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Full Length Research Paper

The contribution of coffee agroecosystem to soil fertility in Southwestern Ethiopia

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To investigate the contribution of coffee agroecosystem to soil fertility, soil samples were collected at the depth of 0 to 20 and 20 to 40 cm from four different land usages: coffee agroecosystem, eucalyptus plantation, grazing and cultivated lands. The soil samples were analyzed for texture, active and exchangeable acidity, organic carbon, total nitrogen, available forms of nitrogen and phosphorus, CEC, exchangeable cations and micronutrients. The results indicated that land use systems significantly (P < 0.05) affected all soil quality indicators except sand content, available Fe and Mn. Except for the exchangeable Mg, available Cu and Zn soils at coffee agroecosystem were superior for all soil quality indicators than other land use systems. The highest values of exchangeable Mg, available Cu and Zn were observed at grazing lands while the lowest values were recorded at coffee agroecosystem. Hence, the existing coffee agroecosystem in the study area contributes a significant role to improve the fertility status of the soil. Therefore maintaining the existing coffee agroecosystem, reducing overgrazing and intensive cultivation and integrated use of inorganic and organic fertilizers are recommended to replenish the degraded soil quality parameters in the study area.

Key words: Coffee agroecosystem, land use systems, soil quality, Ethiopia.

INTRODUCTION

Arabica coffee (*Coffea arabica* L., Rubiaceae) has its centre of origin in Southwestern and Southeastern Ethiopia, where it occurs naturally in the undergrowth of Afromontane rainforests between 1,000 and 2,000 m above sea level (Kassahun, 2006). In Ethiopia, the indigenous communities have been utilizing coffee for centuries, and the art of preparing coffee is a central element of the Ethiopian culture. Furthermore, coffee is Ethiopia's most important export crop contributing 41% of the country's foreign currency income (FAO and WFP, 2006). Coffee is a means of subsistence for rapidly growing population of the country as a complement or even sole source of income, and it plays a fundamental role in both cultural and socio-economic life of the nation. LMC (2003) estimates that there are 1.2 million coffee farmers and approximately 15 million households either directly or indirectly dependent on coffee for their livelihood.

Besides its economical and cultural values, coffee has different ecological importance. In its original habits: coffee naturally occurs in native forests or in agroforestry systems (Taye, 2001; Aga et al., 2003; Gole, 2003). In Ethiopia, farmers traditionally grow coffee as an important cash crop under various types of shade trees, mainly dominated by leguminous tree species (Taye, 2001; Gole, 2003). Agroforestry practices increase soil nutrient availability and accelerate nutrient cycling due to the fact that the deeper tree roots remarkably improve soil conditions (Young, 1997). Leguminous shade trees in coffee agroecosystems are also acknowledged for their good capacity for fixing atmospheric nitrogen (Beer et al, 1998; Taye, 2001; Grossman et al., 2006). Like other agroforestry systems that employ a woody component,

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shade grown coffee agrosystems also contribute to the removal of carbon from the atmosphere and its storage on land. Beer et al. (1998) point out that coffee agroecosystems could prevent the release of up to 1000t/ha carbon. However, very few scientific studies have been made in the study area to quantify the contribution of coffee agroecosystems to soil fertility as compared to other land use systems. Therefore, the objective of the present study is to investigate the impact of coffee agroecosystems on soil quality as compared to other land use systems.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted in Jimma, Southwestern Ethiopia in February, 2011. The study area is located at about 7°, 33' N latitude and 36°, 57' E longitude at an altitude of 1710 m above sea level. The mean annual maximum and minimum temperature are 26.8 and 11.4°C, respectively and the mean maximum and minimum relative humidity are 91.4 and 39.92%, respectively. The mean annual rainfall of the study area is 1500 mm (BPEDORS, 2000). According to WRB (2006), the soils of the study area are classified as Dystric Nitisol.

Site selection and soil sampling

Before collecting the soil samples, a survey was carried out to identify the dominant land uses in the study area. Four land use systems namely, coffee agroecosystem, eucalyptus plantation, grazing and cultivated lands were identified as the major land uses in the study area. To assess the impact of coffee agroecosystem on soil properties as compared to other land use systems, composite soil samples were collected from different randomly selected ten points in a plot of 20 m × 20 m by auger from each land use systems at the depth of 0 to 20 and 21 to 40 cm. Each of the land use systems considered in the study was replicated three times. In order to avoid or at least minimize the impact of topography on soil properties these samples were collected from nearly the same slopes. Twenty four composite soil samples were then prepared after thoroughly mixing the ten sub-samples in a plastic bag.

Laboratory analyses

The soil samples were air dried, mixed well, ground, and passed through a 2 mm sieve and the laboratory analysis were conducted using the following standard procedures. Soil texture was determined by hydrometer method after destroying organic matter and dispersing the soil. Soil pH-H_2O and pH-KCl were measured by using a pH meter in a 1:2.5 soil: water and soil: KCl ratios, respectively. Electrical conductivity (EC) was measured in water at soil to water ratio of 1:2.5. Soil organic carbon was determined by the Walkley-Black oxidation method, total nitrogen by the micro-Kjeldahl digestion, distillation and titration method, and available phosphorus was determined using Bray I extraction method as described by Van Reewijk (1992). Total exchangeable bases were determined after leaching the soils with ammonium acetate. 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 1 N 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. Available micronutrients (Fe, Mn, Zn, and Cu) were extracted with DTPA as described by Lindsay and Novell (1978).

Data analysis

Prior to data analysis the data were checked for the assumption of analysis of variance (ANOVA). ANOVA was then performed to assess the significance of differences in soil parameters between land uses and soil depth, using the general linear model (GLM) procedure of the statistical analysis system SAS 9.2. A post hoc means separation was done using least significant difference (LSD) test after main effects were found significant at $P < 0.05$. Since the treatment interaction was non significant ($P < 0.05$) for all soil parameters, the discussion was based on the main factors (land use and soil depth). Simple correlation analysis was also performed using SAS 9.2 in order to determine the relationship between the selected soil properties.

RESULTS AND DISCUSSION

Soil texture

Soil particle size distribution varied significantly ($P < 0.01$) across different land use systems except for sand fractions. However, the distribution of soil particles showed non-significant differences ($P > 0.05$) between the soil layers (Table 1). The highest clay content (57.50%) was observed under eucalyptus plantation while the lowest clay content (45.00%) was observed at grazing land. On the contrary, the highest silt content (27.00%) was observed at grazing land while the lowest silt content (19.00%) was observed at eucalyptus plantation. The lowest clay content under grazing and cultivated lands could have resulted from low vegetation cover which causes the clay fractions likely to be lost through processes of selective erosion and migration down the soil profile. These results are in agreement with Belayneh and Herbert (2010) who reported high percentage of clay content in forest lands than grazing land. Similarly, Mulugeta et al. (2005) and Solomon et al. (2002) reported that soil under the natural forest showed lower silt fractions than the soils on the cultivated land, which may be attributed to the effect of deforestation and subsequent cultivation. Wakene and Heluf (2003) also reported that intensive cultivation and over grazing contributed to the variations in particle size distribution at the surface horizons.

Soil reaction (pH) and electrical conductivity (EC)

Soil pH-H_2O and pH-KCl were significantly ($P < 0.01$) affected by different land use systems. However, there was no significant difference between soil depths in soil

Table 1. Mean (±SEM) particle size distribution of the upper 40 cm soils under different land use systems.

Land use	Clay (%)	Silt (%)	Sand (%)	Textural class
Coffee agroecosystem	54.67 (±3.67)[ab]	20.67 (±1.74)[b]	24.67 (± 2.51)	Clay
Eucalyptus plantation	57.50 (±0.34)[a]	19.00 (±1.37)[b]	23.50 (±1.54)	Clay
Grazing land	45.00 (±2.31)[c]	27.00 (±1.57)[a]	28.00 (±1.39)	Clay
Cultivated land	50.50 (±1.02)[bc]	26.50 (±0.89)[a]	23.00 (±1.32)	Clay
P-value	**	**	NS	-
LSD (0.05)	6.23	3.83	NS	-
Depth				
0-20cm	50.00 (±1.66)	24.17 (±1.57)	25.83 (±1.16)	Clay
20-40cm	53.83 (±2.35)	22.42 (±1.32)	23.75 (±1.33)	Clay
P-Value	NS	NS	NS	-
LSD (0.05)	NS	NS	NS	-
CV (%)	9.69	13.27	17.73	-

Values followed by the same letters are non-significant (P< 0.05), * significant at *P* < 0.05; ** significant at P<0.01; NS = non significance, CV = coefficient of variance, LSD = least significant difference.

Table 2. Mean (±SEM) for soil acidity measures and EC under different land use systems.

Land use	pH-H$_2$0	pH-KCl	∆pH	TEA meq/100g soil	EC mmho/cm
Coffee agroecosystem	5.76 (±0.08)[a]	4.54 (±0.09)[a]	1.22 (±0.05)[c]	0.21 (±0.05)[b]	0.046 (±0.01)[a]
Eucalyptus plantation	5.70 (±0.14)[a]	4.40 (±0.11)[b]	1.31 (±0.04)[b]	0.41(±0.12)[a]	0.026 (±0.02)[bc]
Grazing land	5.81(±0.05) [a]	4.39 (±0.07)[b]	1.42 (±0.02)[a]	0.23 (±0.05)[b]	0.018 (±0.002)[c]
Cultivated land	5.53 (±0.06)[b]	4.36 (±0.05)[b]	1.17 (±0.02)[c]	0.22 (±0.04)[b]	0.035 (±0.004)[b]
P-value	**	**	***	*	***
LSD (0.05)	0.12	0.10	0.08	0.14	0.01
Depth					
0-20cm	5.66 (±0.07)	4.43 (±0.06)	1.23 (±0.04)[b]	0.266 (±0.06)	0.035 (±0.01)[a]
20-40cm	5.74 (±0.06)	4.41 (±0.06)	1.32 (±0.03)[a]	0.260 (±0.05)	0.027 (±0.001)[b]
P-Value	NS	NS	**	NS	*
LSD (0.05)	NS	NS	0.056	NS	0.007
CV (%)	1.83	1.91	5.02	2.50	24.99

Values followed by the same letters are non-significant (P< 0.05), * significant at *P* < 0.05; ** significant at P<0.01; NS = non significance, ∆pH = pH H_2O – pH KCl; TEA = total exchangeable acidity; CV = coefficient of variance, LSD = least significant difference.

acidity measures. Exchangeable acidity was also significantly (P < 0.05) affected by land use systems. The highest values of pH-H_2O and pH-KCl were observed at coffee agroecosystem while the lowest values were observed at cultivated land (Table 2). The highest value of soil pH in the coffee agroecosystem was probably due to the high organic matter content observed under coffee agroecosystem helped a lot as humified organic matter can bind tightly with aluminum and iron ions and reduce their activity in the soil solution and thereby increase pH and reduce acidity. The increasing trend of soil acidity under cultivated land could be due to the effect of continues application of ammonium based fertilizers such as diammonium phosphate, $(NH4)_2HPO_4$, in such cereal based cultivated fields, which upon its oxidation by soil microbes produces strong inorganic acids. Bouman et al. (1993) reported that intensive cultivation and use of inorganic fertilizers gradually decreases soil pH and render the soil acidic. The results are also in agreement with the reports of Wakene and Heluf, (2003) and Nega et al. (2006).

Since the study area is characterized by high amount of rainfall (>1000mm), the values of electrical conductivity (EC) were very low across all land use systems. Electrical conductivity was significantly (P < 0.001) affected by land use systems and soil depth (Table 2). The highest values of electrical conductivity were recorded at coffee agroecosystem and at the surface of

Table 3. Mean (±SEM) for organic carbon, total n, available forms of nitrogen and phosphorus under different and land use systems.

Land use	OC (%)	TN (%)	N-NO3 (mg/kg soil)	N-NH4 (mg/kg soil)	AVP (mg/kg soil)
Coffee agroecosystem	2.90 (±0.3)[a]	0.26 (±0.02)[a]	341.04 (±51.38)[a]	198.66 (±29.26)[a]	1.28 (±0.08)[a]
Eucalyptus plantation	2.58 (±0.2)[b]	0.24 (±0.03)[a]	121.28 (±25.66)[b]	95.96 (±24.81)[ab]	1.09 (±0.08) [bc]
Grazing land	2.48 (±0.1)[b]	0.25 (±0.02)[a]	113.22 (±24.44)[b]	81.53 (±6.05)[ab]	1.20 (±0.04)[ab]
Cultivated land	2.53±0.07)[b]	0.19 (±0.01)[b]	196.97 ±32.82)[ab]	120.49 (±26.62)[b]	0.97 (±0.02)[c]
P-value	*	*	*	*	***
LSD (0.05)	0.29	0.04	123.48	71.17	0.13
Depth					
0-20cm	3.00±0.15)[a]	0.26 (±0.02)[a]	179.66 (±36.13)	119.53 (±16.02)	1.18 (±0.06)[a]
20-40cm	2.33±0.09)[b]	0.21(±0.01)[b]	206.59 (±39.83)	128.79 (±25.30)	1.09(±0.04)[b]
P-value	***	**	NS	NS	*
LSD (0.05)	0.24	0.03	NS	NS	0.09
CV (%)	10.32	19.95	17.10	12.14	9.05

Values followed by the same letters are non-significant (P< 0.05),* significant at *P* < 0.05; ** significant at P<0.01; ** * significant at P<0.01; NS = non significance, OC = organic carbon, TN = total nitrogen, AVP = available phosphorus; CV = coefficient of variance, LSD = least significant difference.

the soil whereas the lowest values were observed at grazing land and at the subsurface layer. The lowest figures in electrical conductivity were observed in grazing and cultivated lands can be associated to the profound loss of soluble salts after continuous grazing and cultivation. Moreover, accumulation of exchangeable bases from decomposition of organic matter results high EC at coffee agroecosystem. The correlation matrix (Table 6) also showed a positive and significant (P<0.01; r = 0.65) relationship between organic matter and electrical conductivity. Nega et al. (2006) also reported higher EC at forest lands when compared with grazing and cultivated lands.

Soil organic carbon and total nitrogen

The analysis of variance showed that soil organic carbon and total nitrogen were significantly (P < 0.05) affected by land use and soil depth (P < 0.01) (Table 3). Soil organic carbon ranged from 2.89% under coffee agroecosystem to 2.53% under grazing land. Similarly, the highest value of total nitrogen (0.26%) was observed at coffee agroecosystem whereas the lowest value of total nitrogen (0.19%) was observed at cultivated land (Table 3). The highest value of organic carbon in soils under coffee agroecosystem could have resulted from high organic matter accumulation due to increased above and below ground biomass (root biomass) (Reicosky and Forcella, 1998; and Saikh et al. 1998). However, in grazing and cultivated lands, overgrazing and continuous cultivation resulted low soil organic carbon content. The result of the present study is in conformity with the findings of Solomon et al. (2002); Wakene and Heluf (2003); Jianwei et al. (2010); and Belayneh and Herbert (2010).

Generally, cultivated soils had significantly lower total N when compared to other land use systems. Considerably low value of total nitrogen in the continuously cropped fields could be attributed to rapid mineralization of soil organic matter following cultivation, which disrupts soil aggregates, and thereby increases aeration and microbial accessibility to organic matter (Solomon et al., 2002). Significantly higher total nitrogen content in soils under coffee agroecosystem can also be associated with high accumulation of organic matter under coffee agroecosystem and nitrogen fixing capacity of some coffee shade tree species.

According to Taye (2001), more than 40% of coffee shade tree species in southwestern Ethiopia are legumes, that is, *Acacia, Albiza* and *Millettia*. Moreover, wide use of tree legumes for providing shade has been well documented in many coffee growing countries across the globe (Polzot, 2004).

The findings of this study are in harmony with the results of similar recent studies reported by Solomon et al. (2002) and Nega et al. (2006). The vertical distributions of soil organic carbon and total nitrogen are also attributed to the continuous accumulation of undecayed and partially decomposed plant and animal residues in the surface soils.

Available forms of nitrogen (N-NO_3 and N-NH_4) and phosphorus

The impact of land use systems on the available forms of nitrogen and phosphorus is presented in Table 3. The available forms of nitrogen (N-NO_3 and N-NH_4) and phosphorus were significantly (P < 0.05 and P < 0.001, respectively) varied across different land use systems. The highest values of available forms of nitrogen and phosphorous were observed under coffee agroecosystem

Table 4. Mean (±SEM) for exchangeable bases, CEC and BS under different land use systems.

Land use	Cmol (+)/Kg soil					%
	Na	**K**	**Ca**	**Mg**	**CEC**	**BS**
Coffee agroecosystem	0.65 (±0.2)[a]	5.77 (±1.93)[a]	10.18 (±0.66)[a]	1.35 (±0.2)[b]	24.47 (±0.79)[a]	73.49 (±8.59)[a]
Eucalyptus plantation	0.32 (±0.03)[ab]	1.34 (±0.12)[b]	9.35 (±0.49)[a]	2.46 (±0.26)[a]	24.40 (±0.63)[a]	55.31(±3.49)[b]
Grazing land	0.27 (±0.01)[b]	1.31 (±0.07)[b]	6.94 (±0.32)[c]	2.91 (±0.07)[a]	21.20(±0.44)[b]	54.12(±2.82)[b]
Cultivated land	0.24 (±0.01)[b]	1.56 (±0.07)[b]	7.96 (±0.17)[b]	2.68 (±0.24)[a]	23.40 (±0.33)[a]	53.12(±1.27)[b]
P-value	*	**	***	**	***	**
LSD (0.05)	0.31	3.01	0.91	0.71	1.43	12.02
Depth						
0-20cm	0.35 (±0.09)	2.37 (±0.90)	8.98 (±0.53)[a]	2.36 (±0.26)	24.03(±0.64)[a]	58.20 (±4.01)
20-40cm	0.39 (±0.09)	2.62 (±0.92)	8.24 (±0.35)[b]	2.33 (±0.23)	22.70(±0.33)[b]	59.83 (±4.28)
	NS	NS	*	NS	*	NS
LSD (0.05)	NS	NS	0.65	NS	1.01	NS
CV (%)	28. 83	2.19	8.58	24.57	4.93	16.44

Values followed by the same letters are non-significant (P< 0.05), * significant at *P* < 0.05; ** significant at P<0.01; ** * significant at P<0.01; NS = non significance, CEC= cation exchange capacity; BS = base saturation; CV = coefficient of variance, LSD = least significant difference.

whilst the lowest values for available forms of nitrogen and phosphorus were observed at grazing and cultivated lands, respectively. The highest values of available forms of nitrogen under coffee agroecsystem could be due to high accumulation of organic matter and nitrogen fixing ability of some coffee shade tree species. The values of N-NO3 and N-NH4 in soils under cultivated land were relatively high as compared to eucalyptus plantations and grazing land. This could be because of the residual effect of nitrogen contain fertilizers like urea and DAP which contain readily available forms of nitrogen. The highest values of available phosphorus under coffee agroecosystem could be because of high accumulation of organic matter and low activity of Fe and Al to fix phosphorous as they are strongly adsorbed by humic substances. The increase soil pH could be another reason for the highest values of available phosphorous at coffee agroecosystem. The correlation matrix (Table 6) also showed a positive and significant relationship (P<0.05; r = 0.40) between organic matter and available phosphorous and pH and available phosphorous (P<0.05; r = 0.50). The smallest values of available phosphorus under cultivated land however could be because of low accumulation of organic matter and low soil pH value (Tables 2 and 3). Available forms nitrogen also showed no significant difference with soil depth though available forms phosphorus was significantly (P < 0.05) affected by soil depth (Table 3). The value of available phosphorus significantly decreased with soil depth.

Cation exchange capacity and exchangeable bases

Cation exchange capacity was significantly (P < 0.001) affected by land use systems (Table 4). The CEC ranged from 24.47 Cmol (+)/Kg soil under coffee agroecosystem to 21.20 Cmol (+)/Kg soil under grazing land. This variation might be attributed to high accumulation of organic matter under coffee agroecosystem than grazing land. The correlation matrix (Table 6) also showed a positive and significant (P<0.05; r = 0.47) relationship between organic matter and CEC. Therefore, the depletion of organic matter as a result of continuous grazing has reduced the CEC under the grazing land and that is in concurrence with previous findings (Belayneh and Herbert, 2010; Gao and Chang, 1996). Moreover, the highest value of CEC under coffee agroecosystem could be associated with high percentage of clay fraction under coffee agroecosystem (Table 1). Cation exchange capacity was significantly (P < 0.01; r = 0.49) correlated to clay percentage (data not shown). The CEC values were also significantly (P < 0.05) affected by soil depth and it declined from 24.03 meq/100g soil in the surface soils to 22.70 meq/100g soil in subsurface layer (Table 4). The decrease in CEC with depth is due to a decrease in organic matter content with soil depth. The percentage of base saturation was also significantly (P < 0.01) affected by land use system. It ranged from 73.49% under coffee agroecosystem to 53.12% under cultivated land however there was no significant (P > 0.05) difference between soil depth in percentage of base saturation (Table 4). Exchangeable Na, K, Ca and Mg were also significantly affected by land use systems. However, there was no significant (P > 0.05) difference between soil depth in exchangeable bases except for exchangeable Ca which was significance (P < 0.05) across the soil depth (Table 4). The highest values of exchangeable Ca, K and Na were observed under coffee agroecosystem while the lowest value of exchangeable

Table 5. Mean (±SEM) for available micronutrients under different land use systems.

Land use	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
Coffee agroecosystem	22.33 (±1.12)	55.84 (±1.50)	1.17 (±0.11)^{b}	3.27 (±0.27)^{ab}
Eucalyptus plantation	23.16 (±0.57)	56.04 (±1.31)	1.29 (±0.11)^{b}	2.44 (±0.29)^{b}
Grazing land	23.59 (±0.53)	58.06 (±0.53)	1.66 (±0.16)^{a}	4.33 (±0.76)^{a}
Cultivated land	21.02 (±1.37)	56.51 (±0.84)	1.42 (±0.13)^{ab}	2.60 (±0.23)^{b}
P-value	NS	NS	*	*
LSD (0.05)	NS	NS	0.35	1.40
Depth				
0-20cm	23.93 (±0.30)^{a}	58.08(±0.24)^{a}	1.22(±0.11)^{b}	2.73(±0.41)^{b}
20-40cm	21.12 (±0.75)^{b}	55.15(±0.95)^{b}	1.54(±0.08)^{a}	3.60(±0.29)^{a}
P-value	**	***	*	*
LSD (0.05)	1.63	1.51	0.25	0.98
CV (%)	8.24	3.05	20.48	16.15

Values followed by the same letters are non-significant (P< 0.05), * significant at *P* < 0.05; ** significant at P<0.01; *** significant at P< 0.001 ..NS = non significance, CV = coefficient of variance, LSD = least significant difference.

Na was observed under cultivated land and lowest values of exchangeable K and Ca were observed under grazing land. Contrary to this the highest value of exchangeable Mg was observed under grazing land whilst the lowest value was observed under coffee agroecosystem. This could be because of high demand for Mg by coffee plant since Mg was found deficient for the growth of coffee in the study area. According to Malavolta (1990), soils for coffee production should have Mg to CEC percentage of 10-15% however in the present study it was 5.52%.The value of exchangeable K under coffee agroecosystem was 3.5 times greater than cultivated land. This is due to the fact that weathering, intensive cultivation and use of acid forming inorganic fertilizers on acid soils affect the distribution of K in the soil systems and enhance its depletion (Baker et al., 1997; Saikh et al., 1998). The present study is in agreement with the common belief that Ethiopian soils are rich in K. The results; however, were contrary to Alemayehu (1990) and Wakene and Heluf (2003) who reported low K concentration for Nitisols and Alfisol in Ethiopia, respectively.

Micronutrient status under different land use system

From micronutrients, only available Cu and Zn were significantly ($P < 0.05$) affected by land use systems (Table 5). The largest value (1.66 ppm) and the smallest value (1.17 ppm) of available Cu were observed at grazing land and coffee agroecosystem, respectively. Similarly, the value of Zn ranged from 4.33 ppm under grazing land to 2.44 ppm under eucalyptus plantation. The solubility and the availability of the micronutrients considered in the present study could be enhanced by acidic soil reaction. Thus, low concentrations of most of the micronutrients under coffee agroecosystem and eucalyptus plantation are reflections of the soil reaction (Table 2). Fasil and Charles (2009) also reported high solubility and availability of micronutrients under low soil pH.

The vertical trend has also shown a significance difference in available micronutrients. The highest value of available Fe and Mn were observed at the surface of the soil while the highest values of available Cu and Zn were observed at the subsurface soil layer. In general, the micronutrient status of the study area rated as very high across all land use systems.

Conclusion

Most of the important soil quality indicators were significantly affected by different land use systems. Except for micronutrients all soil quality indicators under coffee agroecosystem were superior to other land use systems whilst due to intensive cultivation, over grazing and use of acid forming inorganic fertilizers nearly all of the chemical properties of the soil under grazing and cultivated lands were poor. In general, the current land management system that results continuous succession of coffee agroecosystem with eucalyptus plantation, grazing and cultivated lands has degraded most of the important soil quality indicators. Therefore, maintaining the existing forest coffee, the expansion of scattered tree based agroforestry system; reducing overgrazing and intensive cultivation and integrated use of inorganic and organic fertilizers are recommended in order to replenish the degraded soil quality parameters in the study area. Moreover since the values of available phosphorus was below the critical values, attention should be given for the

Table 6. Pearson correlation matrix for the selected soil physicochemical properties.

Soil parameter	OM	pH	CEC	TN	AVP
OM (%)	-				
pH	0.41*	-			
CEC (Cmol (+)/Kg soil)	0.47*	0.23	-		
TN (%)	0.52**	-0.29	0.25	-	
AVP (ppm)	0.40**	0.50*	0.24	0.16	-
N-NO3 (mg/Kg)	0.10	0.05	0.17	0.16	0.02
N-NH4 (mg/Kg)	0.22	-0.21	0.16	0.20	0.10
Exch. K (Cmol (+)/Kg soil)	0.07	0.36	0.21	0.07	0.37
Exch. Na (Cmol (+)/Kg soil)	0.15	0.40*	0.19	0.07	0.36
Exch. Ca (Cmol (+)/Kg soil)	0.29	0.34	0.69**	0.06	0.51**
Exch. Mg (Cmol (+)/Kg soil)	0.28	0.15	0.33	0.39	-0.19
Available Fe (ppm)	0.56**	-0.12	0.21	0.52**	0.39
Available Cu (ppm)	-0.57**	0.21	-0.79**	-0.37	-0.18
Available Zn (ppm)	0.37	0.23	-0.61**	-0.03	0.11
Available Mn (ppm)	-0.38	0.34	0.05	0.18	0.44*
Available EC (ppm)	0.65**	0.14	0.67**	0.17	0.30
Clay (%)	0.39	0.01	0.49*	0.01	0.22
Sand (%)	0.48*	-0.05	-0.32	0.29	0.26
Silt (%)	0.11	0.03	-0.42*	-0.28	0.08

**'* Significance at P<0.01 and P<0.05, respectively; OM = organic matter; CEC = Cation exchange capacity; TN= total nitrogen; AVP= available phosphorous.

management of this essential plant nutrient.

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