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Carbon stock in topsoil, standing floor litter and above ground biomass in *Tectona grandis* plantation 10-years after establishment in Ile-Ife, Southwestern Nigeria

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ABSTRACT

This paper provides information on carbon stock at the habitat level in the above ground biomass (ABG), standing floor litter and soils in a 10 year-old *Tectona grandis* plantation following restoration of a degraded secondary forest at Obafemi Awolowo University, Ile-Ife Nigeria. Four sample plots 25 m x 25 m, two in *Tectona grandis* plantation and two in a nearby degraded secondary forest were studied. Soil samples were randomly collected at 0-20 cm and bulk density determined. Standing floor litter was randomly collected at five points every three months for one year, sorted into different litter components. Soil and standing floor litters carbon concentration and C stock were determined. Above ground biomass (ABG) and carbon stock were significantly ($p=0.003$ and $p=0.0001$) higher in the plantation, the order is ABG > soil > standing floor leaf litter > standing floor wood litter. Soil C stock varies from 10.47 t ha^{-1} in the plantation to 10.58 t ha^{-1} C in the forest. Above ground biomass, standing leaf and wood litter were estimated as 18.26-5.81, 0.49-0.36, 0.06-0.08 t ha^{-1} C, respectively (plantation to secondary forest). Reforestation after 10 years has increased C stocks by 45% in ABG in the plantations.
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Keywords: Carbon stock, degraded forest, plantation, reforestation, standing litters.

INTRODUCTION

Forests form an active carbon pool that accounts for 60 per cent of carbon storage in the earth's land surface (Wilson and Daff, 2003). Forests contain about 80% of global terrestrial above-ground carbon stocks (biomass), and play an important role in the global carbon cycle (Houghton, 2005). Tropical forests have also been reported to be a strong carbon sink (Stephens et al., 2007) and contributed about one fifth of total anthropogenic CO_2 emissions to the atmosphere through tropical deforestation (Houghton et al., 2007). Despite the above mentioned importance of forest, the forest is being continuously destroyed at a very fast and alarming rate (Pimm et al., 1995). More than 50% of the tree cover has disappeared due to human activities mainly through forest vegetation removal (Kaewkrom et al., 2011). This forest destruction in particular deforestation, is driven by a wide variety of human activities including farming, population growth, bush burning, fuel wood

collection, commercial purposes, illegal logging, urbanization, transmigration programs, road construction, mining, and hydropower development (Kaewkrom et al., 2011). Management of forests as carbon reservoirs have become an important component of broader environmental practices aimed at the protection of biological, soil, water, and air resources. It has been pointed out by many studies that reduction in forest harvesting, skilful management of forest and agro forestry systems, as well as restoration and management of degraded forest lands has potential for the conservation and sequestration of carbon (Dixon et al., 1993). Afforestation is one of the viable options of carbon sequestration in terrestrial ecosystem (Fang et al., 2001). It is recognized as major sink for carbon as well as accumulating carbon above ground, thus making significant contributions to soil carbon even in dry lands (Silver et al., 2000). Depending on the type of vegetation, terrestrial ecosystems could be a source or a sink for atmospheric CO_2 (Guo and Gifford, 2002). Forest and plantation ecosystems management practices can play a significant role in climate change mitigation by sequestering carbon through photosynthesis (Watson et al., 2000; Guariguata et al., 2008; Strassburg et al., 2009). Several studies have been conducted to explore the effect of plantations on ecosystems carbon and nitrogen stock. Post and Kwon (2000) reported that although there is much variability in rates of carbon addition, conditions generally favor increases of soil organic carbon when cultivated soils are converted to perennial vegetation, such as forest or grassland. Guo and Gifford (2002) summarized data from 74 studies that analyzed land uses change on soil carbon stocks and found that when cropland changed to plantation and secondary forest, soil carbon stocks increased by 18% and 53%, respectively, making them to conclude that cropland conversion to forest will result in partial to complete recovery in soil carbon. Redondo-Brenes and Montagnini (2006) have also pointed out that even though in

reforestation projects carbon sequestration may be a secondary objective, the use of mixed plantations with species of different rotation times may allow the system to retain the carbon for longer periods of time than in a monoculture and that species in mixed plantings had higher values of carbon sequestration than the pure plantings in two out of three groups of plantations. Zheng et al. (2008) in their study on the dynamics of ecosystem carbon allocation as affected by different forest management practices, measured the above-and belowground biomass accumulation over 14 years, as well as the tissue carbon concentrations of trees in three monospecific plantations and reported that natural restoration is a superior approach for increasing the carbon storage potential in the hilly red soil region in reforestation projects compared to plantations. Berthrong et al. (2009) found a significant decrease in soil organic C and N with *Pinus* afforestation, but not with other species (Eucalyptus, angiosperm, conifers), and based on their results and a review of other literature, it was suggested that proper site preparation and sustainable harvest practices, such as avoiding the removal or burning of harvest residue, could minimize the impact of afforestation on soils. As part of the effort to re-claim and restore part of the destroyed rich natural forest at the Obafemi Awolowo University Estate, Ile-Ife, Nigeria, wide-scale planting of *Tectona grandis* species among other tree crops species was embarked upon ten years ago (2001) across the University estate. The establishment of *Tectona grandis* plantation looks successful going by the stand of trees that thrived within the University estate, however, no conscious effort has been undertaken to assess the impact of the reforestation activities ten years after on both soil and aboveground biomass carbon stock in this ecosystem. The ten year period was chosen so that we can have gradual information on the impact of afforestation on the nutrients level including carbon content and also to serve as a basis for future comparisons. This study therefore specifically

evaluated the carbon stock in the soil, standing floor litter and in the aboveground biomass as affected by reforestation with *Tectona grandis* after 10 years of planting. This was done with the intention of providing information on the benefit or otherwise of re-forestation with *Tectona grandis* plant on a degraded soil about carbon stock in the soil, standing floor litter and in the above ground biomass in other to increase the understanding of carbon fixation and storage in plantation ecosystems in Nigeria.

MATERIALS AND METHODS
Study Area
The study was conducted at the Obafemi Awolowo University Estate, Ile-Ife, Osun state, Nigeria. Ile-Ife is located on Latitude N 07^0 31.311' and Longitude E 004^0 30.983' and the elevation of Ife ranges from 215 m to 457 m above sea level (Hall, 1969). The study sites lies between Latitude N $007^0$32' and Longitude E $004^0$31' while the elevation ranges from 243 m to 274 m above the sea level. The study sites are shown in figure 1. The climate of the area is a tropical type with two prominent seasons, the rainy and the dry season. The dry season is short, usually lasting 4 months from November to March and the longer rainy season prevails during the remaining months. The annual rainfall average 1413 mmyr^{-1} in a 5-year survey and it showed two peaks, one in July and the other in September, the mean annual temperature range from 22.5 ^{0}C to 31.4 ^{0}C (Duncan, 1974). The soil of the area is derived from material of old basement complex which is made up of granitic metamorphosed sedimentary rock (Hall, 1969). Five major soil types have been recognized in this area: inselberg soils, Hill creep soils, and sedimentary non-skeletal soils, drift soils, alluvial deposits (Hall, 1969). The soil has been classified as lixisols and utisols (FAO/UNESCO, 1974). The original vegetation of Ile-Ife is lowland rainforest as climax vegetation (Keay, 1959). White (1983) described the vegetation as the Guinea-Congolian drier forest type. Most of the original lowland rain forests have been massively destroyed leaving remnant of secondary forest scattered around. Tree crops plantations like *Theobroma cacao, Cola nitida, Tectona grandis,* and *Elaeis guineensis* are now common around the area. The *Tectona grandis* plantation was established in remnant of degraded secondary forest and farmland within the area of the University estate. The seedlings were first raised in the black plastic polyethylene bags at the nursery and later transplanted to the field. The seedlings were planted in August, 2001 (raining month) in the field with a spacing of 2.44 × 2.44 m. Intensive weeding was done during early establishment of the plantation (1-2 years), since the plantation is a light demanding species and its growth development is reduced sharply under poor light conditions and the plantation was never thinned.

Data collection and laboratory analysis
Sampling procedure
Four sample plots each of 25 m x 25 m were used for this study, two plots in the *Tectona grandis* plantation and the other two in a nearby degraded secondary forest. The plots were laid out with a measuring tape and demarcated by narrow cut-lines.
Soil sample collections
Soil samples were randomly collected at five points within each plot at the depth of 0-20 cm using soil auger. The first round of soil sampling took place during the dry season in March, 2011 and the second one in August (rainy season). We concentrated our sampling on the surface soil and standing floor because it was speculated that any differences among the plantation and the degraded forest would be most evident in these locations. Each soil sample was air-dried, passed through a 2 mm sieve, and analyzed for total organic carbon at International Institute for Tropical Agriculture (IITA), Ibadan using automated and semi-automated methods for soil described by Tel and Rao (1982). Soil bulk density measurements are needed to convert soil carbon concentration i.e., mass carbon per unit

mass soil into inventories or storage i.e., mass per unit area. The bulk density was estimated by inserting a fixed-volume steel ring into the soil at five randomly located points in each plot at 0-20 cm. The rings were excavated; soil samples were removed from them, dried at 105°C for 48 hours, and then weighed (Blake and Hartge, 1986). The mean bulk densities from these collected soil samples per depth were used to estimate soil carbon stock at 0-20 cm in the degraded secondary forest and plantation.

Standing floor litter Collection

To quantify standing floor mass, standing floor litter were randomly collected at five points using a 50 cm x 50 cm quadrat size, all the standing floor litter inside the quadrat was collected. This was separated into leaves, wood, reproductive organs (flowers and fruits) and thrash (those that cannot be easily classified into any of the above components), and oven dried at 60 °C weighed and grounded with three replicates per plot. The ground leaf and wood standing floor litter components were analyzed to determine organic carbon at International Institute for Tropical Agriculture (IITA), Ibadan using automated and semi-automated methods for soil analysis described by Tel and Rao (1982). The reproductive and trash components were discarded because they were very small.

Estimation of above ground biomass and carbon stock

Aboveground biomass (AGB) and its existing carbon stock were estimated in both *Tectona grandis* plantations and the degraded secondary forest. All trees with diameter at breast height (DBH) greater than 0.1 m were enumerated, measured, and classified. Ravi's altimeter was used to measure tree height and AGB for the tree species strata was estimated from measured diameter at breast height (DBH) and tree height using a generalized tree biomass regression for the specific precipitation zone (Brown, 1997):

$$Y = \exp(-3.1141 + 0.9719 \ln(DBH^2 \times H)$$

Where Y is the aboveground biomass in kg; DBH, diameter at breast height in cm; H is the height of tree in m and this was converted to t ha^{-1} by multiplying by 0.001.

Standing floor litter stocks were calculated in both the plantation and degraded secondary forest by multiplying the concentrations of total C with the corresponding dry weights and converted to t ha^{-1}. Soil C stock was computed by multiplying the concentration of total C by bulk density and the corresponding depth at which the sampling was done. Carbon stock of AGB was calculated by the conversion factor 0.5 (Atjay et al., 1979; Brown, 1997; Brown and Lugo, 1982; Dixon et al., 1994).

Statistical Analysis

The statistical significant differences in carbon stock in above ground biomass, soil, and standing floor litter were compared between the *Tectona grandis* plantation and the degraded forest using a T-test of an unequal samples size and the significant means were separated using Tukey's pair-wise comparison. The statistical package used is SPSS software, Model 13.0 and the level of testing significance was set at 0.05%.

RESULTS

In the present investigation, AGB analysis using DBH and height of trees yielded different size classes of trees. In general, DBH of tree in class size 31-60 cm (70%) was found dominant in the plantation, while 0-30 cm (80%) was dominant in the degraded secondary forest (Figure 2). Tree height recorded is in the range of 6.7 to 9.1 m and 3.1 to 10.5 m in the plantation and the degraded secondary forest respectively. Aboveground biomass ranged from 38.33 t ha^{-1} in the plantation vegetation to 16.19 t ha^{-1} in the degraded secondary forest. Carbon stock in AGB varied between 19.16 t C ha^{-1} in the plantation to 8.10 t C ha^{-1} (Table 1). Carbon held within total aboveground biomass is higher in the plantation compared with the degraded secondary forest (Table 1).

Standing floor leaf litter nutrients

The results showed that carbon stock in the standing floor leaf litter was significantly (p=0.030) different, carbon stock being lower (0.361 t ha^{-1}) in the *Tectona grandis* plantation compared to (0.467 t ha^{-1}) in the degraded secondary forest (Table 2). The same trend was observed in the standing floor wood litter, where C stock was significantly (p = 0.002) lower in the plantation with 0.06 t ha^{-1} compared to the degraded forest with 0.08 t ha^{-1} (Table 2).

Soil nutrients

Result from this study showed that the bulk density values ranges from 0.74 g cm^{-3} in the plantation to 0.77 g cm^{-3} in the degraded secondary forest and there was no significant (p=0.330) difference in bulk density between the two areas. Soil carbon stock was not significantly different (p = 0.26) (Table 3). Generally it is clear from this study that carbon stock recorded is in the order of above ground biomass > soil > leaf litter > wood litter.
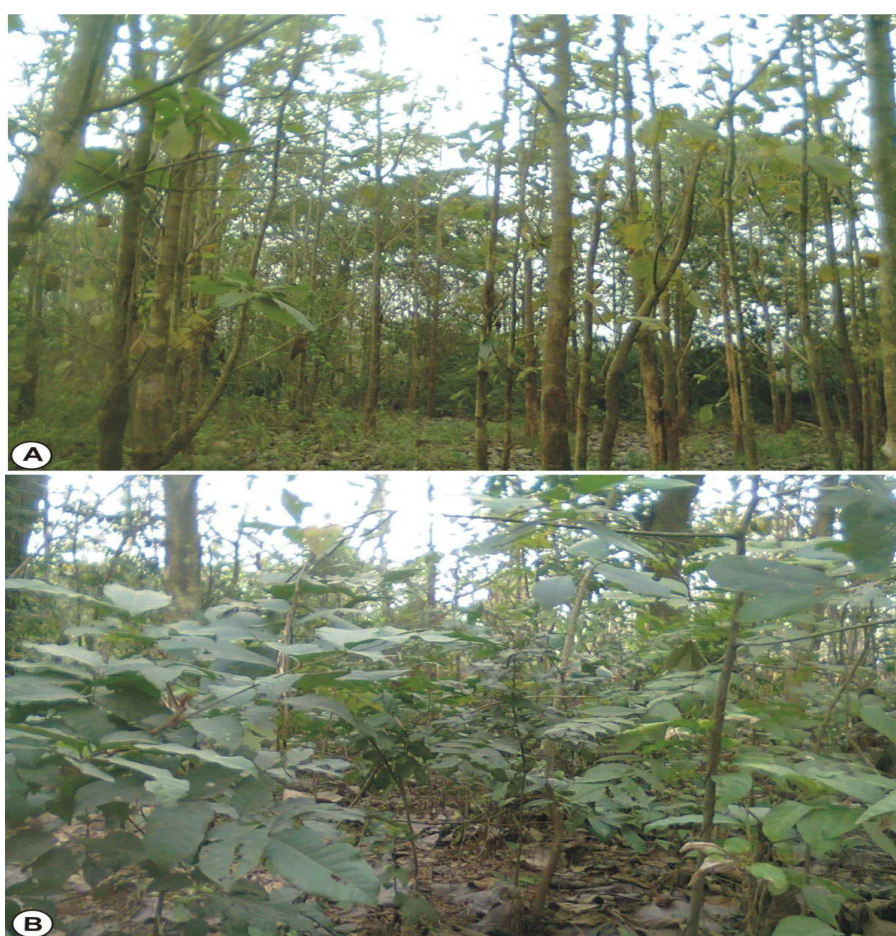

Figure 1: shows (A) = *Tectona grandis* plantation ; (B) = Degraded secondary forest in Ile-Ife, Southwestern Nigeria.
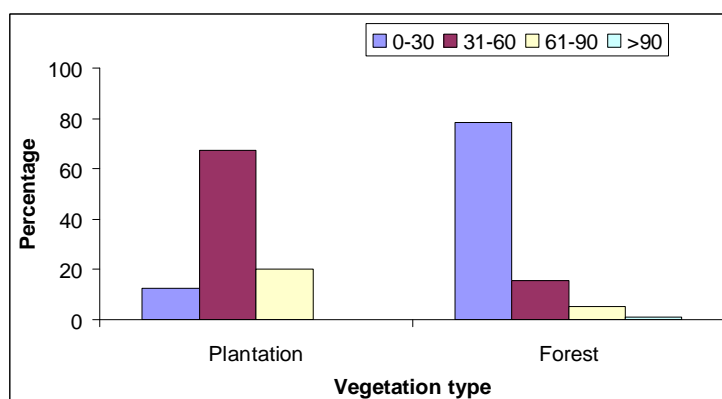
Figure 2: Distribution of above ground biomass (percentage) with respect to diameter at breast height across the plantation and the degraded forest.

Table 1: Above ground biomass and carbon stock in *Tectona grandis* plantations and degraded secondary forest (± Standard error of the mean), n: number of trees in the study sites.

Vegetation type	Above ground biomass t ha^{-1}			Total carbon stock t ha^{-1}
	Maximum	**Minimum**	**Mean ± std. error**	
Plantation	62.07	21.74	38.33±0.40	20.08±0.20
Re-growth forest	20.92	3.71	16.19±0.09	8.10±0.05
Difference between the sites	41.15	18.03	22.14	11.98
p-value				0.0003***

Significant differences across the row between plantation and degraded secondary forest are indicated in bold at 0.001% alpha level.

Table 2: Standing floor litter carbon stock in the *Tectona grandis* plantation and degraded secondary forest. Results are presented as mean and standard error of the mean.

Standing floor carbon stock		Plantation	Re-growth Forest	Difference between the sites	p-value
Leaf litter	Maximum	0.102	0.213	0.11	
	Minimum	0.467	0.73	0.26	
	Mean ± std. error	0.361±0.03	0.467±0.04	0.11	0.002**
Wood litter	Maximum	0.012	0.09	0.08	
	Minimum	0.075	0.169	0.094	
	Mean ± std. error	0.059±0.01	0.079±0.02	0.02	0.030*

Significant differences between plantation and degraded secondary forest are indicated in bold at *0.05% and **0.001% alpha level. std. error = Standard error.

Table 3: Soil carbon stock measured across the study sites. Results are presented as mean and standard error of the mean.

Soil carbon stock	Maximum	Minimum	Mean ± std. error	p-value
Plantation	15.30	3.56	10.47	P=0.26
Re-growth forest	12.36	2.78	10.58	

Significant differences between plantation and degraded secondary forest are indicated in bold at 0.05% alpha level.

DISCUSSION
Above ground biomass and carbon stock

Disturbances can disrupt the C cycle through direct effects on tree biomass, the age-class distribution of the forest shifts to younger stands containing less C as observed in the degraded forest where the Dbh 0-30 cm was the dominant size class (Lindenmayer and Franklin, 2000) and soil organic matter decomposition (Didham, 1998) and therefore, leading to reduction in C stocks. The result of lower size (0-30 cm) class being dominant in the degraded forest illustrates the important contribution of small tree to above ground biomass and the lower biomass densities might indicate that the site is highly disturbed, and is just undergoing succession process. The dominant of 31-60 cm girth size in the plantation could be because the trees were planted at the same time, they are thus uniform and the trees have not been harvested since establishment. It must be noted that this study is a bold attempt to estimate carbon stock in tropical vegetation in Nigeria using data from a 10 year-old *Tectona grandis* plantation and a degraded secondary forest. Since, data on above ground biomass and carbon stock are not generally available in Nigeria, our result was compared to data from other parts of the world. The aboveground biomass recorded in this study sites (38.33 t ha^{-1} in plantation and 16.19 t ha^{-1} in the degraded sites) was smaller compared with other studies. Brown et al. (1989) estimated aboveground biomass to be an average of 215 Mg ha^{-1} and 192 Mg ha^{-1} for undisturbed tropical forests of Asia and the world, respectively. Brown et al. (1991) showed that tropical forests in South and Southeast Asia that appeared to have experienced little human disturbance had aboveground biomass of more than 350-400 Mg ha^{-1}, compared with 194-270 Mg ha^{-1} for forests that were exposed to human disturbance. Results from this study showed that above ground biomass increased at the rate of 3.8 t ha^{-1} Yr^{-1} in a ten year period and is lower than the value of 6.2 t ha^{-1} yr^{-1} reported by Silver et al., (2000) in their study in tropical forests in the first 20 years after afforestation. Nilsson and Schopfhauser (1995) reported the rates of aboveground carbon accumulation to be 6.4-10.0 t ha^{-1} yr^{-1} in tropical Asia, Africa, and Latin America. The values of carbon stock recorded in this study (plantation 20.08 t C ha^{-1} and the degraded forest 8.10 t C ha^{-1}) are generally lower than the values found in other systems in Africa e.g. 152 Mg C ha^{-1} for cocoa agroforestry in south Cameroon (Duguma et al., 2001); 66-88 Mg C ha^{-1} in Oil palm and 248-264 Mg C ha^{-1} rubber plantations in Cameroon (Egbe et al., 2012); and in other parts of the world:150 Mg ha^{-1} (82-242) in Spain (Balboa-Murias et al., 2006); an average of 135 Mg ha^{-1} in *Pinus radiata* and 99 Mg ha^{-1} in *Pinus pinaster* reported by Balboa-Murias et al. (2004). The values from our study are however within the range recorded in Costa Rica (12.4-79.1 Mg C ha^{-1}) by Redondo-Brenes (2007) and in India (7.80-298.56 t C ha^{-1}) by Mohanraj et al. (2011). Generally one must exercise caution in comparing the study results because of differences in the forest types, site types, management systems, monitoring, the methodology and model equation used in

different studies (Masera et al., 2003; Chave et al., 2005; Mani and Parthasarathy, 2007). Redondo-Brenes (2007) reported that fast-growing species accumulate more carbon in the first stages of their life span, while the high specific gravity of slower-growing species accumulates more carbon in the long-term. Above ground biomass and consequently carbon stock has been reported to be influenced in any particular region by factors such as climate, solar radiation, and disturbance, age of forest, species composition, and soil characteristics (Birdsey and Heath, 1995). Dutcă et al., (2009) has also pointed out that the rate of carbon storage in forest biomass depends on tree growth rate: the more biomass is added through photosynthesis the more carbon is stored. It is clear from this study that species composition, disturbance and age of the vegetation are the main factors influencing carbon stock especially in the above ground biomass. The surface leaf litter C stock recorded in this study (0.36 to 0.47 t ha^{-1}) is comparable to the results of 0.16 to 3.26 t ha^{-1} obtained by Mohanraj et al. (2011) in India. The standing floor wood litter carbon stock (0.06 to 0.08 t C ha^{-1}) recorded in this study is also not completely different to the values of 0.0006 to 0.0977 t ha^{-1} reported in Coarse Wood Debris (CWD) carbon stock in India. Nilsson and Schopfhauser (1995) have reported that the carbon stored in litter was estimated to be about 0.5 t ha^{-1} for boreal forests, 2.8 t ha^{-1} for temperate forests and 3.7 t ha^{-1} in tropical forests.

Changes in Soil Carbon

The value of 10.47- 10.58 t ha^{-1} soil C recorded in this study is very low compared with the values of 79.06 - 95.10 t C ha^{-1} carbon stock reported by Anikwe (2010) at the sites representing natural forest, artificial forest and artificial grassland ecosystems in Nigeria. They reported that continuously cropped and conventionally tilled soils were reported to have about 70% lower carbon stock (19.78-28.22 t C ha^{-1}). The lower values

recorded in this study might be related to age of the vegetations, ours is 10 and theirs is 45 years. Our results of lower carbon stock in the degraded forest is consistent with the findings of Lai (2005), who reported that the destruction of the primary forest in the past, for use as agricultural land, or other uses released and increased carbon into the atmosphere thereby reducing the amount of C that is stored in the soil. Land use change, have also been reported to deplete the soil carbon stock. He pointed out that degraded agricultural soils have lower SOC stock than their potential capacity. Important factors like previous land use, the climate and the type of forest installed (Post and Kwon, 2000) have been pointed out to influence the change in soil carbon. Guo and Gifford (2002) showed that planting broadleaf trees into pasture had little effect on soil carbon stock whereas conifer trees reduce soil carbon stocks by 12%. They also reported that climatic factors plays a role, area of lower rainfall areas (<1200 mm yr^{-1}) has little effect on soil carbon stock while area of higher rainfall (1500 mm yr^{-1}) had significantly reduced soil carbon stock. The dynamics of soil carbon has also been reported to be a function of the type of land use change (Guo and Gifford, 2002). The highest loss in SOC was found to occur in area where pasture land has been converted to agricultural crop while the lowest impact on SOC change occurred in change in land use from pasture to plantation and plantation to pasture. It has also been pointed out that when pastures are converted to conifer plantations, SOC declines, while when they are converted to either broadleaf tree plantations or naturally regenerated secondary forest, SOC is unaffected. It is important to note that data collected from tropical environments are used in estimating total world carbon sequestration potential because differences in edaphoclimatic conditions and soil management practices influence the storage of carbon in the soil, therefore effort must be geared toward making some of these data available.

Conclusion

From our findings, re-forestation with *Tectona grandis* after ten years had no significant effect on soil carbon stock, however, it has a considerable effect on standing floor litter and above ground biomass carbon stock. This study has provided some little information on the carbon stock and above ground biomass in tropical area of Nigeria. The *Tectona grandis* species may be selected for establishment and conserve carbon stock especially in above ground biomass and forest floor litter in the short-term.It is clear that the age of the vegetation and site disturbance influenced carbon stock in the above ground biomass and the standing floor litter. A lot of work still needs to be carried out to determine the impact of age and level of disturbance (deforestation, fire, etc.) on above ground biomass and carbon stock in order to better our understanding on carbon sequestration and release to the atmosphere in the face of global climate change in Nigeria. The shifts from fallow (degraded forest) to plantations can also generate other ecological problems which could results from soil disturbance in the process of plantation establishment. There is the need to continue to monitor the impact of reforestation since reforestation of this site occurred only ten years ago-a short period compared with the age of mature forest. Further changes may still be expected to occur in the next few years as it might takes longer years for any considerable changes especially in carbon soil pool
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