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Physico-chemical Soil Properties of Semiarid Ethiopia in Two Land Use Systems: Implications to Crop Production

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ABSTRACT

Physico-chemical study of soil was done to quantify and make comparative analysis of the major soil fertility status of semiarid part of east Shewa. Six study sites (3 from each district) and thirty composite soil samples five plots from each site were analysed to determine the major soil physical and chemical parameters and asses the variation of soil properties across locations. Analysis of variance was performed for soil parameters between locations using the general linear model procedure of the Statistical Analysis System. A post hoc separation of means was done by least significant difference test after main effects were found significant at $p<0.05$. The result indicated that transhumant land use system was more environmental friendly than the settled farmers land use. This was confirmed by the little soil bulk density and high soil organic carbon in transhumants land use system than settled farmers. Silt fraction varied significantly across locations ($p = 0.01$ across locations. The textural class for all locations was silty clay loam except at Galcha which was silty clay. The mean values of bulk density of soils of the study area were less than 1.3 g cm^{-3} ranged from 0.77 g cm^{-3} at DigaluTiyo to 1.01 g cm^{-3} at TiriBiretti. It is an indication of good level of organic matter in the soil. Hence, the area can be used for crop cultivation and forage production provided there is sufficient water in the area.

Key words: Soil fertility, Ethiopia, Boosat, Fantalle, phyisico-chemical properties

INTRODUCTION

In Ethiopia where agriculture is the mainstay of the national economy, agricultural production has been highly dependent on natural resources for centuries (Amsalu *et al*., 2007). However, increased human population has degraded natural resources in the country and became a serious threat to sustainable agriculture (Zeleke and Hurni, 2001). Degradation of soil resource as a result of natural and anthropogenic factors such as soil erosion, nutrient mining, inappropriate land use system and inadequate supply of nutrients was very common in the country. Low soil fertility is one of the bottlenecks to sustain agricultural production and productivity in Ethiopia. Hence, integrated soil nutrient management is an option as it utilizes available organic and inorganic nutrients to build ecologically sound and economically viable farming system (Gruhn *et al*., 2000).

Management of the fertility of soils to preserve soils for the next generation and for their most effective use, it is essential to understand their nature and properties (Page *et al*., 1992). The basic purpose of soil fertility evaluation is to provide information on nutrient status of the soils and to predict the relative response of soils to fertilizer application. Site-specific estimation of fertility status of a soil in a given agroecology is therefore becoming important for rational fertilizer uses and other soil conservation purposes (Gebreselassie, 2002). However, in the study area, Boosat and Fantalle districts, the physical and chemical properties of the soils were not scientifically studied and documented. The knowledge and understanding gained would be essential for managing land without letting it deteriorate and for protecting and restoring it. It also helps to formulate and improve sound policies in land use locally, nationally and regionally. Therefore, the objective of this study was to quantify and make comparative analysis of the major physico-chemical properties of the soil of semiarid parts of east Shewa, Ethiopia.

MATERIALS AND METHODS

Study area: The study was conducted in semi-arid part of east Shewa in Fantalle and Boosat districts located between 7°12'-9°14' N latitudes and 38°57'-39° 32' E longitudes in the northern part of the Great East African Rifty Valley in Ethiopia. The climate of the area is hot with erratic, variable rainfall and unreliable for agricultural activities. Economic activities of the area are mostly livestock production but people in Boosat generally practice mixed agriculture consisting of livestock and crop production.

Soil sampling and laboratory analysis: Soil samples were taken using auger from different points in a plot from six locations, at the depth of 0-25 cm. These samples were collected from nearly the same slopes to minimize the effect of topographical differences on soil properties (Okalebo *et al*., 2002). The soil samples were collected from the same plots where WEPs samples were collected. This was to characterize the habitats of WEPs at least in terms of soil fertility requirement in the wild conditions for future domestication purpose. Thirty composite soil samples were then prepared after thoroughly mixing the sub-samples of each plot in a plastic bowl. To assess the variation of soil properties across locations, laboratory analysis was conducted to determine the major soil physical and chemical parameters.

Laboratory analyses were conducted at the National Soil Testing Center, Ethiopia (NSTCE) using the following standard methods. Texture was determined by hydrometer method (Day, 1965) after destroying organic matter and dispersing the soil. Bulk density was determined by core method (Blake, 1965) after drying a defined volume of soil in an oven at 105°C for 24 h. It was then calculated as the ratio of mass of oven dried soil to the volume of the sampling core. The soil water content at Field Capacity (FC) were determined after soils were subjected to required pressures of 1/3 bars by pressure plate apparatus.

Soil pH-H_2O was measured by using pH meter in a 1:2.5 soil:water ratio using glass-calomel combination electrodes (Van Reeuwijk, 1992). Electrical Conductivity (EC) was measured in water as soil to water ratio of 1: 5 (Van Reeuwijk, 1992). Determination of soil organic carbon was carried out following Walkley-Black oxidation method (Allison, 1965). Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method and available P was determined using the standard Olsen extraction method (Olsen *et al*., 1954). Total exchangeable bases were determined after leaching the soils with ammonium acetate (Thomas, 1990). Amounts of Ca^{2+} and Mg^{2+} in the leachate were analyzed by atomic absorption spectrophotometer and K^+ and Na^+ were analyzed flame photometrically.

Cation exchange capacity was determined at soil pH level of 7 after displacement by using 1N ammonium acetate method in which it was, thereafter, estimated titrimetrically by distillation of ammonium that was displaced by sodium (Chapman, 1965). Percent base saturation was calculated by dividing the sum of the base forming cations (Ca, Mg, Na and K) by the CEC of the soil and multiplying by 100.

Statistical methods: Descriptive statistics was employed to assess the fertility status of the study area. Treatments were also arranged in randomized complete block design format with location as a factor. Analysis of Variance (ANOVA) was performed to assess the significance of differences in soil parameters between locations using the General Linear Model (GLM) procedure of the statistical analysis system (SAS, 1996). Mean separation was done by Least Significant Difference (LSD) test after main effects were found significant at $p<0.05$. Moreover, simple correlation analyses were carried out to determine the magnitude and direction between the selected soil physicochemical parameters using SPSS statistical software version 16.

RESULTS AND DISCUSSION

Physical properties of soil: Physical properties of soils of Boosat (settled farmers) and Fantalle (transhumant) land uses are presented in Table 1. Textural differences were observed within and between land uses particularly in silt fraction. This could be due to the fact that silt fraction is easily transported by water and subjected to erosion. The highest values of silt and clay fractions were observed in the grazing land. Under conditions of high vegetation cover loss of clay and silt fractions, through the processes of erosion are reduced, maintaining the soils physical properties.

The highest variation in sand fraction was observed in settled farmers land use at Xadacha, whereas, the lowest variation was recorded at transhumance areas at Galcha. The highest value in sand fraction was also reported by Haile *et al.* (2002) in their work on the soils of Tigray, North Ethiopia. This variation indicated that in the study area sand percentage is highly variable within study sites than the other soil physical properties. This variation in textural class within land uses was mainly attributed to the variations in slope. The percentage of silt and clay were higher at the lower than the higher slopes.

The lowest mean values of bulk density were observed in soils under transhumance land use system than in settled farmers area. Soil bulk density indicates the compactness of the soil. Soil

Table 1: Mean values of soil physical properties at fantalle and boosat districts

Location	Transhumant land use system			Settled farmers land use system			
soil properties	GA	QO	DH	XA	TB	DT	LSD (0.05)
MC (%)	35.73±2.17	38.02±11.22	32.69±2.32	41.31±10.53	34.72±7.91	38.16±8.34	NS
FC (%)	31.88±0.73^{ab}	26.99±4.56^{bc}	28.76±8.78^{bc}	6.43±0.98^{c}	28.52±1.83^{bc}	35.81±4.87^{a}	6.2718
Bd (g cm^{-3})	0.88±0.04^{bdc}	0.94±0.13^{abc}	0.87±0.14^{dc}	0.98±0.09^{ab}	1.01±0.15^{a}	0.77±0.05^{d}	0.1272
Sand (%)	19.00±3.74	11.00±2.83	11.40±4.10	14.60±14.93	15.80±5.22	16.20±14.81	NS
Silt (%)	40.80±1.10^{c}	52.40±1.67^{a}	51.60±2.19^{a}	48.00±5.66^{ab}	44.40±4.77^{bc}	50.40±5.18^{a}	5.0502
Clay (%)	40.20±4.60	36.60±2.61	37.00±2.00	37.40±12.92	39.80±7.95	33.40±10.90	NS
Textural class	Silty clay	Silty clay loam	Silty clay loam	Silty clay loam	Silty clay loam	Silty clay loam	

Values are as Mean±SD. Values with different letters are significant different at $p<0.05$.GA: Galeha, QO: Qobo, DH: Dheebiti, XA: Xadacha, TB: Trii Biretii, DT: Digalu Tiyo are study sites compaction is a measure of the extent of soil health. Soil compaction could occur due to multi-driving forces (Brady and Weil, 2002). The increase in the soil compaction could be due to prolonged degradation by mismanagement of the rangelands. However, the small value of bulk density in the study area revealed that soil compaction is not the main problem in transhumance land use system. The lowest value of bulk density in settled farmers land use systems was also attributed to its higher soil organic matter content. The small value of bulk density was also reported by Emiru *et al.* (2006) for similar lowlands in western Ethiopia and Mesele *et al.* (2009) in Yabelo rangeland. This could be because of the transhumance nature land use. Low bulk density creates favorable plant growth environment through enhancing root growth and air circulation which in turn has implications for agricultural productivity (Brady and Weil, 2002). Hence, transhumance land use is conducive for crop production. This in turn has the potential to enhance the food security of households.

The highest mean value of soil moisture was observed under the settled farmers land use system while the lowest value was recorded in study sites of transhumance land use. This variation may be due to altitudinal difference, i.e., Dheebiti is located at an altitude below 1000 m.a.s.l and Xadacha above 1000 m.a.s.l. The highest amount of soil moisture content under the traditional agroforestry system is also reported by Boffa (2000) Pandey *et al.* (2000) and Hailu *et al.* (2000).

Chemical properties of soil: The chemical properties of soils of Boosat and Fantalle districts are presented in Table 2. The study revealed that soil pH was significantly affected ($p<0.01$) by land use whereas there was no significant difference ($p>0.05$) in EC across land use. In all land uses the value of soil pH was greater than 7. These high soil pH values were observed mainly due to low precipitation and high evaporation that reduces the loss of the base forming cations from the soil profile. Moreover, the highest soil pH values could be because of high values of exchangeable Ca. As per the classification by Marx *et al.* (1996), the soils all transhumance land use study sites (Galcha, Qobo and Dheebiti) fall in the neutral soil class (pH 6.6 to 7.3) while settled farmers sites (Xadacha and DigalyTiyo) fall in mildly alkaline soil (pH 7.4 to 7.8) and that of TiriBiretti in moderately alkaline (pH 7.9-8.4) soil reaction classes. Generally, the observed electrical conductivity (EC) values in the present study were rated as medium (EC<0.5 dS m^{-1}) (decimole m^{-1}) despite the

Table 2: Chemical properties of soils of Boosat and fantalle districts

Location land use soil properties	GA Transhumant	QO Transhumant	DH Transhumant	XA Settled farming	TB Settled farming	DT Settled farming	LSD (0.05)
pH H^2O	7.30 ± 0.1^{cd}	7.26 ± 0.11^{d}	7.26 ± 0.21^{d}	7.66 ± 0.34^{b}	8.02 ± 0.22^{a}	7.64 ± 0.37^{bc}	0.35
EC (mmhos cm^{-1})	0.25 ± 0.12	0.21 ± 0.11	0.16 ± 0.05	0.23 ± 0.11	0.17 ± 0.05	0.27 ± 0.07	NS
OC (%)	3.81 ± 1.01^{a}	3.12 ± 1.09^{ab}	2.49 ± 0.36^{ab}	3.05 ± 1.20^{ab}	2.07 ± 1.06^{b}	2.53 ± 0.82^{ab}	1.35
TN (%)	0.70 ± 0.26^{a}	0.22 ± 0.04^{b}	0.20 ± 0.04^{b}	0.28 ± 0.11^{b}	0.18 ± 0.06^{b}	0.22 ± 0.06^{b}	0.17
C/N	11.00 ± 2.34	13.6 ± 2.30	12.60 ± 3.13	12.14 ± 6.53	10.80 ± 1.92	11.80 ± 1.92	NS
AVP (ppm)	4.44 ± 0.95^{b}	5.70 ± 1.93^{b}	7.42 ± 1.67^{b}	25.05 ± 14.91^{a}	5.48 ± 1.11^{b}	17.61 ± 6.66^{a}	8.94
Na (Cmolc kg^{-1})	0.73 ± 0.20^{a}	0.27 ± 0.26^{b}	0.20 ± 0.03^{b}	0.20 ± 0.15^{b}	0.59 ± 0.25^{a}	0.29 ± 0.10^{b}	0.25
K (Cmolc kg^{-1})	5.03 ± 0.64^{a}	3.96 ± 0.86^{ab}	4.19 ± 0.75^{ab}	3.54 ± 0.96^{b}	3.82 ± 0.42^{b}	4.07 ± 0.99^{ab}	1.11
Ca (Cmolc kg^{-1})	27.37 ± 3.88^{b}	22.86 ± 1.52^{b}	24.86 ± 2.35^{b}	32.37 ± 3.60^{a}	32.34 ± 5.87^{a}	24.64 ± 2.91^{b}	4.91
Mg (Cmolc kg^{-1})	2.66 ± 0.43^{ab}	2.66 ± 0.38^{ab}	2.95 ± 0.56^{a}	3.00 ± 0.54^{a}	2.26 ± 1.24^{ab}	1.92 ± 0.57^{b}	0.84
CEC (Cmolc kg^{-1})	39.55 ± 4.57^{ab}	34.81 ± 3.16^{b}	37.25 ± 1.57^{b}	43.07 ± 3.49^{a}	42.82 ± 3.76^{a}	36.27 ± 4.61^{b}	5.13
BS(%)	90.47 ± 2.72	85.76 ± 5.59	87.01 ± 3.03	90.82 ± 5.26	91.01 ± 6.44	85.61 ± 5.08	NS

Values are as Mean±SD. Values with different letters are significant different at $p<0.05$

aridity of climate and limited rainfall to leach away base forming cations from the surface soils in the area in general and the study site in particular.

Land use and soil management have a marked effect on the soil organic carbon stock as a result of interaction between detritus input and mineralization mediated by soil microorganisms and other factors (Tate, 1987). The same author explained that soil organic carbon is the most dynamic property of soils and it is highly influenced by land use and land management. Similarly, in the study area there was significant difference ($p<0.05$) in soil organic carbon content of the soils. According to Landon (1991), the organic carbon contents of the study area were generally rated as moderate at transhumance (Dheebiti study site), settled farmers (TiriBiretti and DigaluTiyo study sites) while high at transhumance (Galcha and Qobo study sites) and (Xadacha study site) settled farmers areas.

The lower organic carbon observed in some study sites can be ascribed by low plant cover. Vegetation removal reduces the soil organic matter and affects soil structure and functions of soil (Brady and Weil, 2002). It indicated disturbance factors such as collection of fuel wood, encroachment by agriculture and tree falling for construction which was more intensive than in the transhumance land use systems. The transhumance land use system plays a major role in controlling climatic change by sequestering carbon in the soil. Indeed, the transhumance system of natural resource use can be a foundation on which better integrated resource management can be built.

Carbon to nitrogen (C/N) ratio is an index of nutrient mineralization and immobilization whereby low C/N ratio indicates higher rates of mineralization; the higher C/N ratio observed in this study point to greater rates of immobilization across land uses (Brady and Weil, 2002). This mean the inorganic nitrogen changes to organic nitrate being bound to different organic compounds. However, the observed C/N ratios in the soils of the present study are within the normal range expected in mineral soil worldwide which is about 10: 1 on the average (Brady and Weil, 2002).

The mean value of total nitrogen of the study area was rated as medium (0.15-0.25%) in most study areas whereas was high (0.25-0.5%) in transhumance land use. The highest value of total N transhumance land use systems was comparable with the results reported by Hussein (2002) for the soils of Chilalo area rangeland in Arisi Zone, Ethiopia. The higher value of total nitrogen is probably associated with the higher soil organic matter content which is in turn related to the higher levels of plant biomass or animal manure being returned to the soils under these land uses system. The highest N content observed at Galcha study site, in transhumance area could be also partly because of nitrogen fixing ability of the trees/shrubs species commonly found in transhumanace areas.

According to Fritzsche *et al.* (2002) and Negassa and Gebrekidan (2003), the dynamics of soil phosphorus could be markedly affected by land use, soil management and study sites which often involves changes in vegetation cover, biomass production and nutrient cycling in the ecosystem. Accordingly, Landon (1991) stated that, soils with Olsen P of less than 5 ppm are low, 5-15 ppm P medium and more than 15 ppm high in available P, indicating that the soils at Galcha were low, soils of Qobo, Dheebiti and TiriBiretti were classified as medium and soils of Xadacha and DigaluTiyoo were classified as high. The highest values of available P in settled farmers land use system may be due to the application of P fertilizer sources for quite a longer period in the vicinity of the woodlands. Richards *et al.* (1995) and Juo *et al.* (1996) have also reported that application of P fertilizer would increase the easily available P forms. On the other hand, much of P in transhumance land use system could be in organic form from animal manures.

Cation exchange capacity (CEC) and the extent of saturation (BS) of the soil exchange complex by base forming cations (Ca, Mg, Na and K) are among the basic indices of soil fertility. Highly fertile soils are characterized by high CEC and BS values. As described by Landon (1991), the values of CEC are rated as high in all locations of the study area except Xadacha and TiriBiretti in the settled farmers land use system rated as very high. These results revealed that the fertility status of the study area is very high at grazing land as well as at settled farmers land use systems. This indicates the transhumance land use system is more environmental friendly and more suitable for WEPs production.

Even though, the electrical conductivity of soil of the study area is high, the value of exchangeable Na was rated as low except at TiriBiretti which is rated as moderate. Moreover, the values of exchangeable Mg were rated as moderate in both land uses. In both land uses the values of exchangeable Ca and K were rated as very high. These high values of exchangeable bases could be attributed to the limestone nature of the parent material and to minimum soil leaching and indicates aridity of the study area.

Implications on growing crops: Based on the CEC, total N, O.C and C/N the study site is suitable for general agriculture. The transhumance land use system could be more favourable soil physicochemical properties for plant growth compared to settled farmers. Therefore, these sites offer suitable habitat for cultivation of crops. However, study sites with low soil properties for plant growth will require integrated soil fertility management to make such areas suitable for crop cultivation.

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