

Carbon Stock in Integrated Field Laboratory Faculty of Agriculture University of Lampung

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ABSTRACT

This study aimed to determine the amount of carbon stock and CO₂ plant uptake in the Integrated Field Laboratory (IFL) Faculty of Agriculture University of Lampung. The research was conducted from April to November 2015. The study was arranged in a completely randomized block design (CRBD), consisting of five land units as treatment with four replications for each treatment. Biomass of woody plants was estimated using allometric equation, biomass of understorey plants was estimated using plant dry weight equation, and organic C content in plants and soils were analyzed using a Walkley and Black method. The results showed that land unit consisting of densely woody plants significantly affects total biomass of woody plants, organic C content in woody plants and total carbon content (above and below ground). The highest amount of woody plant biomass was observed in land unit 5, *i.e.* 1,196.88 Mg ha⁻¹, and above ground total carbon was 437.19 Mg ha⁻¹. IFL Faculty of Agriculture University of Lampung has a total carbon stock of 2,051.90 Mg and capacity to take up total CO₂ of 6,656.88 Mg.

Keywords: Allometric equations, biomass, CO₂ plant uptake, organic-C, total carbon

ABSTRAK

Penelitian ini bertujuan untuk mengetahui jumlah karbon tersimpan dan jumlah serapan CO₂ di Laboratorium Lapangan Terpadu Fakultas Pertanian Universitas Lampung. Penelitian dilaksanakan dari bulan April 2015 sampai dengan November 2015. Penelitian disusun dalam rancangan acak kelompok lengkap (RAKL), sebagai perlakuan adalah lima satuan lahan dengan 4 ulangan. Estimasi biomassa tanaman kayu menggunakan persamaan allometrik, estimasi biomassa tanaman bawah menggunakan persamaan berat kering tanaman, untuk analisis C-Organik tanaman dan C-Organik tanah di laboratorium menggunakan metode Walkley and Black. Hasil penelitian menunjukkan bahwa satuan lahan dengan tutupan vegetasi tanaman berkayu yang rapat berpengaruh nyata terhadap total biomassa tanaman kayu, besar C-Organik tanaman kayu dan jumlah karbon total. Biomassa tanaman kayu terbesar pada satuan lahan 5 yaitu sebesar 1.196,88 Mg ha⁻¹, dan karbon total sebesar 437,19 Mg ha⁻¹. LLT FP Unila memiliki total karbon tersimpan sebesar 2.051,90 Mg dengan kemampuan menyerap CO₂ total sebesar 6.656,88 Mg.

Kata kunci: Biomassa, C-organik, karbon tersimpan, persamaan Allometrik

INTRODUCTION

Forest plays an important role, among others, as a source of carbon stock in nature, in which carbon is stored as vegetative biomass and soil carbon. Conversion of forest into other land uses has led an increase of CO₂ emission into atmosphere, which is derived from biomass burning and mineralization of soil organic carbon during

clearing, and loss of vegetation as carbon sink (C-sink) (Widianto *et al.* 2003).

A strong increase of CO₂ concentration has a direct effect on climate change, Mudiyarso (2004) suggested that climate change is caused by an increase of greenhouse gases (GHG) concentrations, such as CO₂, N₂O, CH₄, CO, etc. Intergovernmental Panel on Climate Change (IPCC 2007) reported three major greenhouse gases, namely CO₂, CH₄, and N₂O, since their concentrations in atmosphere are increasing up to twofold recently (Hairiah 2007). At this moment, the amount of carbon dioxide in atmosphere has been enormous, which is about 1,305

gigatons CO₂ released into atmosphere during 1850 until 2000, and that amount is increasing continuously and has led global warming, resulting in an increase of average temperature of atmosphere, sea and terrestrial. The increase of temperature on earth has caused ice melting in the Arctic Pole and an increase of sea water temperature, which further increases sea volume and sea level about 9 to 100 cm. If the global warming goes on, it may cause major disaster worldwide (Apps *et al.* 2003).

Based on the reasons mentioned above, healthy environmental management should be developed by controlling the amount of CO₂ in the atmosphere. One way to control the amount of CO₂ in the atmosphere is by increasing the amount of CO₂ uptake by plants as much as possible and mitigating CO₂ emission into atmosphere as low as possible (Lasco 2002). Forest preservation, tree cultivation on agricultural land and peat preservation are important actions to mitigate excessive amounts of CO₂ in the atmosphere. On the other hand, long term intensive farming can decrease the amount of soil organic matter and increase CO₂ emission into atmosphere (Sleutel *et al.* 2006; Nieder and Richter 2000). Therefore, measuring the amount of carbon stored in plants (biomass) on a certain land use can indicate the amount of CO₂ in the atmosphere that is taken up by plants (Hairiah and Rahayu 2007).

The amount of carbon stock in each land use varies, depending on diversity and density of vegetation, soil types, and soil management. Carbon stock in a land use can be higher if the soil has good fertility status, or in other words the above ground of carbon stock (vegetative biomass) is determined by the the amount of carbon stock in soil (soil organic matter, SOM) (Hairiah and Rahayu 2007). Negash and Starr (2015) reported that the carbon stock in herbage was lower than that in coffee plants, and the highest carbon stock was found in trees. In addition, Chiti *et al.* (2012) indicated that different amount of carbon stock is also determined by climate regime and landscape.

Integrated Field Laboratory (IFL) Faculty of Agriculture University of Lampung is a field that can be used for doing research and practicum for lecturers and students of Faculty of Agriculture University of Lampung, which is located at the campus of University of Lampung, covering about 6.784 ha. Banuwa, Syam and Wiharso (2011) showed that IFL has various slopes, based on slope classification IFL has five different land units, namely land unit 1 with slope of 0-3% (level) covering about 0.737 ha; land unit 2 with slope of 3-8% (gently sloping) covering about 0.245 ha; land unit 3 with slope of 8-15% (undulating) covering

about 3.417 ha; land unit 4 with slope of 15-30% (hilly) covering about 2.034 ha; and land unit 5 with slope of 30-45% (gently steep) covering about 0.351 ha. With various slopes (level up to gently steep) IFL has a high potential erosion, as a result the soil is vulnerable to lose nutrient and organic matter, which are important for plant growth and development. As a supporting facility of learning activities for academia at the University of Lampung, environmental sustainability and soil fertility of IFL should be maintained.

The objective of this study was to determine the carbon stock in IFL Faculty of Agriculture University of Lampung with various slopes.

MATERIALS AND METHODS

Location of the Study

The study was conducted at Integrated Field Laboratory and analysis of soil organic carbon was conducted at Laboratory of Soil Chemistry, Faculty of Agriculture, University of Lampung. The research was performed in April until November 2015. The map of IFL was presented in Figure 1.

Calculation of Carbon Stock

Biomass of woody plants was estimated using allometric equation, without destructing the plants (non destructive). Observations were conducted by recording the names of trees, measuring the diameters of trees at breast height (dbh), *i.e.* 1.3 m above ground using a measuring tape, and measuring the height of woody plants at the experimental plots (5m x 5m) for each land unit using christen meter, then the biomass was calculated using allometric equation. Allometric equation used in this study was developed by Alternative to Slash and Burn (Table 1) (Hairiah and Rahayu 2007). Biomass of understorey plants was estimated by destructing the plants and then the biomass was calculated using plant dry weight equation. Observation was performed by cutting the understorey plants at the experimental plots (1m x 1m) and weighing the plants, and then 100 g of understorey plants were oven-dried at 80°C for 48 h and weighed in. Biomass of understorey plants was calculated using total plant dry weight equation, namely:

$$\text{Total dry weight} = \frac{\text{dry weight of sub sample (g)} \times \text{total fresh weight (g)}}{\text{fresh weight of sub sample (g)}}$$

The content of organic C in woody plants and understorey plants were analyzed using Walkley and Black method (Thom and Utomo 1991). About 0.03

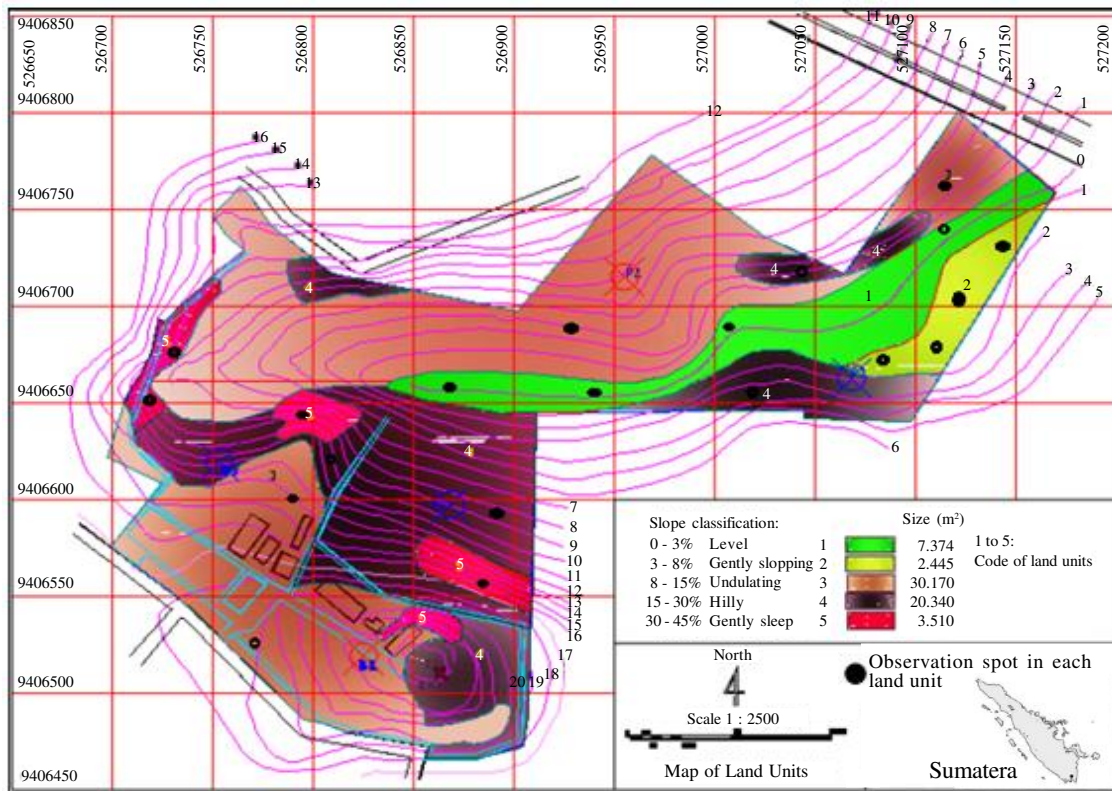


Figure 1. Map of Integrated Field Laboratory Faculty of Agriculture University of Lampung, Lampung, Indonesia (Banuwa *et al.* 2011).

g of plant sample (dry weight) was put in an erlenmeyer flask and then 5 ml of $K_2Cr_2O_7$ and 10 ml of H_2SO_4 were added into erlenmeyer flask (in a fume hood). After the suspension was cooled, 100 ml of distilled water, 5 ml of H_3PO_4 , 2.5 ml of NaF 4% and 5 drops of diphenylamine indicator were added into the suspension. After that, the suspension was titrated with ammonium ferrous sulfate solution into a final color change of light green (Afandi *et al.* 2011).

The above ground carbon stock was calculated after the data of plant biomass and organic C content in plants were collected, then the above ground carbon stock was calculated using equations developed by Alternative to Slash and Burn (Hairiah

and Rahayu 2007). The amount of carbon uptake by plants was calculated using the following equation (Rifyunando 2011).

$$CO_2 \text{ uptake} = \frac{Mr CO_2 \times C \text{ content}}{Ar C}$$

Mr CO_2 = molecular weight of CO_2 (44)
Ar C = atomic weight of C (12)

Data Analysis

The data of woody plant biomass, understorey plant biomass, organic C content in woody plants, organic C content in understorey plants and total

Table 1. Estimation of Tree Biomass using Allometric Equations.

Type of tree	Estimation of tree biomass, kg per tree	Reference
Branched tree	$BK = 0.11_p D^{2.62}$	Ketterings (2001)
Non-branched tree	$BK = \pi_p H D^2/40$	Hairiah <i>et al.</i> (1999)
Banana tree	$BK = 0.030 D^{2.13}$	Arifin (2001)
Bamboo	$BK = 0.131 D^{2.28}$	Priyadarsini (1999)
“Sengon” tree	$BK = 0.0272 D^{2.831}$	Sugiharto (2002)
Necromass	$BK = \pi_p H D^2/40$	Hairiah dan Rahayu (2007)

Notes: DW = Dry Weight; D = diameter of stem; p = wood density; H = Height of tree

carbon were statistically tested using analysis of variance (ANOVA) and least significant difference test (LSD) with a significance level of 5%.

RESULTS AND DISCUSSION

Above ground Carbon Stock

The amount of woody plant biomass in each land unit at IFL varies. The highest amount of woody plant biomass was observed in land unit 5, *i.e.* 1,196.88 Mg ha⁻¹ and the lowest amount of biomass was found in land unit 2, *i.e.* 237.43 Mg ha⁻¹. The amount of plant biomass is determined by the number of stands and the number of population of woody plants in a land unit, land unit 5 with slope of 30 – 45% (gently steep) is rarely used for cultivation for both practicum and research, as a result the population of woody plants in land unit 5 is abundant and diverse, and the predominant plant species observed is woody plants. In addition, land unit 5 is densely covered by woody plants. In contrast, in land unit 2 (slope of 3 – 8%), which is classified as gently sloping, the amount of woody plant biomass is very low because the land unit 2 is frequently used as experimental plots for both practicum and research, which are cultivated with food crops, such as maize, sorghum and cassava, and interplanted with some coconut trees, consequently the amount of plant biomass in land unit 2 is the lowest among other land units (Table 2).

The results of this study showed that the amount of understory plant biomass in different land units is not significantly different. Land unit 1 is dominated by paddy fields and fish ponds including some coconut trees and “pasiran” trees. As a result,

the land was uncovered and hardly any shade that can hamper the growth of understory plants was observed. Chang (1968) and Chambers (1978) suggest that shade can affect environmental factors, such as temperature, soil moisture, aeration, nutrient immobilization and weed control. The non-significantly different of the amount of understory plant biomass in different land units is also observable for the non-significantly different of organic C content in understory plants.

The content of organic C in woody plants among land units is significantly different, which is due to the diversity of woody plants in each land unit, land unit 4 has the lowest organic C content in woody plants among other land units, *i.e.* 36.07%, which is not significantly different from land unit 1 that has 41.02% organic C content. This finding is due to the diversity of plant species in land unit 4 and 1 is relatively similar, which is dominated by banana trees and some coconut trees. On the other hand, land unit 2 (46.50%), land unit 3 (44.49%) and land unit 5 (43.02%) have the highest organic C content in woody plants among other land units, due to the number of plants in those land units are higher than that in land unit 1 and 4.

The above ground carbon stocks in land unit 1, 2, 3, 4 and 5 are 143.07 Mg ha⁻¹; 88.79 Mg ha⁻¹; 260.71 Mg ha⁻¹, 327.04 Mg ha⁻¹; and 437.19 Mg ha⁻¹, respectively, in which land unit 5 has the highest total carbon stock, *i.e.* 437.19 Mg ha⁻¹. The main source of above ground carbon stock is woody plant biomass that grows in land unit 5 including ketapang trees (*Terminalia catappa*), bayur trees (*Pterospermum acerifolium*), “pasiran” trees, randu trees (*Ceiba pentandra*), coconut trees, sugar palm trees (*Borassus falbellifer*), waru trees

Table 2. The effect of land unit on the amount of woody plant biomass, the amount of understory plant biomass, organic C content in woody plants, organic carbon content in understory plants and total aboveground carbon.

Land Unit	Biomass of Woody Plants	Biomass of Understory Plants	Organic C in Woody Plants	Organic C in Understory Plants	Total Aboveground Organic C
	Mg ha ⁻¹	Mg ha ⁻¹	%	%	Mg ha ⁻¹
1	372.97 ab	0.147 (0.38) a	41.02 ab	34.34 a	143.07 ab
2	237.43 a	0.098 (0.31) a	46.50 b	27.79 a	88.79 a
3	655.28 abc	0.11 (0.33) a	44.49 b	35.54 a	260.71 abc
4	938.80 bc	0.12 (0.34) a	36.07 a	31.13 a	327.04 abc
5	1.196.88 c	0.11 (0.33) a	43.02 b	29.66 a	437.19 c
LSD 5%	669.26	0.07 (0.09)	5.51	8.76	254.91

Note: Value followed by the same letter in the same column were not significantly different according to LSD test for 5%. Value in parantheses were transformation by \sqrt{x}

(*Hibiscus tiliaceus*) and bamboo. Plants take up CO₂ from the atmosphere, which is further converted into C₆H₁₂O₆, and O₂ that is released into atmosphere, and food stock (*i.e.* carbohydrate molecules) that is stored as biomass. On the other hand, land unit 2 has the lowest above ground carbon stock, *i.e.* 88.79 Mg ha⁻¹. With slope of 3-8% that is classified as gently sloping, land unit 2 is an ideal land for cultivation, consequently land unit 2 is frequently used for experimental plots for both practicum and research, and generally cultivated with annual crops and food crops. As a result, the above ground organic carbon stock in this land unit is the lowest among other land units.

Bouwman (1990) suggested that plants as carbon sink helps to mitigate CO₂ in the atmosphere via photosynthesis, in which CO₂ is taken up and converted by plants into organic carbon in the form of biomass. Biomass can absorb energy, which is further converted into carbon in plants, especially in woody plants. The absolute carbon content in biomass or the amount of carbon stored in biomass is called carbon storage or carbon stock (Apps *et al.* 2003).

Soil Organic Carbon

The content of organic C in top soils (0 – 20 cm) is between 1.51% and 1.96%. Table 3 presents the content of soil organic C in each land unit.

The content of soil organic C indicates the amount of carbon taken up by plants via photosynthesis, which further goes into soil via decomposition and accumulate in soil. High soil erosion rate can lose carbon that stored in soil (Banuwa 2013). The content of soil organic carbon also indicates the condition of plants that cover the land. In uncovered lands, the ability of plants to take up carbon via photosynthesis is smaller than that of plants in covered lands. Higher organic carbon content in soil indicates higher above ground photosynthesis process in which carbon is found.

The highest soil organic C content is observed in land unit 2, *i.e.* 1.96% in the top soil 0-20 cm. Land unit 5, which has the highest amount of plant biomass or above ground carbon, contains 1.84% soil organic C, which is lower than that in land unit 2 and 3. Land unit 2 and 3 are always used for experimental plots (practicum) of cultivated crops, so N fertilizer is always applied to these lands, as a result both land unit 2 and 3 have the highest soil organic matter content among other land units. This finding is in line with the study of Utomo *et al.* (2012) that indicated that the treatments of zero tillage and application of 200 kg N ha⁻¹ was able to increase 46.1% soil organic carbon in comparison with without N fertilizer application. Further, the low content of soil organic C in land unit 5 may be due to land unit 5 has steep slope (30-45%), causing high erosion rate and runoff that happen continuously, consequently the content of soil organic C in land unit 5 becomes low. In addition, due to erosion, decomposition process of plant residues in the top soil becomes slow and hampered, as a result the content of soil organic C becomes low.

CO₂ Plant Uptake

The results showed that CO₂ uptake by plants in land unit 1 is about 524.65 Mg ha⁻¹ or 386.67 Mg per size of land unit 1, the uptake in land unit 2 is 325.60 Mg ha⁻¹ or 79.77 Mg per size of land unit 2, the uptake in land unit 3 is 956.03 Mg ha⁻¹ or 3,579.38 Mg per size of land unit 3, the uptake in land unit 4 is 1,199.27 Mg ha⁻¹ or 2,048.35 Mg per size of land unit 4, and the uptake in land unit 5 is 1,603.17 Mg ha⁻¹ or 562.71 Mg per size of land unit 5, so the total CO₂ uptake for all land units is 4,608.72 Mg ha⁻¹ or 6,656.88 Mg per 6.78 ha (total size of IFL) (Table 4 and 5). In conclusion, IFL has capacity to take up carbon dioxide of 386.67 Mg ha⁻¹ in land unit 1; 79.77 Mg ha⁻¹ in land unit 2; 3,579.38 Mg ha⁻¹ in land unit 3; 2,048.35 Mg ha⁻¹ in land unit 4 and 562.71 Mg ha⁻¹ in land unit 5. In total, IFL has capacity to take up CO₂ of 6,656.88 Mg.

Table 3. The content of soil organic C.

Land Unit	Size (ha)	Organic C (%)	Organic C (Mg ha ⁻¹)	Organic C (Mg per size of land unit)
1	0.737	1.59	31.8	23.44
2	0.245	1.96	39.2	9.60
3	3.744	1.89	37.8	129.16
4	1.708	1.51	30.2	61.43
5	0.351	1.84	36.8	12.92
Total	6.785	-	-	236.55

Sumber: Banuwa *et al.* (2011)

Table 4. The amount of plant biomass, total aboveground organic C and CO₂ uptake.

Land unit	Total biomass (Mg ha ⁻¹)	Total aboveground organic C (Mg ha ⁻¹)	CO ₂ uptake (Mg ha ⁻¹)
1	373.35	143.07	524.65
2	237.74	88.79	325.60
3	655.60	260.71	956.03
4	939.14	327.04	1,199.27
5	1,197.21	437.19	1,603.17
total	3,403.05	1,256.81	4,608.72

Table 5. Total biomass, total aboveground organic C and CO₂ uptake.

Land unit	Size (ha)	Total biomass (Mg per size of land unit)	Total aboveground organic C (Mg per size of land unit)	Total CO ₂ uptake (Mg per size of land unit)
1	0.737	275.16	105.45	386.67
2	0.245	58.25	21.75	79.77
3	3.744	2,454.59	976.11	3,579.38
4	1.708	1,604.05	558.59	2,048.35
5	0.351	420.22	153.45	562.71
total	6.784	4,812.27	1,815.35	6,656.88

Total Carbon

Total carbon stock in IFL Faculty of Agriculture University of Lampung is presented in Table 6.

The results showed that land unit 5, which is densely covered by woody plants, significantly affect total biomass, total above ground organic C and CO₂ plant uptake, *i.e.* 1,197.21 Mg ha⁻¹, 437.19 Mg ha⁻¹ and 1,603.17 Mg ha⁻¹, respectively. The more plants with dense canopy, the more CO₂ is taken up by plants (Table 4). This finding corresponds to the study of Banuwa and Buchori (2010) about carbon stock in various farming systems of coffee plantation. The study showed that P5 farming system (*i.e.* mixed farming system including coffee, pepper, banana and cocoa) consists of more plant population with highly dense canopy, as a result the availability of soil organic carbon is abundant, which further leads

to high soil microbial activity. Based on this condition, P5 farming system has the highest stock of organic carbon. However, because the size of land unit 5 at IFL Faculty of Agriculture University of Lampung is only 0.351 ha, its contribution to total carbon and CO₂ plant uptake at IFL Faculty of Agriculture University of Lampung is not that high (Table 6).

CONCLUSIONS

Land unit 5 (gently steep with slope of 30-45%) has the highest total biomass of woody plants among other land units, *i.e.* 1,196.88 Mg ha⁻¹ and the highest total above ground carbon, *i.e.* 437.19 Mg ha⁻¹. IFL Faculty of Agriculture University of Lampung has total carbon stock of 2,051.90 Mg and total CO₂ plant uptake of 6,656.88 Mg.

Table 6. Total carbon in Integrated Field Laboratory Faculty of Agriculture University of Lampung.

Land unit	Size (ha)	Aboveground organic C (Mg per size of land unit)	Soil organic C (Mg per size of land unit)	Total organic C in IFL (Mg per 6.784 ha)
1	0.737	105.45	23.44	128.88
2	0.245	21.75	9.60	31.36
3	3.744	976.11	129.16	1,105.27
4	1.708	558.59	61.43	620.02
5	0.351	153.45	12.92	166.37
total	6.784	1,815.35	236.55	2,051.90

REFERENCES

- Apps M, J Canadell, M Heimann, V Jaramillo, D Murdiyarso, D Schimel and M Manning. 2003. Science Statement on Current Scientific Understanding of the Processes Affecting Terrestrial Carbon Stocks and Human Influences upon Them. IPCC. Geneva. 37 p.
- Arifin J. 2001. Estimasi Penyimpanan C Pada Berbagai Sistem Penggunaan Lahan di Kecamatan Ngantang, Malang, Jurusan Tanah, Fakultas Pertanian, Universitas Brawijaya, Malang, 61 p (in Indonesian).
- Banuwa IS dan H Buchori. 2010. C-tersimpan pada berbagai pola usahatani berbasis kopi. Prosiding Seminar Nasional Masyarakat Konservasi Tanah dan Air Indonesia, 24-25 November 2010, FP Universitas Jambi. Jambi, Hal. 595-609 (in Indonesian).
- Banuwa IS, T Syam dan D Wiharso. 2011. *Karakteristik Lahan Laboratorium Lapang Terpadu FP Unila* (Laporan Penelitian). Bandar Lampung (in Indonesian).
- Banuwa IS. 2013. Erosi. Kencana Prenada Media Group. Jakarta. 204 halaman (in Indonesian).
- Bouwman AF. 1990. *Soil and Greenhouse Gases*. John Willy and Sons. United States. Hal 261-266
- Chambers RE. 1978. *Klimatologi Pertanian Dasar*. Bogor. Fakultas Pertanian IPB. Halaman 23-24 (in Indonesian).
- Chang JH. 1968. *Climate and Agriculture An Ecological Survey*. Chicago : Aldine Publishing Company. Hal 304-310.
- Chiti T, L Gardin, L Perugini, R Quarantino, FP Vaccari, F Miglietta and R Valentini. 2012. Soil organic carbon stock assessment for the different cropland land uses in Italy. *Biol Fertil Soils* 48: 9-17. doi:10.1007/s00374-011-0599-4.
- Hairiah K. 2007. *Pengukuran Karbon Stock Diatas Permukaan Tanah*. Transkrip Presentasi Pada Workshop Lahan Gambut Untuk Perlindungan Iklim Global dan Kesejahteraan Masyarakat. Diselenggarakan Climate Change Forests and Peatlands in Indonesia. Wetlands International. Http : www.wetlands.or.id.com/publications/files/book/pdf. Diakses tanggal 12 Maret 2015 (in Indonesian).
- Hairiah K dan S Rahayu. 2007. *Pengukuran Karbon Tersimpan di Berbagai Macam Penggunaan Lahan*. World Agroforestry Center. Bogor. Indonesia. 77 hlm (in Indonesian).
- Hairiah K, MV Noordwijk and C Palm. 1999. Methods for sampling above and below ground organic pools. In: Murdiyarso D, MV Noordwijk and DA Suyanto (eds). *Modelling Global Change Impacts on the Soil Environment*. IC-SEA Report No. 6. SEAMEO BIOTROP-GCTE IC-SEA, Bogor, p: 46-77.
- IPCC [Intergovernmental Panel on Climate Change]. 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: RK Pachauri and A Reisinger (eds.). IPCC, Geneva, Switzerland, 104 pp.
- Ketterings QM, R Coe, MV Noordwijk, Y Ambagau and C Palm. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. *Forest Ecol Manage* 146: 199-209.
- Lasco RD. 2002. Forest Carbon Budgets an Southeast Asia Following Harvesting and land Cover Change. In: Impacts of Land Use Change on the Terrestrial Carbon Cycle in the Asian Pasific Region. *Science in China* 45: 76-87.
- Murdiyarso D, U Rosalina, K Hairiah, L Muslihat, INN Suryadiputra dan Adijaya. 2004. *Petunjuk Lapang Pendugaan Cadangan Karbon Diatas dan di bawah Permukaan Pada Lahan Gambut*. Proyek Climate Change, Forests and Peatlands in Indonesia. Wetlands International-Indonesia Programme dan Wildlife Habitat Canada. Bogor. Indonesia. www.wetlands.or.id.com/climate/publication/reference/files/book/pdf. Diakses Tanggal 12 Maret 2015.
- Negash M dan M Starr. 2015. Biomass and soil carbon stocks of indigenous agroforestry systems on the south-eastern Rift Valley escarpment, Ethiopia. *Plant Soil* 393: 95-107. doi 10.1007/s11104-015-2469-6.
- Nieder R dan J Richter. 2000. C and N accumulation in arable soils of West Germany and its influence on the environment-developments 1970 to 1998. *J Plant Nutr Soil Sci* 163:65-72
- Priyadarsini R. 1999. Estimasi Modal C (C-stock) Masukan Bahan Organik, dan Hubungannya dengan Populasi Cacing Tanah pada Sistem Wanatani. Program Pasca Sarjana, Universitas brawijaya, Malang. 76 pp (in Indonesian).
- Rifyunando dan Regi. 2011. Estimasi Stok Karbon Mangrove di Kawasan Cagar Alam Reuweung Sancang Kecamatan Cibolang Kabupaten Garut. Universitas Pendidikan Indonesia. Bandung (in Indonesian).
- Sleutel S, S DeNeve, B Singier dan G Hofman. 2006. Organic C levels in intensively managed arable soil-long term regional trends and characterization of fractions. *Soil Use Manage* 22: 188-196.
- Sugiharto C. 2002. Kajian Aluminium Sebagai Faktor Pembatas Pertumbuhan Akar Sengon (*Paraserianthes falcataria* L. Nelson). Jurusan Tanah, Fakultas Pertanian, Universitas Brawijaya. Malang. 64 pp (in Indonesian).
- Utomo M, H Buchari, IS Banuwa, LK Fernando dan R Saleh. 2012. Carbon Storage And Carbon Dioxide Emission As Influenced By Long-Term Conservation Tillage And Nitrogen Fertilization In Corn-Soybean Rotation. *J Tanah Trop* 17: 75-84.
- Thom WO dan M Utomo. 1991. Manajemen Laboratorium dan Metode Analisis Tanah. Universitas Lampung. Bandar Lampung. Hlm. 21-41 (in Indonesian).
- Widianto, K Hairiah, D Suharjito dan AM Sardjono. 2003. *Fungsi dan Peran Agroforestri*. World Agroforestry Centre (ICRAF). Bogor. Indonesia. <http://www.worldagroforestry.org/sea/publications/files/book/pdf>. Diakses Tanggal 23 Maret 2015.