ABOVE AND BELOWGROUND CARBON STOCK OF *ACACIA MANGIUM* STAND IN SABAH, MALAYSIA

Tan Chun Hung 1 , Normah Awang Besar 1* , Mohamadu Boyie Jalloh 2 , Maznah Mahali 1 , Nissanto Masri 3

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

2 Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Jalan Sungai Batang, Mile 10, 90000, Sandakan, Sabah, Malaysia.

3 Sabah Forest Development Authority (SAFODA) Jalan Gaya, Wisma Perkasa, 88000 Kota Kinabalu, Sabah, Malaysia

*Corresponding author: normabr@ums.edu.my

ABSTRACT. This study aimed to estimate above and belowground carbon stock in *Acacia mangium* stands of different silvicultural systems (planted and regeneration) at the Bengkoka Forest Plantation, Pitas, Sabah, Malaysia. Aboveground biomass (AGB) and belowground biomass (BGB), and soil organic carbon content (SOC) at depth of 30 cm were quantified. A comparison was done between the two different silvicultural systems of *Acacia mangium*. A random systematic sampling method was used for conducting the forest inventory. Three circular plots of 0.25 ha were established in each of the *Acacia mangium* systems. Diameter at breast high (DBH) of every tree was measured using a diameter tape. Shrub layer and organic layer were measured at five randomly selected positions in each plot. Five litter fall traps (1m x 1m) were set up in the same position as the shrub and organic layer. Three holes (25 cm x 25 cm x 30 cm) were dug to get the roots for quantifying the roots biomass and soil for carbon content. The soil bulk density was determined by using undisturbed soil samples collected by using 51 mm diameter ring (100 cc.). The results showed that the total amount of carbon stock was 73.56 t ha^{-1} and 82.40 t ha^{-1} for planted and regeneration stands, respectively. The study revealed that the major contributor to total carbon stock for both planted and regeneration *Acacia mangium* stands was the aboveground biomass with mean values of 46.99 t ha^{-1} and 53.83 t ha^{-1} followed by belowground biomass with mean values of 26.57 t ha^{-1} and 28.57 t ha^{-1}, respectively.

KEYWORDS: *Acacia mangium*, aboveground biomass, belowground biomass, carbon stock, soil organic carbon

INTRODUCTION

Plantation forestry has been considered an effective medium for removing carbon dioxide (CO_2) from the atmosphere and sequestering it in trees through the process of photosynthesis by fixing carbon in aboveground and belowground biomass (Ogawa *et al*, 2005). Conversely, the carbon fixed in trees could be released to the atmosphere by various means of forest degradation (Hall and Uhlig, 1991; Houghton, 1991; Fearnside, 1996; Houghton *et al.*, 2000). Apart from producing wood for industries, *Acacia mangium* plantation forests also play a role in providing environmental services such as carbon sequestration due to the high growth rate of this species. Due to opportunities to sell the carbon sequestered during afforestation or reforestation for climate change mitigation, information on the capacity of *Acacia* *mangium* plantation forests to sequester carbon in various environmental conditions is needed (Herdiyanti and Sulistyawati, 2010).

Forest plantations increased from 180 million ha in 1990 to 264 million ha in 2010, and occupied about 7% of the world total forest area of 4 billion ha (FAO, 2011). The World's industrial round wood consumption has been rising annually, reaching 1.54 billion m^3 in 2008 (FAO, 2011). According to the State of the World's Forest 2011 report, forest plantations in the Asia-Pacific region have increased by 29.33 million ha in the last decade contributing 16% of forested area in the region and supplying 10% of total wood resources in this region (FAO, 2011). In South-East Asia, planted forests increased by about 2.8 million ha over a 10-year period (2001-2010), an annual increase of 2.16% (FAO, 2011).

Global climate change has inspired an increasing interest of scientific and political communities to conduct global carbon storage and carbon balance studies (Landsberg et al. 1995; INBAR, 2006). Several 'no regret' policies and forest management practices have been considered to address the impacts of climate change (Ravindranath, 2006). It is also essential to evaluate the role of *Acacia mangium* as an effective atmospheric CO_2 mitigator (Arun et al., 2009).

Forests have the potential to be managed to reduce atmospheric concentrations of CO_2 and thus mitigate climate change. Forest management practices that meet the objectives given above can be grouped into three categories based on how they are viewed to curb the rate of increase in atmospheric CO_2 including the management for C conservation, C storage, or C substitution (Brown et al ., 1996).

The objectives of this study were to: 1) Quantify the aboveground biomass (AGB) and belowground biomass (BGB), 2) Determine the soil carbon stocks in the forest plantation areas, 3) Quantify carbon content in AGB and BGB, 4) Comparison of carbon pools in 6 years old planted and regeneration blocks of *Acacia mangium* plantation ecosystems.

METHODOLOGY

The study was conducted in an *Acacia mangium* plantation forest at the Bengkoka Forest Reserve. The forest reserve is located within the Pitas district, Sabah, Malaysia. The coordinates of the study site are N 06°49'47.2" and E 117°09'019". The land belongs to Sabah Forest development Authority (SAFODA) and is managed by Hijauan Bengkoka Plantation Sdn. Bhd.

The study area was situated on a hillside approximately 30-90 m above sea level and is gently undulating. The climate in Bengkoka, Pitas is hot and wet all-year-round consistent with Sabah's climate. The average annual rainfall for over a 10-year period (2001-2010) was 2431.80 mm with a mean monthly rainfall of 202.65 mm. The dry periods occurred between March-April and the wet periods from December to January. Temperature was generally high all year round, ranging from 25°c to 32°c. Mean average Relative Humidity at noon was up to 83.1 (Department of Statistics Malaysia, 2011). The texture of the soil in the planted sites consists of 40-60% of clay. The soil is classified as Kumansi Family according to the Sabah Classification System (Acres *et al.*, 1975), which is equivalent to Typic Tropudult in the USDA soil taxonomy system and Ortic Acrisol based on FAO classification.

The experiment was conducted within a six-year-old planted and six-year old naturally-regenerated *Acacia mangium* stands. The *Acacia mangium* trees in the first treatment area of 25.4 ha were planted in 2004 at a planting distance of 2 m x 4 m. The stand had been thinned and climber-cut once in 2006.

The naturally-regenerated *Acacia mangium* stand of 28.8 ha was located next to the planted stand. The stand was harvested in 2004.

A forest inventory was carried out to determine the total living tree biomass in the *Acacia mangium* stands. Three circular plots of 2500 m^2 (radius=28.21 m) were established in each stand in the study site. The plots were chosen randomly at a distance of 10 m from the road and the border. Each plot in both planted and naturally regenerated stands was 10 m away from each other. Sampling and measuring of plant and soil biomass were conducted within these plots at the respective sites. The biomass of living trees was quantified within the inventory plot. The DBH of *Acacia mangium* trees were measured using diameter tape. Five sub-plots of 1 m X 1 m were randomly chosen for the sampling of shrub layer, organic layer, and litter fall.

In each plot, tree biomass was estimated using an allometry equation (Equation 1) specifically developed for *Acacia mangium* (Heriyanto, 2005).

$AB = a (D^2)^{b}$ ……………………Equation (1)

Where:

Parameter, a = 0.0528 Parameter, b =1.3612, AB = biomass of the stem, D = DBH

The diameter measurements for all stands were done at breast height (DBH). Subsequently, the biomass values were converted into carbon by using a conversion factor of 0.5 (Brown, 1997; Hamburg, 2000).

The biomass of roots, litter fall, shrub layer and organic layer was estimated through destructive sampling whereby the vegetation in the sampling areas were cut and weighed (fresh weight), and the subsamples were dried at 70^{o}C for 72 hours and weighed. The shrub layer used as sample was all live tree specimens with a diameter of less than 5 cm. The organic layer was the remainder of litter on the surface after shrub layer had been accounted for. Litter traps were set up with nylon mesh (8 mm netting size) in each sub-plot and collected monthly for 12 months. For the calculation of carbon stock in the living tree biomass, roots, litter fall, scrub layer and organic layer , the carbon content is assumed to have 50% carbon components (Heriyanto, 2005)

Mixed soil samples were also collected from three locations at random to depths of 0-5 cm, 5-10 cm and 10 -30 cm for carbon content analysis (% C). Undisturbed soil samples were collected for each layer by using diameter rings (10 cm diameter and 100 ml) for bulk density analysis (DIN 19683-2). Soil carbon stock was estimated based on the soil carbon content and soil bulk density.

The total soil organic carbon (SOC) pool was calculated using the thickness of soil horizons, the bulk density (g cm^{-3}) of the different soil layers (0-5, 5-10, and 10-30 cm) and the carbon content of the soil at the horizon depth. The carbon content (C%) of soil and litter materials was determined using the Walkley and Black method (Allison, 1965).

Total carbon stocks comprised the sum of carbon stock from all components, i.e. above ground living tree, belowground living tree (roots), shrub layer, organic layer, litter fall, and soil carbon content (0-30 cm).

RESULTS AND DISCUSSION

The number of *Acacia mangium* trees at the planted sites and naturally-regenerated sites were 890 tree.ha^{-1} and 1016 tree.ha^{-1}, respectively. The total tree biomass was 91.24 t ha^{-1} in the planted block and 104.7 t ha^{-1} in the regeneration sites. The most abundant biomass was 25 cm and above diameter and the least was 0-5 cm in both sites. The tree biomass distribution according to DBH classes is as shown in Figure 1. Aboveground and belowground biomass for shrub, organic layer, litter fall and roots are shown in Figure 2.

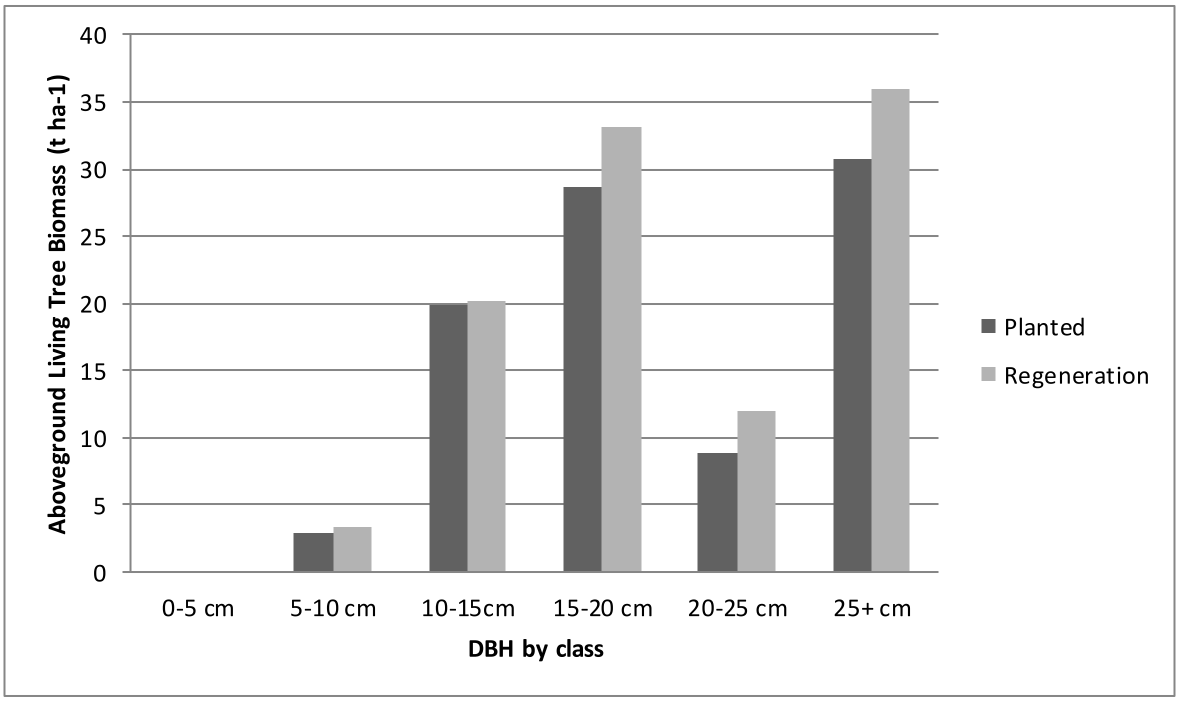

Figure 1: Living tree biomass distribution according to DBH classes

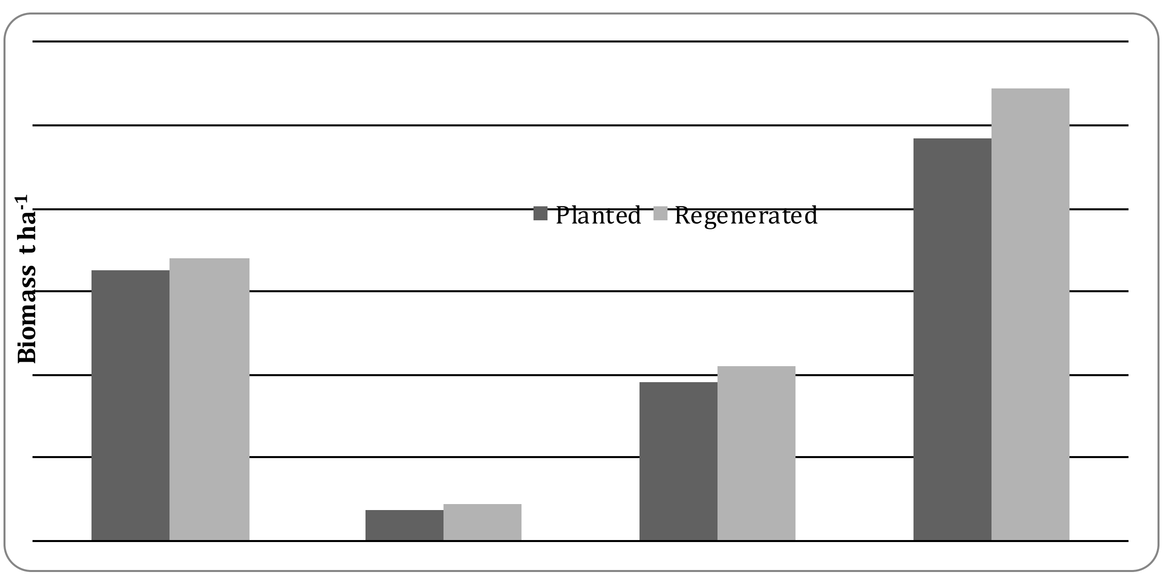

Figure 2: Roots, shrub, organic layer and litter fall biomass in planted and Regenerated study site

The estimated tree biomass of both planted (91.24 t ha^{1}) and naturally-regenerated (104.7 t ha^{1}) stands were higher comparing to the study by Heriansyah *et al.* (2007) who reported that a 5 years old stand biomass was 30.0 t ha^{1} in West Java and 5.5 years old stand was 82.11 t ha^{-1} in South Sumatra. The higher stand density in this study could be the reason why the tree biomass was higher compared to that reported by Heriansyah *et al.* (2007).

Heriansyah *et al.* (2007) also recommended thinning for increasing the growth rate and yield of trees, and longer rotation was available to enhance wood quality and wood utilization. Unthinned *A. mangium* plantations in South Sumatra were capable of accumulating higher volume and biomass per hectare, suggesting that maximum productivity was reached at a younger age despite differences in initial spacing. The study in an un-thinned plantation in South Sumatra recommended a rotation of six years to maximize total biomass accumulation and a rotation of eight years was recommended to maximize benefits.

Lim (1986) estimated that the tree biomass in a 4.5-year-old *A.mangium* stand in Sarawak was 82.1 t ha^{-1}. The stand density was 1084 trees ha^{-1} with DBH ranging from 4.3 cm to 24.2 cm and averaged 14.3 cm. According to Lim (1986), the high productivity of the *A.mangium* in the study plots was due to regular application of fertilizer to the intercropped cocoa trees planted. This confirmed the reported inherent capacity of the species for rapid growth and its ability to overcome competition from other plants. The planted and naturally-regenerated stands in this study consist of fewer trees per hectare compared to the study by Lim (1986) but resulted in higher in biomass. This was because the diameters of the *Acacia mangium* tree in this study were bigger, ranging from 3.5 cm to 39.3 cm and averaged at 14.2 cm.

Total biomass of shrub layer for the planted plots were 0.73 t ha^{-1} and 0.87 t ha^{-1} for the naturally-regenerated sites. In all the study sites, it was found that the canopy of the trees were quite dense which intercepted most of the sunlight with little reaching the ground.

Most of the shrub layer in the study sites had large amounts of lalang (*Imperata cylindrica*) because the study area was minimally disturbed (planted) or undisturbed (naturally-regenerated) before planting. The biomass of the shrub layer in the naturally-regenerated stand was also higher compared to the planted site despite thinning and climber-cutting of the site being done only once throughout the 6 years period. No weeding was done in both the planted and naturally-regenerated plots. It is worth noting that *Imperata cylindrica* could easily adapt to a wide range of soil conditions and its seeds are easily dispersed by wind.

An organic layer is the layer on the soil surface, which usually consists of the organic materials, such as the tree branches, leaves, tree bark, flowers, seeds, and other tree residuals that fall on the forest ground (Young & Giese, 1990). Organic material plays a vital role in the soil as it is a source of nutrients for the trees, and also helps in increasing the soil porosity and aeration of the soil.

The organic layer in the planted plot contributed 3.83 t ha^{-1} of biomass, and it was higher in the naturally-regenerated plot where the organic layer contributed 4.20 t ha^{-1} of biomass to the plantation ecosystem.

Total litter fall biomass collected in current study in this planted site was 9.7 t ha^{-1} yr^{-1} and 10.9 t ha^{-1} yr^{-1} in the naturally-regenerated site. The amount of litter fall collected was higher in the naturally-regenerated site because of the higher number of trees in the regenerated site compared to the planted site.

A study of 4-years-old *A.mangium* plantation in Kemasul Forest Reserve showed that the litter production was 10.2 t ha^{-1} yr^{-1} with leaf litter making up 87.4% of the total (Lim, 1988). The findings are consistent with the results of this study.

The total roots biomass collected in this study was 6.5 t ha^{-1} and 6.8 t ha^{-1} in the planted and naturally-regenerated plots respectively. A study of a natural forest in Central Sulawesi, Indonesia showed that the total root biomass in the area was 2.1 t ha^{-1} (Hertel *et al*, 2009). The results were lower than the planted and naturally-regenerated block in this study. The findings also suggest that the influencing factor of the total roots biomass was the roots reserve belowground.

The total aboveground carbon pools consisting of the aboveground living trees, shrub layer, organic layer and litter fall was 46.99 t C ha^{-1} for the planted plots, and 53.83 t C ha^{-1} for the naturally-regenerated plots (Figure 3, Table 1 and Table 2).

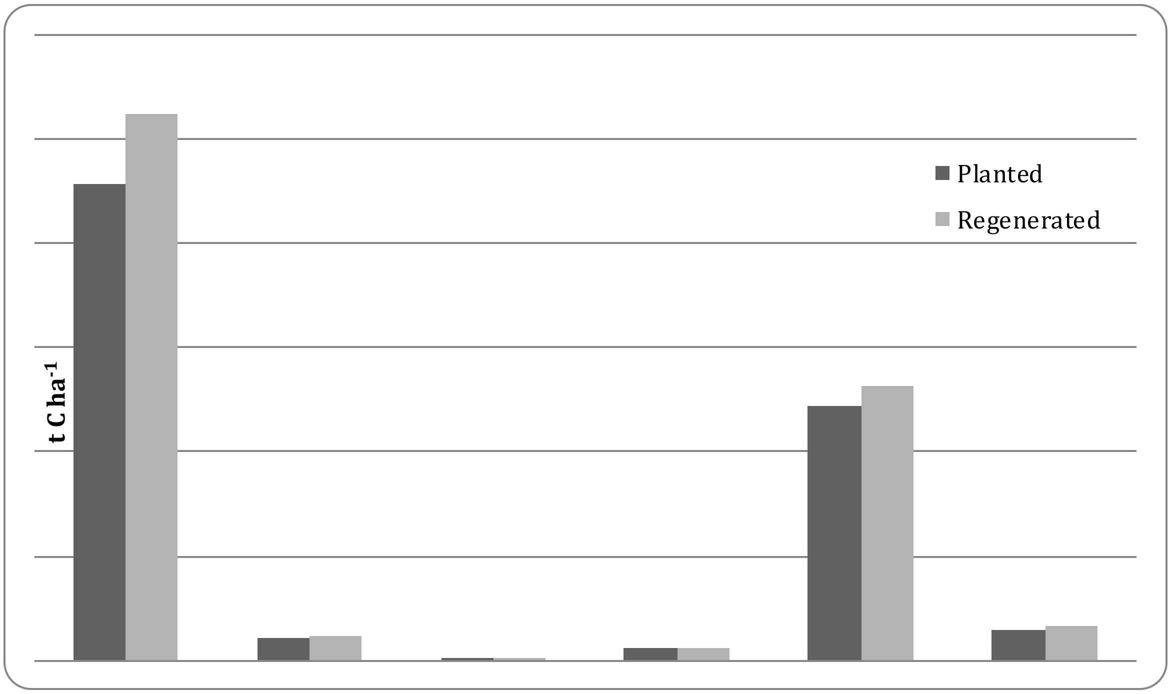

Figure 3 : Distribution of C stock by components: living trees, roots, scrub, organic layer, soils and litter fall (t C ha^{-1})

Table 1 : Carbon Stocks in living tree biomass, shrub layer, litter fall, organic layer under planted and naturally-regenerated Stands.

Study Site	Carbon Stocks (t C ha^{-1})						Total Carbon
	Living Tree			*Shrub Layer	Litter Fall (yr^{-1})	Organic Layer (Leaves, fine wood debris, and rest)	
	Total Above Ground Tree Biomass (Branches , Stem and Leaves)	*Roots (coarse and fine)	Total				
Planted	45.62	2.17	47.79	0.22	2.95	1.15	52.11
Naturally-regenerated	52.35	2.27	54.62	0.26	3.24	1.22	59.34

*shows that there was significant difference across the group (p <0.05)

The total belowground carbon pools consisting of the roots (BGB) and soil organic carbon (SOC) for the planted and naturally-regenerated stands was 26.57 t C ha^{-1} and 28.57 t C ha^{-1} respectively (Table 1 and Table 2). The total carbon (TC) was 73.56 and 82.40 t C ha^{-1} for the planted and naturally-regenerated stands (Table 3).

Table 2: Soil Organic Carbon in Planted and naturally-regenerated Stands

Depth (cm)	Horizon Thickness (cm)	Bulk Density (g cm^{-3})	Carbon Content of the soil at the horizon depth (%)	Total SOC Stocks (t C ha^{-1})
Planted Stand				
0-5	5	1.14	1.79	10.2
5-10	5	1.14	1.11	6.3
10-30	20	1.31	0.30	7.9
Total				**24.4 (±0.71)**
Naturally-regenerated Stand				
0-5	5	1.16	1.98	11.5
5-10	5	1.15	1.20	6.9
10-30	20	1.28	0.31	7.9
Total				**26.3(±1.13)**

Table 3: Total Carbon Stocks of Planted and Naturally-regenerated Stands

Plantation Sites	Carbon Stocks (t C ha^{-1})	
	Planted	Naturally-Regenerated
Aboveground:		
1. Aboveground Living Tree	45.62	52.35
2. Shrub Layer*	0.22	0.26
3. Organic Layer on Soil Surface	1.15	1.22
4. Total Above Ground	46.99	53.83
Belowground:		
5. Roots (Coarse +Fine)*	2.17	2.27
6. Soil Organic Carbon (SOC) 0-30 cm	24.4	26.3
7. Total Belowground	26.57	28.57
Total Carbon		
8. Total Living Tree (1+5)	47.79	54.62
9. Total Carbon (TC) (4+7)	73.56	82.40

*shows that there was significant difference across the group (p <0.05)

Potvin et al. (2011) in their study on carbon pools in a tropical tree plantation reported that the carbon pool in the topsoil (0-10cm) was 34.5 t ha^{-1} in 2001 and decreased to 25.7 t ha^{-1} in 2009. The findings of Potvin et al. (2011) indicated higher carbon content compared to this study, with a topsoil (0-10 cm) carbon content of 16.5 t ha^{-1} in the planted plots and 18.4 t ha^{-1} in the naturally regenerated sites. These differences could be attributed to the different soil properties in both studies, although the report of Potvin et al. (2011) did not include results of the soil properties of the study area. Zhao *et al.* (2006) suggested that the total SOC was significantly related to the clay content of soils.

The pattern of carbon stock accumulation in *Acacia mangium* in this study is comparable with research conducted in West Java, Indonesia by Herdiyanti and Sulistyawati (2010), who found that the *Acacia mangium* tree carbon stock (AGB and soil) for 5 years old and 7 years old stands were 72.88 t ha^{-1} and 77.81 t ha^{-1} respectively.

CONCLUSION

The Total Carbon stocks (TC) for both planted and naturally regenerated sites were 73.56 t C ha^{-1} and 82.40 t C ha^{-1} respectively. There were no significant difference between the planted and the naturally regenerated sites. The living trees in the plantation site are the major contributor to the total ecosystem carbon pools followed by the soil, litter fall, organic layer, and the shrub layer.

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