World Journal of Agricultural Sciences 17 (6): 546-559, 2021
ISSN 1817-3047

DOI: 10.5829/idosi.wjas.2021.546.559

Status of Selected Physicochemical Properties of Soils under Long Term Sugarcane Cultivation Fields at Wonji-Shoa Sugar Estate

Tesfaye Wakgari

College of Natural Resource Management and Veterinary Science, Ambo University, Ethiopia

Abstract: A declining trend in per hectare yield of sugarcane in Wonji-Shoa Sugar Estate is being observed due to altering of soil physicochemical properties resulted from long term sugarcane cultivation. Cognizant of this fact, a study was conducted in 2017 at Wonji-Shoa Sugar Estate with the objective of determining the effects of more than 62 years of sugarcane cultivation on the physicochemical properties of soil. In order to achieve this objective disturbed and undisturbed soil samples were collected from 0-30 and 30-60 cm layers of selected cultivated and uncultivated light and heavy soils for laboratory analysis. Results of the study indicated that long term cultivation of sugarcane at the same depth and low soil organic matter content of cultivated fields induced soil compaction and consequently highest bulk density was recorded in subsoil layer of cultivated than uncultivated land. The bulk density and total porosity values were out of ranges recommended for optimum sugarcane cultivation and suggest the existence of some degree of compaction. The finding further showed that the pH of study area soils is out of the normal pH range for sugarcane plant growth. The soil organic carbon, total nitrogen content and available phosphorus concentration of soils under both land uses of all soils was found within low range. Therefore, based on the result of the study it can be concluded that under condition of strong base soil pH of study area the availability of essential nutrients are critically affected. This indicates that the strong pH values at Wonji-Shoa Estate require more attention. Moreover, the low levels of organic carbon, total nitrogen and available P contents under both cultivated and uncultivated soils indicated that soil fertility is among the constraints for sustainable sugarcane production in the estate. Based on the findings and conclusions of this study one can recommend that to maintain sustainability of sugarcane production in the estate soil management practices that can protect as well as ameliorate soil compaction, increase soil organic carbon, total nitrogen, soil available P and that can decrease soil pH are important. Nevertheless, in order to give conclusive recommendation further research studies are needed for more soil management units in the estate.

Key words: Soil Physicochemical Properties · Sugarcane · Long Term Cultivation · Land Use

INTRODUCTION

Long term intensive mechanized tillage operation under sugarcane production causes soil degradation which results in subsequent decline in cane yield [1]. These situations have worsened by the use of heavy machinery such as tractors for operations like cultivation, planting, fertilizer application, weed control and cane extraction is a common practice [2]. Research report indicated that machinery overuse and long term intensive cultivation have been found to be the main cause for major soil degradation processes such as compaction and loss of organic matter [3].

Several researchers suggested that the most serious factor associated with soil degradation under sugarcane is soil compaction and the loss of soil organic matter [4]. Moreover, soil compaction and loss of organic matter are major soil degradation processes leading to deterioration of soil physical and chemical properties with concomitant decline in cane yield [5, 6]. Tesfaye *et al.* [7] reported that the most serious factor associated with soil compaction under sugarcane production is the loss of soil organic matter due to intensive tillage. Studies in Ethiopian Sugar Estates also showed that declining productivity of the fields is mainly due to deplete of organic matter along with effects of soil compaction on soil properties [8, 9].

Corresponding Author: Tesfaye Wakgari, College of Natural Resource Management and Veterinary Science, Ambo University, Ethiopia.

In Ethiopia sugar cane yield decline is currently becoming the major area of attention in the sugarcane plantations. For instance, Tesfaye [10] clearly indicated the existence of a general decline in cane yield in the Wonji-Shoa Sugar Estate. Accordingly, the cane yield declined by 48.63% over the last 54 years at Wonji-Shoa between 1954-2008 production years. Research report has shown that long-term monoculture and excessive tillage along with practices that deplete organic matter all contribute to yield decline [11]. Moreover, Babbu *et al.* [12] and indicated that long-term sugarcane cultivation under low soil organic matter condition altered soil properties. These changes in soil properties result in increased bulk densities that may consequently reduce nutrition uptake and crop yield [13].

Identifying and understanding the cause of the yield decline has paramount importance to design and recommend appropriate management strategies. Therefore, evidences on the effect 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 sugar estate.

Some studies have been done in Ethiopian Sugar Estates on effect of long term sugarcane cultivation on sugarcane yield [14]. Nevertheless, a few is known regarding the effects of long term mechanized sugarcane production on selected soil physicochemical properties in the Wonji-Shoa Sugar Estate. Such information is of particular important inputs for sugarcane producing community and for land-use-planners in planning land management practices for sustaining the production and productivity of sugarcane in the estate. Keeping all these aspects in consideration, this study was initiated with objective of assessing the effects of long term mechanized sugarcane production on selected soil physicochemical properties at Wonji-Shoa Sugar Estate taking uncultivated soils nearby the farms as references.

MATERIALS AND METHODS

Description of the Study Areas: The study was conducted at commercial sugarcane production fields of Wonji-Shoa Sugar Estate in 2017. It is found at a distance of 107 km from Addis Ababa within the Oromia National Regional State (ONRS). Wonji-Shoa Sugar Estate is located at 8° 21' 3.84 to 8° 27' 25.86?? N and 39°12' 13.28 to 39°18' 34.46 E in the central part of the East African Rift Valley system in the Awash River Basin (Figure 1). The current total area of land covered with cane is about 7050 ha for Wonji-Shoa Sugar Estate [15].

Ten years (2005-2015) climatic data (Figure 2) of the Wonji-Shoa Estate indicated that the area has a bimodal rainfall pattern in which small rain is received from February to April, while the main rainy season that contributes a significant proportion of the total annual rainfall is received during June to September. The mean of ten years annual rainfall of the study area is 831.47 mm [16]. The climate at estate is semiarid and average maximum and minimum temperature was about 15.19 and 27.57°C, respectively.

The range of altitude of the Wonji-Shoa Estate is 950-1540 meters above sea level (m.a.s.l). While, the slope of the fields was generally very gentle and regular and this makes it suitable for gravity irrigation. The estate sugarcane production was undertaken with irrigation [17] and the sources of water for irrigation were Awash River. The major crop of the estate was sugarcane; while, haricot bean and crotalaria are also produced. The average length of growing period of sugarcane (plant cane) in the study area is 22 months.

The major geologic materials of Wonji-Shoa Estate was developed under tropical hot condition from alluvium-colluvium parent materials, which include basic volcanic rocks (such as basalt, limestone) as well as recent and ancient alluvial soils developed from materials laid down by river systems [18]. Vertisols and Fluvisols are major soil types of the estate plantation [19].

At the study area soils were grouped according to their moisture content at pF2, i.e. at 10 kPa matrix potential. This grouping of soil management approach for the estate was adopted from Kuipers [20] though there was no documented information about the exact methodology, depth of sampling, number of measurements of samples and types of sampling for pF_2 grouping of soils under different management units of this estate. There are five pF2 classes (namely A_1, A_2, BA_2, $B_{1.4}$ and C_1) at Wonji-Shoa Estate. The first three soil groups (A_1, A_2 and BA_2) of the estate is heavy textured soils; while the last two soil types ($B_{1.4}$ and C_1) are light textured soils [21].

Site Selection, Sampling and Sample Preparation: At the beginning sampling site selection, preliminary survey, professional judgment and consultation with estate experts were undertaken to identify the sampling locations. Land use representatives such as areas covered

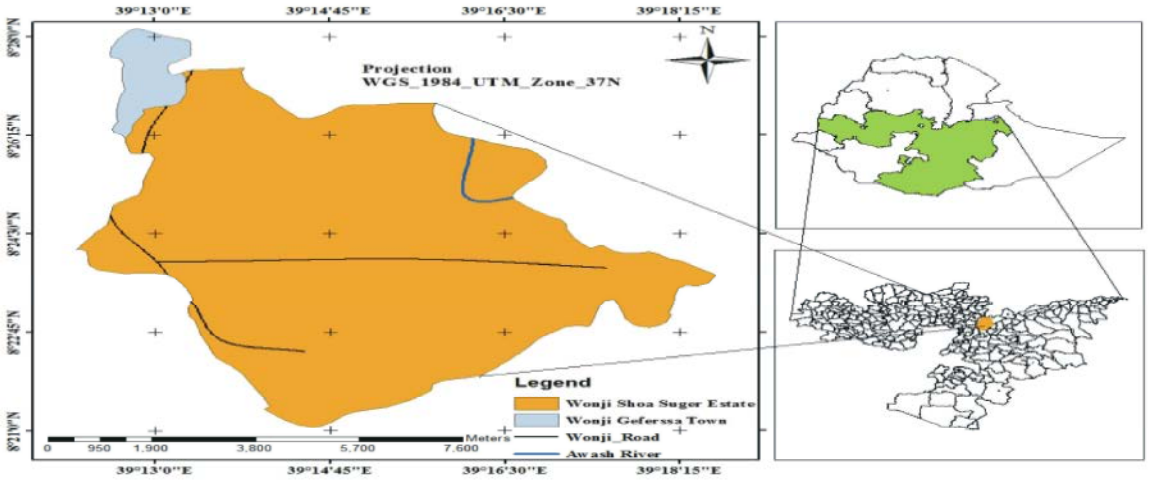

Fig. 1: Location maps of Wonji-Shoa Sugar Estate in Ethiopia

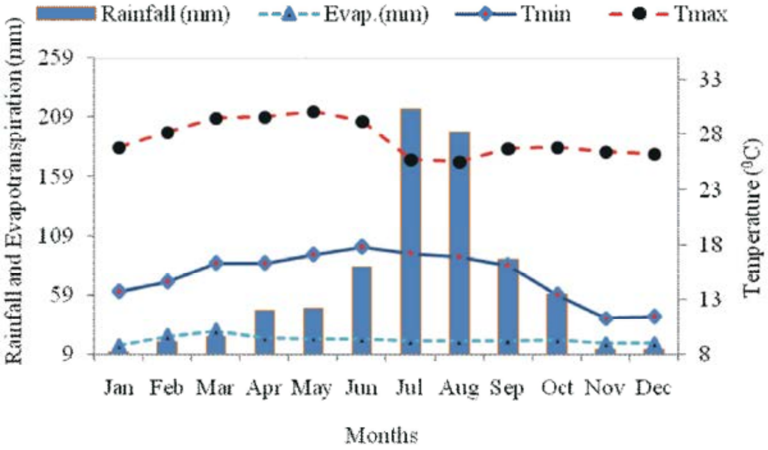

Fig. 2: Ten years mean monthly rainfall, evapotranspiration (Evap) and monthly minimum (Min) and maximum (Max) temperatures of Wonji-Shoa Estate

by sugar cane plantation, areas covered with minimum disturbances (example: forests, bush, bare land, residence area), topography of sites and sugar cane plantation settings were considered.

The experiment was conducted on light and heavy soil management unit groups. Three stages stratified random soil sampling method was used. In the first stage the estate was stratified in to two soil management units. In second stage each soil management unit was categorized into two land use types (cultivated and uncultivated). In the third stage each land use was represented by three sampling sites so that soil samples from each stratum provided good representation of study area soils. Furthermore, qualitative soil compaction diagnosis at field level was undertaken in order to select the final soil sampling sites.

Accordingly, 6 cultivated sugarcane fields with records of recurrent reduced yield and 6 adjacent uncultivated bare fields were identified during field observation for both soil management units per estate. The reports of Babbu *et al*. [22] indicated that the yield reduction was due to soil related constraints. The uncultivated fields were identified per each existing management unit groups and most of them were located between the main drains and access roads. According to information from station officers of the estate, these soils have not been cultivated for about forty years. Each cultivated and uncultivated fields were sampled by replicating three times. Accordingly, 18 sampling sites for each soil management unit was assigned. Global Positioning System (GPS) data was taken from each of the sampling sites.

A representative composite soil samples with three replications per each cultivated and uncultivated bare fields was collected from the two depths. Composite and undisturbed (for bulk density) samples were collected from 0-30 and 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 field was 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 were collected from the estate plantation fields.

About 500 g of the composite soil samples were properly weighed, labeled and kept in plastic bag and transported to Debrezeit Research Center, Wonji Central Laboratory. In the laboratory, sufficient amount of soil samples were air dried and ground to pass through 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.

Laboratory Analysis of Soils: Particle size distribution was determined by the Bouyoucos hydrometer method as described by Okalebo *et al.* [23]. The textural class was determined using the USDA soil textural triangle [24]. Bulk density was determined using the core method as described by Jamison *et al.* [25]. Particle density (ñp) was determined using the pycnometer method following procedures described in Rao *et al.* [26]. Total porosity was calculated from the values of bulk density and particle density using the method described by Rowell [27].

The pH of the soils was measured in water (1:2.5 soil: water ratio) by glass electrode pH meter [28]. Soil organic carbon was determined by the wet digestion method following the procedure of Walkley and Black [29]. The total nitrogen was determined by the Kjeldal method as described by Jackson [30]. Relative amount of carbon to nitrogen was determined by taking the ratio of soil organic carbon to total nitrogen. Available phosphorus was extracted according to Olsen's method [31]. The P extracted with different methods was measured by spectrophotometer following the procedures described by Murphy and Riley [32].

Data Analysis and Interpretation: A randomized complete block design (RCBD) with three replications was used to analysis the variance of soil parameters. 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 [33]. For statistically different 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 significant differences in the soil particle size distribution between the soil management unit groups of cultivated soils as compared with the adjacent uncultivated soils of each soil management groups with the exception that silt content was not significantly ($P \geq 0.05$) affected by land uses of all soil management unit groups (Tables 1). The highest clay content was recorded for cultivated land in contrary to the sand content which was highest for uncultivated land. The results indicated that the soil of all soil management units could be categorized as clay textural class except the uncultivated light soils of Wonji-Shoa soils which is sandy clay loam. This indicates that the significant differences in individual separates between land uses did not cause changes in textural classes.

The increase in clay content in cultivated than uncultivated land might be attributed to the difference in vulnerability of the land uses to eluviation and surface runoff which is normally highest in the cultivated land soils. Moreover, 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. In line with this finding, Wakene [34] also reported the difference in particle size distribution between cultivated and uncultivated soils due to eluviation and surface runoff.

Furthermore, the differences in particle size distribution of cultivated from uncultivated soils could also be due to mixing of soils of the surface and subsurface horizons during tillage activities and subsoiling operations of sugarcane cultivation field soils. Dang [35] 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.

Table 1: Effects of land use on selected physical properties of the soils in Wonji-Shoa Sugar Estate

		Particle size distribution (%)						
SMUG	Land use types	Sand	Silt	Clay	Texture	ρp (g.cm^{-3})	ρb (g.cm^{-3})	*f* (%)
Light	Cultivated	29.12^b	19.85	51.03^a	clay	1.36^a	2.26	39.89^b
	Uncultivated	46.34^a	19.58	34.08^b	San.cl.lo	1.29^b	2.27	42.80^a
	LSD	4.31	ns	4.24	-	0.04	ns	2.40
Heavy	Cultivated	24.58^b	18.27	57.15^a	clay	1.32^a	2.10	38.19
	Uncultivated	33.00^a	20.08	46.92^b	clay	1.26^b	2.14	40.03
	LSD	2.11	ns	2.56	-	0.01	ns	ns

SMUG = soil management unit groups, LSD = least significant difference, ñb = bulk density, ñp = particle density, f = total porosity, San cl lo = sandy clay loam and means with the same letters are not significantly different

Bulk Density and Total Porosity: Bulk density is an important factor in soil fertility studies since it influences the transport as well as utilization rate of nutrients in soil directly. Bulk density values were significantly ($P < 0.05$) affected by land use for all soil management unit groups (Tables 1). Soil bulk density of study area soil ranges from 1.26 to 1.36 g.cm^{-3}. As per dry bulk density ratings suggested by Jones [36] for different textured soils, the bulk density values of both soils of SMUGs were within the normal range suggested for the respective textural classes except that the bulk density of the cultivated light soils of Wonji-Shoa Estate were close to the root restriction initiation bulk density values.

The lowest value of bulk density was observed for uncultivated land use. But the highest value of bulk density was recorded for cultivated land use (Tables 1). The highest bulk density values for cultivated land use might be attributed to soil compaction induced in the soil due to long term cultivation of sugarcane and low soil organic matter content of cultivated fields. This can be evidenced from the strong correlation ($r = -0.51^*$) between the soil organic matter and bulk density (Table 5). Similarly, Negesa and Tesfaye [37] also reported increasing of bulk density due to soil compaction and the negative correlation between soil organic matter and bulk density, respectively.

Moreover, 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 [38]. Based on these critical values, the bulk density values of most of the sampled sites were out of these critical values, which indicate presence of soil compaction and sustainability problem for sugarcane production in the estate.

The different land uses (land uses under light soil management) had significant ($P < 0.05$) effect on total porosity of soil (Table 1). The highest value of total porosity (42.80%) was obtained from light uncultivated land use and the lowest value (38.19%) was recorded from heavy cultivated land use. The total porosity of soils usually lies between 30 and 70% [39]. As suggested by Sarwar *et al*. [40], the optimum soil porosity for sugarcane growth is 50%. Furthermore, according to Hazelton and Murphy [41], 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 this estate was below the optimum value for sustainable sugarcane production and were in the range of root growth restriction.

The relatively highest values of total porosity obtained for uncultivated land use corresponded to the higher amount of organic matter contents and lower bulk density values of uncultivated land uses. In line with this, Brady and Weil [42] reported that the low total porosity was the reflection of the low organic matter content and the high bulk density. This is further supported by Gangwar *et al*. [43] who reported reduced bulk density might be due to increased soil pores as the result of incorporation of higher soil organic matter to soil from organic fertilizer that ultimately improved soil total porosity. 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 (Table 5) suggesting that maintaining higher soil organic matter in soils could result in higher total porosity.

Effects of Soil Depth on Selected Soil Physical Properties

Particle Size Distribution: There was variation in the soil particle size distribution between soil depths of the land use types of the selected soil management unit groups (Table 2). The clay percentage increased whilst the sand and silt contents decreased from the surface to the subsurface horizons in both cultivated and uncultivated light and heavy soil management unit groups of Wonji-Shoa Estate. 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 (Table 2). Texture is an intrinsic soil property, but intensive cultivation, leaching and mixing of the surface and subsurface horizons during deep tillage activities contributed to the variations in particle size distribution between two depths of the cultivated and uncultivated lands.

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 both the SMUGs in the estate. The 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. Chemada *et al*. [44] also indicated that one of the main processes that could likely lead to increase of clay content with depth in a soil profile is the downward transport of clay suspended in percolating soil water. It might also be due to *in situ* formation of clay within the subsurface layers. In line with these findings, Meyer and Antwepen [45] indicated the existence of significant variations in particle size distribution in soil profiles due to elluviation and illuviation processes. Prasad and Govardhan [46] also reported accumulation of clay in subsurface layers and attributed this to the *in situ* formation of clays and weathering of primary minerals in the B horizon.

Bulk Density and Particle Densities and Total Porosity: In all the soil management unit groups bulk density was increased with depth in the soil profile in cultivated soils and decreased with soil depth in the uncultivated soils (Table 2). Numerically the highest mean (1.38 g cm^{-3}) value of bulk density was recorded on the subsoil layer of cultivated land and the lowest mean (1.16 g cm^{-3}) value was under the top layer of cultivated land. Moreover, bulk density values of the surface layers of the uncultivated land were relatively higher than those of the cultivated lands in the estate, while the reverse was true for the subsurface layers. The increase in bulk density in subsoil layer of cultivated than uncultivated soils might be attributed to compaction resulting from intensive cultivation at the same depth for long time (Table 4). This is in line with the findings of Barzegar *et al.* [47] who reported 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, tillage and more root extension 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 Barzegar *et al.* [48] who reported the effectiveness of sugarcane residue in reducing soil compactibility. The subsoil layer data further indicates that the soil bulk density is mostly close to root restriction initiation.

The particle density under the two land uses increased slightly with soil depth (Table 2). This could be attributed to the relatively higher OM content in the top soils and presence of heavy minerals such as Fe and Mn in the subsurface layers. 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 [49].

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 (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. A similar finding was also reported by Smith *et al*. [50] 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 is the most important master chemical soil parameter and it reflects the overall chemical status of the soil and influences a whole range of chemical and biological processes occurring in the soils [51]. Soil pH was significantly ($P < 0.05$) affected by land uses in heavy soil management unit group of the estate (Table 3). The highest soil pH (8.19) was recorded for uncultivated heavy soil management unit group and the lowest soil pH (7.57) was obtained from cultivated heavy soil management unit group (Table 3). According to the ratings of soil reaction by Tekalign [51], soil reactions of the study area were moderately alkaline to strongly alkaline at Wonji-Shoa.

The lower pH values recorded under the cultivated than uncultivated lands in Wonji-Shoa might be due to the depletion of basic cations as a result of leaching during every irrigation of the soils. The higher soil pH recorded for uncultivated heavy soil management unit

Table 2: Variations of selected soil physical properties with soil depth across two land uses of the major soil management units in the Wonji-Shoa Estate

			Particle size distribution (%)						
SMUG*	Land Use	Depth (cm)	Sand	Silt	Clay	TC*	ρb (g.cm^{-3})*	ρp (g cm^{-3})*	*f* (%)*
Light	Cultivated	0-30	29.42	22.55	48.03	Clay	1.22	2.11	42.26
		30-60	28.82	17.14	54.04	Clay	1.38	2.39	42.18
	Uncultivated	0-30	52.00	19.50	28.50	SCL	1.38	2.21	37.56
		30-60	48.67	19.66	31.67	SCL	1.33	2.25	40.89
Heavy	Cultivated	0-30	25.67	18.72	55.61	Clay	1.16	2.06	43.69
		30-60	23.49	17.82	58.69	Clay	1.36	2.07	34.30
	Uncultivated	0-30	34.00	20.50	45.50	Clay	1.34	2.12	36.79
		30-60	32.00	19.67	48.33	Clay	1.29	2.14	39.72

*SMUG = soil management unit group; SCL = sandy clay loam; CL = clay loam; ñb = dry bulk density; ñp = particle density; f = total porosity

Table 3: Effects of land use on selected chemical properties of the soils in the Wonji-Shoa Estate

SMUG	Land uses	pH	SOC (%)	TN (%)	C:N	P (mg kg^{-1})
Light	Cultivated	8.10	0.7^{b}	0.06	18.93^{a}	4.83^{a}
	Uncultivated	8.11	1.18^{a}	0.06	13.24^{b}	3.06^{b}
	LSD	ns	0.07	ns	3.30	0.50
Heavy	Cultivated	7.57^{b}	1.09^{b}	0.08^{a}	16.17	5.89^{a}
	Uncultivated	8.19^{a}	1.24^{a}	0.06^{b}	17.17	3.84^{b}
	LSD	0.10	0.10	0.01	Ns	0.30

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

group soils of Wonji-Shoa Estate could be attributed to the accumulation of exchangeable sodium and calcium carbonate in the soils of the estate. The reaction of exchangeable sodium and $CaCO_3$ under low CO_2 conditions might have led to higher concentration of sodium carbonate [52]. Sodium carbonate in the soil reacts with water to produce carbon dioxide and sodium hydroxide which is alkaline and increases soil pH values. This is in line with Pradeep [53] who reported increase in soil pH due to concentration of sodium carbonate in soils.

The most universal effect of pH on sugarcane growth is nutritional. As reported by Arain *et al*. [54], the ideal soil pH for sugarcane plant growth is pH 6.5 to 7. 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 [55]. Nevertheless, this finding showed that the pH of study area soils is out of this normal pH range. Under such condition the availability of essential nutrients are critically affected. 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 reduce high pH value of soils at Wonji-Shoa Estate have positive effect in improving sugarcane production of the estate.

Soil Organic Carbon, Total Nitrogen and Carbon to Nitrogen Ratio (C:N Ratio): Soil organic matter content of the soils at this estate was significantly ($P < 0.05$) affected by land use in all the soil management unit groups (Table 3). The organic matter contents were in the range of 1.21–2.14% for land uses of the estate (Table 3). As per the rating suggested by Jones [56] the mean values of soil organic matter contents from all soil management unit groups of the estate were rated as low. In all the SMUGs 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 higher organic matter content of cultivated over the uncultivated land uses is due to the agricultural additives such as filter cake and organic residues remaining after harvest. Girma [57] also indicated low status of soil organic matter in Wonji-Shoa Estate.

The result of the study indicates that the soil organic carbon content found in the estate was within the range of minimum quantities required (1.16-1.74%) for sugarcane production as suggested by Yadava [58]. 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.

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 [59]. 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*. [60] 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. Botta *et al*. [61] also demonstrated that soil compactibility caused by heavy machinery can be reduced by raising soil organic matter content by incorporating residues.

Total soil nitrogen was significantly ($P < 0.05$) affected by land uses of the estate (Table 3). The highest soil total nitrogen (0.08%) was recorded from cultivated heavy soil management unit groups and the lowest soil total nitrogen (0.06%) was obtained from cultivated light soil management unit groups. Nevertheless, based on total nitrogen rating suggested by Berhanu [62], the total nitrogen content of soils under both land uses of all the soil management unit groups was within the range of low. This result suggests that nitrogen could be among the major nutrient elements limiting sugarcane production in the estate. The higher total nitrogen content in the cultivated soils could be related to the nitrogen fertilizer applied to cultivated land. 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. This finding is in agreement with Bikila [63] who reported direct association between total N content of a soil and organic carbon (OC) content.

Carbon to nitrogen ratio is an important property of soil which controls the rate of decomposition and whether mineralization or immobilization of N occurs [64]. Conditions which encourage decomposition of organic matter results in narrowing of the C:N ratio of the soil. Narrower ratios permit mineralization to occur. The carbon to nitrogen ratio of the soils was significantly ($P < 0.05$) affected by land use in light soil at Wonji-Shoa only (Tables 3). In these soil management units, the C:N ratio of the cultivated soils was significantly greater than that of the uncultivated soils (Table 3). In cultivated agricultural soils, the C:N ratio ranges from 8:1 to 15:1 [65]. As mentioned by Tesfaye *et al*. [66] 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. As per rating by Newey [67], the C:N ratio of all the soils was within the medium range category except in the uncultivated light Wonji-Shoa which was in the low range. However, the amount of N released by decomposition process may be limited by the amount of organic carbon in the soil.

Available Phosphorus (P): Soil available phosphorus was significantly ($P< 0.05$) affected by land uses of soil management unit groups (Table 3). The content of available P in the cultivated land appeared to be higher than the uncultivated land use type in all the soil management unit groups (Table 3). In the estate, the available P ranged between 3.06 to 5.89 mg kg^{-1}. According to research reported by Arain *et al*. [68], the optimum P content for sugarcane growth should range between 20 and 40 mg kg^{-1}. Similarly, Tekalign and Haque [69] set minimum critical limit (11 mg kg^{-1}) for growth of crop plants in general. Muhammade *et al*. [70] also suggested that below 6 mg kg^{-1}, P may cause deficiency symptoms in sugarcane plants. The available P content in all the SMUGs was even below the 6 mg kg^{-1}, which indicates that available P could also be among the limiting nutrient elements for successful growth of sugarcane. This was also evidenced by the red or purple colours observed on most sugarcane leaves (P deficiency) during soil sampling.

The available phosphorus concentration in the soils of the estate was very low according to the available P rating classes suggested by Landon [71] except for heavy cultivated Wonji-Shoa (low). Nevertheless, the low contents of available P observed in these fields is in agreement with the findings of Tekalign and Haque [72] who reported that the availability of P under most soils of Ethiopia is low. The higher available P in the cultivated than uncultivated land could be due to the P fertilizer added during cultivation. In line with this Birru [73] reported that the concentration of available P was lower in uncultivated lands than in cultivated crop lands.

Table 4: Variation of selected soil chemical properties with soil depth across two land uses of the major soil management unit groups in the Wonji-Shoa Estate

SMUG	Land use	Depth (cm)	pH	SOC (%)	TN (%)	P (mg kg^{-1})
Light	Cultivated	0-30	7.80	1.30	0.07	5.74
		30-60	8.10	1.10	0.06	3.70
	Uncultivated	0-30	8.16	0.80	0.06	3.69
		30-60	8.20	0.70	0.06	2.96
Heavy	Cultivated	0-30	7.59	1.40	0.34	6.90
		30-60	7.48	1.14	0.10	4.50
	Uncultivated	0-30	7.61	1.20	0.09	4.04
		30-60	7.54	1.10	0.07	2.92

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

	Wonji-Shoa Estate					
	ρb	*F*	Cl	SOC	TN	P
ρb	1.00	-0.67^{***}	-0.30^{ns}	-0.51^{*}	-0.44^{*}	-0.59^{**}
f		1.00	0.09^{ns}	0.17^{ns}	0.15^{ns}	0.19^{ns}
Cl			1.00	0.77^{***}	0.42^{*}	0.69^{***}
SOC				1.00	0.62^{**}	0.81^{***}
TN					1.00	0.70^{***}
P						1.00

Cl = clay content, San = sand content, Bd = 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

Variation of Selected Soil Chemical Properties with Soil Depth under Two Land Uses

Soil pH: Data pertaining to the soil pH as influenced by depth is given in Table 4. The maximum value of soil pH (8.20) was recorded from subsoil layer of light uncultivated and minimum soil pH (7.48) was recorded from subsoil layer heavy cultivated layer. Within each land use type of the studied soil management units, soil pH showed some inconsistent variation with soil depth. In light cultivated and uncultivated soils at Wonji-Shoa pH increased with soil depth and the reverse was true for heavy soil management unit group (Table 4). 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 which might be due to the fertilizer and organic inputs applied to cultivated land.

Soil Organic Carbon and Total Nitrogen: The organic carbon (OC) was affected by soil depth in both land uses. The OC was decreased consistently from the surface to the subsurface horizons in all of the land use systems (Table 4). The organic carbon contents were in the range of 0.7–1.4% for both land uses of the estate (Table 4). According to the soil organic carbon rating suggested by Murphy [74], 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 Yadava [75]. 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. Similarly, Angelova *et al.* [76] also reported high organic carbon content over top surface of the cultivated soils.

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 break 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. In line with this, Wakene [77] also reported decrease in organic matter content as a result of continuous cultivation.

The total nitrogen which is a major nutrient element determining sugarcane yield was in the range of 0.06-0.34% for both land uses of the estate (Table 4). 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 [78]. 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.

Available Soil Phosphorus: P is the most commonly plant growth-limiting nutrient in the tropical soils next to water and N. The rate at which the plant absorbs phosphate ions is influenced by their concentration in the soil solutions. The concentration of available p in soils under the two land uses in the estate was ranged from 2.92 to 6.9 ppm. 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 [79] 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 [80] 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 clay content was decreased consistently with depth and higher in cultivated land than uncultivated land. Moreover, long term cultivation of sugarcane at the same depth and low soil organic matter content of cultivated fields induced soil compaction and consequently highest bulk density was recorded in subsoil layer of cultivated than uncultivated land. The bulk density and total porosity values were out of ranges recommended for optimum sugarcane cultivation and suggest the existence of some degree of compaction. The finding further showed that the pH of study area soils is out of the normal pH range for sugarcane plant growth. The soil organic carbon, total nitrogen content and available phosphorus concentration of soils under both land uses of all the soil management unit groups was found within low range.

Therefore, based on the result of this study it can be concluded that under condition of strong base soil pH of study area the availability of essential nutrients are critically affected so that the strong pH values at Wonji-Shoa Estate require more attention. Moreover, the low levels of organic carbon, total nitrogen and available P contents under cultivated soils showed that soil fertility is among the constraints for sustainable sugarcane production in the estate. Based on the findings and conclusions of this study one can recommend that to maintain sustainability of sugarcane production in the estate soil management practices that can protect as well as ameliorate soil compaction, increase soil organic carbon, total nitrogen, soil available P and that can decrease soil pH are important. Nevertheless, in order to give conclusive recommendation further research studies are needed for more soil management units in the estate.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Ministry of Education for guaranteeing their salary during the research work. They would like also to thank Wonji-Shoa Research Station staff members and field workers particularly for providing us laboratory facilities, laboratory analysis, labour and technical support during the implementation of field experiment.

REFERENCES

1. Kodesova, H., 2011. Role of physicochemical properties in soil quality. Chemistry Science Reviews Letters., 4: 57-66.
2. Tesfaye, W., K. Kibebew, B. Bobe, T. Melesse and E. Teklu, 2018. Long Term Effects of Cultivation on Physicochemical Properties of Soils at Metahara Sugar Estate. American- Eurasian Journal of Agricultural Research, 18: 246-257.
3. Barzegar, A.R., S.H. Mahmoodi, F. Hamedi and F.Abdolvahabi, 2005. Long term sugarcane cultivation effects on physical properties of fine textured soils. Journal of Agricultural Science and Technology, 7: 59-68.
4. Hamza, M.A. and W.K. Anderson, 2005. Soil compaction in cropping systems. A review of the nature, causes and possible solutions. Soil and Tillage Research, 82: 121-145.
5. Albiach, K., 2003. Management practices to improve soil health and reduce the effects of detrimental soil biota associated with yield decline of sugarcane in Queensland, Australia. Soil Tillage Research, 72: 125-137.

6. Pankhurst, C.E., G.R. Stirling, R.C. Magarey, B.C. Blair, J.A. Holt, M.J. Bell and A.L. Garside, 2005. Quantification of the effects of rotation breaks on soil biological properties and their impact on yield decline in sugarcane. Soil Biology and Biochemistry, 37: 1121-1130.
7. Tesfaye, W., K. Kibebew, B. Bobe, T. Melesse and E. Teklu, 2020a. Effects of Compaction at Different Moisture Contents on Selected Soil Properties and Sugarcane Growth and Sugar Yield at Metahara Sugar Estate. American Journal of Agricultural Research, 15: 78.
8. Alvarez, C.R., M.A. Taboada, F.H. Gutierrez, P.L. Fernandez and P. Prystupa, 2009. Topsoil properties as affected by tillage systems in the Rolling Pampa region of Argentina. Soil Science Society of American Journal, 73: 242-1250.
9. Tesfaye, W., 2021a. Extent of Soil Compaction under Mechanized Sugarcane Cultivation at Wonji-Shoa Sugar Estate. World Journal of Agricultural Sciences, 17: 338-350.
10. Tesfaye, W., 2021c. Effectiveness of Sugar Industry Organic Wastes in Reducing Soil Compatibility in Soils of Three Ethiopian Sugar Estates. International Journal of Energy and Environmental Science, 6: 86-95.
11. Tesfaye, W., 2021b. Long Term Sugarcane Cultivation Effect on Selected Physical and Hydraulic Properties of Soils at Three Ethiopian Sugarcane Estates. American Journal of Plant Biology, 6: 60-72.
12. Babbu, S.B., Jagdeep, S. Gurbir and K. Gurpreet, 2015. Effects of LongTerm Application of Inorganic and S. Organic Fertilizers on Soil OrganicCarbon and Physical Properties in Maize–Wheat Rotation. Agronomy, 5: 220-238.
13. Reichert, J.M., L. Eduardo, A.S. Suzuki, D.J. Reinert, R. Horn and I. Hakansson, 2009. Reference bulk density and critical degree-of-compactness for no-till crop production in subtropical highly weathered soils. Soil and Tillage, 102: 242-254.
14. Ambachew, D., F. Abiy and T. Zeleke, 2012. Correlation of Foliar Nutrient Status with Yield of Sugarcane Varieties at Different Crop Stages and Nitrogen Levels at Wonji-Shoa and Finchaa Sugarcane Plantations of Ethiopia. Ethiop. J. Appl. Sci. Technol., 3: 9-22.
15. ESC (Ethiopian Sugar Corporations), 2015. Ten Years (2003-2013) Climatic Data Obtained from the National Meteorological Agency of Wonji-Shoa, Metahara and Finchaa Stations. Ethiopian Sugar Corporation Research and Training Service Division, Addis Ababa, Ethiopia.
16. Tadesse, N., 2004. Summary of Metahara Sugar Factory Weather Data for the Year 2004 and Average of the Last Ten Years (1993-2004). Ethiopian Sugar Industry Support Center, Research and Training Service Division, Wonji, Ethiopia.
17. Michael, M. and B. Seleshi, 2007. Irrigation Practices in Ethiopia: Characteristics of Selected Irrigation Schemes. Integrated Water Management Institute, Colombo, Srilanka.
18. Ambachew, D. and F. Abiy, 2009. Assessment of Some Soil Physicochemical Properties of Soils of Wonji-Shoa , Metahara and Finchaa Sugarcane Plantations. Annual research report. Ethiopian Sugar Corporation Research and Training Service Division, Wonji, Ethiopia, pp: 118-130.
19. APECS (Agrima Project Engineering and Consultancy Services), 1987. A Report on the Agricultural Research Services of the Ethiopian Sugar Corporation (ESC). Matha Private, Bombay, India, pp: 1-414.
20. Duiker, W., 2002. Diagnosing soil compaction using a penetrometer. Pennsylvania State University, Pennsylvania, USA.
21. Girma, A., 2009. Effect of Filter Cake and Mineral Fertilizers on Yieldof Plantcane in the Sugarcane Plantations of Ethiopia. Proc. Ethiop. Sugar. Ind. Bienn. Conf., 1: 126-136
22. Babbu, S.B., S. Jagdeep, S. Gurbir and K. Gurpreet, 2015. Effects of LongTerm Application of Inorganic and Organic Fertilizers on Soil OrganicCarbon and Physical Properties in Maize–Wheat Rotation. Agronomy, 5: 220-238.
23. Okalebo, J.R., K.W. Gathua and P.L. Womer, 2002. Laboratory Methods of Soil and Plant Analyses. A Working Manual, 2nd ed. TSBF–CIAT and SACRED Africa, Nairobi, Kenya.
24. Soil Survey Staff, 1999. Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Second edition. Agriculture Handbook 436.Washington, DC, USDA, pp: 886.
25. Jamison, V.C., H.H. Weaver and I.F. Reed, 1950. A hammer-driven soil core sampler. Soil Science, 69: 487-496.
26. Rao, M., P. Singa and M.J. Raju, 2005. Laboratory Manual on Soil Physicochemical Properties. Aditha Art Printers, New Delhi, India.

27. Rowell, D.L., 1994. Soil science: Method and Applications. Longman Scientific and Technical, Longman Group UK Limited Addison, Wesley, England, 350.
28. Peech, M., 1965. Hydrogen-ion activity. pp: 914-926. In: CA, Black, D.D. Evans, J.L. Ensminger and F.E. Clark (eds). Methods of Soil Analysis. Part II.ASA, WI, Madison, USA.
29. Walkly, A. and I.A. Black, 1934. An Examination of digestion method for determining soil organic matter and a proposed modification of the chromic acid titration. Soil Science, 37: 29-38.
30. Jackson, M.L., 1958. Soil Chemical Analysis. Prentice Hall, Inc., Englewood Cliffs. New Jersey.
31. Olsen, S.R., C.V. Cole, L. Watanabe and A. Dean, 1954. Estimation of Available P in Soils Extraction with $NaHCO_3$. USDA Cir. 939, US Government Printing Office, Washington D. C., USA.
32. Murphy, J. and J.P. Riley, 1962. A modified single solution method for the determination of phosphorus in natural waters. Analytica Chimica Acta, 27: 31-36.
33. SAS (Statistical Analysis System), 2002. SAS Version 9.1.3. SAS Institute Inc., Cary, NC, USA.
34. Wakene, N., 2001. Assessment of important physicochemical properties of Dystric Udalf (Dystric Nitosols) under different management systems in Bako area, Western Ethiopia. MSc Thesis, Alemaya University, Haramaya, Ethiopia.
35. Dang, M.V., 2007. Quantitative and qualitative soil quality assessments of tea enterprises in Northern Vietnam. Vietnam. African Journal of Agricultural Research, 2: 455-462.
36. Jones, C.A., 1983. Effect of soil texture on critical bulk densities for root growth. Soil Science Society of America Journal, 47: 1028-1211.
37. Negessa, G. and W. Tesfaye, 2021. Influence of Organic and Chemical Source Fertilizers on Soil Physicochemical Properties and Nutrient Concentration of Nitisol in Welmera District, Central Ethiopia. World Journal of Agricultural Sciences, 17: 295-307.
38. Ridge, R., 2013. Sugarcane Fertilizing for High Yield. IPI Bulletin No. 21. International Potash Institute, Coral Cove, Australia
39. Hillel, D., 1998. Environmental Soil Physics. Academic Press, London, England.
40. Sarwar, A.M., M. Ibrahim, M. Tahir, K. Ahmad, I.Z. Khan and E.E. Valeem, 2010. Appraisal of pressmud and inorganic fertilizers on soil properties, yield and sugarcane quality. Pakistan Journal of Botany, 42: 1361-1367.
41. Hazelton, P. and B. Murphy, 2007. Interpreting Soil Test Results: What Do All the Numbers Mean? 2nd ed. CSIRO Publishing, Colling wood, Australia, pp: 169.
42. Brady, N.C. and R.R. Weil, 2002. The Nature and Properties of Soils, 13th Ed. Prentice- Hall Inc. New Jersey, USA, pp: 960.
43. Gangwar, K.S., K.K. Singh, S.K. Sharma and O.K. Tomar, 2006. Alternative tillage and crop residue management in wheat after rice in sandy loam soils of Indo-Gangetic plains, Soil and Tillage Research, 88: 242-252
44. Mengistu, C., 2017. Influence of different land use types and soil depths on selected soil properties related to soil fertility in Warandhab Area, Horo Guduru Wallaga Zone and Oromiya, Ethiopia.
45. Meyer, J.H. and R. Antwerpen, 2010. Advances in sugarcane soil fertility research in Southern Africa. South African Journal of Plant and Soil, 27: 19-31.
46. Prasad, M.R. and V. Govardhan, 2011. Characterization and classification of soil and land resource environments of Deccan Plateau. Journal of Research ANGRAU, 39: 1-5.
47. Barzegar, A.R., S.H. Mahmoodi, F. Hamedi and F. Abdolvahabi, 2005. Long term sugarcane cultivation effects on physical properties of fine textured soils. Journal of Agricultural Science and Technology, 7: 59-68
48. Barzegar, A.R., M.A. Asoodar and M. Ansari, 2000. Effectiveness of sugarcane residue incorporation at different water contents and the Proctor compaction loads in reducing soil compactibilty. Soil and Tillage Research, 57: 167-172.
49. Ahmed, A., N. Dechassa, S. Gebeyehu and Y. Alemayehu, 2018. Characterization of Soil of Jijiga Plain in the Somali Regional State of Ethiopia. East African Journal of Sciences, 12: 1-10.
50. Smith, E.K., P.A. Misiewicz, K. Chaney, D.R. White and R.J. Godwin, 2013.An investigation into the effect of traffic and tillage on soil properties and crop yields.ASABE Paper No. 1597846. Kansas City, Missouri: ASABE.
51. Tekalign, T., 1991. Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia.
52. Kannan, R.L., M. Dhivya, D. Abinaya, R.L. Krishna and S. Krishnakumar, 2013. Effect of integrated nutrient management on soil fertility andproductivity in maize. Bull. Environ. Pharm. Life Sci., 2: 61-67.

53. Pradeep, H.M., 2007. Studies on sugarcane based industrial wastes on maize-chickpea cropping sequence in Vertisols of North Karnataka. PhD thesis, Dharwad University, New Delhi, India.

54. Arain, A.M., M. Ahmed and A.M. Khan, 2000. Some physicochemical characterstics of soils in sugarcane cultivate areas of Nawabshah, Sindh, Pakistan. Pakistan Jornounal of Botony, 32: 93-100.

55. BAI (Booker Agricultural International), 2009. In association with Generation Integrated Rural Development Consultant. Re-evaluation of the Plantation Soils at Metahara Sugar Factory. Final Report. BAI, London, England.

56. Jones, J.B., 2003. Agronomic Handbook: Management of Crops, Soils and Their Fertility. CRC Press LLC, Boca Raton, FL, USA., pp: 482.

57. Girma, A., 2009. Effect of Filter Cake and Mineral Fertilizers on Yieldof Plantcane in the Sugarcane Plantations of Ethiopia. Proc. Ethiop. Sugar. Ind. Bienn. Conf., 1: 126-136

58. Yadava, R.L., 1991. Sugarcane production technology constraints and potentialities. Oxford and IBH publishing Co. Pvt. Ltd. New Delhi., pp: 291.

59. Tesfaye, W., K. Kibebew, B. Bobe, T. Melesse and E. Teklu, 2020b. Effects of long term sugarcane production on soils physicochemical properties at Finchaa sugar Estate. Journal of Soil Science and Environmental Management, 11: 30-40.

60. Alvarez, C.R., M.A. Taboada, F.H. Gutierrez, P.L. Fernandez and P. Prystupa, 2009. Topsoil properties as affected by tillage systems in the Rolling Pampa region of Argentina. Soil Science Society of American Journal, 73: 242-1250.

61. Botta, G.F., B.A. Tolon and T.F. Bellora, 2009. Effect of the numberof tractor passes on soil rut depth and compaction in two tillageregimes. Soil Till Res., 103: 381-6.

62. Berhanu, D., 1980. The physical criterion and their rating proposed for land evaluation in the highland regions of Ethiopia, Land Uses Planning and Regulatory Department, Ministry of Agriculture, Addis Ababa, Ethiopia.

63. Bikila, T., 2018. Effects of Lime and Compost on acidic Soil Amelioration and Growth of Coffee (*Coffea arabica* L.) Seedlings at Haru, West Wollega. M.Sc. Thesis Submitted to School of Graduate Studies of Jimma University College of Agriculture and Veterinary Medicine, Department of Natural Resource Management.

64. Muscoloa, A., F. Bovalob, F. Gionfriddob and S. Nardi, 1999. Earthworm humic matter produces auxin-like effects on Daucus carota cell growth and nitrate metabolism. Soil Biology and Biochemistry, 31: 1303-1311.

65. Tisdale, S.L., W.L. Nelson, J.D. Beaton and J.L. Havlin, 1995. Soil Fertility and Fertilizer, 5th Ed. Prentice- Hall of India, New Delhi, India, pp: 684.

66. Tesfaye, W., K. Kibebew, B. Bobe, T. Melesse and E. Teklu, 2019. Effects of Subsoiling and Organic Amendments on Selected Soil Physicochemical Properties and Sugar Yield in Metahara Sugar Estate. American- Eurasian Journal of Agricultural Research, 19: 312-325.

67. Newey, A., 2006. Litter carbon turnover with depth. PhD Thesis, Australian National University, Canberra, Australia.

68. Arain, A.M., M. Ahmed and A.M. Khan, 2000. Some physicochemical characterstics of soils in sugarcane cultivate areas of Nawabshah, Sindh, Pakistan. Pakistan Jornounal of Botony, 32: 93-100.

69. Tekalign, M. and I. Haque, 1991. Phosphorus status of some Ethiopian soils. III. Evaluation of some soil test methods for available phosphorus. Tropical Agriculture, 68: 51-56.

70. Muhammad, S., A. Gafoor, T. Hussain and A. Rauf, 1990. Management of salt affected soils for sustainable agriculture Proc. 3rd National congress of soil science. March 20-22, pp: 28-39

71. Landon, J.R., 2014. Booker Tropical Soil Manual: A Hand Book for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Booker Tate limited, London, England.

72. Tekalign, M. and I. Haque, 1991. Phosphorus status of some Ethiopian soils. III. Evaluation of some soil test methods for available phosphorus. Tropical Agriculture, 68: 51-56.

73. Birru, Y., 1999. Phosphorus status and sorption characteristics of the soils of the Northwestern highlands of Ethiopia. MSc Thesis, Alemaya University, Haramaya, Ethiopia.

74. Murphy, H.F., 1968. A report on fertility status and other data on some soils of Ethiopia. Collage of Agriculture HSIU. Experimental Station Bulletin No. 44, Collage of Agriculture: 551.

75. Yadava, R.L., 1991. Sugarcane production technology constraints and potentialities. Oxford and IBH publishing Co. Pvt Ltd. New Dehli., pp: 291.

76. Angelova, V.R., V.I. Akova, N.S. Artinova and K. Ivanov, 2013. The effect of organic amendments on soil chemical characteristics, Bulgarian Journal of Agricultural Science, 19: 958-71.
77. Wakene, N., 2001. Assessment of important physicochemical properties of Dystric Udalf (Dystric Nitosols) under different management systems in Bako area, Western Ethiopia. MSc Thesis, Alemaya University, Haramaya, Ethiopia.
78. Landon, J.R., 2014. Booker Tropical Soil Manual: A Hand Book for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Booker Tate limited, London, England.
79. Dang, M., 2007. Quantitative and qualitative soil quality assessments of tea enterprises in Northern Vietnam. Vietnam. African Journal of Agricultural Research, 2: 455-462.
80. Ahmed, H., 2002. Assessment of spatial variability of some physicochemical properties of soils under different elevations and land use systems in the western slopes of Mount Chilalo, Arsi. MSc Thesis, Alemaya University, Haramya, Ethiopia.