TRANSACTIONS ON SCIENCE AND TECHNOLOGY

Aboveground Carbon Stock Potential of Teak (*Tectona grandis*) under Different Land Use System in Balung Plantation, Tawau Sabah

Daniel James[1*], Mui-How Phua[1], Normah Awang Besar[1] & Mazlin Mokhtar[2]

[1] Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, MALAYSIA.

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

*Corresponding author. E-Mail: danieljames.ums@gmail.com; Tel: +6088-320000; Fax: +6088-435324

Received: *31 March 2016*
Revised: *12 April 2016*
Accepted: *22 May 2016*
In press: *2 June 2016*
Online: *30 June 2016*

Keywords:
Agroforestry; Aboveground Carbon Stock; *Tectona grandis*; Living Biomass

Abstract

Assessment of aboveground carbon stock in different teak plantation systems was conducted in Balung River Plantation, Tawau, Sabah. The objective of this study is to determine the potential of teak as the main tree components to increase the above ground carbon stock in different land use system. The above ground carbon stock of agroforestry and mixed plantation system of teak (*Tectona grandis*) were compared with natural forest and monoculture plantation of the species. The agroforestry combinations investigated are agroforestry system 1, teak (18 years) with snake fruit (8 years) and agarwood (8 years); agroforestry system 2, teak (17 years) with coffee (14 years); and also mixed timber plantation system, teak (18 years) with agarwood (8 years); while 20 years teak monoculture plantation and natural forest reserve was set up as a control. A random systematic sampling method was used in conducting field inventory. The methodologies used include the measurement of height and diameter breast height (DBH) of trees within a 50 m x 50 m plot dimension (for plantation) and 30 m x 30 m (forest). Allometric equations were used to derive the field measured attributes into stand biomass while carbon stock was estimated as 50 percent from the total biomass. The result shows the accumulation of carbon stock goes in the following order: forest reserve (213.84 t C/ha) > mixed timber plantation (69.94 t C ha^{-1}) > agroforestry system 2 (37.75 t C/ha) > agroforestry system 1 (37.34 t C/ha) > teak monoculture (34.53 t C/ha) witnessing the teak trees to increase the total aboveground carbon stock in agroforestry and mixed timber plantation system by more than 60 percent. This study suggested that teak has great potential in transforming a low biomass land use into a carbon-rich tree based systems.

Introduction

Forest is the most significant carbon pools which continuously exchange CO_2 with the atmosphere due to both natural processes and human actions (FAO, 2003). Even so, deforestation activity have undermines this important carbon sink function and it is estimated that 15% of all greenhouse gases emissions are contributed from deforestation. Massive reforestation may have been the best solution proposed in stabilizing the concentration of CO_2 in the atmosphere. However, it is facing difficulties in implementation considering the current rates of deforestation in the tropics and the high demands on the use of large area for agricultural purposes. Realizing the important roles of trees to capture and store carbon in vegetation, soils and biomass products (Malhi *et al.*, 2008), agroforestry have been recognized as an integrated approach in storing carbon especially under the afforestation and reforestation activities that have been approved as greenhouse gases mitigating strategies under the Kyoto protocol (Albrecth & Kandji, 2003). Agroforestry offers viable solution because it increases carbon capacity of land, and potentially enhance agricultural production rather than competing with it (Unruh, *et al.*, 1993). Although the storage of carbon per unit area is lower for agroforestry compared to forest or tree plantations, there are substantially large areas for agroforestry worldwide (Unruh *et al.*, 1993; Albretch & Kandji, 2003; Takimoto *et al.*, 2008). Considering the importance of carbon sequestration, this study aims to evaluate the potential of agroforestry systems in Balung Plantation as carbon storage. Different land use system of teak plantations were studied to determine its potential in storing carbon.

Methodology

Study area

The study was conducted at Balung River plantation, Tawau, Sabah (N 04^0 26’ 18.50”, E 118^0 02’ 55.90”) with an area of approximately 1500 ha. The temperature at the study site ranging from 24 – 33 °C with an average yearly precipitation of 864 mm (Suardi *et al.*, 2016). Balung River plantation comprises of several plantation types such as oil palm plantation, teak plantation, fruit trees plantation, mixed plantations and agroforestry plantations. In this study, plots were established in different plantation system of teak that includes mixed timber, agroforestry and monoculture plantation system. Taman Bukit Tawau Forest Reserve is also located next to the plantation area, separated by the buffer zones of the forest reserve. Plots were also established within the buffer zones of the forest reserve which act as a control. Historically, the forest area has undergone selective logging activities before it was gazetted as forest reserve in 1989.

Field data collection

Three types of mixed teak plantation system that were investigated are agroforestry system 1, teak (18 years) with snake fruit (8 years) and agarwood (8 years); agroforestry system 2, teak (17 years) with coffee (14 years); and mixed timber plantation of teak (18 years) with agarwood (8 years). 20 years old teak monoculture and forest reserve was set up as a control. The methodologies used as field tested by Suardi *et al.*, (2016) include the measurement of height and diameter breast height (DBH) of trees in a 50 m x 50 m plot dimension (plantation area) and 30 m x 30 m plot dimension (forest area).

Biomass and carbon stock estimation

Allometric equations were used to derive the field measured attributes into stand biomass as summarized in Table 2. Species specific allometric equations is used for teak, agarwood and coffee stand, while general equations were used for snake fruit (allometric for juvenile palm) and forest reserve. Carbon stock in trees is approximately 50 percent of the total tree biomass (Houghton & Hackler, 2001).

Table 2. Allometric equation used for aboveground biomass estimation

Tree species	Allometric Equation for AGB	Source
Teak (*Tectona grandis*)	$0.045 \times (D^2H)^{0.921}$	Ounban *et al.*, 2015
Agarwood (*Aquilaria malaccensis*)	$0.1043 \times D^{2.6}$	Hairiah and Rahayu, 2007
Snake Fruit (*Salacca zalacca*)	$10 + 6.4 \times H$	Frangi and Lugo, 1985
Coffee (*Coffea liberica*)	$0.281 \times D^{2.06}$	Ketterings et al.,2001
Tropical Forest	$\exp(-1.935 + (1.981 \times \ln(D)) + (0.541 \times \ln(H)))$	Basuki *et al.*, 2009

Note: *D = DBH, diameter at breast height (cm); H = tree height (m).*

Result and discussion

Stand density, growth performance and total carbon stock

Stand density for the different systems in Balung Plantation is shown in Figure 1 while Figure 2 shows the total aboveground carbon stock (AGC) in each system. Figure 3 and 4 shows the average diameter at breast height (DBH) and height for each species that act as the components in their respective systems.

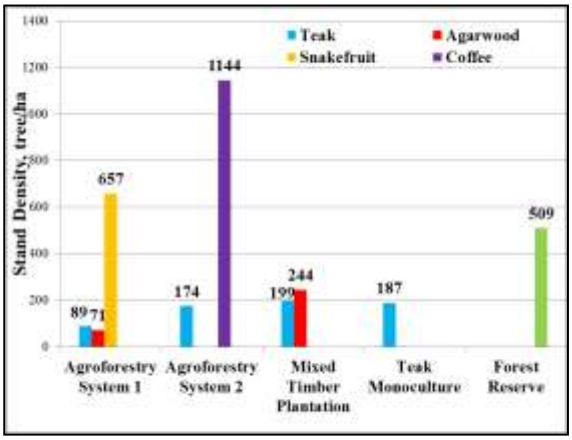


Figure 1. Stand density by species/components

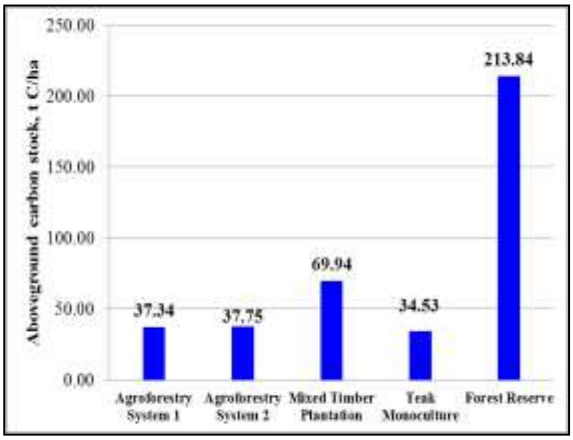
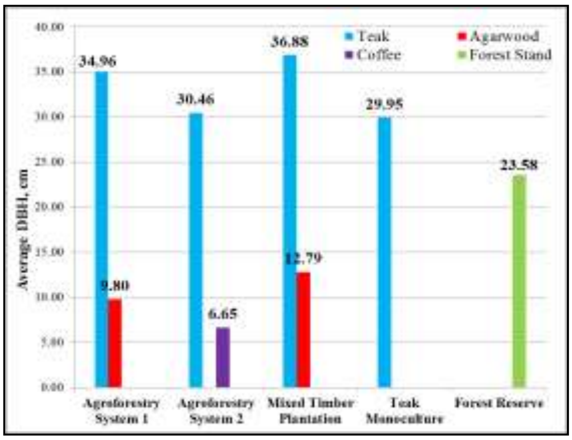


Figure 2. Total aboveground carbon stock



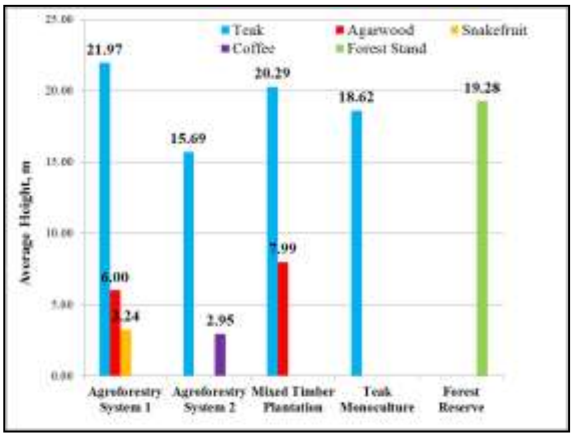


Figure 3. Average DBH **Figure 4.** Average height

A critical review on data across all systems as summarized in Figure 1 reveals that tree density vary considerably among the sites. The tree densities of the plantation systems were attributed by the planting distance applied on the land and it has a major effect in the total carbon stock for upper canopy stand (teak trees). The highest tree density of teak was observed in mixed timber plantation systems with 199 teak stand/ha followed by teak monoculture (187 stand/ha), agroforestry system 2 (174 stand/ha) and agroforestry system 1 (89 stand/ha). The total carbon stock of teak trees in all systems was significantly correlated with stand densities (Pearson's correlation = 0.782, $p<0.01$ (sig. 2-tailed)) in which highest total carbon stock of teak were also observed in mixed timber plantation system (57.84 t C/ha), followed by teak monoculture (34.53 t C/ha), agroforestry system 2 (28.83 t C/ha) and agroforestry system 1 (25.07 t C/ha). For understorey vegetation (e.g. Agarwood, Snake Fruit and Coffee), the stand density does not give any significant influences on the total carbon stock of understorey layers.

The growth parameters of stand such as average DBH and height were also varies according to site. For the plantation systems, teak in mixed timber plantation shows the highest average DBH with 36.88 cm compared to 34.96 cm for teak in agroforestry system 1 and 30.46 cm in agroforestry system 2. Teak monoculture has the lowest average DBH that is 29.95 cm. In terms of average height, teak in agroforestry system 1 have the highest average height (21.97 m) followed by teak in mixed timber plantation (20.29 m), teak monoculture (18.62 m) and teak in agroforestry system 2 (15.69 m). In overall, the teak planted in agroforestry and mixed timber systems shows better growth performance compared to teak planted in monoculture system. The influence of age on the growth performance of teak across all systems was found to be non-significant.

A research conducted by Chia (2011) on the survival and growth performance of teak under monocrop system and intercropped with oil palm also supports the finding that teak growth performance is better when planted in intercropped or mixed plantation. In the research, teak of the same age were assessed for 10 years in both monoculture and intercrop plantation where the results revealed that intercropped teak with oil palm have higher mean DBH and height that is 30.16 cm and 18.22 m respectively in comparison with monoculture teak plantation with average DBH of 28.57 cm and average height of 16.85 m. In addition, Buvaneswarn *et al.* (2001) further supported that age of trees in plantation systems to give no influence on growth performance of trees in which based on their research, it was found that DBH values of teak grown in farmers' field is 15.06 and 27.70 cm respectively at the age of 9 and 12 years old whereas, in 20 years old monoculture teak plantation, it was only 18 cm.

Carbon stock of living biomass across systems

Table 4 shows the total aboveground carbon stock across different systems in Balung Plantation and forest reserves which includes teak and non-teak stand (agarwood, snake fruit, coffee and forest stand). Carbon stock in each system was based on the average from all sampling plots. Highest total carbon stocks was observed in the forest reserve with 213.84 t C/ha followed by mixed timber plantation system (69.94 t C/ha), agroforestry system 2 (37.75 t C/ha), agroforestry system 1 (37.34 t C/ha) and teak monoculture plantation (34.53 t C/ha). The high total carbon stocks of forest reserve supports that natural forest contains the largest carbon pool and carries out a significant function in global carbon cycle.

Table 3. Total aboveground carbon stock in different systems

System	Carbon Stock (Teak), t C/ha	Carbon Stock (Non-Teak)			Carbon Stock (Non-Teak), t C/ha	Total Carbon Stock, t C/ha
		Agarwood	Snake fruit	Coffee		
Agroforestry System 1	25.07^{a}	2.18^{b}	10.09^{c}	-	12.27^{c}	37.34^{a}
Agroforestry System 2	28.83^{a}	-	-	8.92^{c}	8.92^{c}	37.75^{a}
Mixed Timber Plantation	57.84^{d}	12.10^{c}	-	-	12.10^{c}	69.94^{d}
Teak Monoculture	34.53^{a}	-	-	-	-	34.53^{a}
Forest Reserve	-	-	-	-	213.84^{e}	213.84^{e}
ANOVA test (P)	0.000	0.000	-	-	0.000	0.000

Different letter within column and row are significantly different ($P<0.05$) using Tukey's test for aboveground carbon stock in different systems.

In addition, one-way between group analysis of variance (ANOVA) shows that there were statistically significant differences at $P < 0.05$ between all systems indicating different systems were attributable on the total carbon stocks. Post-hoc analysis shows a significant difference between forest reserve and plantation system indicating that land cover conversion from forest to plantation changes carbon stock capacity of vegetation. By viewing across the plantation systems, both agroforestry and mixed timber plantation systems shows higher total carbon stocks compared to teak monoculture plantation suggesting that mixed systems increases carbon stocks capacity of land use through high crop diversity. Similar finding was recorded by Suardi *et al.*, (2016) on the carbon stock estimation of different oil palm plantation systems which is also conducted in the study area. From the research, it was found out that agroforestry system of oil palm with agarwood has higher total carbon stock compared to monoculture oil palm plantation. This supports that intercropping system such as agroforestry and mixed timber plantation has a significant contribution in storing carbon.

Aboveground carbon stock contribution by species

Figure 5 depicts the species contribution on total aboveground carbon stocks within the different plantation systems. From the results, it was observed that large trees such as teak are very important contributor in all plantation systems. Teak increased the amount of carbon stock within mixed plantation systems by 67, 73 and 83 percent for agroforestry system 1, agroforestry system 2 and mixed timber plantation systems respectively. Large timber species tend to contributes to the higher carbon stocks in a mixed or intercropped plantation system as suggested by Moore (2012), based on the research conducted in various types of agroforestry systems in Leyte Island, Philippines. According to Moore (2012), timber based trees contribute more than 50 percent of the total carbon stock within the variety of agroforestry systems and this can be explained as large diameter trees store exponentially more carbon than smaller trees. Understorey vegetation such as agarwood, snake fruit and coffee on the other hand contributes a minimal amount of carbon stocks ranging from 5 to 10 percent on their respective systems.

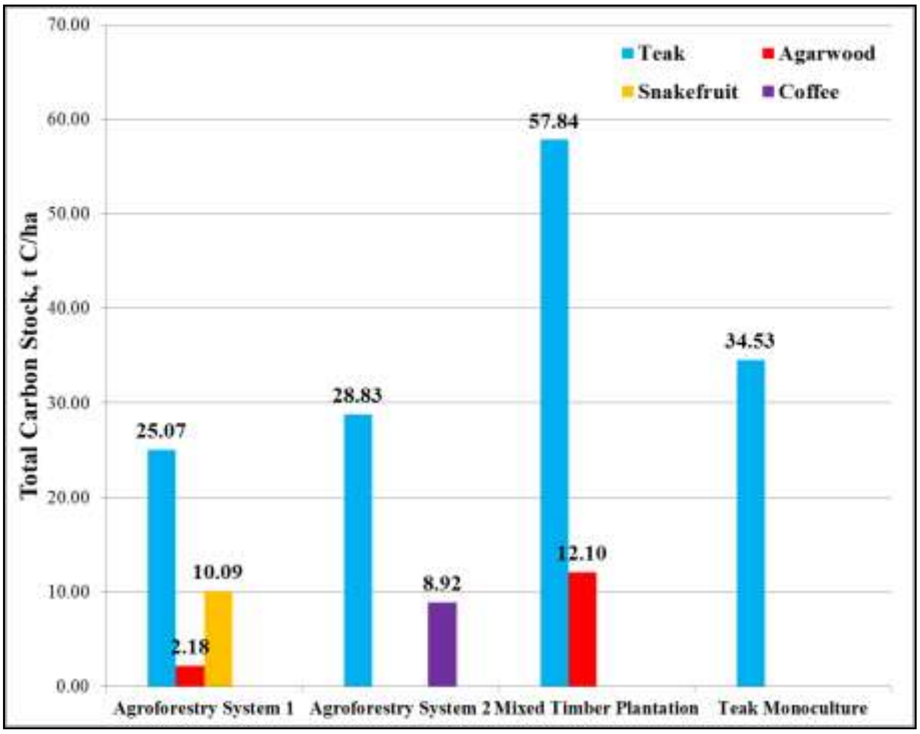


Figure 5. Species contribution to carbon stocks in each plantation systems

In comparison between teak trees as the main tree component in the mixed systems to its monoculture system, teak in mixed timber plantations accumulates the highest total carbon stocks (57.84 t C/ha) followed by teak in monoculture plantation (34.53 t C/ha), teak in agroforestry system 2 (28.83 t C/ha) and teak in agroforestry system 1 (25.07 t C/ha). The total carbon stocks of teak within each system, as discussed earlier were influenced by their stand density. To understand more on the potential of teak trees as the main agroforestry component in storing carbon, it is best to be compared by individual basis.

Carbon stock sequestration of individual teak tree

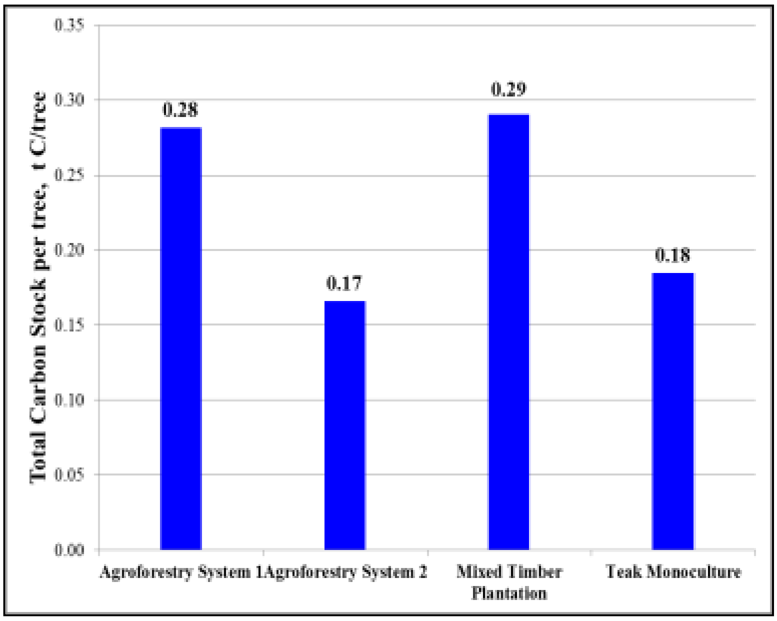


Figure 6. Carbon stock sequestered by individual teak tree

Figure 6 shows the carbon stock stored by average per teak trees across all four different plantation systems. Based on the results, teak in mixed systems shows high ability to store carbon compared to teak tree in monoculture plantation. On average per tree, teak in mixed timber plantation and teak in agroforestry system 1 accumulates the highest carbon at 0.29 t C/tree and 0.28 t C/tree respectively. Although teak in agroforestry system 2 has the lowest accumulation of carbon on individual basis, it is fairly equivalent to its monoculture systems at 0.17 t C/tree vs. 0.18 t C/tree in consideration that teak in agroforestry system 2 is younger (17 years old) than the 20 years old teak monoculture system.

Conclusion

The agroforestry systems of Balung Plantation hold a moderate potential for carbon sequestration as it stored about a quarter percent of the total carbon stocks of a lowland primary rainforest (213.84 t C/ha). Agroforestry systems can have higher carbon sequestration potential when established in low biomass land areas and can produce a significant ecological and economic co-benefit. The establishment of mixed timber plantation yields much higher carbon compared to agroforestry systems and this further suggests the importance of variety of intercropping systems to give better climate change mitigation strategies. Nevertheless, the result of the present investigation shows a very good growth of teak as a component tree in agroforestry and mixed timber plantation system as well as high potential in storing carbon. The ability of teak to store carbon is influenced by the plantation management system such as tree spacing and also the species it were inter-cropped with. Growth performance of teak also significantly influences its efficiency to store carbon under different plantation system. In general, this study has found out that C-stock depend on the species, growth performance and plantation management system.

Acknowledgements

The authors would like to give special thanks to Research University in providing research grants (RACE/F1/STWN2/UMS/6), Universiti Malaysia Sabah and also to Mr. Samalih Kupsa, Manager of Balung River Plantation in providing the study area for this study to take place.

References

[1] Albretch, A. & Kandji, S. T. (2003). Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystem and Envionment*, **99** (1-3), 15-27.

[2] Buvaneswarn, C., George, M., Manivacham, P. & Subramaniam, V. (2001). Comparative studies on performance and productivity of teak in farmland and in forest plantation. *Range Management and Agroforestry*, **22,** 113-117.

[3] Chia, F. R. (2011). Survival and growth performance of teak under monocrop system and intercropped with oil palm. *Sepilok Bulletin*, **13** & **14**, 33-42.

[4] Hairiah, K., Dewi, S., Agus, F., Velarde, S., Ekadinata, A., Rahayu, S. & Noordwijk, M. V. (2011). Measuring carbon stocks across land use systems: A manual. Bogor, Indonesia. World Agroforestry Centre (ICRAF), SEA Regional Office, 154 pages.

[5] Hiratsuka, M., Chingchai, V., Kantinan, P. A., Sirirat, J., Sato, A., Nakayama, Y. & Morikawa, Y. (2005). Tree biomass and soil carbon in 17-and 22-year-old stands of teak (Tectona grandis Lf) in northern Thailand. *Tropics*, **14** (4), 377-382.

[6] Houghton, R. A. & Hackler, J. L. (1999). Emissions of carbon from forestry and land-use change in tropical Asia. Global Change. *Biology*, **5**, 481–492.

[7] Malhi, Y., Roberts, J. T., Betts, R. A., Killeen, T. J., Li, W. C. & Nobre, A. (2008). Climate change, deforestation, and the fate of the Amazon. *Science*, **319**, 169–172.

[8] Moore, C. (2012). *Carbon Stocks of Agroforestry and Plantation Systems of Leyte Island, the Philippines* (http://enrdph.org/wp-content/uploads/2014/08/Carbon_Stocks_Leyte_Agroforestry_Plantations.pdf). Assess on 30 March 2016.

[9] Sharma, A., Singh, R. P. & Saxena, K. (2011). Performance of teak (Tectona grandis Linn. F.) in sole and agroforestry plantation on wheat fields in Eastern Uttar Pradesh. *Research Journal of Agricultural Sciences*, **2**(2), 244-247.

[10] Suardi, H., Besar, N. A., Mui-How, P. & Mokhtar, M. (2016). Carbon stock estimation of agroforestry ststem in Tawau, Sabah. *Transaction on Science and Technology*, **3** (1), 25-30.

[11] Takimoto, A., Nair, P. R. & Alavalapati, J. R. (2008). Socioeconomic potential of carbon sequestration through agroforestry in the West African Sahel. *Mitigation and Adaptation Strategies for Global Change*, **13** (7), 745-761.

[12] Unruh, J. D., Houghton, R. A. & Lefebre, P. A. (1993). Carbon storage in agroforestry: An estimate for sub-Saharan Africa. *Climate Research*, **3**, 39-52.

ISSN 2289-8786. http://transectscience.org/