

Litter and Soil Carbon Stock in Cultivated and Natural Area of Intergrated Forest for Conservation Education of Wan Abdul Rachman Great Forest Park

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ABSTRACT

Intergrated Forest for Conservation Education of Wan Abdul Rachman (IFCE WAR) Great Forest Park is a conservation forest zone which has natural area and cultivated area. The natural area in Wan Abdul Rachman Great Forest Park consists of secondary forest, whereas the cultivated area consists of agroforestry with cacao plants and agroforestry with coffee plants. The different land use in both areas caused the difference in carbon sink specifically in litter and soil. The research was aimed to study the difference of litter and soil carbon stock in natural and cultivated area in IFCE WAR Great Forest Park. The observation plots included in the current study was determined using purposive sampling method. The research was conducted in June until August 2015. Data was analyzed using analysis of variance and continued with honestly significant difference test. The results showed that there was no difference of litter carbon stock in cultivated area and natural area in IFCE WAR Great Forest Park, whereas the soil carbon stock in natural area was higher than that in cultivated area.

Keywords: Agroforestry, conservation forest, litter carbon stock, secondary forest, soil carbon stock

ABSTRAK

Hutan Pendidikan Konservasi Terpadu Taman Hutan Raya Wan Abdul Rahman (HPKT Tahura WAR) adalah areal hutan konservasi yang memiliki areal budidaya dan areal alami. Pemanfaatan lahan areal alami di Tahura WAR terdiri dari hutan sekunder dan areal budidaya yang ditanami kakao dan agroforestri kopi campuran. Perbedaan pemanfaatan lahan menyebabkan kedua area memiliki simpanan karbon yang berbeda, khususnya pada serasah dan tanah. Penelitian ini bertujuan untuk mengetahui perbedaan karbon serasah dan karbon tanah tersimpan di areal budidaya dan areal lindung. Plot di penelitian ini ditentukan dengan menggunakan metode *purposive sampling*. Penelitian ini dilakukan pada bulan Juli-Agustus 2015. Data dianalisis dengan menggunakan Analysis of Variance diikuti dengan Uji Beda Nyata Jujur. Berdasarkan hasil penelitian, tidak ada perbedaan yang nyata pada C serasah tersimpan di areal alami dan budidaya. Selain itu, C tanah tersimpan di areal alami lebih tinggi dibandingkan areal budidaya di HPKT Tahura WAR.

Kata Kunci: Agroforestri, hutan konservasi, hutan sekunder, karbon serasah tersimpan, karbon tanah tersimpan

INTRODUCTION

Climate change has become a global problem and has attracted worldwide attention. Various impacts of climate change have emerged as natural disasters. The cause of this problem is the earth's surface warming due to fossil fuel combustion. The combustion products increased the amount of greenhouse gas emissions into atmosphere, especially carbon dioxide (CO₂). In 2012 the amount

of CO₂ emission worldwide was about 34.5 billion tons, increased approximately 1.4% compared to that in the previous year (Olivier *et al.* 2013).

Greenhouse gas production and release of CO₂ into atmosphere can be mitigated by storing CO₂ in some places. Through photosynthesis, plants absorb CO₂ and convert it into nutrients and oxygen. However, the existing vegetation in the biosphere has not been able to absorb all carbon emissions. In 2012, Indonesia has produced 0.49 billion tons of carbon dioxide (Olivier *et al.* 2013). The major contributor of CO₂ emission in Indonesia is conversion of forest land into other land uses. In

2012, the forest area in Indonesia was about 134 million hectares (Direktorat Jenderal Planologi Kehutanan 2012). Forest as a dominant ecosystem has an important function in CO₂ sequestration in large quantities. In forest, carbon is stored in vegetation including trees that produce litter. In addition to forest, soil plays as carbon pool that able to sequester more carbon in the form of soil organic matter up to 2 Gigatons yr⁻¹ (Lal 2008).

In general, forests have three major functions, namely for protection, production and conservation. Conservation forest plays an important role for preserving natural resources and ecosystems, therefore, hardly any timber harvesting activities in this area. However, due to economic pressures, people have cleared the forest land and planted crops, which is in contrast with the function of conservation forest. This condition will decrease carbon sequestration ability of forest land, so the amount of carbon stored in forests, especially in litter and soil will be reduced (Monde *et al.* 2008).

One of the existing conservation forests in the Lampung Province is the Integrated Forest for Conservation Education of Wan Abdul Rachman (IFCE WAR) Great Forest Park which has natural area and cultivated area. The difference of land use in both areas may affect forest ability to sequester carbon. This study aims to estimate the amount of litter carbon stock and soil carbon stock both in natural and cultivated areas of IFCE WAR Great Forest Park.

MATERIALS AND METHODS

Study Site

The study was conducted in IFCE WAR Great Forest Park, which is about 1.143 ha. It is located in Bandar Lampung, Indonesia, between 105°09'22.17"-105°11'39.13" E and 5°24'09.78"-5°26'11.41" S as shown in Figure 1 (Unit Pelaksana Teknis Daerah Taman Hutan Raya Wan Abdul Rachman 2009). The structure of vegetation in this forest area is shown in Table 1. The study was conducted in June until August 2015.

Research Design and Plot Description

Soil samples and litter samples were taken using purposive sampling method, according to the representative study site conditions in IFCE WAR Great Forest Park. In this study, the experiments were designed in completely randomized design with two factors. The first factor was land use that consisted of 3 plots of natural area and 3 plots of cultivated area. The second factor was soil depth at 0-10 cm, 10-20 cm and 20-30 cm. Litter samples were also taken from 6 land uses with 3 replications.

The natural area in IFCE WAR Great Forest Park consists of secondary forest, which is not utilized by local people. On the other hand, the cultivated area, which is also part of Wan Abdul Rachman Great Forest Park, has been utilized by

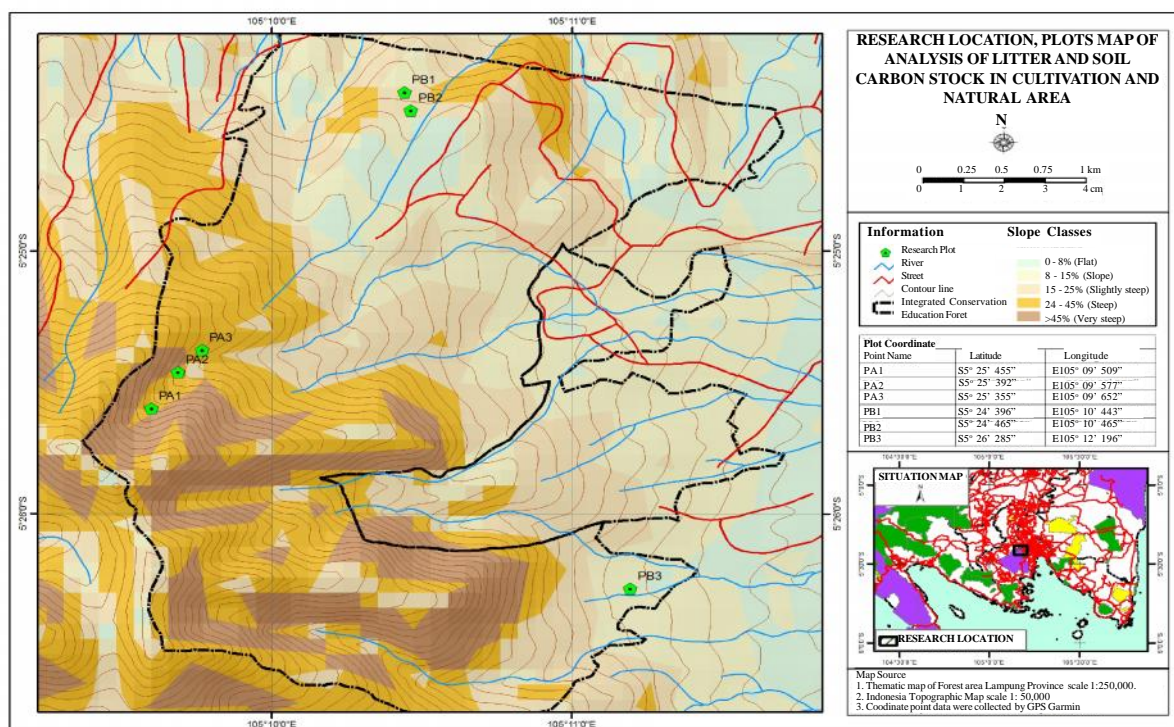


Figure 1. Location of soil and litter sampling in Wan Abdul Rachman Great Forest Park, Lampung.

Table 1. Plants species observed in natural area and cultivated area of IFCE WAR Great Forest Park.

Species	Natural area	Cultivated area
<i>Aleurietes moluccana</i>	✓	✓
<i>Ficus ampelas</i>	✓	-
<i>Dehaasia cuneata</i>	✓	-
<i>Pterocymbium javanicum</i>	✓	-
<i>Litsea firma</i>	✓	-
<i>Acmena melanostica</i>	✓	-
<i>Bridelia glauca</i>	✓	-
<i>Anona sp.</i>	✓	-
<i>Archidendron microcarpum</i>	✓	-
<i>Oraxylum indicum</i>	✓	-
<i>Macaranga tanarius</i>	✓	-
<i>Villebrunea rubescens</i>	✓	-
<i>Ricinus communis</i>	✓	-
<i>Vitex pinnata</i>	✓	-
<i>Coffea robusta</i>	✓	✓
<i>Archidendron pauciflorum</i>	✓	-
<i>Litsea roxburghii</i>	✓	-
<i>Artocarpus integra</i>	✓	-
<i>Spondias pinnata</i>	✓	-
<i>Etlingera solaris</i>	✓	-
<i>Aglaia elaeagnoidea</i>	✓	-
<i>Ficus hispida</i>	✓	-
<i>Dalbergia latifolia</i>	-	✓
<i>Durio zibethinus</i>	-	✓
<i>Theobroma cacao</i>	-	✓
<i>Parkia speciosa</i>	-	✓
<i>Erythrina lithosperma</i>	-	✓
<i>Archidendron pauciflorum</i>	-	✓
<i>Persea Americana</i>	-	✓
<i>Lansium domesticum</i>	-	✓
<i>Myristica fragrans</i>	-	✓

local people as agroforestry with cacao plants and agroforestry with coffee plants. Observation plots in the natural area consisted of more plant species than in the cultivated area. Twenty two species were observed in the plots of natural area, whereas 11 species were observed in the plots of cultivated area (Table 1). Plot 1 of the natural area was located at the highest elevation with an altitude of 1,029 meters above sea level. In this plot 12 plant species were identified and the predominant plant species was *Litsea firma*. Plot 2 of the natural area was located at 1,006 meters above sea level. About 8 plant species were observed in this plot and the predominant plant species were *Litsea firma* and *Vitex pinnata*. Plot 3 of the natural area was located at altitude of 950 meters above sea level. About 10 plant species were identified in this plot and the predominant species was *Villebrunea rubescens*.

Plot 1 of the cultivated area was located at the altitude of 525 meters above sea level, whereas plot 2 of the cultivated area was located at 540 meters above sea level. Both plots consisted of only 3 plant species and the predominant species was *Theobroma cacao*. The difference between both plots was the predominant tree in plot 1 was *Durio zibethinus*, whereas the predominant tree in plot 2 was *Dalbergia latifolia*. Plot 3 in the cultivated area, which was located at the altitude of 369 meters, consisted of 10 plant species. The predominant plant species in this plot was *Erythrina lithosperma*.

Soil Carbon Sampling and Analysis

The soil samples were collected at 0-10 cm, 10-20 cm and 20-30 cm depth using ring sample. The disturbed soil samples were collected to

Tabel 2. *p*-value of bulk density, soil organic C content (%C), and soil C stock.

Source	Bulk Density	% C	Soil C Stock ($\sqrt{\dots}$)
----- <i>p</i> -value -----			
Land use	0.00*	0.00*	0.00*
Soil depth	0.20 ^{ns}	0.00*	0.00*
Land use*soil depth	0.71 ^{ns}	0.02**	0.97 ^{ns}

Table 3. Soil bulk density in natural area and cultivated area of IFCE WAR Great Forest Park.

Land use	Bulk Density (g cm ⁻³)
Natural area plot 1 (secondary forest)	0.8 b
Natural area plot 2 (secondary forest)	0.7 b
Natural area plot 3 (secondary forest)	0.9 ab
Cultivation area plot 1 (agroforestry with cacao plants)	1.1 a
Cultivation area plot 2 (agroforestry with cacao plants)	1.0 a
Cultivation area plot 3 (agroforestry with mixed coffee plants)	1.1 a
HSD _{0.05} = 0.2	

Values followed by the same letter in the same column are not significantly different at the level of 5% HSD

determine soil organic carbon content (percentage of organic C) and undisturbed soil samples were taken to determine soil bulk density. The disturbed soil samples were air-dried at room temperature, then soil organic C content was measured using Walkey and Black method. The undisturbed soil samples were oven-dried at 105°C and weighed in. Bulk density of the soil samples was estimated using the following equation (Hairiah 2011).

$$\text{Soil bulk density (g cm}^{-3}\text{)} = \frac{\text{soil dry weight oven (g)}}{\text{soil volume (cm}^{-3}\text{)}}$$

Further, the soil C stock was estimated using the following equation.

$$Cs = Kd \times \rho \times \%C \text{ organic}$$

Cs = soil carbon stock (g C cm⁻²)

Kd = depth of soil samples (cm)

ρ = bulk density (g cm⁻³)

%C = organic carbon percentage content value.

The soil carbon stock per hectare was calculated using the following equation.

$$\text{Soil C} = Cs \times 100$$

Soil C = soil C stock per hectare (Mg C ha⁻¹)

Cs = soil carbon stock (g cm⁻²)

100 = conversion factor from g C cm⁻² to Mg C ha⁻¹ (Lugina et al. 2011).

Litter Carbon Sampling and Analysis

Litter samples were taken from litter trap with the size of 1 m² and the height of approximately 60 cm. Litter that has been collected within two weeks (Harrison 2013) in a litter trap were weighed in. Litter was oven-dried at 80°C for 48 hours and weighed in. The litter biomass was estimated using the following equation (Hairiah and Rahayu 2007).

$$\text{Litter biomass (g)} = \frac{\text{BK sample (g)} \times \text{BB total (g)}}{\text{BB sample (g)}}$$

BK = dry weight

BB = wet weight

The carbon content in litter were assumed according to *Biomass Expansion Factor* (BEF). BEF value could estimate the carbon stock in forests which is equal to 50% of the biomass (IPCC 2006; Paladinic et al. 2009). Therefore, the litter carbon stock (Cl) can be estimated using the following formula: Cl = Biomass x 50%.

Data Analysis

The data were analysed using analysis of variance for completely randomized design with two factors and three replications, and continued with honestly significant difference (HSD) test with 5% of significance level.

Table 4. Soil organic C content at different land use and soil depth in natural area and cultivated area of IFCE WAR Great Forest Park.

Land use	Soil depth (cm)		
	0-10	10-20	20-30
-----Soil organic C (%)-----			
Natural area plot 1 (secondary forest)	5.53 ab (A)	3.35 cd (B)	3.07 cde (C)
Natural area plot 2 (secondary forest)	4.44 bc (B)	2.89 cde (C)	2.51 cde (C)
Natural area plot 3 (secondary forest)	6.51 a (A)	4.04 bc (B)	2.59 cde (C)
Cultivation area plot 1 (cacao agroforestry)	2.93 cde (C)	1.91 de (C)	1.10 e (C)
Cultivation area plot 2 (cacao agroforestry)	2.85 cde (C)	1.88 de (C)	1.64 de (C)
Cultivation area plot 3 (mixed coffee agroforestry)	1.62 de (C)	1.39 de (C)	1.17 e (C)
HSD _{0.05} = 2.03			

Values followed by the same letter in the same row and column are not significantly different at the level of 5% HSD. Lowercase was read vertical and capital letter (in parentheses) was read horizontal.

Table 5. Soil carbon stock at different soil depths in natural area and cultivated area of IFCE WAR Great Forest Park.

Depth (cm)	Soil C (Mg C ha ⁻¹)	Soil C (Transformation $\sqrt{\frac{\sum x^2}{n}}$) (Mg C ha ⁻¹)
0-10	35.68	5.85 a
10-20	22.31	4.63 b
20-30	20.54	4.32 b
HSD _{0.05} = 0.8		

Values followed by the same letter in the same column are not significantly different at the level of 5% HSD

RESULTS AND DISCUSSION

Soil Carbon Stock

Based on the results (Table 2) land use and soil depth affected the soil carbon stock but there was no interaction between land use and soil depth that would affect the soil carbon stock. On the other hand, the content of soil organic C was significantly influenced by land use, soil depth and interaction between them, and bulk density was significantly influenced by land use but it was not influenced by soil depth and there was no interaction between land use and soil depth that would affect the soil bulk density.

Soil C stock in a land could be influenced by the bulk density (g cm⁻³) and soil organic carbon content (% C). The results showed that the bulk density of soil samples in a cultivated area was significantly higher than the natural area (Table 3).

The land use change in forest may increase bulk density (Lal 1996). Soil carbon content (%C) in each land use could be seen in Table 4. There were significant difference of soil organic C content between natural area and cultivated area, with the highest soil organic C content was observed in plot 3 of natural area. Land use differences led to soil organic carbon content differences in both areas (Van Straaten *et al.* 2015). Soil erosion and soil temperature in cultivated area could be higher than that in natural area, which further affect the soil organic carbon content. Soil depth also affected the soil organic C content (% C), in which the highest soil organic carbon content was observed at 0-10 cm (Table 4).

The significant difference of soil organic C content between land use at different soil depth could be seen, especially at 0-10 cm soil depth (Table 4). In this depth, it showed that the soil organic content in plot 3 of natural area was significantly

Table 6. Soil C stock in different land use (natural area and cultivated area) in IFCE WAR Great Forest Park.

Land use	Soil C stock (Mg C ha ⁻¹)	Soil C Stock (Mg C ha ⁻¹) (Transformation \sqrt{x})
Natural area plot 1 (secondary forest)	31.68	5.58 ab
Natural area plot 2 (secondary forest)	26.11	4.88 abc
Natural area plot 3 (secondary forest)	38.81	6.05 a
Cultivation area plot 1 (agroforestry with cacao plants)	22.11	4.62 bc
Cultivation area plot 2 (agroforestry with cacao plants)	22.32	4.65 bc
Cultivation area plot 3 (agroforestry with mixed coffee plants)	14.79	3.81 c
n = 3		HSD _{0,05} = 1.38

Values followed by the same letter in the same column are not significantly different at the level of 5% HSD.

Table 7. Litter C stock in natural area and cultivated area of IFCE WAR Great Forest Park.

Land use	Litter C stock (kg C ha ⁻¹) ± Standard deviation
Natural area plot 1 (secondary forest)	4.93 ± 0.86
Natural area plot 2 (secondary forest)	4.13 ± 0.30
Natural area plot 3 (secondary forest)	3.98 ± 0.27
Cultivation area plot 1 (agroforestry with cacao plants)	4.37 ± 0.55
Cultivation area plot 2 (agroforestry with cacao plants)	4.40 ± 0.13
Cultivation area plot 3 (agroforestry with mixed coffee plants)	4.03 ± 0.31

higher than that in plot 2. The soil organic C content in the depth of 10-20 cm and 20-30 cm show no significant difference between natural area and cultivated area. The finding indicates that different land use (*i.e.* secondary forest and agroforestry) only affected the content of soil organic C in the soil surface (0-10 cm).

There was significant difference of soil C stock, especially at the depth of 0-10 cm as shown in Table 5. Soil C stock in 0-10 cm depth was 35.68 Mg C ha⁻¹, which was higher than that in 10-20 cm depth (22.31 Mg C ha⁻¹) and 20-30 cm depth (20.54 Mg C ha⁻¹). Litter that was accumulated on the soil surface decomposed into soil organic matter, which further resulted in an accumulation of C in soil organic matter at the soil surface. Litter is a source of food or energy for soil microbes. The decrease of the amount of litter at the depth of 10-20 cm and 20-30 cm may reduce the supply or input of soil C, which further decreases soil microbial activity (Fontaine *et al.* 2007). Vertical root distribution also affects organic matter content in the soil because the roots are able to distribute organic material into the soil (Hess *et al.* 2014). A decrease of the root number in the soil can reduce the organic material content, hence the carbon cycle rate in the soil can be slowed down (Jobbagy and Jackson 2000).

Soil C stock in natural area of IFCE WAR Great Forest Park was significantly different from that in cultivated area. The results of analysis of variance and honestly significant difference test at 5% of significance level were shown in Table 6. Soil C stock in each plot of natural area was significantly different with that in plots of cultivated area. Based on Table 6, the highest soil C stock was observed in plot 3 of natural area, *i.e.* about 38.81 Mg C ha⁻¹. Furthermore, soil C stock in plot 3 of natural area was higher than that in plot 1 and 2 of natural area. Soil C stock in plot 1 was 31.68 Mg C ha⁻¹ and in plot 2 was 26.11 Mg C ha⁻¹. Plot 3 of natural area was located at the lowest altitude among the plots in natural area hence the sediment transport through erosion would be accumulated at the plot 3 of natural area. Plot 1 and 2 of natural area was located at higher elevation and surrounded by steep slopes, as a result plot 1 and 2 had higher erosion rate and the soil C stock in both plots were lower than that in plot 3.

There was no significant difference between soil C stock in secondary forests (plot 1 and 2 of natural area) and agroforestry plots with cacao plants (plot 1 and 2 of cultivated area). Due to the agroforestry plots with cacao plants have gentler slope than plot 1 and plot 2 of secondary forest, soil

that was transported from higher altitude would accumulate at the lower altitude (*i.e.* agroforestry plots with cacao plants), therefore agroforestry plots with cacao plants are able to store the soil carbon well. Soil C stock in plot 1 and 2 of agroforestry plots with cacao plants was 22.11 Mg C ha⁻¹ and 22.32 Mg C ha⁻¹, respectively. The lowest Soil C stock was found in plot 3 of agroforestry plot with mixed coffee plants (cultivated area), which had soil C stock of 14.79 Mg C ha⁻¹.

The significant difference of soil carbon stock was observed between plots 1 and 3 of natural area and agroforestry plot with mixed coffee plants (Table 6). Soil carbon stock in natural area was higher than that in the cultivated area. This finding corresponds to the study of Monde *et al.* (2009) and Hombegowda *et al.* (2015), which showed that forest can store higher soil C than applied agroforestry land. Sediment transport on forest land was lower than that on the agroforestry land, which further affected soil C concentration (Junaidi 2013; Zhang *et al.* 2013). Land with tillage was able to produce higher CO₂ emission compared to land without tillage (Reicosky 2001; Al-Kaisi and Yin 2005). Therefore, the cultivated area that applied soil tillage had lower soil organic carbon content than the natural area.

The decomposition rate of organic matter in the cultivated area was higher than in the natural area, which was affected by microclimate differences in both areas. Soil surface in natural area received slight of sunlight, as a result the soil became more humid and the decomposition process would be slow. The cultivated area with high sunlight intensity and warmed soil temperature would accelerate the decomposition process. Microclimate differences, particularly the moisture greatly affected litter decomposition (Lee *et al.* 2014). Decomposition is the process of organic material breakdown by soil microbes into simpler compounds by releasing CO₂ (Aprianis 2011). Litter decomposition rate in cultivated area was high, consequently soil C stock in cultivated area emitted more carbon to atmosphere. Therefore, the soil C stock in the cultivated area was low.

Litter Carbon Stock

Analysis of variance on the litter C stock indicated that there was no significant difference of litter C stock between natural area and the cultivated area of IFCE WAR Great Forest Park. The average litter C stock is shown in Table 7. The highest litter C stock was observed in plot 1 of natural area (*i.e.* 4.93 kg C ha⁻¹) and the lowest litter C stock was

observed in plot 3 of cultivated area (*i.e.* 4.03 C kg ha⁻¹). The study of Zhang *et al.* (2013) showed that the different vegetation changes did not affect litter C stock in a field. Montane *et al.* (2010) also reported that the litter quantity did not increase accumulation of soil organic C, but the litter quality did. Vegetation composition differences between cultivated area and natural area only lead to differences in the litter quality that affected litter decomposition rate. Litter quality was affected by N concentration, lignin concentration, C: N ratio, N: P ratio, lignin:N ratio, leaf dry matter content, holoselolusa concentration and others. The microbial existence and activity in manipulating the decomposition process depends on these factors thus the litter quality has an important role in the litter carbon sequestration and as a soil C input.

CONCLUSIONS

In conclusion, land use affected the soil C stock resulted in higher soil C stock in natural area (secondary forest) of Intergrated Forest for Conservation Education Wan Abdul Rachman Great Forest Park (IFCE WAR Great Forest Park) than in cultivated area. Land use change also affected soil organic carbon content at 0-10 cm soil depth, therefore soil at 0-10 cm depth had the highest soil C stock. On the other hand, there was no difference of carbon (C) stored in the litter in the natural area and cultivated area of IFCE WAR Great Forest Park.

REFERENCES

- Al-Kaisi MM and X Yin. 2005. Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn-soybean rotations. *J Environ Qual* 34: 437-445.
- Aprianis Y. 2011. Produksi dan laju dekomposisi serasah *Acacia crassicarpa* A. Cunn. di PT. Arara Abadi. *Tekno Hutan Tanaman* 4: 41-47. (in Indonesian).
- Fontaine S, S Barot, HLM Barré, N Bdioui, B Mary and C Rumpel. 2007. Stability of organic carbon in deep soil layers controlled by fresh carbon supply. *Nature* 450: 277-280.
- Direktorat Jenderal Planologi Kehutanan. 2012. Data dan Informasi Pemanfaatan Hutan Tahun 2012. Kementerian Kehutanan. Jakarta. 145p. (in Indonesian).
- Hairiah K, A Ekadinata, RR Sari and S Rahayu. 2011. *Pengukuran Cadangan Karbon: dari Tingkat Lahan ke Bentang Lahan. Petunjuk praktis. Edisi kedua.* World Agroforestry Centre ICRAF SEA Regional. Bogor. 82p.

- Hairiah K and S Rahayu. 2007. Pengukuran Karbon Tersimpan di Berbagai Macam Penggunaan Lahan. World Agroforestry Centre ICRAF. Bogor. 77p. (in Indonesian).
- Harrison ME. 2013. Standard Operating Procedure: Forest Litter-fall. Orangutan Tropical Peatland Project. Palangkaraya. 20p.
- Hess NJ, GE Brown and C Plata. 2014. Belowground Carbon Cycling Processes at the Molecular Scale: An EMSL Science Theme Advisory Panel Workshop (No. PNNL-2219). Pacific Northwest National Laboratory (PNNL), Richland, WA (US).
- Hombegowda HC, O van Straaten, M. Köhler, and D. Hölscher. 2015. On the rebound: soil organic carbon stocks can bounce back to near forest levels when agroforests replace agriculture in southern India. *Soil Discussions* 2: 871-902.
- Intergovernmental Panel on Climate Change. 2006. Agriculture, forestry and other land use. Guidelines for National Greenhouse Gas Inventories (Vol. 4). IGES, Japan.
- Jobbagy EG and RB Jackson. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecol Appl* 10: 423-446.
- Junaidi E. 2013. Peranan penerapan agroforestry terhadap hasil air daerah aliran sungai (DAS) Cisaande. *J Penelitian Agroforestry* 1: 41-53.
- Lal R. 1996. Deforestation and land-use effects on soil degradation and rehabilitation in western Nigeria. I. Soil physical and hydrological properties. *Land Degrad Develop* 7: 19-45.
- Lal R. 2008. Carbon sequestration. *Philosophical Transactions of the Royal Society B: Biol Sci* 363: 815-830.
- Lee H, J Fitzgerald, DB Hewins, RL McCulley, SR Archer, T Rahn and HL Throop. 2014. Soil moisture and soil-litter mixing effects on surface litter decomposition: A controlled environment assessment. *Soil Biol Biochem* 72: 123-132.
- Lugina M, KL Ginoga, A Wibowo, A Bainnaura and T Partiani. 2011. Prosedur Operasi Standar untuk Pengukuran dan Perhitungan Stok Karbon di Kawasan Konservasi. Pusat Penelitian dan Pengembangan Perubahan Iklim dan Kebijakan Baand Penelitian and Pengembangan Kehutanan. Bogor. 28p. (in Indonesian).
- Monde A, N Sinukaban, K Murti Laksono and N Pandjaitan. 2008. Dinamika karbon (C) akibat alih guna lahan hutan menjadi lahan pertanian. *J Agroland* : 22-26.
- Montané F, J Romanyà, P Rovira and P Casals. 2010. Aboveground litter quality changes may drive soil organic carbon increase after shrub encroachment into mountain grasslands. *Plant Soil* 337: 151-165.
- Olivier JG, G Janssens-Maenhout, M Muntean and JAHW Peters. 2013. Trends in Global CO₂ Emissions 2013 Report. PBL Publishers. The Hague. 60p.
- Paladinic E, D Vuletic, I Martinic, H. Marjanovic., K. Indir, M. Benko and V. Novotny. 2009. Forest biomass and sequestered carbon estimation according to main tree components on the forest stand scale. *Periodicum Biologorum* 111: 459-466.
- Reicosky DC. 2001. Effects of conservation tillage on soil organic carbon dynamics: field experiments in the US corn belt. Sustaining the global farm. Purdue University, West Lafayette, 481-485.
- Unit Pelaksana Teknis Daerah Taman Hutan Raya Wan Abdul Rachman. 2009. Buku Informasi Taman Hutan Raya Wan Abdul Rachman. Dinas Kehutanan Provinsi Lampung. Bandar Lampung. 38p.
- Van Straaten O, MD Corre, K Wolf, M Tchienkoua, E Cuellar, RB Matthews and E Veldkamp. 2015. Conversion of lowland tropical forests to tree cash crop plantations loses up to one-half of stored soil organic carbon. *Proc Nat Acad Sci* 12: 9956-9960.
- Wang S, H Ruan and Y Han. 2010. Effects of microclimate, litter type, and mesh size on leaf litter decomposition along an elevation gradient in the Wuyi Mountains, China. *Ecol Res* 25: 1113-1120.
- Zhang K, X Cheng, H Andg, C Ye, Y Zhang and Q Zhang. 2013. Linking litter production, quality and decomposition to vegetation succession following agricultural abandonment. *Soil Biol Biochem* 57: 803-813.
- Zhang X, Z Li, Z Tang, G Zeng, J Huang, W Guo and A Hirsh. 2013. Effects of water erosion on the redistribution of soil organic carbon in the hilly red soil region of southern China. *Geomorphology* 197: 137-144.