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Changes in Carbon Stocks and Sequestration Potential under Native Forest and Adjacent Land use Systems at Gera, South-Western Ethiopia

Mohammed A. [α] & Bekele L. [σ]

Abstract- The current study evaluated the differences in soil and biomass carbon (BC) stocks of native forest, annual crop field and coffee based agroforestry at Gera, South-west Ethiopia. A total of 24 sample plots were collected by Stratified random sampling method. After measuring the required parameters; BC (above and below ground), and SOC, texture, bulk density and pH were analyzed. The results showed that, BC significantly varied with land use types. On the other hand, the SOC under native forest and coffee based agroforestry has no significant difference, while it shows significant difference under the annual crop field. The present study indicated that, the total carbon stock in the native forest is greater than coffee based agroforestry which shows much greater difference than annual crop field. This may indicate that, conversion of annual crop field to coffee based agroforestry can increases carbon stock and sequestration potential in the study area.

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I. Introduction

Forest conversion and land-use change in the tropics are major factors leading to losses in carbon stocks and increasing concentration of greenhouse gases in the atmosphere. The effect of land use changes on soil properties may vary for different soils, vegetation types and ecological zones (Lal 1999; Palm *et al*., 2000; Bekele 2006; Fantaw *et al.,* 2008). Agricultural practices lead to a reduction in carbon stocks mainly due to removal of above ground biomass as harvest with subsequent burning and/or decomposition and losses of soil carbon by erosion (Lal 1999; Balesdent and Balbane 1996; Fahnestock *et al.,* 1996). Thus, there is a need for developing sustainable agricultural systems to maintain and improve biomass and soil organic compound (SOC) content while mitigating the land degradation and greenhouse gas emissions (Patrick et al., 2005; Takahashi et al., 2010). In tropics especially south and south-western highlands of Ethiopia, the deforestation of native forest has been significantly increased during the past 100 or more years (Pohjonen and Pukkala 1990; sited in Bekele 2006), which might be due to human habitation (Bekele 2006). Carbon in the soil is an important factor when studying global carbon budgets (Wilding et al., 2001; Berg and McClaugherty 2003; Lehtonen et al., 2004). Estimating the carbon stock in reliable values is necessary for understanding the global Carbon cycle, as well as for developing national inventories of greenhouse gases (Lehtonen et al., 2004); while estimating its spatial variability is important when developing carbon budgets, explaining climate change and characterizing ecosystems (Davis et al., 2004). Soil carbon can act as a source or as a sink for CO_2 in the atmosphere (Fisher and Binkley 2000; Högberg et al., 2002; Fröberg 2004) and can be considered as the biogeochemical linkage between the other major Carbon reservoirs: biosphere, atmosphere and hydrosphere (Wilding et al., 2001).

Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural brake on climate change (Lal 2005; IPCC 1997; Milne and Brown 1997). Tropical forests account for 40% of carbon stored globally in terrestrial biomass (Alves et al., 1997; Brown 1997) and contribute as much as 36% of the net exchange between atmosphere and terrestrial vegetation (Melillo et al., 1993). Thus, small changes in net carbon stock of tropical forests could result in significant storage or release of carbon to the atmosphere. The high productivity of these forests may make them particularly responsive to the growth enhancement from rising atmospheric CO_2 concentrations (Nabuurs et al., 1997; Prentice and Lloyd 1998; Tian et al., 1998). In order to reduce carbon in the atmosphere, it is important to investigate which type of land use is suitable for long-term carbon sequestration. When native forest is converted to agroforestry and/or, agricultural land, carbon stock may decline to some extent (Price and Willis 1993). Several researchers also revealed that the promising management practices to sequester biomass, and SOC and to reduce soil degradation are adopting agroforestry system (Cannell et al., 1995; Brown et al., 1996; Batjes and Sombroek 1997; Takahashi et al., 2010).

However, little is known of how coffee based agro-forestry practices in the vicinity of Gera Native forest, south western Ethiopia affect the storage of carbon in the biomass and soil matrix. Hence, the

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present investigation was undertaken estimate the difference in carbon stock (biomass and soil) between coffee based Agroforestry land use and other land uses namely annual crop field and native forestland use systems. Research hypothesis raised here is does coffee based agroforestry land use system has higher C Stocks and sequestration potential than annual crop field and native forestlands.

II. Materials and Methods

a) General description of the study area

Gera is found in Jimma Zone of Oromiya Region, South-west Ethiopia. It is located within the longitudinal range 35° 57′ and 37° 37′ East and latitudinal range of 7° 13′ and 8° 56′ North.

The altitude of the area falls in the range between 1500–2900masl. The mean annual maximum and minimum temperature is 24.2°C and 14.2°C, respectively and mean annual rainfall is between 1800 and 2000mm. The major soil types are: *Arcisol, Nitisol* and *Leptosol*. The remnant forest vegetation at Gera area can be categorized as tropical Afromontane moist forests which have been further classified into: natural forest (virgin and disturbed) and plantation forests. The vegetation cover of the area was estimated to be 56% of the total area.

b) Research Methods

i. Site Selection

For this study, coffee based agroforestry, annual crop field and native forest types of land uses were considered. For selection of study site, informal survey was conducted to collect important information about the ages under particular land uses. Farmers were asked the time when they started converting the forest into coffee based agroforestry and annual crop fields. The site was selected along two altitudes: 1890 and 2100 m.a.s.l., where the three treatments were assigned. The selected annual crop fields and coffee based agroforestry are about 20 years old since converted from native forests. The native forest was also sampled adjacent to the selected land uses as control.

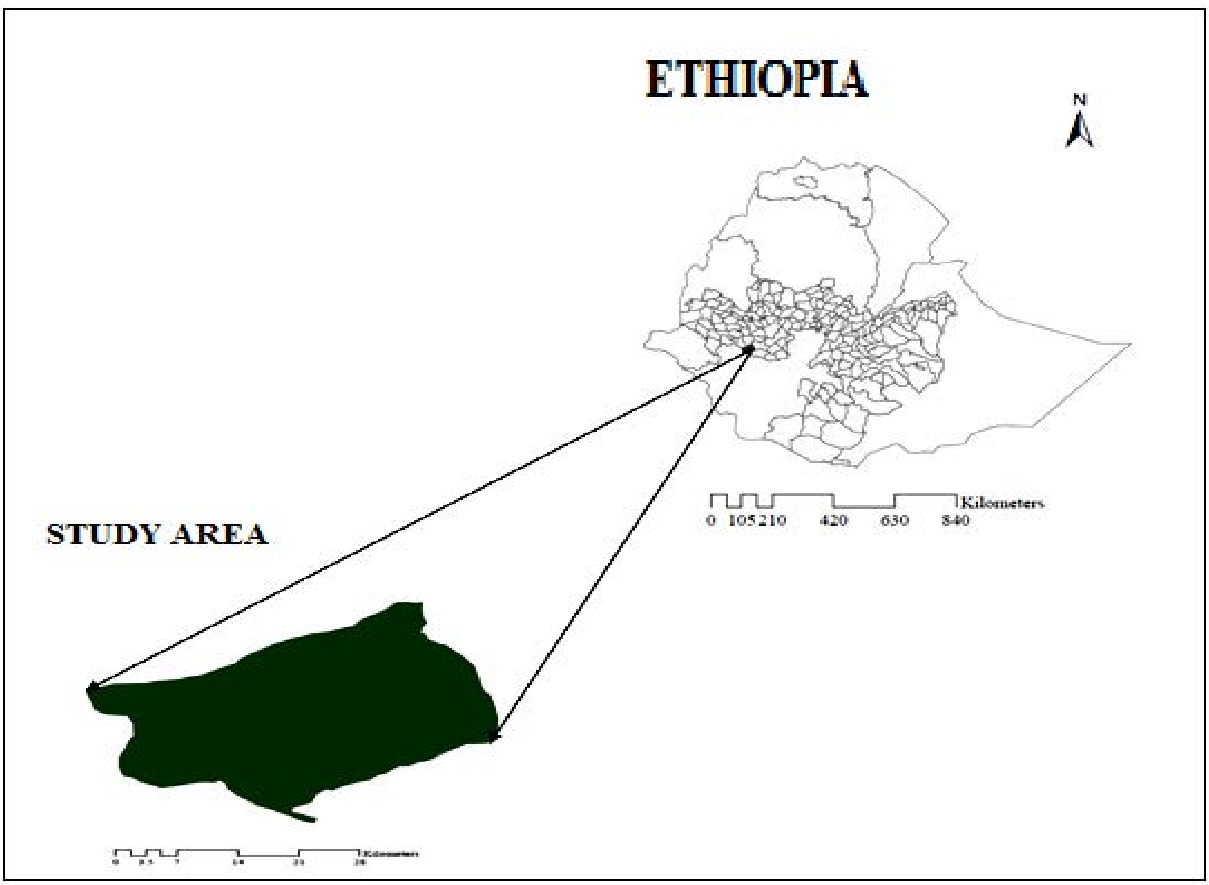

Figure 1 : Map of the study area

ii. Plot Allocation and Measurement

Stratified random sampling was used to collect data for the study. At each land uses, parameters were measured and their GPS coordinates were taken. Most coffee based agroforestry were rectangular in shape and large in size. A 100 m x 100 m sized plots were divided into 25 m x 25 m subplots. To choose the sample plot, each plot was numbered and lottery

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method was used for randomization. The centre points of each division were located and four subplots with 15 m x 15 m were laid out perpendicular to the borders. There were four sample plots for each land uses at each elevation and a total of twenty four sample plots were collected from the site at both elevation.

iii. *Estimating above-ground biomass*

The diameter of all trees in each plot greater than or equal to 5cm at breast height were measured by using calliper and/or tape meter. The species type was recorded and their heights were measured using hypsometers. The diameter for coffee shrub was measured at 15 cm above ground (Sugara et al., 2006), while it was at the ground level for Enset (*Ensete ventricosum*) and Banana (*Musa paradisiaca*) (Blomme et al., 2008). Based on average diameter, total height, above ground biomass and carbon stock were calculated by following appropriate allometric equations. The above ground biomass of individual tree was estimated by following Brown et al., (1989). This equation was used to estimate above ground biomass in several studies (Roshetko et al., 2002; Lascol et al., 2006).

$$Y = e^{x}\{-2.134 + 2.530 * ln\,(D)\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .1$$

Where D = diameter (cm) and Y = total above ground biomass in (Mgha-1).

The equation used for estimating aboveground biomass of banana, based on pseudo-stem diameter was developed in (Hairiah et al., 2001). Thus, the biomass of banana and Enset in this study were estimated following this general biomass allometric equation and then converted to C content.

$$Y = (0.0303\,D)^{2.1345} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where D is diameter (meters)

Above ground biomass of coffee plants was estimated by using the following regression formula as mentioned by Sugara et al., (2006) in shade tree coffee systems.

$$\log 10\,(B_T) = -1.113 + 1.578 * \log 10\,(d_{15}) + 0.581 * \log 10(h) \ldots\ldots\ldots 3$$

Where d15 = diameter at 15cm, h= height and BT= is total aboveground biomass.

The above-ground biomasses of all individual trees, Banana, Enset and coffee in a plot were summed to calculate total biomass for each plot, and the plot-level values of estimated above-ground biomass were then converted to biomass per hectare (Mg ha^{-1}) for each land use. Aboveground biomass was converted into C by multiplying by 0.5 (Mac Dicken 1997):

$$AGBC = Y \times 0.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .4$$

Where Y is total of above ground biomass in (Mg ha^{-1}), and AGBC is above ground biomass Carbon in (Mgha^{-1}).

According to Cairns et al., (1997), root biomass of tropical trees in moist area is about 22% of above ground biomass. Depending on this, root biomass of individual tree was estimated by taking 22% of the above ground biomass (root biomass = 0.22 x Y). Study by Blomme et al., (2008) indicates that, the below ground biomass for Enset and Banana (root + corm) is 35% and 31%, respectively, of their above ground biomass. In this study, below ground biomass was estimated by using these results and, then converted to biomass carbon according to equation 5. The shoot: root ratio (biomass) of coffee often assumed for tropical trees ranged between 4:1 and 2:1 (van Noordwijk et al., 2002). In this study, we have used the least ratio (4:1) for coffee below ground biomass in order to decrease overestimation and then converted it to biomass carbon following equation 5.

$$BGBC = RB \times 0.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .5$$

Where BGBC is below ground biomass carbon, RB is root biomass which is equal to 0.22Y.

$$TBC = AGBC + BGBC \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .6$$

Where TBC is total biomass carbon.

iv. *Soil Analysis*

Soil samples were analyzed for bulk density, soil organic carbon, pH and textural fractions by removing undisturbed soil using core sampler from each land use categories. From each plot, five points were established in each direction (north, east, south and west) one meter inside the plot boundary, and one at the centre. At these five points, soil samples were collected from 0 to 30 cm depth by using soil auger. Soil samples were air dried at room temperature and were then sieved by 2 mm size mesh. The samples were

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mixed and homogenised and sub samples were taken for estimation of Carbon, pH and textural analysis. SOC was analysed according to Walkley and Black (1934), Bulk density was determined by drying the sample in an oven drier at 105°C for 24 hours. Total SOC stock per hectare ($Mgha^{-1}$) was calculated according to the following equation (Bekele, 2006):

$$SOC(Mgha^{-1}) = SOC(gKg^{-1}) \times d \times BD(g^{-3}) \times 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where d is sampled soil depth in meter (m), and BD is bulk density (gm^{-3}).

Soil pH was measured potentiometerically using a pH meter in 1:2.5 (v/v) soil water suspensions and textural fraction was determined by hydrometer method.

c) Data analysis

The results were subjected to analysis of variance (ANOVA). All statistical computations were made by using SAS (2004) version 9.0 computer software. The least significant difference (LSD) at $P \leq 0.05$ was used to determine statistically significant differences within each variable at each altitude. We conducted paired t-tests to test for significant differences in biomass and SOC stocks for each category of land uses at both elevations.

III. Results and Discussion

a) Biomass carbon

Biomass carbon was found significantly higher in the native forest (134.34 ± 26.94 $Mgha^{-1}$) than in the coffee based agroforestry (58.27 ± 12.30 $Mgha^{-1}$) and in the annual crop field land (0.04 ± 0.03 $Mgha^{-1}$). The biomass carbon of coffee based agroforestry was significantly higher than that of annual crop field, but there was no significant difference in biomass carbon between altitudes across land uses.

Table 1 : Mean values of biomass carbon (BC) across the land use types at each elevation

Organic Carbon	Elevation (m.a.s.l)	Land uses types		
		Annual crop fields	Coffee based agroforestry	Native Forest
BC ($Mgha^{-1}$)	1890	0.05±0.03a	54.46±7.45b	135.00±36.63c
	2100	0.02±0.02a	62.23±17.14b	133.79±16.61c

Note: Parameters with similar letter are not significant in each row at P <0.05

Biomass carbon in tree-based systems (native forest and coffee based agroforestry) showed higher biomass carbon than that of annual crop field with few trees. Tree-based land-use systems sequester CO_2 through the C stored in their biomass (Vitousek and Denslow 1986; Clark and Clark 2000; Roshetko et al., 2008). This may subject to increase or decrease in C flux to the atmosphere as a result of harvest, re-growth and conversion to other land uses. In agreement with the present study, the amount of biomass C in the agroforestry systems was several times higher than the C contents in the annual agricultural system (Bangroo et al., 2011). Dossa et al., (2008) also has shown the biomass C stock in the shaded coffee agroforestry system was higher than that in the open agricultural system. Our result in coffee based agroforestry is within the range of Carbon values (50 –75 $Mgha^{-1}$) reported for tropical agroforestry systems (Lefebvre et al., 1993). The lower biomass carbon in annual crop field was consistent with the small number of trees that are included in hedges on the borders of farmland, and other trees left on the farm landscape. After 20 years of land conversion, the amount of BC (above ground and belowground) lost due to conversion to coffee based agroforestry was about 56.65% of the original biomass C of native forest, and the loss due to conversion to annual crop field was about 99.97%. High BC has been lost when native forest was converted to annual crop field land because of huge biomass removal during the process of land use conversion.

The result of this study suggest that losses of biomass C can be minimized when native forest was converted to coffee based agroforestry system than annual crop field, and increased C storage (C sequestration) can be achieved by converting annual crop field land into coffee based agroforestry land use systems or even to forest lands. Coffee based agroforestry systems have the comparative advantage over annual crop field systems in biomass carbon sequestration.

b) Soil organic carbon

SOC at 0-30 cm soil depth within the three land use types is shown in Table 2. SOC ($Mgha^{-1}$) in native forest, coffee based agroforestry and annual crop field land were 95.52 ± 3.65, 92.48 ± 7.02 and 65.17 ± 2.58, respectively. Native forest and coffee based agroforestry contained significantly higher SOC as compared to the annual crop field land but there were no significant difference between coffee based agroforestry and native forest. Moreover, SOC was not significantly different between each land uses at the two elevations.

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Table 2 : Mean values of soil organic carbon (SOC) across the land use types at each elevation

Organic Carbon	Elevation (m.a.s.l)	Land uses types		
		Annual crop fields	Coffee based agroforestry	Native Forest
SOC ($Mgha^{-1}$)	1890	63.34±2.95a	90.65±8.89b	92.57±2.41bc
	2100	66.99±2.21a	94.30±5.14b	98.95±4.84bc

Note: Parameters with similar letter are not significant in each row at P <0.05

The stock of SOC results from the balance between litter input and decomposition over time (Liski et al., 2002), while stored in the soil as humus and related stable organic compounds, the C is not circulating through the atmosphere (Berg and McClaugherty 2003). As a part of the dynamic carbon cycle of forests, soil C is linked to the development of vegetation and also affected by the past events (Liski et al., 2002; Nabuurs et al., 1997). In the present study, about 31.95% of SOC was lost following conversion of native forest to annual crop field land, which was cultivated for 20 years. Consistently, conversion of native forests to annual crop field land resulted in 20-50% loss of SOC (Sampson and Scholes 2000). According to Bekele (2006), deforestation of native forest followed by 75 years of continuous cultivation depleted the SOC by 43% at Belete native forest. The loss of SOC in his study is higher than the present study, but the age of cultivation and larger soil depth might have contributed for the higher amount of loss.

The SOC was not in a linear relationship with the number of years of cultivation as indicated in a chrono-sequence study (Lemenih et al., 2004). In his study, Lemenih et al., (2004) indicated that; much of the SOC was lost in the first few decades. The lower SOC contents in crop field land sites was due to various factors such as the breakdown of aggregates because of cultivation, increase in aeration of the soil and increase in the rate of mineralization by soil micro-organisms (Balesdent et al., 1990; Lal 1999; Lemenih et al., 2004). The SOC depends on the balance between the annual input of dead plant material and the annual loss of SOC by decomposition (Nabuurs et al., 1997, McDonagh et al., 2001; Lemenih et al., 2004; Bangroo et al., 2011).

The SOC loss from the conversion of native forest to coffee based agroforestry remained very low after 20 years of cultivation following deforestation. In most terrestrial ecosystems, the majority of net primary production is shed in the form of plant litter, which originates from above and below ground plant organs. Tree species differ in their allocation of C to above and below ground components and in their fine root mortality (Cairns et al., 1997). There is also a considerable site-specific variation in the quality and quantity of litter produced by different tree species (Aerts 1997). These factors may explain the similar amounts of SOC in coffee based agroforestry as in native forest while having lower biomass C than the native forest. In addition, it may suggest that the coffee based agroforestry system protects the loss of SOC and if the annual crop field reverts to coffee based agroforestry in the study area; it could lead to SOC sequestration.

c) Total carbon stock

Total C (BC + SOC) in native forest, coffee based agroforestry and annual crop field land were 230.09 ± 27.88, 150.73 ± 12.21 and 65.40 ± 2.64 Mgha-1respectively. There were significant differences in total C between the native forest, coffee based agroforestry and annual crop field land. Further, there was no significant difference in total C between the elevations for each land uses (Fig.2). Coffee based agroforestry land uses had the second largest total C stock and has significantly higher total C than the annual crop field. The difference between native forest and coffee based agroforestry was mainly from the difference in biomass C.

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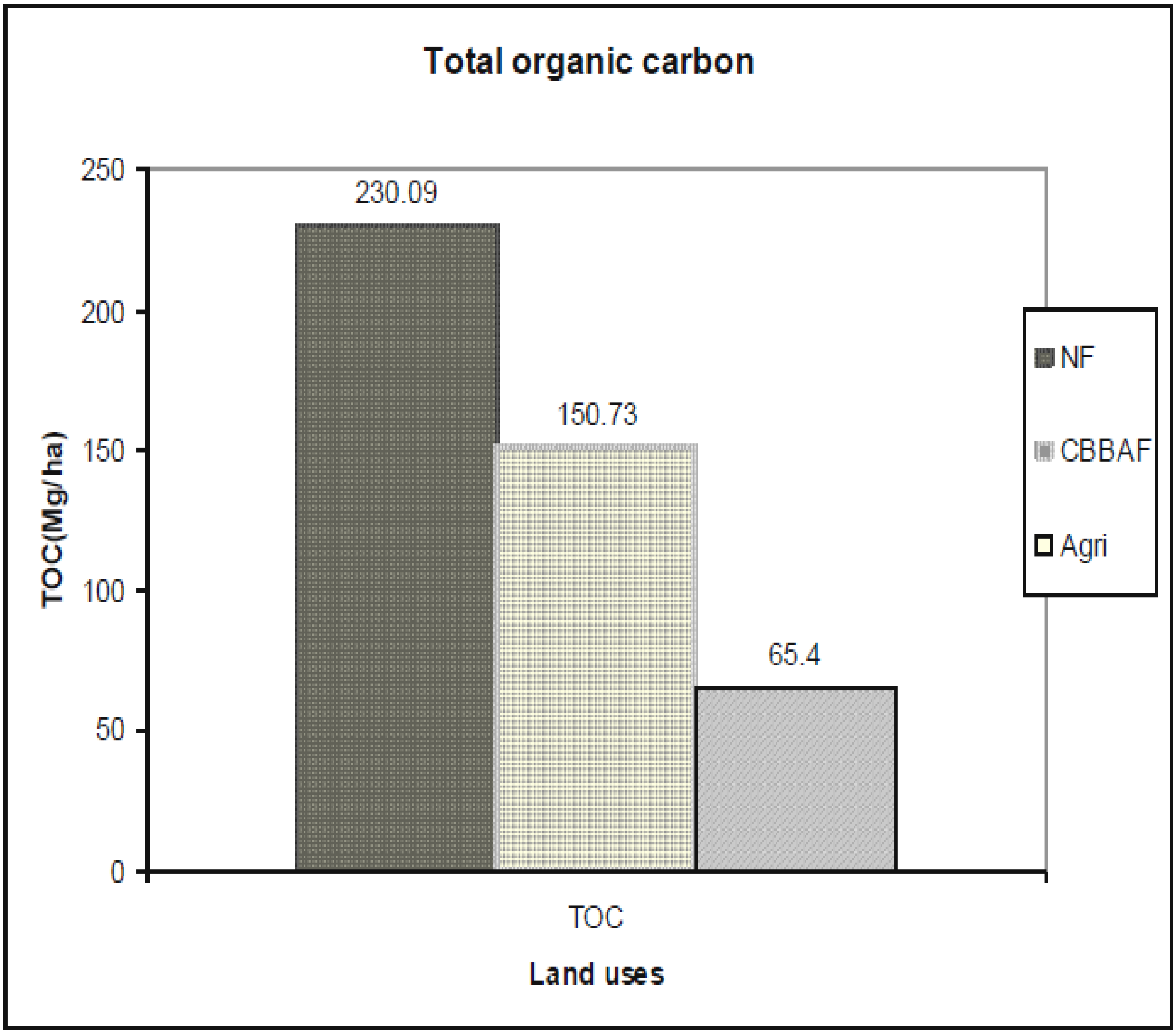

Figure 2 : TOC in each land uses

NF = native forest, CBAF= coffee-based agroforestry and, Agri= annual crop field

In agreement with this finding, Milne and Brown (1997) have shown that, forest land conversion to agroforestry would actually loose C, but to a much less extent than the conversion to annual crop field. The higher total C in coffee based agroforestry than annual crop field is because of the higher SOC as well as the higher biomass C in coffee based agroforestry as compared to that in annual crop field. The coffee based agroforestry has diverse plant communities and higher in number than that of annual crop field land. Any disturbance of vegetation or of the soil itself is likely to alter the balance between litter input to the soil and decomposition loss, and so cause a change in the reservoir of carbon (Milne and Brown 1997). Factors and processes that determine the rate of change in biomass and soil C stock influence the total C stocks.

This study did not consider C from coarse woody debris and associated necromass and this could lead to an underestimation of the total C stocks. According to Keller et al., (2000), coarse woody debris mass varied from 49.7 to 59.9 Mgha-1 in mature forest sites in Eastern Amazonia and it was about 16% of above ground biomass. Delaney and Powell (1998) also found that dead wood mass contributed 33.3 – 42.3 $Mgha^{-1}$ necromass in tropical moist and wet forest zones in Venezuela, which were 9.6 –12.4% of the total above ground biomass. However, the results of present findings indicated that, land use change mainly affects the organic carbon stock either in their biomass and soil matrices. It shows that native forest cleared for crop production and coffee based agroforestry in the study area lose high organic carbon in both biomass and soil within 20 years of subsequent cultivation after deforestation.

IV. Conclusion

The results of this finding indicated that, land use change mainly affects the organic carbon stock

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either in their biomass and soil matrices. It shows that native forest cleared for crop production and coffee based agroforestry in the study area lose high organic carbon in both biomass and soil within 20 years of subsequent cultivation after deforestation. Native forest and coffee based agroforestry have much higher biomass carbon as compared to annual crop field, and native forest has higher biomass carbon than coffee based agroforestry. On the other hand, Native forest has similar amount of SOC as that of coffee based agroforestry, and it has higher SOC than annual crop field. Major declines were observed for annual crop field, which mainly because of biomass removal which is the principal source of plant organic carbon. Despite the clear decline in SOC within 20 years, is resulted from reduced above and belowground litter inputs and increased microbial decomposition, and it may from aeration while land cultivation is undertaken. The higher total C in native forest as compared to annual crop field and coffee based agroforestry shows that; the conversion of native forest to coffee based agroforestry reduces emission of C as compared to annual crop field. In addition, the conversion of annual crop field to coffee based agroforestry can sequester large amount of C in the soil as well as in the biomass.

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