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Evaluation of soil physical and chemical quality indices under different land use scenario in North Ethiopia

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Abstract

Alteration of land use system can potentially influence soil quality. Appraisal of soil quality indexes in different land use scheme is appropriate to design sustainable soil resource conservation strategies. In this study, three commonly used land use scheme (grazing land, crop land and forest land) were considered for soil quality evaluation. Aiming for representative soil sample, thirty-six sub composites soil sample were collected for each land use. Laboratory analysis was made following standardize procedures for soil physical and chemical properties. Some soil quality indicators were significantly influenced ($p \leq 0{\cdot}05$) by the land use systems. Highest proportion of silt was observed in forest land (29.7%) followed by grazing land (27%). Field capacity value was recorded high in crop land (25.6%) followed by forest land (24%) and grazing land (23.33). The highest permanent wilting point was recorded in crop land (13.97%) followed by grazing land (12.8%) and forest land (12.13%). Hydrogen ion concentration (pH) value of the soils range from 6.32-6.54. The highest soil pH value (6.54) was found in forest land followed by grazing land with pH value of 6.51. Highest mean electron conductivity was recorded in crop land (0.12dSm) followed by grazing land (0.11dSm), and the lowest value recorded in forest land (0.10dSm). The highest soil organic carbon is occurred in grazing land (2.02%) followed by forest land (1.85%) and crop land (1.42%). Total nitrogen was highest in grazing land (0.16%) followed by FL (0.15%). The soil quality measurements signposted that soils in grazing land and forest characterized by better soil physical quality and high soil nutrients when compared with the critical values. The soil physical and chemical quality indicator betterment in forest land and grazing area is result of presence of trees.

Keywords: Crop land, forest land, grazing land, land use system, and soil quality.

Introduction

Soil quality (SQ) is considered as a capacity of soil to carry out indented natural ecosystem services. Soils natural function which is entirely governed by soil quality include provision of essential plant nutrients, purify water, sinking carbon, ensure geochemical cycle and sustain human life[1,2]. Even though the concept of soil quality is recently emerging, several studies has been conducted and accomplished regarding soil qualities index dynamics across different land use scheme[1–21]. Unfortunately, almost all earlier studies revealed that soils quality is threatening and hastily decreasing. Soilsdegradation diminishes the capacity of soil resources to perform essential functions and services in ecosystems.

The principal processes of soil degradation include chemical, physical and biological parameters alteration and generally termed as soil quality deterioration (SQD)[22,23]. Currently soil quality deterioration is being a hindrance to boost crop productivity, economic advancement and environmental safety[22,24,25]. The quantity of plant available nutrients diminish and crop productivity is seriously hampered. SQD is being a continuous process which is affecting food security and the prosperity of nations, and has an impact on the livelihood of almost every person whose life is depend on farming.

The primary causes to SQD are highly associated with day to day human being activities which include forest destruction and inappropriate land operation. Natural factors like intense rainfall and steep land scape contribute a lot for accelerated SQD[3].

Among anthropogenic phenomena exacerbating SQD land use transformation takes the first rank[26]. In many parts of the world natural forest and grazing lands (GL)are highly vulnerable to land use transformation due to human being cropping strategy which can degrade soil quality[27]. Conversion of forest and grazing land to any other land use system is associated with loss of organic matter and other essential nutrient. It may disturb the whole ecosystem balance and indicate occurrence of soil degradation. A worldwide evaluation of soil organic carbon succeeding land use transformation revealed at least 20% deduction of initial soil organic carbon[28]. Most of the reasons of soil quality deterioration are originated from inappropriate land based economic activities by landowners to boost crop yield for the alarmingly increasing population. SQD can also associate with social, economic and political features and failure like insecure land right, inability to give incentive, lack of access for credit, abscess of strong institution and education infrastructure[24].

Soil degradation has been going on for centuries in Ethiopia. It is a serious problem hampering crop productivity and that with continued population growth the problem is likely to be even more important in the future. Natural factors coupled with the effects of a long history of settlement, conventional farming methods and increasing population pressure which forces people to cultivate even steeper slopes have exacerbated the devastating land resource degradation in northern region of the country[29]. In addition, increasing population pressure has caused cropping and grazing activities to be shifted to hillsides and ecologically fragile areas, forced the people to use crop residues and dung for fuel rather than using them as sources of organic fertilizer to improve soils quality.

In order to make sound decisions regarding sustainable land use systems, knowledge of soil quality related to different land use scenarios is essential. It is therefore most important to evaluate soil quality indicator under different land use and soil management systems using soil quality index. The effects of land use change on soil degradation or restoration can be evaluated by comparing changes in some selected soil properties. The most basic dials evaluated for soil quality analysis include organic carbon, nitrogen and soil reaction. Among these indicators, organic carbon is principal which envisage comprehensive result regarding quality of soils being studied. Nitrogen level is a key for plant growth and worth to determine it from soil fertility point of view. Soil reaction encompass soil acidity and alkalinity that can be determined by measuring hydrogen ion concentration in the soil solution. It is palpably the first and governing factor for evaluation of soil quality for the purpose of agriculture. The most suitable pH range for plant growth ranges from 5.5 to 6.5. Plant can access al, essential plant nutrient easily only in this pH range.

Evaluation and appraisal of soil quality indicator must be a primary task in the field of soil science. It will help a lot in identification of land use sesames that can maintain soil fertility. In addition, it will give clue regarding hampered soil quality indicator and then soil fertility management strategies will be designed accordingly. The objective of this study was evaluation of soil quality indicators among commonly used land use scenarios in north part of Ethiopia.

Materials and methods

Description of the study site: The study area is *Metema woreda*, which is located in the northern part of Amhara Region of Ethiopia (Figure-1). This arid agricultural district is one of the most known farm investment site of the Ethiopian lowland. Commonly cultivated commercial crops include sesame, cotton and sorghum. The study area has a flat to gentle topography, with an average slope of 9%. The soil types of the study area predominately classified as Nitosols, Regosols and Vertisols. The common land use types practiced in the area are crop land (CL), forest land (FL) and grazing (GL). The detail bio-physical characteristics of the site are shown in Table-1 below.

Table-1: Major bio-physical and socio-economic characteristic of Metema woreda[30].

Characteristics	Metema (study site)
Topography	Flat to gentle slope
Temperature (^oC)	32-43
Farming system	Multiple crops
Major crops' grown	Sesame, cotton, sorghum, teff
Fertility status	Moderate
Food Security condition	Moderately secured
Average land size per households	2.5ha
Total number of farmers	51,322
Dominant tree species	Numerous native species

Selection of land use systems: In the study district, several land use patterns are existing in but quit difficult in consider all at a time and make sense to focus on selected major land use schemes. Preliminary survey, field observation and discussion were conducted with comprehensive team. The team was built from researchers, local people, agricultural affairs office, development agent, and village scholars. All participant are familiar with the study site and able to explicitly explain land use pattern and other biophysical characteristics of the study site. The prevailing land use system, trend of cultivation, biomass management approach, fertilizer application habit, and nutrient management strategies was considered and fully characterized by the team. Biophysical attribute and edaphic type factors were clearly described on the field. After securing information which enable to judgment, three widely practiced land use were selected and located side by side. These study land use scenarios was crop land, grazing and forest land. Detail description of each selected land use scheme is clearly explained in Table-2.

Soil survey and sampling: The experiment was conducted in randomize complete block design (RCBD) with three replication. Experimental blocked was formed based on similarity in slope and altitude so as enable comparison among land use scenario. Crisscross diagonal line were drawn in the block. Then, soil sample was collected on drown line at 0-30cm depth using cylindrical core sampler. Aiming for representative soil sample, 36 sub composites soil sample from each diagonal line were collected for each land use.

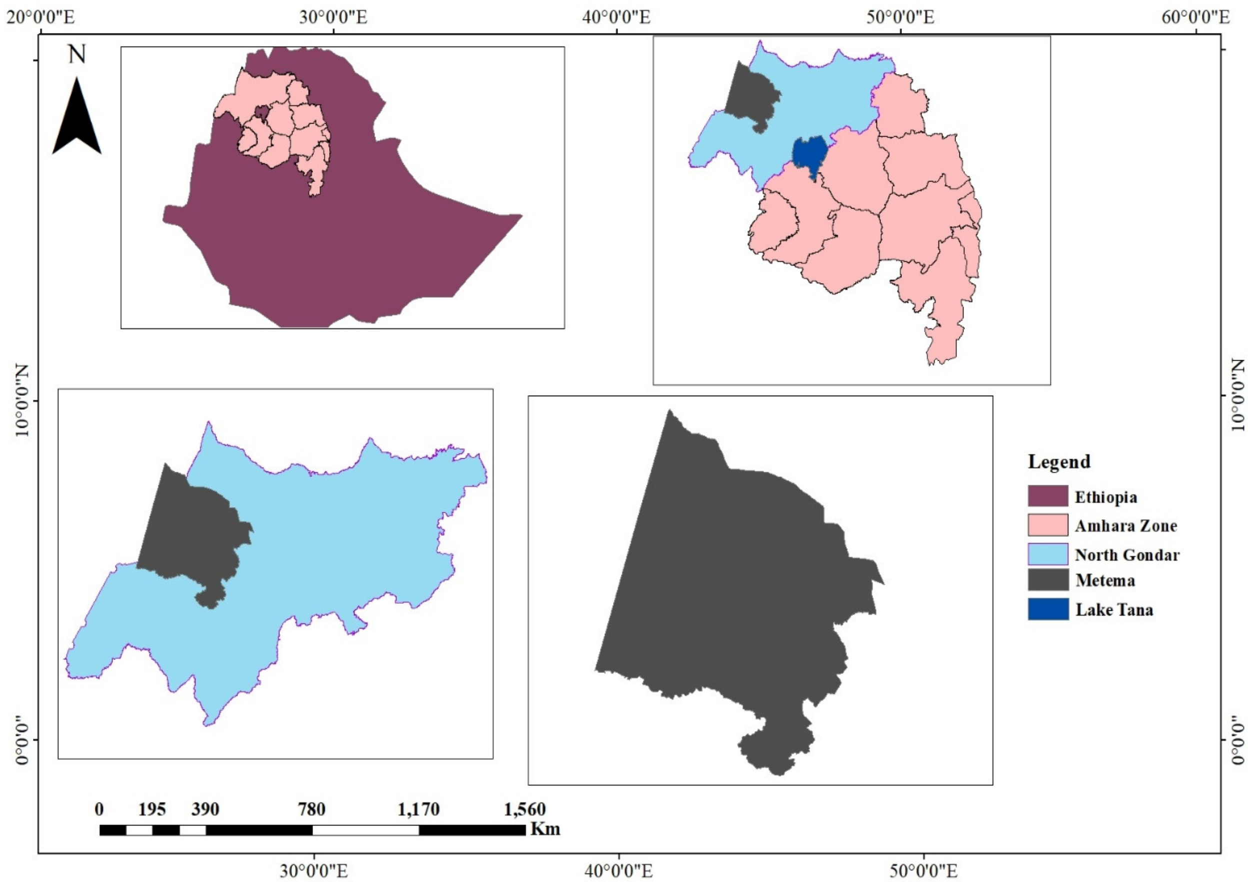

Figure-1: Location of the study site (Metema).

Table-2: Characterization of widely used and selected land use schemes.

Land	Description
Crop land (CL)	The study area is target by investor for production of commercial crops. Dominant crops grown include sorghum, sesame and Teff. Crop production is being practiced for 4-6 consecutive years. After significant yield is reduced due to successive cultivation, the land will be left for rest at least for 4-5 years. During rotation period numerous indigenous tress species regenerate naturally. Litter fall from these trees species will fall over the soil surface and fertility will be restored after years. Currently rest time is reduced two years due to high demand of cultivation land.
Grazing land (GL)	Local communities' livelihood is high dependent on rearing animals. Every house hold owned huge number of cattle. They are grazing their cattle for a long period of time in areas where scattered tress are found. Animal dungs are good source of soil organic matter and huge accumulation of dung were observed.
Forest land (FL)	Though forest encroachment is dramatic, large forest area is found. It is dominated by several indigenous tree species. Currently it is quite difficult to find forest area free from any contact. High intervention of human being to access farm land and grazing land were observed.

Soil sample preparation and analysis: All collected soil samples were prepared for soil physicochemical properties analysis by drying, gridding and sieving. Soil texture were analyzed by the hydrometer method. Soils bulk density was determined from samples collected from field using core sampler. It was calculated by dividing total dry mass of the soil to total volumes of the soil sample. Following result of soil bulk density, the total soil porosity was determined using the following formulae. Particle density was considered as constant with an average value of 2.65g/cm^3.

$$\text{Total porosity (\%)} = \left(1 - \frac{bulk\ density\ (\frac{g}{cm3})}{particle\ density\ (\frac{2.65g}{cm3})}\right) \times 100$$

The soil-water potential values of the composite samples At Field Capacity (FC) and Permanent Wilting Point (PWP) were determined following pressure plate apparatus. Available water holding capacity was calculated just by subtracting PWP from FC. Soil structure was determined on the field with the aid of soil structure classification key.

The pH of the soils was measured potentiometrically at the ratio of 1:2.5 for soil: water solutions using a combined glass electrode pH meter[31]. For the determination of soil organic matter, the samples was first digested with potassium dichromate in sulfuric acid solution (wet oxidation) and titrated with 0.25M ferrous sulfate solutions[31]. The percent organic matter was computed from percent soil organic carbon using a conversion of 1.724[31]. TN content was determined titirimetrically following the Kjeldahal method[32].

Available potassium was measured by flame photometer following extraction of the soil samples by sodium acetate ($CH_3COONa.3H_2O$)[32]. Available phosphorus was determined calorimetrically using spectrophotometer after the extraction of the soil samples with 0.5M sodium bicarbonate ($NaHCO_3$) at pH 8.5 following the Olsen extraction method[33]. To determine cation exchange capacity (CEC), the soil samples was leached with 1M ammonium acetate solution followed by leaching with sodium chloride to displace the adsorbed NH_4^+. The quantity of ammonia was then measured by distillation and taken as the CEC of the soil. The EC of each soil sample was determined by using EC meter. After soil physical and chemical properties determination, soil laboratory results was compared with the results of physical and chemical soil properties which was analyzed for each land use system parcel.

Statistical analyses: The soil physicochemical properties analysis was computed with the help of SPSS computer software (version, 20). Analysis of variance (ANOVA) procedure was carried on to determine the effect of different land use scenario on different soils physicochemical properties. Mean separation was performed via least significance value juts to test statistical significance at 95% of probability.

Results and discussion

Soil physical quality indicators under different land use scheme: Soil physical properties are prime factors governing soil quality. These properties are susceptible for alteration due to different land use systems. Soil particles content showed statistical significant difference ($P \leq 0.05\%$) among different land use schemes. Silt particle content was highest in FL (29.7%) succeeded by GL (275) (Table-3). Silt particles are moderately sized particle in the soil system and their presence in large amount is indicator for good soil quality. Inline to this scientific theory, farmers considered silt dominated farm plot as fertile land since they are getting better yield than other particle dominated farm land. In addition to this betterment of silt dominated land is proved and supported by laboratory analysis[34]. Even though statistically significant difference is not observed among treatment, the mean value of clay was highest in CL (41.67 %) succeeded by FL (24.33%) and GL (19%).

FC and PWP was affected by land use scenarios in significant manner ($p \leq 5\%$). The maximum FC value was found in CL (25.6%) succeeded by FL (24%) and GL (23.33) (Table-3). The highest PWP was recorded in Cl (13.97%) followed by GL (12.8%) and FL (12.13%). The absolute difference occurred in soil water characteristics of different land use may induced by difference in other physical and chemical soil properties. It could be associated with soil particle content, structure and organic matter content. As discovered in prior studies, high soil organic matter content advances soil particle arrangement and stability, spaces among particles, and water movement through the system. All these soil physio-chemical properties advancement could lead to better water holding capacity, which defiantly alleviate run of over soil surface[9].

Soil bulk density (BD) varied from 1.16 to 1.40g/cm^3 across the land use systems. The highest bulk density was recorded in FL 1.4g/cm^3 followed by GL 1.33g/cm^3. The lowest BD was recorded in CL 1.16g/cm^3. There is no any statistical difference among land use systems regarding their bulk density, perhaps the district is commonly known for shifting cultivation, all land use system received organic matter through litter fall. Higher organic matter (OM) accumulation and less soil disturbances in all land use system may contribute a lot for absence of difference in terms of density. Excessive BD derived either from parent material or anthropogenic interference can deteriorate soil water retention capacity and limit downward plant root movement. This result in surface runoff and nutrient erosion from place to place as well as poor plant growth. The BDs in all land use system are found within the critical level, which is suitable for plant growth as distinguished earlier by Arshad and his colleagues[35].

Soil water characteristics and all other soil physical properties are primarily associated with presence of vegetation on the land use scenario. Land use schemes having high forest coverage could receive higher organic matter that can enhance water holding capacity and particles arrangement which can influence probably all other physical properties[34]. Intensive cultivation without appropriate input and management can exploit organic matter and followed by higher bulk density and limited water holding capacity. The application of chemical fertilizer from industries will never enhance any soil physical properties. As far as soil physical qualities considered, existence of vegetation in FL and GL improved all soil physical quality indicators whereas cultivation in CL relatively deteriorated the soil physical quality.

Soil chemical quality indicators under different land use scheme: Mean values of some chemical soil quality indicators showed significant difference ($p \leq 0.05\%$) among land uses (Table-4). Hydrogen ion concentration (pH) value of the soils range from 6.32-6.54. Maximum soil pH was registered in FL (6.54) followed by GL (6.51). The least soil pH was calculated in CL 96.31, which is a bit lower than recommended pH range for plant growth. This infer that the base forming ions concentration is lower in crop land, which may leads to acidification if it is not managed properly[36]. This may associated with exploitation of cations by crops and other higher plants.

Another possible reason for lowest value of pH in CL is that regenerating vegetation growing in rest period of shifting cultivation may reduce pH of the soil while other nutrients concentration is low. This pH decrement can be attained by process like cation adsorption by plants, decomposition of plant and animal remain, microbial and root respiration[36].

Table-3: Soil physical qualities dynamics across land use scheme.

Physical soil quality indexes	Land use system				
	CL	GL	FL	Mean	SD
Sand (%)	34.00[a]	54.00[a]	52.00[a]	44.66	7.56
Silt (%)	24.33[ac]	27.00[a]	29.67[ab]	27	1.33
Clay (%)	41.67[a]	19.00[a]	24.33[a]	28.33	8.69
BD (g/cm^3)	1.16[a]	1.33[a]	1.40[a]	1.30	0.12
FC (%)	25.67[a]	23.33[b]	24.00[b]	24.33	0.44
PWP (%)	13.97[a]	12.80[b]	12.13[b]	12.97	0.40
AWC (%)	11.7[a]	11.2[a]	11.2[a]	11.37	0.25

Mean values followed by different letters in the same raw showed significant difference at probability level of (P) = 0.05%; SD, standard deviation; FC, Field capacity; PWP, Permanent Wilting point; BD, Bulk Density; AWA, Available Water Holding Capacity.

Even though statistical difference is not detected, highest mean EC was recorded in CL (0.12dSm) followed by GL (0.11dSm), and the lowest value recorded in FL (0.10dSm) (Table-4). Despite of this EC discrepancy, neither soil salinity nor acidy problem for the ecosystem. SOC content under different land uses range from 1.42% to 2.02%. In similar way, the highest SOC is occurred in GL (2.02%) followed by FL (1.85%) and CL (1.42%) (Figure-2). The maximum SOC accumulation in grazing land is associated with high abundance of branched and giant scattered trees all over the pasture land. Bulk of litter fall and decomposed organic matter were observed over soil surface. Animals walking over litter fall also facilitate decomposition by breaking litters in to smaller and make easily available for microorganisms. In addition pastoralists are keeping animals in temporary camps for a long time, thus animal dung might accumulate and lead to high concentration of soil organic matters as well as SOC. The calculated organic carbon content in all land use system is above critical level (1%) as reported by Sanchez and his colleagues[36].

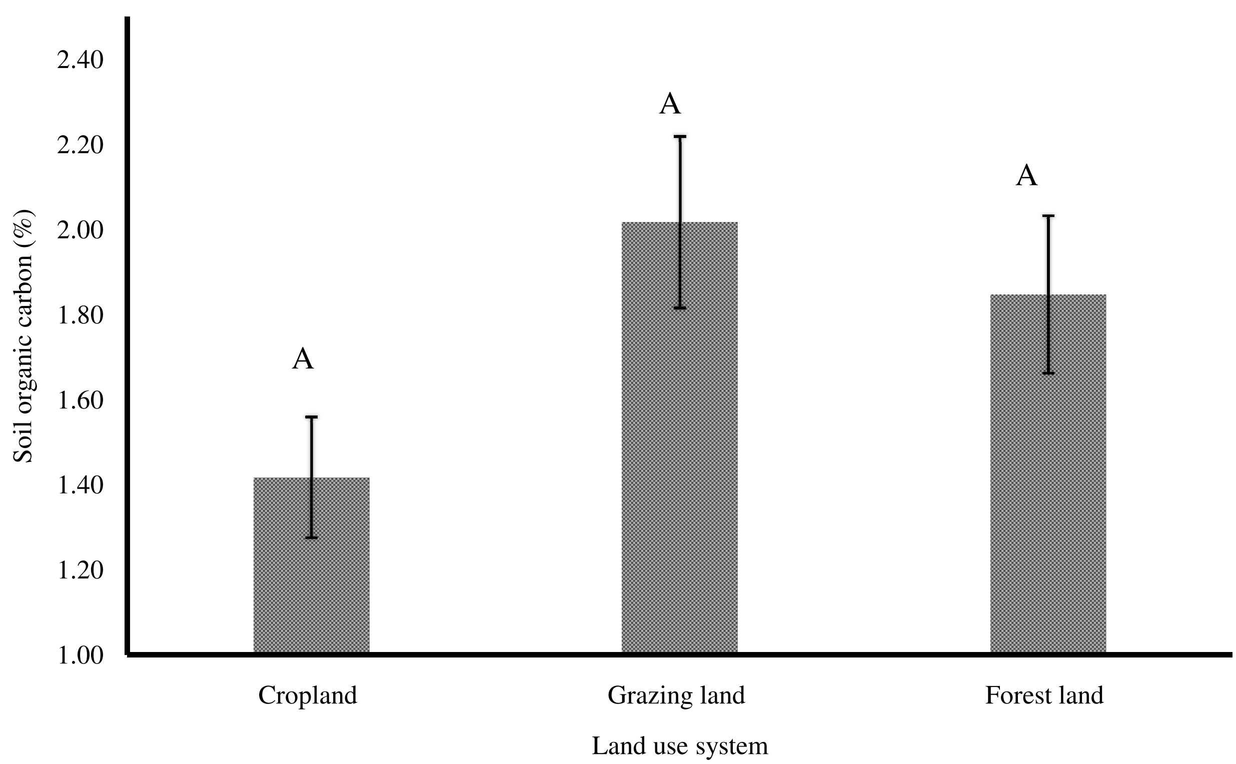

Figure-2: SOC as influenced by land use scheme. Values having same later are not statistically different ($p \leq 0.05$). Bars indicate standard errors.

Total nitrogen (TN) range from 0.12%-0.16%. TN was highest in GL (0.16%) followed by FL (0.15%) (Table-4). Highest nitrogen content at forest land might be due to scattered nitrogen fixing ability trees. Apparently, high concentration of nitrogen in forest land is just due to uninterrupted decomposition of litter fall. Thick decomposed and fresh litter fall was observed on the uppers surface of the soils in grazing and forest land. The nitrogen level in CL was the smallest in amount (0.12%). Just after four and five years rest period, all vegetation could be fall down and burned to prepare land for farm. This time the soil temperature hit high and followed by nitrogen cycle process called ammonification and nitrification. Both of these process will induce rapid and restless loss of nitrogen by volatilization. The amount of nitrogen in all land uses is recorded just below critical level (1.00%) which is determined by Sanchez and his colleagues[36]. This infers the phenomenon of nitrogen loss and requirement of high nitrogen input for sustainability of the ecosystem.

Significant difference is not occurred regarding soil P among different land use scheme. A mean comparison showed that higher availability of P at a CL (6.58ppm) than FL (6.17ppm) and GL (4.56ppm). This higher available phosphorus amount in CL may associated with several reasons. Scattered trees root (course and fine) on farm land excrete low atom weight organic acids which constitute phosphorus atom. On other hand, plants which extract voluminous P from soil might return back to soil due to litter fall decomposition. These, trees can enhance soil phosphorus concentration the above mentioned two mechanisms. Apparently, lower plant components like grass and crop never attempt such nitrogen extraction and addition phenomenon. Application of fertilizer consisting phosphorus during cropping season may also enhance available phosphorus concentration in CLs due to adsorption of P by soil system. Former studies also ensure occurrence of bulk of available phosphorus in crop land than forest[37]. Lower availability of phosphorus also occurred due to phosphorus immobility induced by higher microbial activity which might probably occur in forested area. In this study the amount of available P is just below critical level which is fixed by Sacnches and his colleagues[36].

A significantly higher amount of exchangeable K is recorded in GL (Figure-3). High accumulation of K in GL might be associated with its high organic matter content. Thus, there might be intensive attraction among negatively charge electromagnetic particle and potassium ions. In addition, bulk of litter falls from scattered trees on pasture may contribute for high soil organic matter and in turn it can enhance potassium ion adsorption to the soil surface. In terms of Mg, significantly higher amount is recorded at CL (5.48cmol(+)/kg) and lowest value is at FL (3.47cmol(+)/kg). Exchangeable calcium also showed significance difference with highest value in CL (17.13 cmol(+)/kg) and lowest value in FL (11.54cmol(+)/kg). Just like other cations signicant amount of exchangeable Na is demined in GL (2.57cmol(+)/kg). The lowest exchangeable sodium content was detected in CL (1.47cmol(+)/kg) followed by FL (1.85cmol(+)/kg).

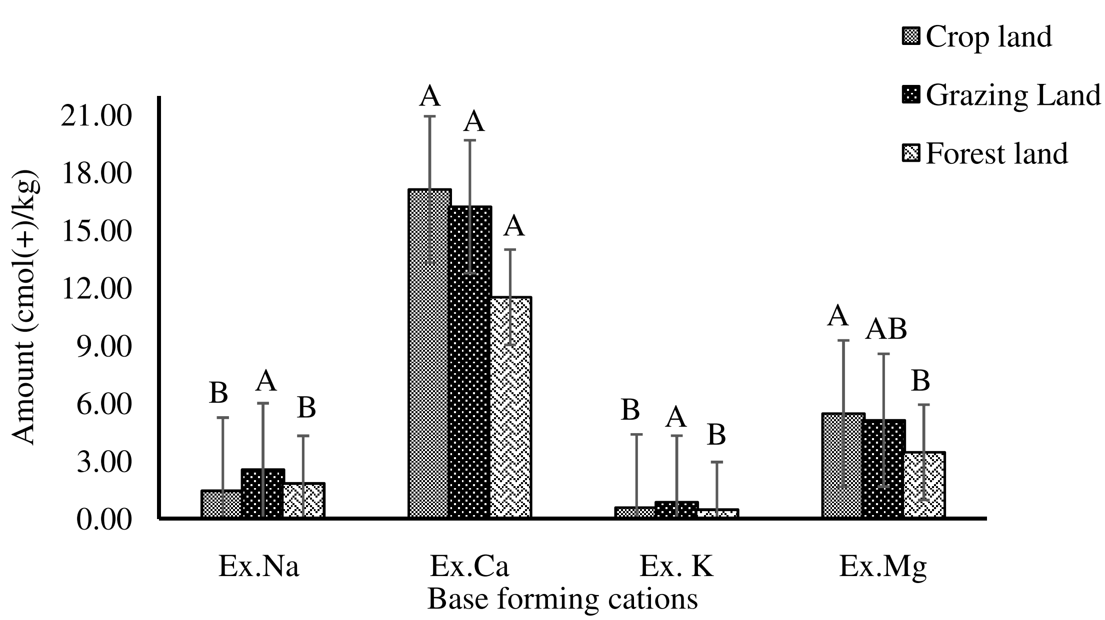

Figure-3: The concentration of exchangeable (base forming) cations among different land use systems. Values having same uppercase letter with in land use are not significantly different ($P<0.05$). Bars indicate standard errors. Ex. Na, exchangeable sodium; Ex. Ca, exchangeable calcium; Ex. K, exchangeable potassium; Ex. Mg, exchangeable magnesium.

The mean CEC is higher in GL (32.27cmol(+)/kg) and FL 31.27 (31.27cmol(+)/kg). The lowest CEC was observed in CL (27.27 cmol(+)/kg). This is definitely associated with high organic matter accumulation in GL and FL uses.

Iron (Fe) was higher in CL (45.20ppm) followed by GL (40.73ppm) and FL (39.53ppm), but statistical significant differences were not observed (Figure-4). Similarly, Cu was higher in CL (6.33ppm) and GL (6.03ppm), whereas the lowest values were observed in FL (3.87ppm). The abundance of Fe and Zn at Cl may associated with fine particles where all these micro nutrients attached closely. In addition it may associated with original parent material were these land use system was arranged. Mn was significantly different among different land uses with highest value in GL (19.97ppm) followed by CL (19.3ppm) and FL (13.3ppm). The concentration of Mn is expected to be high in area where accumulation of dung and other organic matter is abundant.

The current experimental study depicted that presence of vegetation in any land use can maintain soil quality much more than bare lands. All the soil physical qualities are improved and maintained more in GL and FL where abundant of vegetation occurred (Table-4). Laboratory analysis result determined just above critical value for FL and GL wheelie some failure is observed in CL[36]. In general, the comfortable soil system in GL and FL was occurred due to abundant trees grown either naturally or by human being for environmental conservation, shading role, and fuel.

Crop production based livelihood shall united with forest component. Considering forests and vegetation as principal component in farming system may rescue food insecurity crisis of the world. Decomposition of litter fall from the forest is ideal and most sustainable option to reclaim soil fertility[38–42]. Nutrient transfer from vegetation via decomposition is probability the principal mechanism to link living organism with physical environment, which can boost soil fertility as well as crop production[38-54]. Therefore farmers and land owner should get awareness regarding role of trees for soil quality maintenance as well as environmental sustainability.

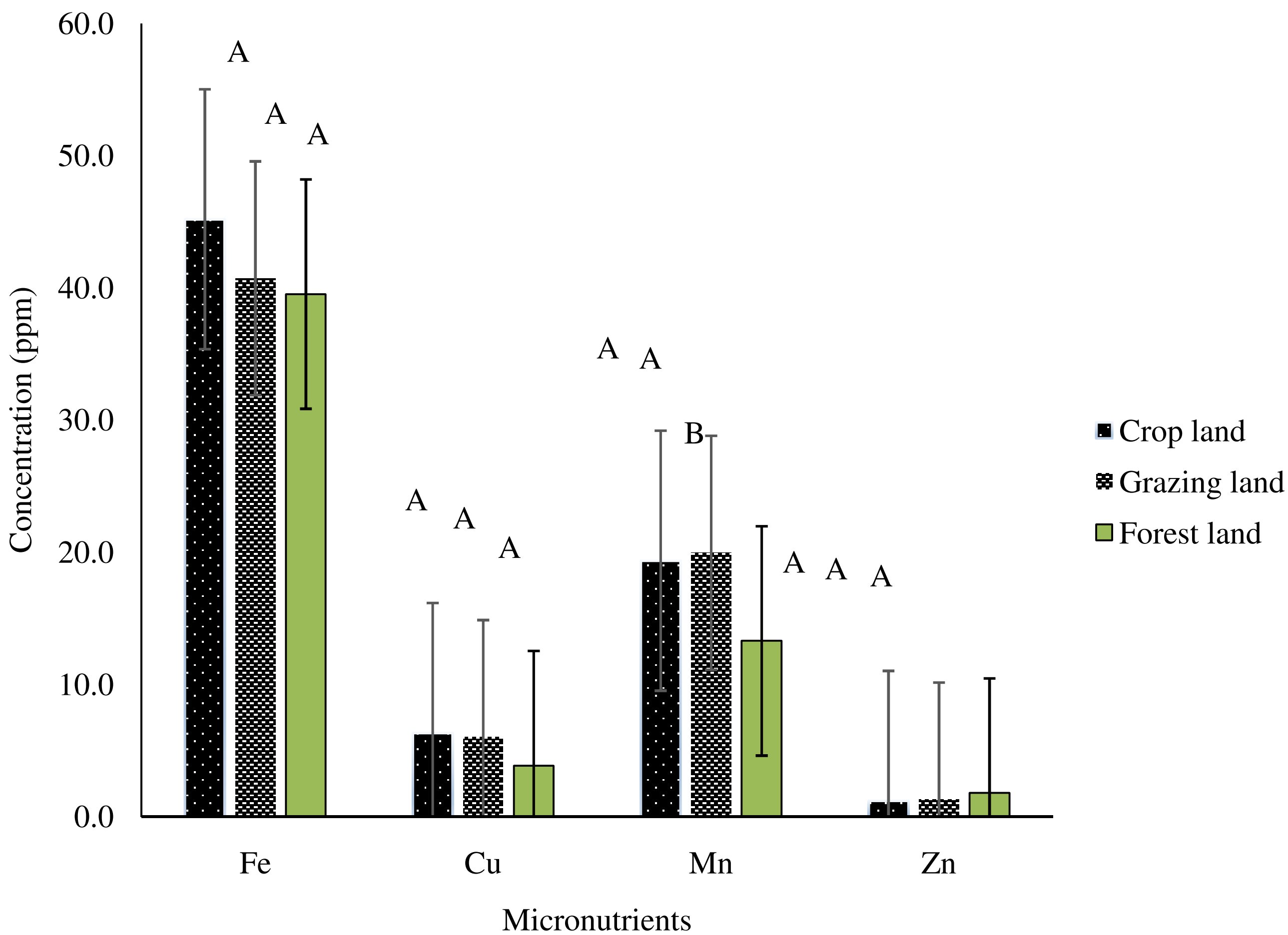

Figure-4: The concentration of micronutrients among different land use systems. Values having same uppercase letter with in land use are not significantly different (P<0.05). Bars indicate standard errors. Fe, Iron; Cu, copper; Mn, Manganese; Zn, Zinc.

Table-4: Soil chemical qualities indicators as influenced by land use scenario.

	Land use system				
	CL	GL	FL	Mean	SD
EC (dS/m)	0.12[a]	0.11[a]	0.10[a]	0.11	0.03
pH (hydrogen ion concentration) (H_2O) (1:2.5)	6.32[a]	6.51[a]	6.54[a]	6.46	0.10
Exchangeable calcium (cmol(+)/kg)	17.13[a]	16.23[a]	11.54[a]	14.97	1.82
Exchangeable magnesium (cmol(+)/kg)	5.48[a]	5.14[ab]	3.47[b]	4.70	0.55
Exchangeable sodium (cmol(+)/kg)	1.47[b]	2.57[a]	1.85[b]	1.96	0.23
Exchangeable potassium (cmol(+)/kg)	0.60[b]	0.88[a]	0.49[b]	0.66	0.09
Iron (ppm)	45.20[a]	40.73[a]	39.53[a]	41.82	2.42
Manganese (ppm)	19.3 [a]	19.97 [a]	13.30 [b]	17.4	1.15
Copper (ppm)	6.33[a]	6.03[a]	3.87[a]	5.41	1.09
Zink (ppm)	1.2 [a]	1.3 [a]	1.8 [a]	1.43	0.51
Cation exchange capacity (cmol(+)/kg)	27.27[a]	32.27[a]	31.27[a]	30.27	3.71
Organic carbon (%)	1.42[a]	2.02[a]	1.85[a]	1.76	0.39
TN (%)	0.12[a]	0.16[a]	0.15[a]	0.14	0.03
Available phosphorus (ppm)	6.58[a]	4.56[a]	6.17[a]	5.77	0.96

Means followed by same letter in same row are not significantly different at p= 0.05; SD is standard deviation, ppm; is parts per million; TN is total nitrogen.

Conclusion

Land use transformation and inappropriate land use can deteriorate soil quality. Soil quality analysis can testify soil degradation level and urges for possible management strategies. The soil physical and chemical indicators in grazing land and forest land is maintained better. Conversely, poor soil quality found the crop land system. Soil particle analysis revealed that medium sized particles are dominant in FL and GL. Exchangeable bases (Ca, Mg, Na, and K) concentration were higher in GL and Fl. Similarly, micro nutrients (Zn, Fe, Mn, and Cu) concentration was affected by land uses. In general, soil quality indicators were found decent in FL and Gl. The discrepancy in soil quality indexes among the different land use systems might be due to abundant biomass which in turn affect all other soil quality parameter. In general vegetation are quit necessary and promising option to safeguard soil quality as well as environmental security.

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