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Physical and Chemical Properties of Cultivated Peat Soils in Four Trial Sites of ICCTF in Kalimantan and Sumatra, Indonesia

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ABSTRACT

The large distribution of peat soils in Indonesia have important role in carbon stock and greenhouse gas emission which contribute to global warming issue. The objective of this study was to characterize physical and chemical properties of cultivated peat soils in four trial sites of Indonesia Climate Change Trust Fund (ICCTF) in Central Kalimantan, South Kalimantan, Riau and Jambi Provinces to provide a baseline data by a greenhouse gas emission study. Detailed soil observations were conducted using grid system with spacing of 25 × 50 m. A total of 16 representative peat soil profiles consisting of 74 soil samples of horizons were selected for laboratory analyses. The results showed that peat maturity varied from hemic to sapric in the surface layers and hemic in the subsurface layers, except in Site-2 that was fibric. The peat thickness ranged respectively from 5.4 to 7.0 m in Site-1 and Site-3, and from 0.5 to 2.5 m in site-2 and site-4, and all overlying fine-textured mineral soil (substratum). Depth of water table varied from 10 to 30 cm in Site-2 and Site-4, and from 30 to 70 cm in Site-1 and Site-3. Fiber content ranged from 13 to 57% and increased with depth indicating the peat was less decomposed. The bulk density was very low (0.07-0.24 g cm^{-3}) and negatively correlated to fiber content (r = 0.74 for Kalimantan and r = 0.66 for Sumatra). The ash content was low (0.1-8.5%) and negatively correlated to organic carbon content (r = 0.89 for Kalimantan and r = 0.65 for Sumatra). Soil CEC was high and positively correlated to organic carbon content (r = 0.86 for Kalimantan and r = 0.93 for Sumatra). These soils showed very acid reaction (pH 3.3-4.7), low content of exchangeable bases and total P_2O_5 and K_2O (HCl 25%). Based on these properties, the peat soils were grouped as oligotrophic ombrogenous peat. The estimated carbon stock for all the trial sites with total extent of 22.58 ha was 57,282 Mg C. The variation of thickness, maturity, and water table depth will imply to the magnitude of carbon reserves and greenhouse gas emissions.

***Keywords**:* Ash content, fiber content, Kalimantan, ombrogenous peat, Sumatra

INTRODUCTION

Peat soils are formed by the process of deposition of organic matter resulted from accumulation of plant debris or vegetation decaying in a basin. In anaerobic condition the rate of decomposition of organic matter is slow, resulting in the accumulation of thick organic material which can form a peat dome. The soils are known as Organosol (Soepraptohardjo 1961; Soil Research Institute 1978) or Histosols (FAO 1990; Soil Survey Staff 2010). The formation of peat soil is considered as geogenic processes, caused by the deposition and transportation process, in contrast to the formation of the mineral soil that is generally a pedogenic process (Hardjowigeno 1986). In Indonesia, peat formation has started since 4,000-4,500 years when the sea level rise after the end of the ice age ended (Van Wijk 1951; Verstappen 1975).

Most of the peat soils in Indonesia are classified as ombrogenous peat with oligotrophic properties which occupy the fresh and tidal swamplands, and locally as homogenous peat with eutrophic properties which found in lowland and highland areas (Polak 1941). The extent of peat soils in Indonesia formerly is estimated around 17.0 million ha, which is distributed in various physiographic units of peat dome, river and marine backswamps, and alluvial depression (Soepraptohardjo and Driessen 1976; Soekardi and Hidayat 1994). Recent revision showed that the extent of peat soils is estimated about 14.9 million ha, which spread over an area of 6.4 million ha in Sumatra, 4.8 million ha in Kalimantan and 3.7 million ha in Papua (Ritung *et al.* 2011). Under natural conditions, peat soil can sequester carbon faster than the decomposition rate, thus it can increase the peat thickness. Conversely, if the peat soils are cleared or cultivated for agricultural land and drained, the rate of decomposition increases and it will be a source of greenhouse gas emissions (Agus and Subkisa 2008). Peat soils have important role in contributing greenhouse gas emission and carbon sequestration in relation to global warming issue. Tropical peat soils have significant carbon sinks and store large amounts of carbon and their destruction can significantly impact on the amount of atmospheric CO_2. Indonesia peat soils store huge amount of carbon, estimated about 37 G Mg CO_2 which is distributed mainly in Sumatra 3,093 Mg C ha^{-1} on around 7.2 M ha, Kalimantan 1,954 Mg C ha^{-1} on around 5.8 M ha, and Papua 454 Mg ha^{-1} on around 7.6 M ha (Las *et al*. 2011). Under natural forest, peat sequesters carbon and grows between 0.5 and 1.0 mm $year^{-1}$, while drained peat emits carbon and subsides at the rate of 1.5 to 3.0 cm $year^{-1}$ (Andriesse 1988).

The degree of peat decomposition can be distinguished into fibric, hemic and sapric. Fibric is little decomposed peat with fiber content of >75% volume. Sapric is mostly decomposed peat with fiber content of <17%, while hemic has fiber content in between of fibric and sapric (Soil Survey Staff 2010). But according to the former definition, fibric maturity has fiber content of >66% volume, while sapric has fiber content of < 33% volume, and hemic has fiber content in between of the values (Soil Survey Staff 2010). The fiber content and bulk density are the important physical properties of peat soils which are often used to determine the rate of peat decomposition (Boelter 1969). The more decomposed peat soils have lesser fiber content and the bulk density increases. Normally, peat soils consist of three zones within the depth, namely: (a) the upper zone, about 20-30 cm thick, is the most decomposed, (b) middle zone, about 30-40 cm thick has more decomposed, and (c) the lower zone (> 50-70 cm thick) has less decomposed and mixed with wood twigs and leaves (Mutalib *et al*. 1991). Chemical composition and fertility of peat soils is determined by the thickness, maturity of the layers, mineral enrichment, substratum underlying the peat layer, and quality of water from rivers or tidal that influences the formation and maturation of peat soils (Widjaja Adhi 1986).

Related to fertility status, the formation of peat soil can be divided into: (a) oligotrophic, the peat is formed in an environment that influenced by rain water only, forming a dome, generally thick, poor nutrient status, and low ash content, (b) eutrophic, the peat is formed in the inland parts of coastal or river that is affected by tidal water or surrounded by higher area, which supplying minerals, making it more fertile, not too thick, and high ash content, and (c) mesotrophic, the transition between the two types of peat, which is better than oligotrophic peat (Driessen and Sudjadi 1984). Based on their formation and water influence, peat soil can be divided as ombrogenous and topogenous peats. The ombrogenous peat is formed in the environment which influenced by rain water only, very thick and formed peat dome, while topogenous peat is formed in the environment that influenced by mineral enrichment from tidal fluctuation or river. Therefore, the ombrogenous peat soils are less fertile because of low nutrient status, while the topogenous peat soils are considered more fertile than those of ombrogenous peat, such as found in the Lakbok swampland, South Priangan area, West Java (Polak 1949), in the Toba highland of North Sumatra (Prasetyo and Suharta 2011), and in the west coast of Seluma, Bengkulu, Sumatra (Hikmatullah 2007). Related to agricultural use, the peat thickness may be divided into four classes, namely shallow (<1 m), medium (1-2 m), thick (2-3 m), and very thick (> 3 m). The peat soils with thickness of <3 m, hemic to sapric decomposition, and clayey substratum may be recommended as suitable peatland for agriculture use (Balsem and Buurman 1990; Agus and Subiksa 2008).

The objective of this study was to identify and characterize physical and chemical properties of cultivated peat soils in four trial sites of ICCTF in Central Kalimantan, South Kalimantan, Riau and Jambi Provinces as a baseline data to support planning studies of carbon stocks and greenhouse gas emissions assessment.

MATERIALS AND METHODS

Description of Study Area

The study was conducted in cultivated peat soils in four trial sites of ICCTF of two physiographic positions. Site-1 and Site-3 represented physiographic unit of peat domes, while Site-2 and Site-4 represented physiographic unit of river backswamps. The study areas have been cultivated with food crops (maize, paddy rice), rubber and oil palm plantation of local farmer (Table 1). The areas were mapped at scale of 1:500 by the Center for Agricultural Land Resource Research and Development to support greenhouse gas emission study. The study areas had a rainfall type A and B_1 agro-climatic zone as characterized by 7 to 9 consecutive wet months (>200 mm) and less than 3 dry months (<100 mm). The mean annual rainfall in Site-1 and Site-2 represented by Palangkaraya and Banjarbaru

Table 1. The location of the ICCTF trial sites in Kalimantan and Sumatra.

Site	Location	Geographic position (Latitude and longitude)	Land use	Extent (ha)
Site-1	Jabiren, Pulangpisau, Central Kalimantan	2°30'55"S - 114°10'12"E	Rubber plantation	5.01
Site-2	Tegal Arum, Banjarbaru, South Kalimantan	3°25'55" S - 114°46'02" E	Maize, wetland rice	6.72
Site-3	Lubuk Ogong, Pelalawan, Riau	0°21'03"N - 101°41'18" E	Oil palm plantation	5.25
Site-4	Arang Arang, Muaro Jambi, Jambi	1°40'41"S - 97°48'49"E	Oil palm plantation	5.60

stations was 2,488 and 2,605 mm, respectively, while in Site-3 and Site-4 represented by Pekanbaru and Jambi stations, the mean annual was 2,546 and 3,063 mm respectively (Hidayat *et al.* 2011).

Field Observation and Sampling

Detailed soil observations were conducted using grid system for all the trial sites with spacing of 25 × 50 m, which cut perpendicular to river channel in order to allow observation for soil variability within vertical or horizontal directions. The coordinate position of each observation point was determined by GPS tool. Soil augering was executed using peat auger of *Eijkelkamp* type until reached mineral soil (substratum). The description of soil morphological features include thickness, level of maturity, color, mineral soil enrichment, soil pH, depth of water table, substratum, and other features. The soil observation procedure referred to the Guidelines for Soil Profile Description (FAO 1990) and Guidelines for Soil Observations (Soil Research Institute 2004). A total of 16 representative peat soil profiles were selected and described in the field and 74 soil samples of horizons from these profiles were selected for chemical analyses. In addition, 40 peat soil samples consisting of top and lower layers based on peat maturity level of each profile were taken to determine soil physical properties. In this paper only 8 of 16 representative peat soil profiles were presented. These soils were classified into subgroup level according to *Keys to Soil Taxonomy* (Soil Survey Staff 2010).

Soil Sample Analyses

The soil analyses consisted of physical and chemical properties. Bulk density (BD) was determined by gravimetric method. Moisture content was measured at field and dry conditions. Fiber content was determined by filtering at 100 meshes (0.149 mm). Ash content was determined by loss on ignition method at 550-600° C. Soil pH was measured with a glass electrode in soil/solution suspensions of 1:2.5 H_2O. The Walkley and Black wet oxidation method was used to determine organic carbon. The total N content was measured by the Kjeldahl method. Total P_2O_5 and K_2O contents were extracted with 25% HCl. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+) were extracted with 1 *M* NH_4OAc at pH 7.0 and determined by atomic absorption spectrometry (AAS). The cation exchange capacity (CEC) was determined by saturation with 1 M NH_4OAc at pH 7.0. Exchangeable Al was extracted with 1 *M* KCl. Content of available micro-nutrients (Fe, Mn, Zn, Cu) were extracted by dietilene triamine penta acetic acid (DTPA) at pH 7.3. The methods of soil sample analyses were described in the Technical Guidelines for Chemical Analysis of Soil, Water, Plant and Fertilizer (Eviati and Sulaeman 2012) and Soil Survey Laboratory Method (Burt 2004).

Carbon stock was estimated based on the representative peat soil profile data and the extent of each soil mapping unit using the formula: $Cs = L \times D \times BD \times org.\ C$, where Cs = carbon stocks (ton), L = area (m^2), D = peat thickness (m), BD = bulk density (g cm^{-3} or t m^{-3}) and Org C = organic C content (%) (Agus *et al.* 2011). A simple regression analysis was calculated based on the physical and chemical properties to determine the correlation between fiber content and BD, organic C and ash content, and organic C and soil CEC.

RESULTS AND DISCUSSION

Soil Morphological Properties

The peat soil colors were generally dark in all layers of the soil profiles of the trial sites due to the high content of organic matter and in moist or wet soil conditions. The soil colors of top layers varied from black to very dark red (10YR2/1; 7.5YR3/1; 2.5YR2.5/2), and in the lower layers the color was dark reddish brown to dark brown (7.5YR3/3-3/4; 5YR3/2; 2.5YR3/3). The colors of mineral soils (substratum) were gray to light gray (2.5Y5/1; 5Y6/1-6/2) due to reduction condition and were generally fine-textured (clay, silty clay, sandy clay), sticky and plastic consistency.

Based on field observations, the peat maturity of top layers was generally more decomposed than those lower layers as the effect of cultivation or drainage condition. In Site-1, Site-3 and Site-4, the maturity of top layers were sapric and the lower layers were hemic with ground water table of 45-50, 60-70 and 25-35 cm depth respectively. With exception in Site-2, the top layer was hemic and the lower layer was fibric with shallow water table (10-15 cm). The depth of ground water table could probably influence the decomposition rate of peat soils, where the deeper ground water table increases the rate of peat decomposition. Conversely, the shallow water table could retard peat decomposition as indicated by fibric maturity of peat soils in Site-2. The depth of ground water table can also affect the amount of greenhouse gas emissions, where the deeper the ground water table, the higher the amount of greenhouse gas emissions (Moore and Knowles 1989; Handayani *et al.* 2010). Therefore, managing the ground water table at certain level in the cultivated peat soils is absolutely necessary to maintain wet or moist condition in order to reduce emission (Rumbang *et al.* 2009). The peat maturity as reflected by fiber content was similar for all the sites, except in subsurface layer of Site-2. In Site-1 the fiber content of top layer ranged from 13 to 34% and was classified as sapric to hemic maturity. In other sites, the fiber content of top layers ranged from 21 to 48% and was classified as hemic maturity. The fiber content in the subsurface layers ranged from 19 to 65% and increased within depth indicating the peat less decomposed.

The maturity level or degree of decomposition of peat soils based on field data can be confirmed to the fiber content of laboratory analyses. In this study, the different level of maturity between field observation and laboratory data was found. As indicated by Site-2 (South Kalimantan), the contrast difference was found between field and laboratory data of maturity level for the subsurface layers. Laboratory data showed that the fiber content ranged from 24 to 57% and classified as hemic maturity, but according to field observation it was clearly identified as fibric maturity (> 2/3 or 66 % fiber content) which was different with other trial sites. Therefore, it seems better to use field data to estimate the peat maturity level rather than laboratory data, because it is closer to the former definition of Soil Taxonomy (Soil Survey Staff 2010).

Soil Physical Properties

The bulk density (BD) values of peat soils were quite variable due to differences in maturity levels or fiber content, but all the BD values which ranged from 0.07 to 0.24 g cm^{-3} were classified as low. Normally, the higher maturity of peat soils will be followed by increasing BD value. In Kalimantan, the BD of top layer with sapric to hemic maturity ranged from 0.17 to 0.23 g cm^{-3}, while in the lower layer of Site-1 with hemic maturity the BD ranged from 0.21 to 0.22 g cm^{-3}, and in the Site-2 with fibric maturity, the BD was very low, ranged from 0.07 to 0.09 g cm^{-3}. In Sumatra, the top layer of peat soils with hemic to sapric maturity, the BD ranged from 0.16 to 0.24 g cm^{-3}, while in the lower layer with hemic maturity the BD ranged from 0.14 to 0.20 g cm^{-3}. The data showed that the BD values of upper layer were higher than the lower layer, as the effect of cultivation or drainage condition. Similar result was found in cultivated hemic peat soils of Seluma area in Bengkulu which had BD value ranged from 0.20 g cm^{-3} in the top layer to 0.16 g cm^{-3} in the lower layer (Hikmatulah 2007). Driessen and Rochimah (1976) reported that BD of peat soils in swampy forest in Kalimantan ranged from 0.14 to 0.23 g cm^{-3}. Sari (2013) mentioned that BD value at forested fibric to sapric peat soils in Sebangau, Central Kalimantan, varied from 0.08 to 0.24 g cm^{-3}. Kool *et al.* (2006) stated that BD value of peat soils increased in the collapsed peat dome in Central Kalimantan caused by compaction and oxidation. Meanwhile, Wahyunto *et al.* (2010) compiled data from various sources and showed that the average BD values of peat soils in Sumatra were around 0.08, 0.09 and 0.18 g cm^{-3} for fibric, hemic and sapric maturity respectively, while in Kalimantan the average BD values were a little bit higher namely 0.07, 0.17 and 0.20 g cm^{-3} for fibric, hemic and sapric maturity respectively. Compared to the previous data, the BD values of all the trial sites were still in agreement with those obtained from the above study. Related to fiber content, the BD values showed a negative linear relationship to fiber content ($r = 0.74$ for Kalimantan and $r = 0.66$ for Sumatra). This means that BD value was influenced by fiber content, where increasing fiber content would be followed by decreasing BD value (Figure 1). Furthermore, decreasing BD value would also be followed by increasing total pore space. This was indicated by Site-2 which had the highest total pore space (94-95%) with the lowest BD value in the lower layer.

The water content in dry and wet conditions showed relatively little variations among the sites. In Site-1, Site-3 and Site-4 the water content was similar which ranged from 73 to 79%, 78 to 86% and 78 to 87% respectively, but in Site-2 it was slightly higher which ranged from 78 to 95%. Under moist or wet conditions, the water content of peat soils was very high. In Site-1, Site-3 and Site-4 the water content under wet condition was similar which ranged from 265 to 373%, from 270 to 390% and from 268 to 370% respectively, except in Site-2 with shallow water table and fibric maturity, the water

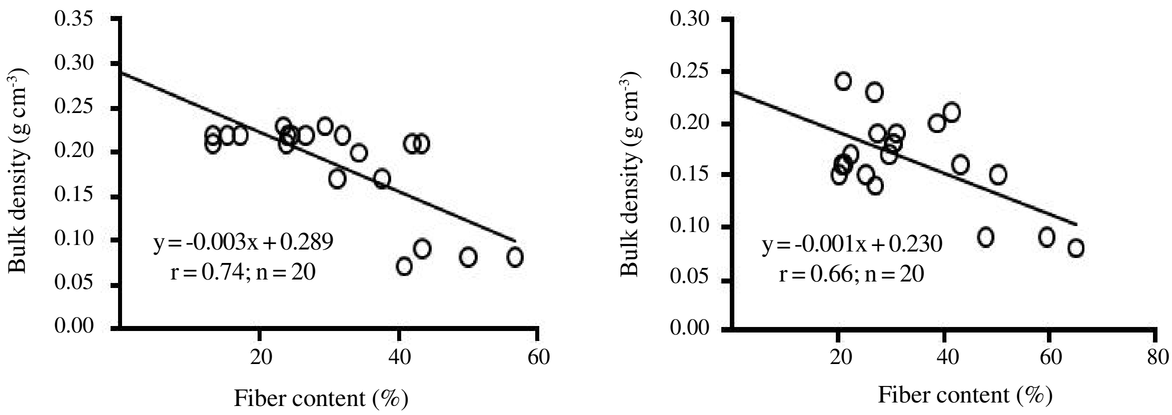

Figure 1. Correlation between fiber content and bulk density in Kalimantan (left) and Sumatra (right).

content was the highest which ranged from 364 to 1,409%. Mutalib *et al.* (1991) mentioned that the water content of peat soils ranged from 100 to 1300% of the dry weight of the soil, that means the soils capable to absorb much more water up to 13 times of its weight. In this study, the water content in wet conditions reached 265 to 1409%. Nugroho *et al.* (1997) mentioned that the high water content of peat soils could affect low BD, soft, and low bearing capacity, and it caused crop leaning, such as oil palm and coconut trees.

Soil Chemical Properties

All the peat soils of four trial sites were generally very acid soil reaction with pH (H_2O) ranged from 3.3 to 3.9 in all layers of the soils, except at Site-2 it was slightly higher (pH 4.0 to 4.2) which belonged to shallow peat. The pH of the mineral soil underlying peat soils (substratum) was slightly higher than the peat soils (pH 4.1 to 4.7). The pH of peat soil has the same value with those soils from other locations in Sumatra and Kalimantan (Suhardjo and Widjaja Adhi 1976; Wahyunto *et al.* 2010; Sari 2013). The peat soil acidity level was closely linked to the content of organic acids that contained of fulvic and humic acids (Andriesse 1974). The pH of peat soil tends to decrease with depth, where the deeper the peat soil, the pH decreases (Suhardjo and Widjaja Adhi 1976). Ismawi *et al.* (2012) reported that deforestation of peat swamp forest in Sibu, Serawak, Malaysia decreased significantly the chemical properties including soil pH, soil organic matter, total carbon, total nitrogen, CEC, total P, total K, and C/N ratio. Meanwhile, Salimin *et al.* (2010) compared chemical properties of peat swamp soil before and after timber harvesting, and the result showed that chemical properties decreased significantly after timber harvesting, mainly the CEC, content of soil organic matter, pH-KCl, total carbon, total N and total P.

The organic carbon content was very high at all layers of the peat soil profiles and was likely to increase with depth, which reflected the upper layers tend to be more decomposed than the lower layers. This situation was in accordance with that obtained by Suhardjo and Widjaja Adhi (1976) in peat soils of Riau. Close to the mineral soil layers, the organic carbon content decreased and at the mineral soils the organic carbon content decreased drastically (<12%). In Kalimantan, the C/N ratio was quite high ranged from 25 to 68, while in Sumatra, it ranged from 16 to 61, but generally it was 20 to 40. The value of C/N ratio increased with depth indicating the decomposition of organic matters in the surface layer was higher than that in the subsurface layer. It seems that the decomposition of organic matters in the subsurface layer is hampered perhaps by water stagnant condition. The above C/N ratio indicated that the peat soils of Sumatra were relatively more decomposed than of Kalimantan.

The ash content reflects the mineral enrichment of peat soils. The higher ash content indicates higher mineral enrichment, and the peat soil is more fertile. Data in Table 2 and Figure 3 showed that the ash content was generally low ($\leq$ 5%), except at the top layer and transition to mineral soil of Site-2 and Site-3 it was slightly higher (> 5%). In this case, the higher ash content was probably due to the influence of cultivation or burning of the area. The above ash content was different with the ash content of topogenous peat soils from Seluma, Bengkulu which was higher content (>10%) as the effect of mineral enrichment (Hikmatullah 2007). In the thick peat soils, the ash content decreases with depth and it will be followed by lower exchangeable bases, and increase soil acidity. There was a negative logarithmic relationship between the organic carbon content and ash content as showed in Figure 2 (r = 0.89 for Kalimantan and r = 0.65 for Sumatra)

Table 2. Morphological and physical properties of peat soils from four trial sites of ICCTF in Central Kalimantan, South Kalimantan, Riau and Jambi.

Profile/ depth	Matrix color	Level of maturity	pH H_2O	Organic matter			Fiber content	Ash content	Moisture		BD	TPS	water table
				C	N	C/N			Dry	Wet			
cm				---------%--------			-------------------- % -------------				g cm^{-3}	%	cm
KT1 (Central Kalimantan)													
0-25	10YR 2/1	Sapric	3.6	35.39	0.66	54	13.2	0.7	78	350	0.22	84	46
25-60	2.5YR3/2	Hemic	3.5	57.26	0.84	68	31.8	0.1	78	345	0.22	84	
60-120	2.5YR3/3	Hemic	3.4	57.59	0.88	65	30.4	8.5					
120-700	2.5YR3/2	Hemic	3.7	44.19	0.65	68	39.0	6.5					
700 +	2.5Y6/2	C	4.2	0.99	0.09	11	-	86					
KT2 (Central Kalimantan)													
0-23	7.5YR3/2	Hemic	3.6	46.91	0.81	58	23.3	0.8	77	335	0.23	84	33
23-200	2.5YR3/2	Sapric	3.4	50.70	1.00	51	17.1	0.5	78	354	0.22	84	
200-340	2.5YR3/2	Hemic	3.6	54.85	1.78	31	31.6	0.9					
340-650	5YR2.5/2	Hemic	3.5	31.28	0.67	47	27.9	13.6					
650-700	2.5Y6/2	C	4.4	1.48	0.13	11	-	2.6					
KS1 (South Kalimantan)													
0-9	10YR2/1	Hemic	4.0	42.92	1.69	25	24.4	12.5	78	364	0.22	84	15
9-75	7.5YR3/3	Fibric	4.2	55.61	1.14	49	56.7	0.6	92	1128	0.08	94	
75-80	10YR2/1	Hemic	4.0	52.97	0.85	62	28.6	4.3					
80-135	7.5YR4/3	Fibric	4.0	40.42	0.93	43	37.0	4.8					
135-143	10YR2/1	Hemic	4.1	36.62	1.28	29	23.8	6.5					
143-200	2.5Y7/1	SC	4.1	1.55	0.11	14	-	89.4					
KS2 (South Kalimantan)													
0-10	10YR3/2	Hemic	4.7	43.57	1.47	30	31.1	9.1	83	472	0.17	88	10
10-60	7.5YR3/3	Fibric	4.3	47.19	1.20	39	30.8	3.3	93	1409	0.07	95	
60-75	10YR2/1	Hemic	4.0	38.02	1.06	36	18.8	6.6					
75-220	7.5YR3/3	Fibric	3.9	44.32	0.98	45	36.6	0.8					
220-230	10YR3/3	Hemic	4.1	25.05	0.51	49	16.7	20.3					
230-250	2.5Y6/1	SC	4.4	2.27	0.21	11	-	49.9					
RA2 (Riau)													
0-40	7.5YR3/2	Hemic	3.3	17.86	0.86	21	41.3	14.9	79	400	0.21	85	70
40-120	5YR3/2	Hemic	3.6	20.93	0.70	30	27.3	4.4	81	560	0.19	86	
120-545	5YR3/2	Hemic	3.6	21.08	0.55	38	34.5	2.5					
>545	7.5YR7/1	SiC	-	-	-	-	-	-					
RA3 (Riau)													
0-40	7.5YR3/2	Sapric	3.3	17.19	1.05	16	38.5	12.5	81	441	0.22	86	60
40-110	5YR3/2	Hemic	3.5	50.15	2.16	23	26.7	7.7	78	360	0.23	84	
110-580	5YR3/2	Hemic	3.7	49.49	1.25	40	35.7	3.2					
>580	10YR7/2	SiC	-	-	-	-	-	-					
JB3 (Jambi)													
0-15	7.5YR3/1	Sapric	3.7	49.09	1.31	37	20.7	5.9	78	308	0.24	83	15
15-50	7.5YR3/2	Sapric	3.6	23.95	0.74	32	20.5	2.9	85	545	0.16	89	
50-150	7.5YR3/3	Hemic	3.6	17.82	0.37	48	41.9	2.3					
150-190	7.5YR3/2	Sapric	3.8	49.46	1.03	48	64.7	3.8					
190-200	2.5Y5/3	C	3.9	5.01	0.27	19	-	30.1					
JB4 (Jambi)													
0-35	7.5YR3/1	Sapric	3.7	48.72	2.15	23	29.4	5.4	83	476	0.17	88	35
35-60	7.5YR3/2	Hemic	3.8	44.18	1.18	37	22.2	5.5	83	490	0.17	88	
60-160	7.5YR3/3	Hemic	3.8	25.99	0.78	34	30.2	1.5					
160-240	7.5YR3/4	Hemic	3.7	11.73	0.40	29	50.0	1.1					
240-290	2.5Y5/2	Clay	3.7	11.75	0.26	45	-	10.5					

Note: C=clay; SC=sandy clay; SCL=sandy clay loam SiC=silty clay; SiCL=silty clay loam; BD=bulk density; TPS=total pore space.

indicating that increasing organic carbon content would be followed by decreasing ash content.

The cation exchange capacity (CEC) values at all layers of peat soils were high to very high in the range of 28 to 127 cmol (+) kg^{-1}. The high CEC was caused by pH-dependent negative charge that most of the carboxyl and hydroxyl groups of the phenolic acids (Driessen and Soepraptohardjo 1974).

Figure 3 shows that the soil CEC had a positive linear relationship to organic carbon content (r = 0.86 for Kalimantan and r = 0.93 for Sumatra). It indicates that most of soil CEC is strongly influenced by organic carbon content. The content of exchangeable bases (Ca, Mg, K and Na) and base saturation were low to very low in all layers. The low content of exchangeable bases is typical for peat soils. Driessen and Suhardjo (1976) reported that the thick peat soils have low exchangeable bases and more acid reaction. It relates to the formation process of thick peat soils which it is more influenced by rainwater only.

Similarly, the nutrient contents of total P_2O_5 and K_2O (25% HCl extract) were low, but the content of micro elements of Cu, Mn and Zn were generally moderate to high, except Fe content was very high, such as in Site-2 as the effect of shallow water table in acid condition. In general, peat soils do not have Al toxicity (Agus and Subiksa 2008), but in the peat soils of the study area the content of exchangeable Al was high, ranged from 1.72 to 17.72 cmol (+) kg^{-1} and Al saturation was also low to very high, ranged from 17 to 91%, indicating the potential danger of Al toxicity. Compared to the cultivated peat soils of Toba highland in North Sumatra, the chemical properties were similar with above lowland peat soils in general. The differences of peat soils from the Toba highland were in high P retention and andic soil properties, as the effect of mineral enrichment from volcanic materials (Prasetyo and Suharta 2011). From the forgoing discussion, the peat soils of four trial sites were considered as poor nutrient status, low ash content and very acid reaction. Therefore, the peat soils in the study areas could be classified as oligotrophic ombrogenous peat.

Soil Classification

The peat soils of the study area were classified based on field observation and laboratory data according to Soil Taxonomy system (Soil Survey

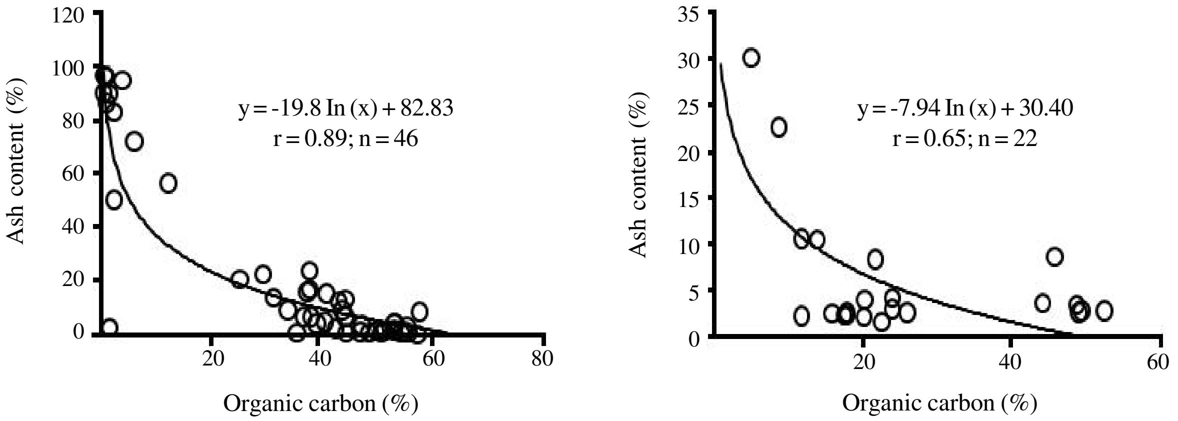

Figure 2. Correlation between organic-C and ash content in Kalimantan (left) and Sumatra (right).

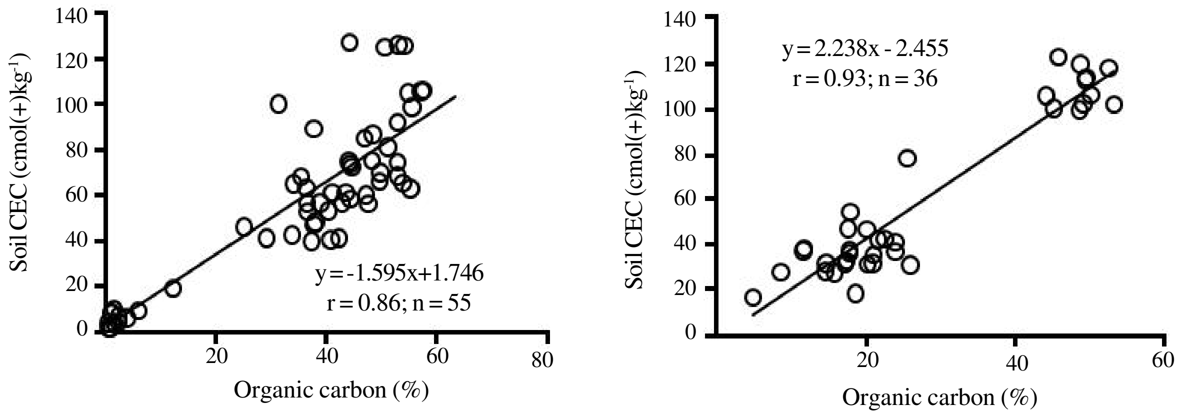

Figure 3. Correlation between organic-C and soil CEC in Kalimantan (left) and Sumatra (right).

Staff 2010) at subgroup level. All the profiles had high organic C content of >12% and hemic to fibric materials, so that all the profiles fulfill the criteria of peat soils. The main class differentiation is the degree of decomposition within the control section and the peat soil thickness. The peat soils in Site-1 were classified as Typic Haplohemists and Hemic Haplosaprists. In Site-2, the soils were dominated by fibric maturity within the control section and thus were classified as Typic Haplofibrists and Hemic

Table 3. Chemical properties of peat soils from four trial sites of ICCTF in Central Kalimantan, South Kalimantan, Riau and Jambi.

Profile/	HCl 25%		Exch. Bases (NH4oAc pH 7)				Soil	Base	exch.	Al satu-	DPTA extract			
depth	P_2O_5	K_2O	Ca	Mg	K	Na	CEC	sat.	Al	ration	Fe	Mn	Cu	Zn
cm	g 100g^{-1}		------------- cmol$_c$ kg^{-1} ------------					%	cmol$_c$	%	----------- ppm ----------			
KT1 (Central Kalimantan)														
0-25	13	8	2.55	1.24	0.12	0.33	68	6	1.33	24	320	6.2	0.2	4.0
25-60	14	13	3.50	1.54	0.17	1.87	105	7	1.89	21	467	13.4	0.3	5.6
60-120	7	8	1.98	0.87	0.10	2.20	106	5	8.04	61	212	7.4	0.3	5.8
120-700	4	13	0.93	0.46	0.22	1.12	127	2	17.72	87	247	4.0	3.5	5.4
700 +	6	2	0.78	0.97	0.03	0.07	8	23	3.17	63	1191	2.4	1.9	0.5
KT2 (Central Kalimantan)														
0-23	17	6	2.12	1.26	0.04	0.21	85	4	1.22	25	340	9.5	0.0	4.3
23-200	15	14	4.09	2.36	0.28	2.12	125	7	2.22	20	552	17.0	0.4	5.7
200-340	2	18	1.87	1.89	0.36	3.29	105	7	7.19	49	1172	17.2	0.0	9.7
340-650	3	21	0.82	0.42	0.31	0.25	100	2	17.65	91	462	2.2	2.0	2.2
650-700	6	2	0.63	0.87	0.03	0.12	10	17	3.37	67	1154	1.5	2.4	0.1
KS1 (South Kalimantan)														
0-9	26	8	1.42	0.41	0.07	0.35	56	4	4.68	68	1157	0.3	0.4	1.3
9-75	5	20	6.77	2.08	0.40	2.13	98	12	5.73	33	3144	23.0	1.2	5.4
75-80	6	9	1.21	1.55	0.18	1.40	68	6	12.62	74	2499	4.1	2.3	1.6
80-135	3	4	0.81	0.89	0.08	1.74	53	7	6.08	63	2457	7.2	0.9	1.3
135-143	5	5	1.70	0.57	0.10	0.45	57	5	5.29	65	3390	1.1	2.9	2.4
143-200	1	2	0.49	0.24	0.03	0.14	4	23	1.66	65	672	0.5	3.3	0.5
KS2 (South Kalimantan)														
0-10	28	7	21.21	1.99	0.13	0.63	61	39	1.72	7	3047	57.6	35.1	76.4
10-60	12	11	4.19	2.96	0.22	0.55	60	13	1.80	19	2065	33.3	1.5	8.2
60-75	9	9	0.92	1.14	0.12	1.28	48	7	4.87	58	1631	12.7	0.9	1.2
75-220	7	20	1.61	2.45	0.39	4.08	74	12	7.21	46	3407	8.3	0.8	2.3
220-230	7	11	0.75	1.97	0.22	1.35	46	9	5.28	55	1876	0.1	4.1	0.2
230-250	4	4	0.24	0.63	0.08	0.09	4	24	1.59	60	534	0.1	3.3	0.2
RA2 (Riau)														
0-40	13	12	2.67	1.27	0.23	0.74	38	13	2.23	31	283	2.90	0.00	5.40
40-120	9	10	0.77	0.51	0.20	0.32	32	6	1.58	47	170	6.30	0.00	4.10
120-545	6	19	0.48	0.41	0.37	0.44	35	5	2.13	56	108	5.20	0.50	4.10
>545	mineral soil													
RA3 (Riau)														
0-40	17	13	4.68	1.81	0.55	1.04	32	15	2.49	35	286	7.50	0.40	5.80
40-110	24	28	2.38	1.66	3.66	0.58	106	6	5.41	40	139	7.50	0.50	4.20
110-580	10	183	2.67	1.27	0.23	0.74	114	7	5.51	40	283	2.90	0.00	5.40
>580	mineral soil													
JB4 (Jambi)														
0-35	31	28	7.16	3.19	0.58	0.62	120	10	0.98	8	1287	19.10	0.90	7.00
35-60	8	14	2.28	1.69	0.28	0.43	106	4	1.05	18	346	8.00	0.20	3.30
60-160	5	10	0.71	0.33	0.20	0.31	31	5	0.45	23	637	6.90	3.50	3.60
160-240	5	5	0.48	0.28	0.10	0.44	37	3	1.73	57	773	4.60	0.80	1.80
240-290	6	19	0.49	0.24	0.37	0.16	38	3	11.00	90	2128	2.50	3.80	3.30
JB3 (Jambi)														
0-15	17	26	5.41	2.66	0.51	0.27	102	9	1.49	14	441	12.40	0.30	4.80
15-50	6	10	2.26	0.82	0.20	0.44	37	10	0.58	13	311	11.70	0.80	4.10
50-150	5	15	1.32	0.37	0.29	0.46	36	7	0.72	23	1141	7.40	0.60	2.20
150-190	8	21	1.23	0.66	0.42	0.40	113	2	5.51	67	1337	4.20	0.00	1.90
190-200	6	6	0.40	0.11	0.12	0.10	17	4	8.14	92	625	0.90	2.20	0.50

Haplofibrists. In Site-3 the soils had hemic maturity level within the control section and classified as Typic Haplohemists. In Site-4 the soils were dominated by sapric maturity level within the control section, and therefore they were classified as Typic Haplosaprists and Hemic Haplosaprists. It was clear that the cultivated peat soils in the study area were in the maturity level of hemic to sapric, except in Site-2 was classified as fibric maturity.

Estimation of Carbon Stocks

The extent soil mapping unit of detailed soil maps of the four trial sites (Hidayat *et al.* 2011) was used to calculate carbon stocks. Soil mapping unit is a collection of soil units that have homogenous or nearly equal properties which can be delineated in a soil map. Carbon stocks of peat soils from each site was calculated based on the representative soil profiles of each soil mapping unit, by measuring the soil peat thickness, BD, organic C content and the extent. The results showed that the carbon stocks in Site-1 and Site-3 were very high, namely 26,404 tons and 21,029 tons of C respectively, which were equivalent to 5,270 and 4,005 Mg C ha^{-1}. While carbon stocks in Site-2 and Site-4 were lower, namely 3,775 and 6,073 tons of C respectively, which were equivalent to 562 and 1,084 Mg C ha^{-1} (Table 4). The peat thickness and peat maturity or BD values greatly affects the amount of carbon stocks. The higher carbon stocks can potentially lead to higher greenhouse gas emissions. The thickness and the maturity of peat soils will be dynamic change due to exploitation or cultivation that imply to change the magnitude of carbon stocks and greenhouse gas emission.

Potency for Agricultural Development

The peat soils of the study area have good potential for agriculture use. Since the peat ecosystem is considered to be fragile, its management should be carried out cautiously based on its specific characteristics and kind of crops (Las *et al.* 2011). The peat soil suitability for crop commodity is determined by several factors such as thickness, maturity, mineral enrichment and the subtratum underlying the peat. Based on the criteria of land suitability for agriculture commodity (Ritung *et al.* 2011) the peat soils of Site-1 (Central Kalimantan) and Site-3 (Riau) with hemic to sapric maturity, thickness of more than 3 m and clay substratum were classified into marginally suitable for perennial crops (rice, maize, legumes), but moderately suitable for annual crops, such as oil palm and coconut. While the peat soils of Site-2 (South Kalimantan) and Site-4 (Jambi) with shallow to moderate thick, hemic to fibric maturity, and fine substratum were classified into moderately suitable both for perennial and annual crops.

Table 4. The estimated carbon stocks in each trial site.

Site	Area (ha)	Carbon stocks (Mg C)	Average Mg C ha^{-1}
Site-1	5.01	26.405	5.270
Site-2	6.72	3.775	562
Site-3	5.25	21.029	4.005
Site-4	5.60	6.073	1.084
Total	**22.58**	**57.282**	**2.537 Mg C ha^{-1}**

The peat soils need inputs such as fertilizers and ameliorants to improve and maintain soil fertility. Some ameliorants such as pugam, manure, inorganic fertilizers, dolomite, and zeolite can be used for peat soils. Subiksa (2013) suggested to use pugam to improve peat soils fertility, because it had functioned not only as ameliorant, but also as fertilizer and decreasing greenhouse gas. Water management should be applied through managing the water table at about 10-50 cm depth to maintain soil moistness or saturation condition, and reduce the excess water and some toxic organic acid of the peat soils. Maintaining the moist condition of peat soils at above critical level of moisture content ($\geq$ 250%) is strongly suggested, because the peat soils are relatively more stable compared to dry condition (Sabiham and Sukarman 2013).

CONCLUSIONS

The cultivated peat soils of four trial sites of ICCTF showed variation of physical and chemical properties in the terms of thickness, maturity, bulk density, fiber content, ash content, and depth of ground water table, as well as chemical properties. However, these cultivated peat soils were grouped as ombrogenous peat with oligotrophic properties, as indicated by low ash contents, poor nutrients status, and very acid soil reaction.

The cultivated peat soils of Site-1 (Central Kalimantan) and Site-3 (Riau) were classified as very thick peat (> 3 m) at position of peat dome physiographic unit, more decomposed, deeper ground water table, and higher BD values, and thus they have higher carbon stocks and potential greenhouse gas emission compared to the shallower peat soils of Site-2 (South Kalimantan) and Site-4 (Jambi) at position of river backswamps physiographic unit.

The study showed there was good correlation between fiber content and BD, organic C and ash content, and between organic C and soil CEC, indicating that the peat soil properties can be predicted from other properties of that soils.

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