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Original Research

Forest Carbon Stocks and Variations along Altitudinal Gradients in Egdu Forest: Implications of Managing Forests for Climate Change Mitigation

Adugna Feyissa[1*], Teshome Soromessa[2], Mekuria Argaw[3]

[1]Department of Natural Resource Management, College of Agriculture and Veterinary Science, Ambo University, Post Box No: 19, Ambo, Ethiopia

[2] Center for Environmental Science, College of Natural Science, Addis Ababa University, Post Box No: 1176, Addis Ababa, Ethiopia

[3] Center for Environmental Science, College of Natural Science, Addis Ababa University, Post Box No: 1176, Addis Ababa, Ethiopia

Abstract

The role of forests in mitigating the effect of climate change depends on the carbon sequestration potential and management. Although a number of studies have been done on carbon stock estimations, the influence of environmental factors on forest carbon stocks has not been properly addressed. This study was conducted to estimate the carbon stock and its variation along the altitudinal gradients in Egdu dry afromontane forest. The carbon stock in the different carbon pools and analysis of the influence of the environmental variables were studied by collecting data in quadrat plots of 10 X 20 m distributed along transect lines. The mean total carbon stock density of Egdu forest was found to be 614.72±35.79 t ha^{-1} (ranging from 182.6 to 1416 t ha^{-1}), of which 278.08±25.72 (19 to 782.28 t ha^{-1}) was contained in the above ground biomass, 55.62 t ha^{-1} (8.06 to 332.89 t ha^{-1}) in below ground biomass, 3.47±0.2 (0.33 to 7.53 t ha^{-1}) in litter carbon and 277.56±11.56 t ha^{-1} (148.74 to 551.30 t ha^{-1}) was stored in soil organic carbon (0-30 cm depth). The carbon stocks in above ground biomass, below ground biomass, litter biomass and soil organic carbon exhibited distinct patterns along altitudinal gradients. The above ground, below ground and soil organic carbon stock showed an increasing trend with increasing altitude while the litter carbon stock showed irregular patterns along altitude though statistically there was no strong relationship between each of these carbon pools and altitudinal gradients. This study concluded that the carbon stock value of Egdu forest is large, and the carbon storage in different carbon pools of the forest area varies with altitudinal gradient.

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***Corresponding Author:**
Adugna Feyissa

E-mail:
adugnafeyissa@gmail.com

INTRODUCTION

The dramatic increase in global surface temperature is mainly due to the increase in carbon dioxide (CO_2) concentration in the atmosphere which is largely attributed to human activities (Petit *et al.*, 1999). Thus, the global climate change is a widespread and growing concern that has led to extensive international discussions and negotiations. Responses to these concerns have focused on reducing emissions of green house gases (GHGs), especially CO_2, and on measuring carbon absorbed by and stored in forests, soils, and oceans. One option for slowing the rise of GHG concentrations in the atmosphere, and thus possible climate change, is to increase the amount of carbon removed by and stored in forests (Broadmeadow and Robert, 2003; IPCC, 2000; IPCC, 2007b).

Forests play a critical role in the natural global carbon cycle. It sequesters and stores more carbon than any terrestrial ecosystem i.e. they store more than 80% of all terrestrial above ground carbon and more than 70% of all soil organic carbon (Jandl *et al.*, 2006; Sundquist *et al.,* 2008). As a result, forest ecosystems are regarded as the largest terrestrial carbon pool. According to the inter-governmental panel on climate change (IPCC) (2007a) report, forests have an average biophysical mitigation potential of 5,380 Mt CO_2/yr until 2050.

In Ethiopia different factors like deforestation, over-harvesting and permanent conversion to other forms of land use is leading to shrinkage of forest resources. As a result, forest cover has been declining rapidly and only remnant forests are confined to some areas especially in the south and south-western parts of the country, which are less populated (Tesfaye Bekele, 2002). Deforestation is one of the main causes of the prevailing land degradation in Ethiopia. Tree cutting is a common practice, which has been taking place for centuries. Some parts of northern Ethiopia that currently are bare and experience severe land degradation once had a good vegetation cover (FDRE, 1998). Even though the original forest cover of Ethiopia is not well documented, and estimates are not consistent, about 420,000 square kilometers (35% of Ethiopia's land) was covered by forests in the twentieth century. These forest cover have declined to 16% in 1952, 3.6% by 1980, 2.6% by 1987, and an estimated 2.4% in 1992 (FDRE, 1998).

According to Demel Teketay (2001), the reduction of forests in the tropics impairs important atmospheric functions as carbon sinks, and the combustion of forest biomass releases atmospheric CO_2, contributing to the buildup of GHGs and global warming. The climate of Ethiopia has been changing due to global and local effects of vegetation degradation (Demel Teketay, 2001). As indicated by Yitebitu Moges *et al.* (2010), Ethiopian forests contain about 272 million metric tons of carbon, which is almost 83% of the country's global annual carbon emission (333 Mega tone of carbon per year). Today, forest management activities are increasingly taking into consideration the role of forests as carbon sinks and information on factors that determine the forest carbon stock is given concern (McEwan *et al*., 2011). The carbon storage in forest can be affected by different environmental factors such as altitude, slope and aspect by affecting the patterns of tree species distribution and this further affects carbon stored in forest ecosystem (Valencia *et al.,* 2009; McEwan *et al*., 2011).

Unlike in the developed countries, Ethiopia does not have carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests. Only small efforts have been made so far to assess the biomass and soil carbon sequestration potential at small scale level. Even though this study only covers a very small area of the Ethiopian forest coverage, and only small sample areas within the study site, the study is important for sustainable forest management to show the win-win strategies (economically and environmentally sound forest management) can be achieved. As indicated above, no study has been conducted in the Egdu forest that aimed at investigating the carbon sequestration potential and associated dynamics of this forest. Therefore, this study was taken up to estimate the carbon stock of the Egdu forest and to see the variations of the carbon stocks density of different carbon pools under different altitudinal gradient.

MATERIALS AND METHODS

Description of the Study Area

This study was undertaken in Welmera District, Oromia National Regional State, central high lands of Ethiopia in a forest located at about 30 km West of Addis Ababa and 5km from Menagasha town to the South (Figure 1). Egdu forest is one of the remnant dry afromontane forests in central Ethiopia and the forest has an altitudinal gradient ranging from 2580 to 2910 m above sea level. The forest covers a total area of 486 ha and it is home for a wealth of flora and fauna. The topography of Egdu forest which is sometimes called Menagasha Amba Mariam Forest (MAMF) is characterized by dissected island plateau surrounded by cultivated land in all direction.

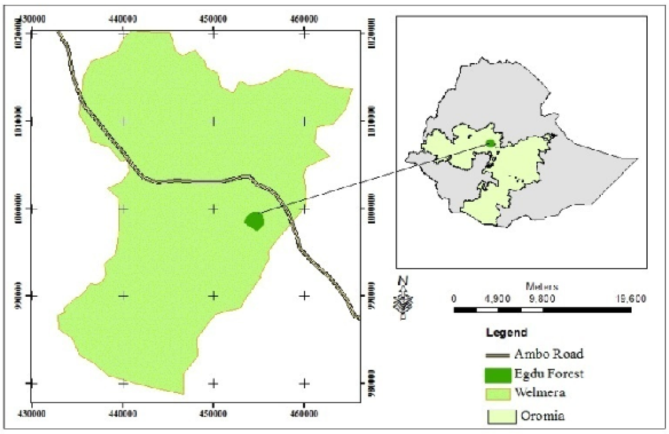

Figure 1: Map of the study area.

The annual rainfall of the study area is 1028 mm ranging from 1236.6 mm maximum in 1990 to minimum of 777.2 mm in 1997 with the rains mainly falling from the end of May to September. The monthly rainfall has a unimodal distribution. Nevertheless, there are rains in any months of the year from small amount of clouds letting additional moisture for the forest. There is high amount of rainfall from June to September. The mean annual temperature of the surrounding area is about 14.3^0C with a maximum of 24.5^0C recorded from January to May and minimum of 1.6^0C which is recorded during December (National Meteorological Services Agency).

Juniperus procera, *Olea europaea* subsp. *cuspidata, Olinia rochetiana, Maytenus arbutifolia, Rhamnus staddo, Rhus vulgaris, Eucalyptus globulus, Acacia abyssinica* and *Myrica salicifolia, Pittosporum viridiflorum, Maytenus obscura* and *Osyris quadripartita* are the species dominating the forest under the study. *Acacia mearnsii, Erica arborea* and *Cupressus lusitanica* are the dominant species at the higher altitudes. During past times the forest was highly exploited by local communities and residents of nearby towns to deteriorate the forest extensively and thus the forest has experienced long and intensive deforestation, exploitation and reforestation**.** However, the current practice of management system of the forest seems at good position, since its entry in Menasha Suba State Forest administration and protected by enough number of employed guards. There are planted species as a result of plantation activities at the peak and in most of open areas bordering the forest. *Pinus patula, Cupressus lusitanica*, *Acacia mearnsii* and *Eucalyptus globulus* are the planted species found in the study site.

Delineation and Stratification of the Study Area

The boundaries of the study forest area were delineated to facilitate accurate measurement and accounting of the forest carbon stock. GPS points were used for delineation of boundary of the study area. In order to form relatively homogenous units and obtain accurate data from the field work, the stratified sampling by elevation segments was used since the area under the study has an altitudinal variation that help to determine the elevation variations as predictor variable to relate with forest carbon stocks. The strata were defined at every 110m elevation, starting from the bottom to the top of the mountain.

Sampling Techniques

A systematic transect sampling technique was adopted in this study. Sample plots were laid along line transects from the bottom of the mountain to the top of the mountain at different altitude range. Due to the conical nature of the mountain, eight transects were laid with an interval at the bottom, middle and the top of the mountains. Transects were laid using GPS and compass.

A quadrat plot of size 10 x 20 m (200 m^2) was used for vegetation sampling. In each plot, trees with a DBH of ≥ 5 cm were measured for DBH and height. A total of sixty nine plots were laid to sample the vegetation. In order to eliminate any influence of the edge effects on the forest biomass, all the plots were laid at least 150 m away from nearest roads.

Field Measurements

Tree Measurement and Identification: For each sample plot, altitude was measured using Pretel digital altimeter and the areas of the forests of each sample plots were determined from recording the UTM coordinates. Plant specimens were collected, dried, and identified and checked at the National Herbarium of the Addis Ababa University using specimens in the Herbarium and published volumes of Flora of Ethiopia and Eritrea.

Carbon Stock Estimation

Above Ground Biomass (AGB): Trees with DBH ≥ 5 cm were measured in each plot using diameter tape, starting from the edge and working inwards, and marking each tree to prevent accidentally counting it twice. Each tree was recorded individually, together with its species name and ID.

Leaf Litter: Litter samples were collected in a 1 x 1 m rectangular sub-plot within the larger plot. A total of five sub-plots (four at corners and one in the center) were used for litter collection. The leaf litter within each 1 m^2 sub plot was collected and weighed. A composite sample of 100g was submitted for laboratory analysis placing in a plastic bag. The total dry weight was determined in the laboratory using dry ashing method as per Allen *et al.* (1986). Finally, carbon in leaf litter t ha^{-1} for each site was determined.

Soil Organic Carbon (SOC): Soil samples were collected from the five sub-plots used for litter collection. A 30 cm soil probe was used to collect the soil samples. Samples were collected using a 30 cm depth core sampler with a diameter of 5 cm. The volume of the soil sample was determined from the height and radius of core sampler. All samples were placed in paper bags with appropriate label. Five equal weights of each sample from each sub-plot were taken and mixed homogenously while a composite sub sample of 100 gm from each plot was submitted for laboratory analysis. Finally, the bulk density, soil organic matter and soil organic carbon were calculated.

Estimation of Carbon in Different Carbon Pools

Estimation of Carbon in the Above Ground Biomass (AGB): From the different available allometric equations to estimate the AGB, the model that was developed by Brown *et al.* (1989) is selected for the study site since the general criteria described by the author are similar to the study area. Since the plot areas are part of tropical region carbon content in the biomass were estimated by multiplying 0.47. The general equation that was used to calculate the above ground biomass is given below:

$$Y= 34.4703 - 8.0671(DBH) + 0.6589(DBH^2) \ldots\ldots\ldots \text{(eq.1)}$$

Where, Y is above ground biomass, DBH is diameter at breast height.

Estimation of Carbon in Below Ground Biomass (BGB): Below ground biomass estimation is much more difficult and time consuming than estimating aboveground biomass (Geider *et al.,* 2001). According to MacDicken (1997), standard method for estimation of below ground biomass can be obtained as 20% of above ground tree biomass i.e., root-to-shoot ratio value of 1:5 is used. Thus, the equation developed by MacDicken (1997) to estimate below ground biomass was used.

Estimation of Carbon in the Litter Biomass (LB): Carbon stocks in litter were calculated by multiplying litter dry weight per area with the relative carbon concentration of the samples using (Pearson *et al.*, 2005).

Estimation of Carbon in Soil Organic Carbon (SOC): The carbon stock density of soil organic carbon was calculated as recommended by Pearson *et al.* (2005) from the volume and bulk density of the soil. Then, the carbon stock in soil was calculated as follows:

$$SOC = BD * d * \% C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(eq.2)}$$

Where,
SOC= Soil Organic Carbon stock per unit area (ton/ha^{-1}),
BD = soil bulk density (g cm^{-3}),
D= the total depth at which the sample was taken (30 cm),
%C= Carbon concentration (%) determined in the laboratory

Total Carbon Stock Density

The total carbon stock density was calculated by summing the carbon stock densities of the individual carbon pools using the Pearson *et al.* (2005) formula.
Carbon stock density of the study area:

$$C_{density} = C_{AGB} + C_{BGB} + C_{Lit} + SOC \ldots\ldots\ldots\ldots \text{(eq.3)}$$

Where:
$C_{density}$ = Carbon stock density for all pools (t ha^{-1})
C_{AGTB} = Carbon in above -ground tree biomass (t ha^{-1})
C_{BGB} = Carbon in below-ground biomass (t ha^{-1})
C_{Lit} = Carbon in dead litter (t ha^{-1})
SOC = Soil organic carbon (t ha^{-1})

Data Analysis

The data obtained from DBH, diameter, height of each species, fresh weight and dry weight of litter and soil were analyzed using Statistical Package for Social Science (SPSS) software version 20. The height and diameter data was arranged in classes for applying appropriate model of biomass estimation equation. Altitudinal gradients were divided in to three different classes for similar pattern analysis: lower (2580-2690 m), middle (2691-2800 m) and higher (> 2800 m). Analysis of variance (one-way ANOVA) was used to determine statistically significant differences of carbon stocks along environmental variables for each carbon pools. Differences at the 0.05 level were reported as significant.

RESULTS

Carbon Stock in the Different Carbon Pools

The carbon stock value of the study site in different carbon pools showed different storage of carbon. About 82.53% (591.66±54.74) of the biomass was contained in above ground, while below ground biomass comprised 16.51% (118.33±11.59) of the total biomass. It was found that about 0.99% (7.3±0.44) of the biomass was contained in the litter. The carbon stock that was stored in the AGB was 45.24% (278.08±25.72) whereas 45.15% (277.56±11.56) was contained in the soil. The least amount of carbon was stored in litter carbon pool (0.56% (3.47±0.2)) followed by below ground carbon pool (9.05% (55.62±5.14)). The mean carbon density in all carbon pool of the study site was 614.72±35.79 t ha^{-1}.

Carbon Stock and Altitudinal Gradient

Above and Below Ground Carbon Stock along Altitudinal Gradient: The carbon stock of different components of the forest carbon pools (above ground and below ground, litter and soil) responded differently along altitudinal gradient. As shown in Table 1 below, the upper altitude parts of the vegetation is high in above ground biomass carbon while the lower and middle altitude parts have low to moderate carbon stock in above ground biomass. Similar result was recorded for the tree biomass. Values of the biomass and carbon stocks for different altitude class are given in Table 1**.** The mean AGB and carbon stocks for higher altitude was estimated at 746.89±38.71 and 351.04±26.09 t ha^{-1}, respectively. Mean values of AGB for lower and middle altitude were 461.64±35.34 and 589.54±37.04 t ha^{-1} and comprised carbon stocks of 216.97±18.04 and 277.09±25.91t ha^{-1}, respectively.

Table 1: Mean biomass and carbon stock (t ha^{-1}) in above and below ground biomass along altitudinal gradient (AGB: Above ground biomass; AGC: Above ground carbon; BGB: Below ground biomass; BGC: Below ground carbon).

Altitude	AGB	AGC	BGB	BGC
Lower	461.64 ± 35.34	216.97 ± 40.14	92.33 ± 17.08	43.39 ± 8.03
Middle	589.54 ± 37.04	277.08 ± 40.91	117.91 ± 17.41	55.42 ± 8.18
Higher	746.89 ± 38.71	351.04 ± 26.09	149.38 ± 21.74	70.21 10.22

Similarly, BGB and its carbon stock showed similar pattern to that observed carbon stock in the AGB since it was obtained from the AGC pool. Thus, an increasing trend in BGB and carbon stock level was observed with increased altitude. The mean largest and lowest BGB and BGC were observed in higher altitude (149.38±21.74 and 70.21±10.22 t ha^{-1}) and lower altitude (92.33±17.08 and 43.39±8.03 t ha^{-1}), respectively (Table 3). However, the differences were not significant both for above and below ground carbon (F= 1.344, *p*= 0.278), despite an overall increasing trend with increasing altitude (Table 4).

Litter Carbon Stock along Altitudinal Gradient

In contrast to the above ground and below ground biomass, the litter carbon density did not show clear patterns along the altitudinal gradient and reached higher in middle altitude with the mean biomass of 8.27±0.71 t ha^{-1} and carbon value of 3.9±0.34 t ha^{-1}, but they were not statistically significant (F= 1.329, *p*= 0.287) (Table 4). The lowest litter biomass and its carbon were recorded in lower altitude (6.57±0.75 and 3.05±0.35 tha^{-1} respectively) (Table 2)**.**

Table 2: Mean litter biomass and carbon stock (t ha^{-1}) along the altitudinal gradient (LB: Litter biomass; LC: Litter carbon).

Altitude	LB	LC
Lower	6.57 ± 0.75	3.05 ± 0.35
Middle	8.27 ± 0.71	3.9 ± 0.34
Higher	6.56 ± 0.79	3.24 ± 0.39

Soil Organic Carbon Stock along Altitudinal Gradient

As Table 3 below shows, the soil organic carbon density with specific to this study site was lower in lower altitude (243.38±14.8 t ha^{-1}) compared to the middle and higher altitude. Higher altitude had stored the highest SOC density with mean carbon value of 328.57 ± 24.4 t ha^{-1} showing an increasing trend with an increase in altitude like that of the above and below ground carbon density, but the differences were not significant (F= 1.288, *p*= 0.311) (Table 4). Middle altitude had stored carbon stock situated in between the maximum and minimum soil organic carbon.

Table 3: Mean soil organic carbon (SOC) stock (t ha^{-1}) along the altitudinal gradient

Altitude	SOC
Lower	243.38 ± 14.8
Middle	270.87 ± 18.03
Higher	328.57 ± 24.24

Table 4: Summary of values of significance for one-way ANOVA between the altitudinal gradients for AGC, BGC, LC and SOC (AGC: Above ground carbon; BGC: Below ground carbon; LC: Litter carbon; SOC: Soil organic carbon stock).

Gradient	Carbon pools	F-value	*p*-value
Altitude	AGC	1.344	0.278
	BGC	1.344	0.278
	LC	1.329	0.287
	SOC	1.288	0.311

DISCUSSIONS

Forest Carbon Stock

While comparing with other studies, the mean carbon stock in above and below ground biomass of Egdu forest was twice higher than those reported from Menagasha Suba state forest (Mesfin Sahile, 2011) and selected church forests in Addis Ababa (Tulu Tolla, 2011) (Table 5). However, this result is comparable to those reported for the global above ground carbon stock in tropical dry and wet forests ranged between 13.5-122.85 t ha^{-1} and 95-527.85 t ha^{-1}, respectively (Murphy and Lugo, 1986). Tree species in the forest area were dense and has protection due to its reserved status. The higher carbon stock in above ground biomass in the study site could be related to the higher tree density in forest area and presence of protection from human interference. Preventing deforestation from conifer dominated stands would have the largest per unit area impact on reducing carbon emissions from deforestation (Yetebitu Moges *et al.,* 2010).

The mean carbon stock in litter pool of the present study was less compared to values recorded for selected church forests in Addis Ababa (Tulu Tolla, 2011) but greater than values reported for tropical dry forests (2.1 t ha^{-1}, IPCC, 2006) (Table 5). The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density) and climate (Fisher and Binkly, 2000). Similarly, the tree stands in the forest area were relatively still young and this could result in low amount of litter fall. In addition, since the study area is located in tropical areas, the rate of decomposition is relatively fast (Fisher and Binkly, 2000). Thus, the lowest carbon stock in litter pool could probably be due to the high decomposition rate and less amount of litter fall. The mean bulk density of the forest site was low (0.46 g cm^{-3}, ranging between 0.21 to 0.79 g cm^{-3}) which indicates that the study site has high organic matter content in the soil (Brady, 1974). Thus, the higher mean SOC stock is may be due to the presence of high SOM and fast decomposition of litter which results in maximum storage of carbon stock (Sheikh *et al.,* 2009). Overall, the present result revealed that the study forest had large carbon stock and thus sequestered large amount of CO_2 contributing to the mitigation of global climate change.

Table 5: Comparison of carbon stock (t ha^{-1}) of the present result with other studies (AGC: Above ground carbon; BGC: Below ground carbon; LC: Litter carbon; SOC: Soil organic carbon).

Study Place	AGC	BGC	LC	SOC
Egdu Forest	278.08	55.62	3.47	277.56
Menagasha Suba StateForest	133	26.99	5.26	21.28
Selected Church Forest	122.85	25.97	4.95	135.94

Influence of Environmental Variables on Carbon Stock

In many previous works (Luo *et al*., 2005; Mooser *et al*., 2007; Alves *et al*., 2010), altitude is known to have a major impact on the diversity, biomass and carbon stock in the forest ecosystems. Although it has been reported in many studies in other parts of the world that the result of above and below ground tree biomass and its carbon stock decline with an increase in altitude (Luo *et al*., 2005, Leuschner *et al*., 2007; Mooser *et al*., 2007; Zhu *et al*., 2011).

In the present study area, it was observed that the mean above and below ground biomass carbon and SOC had showed relatively an increasing trend with increasing altitude though there was no significant variation in carbon stock in all carbon pools along altitudinal gradient. Similar to the present result there were similar results also reported in tropical Atlantic moist forest in Brazil by Alves *et al.* (2010), in central Amazonian forest (de Castilho *et al.,* 2006), in moist temperate valley slopes of the Garhwal Himalaya of India (Gairola *et al.,* 2011) and in Mt Changbai of china (Zhu et *al.*, 2011). According to Abiyou Tilahun (2010), the lower areas of the study forest is highly influenced by the local people as it is more accessible for cultivable land expansion and procuring essential forest products which probably be the cause for lower biomass at lower elevations. The presence of species characterized by large individuals occurring on higher altitude could have an effect on AGB and carbon stock, because few large individuals can account for large proportion of the plots above and below ground carbon (Brown and Lugo, 1982). This could probably be the case in the present study area, where bigger trees with maximum DBH were more frequent in higher altitude and flat areas.

On the other hand, unlike the other carbon pools, the mean carbon density in litter pool of the present study showed no clear pattern with altitude. Thus, the biomass and carbon density of litter relatively both peaked in middle altitude of the study forest. Similar result was reported in Mt Changbai of China (Zhu et *al.*, 2011) indicating insignificant relation between the litter carbon and altitude with absence of clear pattern along the gradient. The absence of the clear pattern in litter carbon density of the present study may be due to the decline in litter fall amount and decomposition with increasing altitude (Zhang *et al.*, 2008) in Egdu Forest.

As indicated by Jobbagy and Jackson (2000), SOC density increased with precipitation and decreased with temperature. In the present study, relatively an overall increasing trend in mean SOC density with increasing altitude (decreasing temperature and increasing precipitation) was observed. Zhu *et al.* (2011) found that SOC increased with increasing altitude which is similar to the present study. As altitude increase the net primary productivity (NPP) and the carbon input (litter fall) to the soil decreases (Zhu *et al.*, 2011). The increase in SOC with increasing altitude in Egdu forest despite the decrease in NPP and litter fall may be due to the carbon output (decomposition), which generally decreases with increasing altitude (Garten and Hanson, 2006).

CONCLUSIONS

Overall, this present result point out that forest carbon pool density of the study area did not show significant variation and a clear pattern along altitudinal gradient as above-, below-, litter- and soil carbon density showed distinct patterns along altitudinal gradient. This further revealed that the carbon pool components of forest ecosystem may respond to altitude differently and plays an important role in knowing possible change in carbon stock and thus carbon sequestration capacity in response to future climate change (Zhu *et al.*, 2011).

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