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EFFECTS OF LANDUSE ON SOIL ORGANIC CARBON AND NITROGEN IN SOILS OF BALE, SOUTHEASTERN ETHIOPIA

[EFECTO DEL USO DEL SUELO SOBRE EL CONTENIDO DE CARBONO ORGÁNICO Y NITRÓGENO DEL SUELO EN BALE, ETIOPÍA]

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SUMMARY

Agricultural and economic growth in Ethiopia are constrained by the deteriorating natural resource base, especially in the highlands where 80% of the population lives. This threat stems from the depletion and degradation of the vegetation cover of the country, especially forests and unsustainable farming practices. This study investigated the effects of different land-uses on soil organic carbon and total nitrogen. Both, soil organic carbon (SOC) and total nitrogen (TN) were responsive to land use change. Considering the top 0-5 cm depth, the highest SOC (12.95%) and TN (0.8%) were recorded in natural forest while the least, 2.56 and 0.21%, respectively from cultivated lands. The lowest SOC content in cultivated soils could be due to reduced inputs of organic matter and frequent tillage which encouraged oxidation of organic matter. SOC and TN consistently declined with increasing soil depth in all land use systems. The SOC and TN content calls for restoration of soil organic matter through sustainable soil management.

Keywords: Land use; soil organic carbon; soil quality; total nitrogen; vegetation cover

RESUMEN

El crecimiento agrícola y económico de Etiopía está limitado por el deterioro de sus recursos naturales, especialmente en los altiplanos donde vive el 80% de su población. Esta amenaza es resultado de agotamiento y degradación de cobertura vegetal del país, especialmente el bosque, y prácticas agrícolas no sustentables. Este trabajo investigó los efectos de diferentes usos del suelo sobre su contenido de carbono orgánico y nitrógeno total. Tanto el carbono orgánico (SOC) como el nitrógeno total (TN) tuvieron variación en función del uso del suelo. Considerando la capa superior (0-5 cm profundidad), el mayor contenido de SOC (12.95%) y TN (0.8%) fue obtenido en los suelos de bosque, mientras que los menores valores (2.56 y 0.21% respectivamente) se observaron en suelos cultivados. El menor SOC en suelos cultivados puede ser resultado de las menores entradas de materia orgánica y prácticas frecuentes de preparación del suelo que promueven la oxidación de la materia orgánica. El contenido de SOC y TN declinó consistentemente a mayor profundidad del suelo bajo todos los esquemas de uso de suelo. Los valores SOC y TN indican la necesidad de restablecer la materia orgánica del suelo mediante prácticas sustentables de manejo del suelo.

Palabras clave: uso del suelo; carbono orgánico; calidad del suelo; nitrógeno total; cubierta vegetal

INTRODUCTION

Ethiopia has one of the oldest agrarian cultures in the sub-Saharan Africa with a large agricultural potential. Agriculture is not only the back bone of the economy but also the major occupation for nearly 85% of the population. Furthermore, long-term economic development and poverty alleviation programs in Ethiopia are based on the development in agricultural economy (EFAP, 1994; Anonymous, 2002). Survival and well being of communities that are dependant on subsistence agriculture and centuries old farming practices such as Ethiopia depend on the extent of maintaining soil fertility and other soil quality parameters (Heluf and Wakene, 2006).

Soil organic C (SOC) and total N (TN) contents play a crucial role in sustaining soil quality, crop production, and environmental quality (Bauer and Black, 1994; Robinson *et al*., 1994) due to their effects on soil physical, chemical, and biological properties (Sainju and Kalisz, 1990).The type of land use system is an important factor that controls soil organic matter levels since it affects the amount and quality of litter input, the litter decomposition rates and the processes of organic matter stabilization in soils (Römkens *et al*., 1999; Six *et al*., 1999, 2002a). Changes of land use and management practices influence the amount and rate of SOM losses (Guggenberger *et al*., 1994, 1995).

There is considerable concern that land use change could alter soil carbon(C) (Houghton, 1999) and nitrogen (N) (Potter *et al*., 1996) cycle. According to Du Preez and Synman, (1993) loss of SOM results in soil degradation and once organic matter is lost, recuperation is slow process and both C and N are needed for its restoration. The rapidly increasing population pressure on the highlands of Ethiopia has led to vast changes in land use pattern mainly caused by increasing agricultural production. In this region, cultivated lands showed slow but continuously increasing trend at the expense of forest and grasslands over the last four decades (Getu, 2000; Kebrom and Dedlund, 2000; Selamyihum and Tekalign, 2003; Zewdu *et al*., 2004). Too, information on the influence of these changes in land use system on soil chemical properties is limited especially in Bale highlands, southeast Ethiopia which are normally compared to a reference soil that has remained under permanent pasture or virgin vegetation, considered a natural control (Gregorich *et al*., 1997).This study investigated the influence of different land use systems on soil organic carbon and nitrogen in Bale highlands of Ethiopia.

MATERIAL AND METHODS

Description of study sites

The sites are located in Bale Zone of Oromiya region, Southeastern Ethiopia both of which receive bimodal rainfall pattern. Accordingly, there are two distinct seasons favorable for crop production. These seasons are named locally based on the time of crop harvest, *ganna* and *bona*. The *ganna* season usually extends from March to July while the *bona* season extends from August to December. The total annual rainfall for Sinana Dinsho ranges from 750 to 1000 mm (average 860 mm), with average maximum and the minimum temperature of 21°C and 9°C, respectively and for Gassera District the mean annual rainfall is 1169 mm.

The sites in Gassera lies at an altitude of 2305–2400 m a.s.l, with a 2-13% slope and Sinana-Dinsho site lie at an altitude ranging between 2320-3120 m a.s.l. Both study sites were characterized by mixed farming systems, where both livestock and crop farming are the important agricultural practices. Cattle are important in the agricultural production system as they provide draught and threshing power, as well as manure to improve soil fertility. Crop residues are used as for livestock feed. Monocropping of cereals, mainly wheat and barley, is a common practice in the area.

Soil sampling and laboratory analyses

In 2005, soil samples were collected from four depths (0-5, 5-15, 15-30 and 30-60 cm) for all land uses. The number of soil samples collected in the study areas were: 2 Fallow, 9 cultivated, 3 natural forest and 5 grasslands from Sinana-Dinsho; and 5 Fallow, 16 cultivated and 7 natural grasslands from Gassera.

Soil samples were dried at room temperature and ground and sieved to pass through a 2 mm sieve screen. The samples were analyzed for OC using wet oxidation methods of Walkley and Black (1934) and TN by Kjeldahl procedure of Bremner and Mulvaney (1982).

Data analysis

One way analysis of variance (ANOVA) was used to compare the effects of different land uses on organic carbon (C), total nitrogen (N) and C/N ratios at the four soil depths separately. The LSD test was employed to compare the means. Data analyses were conducted using SAS software, Version 9.0 (SAS Institute, 2002).

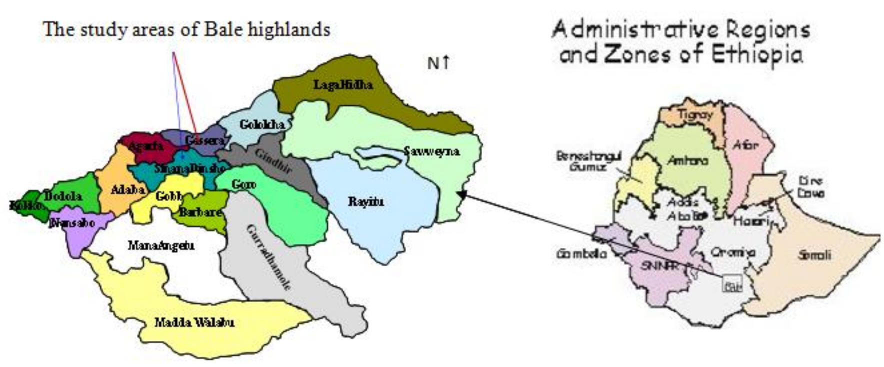

Figure1. Map indicating the study areas in Bale highlands, southeast Ethiopia

RESULTS AND DISCUSSION

Soil Organic Carbon

The effects of land use systems on soil organic carbon and total nitrogen are presented in Tables 1 and 2. Soil organic carbon was significantly affected by the type of land use systems. In all soil depth, except 30-60 cm, organic carbon is lower in cultivated fields as compared to other land uses. For instance, the analysis of surface sample (0-5 cm) at Sinana Dinsho showed that the highest SOC (12.95%) was recorded from soils under virgin forest and the least SOC (2.75%) was in cultivated soil. Similarly, the highest SOC (7.58%) was recorded in soils under grassland followed by fallow lands (4.09%) and the least in cultivated soils (2.56%) at Gassera district in similar depth. Most cultivated soils of Ethiopia are poor in organic matter contents due to low amount of organic materials applied to the soil and complete removal of the biomass from the field (Yihenew, 2002), and due to severe deforestation, steep relief condition, intensive cultivation and excessive erosion hazards (Eylachew, 1999). In agreement with this all agricultural fields in the study areas had low organic carbon content according to the classification presented in Landon (1984). Barrow (1991) states that an organic matter content of less than two per cent for tropical soils is an indication of soil degradation involving a highly raised risk of soil erosion.

The lowest soil organic carbon in cultivated fields could be due to low organic matter inputs coupled by reduced physical protection of SOC as a result of tillage and increased oxidation of soil organic matter. This was in agreement with John *et al*. (2005) who reported an increasing SOC concentration in the A horizons in the order arable soils < grassland soil <forest soil. The result of the present study is also in conformity with the findings of many other authors (Dawit *et al*., 2002; Celik, 2003; Merino *et al*., 2004; Heluf and Wakene, 2006; Gebeyaw, 2007) elsewhere.

The SOC of virgin forestlands were higher than the virgin grasslands most probably because of differences in management practices between the two-land use systems. Soils of the forest sites were well protected (under National park at Sinana-Dinsho), with little disturbance but that of the virgin grassland were poorly managed; heavily overgrazed, and mostly they were susceptible to surface erosion and water logging. In addition to this cow dung is largely used as fuel source rather than enriching SOC of grassland sites.

Irrespective of the land use considered, there were decreasing trends of SOC stock with increasing soil depth, implying that the surface soil layer is the most biologically active part of the soil profile. However, the decrease of SOC was gradual in cultivated and fallow lands as compared to virgin forestland, may be due to disturbances by tillage implements, which could mix different soil layers. In line with this, Gregorich *et al*. (1995) reported that the concentration of organic carbon (OC) in the forest soil decreased with depth by more than 10-fold in the surface 30 cm, from 139 g/kg soil in the 0-15 cm layer to 12 g/kg soil in the 15-30 cm layer. In contrast, the OC concentration under corn was similar for soil layers within the plow layer, ranging between 19 and 21 g/kg of soil. This finding also corroborates the reports of various workers (Grunzweig *et al*., 2004; Lal and Puget, 2005; Malo *et al*., 2005; Heluf and Wakene, 2006).

Total Nitrogen

Similar to organic carbon, there was significant variations in total nitrogen among different land use (Tables 1 and 2). Total nitrogen increased in order of fallow land < cultivated land < grassland < forestland at Sinana Dinsho district (Table 1). Similarly, higher total nitrogen was recorded in grassland soils than cultivated soils at Gassera (Table 2). But, as opposed to Sinana Dinsho, the total nitrogen content was higher in fallow lands than cultivated soils in 0-5 and 5-15 cm depth at Gassera.

Generally, cultivated soils had significantly lower total N at all depths when compared to grasslands and forestlands, indicating that continuous cultivation ultimately reduces the total nitrogen contents in the soil. The findings of Nega (2006) indicated that average total N increased from cultivated to grazing and forest land soils in that order. According to Malo *et al*. (2005), the lower level of nitrogen in cultivated fields compared to other land use implies that fertilizer additions have not replaced the total N lost due to harvest removal, leaching, and humus losses associated with cultivation. The continuous cultivation could have also aggravated organic carbon oxidation and loss of nitrogen in cultivated fields resulting in lowest contents.

In agreement with these findings, Heluf and Wakene (2006) recorded the highest total N on surface soil layers of vigin land compared to research field and farmer's field around Bako area, Ethiopia. Dawit *et al*. (2002) and Malo *et al*. (2005) also independently reported higher total nitrogen in uncultivated lands than cultivated lands.

The contents of total nitrogen was strongly associated ($r = 0.85$) with total organic carbon and decreased consistently with increasing soil depth under all land use systems. The result of the present study agrees with the findings of many other workers (Malo *et al*., 2005; Heluf and Wakene, 2006). According to Malo *et al*. (2005) the decrease in total nitrogen with increasing depth was due to declining humus with depth. Following the rating indicated by Landon (1984) for tropical soils, the surface soils of the forest lands and grasslands qualify for high and medium status of N, respectively whereas, the fallow and cultivated fields qualifies for low to medium level.

C/N ratio

In this study the carbon to nitrogen (C/N) ratio was affected by land use systems (Table 3). Moreover, the ratio was narrower in soils of cultivated lands as compared to other land uses indicating that mineralization and oxidation of organic matter is higher in cultivated soils. This is in agreement with Seeber and Seeber (2005) who reported that cultivation alters humus content and thus narrows the C/N ratio. Native lands usually have higher C-and N-contents than abandoned and cultivated areas, because cultivation leads to losses of C and N. As the loss of N due to cultivation is much lower than the loss of C, the C/N ratio narrows. Abandonment, on the other hand, organic matter to accumulate and the C/N ratio widens (Sebber and Seeber, 2005).

Such differences in C/N ratios among land use systems may also reflect variations in qualities of organic residues entering the soil organic matter pool and could be attributed to contrasting vegetation covers. Caravaca (2002) found lower C/N ratios in cultivated fields than for uncultivated soils and ascribed the higher C/N ratios to the input of relatively recent materials of plant or microbial origin in non-cultivated soils. The present study is also in agreement with the findings of John *et al*. (2005) which reported greater C/N ratios in forest soils than agricultural soils. Similarly, Puget and Lal (2005) reported higher C: N ratio in forest soil as compared to soils under cultivation and pasture.

Table 1: Effects of Land use types on carbon and total Nitrogen at Sinana Dinsho

Land use system	Total Nitrogen (%)				Organic carbon (%)			
	Soil depth				Soil depth			
	0-5	5-15	15-30	30-60	0-5	5-15	15-30	30-60
Forestland	0.80	0.50	0.34	0.19	12.95	7.76	4.54	2.86
Grassland	0.44	0.31	0.25	0.17	7.03	4.65	2.31	2.39
Fallow	0.21	0.13	0.12	0.09	5.71	3.33	2.64	1.72
Cultivated	0.21	0.19	0.17	0.16	2.75	2.45	2.18	1.97
LSD (P<0.05)	0.07	0.05	0.05	0.03	1.44	0.91	0.69	0.65

Table 2: Effects of Land use types on organic carbon and total Nitrogen at Gassera

Land use system	Total Nitrogen (%)				Organic carbon (%)			
	Soil depth (cm)				Soil depth (cm)			
	0-5	5- 15	15-30	30-60	0-5	5- 15	15-30	30-60
Grassland	0.39	0.29	0.22	0.15	7.58	4.81	2.83	1.86
Fallow	0.34	0.25	0.18	0.13	4.09	2.88	2.18	1. 52
Cultivated	0.23	0.22	0.19	0.16	2.56	2.45	2.17	1.75
LSD (P<0.05)	0.04	0.03	0.029	0.029	0.63	0.44	0.34	0.3

Table 3. Effects of Land use types on C/N ratio.

	Land use systems				
	Sinana Dinsho				
	Forestland	Grassland	Fallow	Cultivated	LSD (P<0.05)
0-5	16.04	16.91	27.42	13.53	3.73
5-15	15.41	15.74	24.99	12.57	2.99
15-30	13.77	9.89	21.22	13.28	3.57
30-60	14.19	14.62	20.34	12.43	3.57
	Gassera				
0-5 cm	n.d*	20.15	13.55	11.54	2.59
5-15 cm	n.d	16.84	12.83	11.86	2.11
15-30 cm	n.d	13.83	14.50	12.57	2.98
30-60 cm	n.d	13.55	16.66	13.10	4.57

*n.d = not determined

NS= not significant at 5% level of probability

CONCLUSIONS

Land use systems influences soil organic carbon and total nitrogen in soils. Accordingly, cultivated soils had lower amounts of organic carbon and nitrogen than other land use systems, suggesting the need for sustainable cropping systems such as crop rotation, addition of organic matter and crop residues to reverse the situation. The low carbon input from the agricultural crop could not compensate for the large mineralization of organic matter and N-losses in cultivated fields. Variation of organic carbon and nitrogen among different land use systems were minimal on the lower soil layer as compared to the surface soil layer, implying that the surface soil layer was most affected by different management practices. On the basis of the above findings, there is a need to develop proper land use policy and sustainable soil management and cropping practices to combat the ongoing soil degradation and improve soil fertility in the study area.

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REFERENCES

Anonymous, 2002. Ethiopia: sustainable development and poverty reduction program. Federal Democratic Republic of Ethiopia, Ministry of Finance and Economic Development, Addis Abeba.

Barrow, C.J. 1991. Land degradation: Development and break-down of terrestrial environments. Cambridge University Press, Cambridge.

Bauer, A., and Black, A.L. 1994. Quantification of the effect of soil organic matter content on soils productivity. Soil Science Society of America Journal. 58: 186-193.

Batjes, N.H. 1996. Total carbon and nitrogen in the soils of the world. European Journal of Soil Science. 47:151-163.

Bremner, J.M., and Mulvaney, C.S. 1982. Nitrogen-Total. In: Page, A.L., Miller, R.H., and Keeney, D.R. (eds.). Methods of soil analysis. Part 2: Chemical and Microbial Properties, 2nd ed. Agronomy No. 9. American Society of Agronomy. Madison, Wisconsin, USA. 595-624.

Caravaca, F., Masciandaro, G., and Ceccanti, B. 2002. Land use in relation to soil chemical and biochemical properties in a semiarid Mediterranean environment. Soil and Tillage Research. 68: 23-30.

Celik, I. 2005. Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. Soil and Tillage Research. 83: 270-277.

Dawit Solomon, Fritzasche, F., Tekalign Mamo, Lehmann, J. and Zech, W. 2002. Soil organic matter composition in the sub-humid Ethiopian highlands as influenced by deforestation and agricultural management. Soil Science Society of America Journal. 66:68-82

Du Preez, C.C. and Snyman, H.A. 1993. Organic matter content of a soil in a semi-arid climate with three long standing veld conditions. African Journal of Range and Forage science. 10(2): 108-110.

EFAP (Ethiopian Forestry Action Program). 1994. The Challenge for Development, vol.2. Ministry of Natural Resources Development and Environmental Protection, Addis Ababa.

Eylachew Zewdie. 1999. Selected physical, chemical and mineralogical characteristics of major soils occurring in Chercher highlands, eastern Ethiopia. Ethiopian Journal of Natural Resource. 1(2): 173-185.

Getu Zeleke. 2000. Landscape dynamics and soil erosion process modeling in the northwestern Ethiopian highlands. African Studies Series A16. Berne, Switzerland. Geographica Bernensia.

Gebeyaw Tilahun. 2007. Soil fertility status as influenced by different land uses in maybar areas of south Wello zone, north Ethiopia, M.Sc. Thesis Submitted to School of Graduate Studies, Alemaya University, Ethiopia. 86p.

Gregorich, E.G., Ellert, B.H., and Monreal, C.M. 1995. Turnover of soil organic matter and storage of corn residue carbon estimated from natural ^{13}C abundance. Canadian Journal of Soil Science. 75: 161-164.

Gregorich, E.G., Carter, M.R., Doran, J.W., Pankhurst, C.E., and Dwyer, L.M. 1997. Biological attributes of soil quality. In: Gregorich, E.G., Carter, M.R. (Eds.), Soil Quality for Crop Production and Ecosystem Health. Elsevier, Amsterdam, pp.81–113.

Grunzweig, J.M., Sparrow, S.D., Yakir, D., and Chapin III, F.S. 2004. Impact of Agricultural Land-use Change on Carbon Storage in Boreal Alaska. Global Change Biology. 10: 452-472.

Guggenberger, G., Christensen, B.T., and Zech, W. 1994. Land use effects on the composition of organic matter in particle-size separates of soil: I. Lignin and carbohydrate signature. European Journal of Soil Science. 45: 449–458.

Guggenberger, G., Zech, W., and Thomas, R.J. 1995. Lignin and carbohydrate alteration in particle-size separates of an Oxisol under tropical pastures following native savanna. Soil Biology and Biochemistry. 27: 1629–1638.

Heluf Gebrekidan and Wakene Negassa. 2006. Impact of land use and management practices on chemical properties of some soils of Bako area, western Ethiopia. Ethiopian Journal of Natural Resources. 8(2): 177-197.

Houghton, R.A. 1999. The annual net flux of carbon to the atmosphere from changes in land use 1850-1990. Tellus. 51B: 298-313.

John, B., Yamashita, T., Ludwig, B., and Flessa, H. 2005. Storage of organic carbon in aggregate and density fractions of soils under different types of land use. Geoderma. 128:63-79.

Kebrom Tekle and Hedlund, L. 2000). Land-cover changes between 1958 and 1986 in Kalu district, Southern Wello, Ethiopia. Mountain Research and Development. 20:42-51.

Lal, R., and Puget, P. 2005. Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. Soil and Tillage Research. 80: 211-213.

Landon, J.R. 1984. Booker tropical soil manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Booker Agriculture International, London.

Malo, D.D., Schumacher, T.E., and Doolittle, J.J. 2005. Long-term cultivation impacts on selected soil properties in the northern Great Plains. Soil & Tillage Research. 81: 277-291

Merino, A., Perez-Batallon, P., and Macias, F. 2004. Responses of soil organic matter and greenhouse gas fluxes to soil management and land use changes in a humid temperate region of southern Europe. Soil Biology and Biochemistry. 36: 917-925.

Nega Emiru. 2006. Land use changes and their effects on physical and chemical properties in Senbat sub-watershed, western Ethiopia. M.Sc.Thesis Submitted to School of Graduate Studies, Alemaya University, Ethiopia. 72p.

Potter, C.S., Matson, P.A.,Vitousek, P.M., and Davidson, E.A. 1996. Process modeling of controls on nitrogen trace gas emissions from soils worldwide. Journal of Geophysical Research. 101(D1): 1361-1377.

Robinson, C.A., Cruse, R.M., and Kohler, K.A. 1994. Soil management. In: Hatfield, J.L. and D.L. Karlen (Eds.), Sustainable Agricultural Systems. CRC Press, Boca Raton, FL, pp. 109-134.

Römkens, P.F.A.M., van der Pflicht, J., and Hassink, J. 1999. Soil organic matter dynamics after the conversion of arable land to pasture. Biology and Fertility of Soils. 28: 277–284.

Sainju, U.M., and Good, R.E. 1993. Vertical root distribution in relation to soil properties in New Jersey Pinelands forest. Plant and Soil. 150: 87-97.

Sainju, U.M., and Kalisz, P.J. 1990. Characteristics of “coal bloom” horizons in undisturbed forest soils in eastern Kentucky. Soil Science Society of America Journal. 54: 879-882.

SAS Institute. 2002. The SAS System for Microsoft Windows. Release 9.0, Cary, NC, USA.

Schlesinger, W.H. 1990. Evidence from chronosequence studies for a low carbon storage potential of soils. Nature. 348:232-234.

Seeber, J., and Seeber, G.U.H. 2005. Effects of land-use changes on humus forms on alpine pastureland (Central Alps, Tyrol). Geoderma. 124:215-222.

Selamyihun Kidanu and Tekalign Mamo. 2003. Land-use changes and Erosion on some highland soils of Ethiopia. Ethiopian Journal of Natural Resources. 5(2):215-231.

Six, J., Elliott, E.T., and Paustian, K. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Science Society of America Journal. 63: 1350–1358.

Six, J., Conant, R.T., Paul, E.A., and Paustian, K. 2002a. Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. Plant and Soil. 24: 155–176.

Walkley, A., and Black, C.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science. 37: 29-38.

Yihenew Gebreselassie, 2002. Selected chemical and physical characteristics of soils Adet research center and its testing sites in North-Western Ethiopia. Ethiopian Journal of Natural Resources 4(2): 199-215.

Zewdu Eshetu , Giesler, R., and Hogberg, P. 2004. Historical land use pattern affects the chemistry of forest soils in the Ethiopian highlands. Geoderma 118: 149-165.

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