Soil carbon sequestration under chronosequences of agroforestry and agricultural lands in Southern Ethiopia

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Abstract
When forest is converted to other land uses, it often may lead to loss of organic carbon and nitrogen in terrestrial ecosystems. Soil organic carbon (SOC) and total nitrogen (TN) concentration and stocks, and the rate of change in the chronosequences of 12, 20, 30, 40, 50 years of agroforestry and agricultural lands in an Andic Paleudalf were investigated. A greater proportion of SOC and TN was concentrated in 0 to 20 cm depth and their concentration in agroforestry and agricultural lands was significantly lower than in the natural forest. The SOC stocks in all chronosequences of traditional agroforestry were higher than the corresponding chronosequences under agricultural lands. The loss of SOC stock under the chronosequence of 12 to 50 years of agroforestry and agricultural lands varied from 35 to 92 Mg/ha or 16 to 42 % of the stock under natural forest. The rate of SOC loss after 12 yrs of agroforestry was 5. 6 Mg /ha/yr, while it declined to 0.9 Mg /ha/yr after 50 yrs. The corresponding losses under agricultural lands were slightly higher. The trend of N losses, although of much lower magnitude (0.24 Mg /ha/yr after 12 yrs to 0.04 Mg /ha/yr after 50 yrs of agroforestry), was generally the same. These results show that the losses of SOC and TN stocks were higher in agricultural lands than in agroforestry but the stocks in both land uses increased with increasing chronosequences of 12 to 50 years.

Key Words
Soil organic carbon, soil nitrogen, SOC and TN stocks, agroforestry, agricultural land, soil profile.

Introduction
The major sources of the emission of greenhouse gases (GHGs) in addition to fossil fuel combustion are conversion of natural ecosystems such as forests and peat land areas to farm and other land uses (Kirby and Potvin 2007). In agricultural landscapes, agroforestry systems can be used as an alternative for economically sound and environmentally friendly land use approach.The C sequestration potential of agroforestry systems is estimated to be between 12 and 228 Mg/ha (Albrecht and Kandji 2008). Sequestering C in soils is often seen as a 'win-win' proposition; it not only removes excess CO_2 from the air, but also improves soils by augmenting organic matter, an energy and nutrient source of biota (Janzen 2006)

In the rift valley of Southern Ethiopia, extensive deforestation, overgrazing and conversion of natural ecosystem into arable land are rampant (Ashagrie *et al.* 2005). Remnant trees deliberately left from the clearance of the wood land and natural forest are scattered all over the agricultural lands. This is the local traditional (park land type of) agroforestry (AF) system prominent in the study area. Crops are grown during the rainy season in both the traditional agroforestry and agricultural lands.

It was reported that soil C and total N stocks in crop land soils was significantly lower than the soil C and total N stocks under natural vegetation in the southern highlands of Ethiopia but quantitative data that show the changes in soil C and N pools following the clearance of natural forest and the eventual land use change are rare. Thus the present study aims to: (i) to investigate the changes in SOC and TN stocks and their concentration under the chronosequences of 12, 20,30 ,40 and 50 years after conversion of forest to agroforestry and agricultural lands, (ii) to assess the distribution of SOC and T N in the soil profile (100 cm depth) ,and (iii) calculate the loss of SOC under chronosequences of these land uses.

Methods
Site description
Three sites namely, Ashoka, Leye and Beseko (7°17´N and 7°20´N and 38°48´E 38°49´E) in Gambo district of the Munessa shashemene forest enterprise of the south eastern highlands were selected. The altitude of the study site ranges from 2137 to 2215 m.a.s.l, with precipitation of 973 mm and maximum temperature of 26.6

^{o}C and minimum of 10.4^{o}C.The dominant forest species are *Podocarpus falcatus* Thunb.ex Mirb*., Croton macrostachys* Hochst.ex Rich., *Prunus africana* (Hook.F.) Kalkm. and *Schefflera abyssinica* (Hochst. Ex A. Rich). Soils of the study area are classified as Andic Paleudalf.

Soil sampling and analysis
Three adjacent land use types; natural forest, traditional agroforestry system and agricultural lands were selected. The later two land uses were of 12, 20, 30, 40 and 50 years of age after conversion from the natural forest. The sampling design followed was complete randomized design with four replicates and soil samples were collected at 0-10, 10-20, 20-40, 40-60, 60--100 cm depth increments from each replicate. The collected soil samples were air dried, grounded and passed through a 2 mm sieve prior to analysis. Separate core samples were drawn for bulk density determination. pH was measured by potentiometric method (Tan 2005) and SOC by titrimetric method (Walkley and Black 1934). Total N was measured using a LECO CHN-1000 Carbon and Nitrogen Analyzer

Measurements and calculations
Soil C stock (Mg/ha) was calculated by equation1.

$$C \text{ stock (Mg/ha)} = BD*C_{conc.}* T*CF_{coarse} \quad \text{(eq.1)}$$

Where Cconc.is carbon concentration (g/100g), BD is bulk density (Mg/m^3), T is depth thickness (m), and CF is correction factor (1- (Gravel % +Stone %) /100).

Statistical Analysis
The effect of land use, soil depth and other parameters were analyzed by the general linear model procedures of SAS. Multiple comparison of means for each class variable was carried out using the student-Newman-keuls (SNK) test at α =0.05.

Results
Distribution of SOC and TN in soil profile under the chronosequences of agroforestry and agricultural lands
In the 0-10 cm depth, SOC and TN under the chronosequence of 12, 20, 30, 40 and 50 of agroforestry and agricultural lands were significantly lower than that under natural forest (P<0.0001). However, SOC and TN under chronosequences of agroforestry and agricultural lands did not differ significantly. In lower depths (>20 cm) chronosequences did not show any significant difference with few minor exceptions.

Stocks of SOC and TN under agroforestry and agricultural lands
The SOC stock under natural forest and agroforestry chronosequence of 40yrs was significantly higher than that under the chronosequence of 12, 20, 30 years of both land uses (P<0.0004). The differences in the SOC stocks under the remaining land uses were not statistically significant. The SOC stock under all chronosequences of agroforestry was in general higher, although not statistically significant, than the corresponding chronosequences of agricultural lands (Table 1). The stocks of SOC and TN consistently increased with increasing chronosequence (from 12 to 50 years) of both land uses, suggesting that with time a new equilibrium in SOC sequestration was attained. The TN stock generally followed the same pattern as SOC. Similar to SOC, the average value of TN stocks under chronosequences of agroforestry were slightly higher than under those of agricultural lands.

Rate of losses of SOC and TN under chronosequence of agroforestry and agriculture
The loss of SOC stock under the chronosequence of 12, 20, 30, 40 and 50 years of agroforestry and agriculture varied from 35 to 92 Mg/ha or 15.9 to 41.5 % of that under natural forest, while the loss TN ranged from 2 to 5 Mg/ha or 11.1 to 27.8 %. Generally, the rate of loss of SOC stocks was higher for the first 12 to 20 years and it declined and approached a steady state in the chronosequences of 40 to 50 years under both land uses (Table 1). The rate of SOC was slightly lower under agroforestry (5.6 to 0.9 Mg /ha/yr) than under agricultural land (6.1 to 1.2 Mg/ha/yr). Similar to SOC, the loss of TN also declined with time. The rate of loss of TN was 0.24 Mg /ha/yr under the chronosequence of 12 yrs but it declined to 0.04 Mg/ha/yr at 50 yrs chronosequence and the corresponding decline under the chronosequence of agricultural lands were 0.32 and 0.07 Mg /ha/yr.

Table 1. Soil organic carbon (SOC) and TN stocks and the rate of change under agroforestry and agricultural lands after conversion from natural forest.

Land uses	SOC		TN	
	Stock (Mg/ha)	Rate of loss (Mg/ha/y)	Stock (Mg/ha)	Rate of loss (Mg/ha/y)
NF	221 ± 13.7 **a**		18 ± 2.2 **a**	
AF_{12}	154 ± 6.2 **bc**	5.6	15 ± 0.6 **a**	0.24
AF_{20}	156 ± 5.2 **bc**	3.2	16 ± 0.6 **a**	0.11
AF_{30}	144 ± 9.4 **bc**	2.6	15 ± 1.0 **a**	0.10
AF_{40}	186 ± 16.1 **b**	0.9	20 ± 3.3 **a**	-0.04
AF_{50}	174 ± 10.6 **bc**	0.9	16 ± 0.8 **a**	0.04
A_{12}	147 ± 8.4 **bc**	6.1	14 ± 0.6 **a**	0.32
A_{20}	129 ± 5.2 **c**	4.6	13 ± 0.7 **a**	0.24
A_{30}	137 ± 10.8 **c**	2.8	16 ± 1.7 **a**	0.06
A_{40}	173 ± 12.6 **bc**	1.2	18 ± 1.4 **a**	0.00
A_{50}	159 ± 10.3 **bc**	1.2	14 ± 0.7 **a**	0.07
	P=0.0001		P=0.1159	

Means followed by the same letter (s) in columns with stocks under land uses are not significantly different ($p \geq 0.05$)
AF= Agroforestry land use of 12, 20, 30.40,50 years and A= Agricultural land use of 12, 20,30,40,50 years of age after conversion of the natural forest

Conclusions

Conversion of natural forest into agroforestry and agricultural lands affected the SOC and TN negatively. Larger proportion of SOC and TN was concentrated in 0 to 20 cm depth and the concentration in this layer in both land uses was significantly lower than in the natural forest. In all chronosequences of agroforestry, SOC stocks were higher than in the corresponding chronosequences of agricultural lands but the SOC loss in the former land use was lower than in the later. The loss of SOC in both agroforestry and agricultural lands was many folds higher in the initial chronosequence of 12 and 20 years than in the later chronosequences of 40 and 50 years. Higher SOC stocks suggest that integrating more trees with proven multipurpose functions in all agricultural landscapes has a higher potential of sequestering SOC.

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