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EFFECTS OF DIFFERENT CROPPING AND LAND MANAGEMENT PRACTICES ON THE QUALITY OF IRRIGATED SOILS OF THE UPPER AWASH BASIN, CENTRAL RIFT VALLEY OF ETHIOPIA

ALMAZ DECHE ✉[1,2], MOHAMMED ASSEN[1], SHIMELES DAMENE[3], ASMAMAW LEGASS[1]

[1]Department of Geography and Environmental Studies, Addis Ababa University, Addis Ababa, Ethiopia; e-mail: almidech@gmail.com
[2]Department of Geography and Environmental Studies, Assosa University, Assosa, Ethiopia
[3]College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia

✉ Corresponding author

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Abstract

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Irrigation is one way of utilizing the land resources to enhance agricultural production. Irrigation crop production is crucial in the present study area due to its arid and semi-arid climatic characteristics. However, little is known about the influence of different cropping and land management practices on soil quality (SQ). This study aimed to determine the effects of different cropping systems and land management practices on variability of SQ indicators in the Central Rift Valley of Ethiopia (CRVE). To this end, 45 disturbed surface (0–20 cm) and 24 undisturbed (upper 7 cm) soil samples were collected from four adjacent farms: large-scale perennial farms (LSPF), large-scale annual farms (LSAF), smallholder subsistence annual farms (SHAF), and non-cultivated lands (NCL). Soil analyses were made for selected SQ indicators – particle size analysis, bulk density, soil water content, organic matter, pH, total nitrogen, available potassium and phosphorus, exchangeable bases, and cation exchange capacity. One-way analysis of variance (ANOVA) and Pearson correlation coefficient (r) were computed. Key informants' interview was conducted to substantiate the data obtained from soil laboratory analyses. As the results confirmed, different cropping and land management practices had significant effects on some SQ indicators. Soil organic matter, total nitrogen, available P, and available K declined significantly ($P < 0.05$) in the soils of LSAF and SHAF. This is attributed to land management-induced problems such as frequent tillage practice of mono-cropping, high level of mechanization, removal of crop residues/above-ground biomass in LSAF, and use of low external inputs and overcultivation without appropriate land management practices in SHAF. However, LSPF practice resulted in the improvement of key SQ indicators, next to NCL. Therefore, LSPF can be an alternative cropping and land management practice to achieve sustainable agricultural production and land management in semi-arid irrigated lands of CRVE and in places with similar environments.

Key words: agricultural investment, annual farming, perennial farming, smallholders, soil quality.

Introduction

The demand for land by humans to produce food crops and feed has increased globally over the past 50 years (FAO, 2014). This has further been aggravated by climate change, resources depletion, and the need for additional land to expand human settlement (Deininger, 2013). These situations, in turn, have been challenging the capability of the agriculture sector to deliver sufficient and sustainable food supply (Godfray et al., 2010). In overcoming the shortages of food crop production, large-scale agricultural investments (LAIs) have been employed as a solution to satisfy the growing food demand in many parts of the world (Deininger, 2013). However, in some parts of the world, expansion of LAI has been accomplished by substituting the original native vegetation and land use with systems dominated by a single (mono) or a few crop species and by favoring annual over perennial species (Asbjornsen et al., 2013), both of which have some socio-environmental implications. For instance, in North America's Corn Belt, LAI has changed the native vegetation into annual mono-cropping system (CS) that resulted in soil loss from such fields (Glover, 2003). In Brazil, the expansion of LAI has transformed the Brazilian Cerrado into soybean and cotton crops-based annual farming system (da Silva, Bates, 2002). Similarly, in Kenya and Sudan, LAI expansion has replaced the extensive original native vegetation and pastoral grazing lands into mechanized and irrigated farmlands (Campbell et al., 2005).

As the economy of developing countries including Ethiopia is primarily dependent on agriculture, it is important to look at the current land management practices and their impacts on soil quality (SQ) (Martin, 2002). In this context, SQ can be considered as the capacity of the soil to function in response to land management practices and stress made by natural and anthro-

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pologically induced factors (Schjønning et al., 2004). Hence, SQ assessment is vital to examine the degree of soil degradation (Yitbarek et al., 2013) using soil's physical, chemical, and biological indicators (Karlen et al., 2003; Zhao et al., 2015). Variations in cropping and land management practices are also major factors of SQ dynamics at a local scale (Yitbarek et al., 2013), and hence, it will be useful to analyze the existing SQ status and evaluate the restoration effects of different CSs to develop sustainable land management strategies (Karlen et al., 2003; Khreast et al., 2008).

Nevertheless, several studies have given more attention largely to the issue of soil erosion studies, with little attention to the influence of CSs and land management practices on SQ indicators (Karlen et al., 2003). It is, therefore, important to assess SQ indicators related to different cropping and land management practices, so as to improve land management strategies and to sustain natural SQ for sustainable soil management (Teferi et al., 2016). Studies show that land-use changes (e.g., from natural vegetation to agriculture) in general and CSs in particular have significant influence on SQ indicators (Alem, Pavlis, 2014; Singh et al., 2014; Swinton et al., 2007; Tesfahunegn, 2016; Yitbarek et al., 2013; Zhao et al., 2015).

Nevertheless, the impact of LAIs on the environment, particularly on SQ, depends on the type of cultivated crops, employed production systems, and land management practices not sufficiently researched so far (Deininger, 2013) and, even where it existed, findings of many studies on this aspect of the study are contentious. For instance, some studies confirmed that perennial-based farming systems improve the SQ as deeper roots retrieve nutrients to the soil surface through leaf litter accumulation and decay process (Acharya, Kafle, 2009; Randall et al., 1997), where these demand planting of suitable crop types and use of appropriate CSs to improve the SQ (Yesilonis et al., 2016).

Similar to other developing countries, Ethiopia introduced LAI as a strategy to improve food security and to increase its agricultural export earnings (Keeley et al., 2014), particularly in its arid and semi-arid climatic regions (Awulachew et al., 2007). In this regard, some studies in Ethiopia have shown that LAIs without appropriate soil and water management practices and with limited use of agricultural inputs have caused SQ deterioration (Awulachew et al., 2007; Edossa et al., 2014; Teklu et al., 2018). However, these studies were limited by quantitative evidence that evaluates SQ changes occurring under different CSs and other land-use systems managed by large-scale irrigation agricultural investments in Ethiopia in general and in the Central Rift valley of Ethiopia (CRVE) in particular. The available previous studies also paid little attention to the roles, contributions, and implications of the different CSs and land management practices of LAI on the SQ dynamics (Awulachew et al., 2007; Teklu et al., 2018).

In the study area, land is used for perennial and annual crop production under large-scale irrigated agricultural investment and smallholders. The latter primarily applies subsistence farming, and it is characterized by low yield resulting from little or no use of external inputs (Awulachew et al., 2007). On the other hand, large-scale irrigated annual and perennial cropland is characterized by high use of chemical fertilizer, overuse of agrochemicals, and mechanization (Edossa et al., 2014). These have led to negative changes in SQ indicators from the perspective of sustainable land use (FAO, 2001).

Therefore, evaluation of SQ through multi SQ indicators in relation to different cropping and land management practices is required (Andrews et al., 2004). In fact, sustainability of agricultural production and productivity can be viewed as improving the SQ to advance sustainable resource use and suggesting appropriate remedial management measures and suitable land management options by considering the potentials and constraints of different CSs (Fallahzade, Hajabbasi, 2013). Therefore, this study aimed to analyze the effects of different cropping and land management practices on selected SQ indicators in the Upper Awash Basin, CRVE.

Material and methods

Description of the study area

The study was conducted in the Upper Awash Basin, CRVE, which is geographically located between 8°30¢ and 8°40¢ N latitude and 39°40¢ and 39°50¢ E longitude (Fig. 1). The geological and topographical features of the area have resulted from the recent past tectonic and volcanic activities of the tertiary period of Cenozoic era (Mohr, 1971). It has slope gradients generally ranging from 0 to 2% and interrupted by local hills in some areas. The altitude ranges from 1070 m to over 2400 m above mean sea level (amsl) on the hilly areas. The area consists of several individually standing volcanoes and volcanic complex products such as felsic tuffs, ignimbrites, pumice, and subordinate lavas, and their weathered products (Azeb et al., 2015). The rift floor is mainly composed of volcanic products that have been locally weathered and have formed fluvial–lacustrine sediments through surface runoff (Billi, 2015).

Hydrologically, the area is drained by the Awash River, which rises in the central Ethiopian highlands, flows to the north-easterly direction, and finally empties into Lake Abe, located between the border of Ethiopia and Djibouti. The Awash River is one of the most utilized rivers of Ethiopia for large-scale irrigation agriculture, hydroelectric power production, and other human uses (Kinfe, 1999).

Based on the traditional agroclimatic classification of Ethiopia (Hurni, 1998), the study area partly belongs to *kola* (warm, semi-arid lowlands, 1070–1500 m above sea level [m.a.s.l.]) and *weyna-dega* agroecology (mild, sub-humid highlands, 1500–2300 m.a.s.l.). Analysis of three-decade (1988–2016) metrological data of Abomsa weather station (located within the study area) indicated that the area is characterized by high temperature and erratic rainfall (Fig. 2). The mean annual total rainfall of the analysis period (1988–2016) was 910 mm, with high interannual variability ranging from 643 to 1156 mm. The mean annual temperature is about 21.8 °C, with the mean minimum temperature being 12.7 °C and the mean maximum temperature being 31 °C, which causes high rates of evaporation.

Depending on local variations, soils of the rift valley are largely derived from recent volcanic rocks of basalt, ignimbrites, gneiss, volcanic ash, alluvium, and pumice deposits (Tefera et al., 1996). According to the WRB soil classification system (FAO/UNESCO, 1990), the dominant soil types include Vertisols, Andosols, and Fluvisols. Micronutrient imbalances, low availability of phosphorus, and different rates of infiltrations and runoff potential, which pose problems of irrigation soil and water management, are among the problems of the soils of the study area (Mezegebu et al., 2014).

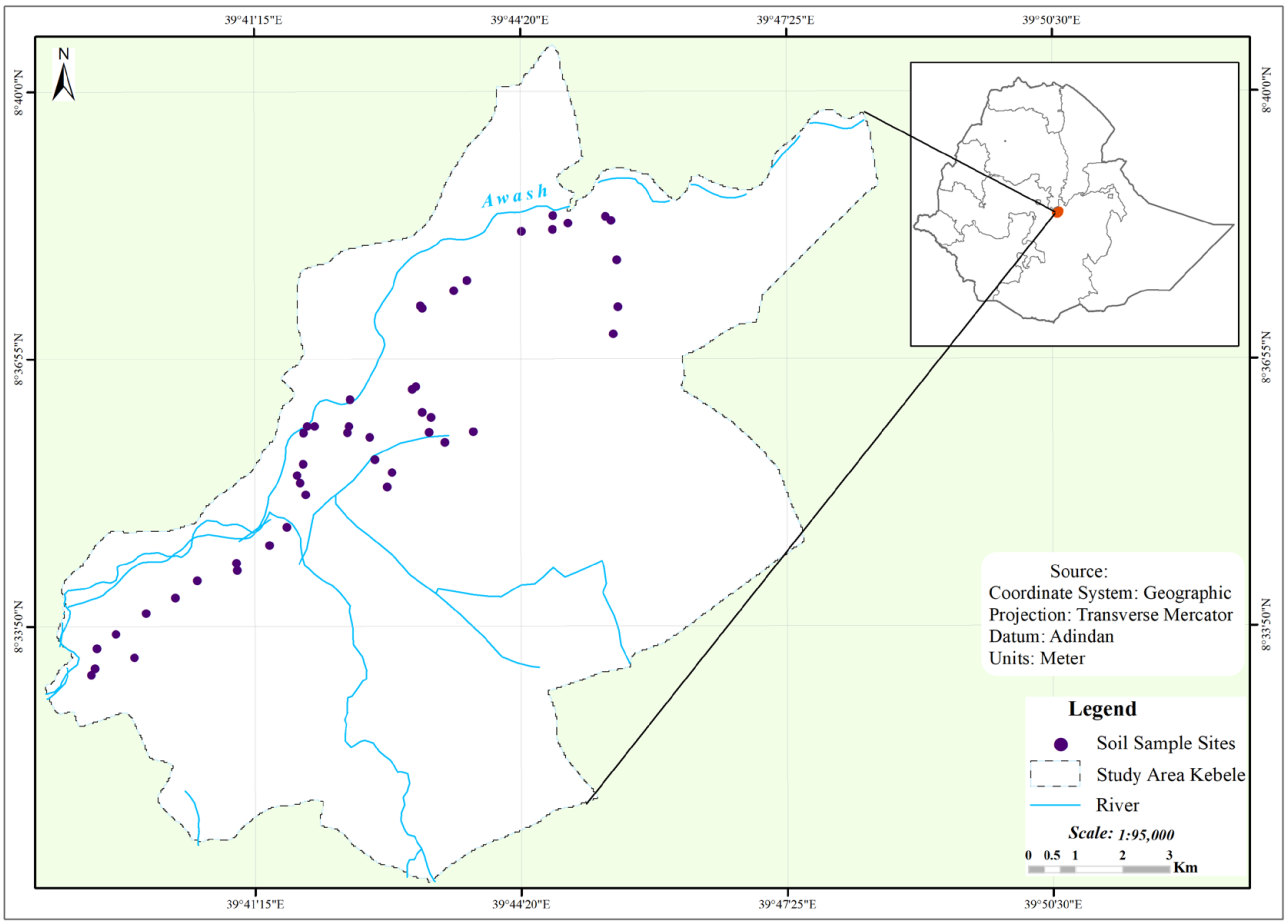


Fig. 1. Location of the study and sampled soil sites in the Upper Awash Basin, Central Rift valley of Ethiopia.

In the study area, land is used both for crop and livestock production. Crop production is practiced under rainfed and irrigation systems (Awulachew et al., 2007). However, the current study considers only land under irrigated crop production system. This is because the selected study sites were largely covered with large- and small-scale irrigated agricultural farms. The farming practices are both irrigated subsistence smallholder farming and LAI farms. According to the information obtained from key informants, about 50 years back, large-scale agriculture and smallholder-irrigated farmland areas were part of the current adjacent woodland and grassland covers. In the past five decades, commercial vegetables and fruits were cultivated under large-scale irrigated agriculture consisting of both annual and perennial crops (Table 1).

The perennial crops grown in the study area, mainly on LAI farms, included papaya (*Carica papaya),* orange (*Citrus sinensis*), banana (*Musa paradisiacal*), and mango (*Mangifera indica*), whereas the annual crops in these farms included tomato (*Solanum lycopersicum*) and soybean (*Glycine max*) produced both for local and export markets (Edossa et al., 2014). On the other hand, smallholder farmers cultivated irrigated annual crops such as maize (*Zea mays* L.) and irrigated vegetables such as onion (*Allium cepa*) and tomato (*Solanum lycopersicum*). Elsewhere in the neighboring study area, mainly in the floor of the Rift Valley, deciduous plants like acacia woodland and wooded grasslands formed the dominant natural vegetation types, whereas the eastern plateaus of the Rift Valley were covered by bushy grassland and remnants of mountain forest trees (Tewodros, 2009).

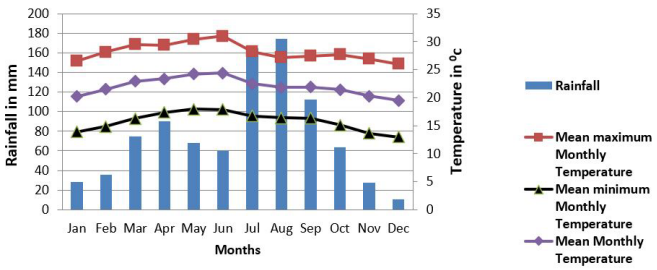


Fig. 2. The mean maximum and minimum monthly temperatures and monthly total rainfall (1988–2016) of the study area in the Upper Awash Basin, Central Rift valley of Ethiopia.

Soil sampling and laboratory analysis

Sample design and sampling

Using a multi-stage sampling procedure, in March 2018, a soil field sampling was carried out on different cropping and land management practices. In this process, as the first step, the study area was subdivided into different land units (LUs) of CSs based on key informant interviews (KIIs), reference base map developed through unsupervised classification of satellite images, and field observation. The KII was conducted with a team consisting of the *kebele* (lower administrative units of Ethiopia) administrators, two local development agents, and five farmers who know the study area's CSs. Based on these, two main land-use types, that is, uncultivated land (mainly woodland) and cultivated land-with-irrigation farmland, were identified. Then, the irrigated farms were further classified into different cropping and land management systems, which included(1) large-scale commercial irrigated farms with perennial crops (LSPF), (2) large-scale commercial irrigated farms with annual crop (LSAF), and (3) smallholders-irrigated farms with only annual CSs (SHAF). The LSAF occupied similar topographic features, such as slope gradient, as large-scale irrigation perennial farms (Table 1). The choices of LUs were based on the assumption that SQ indicators vary with both CSs and land management practices (Table 1), which could potentially impact soil function. At last, soil samples were collected from recognized LUs with four replicates from each LU of small-scale holder farms, but more than four sites of replicates from LUs of large-scale commercial farms, proportionate to the area of each land-use type. As a point of reference, soil samples were included from non-cultivated lands (NCL), where this was assumed to approximate the natural SQ status and considered as a benchmark for analysis and interpretation of SQ dynamics.

In the sampling, soils from representative sites, both disturbed and undisturbed, were collected. On each identified cropping and land management practice, a 10 × 10 m sampling polygon was marked at the center of the LU for collecting the soil samples. Disturbed soil samples were collected from four sides at 5-m intervals and from the center of the polygon in an X fashion to extract composite samples (Damene et al., 2013). Totally, 45 disturbed samples were collected using a sampling auger (Fig. 1). The samples were collected from a depth of 0–20 cm (a plow depth), as this is where most SQ changes could occur due to the impact of long-term CSs, land-use changes, and soil and water management practices, including irrigation agriculture (Adugna, Abegaz, 2016). All the selected CSs were on irrigated agriculture land, whereas the NCL were non-irrigated woodland. This NCL use type is sampled assuming that it has gone through slight or little changes and that it approximates and/or is equivalent to the original status of SQ indicators.

The disturbed composite sampled soils from each site were pooled into a bucket and mixed thoroughly to be homogenized. Then, a subsample of about 1 kg from the pooled samples was taken, air dried, and sieved to pass through 2-mm mesh sieves before analysis. Moreover, the undisturbed core samples were collected from each site at the upper 7 cm depth from the center of each sampling plot with cylindrical core samplers (270 cm^3) for bulk density (BD) and soil moisture content determination.

Soil laboratory analysis

Fourteen SQ indicators were analyzed at the National Soil Testing Centre of the Ministry of Agriculture and Natural Resources, Addis Ababa (Ethiopia), and five other SQ indicators were derived from the analyzed laboratory data. The collected undisturbed soil samples were used to estimate BD and moisture contents of the soil (Black, 1965). Soil water content at the field capacity (FC) and permanent wilting point (PWP) were determined at 1/3 and 15 bars, respectively, by the pressure membrane suction method (Estefan et al., 2013). Bouyoucos hydrometer method was used to analyze the particle size distribution of the soils (Bouyoucos hydrometer method, 1962). Soil pH was determined in 1:2.5 (pH H_2O) soil to water ratio using a pH meter (van Reeuwijk, 2002). Dichromate oxidation method (Walkely, Black, 1934) and micro-Kjeldahl procedure were used to determine soil organic carbon and total nitrogen (TN), respectively (Bremner, Mulvaney, 1982). In order to determine cation exchange capacity (CEC) and exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+), ammonium acetate method at pH 7 was used (Landon, 1991). Available phosphorus (Av. P) and available potassium (Av. K) were measured and determined following the Olsen (1965) and the Morgan extraction methods (Morgan, 1957), respectively.

Derived soil parameters

In this study, five derived soil parameters, soil organic matter (SOM), CEC- clay, available water content (AWC), total porosity, and crusting index (CI), have been considered.

The values of BD and assumed average particle density (PD) of 2.65 g/cm^3 (Haan et al., 1994) were used to calculate the value of total porosity using the following formula:

$$P = 1 - \frac{(BD)}{(PD)} \times 100,$$

where P = total porosity (%), BD = the value of bulk density (g/cm^3), and PD = assumed particle density (g/cm^3) (Landon, 1991).

To show susceptibility of the soils to crusting, soil CI was calculated using the following formula (FAO, 1979):

$$CI = \frac{\text{Silt (\%)}}{\text{Clay (\%)}} \times 100.$$

The contents of CEC- clay were estimated using the formula (Carter, 2007):

$$\text{EC of clay } \left(\frac{\text{cmol}}{\text{kg}}\text{soil}\right) = \frac{\text{CEC of soil}}{\text{percentage of clay}} \times 100.$$

Contents of SOM were obtained by multiplying the values of percentages of soil organic carbon by a factor of 1.724, assuming that SOM contains 58% of SOC (Carter, 2007).

The AWC was determined by finding the difference between the percentages of FC and PWP, and is expressed in percentage (Estefan, 2015).

Moreover, 12 local stakeholders were selected and interviewed as key informant interviewees (KII). These comprised experts in natural resource management at the *woreda* and *kebele* levels, four workers in the field of LAI, and five model farmers

Table 1. Description of land management and number of soil samples collected from each CS (cropping system) and land management practices.

CS code	CS types	Description	Land management practice	No. of samples
LSPF	Agricultural Investments Perennial Farms	These are farms of agricultural investment land planted with perennial crops (such as oranges, mangos, papayas and bananas)	Cultivated for commercial fruit through large scale ring basin irrigation methods, apply fertilizer three times a year (before, during and after planting), use pesticide, while timing of water application is based on rainfall amount and distribution (supplementary irrigation during summer or rainy and main irrigation in dry seasons), use soil and water management such as water way and soil bund, use tractor only for planting once, then stay for long period without plowing, use crop cover, residual management and practices, different agronomic methods like short period fallowing, row planting, intercropping (the fields of orange were further intercropped with short season crops such as soybean).	12
LSAF	Agricultural Investment Annual Farms	These are agricultural investment farmlands mainly dedicated for annual crop production such as vegetables (tomato), cereals (mainly beans) and industrial raw material like cotton	Continuously cultivated using flooded irrigation methods, while timing of water application is based on rainfall amount and distribution (supplementary irrigation during summer/ rainy and main irrigation in dry seasons), use machinery (tractor for land preparation every season), and combiners for harvesting and widely applied chemical fertilizer once a year, and agro-chemicals, use management methods such as soil bund and row seeding, use improved seed. In this system, rotations, cropping of bean and tomato are common practices, remove most or all of above ground biomass during harvesting.	10
SHAF	Smallholders' Subsistence Annual Farms	These are small-scale subsistence farmlands used to cultivate for annual crops such as cereal like maize and vegetables such as tomato and onion	Frequent plowing using traditional methods (oxen) except for some model farmers who got rent tractors from large scale investors, while timing of water application is based on rainfall amount and distribution; farmers apply organic fertilizer once a year to be applied according to farmers own preferred rate but according to KII from agricultural office, smallholders' farmers apply less than the recommended rate by research centers), use crop rotation (rotation of maize and onion is a common practice). There is no fallowing and use of some management methods such as soil bund and water way, remove most or all of above ground biomass during harvesting.	13
NCL	Non- Cultivated Lands	The non-cultivated land and it is recognized to be the slightly disturbed land as represented by local woodland land use	Land use type in which human interference is minimal and covered with thick growth of natural vegetation. This type of land use is non irrigated land.	10

(as recognized by local experts). These interviews provided us with more in-depth information that allowed the laboratory results to be confirmed, contextualized, and deepened.

Statistical analysis

A one-way analysis of variance (ANOVA) was run in Statistical Package for the Social Sciences (SPSS) software, version 20. This was conducted to assess the effects of different CSs and land management practices on the spatiotemporal variation of selected SQ indicators. The Scheffe post hoc multiple comparison test was applied to estimate the SQ indicators that showed statistically significant ($P < 0.05$) mean differences. A Pearson correlation coefficient analysis was conducted to determine the relationship between selected soil variables. Data obtained from key informants of SQ changes and land management practices were analyzed qualitatively.

Results

Effects of cropping and land management practices on soil physical quality indicators

Soil particle size, classes, and crusting

As our analysis showed, proportions of soil particle size did not significantly vary across the different cropping and land manage-

Table 2. Mean values of topsoil (0–20 cm) physicochemical soil quality indicators and results of one-way ANOVA across the different cropping and land management systems.

Soil properties	Cropping and management practice [1]				F-value	P-value[2]
	LSPF	LSAF	SHAF	NCL		
Sand (%)	24	22	24	21	.422	.738 ns
Silt (%)	35	34	32	37	.818	.492 ns
Clay (%)	43	44	43	42	.058	.981 ns
BD (g cm-^{3})	1.1	1.14	1.2	1	.340	.797ns
FC (% Wt)	42	41	42	42	.022	.995 ns
PWP (% wt)	26	24	25	25	.206	.891 ns
AWC (% wt)	16	17	16	17	----	---
pH (H_2O)	7.5	8.0	8.0	7.7	3.454	. 025
SOM (%)	3	2.8	2.8	4	5.760	.002**
TN (%)	0.2	0.12	0.13	0.2	9.916	.000**
Ex.Na(comol$_{(+)}$ /kg soil)	0.5	1.3	1.1	0.6	1.462	. 239 ns
Ex. K (cmol$_{(+)}$ /kg soil)	2.4	0.7	0.7	0.4	8.789	.000**
Ex_Ca (cmol$_{(+)}$ /kg_soil)	91	105	103	98	2.169	. 107 ns
Ex_Mg_(comol$_{(+)}$ /kg soil)	43	49	48	45	2.149	.109 ns
CEC (comol$_{(+)}$ /kg soil))	41	47	44	45	1.649	. 193 ns
Available K (mg/kg)	355	274	236	390	5.703	.002**
Available P(mg/kg)	18	7	9	9.7	5.500	.003**
Crusting Index (CI) (%)	0.9	0.9	0.8	.9	---	---
Total porosity (%)	59	57	56	58	---	---
CE clay/kg soil	113	100	100	115	-	

Notes: ns – not significant at p < 0.05; * – significant at p < 0.05; ** – significant at p < 0.001.

ment practices. Although it was not found to be statistically significant, a uniformly high proportion of clay content was found in all CSs and management practices, for example, LSPF- 43%, LSAF- 44%, SHAF- 43%, and NCL- 42% (Table 2). A relatively high mean sand fraction was experienced in LSPF and SHAF (24%), followed by LSAF, (22%) and a low man sand fraction in NCL (21%). The lowest mean silt (32%) contents were observed in SHAF, followed by LSAF (34%) and LSPF (35%), whereas the NCL had the highest (37%) silt content. Moreover, the descriptive statistics and results of ANOVA indicated the absence of differences in mean value of confidence interval (CI) among the different cropping and land management systems (Table 2). As per the results, the CI indicated (FAO, 1979) that more than 87% of the soil samples of the study area was not susceptible to crusting (CI < 1.5).

BD and total porosity

The values of BD measured in the study area ranged from 0.89 g/cm^3 in LSPF soils that have a relatively high amount of SOM to1.3 g/cm^{3}in SHAF soils a with low content of SOM. A relatively high mean BD value (1.2 g/cm^3) was observed in SHAF, which was followed by LSAF (1.14 g/cm^3) and LSPF (1.1g/cm^3), and a relatively low mean BD value was recorded in NCL soils (1 g/cm^3). Considering the NCL soils as a benchmark, the value of BD increased by 10%, 20%, and 14% in the soils of LSPF, SHAF, and LSAF, respectively (Table 2). Moreover, as shown in Table 2, the highest average total porosity (59%) was estimated to occur in the LSPF soils, followed by a small difference in the soils of NCL (58%), LSAF (57%), and SHAF (56%).

Soil water content

One-way ANOVA results showed that water retained a the FC, PWP, and available water-holding capacity (AWC) did not show significant ($P < 0.05$) differences among the four CSs and land management practices. Generally, the soils in the NCL and LSAF retained slightly higher water content at FC and AWC than the soils of LSPF and SHAF cropping and land management practices. The percentage of AWC was as follows: NCL (17%), LSAF (17%), LSPF (16%), and SHAF (16%) soils.

Effects of cropping and land management practices on soil biochemical quality indicators

The nutrient reserve and supply capacity of soils are largely related to their chemical properties which considerably affect soil fertility and productivity (Habtamu et al., 2014). Therefore, some soil biochemical qualities that were studied here were affected by the cropping and land management practices of the study area, as presented in Tables 2–4.

Soil reaction

Soil reaction (pH) is an important indicator of plant nutrient supply and microbial activity (FAO, 2015). Our analysis showed that the soil pH (H_2O) of the study area ranged from slightly acidic (6.4) in LSPF to moderately alkaline (8.3) in LSAF. The data obtained showed that soils of SHAF and LSAF had higher average soil pH (8) value, followed by the NCL (7.7), and rel-

Table 3. Correlation matrix for linear relationships between selected SQ indicators of Merti area. SQ: soil quality.

		pH (H_2O)	SOM (%)	TN (%)	CEC meq/100g	Av.P (mg/kg)	Av.K (mg/kg)	Exchan. bases ($cmol_{(+)}$ /kg soil)				Sand	Silt	Clay	Crusting Index (CI)
								Na^+	K^+	Ca^{++}	Mg^{++}				
pH (H_2O)		1													
SOM (%)		-.331*	1												
		.028													
TN (%)		-.364*	.431**	1											
		.015	.003												
CEC meq/100g		.274	.196	-.076	1										
		.072	.201	.622											
Av.Pmg/kg		-.692**	.286	.436**	-.241	1									
		.000	.059	.003	.115										
Av.K(mg/kg)		-.387**	.386**	.376*	.031	.185	1								
		.010	.010	.012	.840	.230									
Exchan. bases ($cmol_{(+)}$ /kg soil)	Na^+	.250	.063	-.163	.496**	-.173	-.295	1							
		.102	.682	.291	.001	.262	.052								
	K^+	-.334*	.061	.215	.056	.560**	.333*	-.351*	1						
		.027	.696	.161	.717	.000	.027	.019							
	Ca^{++}	.316*	.093	-.081	.827**	-.247	-.006	.388**	.059	1					
		.037	.550	.603	.000	.106	.969	.009	.704						
	Mg^{++}	.315*	.090	-.078	.825**	-.245	-.007	.388**	.059	1.000**	1				
		.037	.560	.615	.000	.108	.965	.009	.701	.000					
Sand		-.094	-.391**	-.008	-.742**	.126	-.180	-.335*	-.150	-.548**	-.545**	1			
		.545	.009	.957	.000	.415	.243	.026	.330	.000	.000				
Silt		-.217	.104	.264	-.156	.031	.456**	-.192	.017	-.079	-.079	-.021	1		
		.156	.501	.084	.313	.842	.002	.212	.914	.609	.610	.891			
Clay		.224	.198	-.187	.632**	-.111	-.207	.374*	.093	.441**	.439**	-.684**	-.715**	1	
		.143	.199	.225	.000	.474	.177	.012	.548	.003	.003	.000	.000		
Crusting Index (CI)		-.264	.015	.340*	-.390**	.095	.378*	-.322*	-.024	-.252	-.251	.417**	.850**	-.912**	1
		.083	.924	.024	.009	.540	.012	.033	.879	.098	.100	.005	.000	.000	

Notes: ** – significant at the P≤ 0.01; * – significant at the P ≤ 0.05.

atively low mean pH (H_2O) values were obtained in the LSPF (7.5). The one-way ANOVA also revealed statistically significant differences ($P \leq 0.05$) in the pH (H_2O) values across the different cropping and land management practices (Table 2). Pearson's coefficient of correlation (Table 3) has also indicated an existence of positive correlation value between the values of pH and the exchangeable cations, mainly calcium and magnesium ($r = 0.316^*$, $P \leq 0.05$ and $r = 0.315^*$, $P \leq 0.05$, respectively).

SOM and TN

The study revealed that different cropping and land management practices resulted in variation of SOM and TN. Consequently, mean SOM value of 4% was experienced in NCL, 3% in LSPF, 2.8% in SHAF, and 2.8% in LSAF soils (Table 2). The one-way ANOVA also showed a significant difference ($P < 0.01$) in SOM content among cropping and land management practices. Accordingly, NCL soil had relatively high content of SOM, followed by the LSPF soils (Scheffe post hoc multiple comparison test; Table 4). Considering the NCL soils as a reference, SOM declined by 25, 38, and 40 % in the soils of LSPF, LSAF, and SHAF, respectively.

Furthermore, the average TN contents of the soils of NCL, LSPF, LSAF, and SHAF were 0.2, 0.2, 0.12, and 0.13 %, respectively. Thus, the amount of TN almost corresponded to the content of SOM. Again, considering the NCL soils as a reference, content of TN declined by 40 and 35 % in the soils of LSAF and SHAF, respectively. The one-way ANOVA confirmed the presence of statistically significant differences in soil TN ($P \leq 0.05$) content across the various cropping and land management practices of the study area (Table 2). The correlation analysis (Table 3) also proved the existence of significant and positive correlation between the soil SOM and TN contents of the different cropping and land management systems ($r = 0.431^{**}$, $P \leq 0.01$).

Exchangeable bases

In all CSs of the sampled soils, the content of exchangeable bases was in the order $Ca^{2+} > Mg^{2+} > K^+ > Na^+$ (Table 2). The results of one-way ANOVA test indicated that the distribution of ex-

changeable bases, except for exchangeable K^+, did not show statistically significant ($P < 0.05$) difference among the four CSs and land management practices. The significant difference in exchangeable K^+ content was explained by variation in CSs and land management in the study area (Table 2). Relatively high exchangeable K^+ (2.4 $cmol_{(+)}$/kg soil) was recorded in the LSPF soil, followed by LSAF (0.7 $cmol_{(+)}$/kg soil) and SHAF (0.7 $cmol_{(+)}$/kg soil), whereas a relatively low mean exchangeable K^+ (0.4 $cmol_{(+)}$/kg soil) was recorded in the NCL soils.

Cation exchange capacity

The results of ANOVA indicated that CEC of the sampled soils did not have statistically significantly difference among CSs and land management practices. As a result, the soils of the study area had little CEC variation ranging from 41 $cmol_{(+)}$/kg soil in LSPF to 45 $cmol_{(+)}$/kg soil in NCL (Table 2).

Av. K and phosphorus

Potassium availability and utilization by crop is partly related to soil clay content and mainly related to CEC (IAEA, 2003). The one-way ANOVA confirmed that the Av. K had statistically significant ($P < 0.05$) difference among the four cropping and land management practices (Table 2). A relatively high Av. K was experienced in NCL soils (390 mg/kg), but it was low in LSPF (355 mg/kg), LSAF (279 mg/kg), and SHAF (236 mg/kg) land management systems. Taking the NCL soils as a benchmark, the content of Av. K decreased by 9%, 28%, and 39% in the soils of LSPF, LSAF, and SHAF, respectively.

The results of ANOVA indicated that the Av. P of the sampled soils had a statistically significant ($P < 0.05$) difference among the studied cropping and land management systems (Table 2). The content of Av. P was in the order LSPF > NCL > SHAF > LSAF. Thus, relatively high mean Av. P (18 mg/kg) was measured in LSPF and NCL (about 10 mg/kg) soils, followed by SHAF soils (9 mg/kg). However, relatively low mean Av. P (7 mg/kg) was obtained in LSAF soils. For most cereal crops, the adequate amount of Av. P should be higher than 8 mg/kg (Landon, 1991). However, the Av. P of LSAF soils of the study area was below this suggested critical value. Compared to the soil of NCL, the Av. P declined by 10% and 30% in the SHAF and LSAF soils, respectively. Scheffe post hoc multiple comparison test (Table 4) indicated that the LSPF had statistically significant ($P < 0.01$) higher Av. P content than the soils of other CSs and land management practices.

Discussion

The results of the study revealed the presence of statically insignificant differences in soil particle size distribution across the different CSs and land management practices. This might be attributed to the inherent property of the studied soils that insignificantly affects its particle size distribution by the CSs (Brady, Weil, 2007). Moreover, the soils of the study area are derived from similar volcanic parent materials: felsic tuffs, ignimbrites, pumice, and/or subordinate lavas (Azeb et al., 2015; Billi, 2015), which would result in a similar particle size distribution. Thus, the soils under different CSs and land management practices have almost similar soil textural class distribution (Mohr, 1971; Tefera et al., 1996). The observed high clay content of the soils can be attributed to the property of the parent material, that is, tertiary volcanic rocks that quickly weather to clay-size particles (Azeb et al., 2015; Billi, 2015). Silts are the most mobile elements by erosion (Wondwosen, Mohammed, 2019). Hence, lower silt content (32%) in SHAF compared to textural class in NCL (37%) implies the presence of a relatively high rate of selective removal of silt-size particles through sheet and even wind erosion, as the area is found in semi-arid climatic region. However, the sand content (24%) of SHAF was high as compared to the NCL (21%) soils. The higher sand proportion in the soils of the study area might potentially affect the water-holding capacity and availability, as well as the nutrient reserve of the irrigated agricultural lands (Khreast et al., 2008).

Table 4. Scheffe post hoc multiple comparison test of soil properties across the different cropping and management practices.

Dependent Variable	Cropping and land management system		P
PH(H2o)	LSPF	SHAF	.036
SOM	NCL	LSPF	.043
		LSAF	.016
		SHAF	.007
TN	LSAF	LSPF	.003
		NCL	.000
Av.P	LSPF	LSAF	.010
		SHAF	.026
		NCL	.058
AV. K	NCL	LSPF	.879
		LSAF	.112
		SHAF	.008
Ex.K	LSPF	LSAF	.004
		SHAF	.004
		NCL	.001

The results of this study showed a high value of BD in the soils of LSAF (1.2 g/cm^3) and SHAF (1.14 g/cm^3) compared to that in NCL (1 g/cm^3) (Table 2). The higher BD value in the soil of SHAF might have resulted from the differences in land management practices. For example, plowing through animal trafficking tends to reduce SOM content of the soils and even compacts the soils (Yitbarek et al., 2013), whereas the high BD value in the soils of LSAF might be related to soil compaction resulting from the use of heavy agricultural machinery (Dauda, Samari, 200). In addition, the increment of BD value in both SHAF and LSAF systems might have also resulted from continuous cultivation with flooded irrigation over an extended period (Emadi et al., 2008).

On the other hand, the relatively low BD value in NCL (1 g/cm^3) and LSPF (1.1 g/cm^3) could be due to the low disturbance of the soil under NCL and the relatively high accumulation of SOM (Awotoye et al., 2011). As a result, total porosity was relatively better in the LSPF (59%) and NCL (58%) soils than in the LSAF (57%) and SHAF (56%) soils. Therefore, irrespective of the cropping and land management practices, the cultivation of previously uncultivated land in LSAF and SHAF has resulted in lower contents of SOM, as a result of which a rise in BD value and reduced total porosity were observed. Thus, this relatively high BD value in the soils of LSAF and SHAF causes low infiltration rate (adversely affecting irrigation) and water availability and soil moisture shortages for crops that, in turn, would negatively impact agricultural production. Therefore, land management practices that increase SOM, application of organic fertilizers, and minimum tillage practices need to be emphasized in SHAF and LSAF CSs.

As various studies confirmed, soil texture is one of the major factors that influence water-holding capacity (Kramer, Boyer, 1995; Asmamaw, Mohammed, 2013). The present study showed an insignificant difference in soil water content across the cropping and land management systems. The possible reason for the insignificant difference in the water retention capacity of the soils at FC, PWP, and AWC could be related to the insignificant difference in soil texture classes. As mentioned, the soils of the study area are developed from similar volcanic parent materials, which could have resulted in similar textural classes. Besides, the high proportion of clay content, possibly with rich smectitic clay minerals that have high CEC in the study soils, which was found in all CSs and management practices, raised the water content at FC and PWP (Asmamaw, Mohammed, 2013). The differences in soil water of the studied soils might also be better explained by topographic attributes such as slope gradients (Asmamaw, Mohammed, 2013). However, this attribute is not considered in the present study.

ANOVA proved that the cropping and land management systems significantly affected the pH (H_2O) of the soils of the study area (Table 2). As shown in Table 2, relatively higher soil reaction values of pH (H_2O) were measured in the soils of LSAF (8.0) and SHAF (8.0) compared to those in NCL (7.7) and LSPF (7.5). The higher mean pH value (H_2O) in LSAF and SHAF could be related to frequent irrigation, which might contain and add soluble cations to the irrigated soils (Azeb et al., 2015; Billi, 2015). In addition, as the study area is located at the floodplain of the Upper Awash Basin, it regularly receives sediments rich in soluble cations. In fact, calcium ions are accumulated at the soil surface where leaching is hindered and continuous release of early weathering process of tertiary basaltic parent material leads to increased pH (H_2O) value (Beukes, Ellis, 2003). The relatively low pH (H_2O) value of NCL and LSPF soils is probably due to the release of organic acids related to mineralization of organic matter (Mohammed et al., 2005). It is also indicated that perennial-based soils are often more acidic than annual crop cultivated soils (Barker, Pilbeam, 2007). Thus, high pH value in the soils of LSAF and SHAF influences the CS indirectly via its effects on availability of nutrients, that is, high-pH soils would result in an inadequate availability of some plant micronutrients such as copper and zinc (Beukes, Ellis, 2003).

Another key finding of the study shows that variation in cropping and land management system significantly affected the contents of SOM (Table 2). A relatively high mean SOM content was measured in the NCL soils (Table 2). The difference in SOM content among the cropping and land management systems may be due to variations in land management practices. For instance, the reduction in SOM content of the LSAF soils is attributed to human factors such as removal of crop residues, which could have enhanced loss of organic matter through hastening oxidation, and excessive tillage practices accelerating decomposition of organic matter (Wild, 2003; Adugna, Abegaz, 2016). Similarly, the removal of crop residues and absence of turning animal wastes to the soils of SHAF might have resulted in low contents of SOM (Six et al., 2002). The LSPF soils have better levels of SOM following NCL soils. This is because of (i) the low level of mechanization used for land preparation (Deininger, 2013) and (ii) the harvest methods that leave most or all of the above-ground biomass and different agronomic practices like fallowing and intercropping, both of which might have led to higher biomass input (Acharya, Kafle, 2009). Thus, relatively high content of SOM in the soil of LSPF next to NCL has resulted in good AWC and possible moisture and fertilizer adsorption as well as good fertility status (Lal, Shukla, 2004). In the currently studied soils, perennial-based CS has better implications for the improvement of SOM and SQ in general.

The TN content of the present soils revealed variations among the different cropping and land management practices with a similar variation pattern of SOM content (Table 2). Thus, SOM was the major source of TN in the soils under study. A relatively high content of TN was recorded in the NCL (0.2%). The removal of the above-ground biomass though crop residue harvesting and intensive cultivation in SHAF and LSAF might have significantly degraded the TN content (Acharya, Kafle, 2009; Aghasi et al., 2011). The conversion of natural woodland into CSs, particularly into annual cropping, results in a decline of the TN, as observed in the cultivated lands of the study area (Asbjornsen et al., 2013). Therefore, relatively higher SOM and TN in NCL and LSPF could have resulted from relatively higher plant litter accumulation in the perennial crop coupled with long-term soil management practices (Khreast et al., 2008). Consequently, there was a significant and positive correlation between SOM and TN of the soils in different cropping and land management systems ($r = 0.431^{**}$, $P \leq 0.01$) (Table 3).

Accordingly, in semi-arid CRVE, perennial farming could be considered as a better option of farmland management, for it can maintain and/or improve SQ than annual farming does. This reveals that relative to SHAF (annual crop), the LSPF (perennial crops) would address many of the agricultural problems and could offer substantial ecological and economic benefits, as they can produce more ground cover and perform longer growing

seasons and more extensive root systems, all of which contribute to effective withdrawal of nutrients and water from deeper soil profile into the surface (Zhang et al., 2011).

The distribution of exchangeable Ca^{2+}, Mg^{2+}, and Na^{+} could not be explained by land management practices and CSs of the study area (Table 2). Accordingly, the three exchangeable bases might have been inherited from the parent material of the soils of the rift valley, which are rich in $CaCO_3$ content and are considered to be young soils (FAO, 2006). Young soils mainly formed on $CaCO_3$- rich parent materials have high Ca^{2+} and Mg^{2+} contents (FAO, 2006). The contents of exchangeable Ca^{2+} and Mg^{2+} are relatively high in the soils of SHAF and LSAF compared to the NCL soils (Table 2). As a result, high contents of exchangeable Ca^{2+} and Mg^{2+} are available in the present soils, and the slight differences that exist between them could not be explained by the differences in the current CSs and land management practices, as discussed above. However, significant difference in exchangeable K^{+} was explained by variation in land management and CSs in the study area. The highest mean exchangeable K^{+} (2.4 $cmol_{(+)}$/kg soil) was recorded in the soil of LSPF, followed by LSAF (0.7 $cmol_{(+)}$/kg soil) and SHAF (0.7 $cmol_{(+)}$/kg soil), whereas the lowest mean exchangeable K^{+} (0.4 $cmol_{(+)}$/kg soil) was recorded in NCL (Table 2). The high mean exchangeable K^{+} in the soil of LSPF could be attributed to the application of K fertilizer on these soils compared to the soils of LSAF and SHAF.

The CEC of the soils under study was high, which is a typical characteristic of young soils (Aghasi et al., 2011; Landon, 1991; Wondwosen, Mohammed, 2019). The CEC of the study area was not explained by the CSs and land management practices. However, the existing differences in CEC of the studied soils might be better explained by the nature of the parent materials from which the study soils are assumed to be derived, which is not considered in the present study. In fact, the CEC content of young soils is more influenced by some other factors like parent material and types and amounts of clay (Aghasi et al., 2011; FAO, 2006). The possible clay mineralogy of the soils of the study area, as estimated from CEC- clay, is smectitic, as they might have been derived from volcanic rocks that quickly weather into clay-size particles (Mohr, 1971; Tefera et al., 1996). As a result, smectitic clay deposit could have been formed from the hydrolysis of volcanic rock, which resulted in high contents of Ca and Mg (Baribault et al., 2012).

Another key finding from this study is that Av. K variation could strongly be associated with the difference in cropping and land management practices. Of the different cropping and land management practices, low Av. K in the soils of SHAF and LSAF could be due to intensive cropping, complete removal of crop residues for livestock feeding and household energy use (particularly maize, sorghum, and cotton stacks), direct overgrazing by the livestock, and low external inputs use, which possibly resulted in the depletion of Av. K in the soil of SHAF (Acharya, Kafle, 2009; Aghasi et al., 2011). A similar study conducted in Ethiopia (Yetbarek et al., 2013) has shown that the Av. K. content was among the SQ indicators that showed the presence of high Av. K. content in the topsoil of agroforestry and low content of its availability in the soils of annual cropland.

Moreover, TN and Av. K could be partly obtained from the decomposition and mineralization of SOM (Six et al., 2002). Positive and significant correlation between Av. K versus SOM and TN ($r = 0.386^{**}$ at $P = 0.010$ and $r = 0.376^{*}$, $P = 0.012$, respectively) (Table 3) was probably related with the content of SOM, as decomposition of crop residues releases N and Av. K (Six et al., 2002). These results also agree with the findings that showed positive correlations between SOM, nitrogen, and potassium (Baribault et al., 2012). Therefore, the annual CS, mainly of the smallholder farmers, should consider soil management with organic fertilizers, mixed cropping with leguminous crops, and fallowing for enhancing SOM and other nutrients (e.g., Av. K and TN) (IAEA, 2003). Other studies (Funes-Monzote, 2008) also showed that smallholder farmers in sub-Saharan Africa practice intensive cropping on small farms with low or no use of external inputs that facilitate rapid depletion of nutrients. Apart from the aforementioned reasons, there is usually an inverse relationship between the availability and uptake of one cation by the crop and a very high concentration of other cations (disproportionate quantity) in the soil (Laekemariam et al., 2016). This implies that in the present soil, availability of K does not only depend on the K content of soils, but also depends on the relative amounts of other cations (e.g., Ca and Mg).

Variation in cropping and land management systems had significantly affected the Av. P content of soils. For instance, the low availability of phosphorus in SHAF might be due to frequent cultivation and/or application of low-phosphorus fertilizers, which could not replace the losses due to the prevailing land management practices in SHAF (Adugna, Abegaz, 2016). On the other hand, the high Av. P in the soils of LSPF could be attributed to high-phosphorus fertilizer application in LSPF (Schjønning et al., 2004). The discussion made with commercial farm mangers indicated supply of about 200 kg of DAP/ha in the farms of the perennial crops three times a year. Thus, the amount of Av. P in soils is a function of intensity of cropping and land management practices, the amount of organic matter and/or microbial biomass, and history of land use like artificial fertilizer application (Schjønning et al., 2004). The relatively high Av. P in the soils of NCL following the soils of LSPF could be due to the high content of SOM, which could have released organic phosphorous.

Thus, the lowering of SOM content and frequent cultivation using heavy tractors in LSAF and the removal of all crop residues from the soil of SHAF can lower the availability of phosphorus (Acharya, Kafle, 2009; Adugna, Abegaz, 2016). The present differences in land management practices and CSs had significantly affected the content of Av. P across the soils of the study area. As described by the farmers and farm managers of LAI, P fertilizer application has enhanced crop production in their farms.

Conclusion

The study confirmed that the current CSs and land management practices had significantly impacted some key SQ indicators like BD, SOM, TN, soil reaction (pH), Av. P, and Av. K of the studied soils. As the results of the research proved, there was a decline in the levels of SOM, TN, Av. K., and phosphorus, while the values of BD and soil pH had experienced an increment in the LSAF and SHAF soils. This could be attributed to the cropping and land management practices-induced constraints, which largely involved repeated cultivation, removal of surface biomass, low application of external inputs, and absence of appropriate soil management methods in annual cropping lands. The present adverse dynamics of SQ indicators can be an early warning about SQ degradation in the annual cropping farms, LSAF and SHAF.

Hence, strategies that improve key SQ indicators such as SOM required improvement of soil management, like application of organic fertilizers, cover crop, residue and tillage management, soil water conservation, crop harvesting and processing, and soil fertility management. As verified by this study, major SQ indicators of the LSPF (perennial crop farms) soils were consistently better than the SQ indicators of LSAF and SHAF soils (annual crop farms). Thus, perennial CS has multiple benefits than annual CS in providing food, firewood, and fodder and, at the same time, maintaining and/or improving local SQ. Therefore, more attention should be given to perennial CS to minimize SQ degradation. Hence, investment in LSPF should be encouraged by the Government of Ethiopia (GOE). In addition, the inclusion of appropriate and locally suitable CSs and land management practices is important in enhancing SQ and monitoring SQ status. In general, perennial-based farming system has been identified as one of the more promising farming systems for sustainable agricultural development and to keep the equilibrium of the environment in the semi-arid region of CRVE.

Data availability statement

The data that support the findings of this study are available from the corresponding author (first author), which are freely available upon request.

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