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Effects of long term sugarcane production on soils physicochemical properties at Finchaa sugar Estate

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In Ethiopia, where sugarcane has been cultivated for over 20 years, changes in soil physicochemical properties are expected to occur albeit information on the extent of change is scanty. A study was conducted in 2015 at Finchaa Sugar Estate with the objective of assessing the status of selected soil properties under long term mechanized sugarcane cultivation. Disturbed composite and undisturbed soil samples from 0-30 and 30-60 cm layers of selected Luvisols and Vertisols at Finchaa were collected for laboratory analysis of selected soil properties. The result of the study indicated that clay content of the land under sugarcane was higher than that of the adjacent uncultivated land use types. The bulk density values for a clay texture for most of the studied soils were higher than the critical values recommended for successful sugarcane production. The pH of the two land uses also ranged from 5.35 to 6.63. Organic carbon (0.95 to 1.32%), total nitrogen (< 0.12%), and available P (2.51-8.63 mg kg^{-1}) were also in the range of those not adequate for sugarcane cultivation. Overall, the measured soil properties indicated that the management practices the estate has been implementing were not adequate to sustain sugarcane production on a profitable basis and, thus, require revisiting the practices. To maintain sustainability of sugarcane production in the estate; soil management practices that can increase soil organic carbon, pH, total nitrogen and soil available P should be employed.

Key words: Sugarcane, soil physical property, soil chemical property.

INTRODUCTION

Sugarcane is one of the main economic commercial crops grown in Ethiopia. Sugarcane production in Ethiopia involves mechanized cultivation for increased cropping intensity, timeliness, higher work rates, and lower labour requirements in order to satisfy the local high demand for white sugar. However, machinery overuse has been found to be the main cause of soil compaction (Barzegar et al., 2005; Abdollahi et al., 2014). Due to its persistence,

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compaction of the subsoil can be seen as a long-term degradation, however compaction also concerns surface soils (Ahmad, 2007; Berisso et al., 2012).

Yield decline is an issue that has plagued sugarcane production systems worldwide for more than half a century (Ridge, 2013). Studies in Ethiopian Sugar Estates also showed the declining productivity of the fields due to the effects of soil compaction on soil physicochemical properties (Ambachew and Abiy, 2009; BAI, 2009). Long-term annual yield data obtained from the estate showed a decline in cane yield (Ambachew and Abiy, 2009; BAI, 2009). For instance, the annual cane yield at Finchaa Sugar Estate reduced from 169 to 124 t ha^{-1} (26.63% decrease) (1997-2008) (ESC, 2015). This clearly shows the existence of yield decline in the fields under long-term sugarcane production in Ethiopia (ESC, 2015).

In more recent times, yield decline has been clearly associated with soil compaction caused by the long-term mechanized cultivations (Hamza and Anderson, 2005). A major conflict in sugar cane production is the requirement of optimum soil conditions for plant growth versus trafficability to support cultivating, planting and harvesting machines. In mechanized sugarcane cultivation, the use of heavy machinery, such as tractors for operations like cultivation, planting, fertilizer application, weed control and cane extraction, is a common practice. Harvesting and cane extraction during wet conditions are, for instance, unavoidable at certain times of the year and past field studies have shown that compactive force due to uncontrolled infield traffic will cause damage to soils (Duttmann et al., 2014). The weight of machines (axle load) will compact soils sometimes to an extent that it becomes hostile to plant root growth (Chamen et al., 2014).

Specific research has shown that long-term monoculture and excessive tillage along with practices that deplete organic matter all contribute to yield decline (Alvarez et al., 2009). Several researchers have suggested that the most serious factor associated with soil compaction under sugarcane production is the loss of soil organic matter due to intensive tillage (Hamza and Anderson, 2005). Moreover, Barzegar et al. (2000) indicated that long-term sugarcane cultivation under low soil organic matter condition alter soil properties. These changes in soil properties result in increased bulk densities and lower water infiltration (Tullberg and Freebrain, 2001) that may consequently reduce nutrition uptake and crop yield (Zhang and Lovdahi, 2006).

Currently, there is dramatic increase in irrigated areas along with increased machinery uses in most monoculture sugarcane farms in Ethiopia. If not properly managed, this has a potential to induce land degradation due to soil compaction. Therefore, evidences on the impact of long-term mechanized cultivation for sugarcane production on soil physicochemical properties are important inputs for planning soil and land management practices in large scale mechanized irrigated sugarcane farms in the estate. Hence, this study evaluated the effects of long term mechanized sugarcane production on selected soil physicochemical properties at Finchaa Sugar Estate taking uncultivated soils nearby the farms as references.

MATERIALS AND METHODS

Description of the study areas

The study was conducted in 2015 at commercial sugarcane production fields of Finchaa Sugar Estate. Finchaa Sugar Estate is located at a distance of 374 km from Addis Ababa within the Oromia National Regional State (ONRS). Finchaa lies between 9° 21' 18.12" to 9° 25' 23.01" N and 39°11' 8.85" to 39°15' 3.2" E in the valley of southwestern highlands of Ethiopia in the Abay River Basin at an altitude of 1500 meters above sea level (BAI, 2009) (Figure 1). Finchaa Estate farm is dominated by a gentle undulated surface with a general slope of 1 to 8%. This made the preferred irrigation system at Finchaa to be sprinkler irrigation system (Michael and Seleshi, 2007). The current total area of land covered with cane is about 9,000 ha at Finchaa Sugar Estate (ESC, 2015).

Ten years (2006-2016) climatic data (Figure 2C) of the Finchaa Estate showed unimodal rainfall pattern, in which majority of the annual rain falls between May to September. The mean of ten years annual rainfall of Finchaa is 1399.72 mm (ESC, 2015).

Finchaa has sub humid climate conditions. Average maximum and minimum temperatures of the estate were about 14.40 and 30.54°C. The estate sugarcane production was undertaken with irrigation (Tadesse, 2004; Michael and Seleshi, 2007). The sources of water for irrigation at Finchaa is Finchaa River. The major crop of the estate is sugarcane; while sesame and horticultural crops are minor crops. The average length of the growing period of sugarcane (plant cane) in the study area is 22 months (ESC, 2015). The major geologic materials of Finchaa Estate were developed under tropical hot condition from alluvium-colluvium parent materials, which include basic volcanic rocks (such as basalt, limestone), acidic volcanic rocks (such as granite, sandstone) as well as recent and ancient alluvial soils developed from materials laid down by river systems (Ambachew and Abiy, 2009; BAI, 2009). Vertisols and Luvisols are dominant soils at Finchaa (BAI, 2009). More than 95 percent of the cultivated and irrigated land soils in Finchaa are grouped in to Luvisols and Vertisols (Ambachew and Abiy, 2009).

Site selection, soil sampling and sample preparation

The study was conducted on Vertisols and Luvisols soil management unit groups of Finchaa Estate. Accordingly, 6 cultivated sugarcane fields with records of recurrent reduced yield were identified for field observation. Each cultivated field was sampled by replicating three times. The reports of Ambachew and Abiy (2009) and BAI (2009) indicated that the yield reduction was due to soil related constraints. Furthermore, qualitative soil compaction diagnosis at field level was undertaken in order to select the final soil sampling sites (Ridge, 2013).

Similarly, 6 adjacent uncultivated bare fields were identified at the estate during the field observation. The uncultivated soils were identified per each existing management unit groups between the main drains and access roads. According to information from station officers of the estate, these soils have not been cultivated

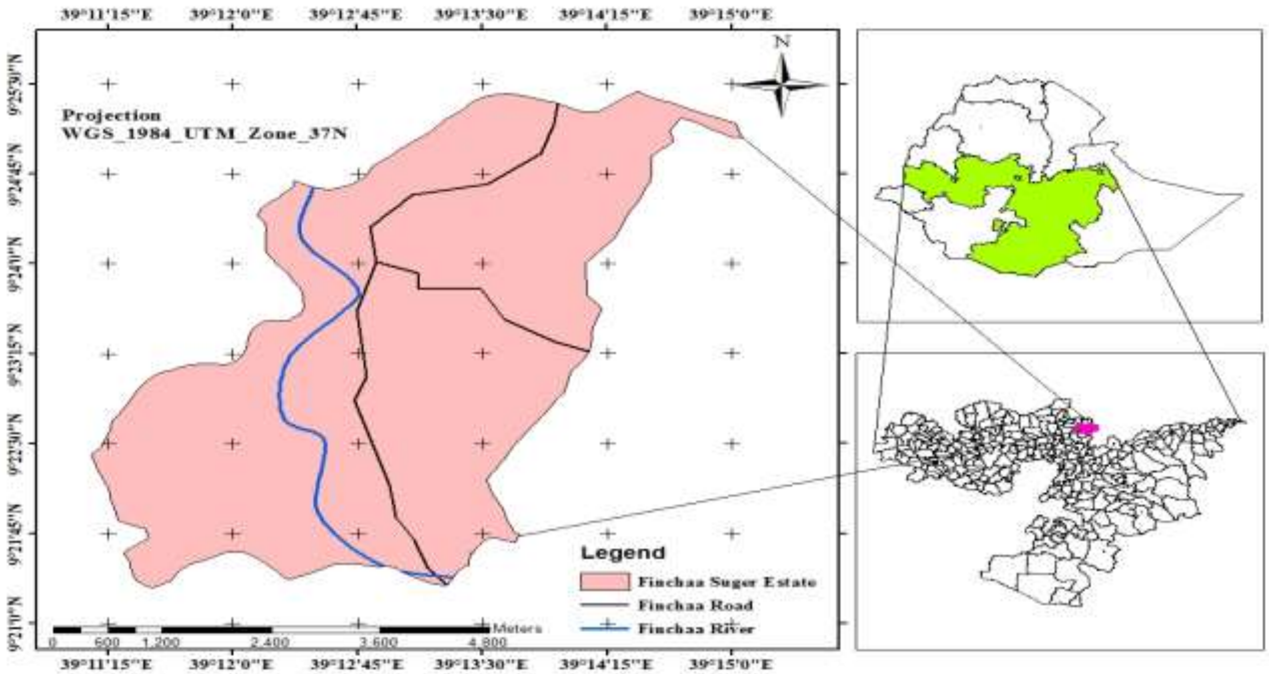

Figure 1. Location maps of Finchaa sugar estate in Ethiopia.

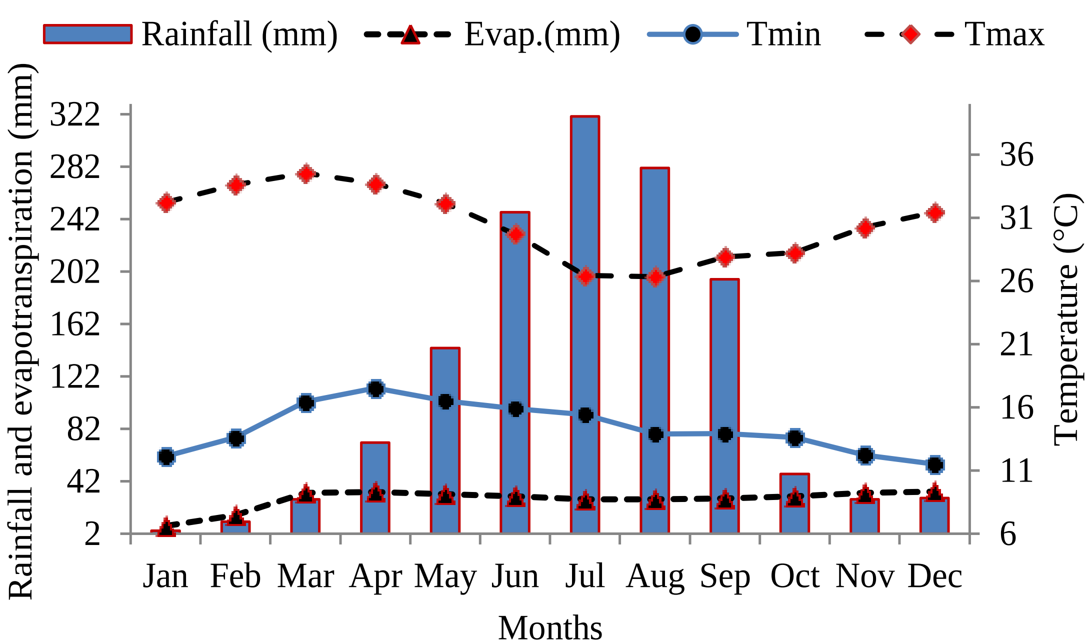

Figure 2. Ten years mean monthly rainfall, evapotranspiration (Evap), and monthly minimum (Min) and maximum (Max) temperatures of Finchaa estate.

for about forty years (ESC, 2015). Representative composite soil samples with three replications per each cultivated and uncultivated bare fields were collected from the two depths. Composite and undisturbed (for bulk density) samples were collected from 0-30 and

Table 1. Effects of land use on selected physical properties of the soils in the Finchaa sugar estate.

Estate	SMUG	Land use types	Particle size distribution (%)			ρb ($g.cm^{-3}$)	ρp ($g.cm^{-3}$)	f (%)
			Sand	Silt	Clay			
Finchaa	Luvisols	Cultivated	38.50^b	18.59	42.91^a	1.51^b	2.62	42.48^a
		Uncultivated	40.84^a	17.50	41.66^b	1.54^a	2.55	39.61^b
		LSD	0.59	ns	0.31	0.008	ns	2.70
	Vertisols	Cultivated	34.09^b	20.14	45.77^a	1.39^b	2.47	43.65^a
		Uncultivated	36.00^a	19.83	44.17^b	1.47^a	2.45	39.94^b
		LSD	0.48	ns	0.40	0.01	ns	0.93

SMUG = soil management unit groups, LSD = least significant difference, ρ_b = bulk density, ρ_p = particle density, f = total porosity, and means with the same letters are not significantly different.

30-60 cm soil depths using auger and core samplers, respectively. Ten sub-samples were collected from each sampling site using the X-pattern of sampling technique to make one composite sample per depth. Three undisturbed samples per each cultivated and uncultivated bare fields were taken using core sampler into which 5 cm height and diameter cores were fitted. On the basis of this, a total of 72 composite and undisturbed samples (for bulk density) were collected from the estate plantation fields. About 500 g of the composite soil samples were properly weighed, placed in plastic bags, labeled and transported to Debrezeit Research Center, Wonji Central Laboratory. In the laboratory, soil samples were air dried and ground to pass through a 2 mm diameter sieve for further laboratory analysis of selected soil physicochemical properties except organic carbon and total nitrogen, in which case the samples were crushed further to pass through 0.5 mm diameter sieve (Sahlemedin and Taye, 2000).

Laboratory analysis of soils

Particle size distribution was determined by the Bouyoucos hydrometer method as described by Okalebo et al. (2002). The textural class was determined using USDA soil textural triangle. Bulk density was determined using the core method and computed from the values of oven dry soil mass and volume of core sample as described by Jamison et al. (1950). Particle density (ρp) was determined using pycnometer method, following procedures described in Rao et al. (2005). Total porosity was calculated from the values of bulk density and particle density using the method described by Rowell (1994).

The pH of the soils was measured in water (1:2.5 soil: water ratio) by glass electrode pH meter (Peech, 1965). Soil organic carbon was determined by the wet digestion method following the procedure of Walkley and Black (1934).The total nitrogen was determined using the Kjeldahl method as described by Jackson (1958). Relative amount of carbon to nitrogen was determined by taking the ratio of soil organic carbon to total nitrogen. Available phosphorus was determined according to the Bray II (Bray and Kurtz, 1945) extraction method. The P extracted with different methods was measured by spectrophotometer following the procedures described by Murphy and Riley (1962).

Data analysis and interpretation

Analytically determined soil physicochemical parameters for each soil management unit group land uses were tested using the general linear model procedure of the SAS computer package (SAS, 2002). Analysis of the variance of soil parameters in randomized blocks was run to establish differences. For statistically significant parameters ($P < 0.05$), means were separated using the Fisher's least significant difference (LSD) comparison. Pearson correlation analysis was also executed to reveal the magnitudes and directions of relationships between the selected soil physicochemical properties.

RESULTS AND DISCUSSION

Effects of land use types on selected soil physicochemical properties

Particle size distribution

There were textural variations among the soil management unit groups of cultivated soils as compared to adjacent uncultivated soils of each soil management group, with the exception that silt content was not significantly ($P \geq 0.05$) affected by land uses of all soil management unit groups (Table 1). Soils under sugarcane cultivation had significantly ($P < 0.05$) higher clay and lower sand contents as compared to the uncultivated soils at all the soil management unit groups (Table 1). Nevertheless, the significant differences in individual separates did not cause changes in textural classes (Table 2).

The difference in the distribution of sand and clay fraction between the cultivated and uncultivated soils is likely attributed to the difference in vulnerability of the land uses to eluviation and surface runoff which is normally highest in the cultivated soils. In line with this, occurrence of higher sand fraction in the layer of uncultivated land could be ascribed to the removal of clay particles through erosion of the area, leaving the sand particles behind. The differences in particle size distribution could also be due to mixing of soils of the surface and subsurface horizons during tillage activities and subsoiling operations of sugarcane cultivation field

Table 2. Variations of selected soil physical properties with soil depth across two landuses of the major soil management units in Finchaa estate.

Estate	SMUG*	Land use	Depth (cm)	Particle size distribution (%)			TC*	ρb ($g.cm^{-3}$)*	ρp ($g\ cm^{-3}$)*	f (%)*
				Sand	Silt	Clay				
Finchaa	Luvisols	Cultivated	0-30	43.00	19.00	38.00	CL	1.49	2.55	41.57
			30-60	34.00	18.17	47.83	Clay	1.52	2.59	41.31
		Uncultivated	0-30	44.00	18.67	37.33	CL	1.61	2.53	36.36
			30-60	37.67	16.33	46.00	Clay	1.47	2.56	42.58
	Vertisols	Cultivated	0-30	35.17	22.91	41.92	Clay	1.30	2.37	45.15
			30-60	31.00	19.17	49.83	Clay	1.47	2.48	40.73
		Uncultivated	0-30	32.00	30.67	37.33	CL	1.52	2.39	36.40
			30-60	28.00	26.00	46.00	Clay	1.42	2.44	41.80

*SMUG = soil management unit group; SCL = sandy clay loam; CL = clay loam; ρ_b = dry bulk density; ρ_p = particle density; f = total porosity; TC = textural class.

Table 3. Effects of land use on selected chemical properties of the soils in the Finchaa sugar estate.

Estate	SMUG	Land uses	pH	SOC (%)	TN (%)	C:N	P ($mg\ kg^{-1}$)
Finchaa	Luvisol	Cultivated	6.25^a	1.07	0.08^a	13.17	6.34^a
		Uncultivated	5.35^b	0.95	0.06^b	15.98	2.51^b
		LSD	0.20	ns	0.01	ns	0.60
	Vertisol	Cultivated	6.63^a	1.32^a	0.10^a	13.73	8.63^a
		Uncultivated	6.00^b	1.02^b	0.07^b	14.24	3.24^b
		LSD	0.40	0.04	0.01	ns	0.06

SMUG = soil management unit groups, LSD = least significant difference, pH = soil pH, SOC = soil organic carbon content, TN = total nitrogen, C:N = carbon to nitrogen ratio, P = available soil phosphorus, and means with the same letters are not significantly different.

soils. Dang (2007) also reported the variation in particle size distribution due to the removal of soil particles through erosion and mixing of the surface and subsurface soils during deep tillage activities. The textural class of the estate subsoil layer for all land use is clay, with the clay content ranging between 41.66 and 45.77% (Table 2).

Bulk density and total porosity

Bulk density values were significantly ($P < 0.05$) affected by land use for all soil management unit groups (Table 1). Accordingly, the dry bulk density values of the uncultivated fields were significantly ($P < 0.05$) higher than the bulk density values of the adjacent cultivated fields (Table 1). This could be due to either loosening of the soils under long-term cultivation than the uncultivated land or might be due to cane residuals left after harvesting on surface soil layer of the cultivated fields and the use of soil agricultural additives (filter cake, silt, and vinasse) during cultivation. Barzegar et al. (2005) also reported sugarcane residue effect in reducing soil bulk density. The higher organic matter content in the cultivated fields (Table 3) is an indication of the addition of organic inputs, which might have enhanced aggregation and created a porous condition in the various soils. The negative and non significant correlation between organic matter and bulk density in soils of Finchaa (Table 4) confirms the favorable effects of soil organic matter in lowering bulk density in the cultivated soils. Similarly, Barzegar et al. (2005) also reported the negative correlation between soil organic matter and bulk density. As per dry bulk density ratings suggested by Jones (1983) for different textured soils, the bulk density of Luvisols (both cultivated and uncultivated) were within the range that causes restriction to root penetration (> 1.40 g cm^{-3}). On the other hand, the bulk density values

Table 4. Variation of selected soil chemical properties with soil depth across two land usesof the major soil management unit groups in the Finchaa Estate.

Estate	SMUG	Land use	Depth (cm)	pH	SOC (%)	TN (%)	P (mg kg^{-1})
Finchaa	Luvisols	Cultivated	0-30	6.22	1.30	0.10	6.40
			30-60	5.95	0.72	0.06	2.60
		Uncultivated	0-30	5.73	1.25	0.08	4.00
			30-60	5.27	0.63	0.05	2.40
	Vertisols	Cultivated	0-30	6.57	1.63	0.40	9.30
			30-60	6.68	0.94	0.07	8.64
		Uncultivated	0-30	5.91	1.52	0.09	7.15
			30-60	5.89	0.67	0.06	3.92

SMUG = soil management unit groups, pH = soil pH, SOC = soil organic carbon content, TN = total nitrogen, P = available soil phosphorus.

Table 5. Pearson correlation analysis of some selected soil physicochemical parameters.

Finchaa estate						
	ρb	F	Cl	SOC	TN	P
ρb	1.00	-0.77***	-0.29^{ns}	-0.31^{ns}	-0.50*	-0.47*
f		1.00	0.34^{ns}	0.11^{ns}	0.33^{ns}	0.45*
Cl			1.00	0.68**	0.34^{ns}	0.19^{ns}
SOC				1.00	0.84***	0.72***
TN					1.00	0.79***
P						1.00

Cl = clay content, B_d = bulk density, f = total porosity, N = total nitrogen, P = soil available P, SOC = soil organic carbon, and ***, ** and * = Significant at P <0.001, P < 0.01 and P <0.05, respectively; ns = not significant.

of all the Vertisols of Finchaa SMUG was close to the root restriction initiation bulk density values (Table 2).

The optimum bulk density for sugarcane production is 1.10 to 1.20 g.cm^{-3} for both clay and loam soils, and 1.30 to 1.40 g.cm^{-3} for sandy soils (Ridge, 2013). Based on these critical values, the bulk density values of most of the sampled sites were higher than these critical values, which indicate presence of soil compaction and sustainability problem for sugarcane production in the estate (Table 2). Total porosity was also significantly (P < 0.05) affected by differences in land use ((Table 1). The total porosity of the cultivated lands was higher than the corresponding values for adjacent uncultivated lands (Table 1). The higher total porosity values in the cultivated fields might be attributed to the lower bulk density values resulting from the positive effects of the different organic matter additions into the cultivated soils. This is also supported by the negative and significant correlation between bulk density and total porosity in soils of the estate (Table 5). Furthermore, though non-significant, the correlation between total porosity and organic carbon was also positive suggesting that maintaining higher soil organic matter in soils could result in higher total porosity (Table 5).

The total porosity of soils usually lies between 30 and 70% (Hillel, 1998). As suggested by (Ridge (2013), the optimum soil porosity for sugarcane growth is 50%. Furthermore, according to Landon (2014), in clay soils total porosity less than 50% can be taken as critical value for root restriction. As per these ratings, total porosity values for the cultivated lands in the estate was less than the optimum value for sustainable sugarcane production and were in the range of root growth restriction (Table 2).

Effects of soil depth on selected soil physical properties

Particle size distribution

Variations in particle size distribution with soil depth under the two land use types of the selected soil Finchaa management unit groups in the estate are presented (Table 2). In cultivated and uncultivated Luvisols and Vertisols of Finchaa, sand and silt contents generally decreased with soil depth (Table 2). The general decrease in sand and silt content and increase in clay content with soil depth, nonetheless, did not result in change in textural class name was observed in cultivated Vertisols of Finchaa (Table 2). Moreover, on a relative basis, the clay content at both the surface and subsurface layers are higher for the cultivated than the uncultivated soils of almost all the SMUGs (Table 2).

The generally higher sand and silt content at the surface and relatively higher clay content at the subsurface layers of the two land uses may indicate the selective removal of clay from the surface layers by downward movement and its subsequent accumulation in the subsurface layers. It may also indicate *in situ* formation of clay within the subsurface layers. In line with these results, Brady and Weil (2002) indicated the existence of significant variations in particle size distribution in soil profiles due to elluviation and illuviation processes. Prasad and Govardhan (2011) also reported accumulation of clay in subsurface layers and attributed this to the *in situ* formation of clays, weathering of primary minerals in the B horizon, or the residual concentration of clays from the selective dissolution of more soluble minerals of coarser grain sizes in the B horizon (Duttmann et al., 2014).

Bulk density and particle densities, and total porosity

In the estate, bulk density increased with soil depth in the cultivated soils and decreased with soil depth in the uncultivated soils of all the SMUGs (Table 2). Furthermore, bulk density values of the surface layers of the uncultivated land were relatively higher than those of the cultivated lands in all the SMUGs of the estate, while the reverse was true for the subsurface layers. The increase in bulk density with soil depth in the cultivated than uncultivated soils might be attributed to compaction resulting from intensive cultivation at the same depth for long time as well as due to low organic matter content of the subsoil layers (Table 4). This is in line with the findings of Barzegar et al. (2005) who reported similar increase in subsoil bulk density following long term cultivation. Likewise, the relatively low bulk density in top soil layers of cultivated land may be attributed to the existence of high organic matter in the top layers as a result of cane residues left after harvesting on surface soil layer of cultivated fields or due to soil agricultural additives (filter cake, silt, and vinasse) during cultivation at top soil layer (Table 4). This is in line with Abdollahi et al. (2014) who reported the effectiveness of sugarcane residue in reducing soil compactibility. The subsoil layer data further indicates that the soil bulk density for Estate was in excess to root restriction initiation level. On the other hand, the decrease in bulk density with depth in the uncultivated soils suggests that these soils were also compacted at their surfaces by field traffic during different field operations (Barzegar et al., 2005).

The particle density also increased slightly with soil depth in both land uses of all the soil management unit groups (Table 2). This could be attributed to the relatively higher OM content in the top soils. The particle density values recorded in this study, are less than the average mineral particle density of 2.65 g cm^{-3} implying that the soils are composed of relatively light minerals. Similarly, increase in particle density with increasing soil depth was reported by Ahmed (2002). Following the variations in bulk and particle densities, total porosity of the SMUGs showed a generally decreasing trend with soil depth in the cultivated soils and an increasing pattern in the uncultivated soils (Table 2). In soils, which have the same particle density, the lower the bulk density the higher is total porosity. Furthermore, total porosity was lower in cultivated land subsoil layers than uncultivated land at Vertisols subsoil layer (Table 2). The lower total porosity in the subsoil layer of the cultivated land is likely attributed to the higher bulk density as a result of compaction (Table 2). A similar finding was also reported by Barzegar et al. (2005) that total porosity was lower in the subsoil layer of cultivated land.

Effects of land use types on selected soil chemical properties

Soil pH

Soil pH was significantly ($P < 0.05$) affected by land use in heavy SMUGs at Luvisols and Vertisol of Finchaa (Table 3). In the Luvisols and Vertisols of Finchaa, the pH of the cultivated soils was significantly ($P < 0.05$) higher than the pH of the adjacent uncultivated lands. The higher pH values recorded in the cultivated than uncultivated Luvisols and Vertisols at Finchaa could be related to the amendments (e.g., lime) applied to the cultivated lands since the soils are acidic (Table 3). According to the ratings of soil reaction by Tekalign and Haque (1991), soil reaction of the study area was slightly acidic compared to moderate acid. The low soil pH at the Finchaa Estate could be related to removal of basic cations by excessive rainfall or leaching of bases by percolating water. Similar to this, BAI (2009) indicated that soils are acidic as a result of removal of basic cations by excessive rainfall. There can be increase in soil pH after long years of cane production due to liming practices and irrigation with high-pH water in Finchaa Estate (Ambachew and Abiy, 2009; BAI, 2009).

The most universal effect of pH on sugarcane growth is nutritional. There is a strong relationship between soil pH and nutrient availability. As reported by Arain et al. (2000), the optimum soil pH required for sugarcane cultivation should be between 6.50-7.00. Moreover, most of the primary nutrients like nitrogen, phosphorus and potassium and secondary nutrients like calcium and magnesium are best utilized by sugarcane crop when the soil pH ranges between 5.50 and 7.90 (Arain et al., 2000). Soil reaction of the estate ranged from 5.35 to 6.63. In this regard, the pH of the uncultivated Luvisols was lower than the minimum optimum pH range that limits the availability of these nutrients. This indicates that in the estate pH could be one of the major factors affecting sugarcane production. Therefore, improving soil pH is clearly valuable in these soils in terms of improving availability of nutrients for sugarcane crops. Soil management practices that increase soil pH at Finchaa Estate have positive effect in improving sugarcane production of the estate (Table 3).

Soil organic carbon, total nitrogen and carbon to nitrogen ratio (C:N ratio)

Soil organic carbon content of the soils at the estate was significantly ($P < 0.05$) affected by land use in all the soil management unit groups except in Luvisols at Finchaa (Table 3). In all the SMUGs of the estate, the soil organic carbon content of the cultivated soils was significantly higher than the organic carbon content of the adjacent uncultivated lands (Table 3). The agricultural additives such as filter cake and organic residues remaining after harvest might have brought about significant variations in organic carbon content between the cultivated and uncultivated lands (Table 3). As per the rating suggested by Tekalign and Haque (1991), the mean values of soil organic carbon from both soil management unit groups of the estate were rated as low. This indicates that the soil organic carbon content found in the Finchaa Sugar Estate was within the range of minimum quantities required (1.16-1.74%) for sugarcane production as suggested by Arain et al. (2000). Such low organic matter content in the soils of the estate could presumably be due to the hot climate and intensive cultivation which increases rate of decomposition. It also indicates that the current rate of organic matter addition followed by the estate is not adequate to maintain the organic matter content of the soils at the required level. If decomposition rate is faster than the rate at which organic matter is added, soil organic matter levels will decrease. As a result, nutrient supplying capacity of soil declines steadily. Ambachew and Abiy (2009) also indicated low status of soil organic matter in the Finchaa Sugar Estate (Table 3).Total nitrogen was significantly ($P < 0.05$) affected by land use (Tables 3).The total nitrogen content of the cultivated soils was significantly ($P < 0.05$) higher than the total nitrogen content of the adjacent uncultivated lands in all the soils (Table 3).

The higher total nitrogen content in the cultivated soils could be related to the better organic matter content recorded in these soils than uncultivated. The significant and positive association between soil total nitrogen and organic carbon in the estate confirms this (Table 5). Application of N fertilizer and agricultural organic additives in the long and short-term cultivation probably increased N content of the cultivated fields as compared with uncultivated ones. Nevertheless, based on total nitrogen rating suggested by Tekalign and Haque (1991), the total nitrogen content of soils under the two land uses of all the SMUGs was within the range of low. This result suggests that nitrogen could be among the major nutrient elements limiting sugarcane production in the estate (Table 3).

The low rating values of soil organic carbon in cultivated and uncultivated lands may increase susceptibility of soil to compaction during machinery operations. Different studies made hitherto have indicated that the degree to which soils will compact when a force is applied by heavy machine on soil is primarily dependent on the amount of organic matter content present in the soil (Hamza and Anderson, 2005; Godwin et al., 2015). The average organic matter content was found to be 1.98% for the estate soil management unit groups (Table 3). However, as per the suggestion by Alvarez et al. (2009) soils with organic carbon levels above 1.97% (threshold value) are less vulnerable to soil compaction. This indicates that the organic carbon level in the estate was even below the threshold value, which can aggravate soil compaction. Therefore, management of soil organic matter is at the heart of sustainable agriculture. One way to reduce susceptibility of soil to compaction is to raise organic matter content of soils (Table 3).

The carbon to nitrogen ratio of the soils was not significantly affected by land use in Finchaa Sugar Estate (Tables 3). Carbon to nitrogen ratio is an important property of soil which controls the rate of decomposition, whether or not mineralization or immobilization of N occurs (Abdollahi et al., 2014). In cultivated agricultural soils, the C:N ratio ranges from 8:1 to 15:1 (Tisdale et al., 1995). In terms of this, soil organic reserve of Finchaa Estate is well decomposed. As mentioned by Ambachew and Abiy (2009) when C:N ratio is less than 20:1 mineral N can be released. In this regard, the C:N ratio of the estate is in the range where mineral N can be released for sugarcane use. However, the amount of N released by decomposition process may be limited by the amount of organic carbon in the soil. In general it can be said that conditions which encourage decomposition of organic matter result in narrowing of the C:N ratio of the soil. Narrower ratios permit mineralization to occur (Tables 3).

Available phosphorus (P)

Similar to the other soil properties, the variation of available P with land use was significant (Table 3). Accordingly, the content of available P in the cultivated land appeared to be significantly ($P < 0.05$) higher than the uncultivated land use type in all the soil management unit groups (Table 3). The higher available P in the cultivated than uncultivated land could be due to the relatively higher organic matter content of the cultivated land and P fertilizer added during cultivation. This was also supported by the significant positive correlation between the available P and soil organic carbon content at the estate (Table 5). Further, Sarwar et al. (2010) noted that organic matter increases the availability of P for plant uptake by forming complexes with Fe and Al in acid and Ca in alkaline soils, competes for adsorption sites and displaces adsorbed P. Soil P content varies with soil management factors such as land use pattern. In line with this, Birru et al. (2003) reported that the concentration of available P was lower in uncultivated lands than in cultivated crop lands. The available phosphorus concentration in the soils of the estate was low according to the available P rating classes suggested by Landon (2014) for Finchaa cultivated Luvisols and Vertisols. Nevertheless, the low contents of available P observed in these fields is in agreement with the findings of Tekalign and Haque (1991) who reported that the availability of P under most soils of Ethiopia is low (Table 3).

According to Arain et al. (2000), the optimum P content for sugarcane growth should range between 20 and 40 mg kg^{-1}. Similarly, Landon (2014) set minimum critical limit (11 mg kg^{-1}) for growth of crop plants in general. Arain et al. (2000) also suggested that below 6 mg kg^{-1}, P may cause deficiency symptoms in sugarcane plants. In the Finchaa Estate, the available P ranged between 2.51 to 8.63 mg kg^{-1}. Except at Finchaa cultivated Luvisols (6.34 ppm) and Vertisols (8.63 mg kg^{-1}), the available P content in the uncultivated fields was even below the 6 mg kg^{-1}(Table 3).

Variation of selected soil chemical properties with soil depth under two land uses

Soil pH

Within each land use type of the studied soil management units, soil pH showed some variation with soil depth albeit inconsistently. In cultivated Vertisols at Finchaa, pH increased with soil depth (Table 4). In the other SMUG, pH decreased with soil depth. Comparing the surface layers of the two land uses, it was observed that the pH of the cultivated soils was relatively lower than the pH of the adjacent uncultivated lands. Based on soil pH rating suggested by Tekalign and Haque (1991), the pH of the soils was within moderately acidic at Finchaa.ref.

Soil organic carbon and total nitrogen

Under both land uses of the SMUGs, organic carbon decreased consistently with soil depth (Table 4). Furthermore, the organic carbon content of the uncultivated soils at the respective depths was relatively lower than the corresponding organic carbon content in the cultivated soils. The relatively higher soil organic carbon content in the top soil layer than the respective subsoil layer of the cultivated soils could be due to addition of the organic agricultural additives to the top soil layer. Similarly, the relatively higher organic carbon content in the top layer of the uncultivated soils is an indication that most of the organic matter sources are within the upper 0-30 cm layer (Table 4).

According to the soil organic carbon rating suggested by Landon (2014), the soils of the study area were very low (< 2%) in their organic carbon content. The present study shows that organic carbon content of the soils is even below the minimum quantity of OM required for sugarcane cultivation (2-3%) as suggested by Arain et al. (2000). The low organic carbon content in the study area might be attributed to the low level of organic matter addition and exploitative and continuous tillage activities during seed bed preparation under continuous and intensive cane cropping. Tillage introduces oxygen and breaks aggregates to expose soil organic carbon that was formerly protected from decomposition. Then, this condition increases the rate of decomposition of soil organic matter and steadily decreases the organic carbon content of soils (Table 3). Wakene and Heluf (2003) also reported decrease in organic matter content as a result of continuous cultivation. There was a decrease of soil total N down the depth. The total nitrogen content which decreased with soil depth was also in the range of very low (< 0.1%) as per rating suggested by Landon (2014). Similarly, total soil nitrogen of the study area decreased down the depth from 0.40 to 0.05%. This very low level of total nitrogen is in line with the very low level of organic carbon. The differences of nitrogen contents between soil layers may be attributed to the observed differences in soil organic matter contents between the two layers (Table 4).

Available phosphorus

In the cultivated and uncultivated soils of the SMUGs in the estate, available P exhibited a decreasing trend with soil depth (Table 4). The decrease in available soil phosphorus with soil depth in both the cultivated and uncultivated soils might be ascribed to the increment of clay content with depth (Table 2), which can cause fixation of P, and higher organic matter content in the top layers (Table 4). The better accumulation of sugarcane root residues and better biological activities in the topsoil layer than that of the subsoil layer can improve available P in the top layer soil. Further, the lower concentration of available P in the subsoil layer might also be due to fixation by clay, which was observed to increase with profile depth. Sugarcane also takes up phosphorus from the subsoil and in combination with its low mobility of P at the top soil layer the values of phosphorus can be found to be very low in the subsoil. These results are in line with the findings by Dang (2007) who reported the restriction of soil P in top soil layer due to its low mobility and decrease of soil P in subsoil due to fixation with clay. Ahmed (2002) also observed the highest value of available P at the top soil layer in soils of Mount Chilalo.

CONCLUSION AND RECOMMENDATION

The results of the study indicated that most of the selected soil properties were affected by land use types. In general, clay content of the land under sugarcane was higher than that of the adjacent uncultivated land use types, although this resulted in change in textural class in few instances. The bulk density and total porosity values were below the threshold values recommended for optimum sugarcane cultivation and this suggests the existence of some degree of compaction. The moderately acidic pH values recorded at Finchaa Estate require attention. The low levels of organic carbon, total nitrogen, and available P contents under both cultivated and uncultivated soils indicate that soil fertility is among the constraints for sustainable sugarcane production in the estate. To maintain sustainability of sugarcane production in the estate; soil management practices that can increase soil organic carbon, pH, total nitrogen and soil available P should be employed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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