehensive information of the issue, a field observation on peat properties in relation to CO_2 emission under several land use types had been done at Lubuk Ogong Village, Pelalawan District, Riau Province from May 2011-April 2012. Five land use types, namely *A. mangium*, bare land, oil palm, rubber, and secondary forest have been selected in the study site. Observations were made for chemical and physical properties, above and below ground C-stock and CO_2 emissions. The results showed a higher variation of peat depth and a below ground C-stock was almost linearly with a peat depth. Below ground C-stock for each land use was around 2848.55 Mg ha^{-1}, 2657.08 Mg ha^{-1} 5949.85 Mg ha^{-1}, 3374.69 Mg ha^{-1}, 4104.87 Mg ha^{-1} for secondary forest, rubber, oil palm, bare land, and *A. mangium,* respectively. The highest above ground C-stock observed on a secondary forest was 131.5 Mg ha^{-1}, followed by the four years *A. mangium* 48.4 Mg ha^{-1}, the 1-2 years *A. mangium* 36.6 Mg ha^{-1}, and the 4 years *A. mangium* 34.4 Mg ha^{-1}. While, CO_2 emissions in the study sites were 66.58±21.77 Mg $ha^{-1}yr^{-1}$, 66.17±25.54 Mg $ha^{-1}yr^{-1}$, 64.50±31.49 Mg $ha^{-1}yr^{-1}$, 59.55±18.30 Mg $ha^{-1}yr^{-1}$, 53.65±16.91 Mg $ha^{-1}yr^{-1}$ for bareland, oil palm, secondary forest, *A. mangium,* and rubber, respectively.

Keywords: *A. mangium*, C-stock, CO_2 emission, land use change

INTRODUCTION

Indonesia has been regarded to be the third biggest emitter after the USA and China in producing green house gases (GHGs) due to rapid conversion of peatlands forest to other land uses. It is reported that about 21 M ha of Indonesian peatlands has been converted into other alternative land use types such as plantation and agriculture (Wahyunto *et al*. 2004). Realizing that emission reduction is being a national concern, apart from the international allegations, the Indonesian government has pledged to reduce GHGs emission by 26% using internal sources, and 41% within international support relative to the business as usual by 2020. Based on Light Detection and Ranging (LIDAR) and ground truth approaches, total carbon stock of peatlands in Indonesia is about 55 Gt (Jaenicke *et al*. 2008) indicating the importance role of Indonesia to store carbon. Under natural peat forest, accumulation of carbon stock is reported around 0.59 to 1.18 Mg C ha^{-1} yr^{-1} (Neuzil 1997). In general, CO_2 emission from natural peat forest is lower than its sequestration resulted in the average growth of natural peatlands are between 0.5 to 1.0 Mg C $ha^{-1}yr^{-1}$ (Parish *et al*. 2007), while CO_2 sequestration in restored peatlands are greater than 1 Mega ton ha^{-1} yr^{-1} (Lal 2009).

From the 21 millions hectares of peatlands in Indonesia, about 4 million hectares is located in Riau Province, this is equal to 45% of the total areas of Riau Province (Agus and Subiksa 2008). Correlated to the current economic issue, the Indonesian peat forest is under tremendous presure to conversion to alternative land uses and which is resulting high emission of GHGs. Indonesia's LULUCF (Land Use, Land Use Change and Forestry) reported that emisions in year 2000 (from several sources) were estimated as much as 496 MT CO_2 (IFCA) and 1.1 GT (CAIT-WRI), and most of this was caused by deforestration and peat fire (Hooijer *et al*. 2010; World Resources Institute 2007).

Land use change is one of important factor affecting GHGs emission. Different land cover requires different environmental conditions, mainly water table depth, soil and air temperature, and soil humidity as the key factors in controlling GHGs

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emission, and soil fertility. The C sequestration of rubber trees per hectare accounts for 272 Mg within 30-year life period and 57.91% of them was fixed in litters. In comparison with C sequestration by rain forest (234 Mg ha^{-1}) and by secondary rain forest (150 Mg ha^{-1}), rubber forest has more potentials for C fixation (Cheng *et al*. 2007). According to Germer and Sauerborn (2007), both oil palm and understory together can fix 129.3 ± 40.3 Mg CO_2 ha^{-1}. In recent years, the activity of LULUCF became the most important sources of climate change. It was estimated that 8 Gt CO_2 has been emitted from the tropical region, equals to 25% of total annual CO_2 emission (IPCC 2001). Subsidence is one of important character of drained peatlands. Subsidence rate of cultivated peat soils with average of 2.5 cm yr^{-1} indicated that peat loss and compaction were respectively responsible for 38% and 62% ot the total subsidence during a 25 year period of drainage. Based on this estimation, the corresponding C loss equals to 0.80 kg cm^{-2} yr^{-1} (Gronlund *et al*. 2008).

Once peat forest is converted into other alternative land uses, water table depth and soil temperature seems to be dominant factors affecting CO_2 emission. As reported by Jauhiainen *et al* (2012) that under *Acacia* plantation, grown on converted peatlands, the time series observation showed a positive correlation between water table depth and soil temperature with CO_2 emission. Meanwhile C-stock is dominantly influenced by bulk density and peat thickness (Wahyunto *et al*. 2010). The amount of CO_2 released by farmed tropical peatlands was influenced by water level from the peat surface, pH of peatland and duration of peatland clearing period. The lower the water level from the surface of peat land soil, the higher the CO_2 emission from the soil. The increasing pH of peatland was followed by an increasing amount of CO_2 emissions, and the longer of the peatland clearing period, the more CO_2 emissions occurs (Rumbang *et al*. 2009). Meanwhile, Nusantara *et al*.(2014) reported factors that affecting to CO_2 emission of peatlands are soil temperature, water table depth, and land management.

MATERIALS AND METHODS

The study was conducted at Lubuk Ogong Village, Bandar Sei Kijang Sub District, Pelalawan District, Riau Province from June 2011 to May 2012. The study site was located on large peat dome areas, near Kampar river, laid on one landscape unit with flat topographic, and under tropical climatic conditions with long term annual rainfall average of around 2500 mm yr^{-1}. Since it was cleared on 1980's decade, the water table depth was control by application of a network of drainage canal, 2-3 meters wide and over 1.0 – 1.5 meters deep that can reduce the water table depth to a level suitable for crops growth. In addition, from land cleared story, it was known that *A mangium* as the previous vegetation under Riau Andalan Pulp and Paper (RAPP) factory management. Five selected land uses, namely *A mangium* (4 years old), bare land (1-2 years old, dominated by *A mangium* regrowth and shrubs vegetation), 4 years old of oil palm, 6 years old of rubber, and secondary forest had been selected to implement the experiment. Assuming that *A mangium* and bare land as benchmark point, the distance within land uses are 300 meter, 550 meter, and 3200 meter for oil palm, rubber, and secondary forest, respectively (Figure 1). There were 5 observation points on each land use type, laid on transect perpendicular to the drainage canal with the distance of 15, 30, 45, 60, and 75 meter. The study consisted of three activities: measurement of bellow ground C-stock, above ground C-stock and CO_2 emission on each selected land use type.

Measurement of Bellow Ground C-Stock

Below ground C-stock was measured at each selected land use. Peat samples were collected using a peat auger (Eijkelkamp type) of depths 0-20, 20-50, 50-100 cm and down to the substratum at 50 cm depth increment or based on peat maturity layers. For each depth, peat maturity has been evaluated in the field using manual technique as explained in Agus and Subiksa (2008). Other information related to CO_2 emission were also monitored such as drainage pattern, water level at nearest drainage canal, water table depth at the sampling points and the presence of clay and charcoal residue due to pas clay deposition by flood and burning, if any. All of the selected samples on each land use have been analyzed for bulk density using gravimetric method while ash content using combustion (loss of ignition) method.

Soil samples for chemical analyses were taken from surface soil (0-20 cm) and sub surface soil (20-50 cm) depths. Each composite sample was collected from 3 sub-samples, at the distance of 10 meter, 20 meter, and 30 meter from the CO_2 emission measuring points, perpendicular to the drainage canal. Chemical analyses for these samples included C, total N ; C/N ratio; Bray-1 P; total P (HCl 25%); 1 *M* NH_4OAC pH 7.0 extractable K, Na, Ca, and Mg; total K (HCl 25%); and micro element such as Fe, Mn, Cu, and Zn using DTPA extraction. All the analyzed elements were determined using an Atomic Absorption Spectrophotometer (AAS). The rest of chemical composite samples has been analyzed for

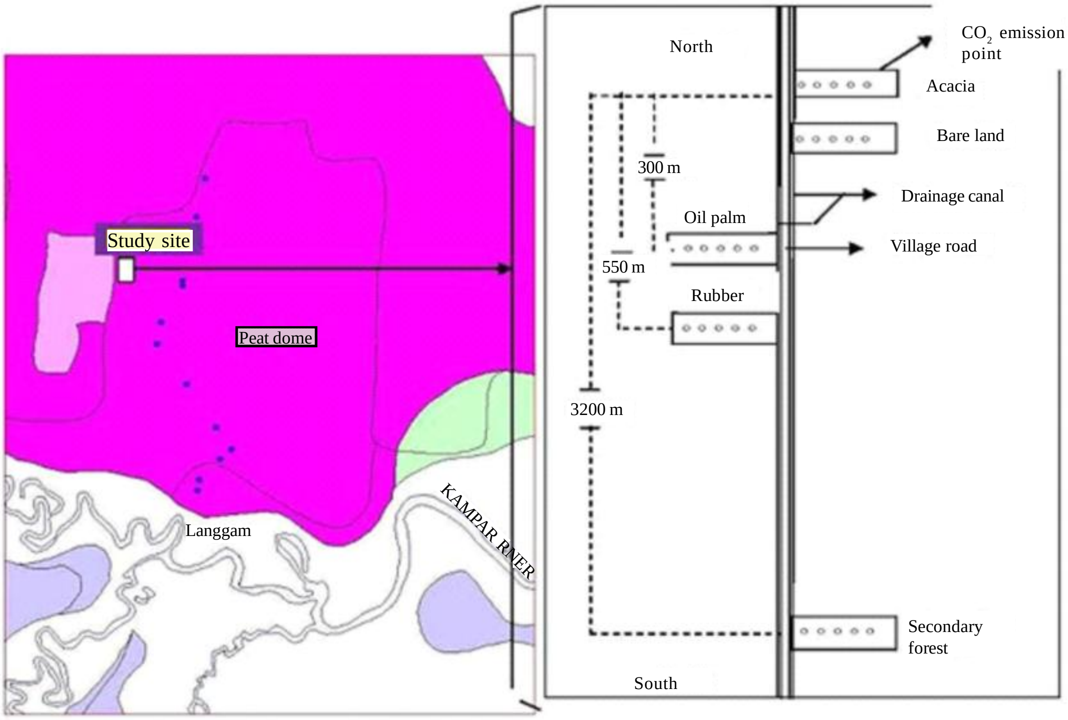


Figure 1. The field experiment site, selected land covers, and observation point scheme position on each land cover.

determining of C and N content using C and N Auto Analyzer.

Below ground soil carbon stocks (C_{stocks}) of peatsland has been calculated based on the following equation (Hairiah *et al*. 1999):

$$(C_{stocks}) = Cd * d * A; \quad \text{Where:}$$

(C_{stocks}) = Below ground (peat) C stock (g; kg; or ton)
C_d = Carbon density (g cm^{-3}; or Mg m^{-3})
d = Depth increment of peatlands (cm; or m)
A = area (m^2; or ha)

Carbon density (C_d = g cm^{-3}) is the carbon mass per unit volume and is calculated using the following equation:

$$C_d = D_b * C;$$

Where: D_b = Bulk density; C = Carbon content

Measurement of Above Ground C-Stock

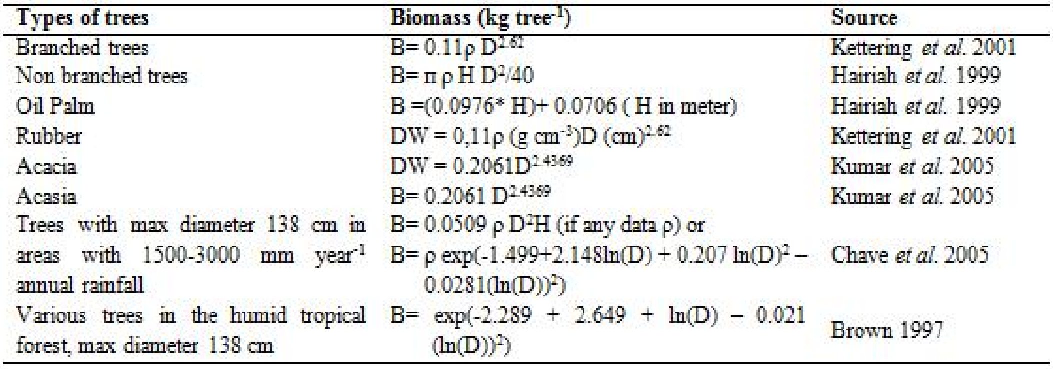
The above ground C stocks were determined from surrounding of soil sampling point for *A. mangium* and *secondary forest* land use types. The measurement included non-destructive measurement of tree girth at breast height of trees with >5 cm diameter dbh, and destructive technique for under story (< 5 cm diameter), and necromass; it was replicated three times. For the *A. mangium*, measurement has been conducted at 3 crop growth stage, namely for 1-2 year, 3 year, and 4 year of crop growth stages. Determination of trees C-stock has been done using Allometric Equation (Hairiah and Rahayu 2007) (Table 1).

Measurement of CO_2 Emission

The CO_2 emission has been monitored at 5 points on each land use based on the distance between sampling point and the drainage canal. The distance of each point from drainage canal were 15, 30, 45, 60, and 75 meter on transect perpendicular to the canal. Measurement has been conducted every six weeks for observation period about 6 months.

The CO_2 gas emission through the surface of peat land was trapped by a PVC *closed chamber* with the size 25 cm in diameter and 23 cm in height. The gas from the closed chamber was circulated into the IRGA unit using a presure pump and its CO_2 concentration is read immediatly in the field every second for about 2.5 minutes using Infra Red Gas Analyzer (IRGA), Li-COR 820 model. The linier relationship between time and CO_2 concentration used for CO_2 flux with its calculation using the following equation (Davidson *et al*. 2002):

Table 1. Allometric equation for estimating tree biomass.



Types of trees	Biomass (kg $tree^{-1}$)	Source
Branched trees	$B = 0.11 \rho D^{2.62}$	Kettering *et al.* 2001
Non branched trees	$B = \pi \rho H D^2/40$	Hairiah *et al.* 1999
Oil Palm	$B = (0.0976 * H) + 0.0706$ (H in meter)	Hairiah *et al.* 1999
Rubber	$DW = 0{,}11 \rho\ (g\ cm^{-3}) D\ (cm)^{2.62}$	Kettering *et al.* 2001
Acacia	$DW = 0.2061 D^{2.4369}$	Kumar *et al.* 2005
Acasia	$B = 0.2061\ D^{2.4369}$	Kumar *et al.* 2005
Trees with max diameter 138 cm in areas with 1500-3000 mm $year^{-1}$ annual rainfall	$B = 0.0509\ \rho D^2 H$ (if any data ρ) or $B = \rho \exp(-1.499 + 2.148 \ln(D) + 0.207 \ln(D)^2 - 0.0281 (\ln(D))^3)$	Chave *et al.* 2005
Various trees in the humid tropical forest, max diameter 138 cm	$B = \exp(-2.289 + 2.649 + \ln(D) - 0.021 (\ln(D))^2)$	Brown 1997

Notes: B=Biomass weight (kg $tree^{-1}$), D=tree diameter (cm), H=tree height (cm, except for oil palm, in m), ρ=Tree bulk density (g cm^{-3}) C = 0.46*B; sum up C for all trees in plot and count C stock in kg ha^{-1} or Mg ha^{-1}.

$$f_c = \frac{Ph}{RT} \frac{dC}{dt}$$

Where:

fc = CO_2 Flux (umol m^{-2} sec^{-1})

P = atmospheric pressure based on the average *reading of* IRGA (kPa)

h = height of chamber (cm)

R = gas constant (8,314 Pa $m^3/^oK$/mole)

T = temperature

dC/dt = concentration of CO_2 per area at time duration (mol ppm m^{-2} sec^{-1})

Beside on the carbon stock and CO_2 measurement, several additional parameters have been observed such as water table depth, soil and air temperature, and volumetric soil water content from 0 to 20 cm depth.

RESULTS AND DISCUSSION

Site Characteristics

Geographycally, the site was laid on one landscape unit with plate topographic condition, and between Latitude of 0°20’46.3" - 0°19’10.4" and Longitude of 101°40’40.1" - 101°41’10.9", 50-100 meter above sea level. Each land use has different characteristics such as peat depth and maturity of each layer. Generally, all selected land uses showed sapric on surface layer and fibric at sub layer. Mean while, peat depth showed high ranged from 600 cm on *A mangium*, bare land, and rubber land covers, and more than 800 cm on oil palm and secondary forest. Peaty clay becomes substratum of almost land cover, except on oil palm with peaty sand as substratum (Figure 2). The same trend of peat maturity reported by Hooijer *et al*. (2012) that on drained peatlands, the surface layer is generally dominated by sapric peat condition and followed by nearly *fibric* condition at greater depth, and often woody, except the lowest few meters where peat was often *hemic* or *sapric* and sometimes described as muddy, indicating higher mineral content.

Characteristics of each land use were close by correlated to any factor such as land clearing process, water table depth control, and inherent properties of the vegetation. *A. mangium* can be categorized as fast growing leguminous crop, its population density is higher than other cultivated land covers which can produce higher biomass both above and below ground. Another important effect of higher biomass produced is more intensive to peat compaction when canal drainage is established to achieve a suitable water depth for cultivated crops growth. Combination of inherent crop properties and intensive management may be lead to the change of the peal physical properties and has more effects to higher CO_2 emission. On bare land site, vegetation dominated by 1-2 years old natural *A. mangium* regrowth combined with natural shrubs, CO_2 emissions tended to higher than the 3 others land use although it was not as high as *A. mangium.*

The previous vegetation of oil palm and rubber land covers was secondary forest, cleared 4 years ago for oil palm and 7 years ago for rubber. A traditional method of land clearing on the two land use types causes a minimum impacts to physical peat characteristics and may be correlated to a lower CO_2 emission than *A. mangium* and bare land. Meanwhile, the previous vegetation of secondary forest was primary tropical wet land forest, cleared at the end of 1980 decades. Under tropical condition, many tropical species growth well at the site and by

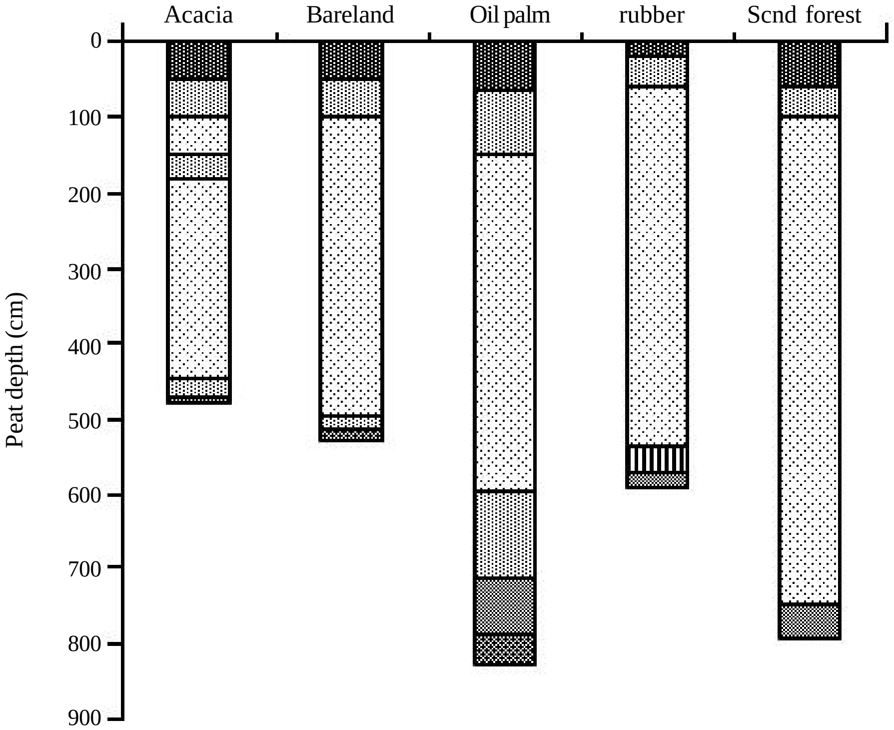


Figure 2. Peat Characteristics on Selected Land Use Types. Sapric peaty clay: ▩ , hemic peaty clay: ▦, peaty clay: ◫, hemic: ▤, fibric: ▢, sapric: .

time, the site was over grown with tropical vegetation.

Physical and chemical properties of the site are presented at Table 2. Based on dry weight, water content of the experimental site at surface layer ranged from 539.6 ±323.7 – 933.5±430.9%, while sub surface layer had higher water content ranged from 1072.3 ± 430.9 – 1361.8 ± 300.5%. This is likely to be correlated to the inherent properties of peatlands that can retain considerable quantities of water whereas woody peat is generally nearly very permeable to water, compacted (drained) peat has much lower for the degree of its permeability. This result was also inaccordance to Mutalib *et al.* (1991) which reported that water content of tropical peat is usually ranged from 100-1300% from its dry weight. Intensive land use management such as *Acacia*, oil palm, and rubber showed lower C-organic content at surface layer which was around 47.20±1.10 - 47.93±3.99% than sub surface which was around 49.97±3.34 – 53.53±7.52%. However, C-organic was higher at surface layer on an intensive land use management such as bare land and secondary forest, which was ranged from 52.33±4.16 – 54.03±7.41% than sub surface layer which was ranged from 48.83±1.94 – 49.20±1.54%. The similar trend of C-content was reported by Ywih *et al.*(2009) that the amount of stable C of secondary forest and oil palm plantation at 0 – 25 cm depth were generally higher than those in the 25 – 50 cm.

In contrast, bulk density, C-density, and ash contents were higher at surface layer than sub surface layer. Similar to water content, higher values of bulk density, C-density, and ash content were observed in intensive land use management. Those values of the selected physical properties at surface layer were ranged from 0.13±0.02 – 0.16±0.03 g cm^{-3} for bulk density, 7.12±1.03 – 8.83±1.66 kg m^{-3} for C-density, and 5.24±2.38 – 5.40±2.66% for ash content. On an intensive land use management, those values were ranged from 0.10±0.04 – 1.13±0.02 g cm^{-3}, 5.78±2.04 – 7.30±0.84 kg m^{-3}, and 4.27±1.22 – 5.98±2.18%, respectively. The same patterns of BD value were reported by Tie and Lim (1991) that bulk density at surface layer of tropical peat ranged of 0.1-0.2 g cm^{-3}, and at sub layer was usually $\leq$ 0.1 g cm^{-3}. While Wahyunto *et al.* (2010) found that drained topical peat for agriculture activities on Kalimantan and Sumatera Islands ranged from 0.11-0.15 g cm^{-3} at surface layer and around 0.08-0.11 g cm^{-3} at sub surface layer. In this case, they claimed that the higher peat BD at surface layer may be closely correlated to the more mature of peat and tend to have higher BD at surface layer. Vertical BD variation pattern of tropical peatlands which were converted to shrub, rubber, and oil palm land

Table 2. Physical and chemical properties of peat under selected land use types.

Parameter	**Land use types**				
	Acacia	**Bare land**	**Oil palm**	**Rubber**	**Secondary forest**
Water content (%)*:					
• Surface	933.5 ± 430.9	703.4 ± 495.6	539.6 ± 323.7	818.6 ± 432.2	820.1 ± 476.6
• Sub surface	1100.3 ± 198.1	1089.9 ± 94.9	1072.3 ± 92.9	1101.9 ± 162.9	1361.8 ± 300.5
Ash content (%)					
• Surface	5.24 ± 2.38	4.27 ± 1.22	5.40 ± 2.66	5.32 ± 1.16	5.89 ± 2.18
• Sub surface	3.03 ± 0.37	3.14 ± 0.94	2.03 ± 0.30	3.55 ± 0.56	2.37 ± 0.61
C-Organic (%):					
• Surface	47.93 ± 3.99	54.03 ± 7.41	47.20 ± 1.10	47.43 ± 7.29	52.33 ± 4.16
• Sub surface	48.30 ± 6.99	49.20 ± 1.54	49.97 ± 4.34	53.53 ± 7.52	48.83 ± 1.94
C-density (kg m^{-3}):					
• Surface	7.88 ± 3.09	5.78 ± 2.04	8.83 ± 1.66	7.12 ± 1.03	7.30 ± 0.84
• Sub surface	4.73 ± 0.32	3.93 ± 1.06	5.00 ± 0.25	4.13 ± 0.30	3.74 ± 1.05
Bulk Density (g cm^{-3}):					
• Surface	0.14 ± 0.06	0.10 ± 0.04	0.16 ± 0.03	0.13 ± 0.02	0.13 ± 0.02
• Sub surface	0.08 ± 0.01	0.07 ± 0.02	0.09 ± 0.01	0.07 ± 0.01	0.07 ± 0.02
Total N (%):					
• Surface	1.60 ± 0.46	1.55 ± 0.02	1.95 ± 0.19	1.40 ± 0.11	1.84 ± 0.09
• Sub surface	1.19 ± 0.35	1.26 ± 0.21	1.77 ± 0.24	1.48 ± 0.21	1.14 ± 0.14
C/N ratio:					
• Surface	30.02 ± 8.71	34.94 ± 485.39	24.16 ± 5.76	33.80 ± 65.34	28.39 ± 47.64
• Sub surface	40.59 ± 20.21	38.94 ± 7.20	28.23 ± 18.23	36.25 ± 35.85	42.84 ± 14.11
pH:					
• Surface	3.47 ± 0.06	3.60 ± 0.26	3.57 ± 0.12	3.77 ± 0.15	3.30 ± 0.10
• Sub surface	3.43 ± 0.06	3.33 ± 0.25	3.23 ± 0.12	3.57 ± 0.15	3.23 ± 0.12
CEC (c mol kg^{-1}):					
• Surface	102.9 ± 9.3	111.5 ± 2.8	93.9 ± 17.2	108.4 ± 1.4	96.2 ± 19.4
• Sub surface	105.3 ± 7.2	107.9 ± 12.9	97.9 ± 1.4	95.3 ± 1.6	109.4 ± 4.9
Base saturation (%):					
• Surface	14.33 ± 7.51	17.33 ± 4.04	7.33 ± 1.53	15.33 ± 6.11	6.00 ± 2.00
• Sub surface	9.33 ± 2.89	11.67 ± 8.14	7.00 ± 1.73	8.00 ± 1.00	5.67 ± 1.15

*Water content by weight

uses showed higher at surface layer around 0.08-0,12 g cm^{-3}, decreased at middle layer around 0.06-0.08 g cm^{-3}, and increased at lower layer around 0.09-0.14 g cm^{-3} (Maswar 2011). An intensive observation established from 2000-2009 on drained tropical of Kalimantan and Sumatera peatlands showed that C-density at surface layer was around 42.45-68.4 kg m^{-3}, higher than sub surface layer around 29.36-53.76 kg m^{-3} (Wahyunto *et al*. 2010). Correlated to this result, Dexter *et al*. (2009) reported that on farmed lands, increased bulk density, which is an indication of compaction, decreases with depth within the autoxidized peat zone, whereas on natural peat forest, it is generally constant with depth.

Those physical peat properties strongly suggested that peat maturity of peatlands have high correlated with physical properties, both for surface and sub surface layers. Surface layer, commonly has achieved sapric maturity condition due to the aerobic condition which is higher oxygen concentration and lead to accelerate decomposition of organic matter compare to sub surface layer which is anaerobic condition, inhabit organic matter decomposition. In addition, it is another interesting peat property that low bulk density of peatlands cause lower bearing capacity and inhabit the perennial crops growth (Widjaja Adhi 1997). While Prajitno *et al*. found that peat depth, bulk density, and organic C content of tropical peatlands of Ogan Komering Ilir District, South Sumatera, which was converted for oil palm agroecosystem were 200 – 800 cm, 0.211 – 0.347 g cm^{-3} and 56.30 – 58.31%, respectively.

Chemically, pH at surface layer of selected land use types ranged from 3.30±0.10 - 3.77±0.15, which was higher than sub surface ranged from 3.23±0.12 - 3.57±0.15. Total nitrogen was also higher at surface layer (around 1.40±0.11 – 1.95±0.19%) than sub layer (around 1.14±0.14 - 1.77±0.24%). The similar trend of peat pH was reported by Agus *et al.* (2009) that peat pH on Kubu Raya District, West Kalimantan at surface layer ranged from 3.0 – 5.6, higher than sub surface which had pH around 2.7-4.5. While Salampak (1999) reported that pH value of oligotropic peat at Berengbengkel, Central Kalimantan ranged from 3.25-3.75.

Cation exchange capacity (CEC) of site experiment showed high value, both at surface and sub layers. At surface layer, CEC ranged from 93.9±17.2 - 111.5±2.8 cmol kg^{-1}, while at sub layer ranged from 95.3±1.6 - 109.4±4.9 cmol kg^{-1}. In contrast with CEC, base saturation showed lower value both for surface and sub surface layers. At surface layer, base saturation ranged from 6.00±2.00 – 17.33±4.04%, while at sub surface layer ranged from 5.67±1.15 – 11.67±8.14%. This condition was also reported by Agus and Subiksa (2008) that determining peat pH using NH_4^- Acetate 1.0 *N*, pH 7 method, resulted higher, pH value compared to NH_4^- Chloride pH actual method. The highest pH effects to the lowest base saturation value as reported by Suhardjo and Widjaja Adhi, (1976) that base saturation value of peat at Central Kalimantan was lower than 10%.

Carbon Stock

Carbon stock (C-stock) of selected land use types consisted of 2 components, namely below ground and above ground C-stock (Figure 3). The highest C-stock was shown on oil palm as much as 5,949.60 Mg ha^{-1} followed by secondary forest, rubber, *A. mangium*, and bare land which were 4,236.37 Mg ha^{-1}; 3,434.69 Mg ha^{-1}; 2,896.95 Mg ha^{-1} and 2,657.08 Mg ha^{-1}, respectively. Below ground C-stock generally has a correlation to any peat property such as bulk dencity, organic matter content, and peat thickness (Hooijer *et al.* 2006). The experiment results showed that below ground C-stock under selected land use types became higher as the peat thicknes increase with ranged

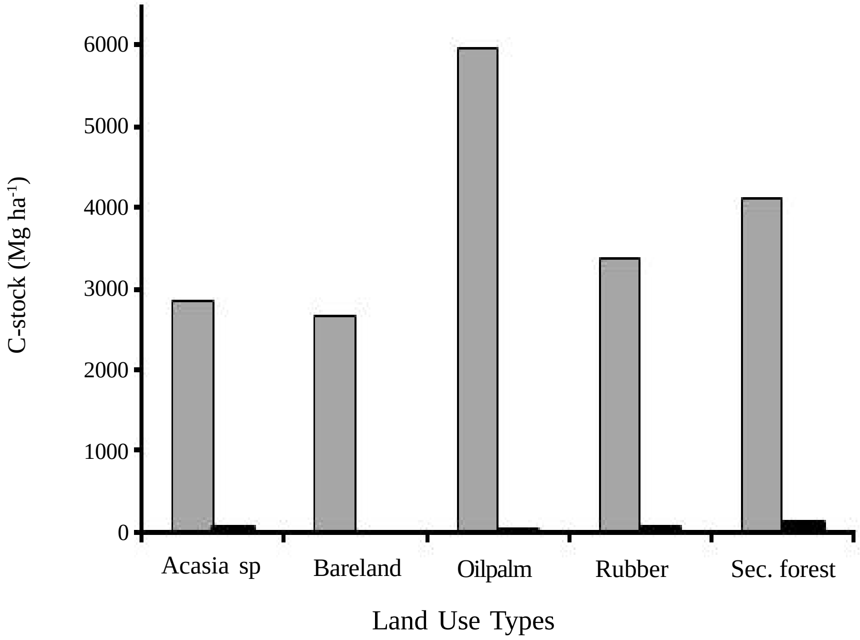


Figure 3. Above Ground and Below Ground C-stock of Selected Land Use Types. Above ground C-stock: ■, Bellow ground C-stock: ■.

from 2,657 - 5,950 Mg ha^{-1} . This results showed the same trend as reported by Agus *et al.* (2009) that below ground C-stock of peat at Kubu Raya Sub District, West Kalimantan Province were about 3,000.00 Mg ha^{-1} with peat thicknes 600-700 cm. Other review study reported that below ground C-stock of tropical peatlands varied from 300.00 – 6000.00 Mg ha^{-1} (Agus and Subiksa 2008).

Interesting result showed that below ground C-stock of *A. mangium* of 2,849 Mg ha^{-1}, was higher than bare land of 2,657 Mg ha^{-1}, although peat thicknes under bare land was about 532 cm, deeper than *A. mangium* of 481 cm. Peat maturity and C-organic contents of the two land use types were not significantly different at all peat layers, but BD on *A. mangium,* at surface layer of 0.13-0.24 g cm^{-3}, and sub surface layers of 0.09-0.11 g cm^{-3}, was higher than BD of bare land for both layers, at surface layer of 0.12-0.14 g cm^{-3} and sub surface layer of 0.05-0.09 g cm^{-3}. In term of below ground C-stock, it is strong suggested that higher below ground C-stock on *A. mangium* was directly caused by the higher BD both at surface and sub surface layers.

Above ground C-stock was estimated for *A. mangium* and secondary forest land covers, and there was no esimated of above ground C-stock for oil palm because the three years old oil palm did not form the trunk yet, and there was no trees growth on bare land area. While for rubber, the above ground C-stock was estimated refering to the previous field experiment results. The above ground C-stock consisted of C-trees, C-necromass, C-litter, and C-understory components. Commonly, there were a positive correlation between crops age and total above ground C-stok, however, due to the different of necromass C-stok, the 3 years old of *A. mangium* produced about 34.4 Mg ha^{-1}, which was lower than the 1-2 years old of *A. mangium* around 36.6 Mg ha^{-1}. Asmani *et al.*(2011) reported that above ground C-stock of 2 years, 3 years, and 4 years age of *Acasia* sp. were 24.876 Mg ha^{-1}, 33.468 Mg ha^{-1} and 49.752 Mg ha^{-1}, respectivelly.

The highest above ground C-stock was shown by secondary forest of 131.5 Mg ha^{-1}, and might be correlated to the highest of crops biodiversity grown at the areas. This result suggested that secondary forest at Lubuk Ogong Village has been severely disturbed as indicated by the number of above ground C-stock of 131.5 Mg ha^{-1} compared to natural peat forest of 240 Mg ha^{-1}, which can be classified into lower above ground C-stock (Hairiah *et al.* 2011). Meanwhile, based on time average estimation over 25 years, rubber agroforestry with drainage depth of 30 cm, above ground C-stock was around 60 Mg ha^{-1} (Agus *et al.* 2009).

CO_2 Emission

The result of CO_2 emission is presented in Table 3. It was observed that environmental factors such as water table depth (WTD), water content, soil temperature, and air temperature affected CO_2 emission. All selected land uses showed a positive correlation to water table depth and soil temperature with correlation value ranged from 0.271 – 0.688 and from 0.007–0.559, respectively. Different to these factors, there were inconsistency correlations between CO_2 emission with water content and air temperature. For soil water content, a negative correlation was observed under *A. mangium*, rubber, and secondary forest, while bare land and oil palm showed a positive correlation. For air temperature, a positive correlation with CO_2 observed under bare land, oil palm, and secondary forest, but *A. mangium* and rubber showed a negative correlation.

Simillar to this results, Agus and Subiksa (2008) reported that environmental factors affected CO_2 emission on peatland are soil water content, soil temperature, water table depth, and fertilization

Table 3. Correlation matrix between CO_2 emission with water table depth, soil water content, soil temperature, and air temperature under selected land use types.

Land use	Correlation value				CO_2 emission (Mg $ha^{-1}yr^{-1}$)
	Water table depth (cm)	Soil water content (%)	Soil temperature (°C)	Air temperature (°C)	
Acacia mangium	0,27*	-0,21	0,10	-0,20	59.55 ± 18.30
Bareland	0,51**	0,33*	0,23	0,38*	66.58 ± 21.77
Oil palm	0,51**	0,17	0,56**	0,39*	66.17 ± 25.54
Rubber	0,64**	-0,09	0,01	-0,05	53.65 ± 16.91
Secondary forest	0,69**	-0,19	0,41**	0,39*	64.50 ± 31.49

Note: **Critical value of Pearson Correlation Coefficient: 0.01 = 0.39
*Critical value of Pearson Correlation Coefficient 0.05 = 0.30
Critical value of Pearson Correlation Coefficient 0.10 = 0.26

treatment. The same trend correlation between CO_2 emission and WTD was also reported by Hooijer *et al*. (2006) that on WTD with range from 30-120 cm, CO_2 emission will increase around 0.91 Mg ha^{-1} as WTD increase 1 cm. In case of soil temperature, Jauhiainen *et al.* (2012) found that under *Acacia* plantation on tropical peatlands, the effects of diurnal temperature fluctuations, which may result in a 14.5% reduction of the day time CO_2 emission by 14.5 Mg ha^{-1}yr^{-1}. Other factor, mainly root respiration was also responsible for high variation of CO_2 emission, and the interference of viable root respiration should be minimized in CO_2 measurement. Referring to Jauhiainen *et al.* (2012), we corrected the CO_2 emission of root interference by 21% for *A. mangium.*

Other result reported by IPB (2011) also showed the same trend that CO_2 emission from peat land has a positive correlation with WTD as shown on Table 4. A non significant different of CO_2 emission was observed on WTD< 52 cm, quantitativelly< 20 Mg ha^{-1}yr^{-1} on all selected crops. CO_2 emission increased as WTD increased as well, where on WTD $\geq$ 90 cm, the highest CO_2 emission was provided by oil palm around 50-85 Mg ha^{-1}yr^{-1}, while rubber resulted the lowest around 35-65 Mg ha^{-1}yr^{-1}. This phenomenon is closely correlated to the aerobic and anaerobic condition of peat land. If WTD increase due to the deep drainage or dry season, environmental conditions tend to aerobic condition, lead to increase peat decomposition, and release higher CO_2 to the atmospheer. In contrast, on sellow WTD, environmental conditions tend to anaerobic, inhabit peat decomposition, and release lower CO_2 to the atmospheer.

Quantitatively, the highest CO_2 emission showed on bare land around 66.58 ± 21.77 Mg ha^{-1}yr^{-1} with water table depth and soil temperature around 74.91 ± 28.98 cm and 30.6 ± 2.23°C, respectively. It's seemed a non significant CO_2 emission with oil palm around 66.17 ± 25.54 Mg ha^{-1}yr^{-1} with WTD and soil temperature around 71.14 ± 36.55 cm and 30.6 ± 2.72° C; and secondary forest around 64.50 ± 31.49 Mg ha^{-1}yr^{-1} with WTD and soil temperature around 81.68 ± 22.64 cm and 27.4 ± 1.40°C. CO_2 emission under *A mangium* after corrected by root respiration was around 59.55 ± 18.30 Mg ha^{-1}yr^{-1} with WTD 81.2 ± 34.18 cm and soil temperature 28.6 ± 0.98°C. Rubber showed the lowest CO_2 emission around 53.65 ± 16.91 Mg ha^{-1}yr^{-1} with WTD around 59.29 ± 24.47 cm and soil temperature around 29.0 ± 2.78°C.

The field experiment result showed a non significant of CO_2 emission compare to the previous results as Agus *et al*. (2009) found that by average, CO_2 emission from oil palm, cultivated on peat land converted from peat forest was around 66 Mg ha^{-1}yr^{-1}, rubber around 50 Mg ha^{-1}yr^{-1}, and shrub around 56 Mg ha^{-1}yr^{-1}. Meanwhile, Anonimous (2010) reported that by average, CO_2 emission from oil palm grown on peat land which was coverted from peat forest was around 71.4 Mg ha^{-1}yr^{-1}. However, CO_2 emission on *Acacia* showed lower than Jauhiainen *et al*. (2012) which was reported that under *Acacia* plantation of tropical peatlands, the daytime mean annual CO_2 emission from peat oxidation alone of 94 Mg ha^{-1}yr^{-1} at a mean WTD of 80 cm, and a minimum emission value of 80 Mg ha^{-1}yr^{-1} after correction for the effects of diurnal temperature fluctuations, which resulted in a 14.5% reduction of the daytime emission. The highest CO_2 emission under oil palm might be correlated to its physical charachterization mainly BD and C-density. Agus *et al.* (2012) claimed that land use changes from natural peat forest into plantation and cleared using an heavy mechanization such as oil palm, it was commonly observed that peat BD tend higher than others land use types due to compaction and also consolidation, and lead higher CO_2 emission.

CONCLUSIONS

Peat depth under selected land use types showed high variation and affected below ground C-stock almost linearly with peat depth. Below ground C-stock on *A. mangium* was around 2848.55

Table 4. Correlation between CO_2 emission and water table depth (cm)

Crop	CO_2 emission (Mg ha^{-1} year^{-1})		
	WTD< 52 cm	WTD< 53 - 89 cm	WTD $\geq$90 cm
Secondary forest	CO_2 emission were not signifcant different on all selected land use types, quantitativelly < 20 Mg ha^{-1} yr^{-1}	20-30	40-65
Shrub		25-35	40-65
Rubber		< 25	35-65
Oil palm		30-75	50-85

Source: Bogor Agriculture university, data was reanalysed (2011).

Mg ha^{-1} with peat depth 481 cm, on bare land 2657.08 Mg ha^{-1} with peat depth 532 cm, on oil palm 5949.85 Mg ha^{-1} with peat depth 830 cm, on rubber 3374.69 Mg ha^{-1} with peat depth 595 cm, and on secondary forest 4104.87 Mg ha^{-1} with peat depth 795 cm.

The highest above ground C-stock observed on secondary forest about 131.5 Mg ha^{-1}, followed by the 4 years *A. mangium* of 48.4 Mg ha^{-1}, the 1-2 years *A. mangium* of 36.6 Mg ha^{-1}, and the 3 years *A. mangium* of 34.4 Mg ha^{-1}.

Water table depth (WTD) and soil temperature have dominant effects and a positive correlation to CO_2 emission under all selected land covers. Bare land showed the highest CO_2 emission of 66.58 ± 21.77 Mg ha^{-1}yr^{-1} with WTD of 74.91 ± 28.98 cm and soil temperature of 30.6 ± 2.23°C. It's seemed that CO_2 emission on bare land was not significantly different with oil palm of 66.17 ± 25.54 Mg ha^{-1}yr^{-1} and secondary forest of 64.50 ± 31.49 Mg ha^{-1}yr^{-1}. CO_2 emission under *A. mangium* after corrected by root respiration was around 59.55±18.30 Mg ha^{-1}yr^{-1}, and the lowest CO_2 emission was shown under rubber of 53.65 ± 16.91 Mg ha^{-1}yr^{-1} with WTD and soil temperature of 59.29 ± 24.47 cm and of 29.0 ± 2.78 °C, respectively.

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