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EFFECT OF CHANGING NATURAL FOREST AND WETLAND TO OTHER LAND USES ON SOIL PROPERTIES AND STOCKS OF CARBON AND NITROGEN IN SOUTH ETHIOPIA

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Abstract: In South Ethiopia, effects of changing two land uses, namely, natural forest (NF) and wetland (WL) each to cropland (CL) and eucalyptus plantation (EP) on soil physical and chemical properties at 0-15 and 15-30 cm depth as well as stocks of soil organic carbon (SOC) and total nitrogen (N) in upper 30 cm depth were studied. In general conversion of both NF and WL to CL and EP in surface soil increased the bulk density, reduced the soil pH, available P and cation exchange capacity (CEC). SOC and total N concentrations declined by conversion of both NF and WL to CL and EP. Stocks of SOC also declined and it was in the order NF or WL > CL > EP for each conversions. On changing NF to CL-1 and EP-1, stocks of SOC declined by 43.2 and 65.0 Mg ha^{-1}; and WL to CL-2 and EP-2 the respective reductions were 14.1 and 24.4 Mg ha^{-1}. Total N stocks declined by 1.3 and 1.1 Mg ha^{-1} on changing NF to CL-1 and EP-1, respectively. For WL changing to both CL-2 and EP-2, total N stock declined by 0.8 Mg ha^{-1}.The results suggested that integrated nutrient management (INM) is necessary to restore degraded soil quality and sequester SOC under changed land uses.

Key word: Land use, natural forest, wetland, cropland, eucalyptus plantation, soil properties, C and N stocks.

1. INTRODUCTION

Land use changing for various functions varies rapidly in many parts of the world. It refers to a change in the use or management of land by humans leading to change in land cover (IPCC, 2000). For instance, wetlands are under a huge threat from conversion to intensive irrigation agriculture, the expansion of human settlements, industrial pollution, agricultural pollution by pesticides, use of fertilizers, water diversion for drainage, and the construction of dams (Atnafu et al., 2011).

Therefore, wetlands are being cultivated due to drop in upland production during drought to meet food demands (Mekonnen & Aticho, 2011). Large shifts in land use have occurred during the 20th century in the south and south western Ethiopia. During this period, forest area declined from 40 to 3 percent as a result of biophysical and social conditions (Dessie & Christiansson, 2008) and currently wetland area is much smaller in size and number. Thus, both natural forest (NF) and wetland (WL) are still under the risk of degradation due to population growth, policy related issues and site management problems. These land use change have their consequence on plants, animals and more generally on soil ecosystems.

As soil sustains vegetation in a given land use by supplying nutrients through recycling of fallen leaves and other plant and organic materials. Land use changes such as forest clearing, cultivation and pasture introduction cause changes in soil chemical, physical and biological properties (Houghton et al., 1999), but their direction and magnitude depend on land cover and land management (Celik, 2005). Further, conversions of natural forest and wetland to crop production have been found to contribute to emission of green house gases (GHGs) causing climate change and create environmental degradation, but little is known in south Ethiopia. Therefore, the aim of the present study was to investigate the effect of changing original natural forest (NF) and wetland (WL) to cropland (CL) and eucalyptus plantations (EP) on the soil properties and stocks of soil organic carbon (SOC) and total nitrogen (TN).

2. MATERIALS AND METHODS

2.1. Description of the study area

The study was conducted at Bera-challekebele of Dale district in Sidama Zone of Southern Nations and Nationalities Peoples Regional (SNNPR) state of Ethiopia (Fig. 1). It lies between $06^{o} 42^{'} 376^{''}$ - $06^{o} 45^{'} 039^{''}$ N and $038^{o}23^{'} 618^{''}$ - $038^{o}23^{'} 886^{''}$E at an altitude range of 1100 to 2800 m with 96, 3 and 1 percent of midland (*Weynadega*), lowland (*Kolla*), and highland (*Dega*) agro climatic characteristics, respectively. It is situated at about 320 km south of Addis Ababa and 42 km south east from Hawassa near Yirgalem town. It receives mean annual rainfall of 1102 mm with mean annual minimum and maximum temperature of 11.8 and 25.3^{o}C, respectively.

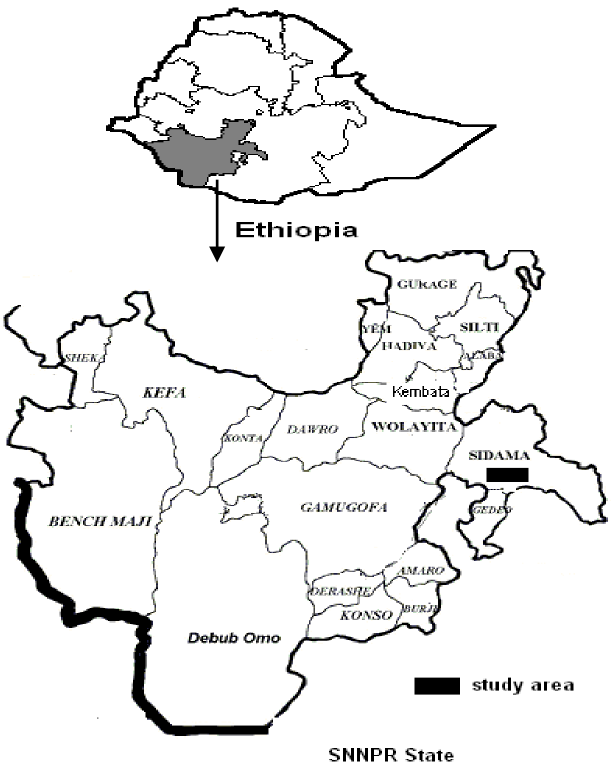


Figure 1. Location of study area in Sidama, SNNPR state, Ethiopia (SNNPR-BoFED, 2004).

Based on FAO soil map of world legend, chromic luvisols derived from fine textured alluvium and colluviums deposits dominate in the study area (SNNPR-BoFED, 2004). Major field crops in the study area include cereals like teff (*Eragrosts teff*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and maize (*Zea mays*), pulses like bean (*Vicia faba*), field pea (*Pisum sativum*), haricot bean (*Phaseolus vulgaris*); and rootand tuber crops like potato (*Solanum tuberosum*), sweet potato (*Ipomea batata*) and enset (*Ensete ventricosum* W.); and cash crops like coffee (C*offea arabica* L.) and plantation trees like *Eucalyptu*s tree are widely grown.

2.2. Land uses and their changes

For the present study, two existing original land uses namely, NF and WL were selected. Two conversions of each to cropland (CL) and eucalyptus plantation (EP) were dominating in the study area. Thus, soil samples were collected from 6 lands uses i.e. NF and its changes to cropland-1 (CL-1) and eucalyptus plantation-1 (EP-1); and WL and its changes to cropland-2 (CL-2) and eucalyptus plantation-2 (EP-2). For the study, remnant NF selected exists on 6 ha with native trees of *Ficus vasta*, *Podocarpus falcatus*, *Syzygium guineense* ,*Cordia africana*, *Millettia ferruginea*; and shrubs and lianas in the understory. Since 1990, by clearing trees of this forest, CL expanded. In this study, 4 ha of continuously cultivated CL-1 under rain fed condition with low inputs for more than 10 years by small farmers was selected. Deforestation of original natural forest at the site introduced plantation of eucalyptus species. Since 1987, its planting was widely adopted by farmers due to its fast growth.
Consequently, for this study, nearly 8-years old EP-1 on 4 ha was selected. Remnant original WL selected for the study existed on 8 ha at the site remains water saturated for more than 6 months per year. However, since 1982, original WL was converted to crop production and 4 ha of CL-2 was selected. Wetland has also been put under eucalyptus plantation since 2007, from which 4 ha of EP-2 was also selected for the study.

2.3. Soil Sampling and analysis

Soil samples were collected at 0-15 and 15-30 cm depths in triplicate from representative fields of 6 lands uses i.e. NF with its two conversions to CL-1 and EP-1 as well as WL with its two conversions to CL-2 and EP-2. Thus, 36 composite samples were collected. Then soil samples were air-dried and ground to pass 2 mm sieve (0.5 mm sieve to determine organic C and total N). Analyses of the soil properties were carried out by adopting standard procedures. Particle size distribution was determined by the modified hydrometer method. The pH and electrical conductivity (EC) were determined using a 1:2.5 soil to water solution ratio. The organic C was estimated by the wet digestion method (Walkley & Black, 1934), total N by Kjeldahl wet digestion and distillation method (Bremner & Mulvaney, 1982), available soil P was analyzed according to Olsen method (Olsen *et. al.*,1954) and cation exchange capacity(CEC) by 1M neutral ammonium acetate method (Chapman, 1965). Additionally, separate core samples were withdrawn from both depths to determine bulk density. Stocks of soil organic C (SOC) and Total N (TN) in mega grams per hectare (Mg ha^{-1}) in the 0-30 cm soil depth were computed by following equation (Wairu & Lal, 2003):

SOC (Mg ha^{-1}) = SOC (g kg^{-1}).T.BD.10… (1)

TN (Mg ha^{-1}) = TN (g kg^{-1}).T.BD.10… (2)

Where: SOC = Soil organic carbon; TN = Total Nitrogen; T = soil depth (m); BD = Bulk density (Mg m^{-3})

The stocks of SOC and total N were estimated in 30 cm soil depth by adding the stocks of two soil depth. Data from the different land uses were analyzed using SAS software, version 9.0 (SAS Institute, 2004). Analysis of variance (ANOVA) was conducted and LSD test was employed to compare the means when they are significantly different.

3. RESULTS & DISCUSSIONS

3.1. Soil properties

The texture of the surface soil varied from clay loam to sandy clay loam under both original land uses and their conversions (Table 1). By converting both natural NF and WL to croplands i.e. CL-1 and CL-2, the sand fraction increased by about 15 and 17 per cent, respectively at 0-15 cm depth. Consequently, converting these original lands uses to CL changed their textural classes to sandy clay loam at this depth. It is attributed to selective removal of clay through water erosion from the surface, as clay declined by 7 and 9 per cent as compared to respective original land uses. Whereas, no change was noticed by converting these original land uses to eucalyptus plantation i.e. EP-1 and EP-2. Similarly, at subsurface no change in texture was observed as it was clay loam under original land uses and their conversions.

Bulk density differed significantly among land uses ($P < 0.05$) and increased significantly with soil depth ($P< 0.01$; Table 1). The highest bulk density of 1.38 and 1.36 g cm^{-3} was found by changing the original NF and WL to CL-1 and CL-2, respectively as it rose by 6.2 and 4.2 per cent at 0-15 cm depth over their respective original land uses. Increased bulk density could be related with long-term cultivation of virgin lands (Rawat et al., 1996) and the breakdown of soil aggregates in cultivated soils (Khormali & Shamsi, 2009). Soil also gets compacted owing to loss of soil organic matter due to accelerated oxidation (Nand Ram, 2000) as well as removal of crop residues from the field (Mohammed et al., 2005). It is also reflected in the relationship between SOC and bulk density at surface soil for original land uses and their conversions by showing significant correlation coefficients of r=-0.92 (p<0.001) for NF and r=-0.95 (p<0.001) for WL.

Table 1.Effect of land use change on physical properties of soils

Original land use	Present land use	Soil depth (cm)	Bulk density (g cm^{-3})	Particle size distribution (%)			Textural class
				Sand	Silt	Clay	
NF	NF	0-15	1.30^c	40.0^b	31.3^a	28.7^a	Clay loam
		15-30	1.34^c	34.7^b	32.3^a	33.0^a	Clay loam
	CL-1	0-15	1.38^a	54.7^a	23.7^b	21.7^b	Sandy clay loam
		15-30	1.42^a	48.7^a	24.0^b	27.3^a	Sandy clay loam
	EP-1	0-15	1.34^a	42.7^b	31.3^a	26.0^a	Loam
		15-30	1.38^b	36.0^b	30.0^a	34.0^a	Clay loam
WL	WL	0-15	1.29^a	36.0^b	31.0^a	33.0^a	Clay loam
		15-30	1.40^a	30.0^b	33.7^a	36.3^a	Clay loam
	CL-2	0-15	1.36^b	52.7^a	23.3^b	24.0^b	Sandy clay loam
		15-30	1.42^a	44.3^a	27.0^b	28.7^b	Clay loam
	EP-2	0-15	1.30^a	36.0^b	33.7^a	31.3^a	Clay loam
		15-30	1.31^b	32.0^b	34.0^a	34.0^a	Clay loam

Mean value within column at each depth and original land uses followed by same letter(s) are non- significantly different.

Moreover, EP-1and CL-1 had more bulk density than NF in the subsoil. The lower bulk densities at subsurface soil under NF could be due to more organic matter, which makes soil loose, more porous and well aggregated thereby reducing the bulk density (Celik, 2005) and soils compacted with increase in soil depth (Everndilek et al., 2004). On the other hand higher soil bulk density was found under original WL than that of EP-2. More compactness under WL could be due to high animal and human trampling in dry season.

Soil pH under NF (5.7 and 5.4) and WL (5.4 and 5.2) was significantly higher than their conversions to CL and EP at both soil depths (Table 2). Change in land use from NF to CL-1 caused a drop of 0.6 and 0.4 pH units; and that from WL to CL-2 of 0.3 and 0.2 pH units at surface and subsurface soils, respectively. The soil pH was significantly low ($P < 0.05$) under croplands and Eucalyptus plantations. This might be due to leaching of bases, harvest and/or removal by crop residues (Kiflu & Beyene, 2013). Eucalyptus plantation made the soil more acidic due to more uptakes of basic cations from soil which is enhanced with growth of the plant (De Bell et al., 1989). It is evident as pH declined by 0.5 to 0.7 units at 0-15 and 15-30 cm under CL-1 and EP-1 and by 0.3 to 0.4 units under CL-2 and EP-2 at the respective depths. It demonstrates that changing of both original land uses of NF and WL to CL and EP can increase acidity in soil.

Electrical conductivity (EC) of NF being 0.08 and 0.07 dSm^{-1} at 0-15 and 15-30 cm depths was highest among all land uses (Table 2). Change of this land use to CL had no effect on EC, whereas to EP-1 decreased EC by 0.02 and 0.03 dSm^{-1} at the respective depths. Similar trends were also noticed in WL on its conversions. In general, the EC values of the soils in the land uses were very low and there is less soluble salt concentration in the study area soil.

Available P in the soil was significantly affected by land use ($P < 0.05$) and soil depth ($P < 0.01$). The highest available P was observed in soils of NF, intermediate in CL-1 and the lowest in EP-1 at both soil depths. Available P in the soil did not differ between WL and CL-2, but it was significantly lower ($P < 0.05$) in EP-2 than WL and CL-2. The high available P could be attributed to the high SOC and its mineralization. Further the high available P could also be attributed to organic ions which may compete with available P for sorption sites, thereby increasing P availability (Nziguheba et al., 2002).

CEC differed significantly by land use ($P <0.001$) and soil depth ($P < 0.05$). The CEC of original land uses and their conversions ranged from 19.6 to 27.6 for NF and from 20.7 to 24.5cmol (+) kg^{-1} for WL (Table 2). It was higher at surface soil than at subsurface. Among land uses of NF and its changes, the NF had the highest CEC at both depths while the lowest CEC was found under EP-1 (Table 2). In the case of WL and its conversions, the original WL showed highest CEC whereas the lowest was under CL-2 at both depths. It is due to soil organic matter which regulates CEC directly. Soil management practices with reduced residue input and intensive cultivation also resulted in reduced soil organic matter and thus reduced CEC (Lemenih et al., 2005).

Soil organic carbon (SOC) and total N concentrations varied considerably ($P < 0.0001$) among land uses (Table 2). Natural forest had the highest SOC concentration (40.9 g kg^{-1}) and it declined to about 34% and 50% by its change to CL-1 and EP-1, respectively in the surface soil layer. Similarly, total N was maximum (2.7 g kg^{-1}) under NF and reduced when converted to other land uses.

Table 2.Effect of land use change on chemical soil properties**.**

Original land use	Present land use	Soil depth (cm)	pH	EC (dSm^{-1})	SOC (gkg^{-1})	Total N (gkg^{-1})	Av. P	CEC (cmol (+)kg^{-1})
NF	NF	0-15a	5. 7a	0.08a	40.9a	2.7a	3.37a	27.6a
		15-30	5.4a	0.07a	33.4a	2.3a	3.0a	25.5a
	CL-1	0-15	5.1b	0.07a	26.2b	2.3b	2.73b	22.7b
		15-30	5.0b	0.05a	23.2b	1.8b	1.81b	21.6b
	EP-1	0-15	5.0b	0.06b	20.6c	2.0b	1.68c	19.6c
		15-30	4.9b	0.04b	19.6c	2.3b	1.53c	18.3c
WL	WL	0-15	5.4a	0.07a	28.8a	2.3a	3.25a	24.5a
		15-30	5.2a	0.05a	25.9a	1.7a	2.03a	21.4a
	CL-2	0-15	5.1b	0.07a	25.5b	2.2b	3.1a	20.7b
		15-30	5.0b	0.05a	21.3b	1.4b	2.34a	19.5b
	EP-2	0-15	5.0b	0.05b	23.9b	2.0b	1.87b	21.0b
		15-30	4.9b	0.04b	20.8b	1.6b	1.57b	20.7b

Mean values within columns among land uses at each depth followed by same letters are non-significant at $P<0.01$

In case of remnant WL and its change to CL-2 and EP-2, the original WL showed the highest SOC (28.8 g kg^{-1}) and the lowest under EP-2 even if the time of conversion to EP-2 was shorter (5 years old) as compared to EP-1 (8 years old). Therefore, the soil showed rapid reduction in SOC under EP and CL. It is explained by the faster decomposition rate of soil organic matter due to soil disturbance under converted land uses. Further faster SOC decomposition can be attributed to draining of the WL and deforestation of NF.

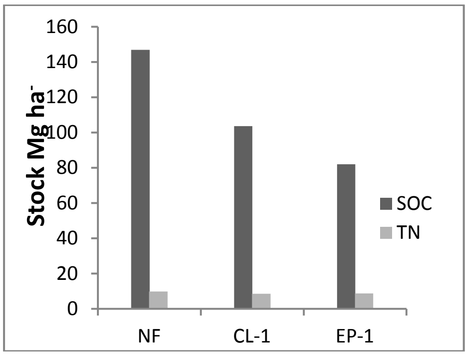
SOC concentration differed significantly by soil depth ($P < 0.001$), but soil total N did not differ significantly. Decline in SOC of remnant NF to its conversions is attributed to the loss of SOC through land use change during forest clearing and soil disturbance. Yifru & Taye (2011) also reported the order: virgin forest > cultivated land for SOC status. Mostly cultivated soils in Ethiopia are poor in SOC as a result of low organic inputs applied and complete removal biomass from the surface soil (Yihenew, 2002) along with oxidation of organic matter due to breakdown of soil aggregates on cultivation. The amount of N lost or sequestered was closely related to SOC dynamics showing that similar controls apply to both (Lemma &Olsson, 2006).

3.2. Stocks of organic carbon and total N

SOC and total N stocks under various land use types differed significantly ($P < 0.001$; Fig.2). Stocks of organic C for NF and its conversions ranged from 82.0 to 146.9 Mg ha^{-1} and between 87.6 - 111.0 Mg $ha^{-1}$for WL and its conversions. Highest stocks of organic C was observed under original land uses of NF and WL. In case of NF, it declined by 43.2 and 65.0 Mg ha^{-1} by changing original land use to CL-1 and EP-1, respectively. For WL, stocks of organic C reduced by 14.1 and 24.4 Mg ha^{-1} by converting original land use to CP-2 and EP-2, respectively; but SOC stock in both of these conversions was at par. Total N stocks declined by 1.3 and 1.1 Mg ha^{-1} on changing NF to CL-1 and EP-1, respectively. For WL conversion to both CL-2 and EP-2, total N stock declined by about similar amounts (0.8 Mg ha^{-1}).

From those results, it is evident that change in land use affected the SOC stock drastically particularly in NF. In similar study in the upper 30 cm 24% of SOC following sugarcane cropping in Ecuador (Rhoades et al., 2000) which is closely related to the loss in the present study. Our findings are also in conformity to those of Lemenih et al., (2005) where low SOC stocks were noticed under cropland as compared to adjacent forest. Yiru & Taye (2011) also reported more SOC in virgin forest than in cultivated land. Most cultivated soils are poor in SOC due to less application of organic inputs and complete removal of biomass from the soil. The removal of crop residues from croplands (CL-1 and CL-2) at the present study sites decreased the SOC (Table 2) than the original land uses of NF and WL owing to its oxidation as a result of long-term cultivation (Nand Ram, 1995). Mekonnen & Aticho (2011) also found reduced organic C under eucalyptus plantation and cultivated land than the nearby wetland attributable to increased drainage resulting in oxidation of organic matter under changed land uses.

Lemenih et al., (2005) also noted total N in the soil declines exponentially following conversion of NF to CL with increasing years of cultivation. After conversion to CL, NF soils lost 38% of their initial total N (Lemma & Olsson, 2006), which is much higher than lost in the present study. This could be attributed to the small age of cultivation in the present study. In pine plantation, total N in the soil were depleted (Markewitz et al., 2002), much of which was accounted for uptake into plant biomass.



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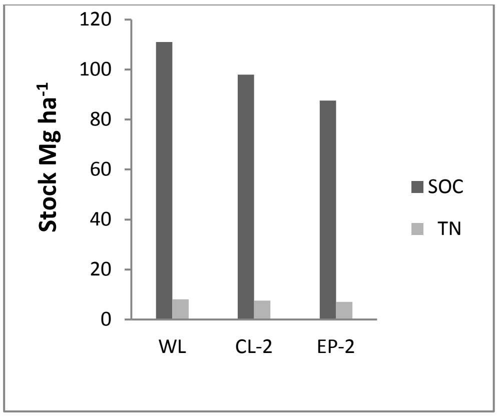

b.

Figure 2. Effect of a. NF and b. WL conversion to CL and EP on stocks of SOC and total N in South Ethiopia

Stocks of total N for original land uses and their conversions ranged from 7.6 to 9.9 Mg ha^{-1} for NF and 7.1 to 8.1 Mg ha^{-1} for WL. The highest N stock was observed under original NF and WL By changing NF to CL-1 and EP-1 it was lowered by 2.3 and 0.9 Mg ha^{-1}as compared to NF, respectively. For WL and its conversions not much appreciable decrease was noticed. Slightly lower total N stock under CL-2 and EP-2 than WL may be owing to removal of crop residues from cropland and lack of residues under the shade of eucalyptus plants as reflected in lesser N in soil (Table 2).

4. CONCLUSIONS

Changing both original land uses of NF and WL to CL and EP affected surface soil physical and chemical soil properties. Soil texture changed to sandy clay loam from clay loam under CL due migration of clay by water erosion, soil got compact due to increased bulk density, and acidity increased owing to base cations removal from the soil by leaching, crop harvest and removal of crop residue. Status of SOC and total N as well as CEC reduced. Stocks of SOC and total N showed a declining trend as a result of reduced organic matter owing to its oxidation and crop residue removal. Therefore, to arrest the decline in soil quality integrated nutrient management (INM) using both organic and inorganic sources of nutrients should be adopted for replenishing the degraded soil properties and sequestering SOC under CL and EP.

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