TRANSACTIONS ON SCIENCE AND TECHNOLOGY

Carbon Stock Estimation of Agroforestry System in Tawau, Sabah

Herawandi SUARDI[1]*, Normah AWANG BESAR[1], Mui-How PHUA[1] & Mazlin MOKHTAR[2]

[1]Faculty of Science and Natural Resources, University Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia

[2]Institutes of Environment and Development (LESTARI), University Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

*Corresponding author: wandi1363@yahoo.com; Tel: 088-320000.

Received: *16 June 2015*
Revised: *10 July 2015*
Accepted: *16 July 2015*
In press: *5 November 2015*
Online: *1 April 2016*

Keywords:
Agroforestry; monoculture, forest; aboveground carbon stock; belowground carbon stock

Abstract

Studies on total aboveground carbon (TAC) and belowground carbon (TBC) stock has been conducted in Balung Plantation, Tawau, Sabah. The main objective of the study was to determine the above and below ground carbon stock in agroforestry system. The combination of agroforestry systems with different ages were investigated, which is oil palm (25 years) and agarwood (7 years), oil palm (20 years) and agarwood (7 years), and oil palm (17 years) and agarwood (5 years). Monoculture of oil palm (16 years) and Tawau Hill Park forest reserve was set as control. A random systematic sampling method was used in conducting field inventory and soil sampling. The size of the sampled area in agroforestry and monoculture is 3 × 50m × 50m, while for forest reserve, the sampled area is 3 x 30m x 30m. Allometric equations were used to calculate the stand biomass. Sampling for organic and shrub layers were collected in a square frame (1m × 1m). Soil samples and bulk density was collected from three different layers which are 0 – 5 cm, 5 – 10 cm and 10 – 30 cm in randomly located sites within the plots. Soil samples, organic and shrub layer were analyzed using CHN628 series for carbon content. Result shows that the amount of total carbon stock in agroforestry was 79.12 tan C ha-1, 85.39 tan C ha-1 and 78.27 tan C ha-1, respectively. Monoculture of oil palm (16 years) has 76.44 tan C ha-1 while Tawau Hill Park forest reserve has total carbon stock at 287.38 tan C ha-1. Forest reserve stand has the highest total carbon stock compared to agroforestry and monoculture systems. But, in terms of soil carbon, forest reserve has the lowest TBC compared to agroforestry and monoculture systems. ANOVA was conducted to explore the impact of planting systems on total carbon stock. There was a statistically significant difference at the $p < .05$ level for soil carbon, living tree and organic layer between agroforestry, monoculture and forest reserve. Good crop and fertilizer management in agroforestry and monoculture systems helps in increasing soil organic carbon (SOC).

Introduction

Forest has the unique roles as the major source of carbon pool, as well as timber production for economic benefits. The conversion of forest landscape into variety of land cover has reduced its potential in storing carbon. The rapid expansion of oil palm over the past two decades has led to the transformation of large areas of forest and plantation landscapes throughout Southeast Asia and is believed to be one of the major sources of greenhouse gas (GHG) emissions linked to land use in the region (Agus *et al.*, 2010; Ekadinata and Dewi, 2011). Agroforestry plantation offers a compromise solution in improving carbon storing capability of converted lands. Agroforestry system was proved to give positive impact to conventional agricultural and forest tree production through increase in

productivity, biodiversity, social, economic and ecological benefit (ICRAF, 1995). The main objective of the study was to determine the above and below ground carbon stock in agroforestry system and the factor that affects carbon storage.

Methodology

Study site

This study was conducted at Balung River Plantation, Tawau, Sabah. Balung River Plantation (1,500 hectare) is located at N 040 26' 18.50'' E 1180 02' 55.90''. The temperature at the study site was high year round ranging from 24 – 33°C. Average yearly rainfall was 864 mm. Three different land use were investigated which is agroforestry, monoculture and forest reserve. The combinations of agroforestry system with different ages are oil palm (25 years) and agarwood (7 years), oil palm (20 years) and agarwood (7 years), and oil palm (17 years) and agarwood (5 years). Monoculture of oil palm (16 years) and Tawau Hill Park forest reserve was set as control.

Carbon stock estimation

TAC and TBC in the soil were investigated. A random systematic sampling method was used in conducting forest inventory and soil sampling. The size of the sampled area in agroforestry and monoculture plantation is 3 × 50m × 50m, while for forest reserve, the sampled area is 3 x 30m x 30m. For aboveground tree inventory, plots location (North-South) were recorded with a differential global positioning system (DGPS Triumph 1, brand Javad) to 0.5m real-time accuracy. Diameter at breast height (dbh) of trees was measured using diameter tape while the height is measured using laser range finder. Sampling for organic and shrub layers were collected in a square frame (1m × 1m) within plots. Soil was collected at three different layers which are 0 – 5 cm, 5 – 10 cm and 10 – 30 cm from randomly located sites inside the plots. Bulk density was collected by using standard soil corers (brand Eijkelkamp, Netherlands). Soil sample, organic and shrub layer were analyzed in the laboratory using CHN628 series for carbon content.

Allometric equations

Table 1: Allometric equations

Tree Species	Allometric Equation	Source
Oil Palm	$w=(725+197h) \times 0.2$	Khalid *et al*., (1999)
Agarwood	$w=0.1043dbh^{2,6}$	Hairiyah and Rahayu (2007)
Forest Stand	$w= exp(-1.935+(1.981 \times ln\ dbh)+(0.541 \times ln\ h)$	Basuki *et al*., (2009)

* w: Tree biomass (kg), h: tree height (m), dbh: diameter at breast height (cm)

Site specific allometric equations were used to convert field measured attributes (i.e. height and dbh) into stand biomass as shown in Table 1. Total stand carbon was estimated to be 50 percent of the total tree biomass (Houghton and Hackler, 2001).

Result and discussion

Above - Ground Biomass

Number of trees per hectare in different land use is shown in Figure 1. Total tree biomass in different land use is shown in Figure 2. Forest reserve shows the highest total tree biomass at 500.00 tan ha^{-1}. Total organic and shrub layer biomass within all land use was almost equal except for organic layer in the forest reserve area as shown in Figure 3. Total organic layer biomass in the forest reserve area was the highest compared to agroforestry and monoculture at 3.70 t ha^{-1}.

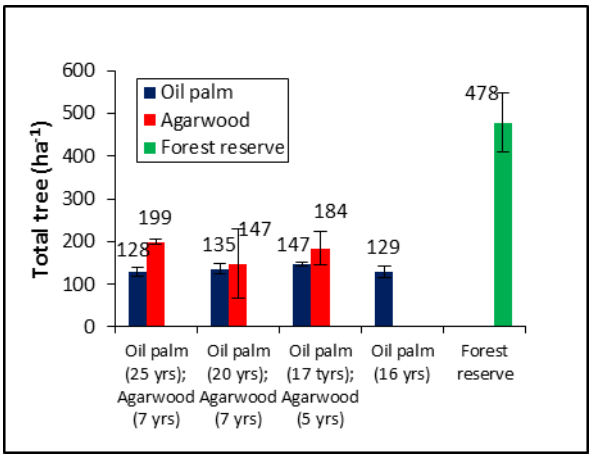

Figure 1: Tree distribution in different land use

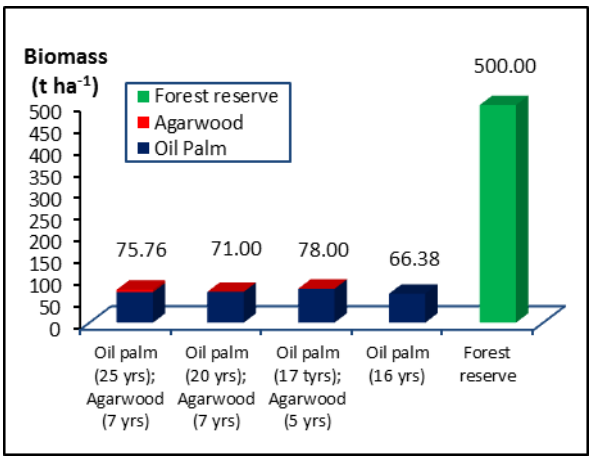

Figure 2: Tree biomass in different land use

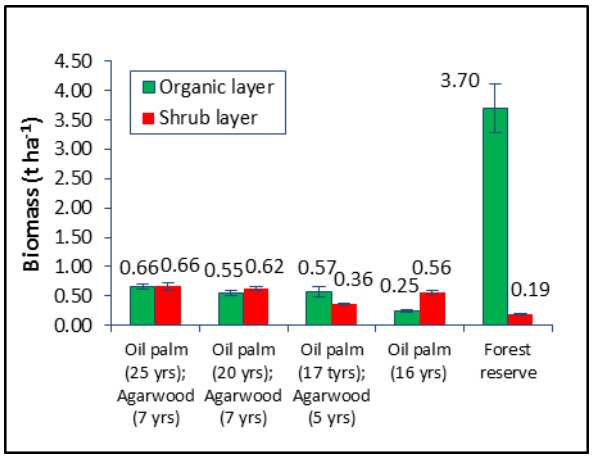

Figure 3: Organic and shrub layer biomass

Total carbon stock

Table 2 shows the total above and below ground carbon stock including soil, living tree, organic and shrub layer. Total above and below ground carbon stock in forest reserve is the highest compared to other land use.

Table 2: Total Above and below ground carbon stock in different land use.

Land use	Carbon Stock (t C ha^{-1})				Total Carbon Stock* (t C ha^{-1})
	Soil	Living Tree	Organic Layer	Shrub Layer	
Oil Palm (25 years) ; Agarwood (7 years)	41.06^{a}	37.88^{a}	0.137^{a}	0.047^{a}	79.12
Oil Palm (20 years) ; Agarwood (7 years)	49.75^{a}	35.50^{a}	0.102^{a}	0.042^{a}	85.39
Oil Palm (17 years) ; Agarwood (5 years)	39.12^{a}	39.00^{a}	0.116^{a}	0.034^{a}	78.27
Oil Palm (16 years)	43.09^{a}	33.19^{a}	0.067^{b}	0.093^{b}	76.44
Forest Reserve	36.30^{b}	250.00^{b}	1.019^{c}	0.066^{a}	287.38
Anova Test (P)	0.000	0.000	0.000	0.000	-

* indicates means followed by the different letter within column are significantly different (P<0.05) using Tukey's test for above and below ground carbon stock in different land use.

Result shows that the amount of total carbon stock in agroforestry was 79.12 tan C ha^{-1}, 85.39 tan C ha^{-1} and 78.27 tan C ha^{-1} respectively. Monoculture of oil palm (16 years) has 76.44 tan C ha^{-1} while Tawau Hill Park forest reserve has a total carbon stock of 287.38 tan C ha^{-1}. Research findings were compared to previous study by Yanto Rochmayanto (2011). The study reported that aboveground carbon stock in agroforestry system of oil palm and agarwood in 25 planting cycle is about 36.87 tan C ha^{-1}. Forest reserve has the highest total carbon stock compared to agroforestry and monoculture systems. Aboveground standing trees alone contribute about 87 % of total above and below ground carbon in forest reserve.

Forest reserve has the lowest TBC due to low soil carbon (%) within the lower layer (10 – 30 cm). The percentage of soil carbon (10 – 30 cm) in forest reserve was the lowest at 0.586 % compared to agroforestry of oil palm (27 years) and agarwood (7 years) at 0.800 %, agroforestry of oil palm (20 years) and agarwood (7 years) at 0.900 %, agroforestry of oil palm (17 years) and agarwood (5 years) at 0.958 % and monoculture of oil palm (16 years) at 0.883 %. The use of Nitrophoska Blue (12-12-17-2+8S+TE) NPK fertilizer in the oil palm plantation for agroforestry and monoculture are believed to increase SOC. Campbell *et al*., (2000) reported that long term application of adequate fertilizer (nitrogen and phosphorus) increase SOC. Mathews *et al*., 2010 also reported that conversion of forest area to oil palm plantation increase SOC about 32 % in the first crop rotation and 15 % in the second crop rotation. According to Lal *et al*., (1997), there are four factors that helps in increasing the efficiency of carbon sequestration which are soil fertility, good crop management, high crop diversity at the same unit of land and the ability of crop to absorb carbon in the atmosphere. Good crop and fertilizer management in agroforestry and monoculture systems in Balung Plantation helps in increasing SOC. Intensive cropping systems such in agroforestry enhanced nutrient and water use

efficiencies, reduced nutrient leaching to groundwater and improved soil physical and biological properties (IAEA, 2008).

A one-way between - groups analysis of variance (ANOVA) was conducted to explore the impact of planting systems on total carbon stock. There was a statistically significant difference at the $p < .05$ level for soil carbon, living tree and organic layer. Post-hoc analysis show a significant different between forest and plantation area. This is because, conversion of land use from forest area to oil palm plantation changes soil carbon (%), and vegetations.

Conclusion

Total carbon stock in the three agroforestry systems was 79.12 tan C ha-1, 85.39 tan C ha-1 and 78.27 tan C ha-1. Monoculture of oil palm (16 years) has 76.44 tan C ha-1 while Tawau Hill Park forest reserve has a total carbon stock of 287.38 tan C ha-1. Total carbon stock in forest reserve is the highest, followed by agroforestry system and monoculture. In term of soil, agroforestry and monoculture system has higher TBC compared to forest reserve. Total carbon stock in different land use depends on vegetations, tree ages, and soil management.

Acknowledgements

We would like to thanks to ministry of Higher Education (MOHE) in providing research grant (RACE/F1/STWN2/UMS/6), University Malaysia Sabah, Balung River Plantation and other support for the study.

References

[1] Agus, F., Handayani, E., van Noordwijk, M., Idris, K. & Sabiham, S. (2010). Root respiration interferes with peat CO2 emission measurement. *Proceedings of the 19th World Congress of Soil Science*. 1-6 August 2010, Brisbane, Australia.

[2] Basuki, T. M., Van Laake, P. E., Skidmore, A. K., & Hussin, Y. A. (2009). Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. *Forest Ecology and Management*, **257,** 1684-1694.

[3] Campbell, C. A., Zentner, R. P., Liang, B. C., Roloff, G., Gregorich, E. C. & Blomert, B. (2000). Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan - Effect of crop rotations and fertilizers. *Canadian Journal of Soil Science*, **80,** 179–192.

[4] Ekadinata, A. & Dewi, S. (2011). *Estimating losses in above ground stock from land use and land cover changes in Indonesia (1990, 2000, 2005). ALLREDDI Brief 03.* Bogor: World Agroforestry Centre.

[5] Hairiah, K & Rahayu, S. (2007). *Pengukuran Karbon Tersimpan di Berbagai Macam Penggunaan Lahan.* Bogor: World Agroforestry Centre.

[6] Houghton, R. A. & Hackler, J. L. (2001). *Carbon Flux to the Atmosphere from Land-Use Changes: 1850 to 1990.* Carbon Dioxide Information Analysis Center, US Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN. pp 86.

[7] International Centre for Research in Agroforestry (ICRAF). (1995). Annual Report, 1995. ICRAF, Nairobi.

[8] International Atomic Energy Agency (IAEA). (2008). *Management of Agroforestry Systems for Enhancing Resource use Efficiency and Crop Productivity*. IAEA-TECDOC-1606. Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

[9] Khalid, H., Zin, Z. & Anderson, J. M. (1999). Quantification of oil palm biomass and nutrient value in a mature plantation: Above ground biomass. *Journal of Oil Palm Research*, **11(**1), 3-32.

[10] Lal, R., Kimble, J. & Follett, R. (1997). Land use in soil carbon pools in terrestrial ecosystems. *In*: Lal, R., Kimble, J. M. Follett, R. F. & Stewart, B. A. (eds). *Management of Carbon Sequestration in Soil*. CRC Press. pp 1-10.

[11] Mathews. J., Tan, T. H. & Chong, K. M. (2010). Indication of soil organic carbon augmentation in oil palm cultivated inland mineral soils of Peninsular Malaysia. *Planter*, **86**(1010), 293-313.

[12] Yanto, R. (2011). Enhancing carbon stock and economic potency for REDD+ activity on oil palm – eaglewood agroforestry systems. *First International Conference of Indonesian Forestry Researchers (INAFOR)*. 5-7 December 2011, Bogor, Indonesia.

TRANSACTIONS ON SCIENCE AND TECHNOLOGY