

Long Term Sugarcane Cultivation Effect on Selected Physical and Hydraulic Properties of Soils at Three Ethiopian Sugarcane Estates

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Abstract

The long term use of heavy weighted agricultural tractors for sugarcane cultivation has caused long lasting soil physical and hydraulic properties altering. However, information on the extent of change is scant. In this context, a study was conducted in 2017 at Wonji-Shoa, Metahara, and Finchaa Sugar Estates with the objective of assessing the status of soil physical and hydraulic properties under long term mechanized sugarcane cultivation by taking uncultivated soils nearby the farms as references. Disturbed composite and undisturbed soil samples from 0-30 layer of selected cultivated and uncultivated light and heavy Soil Management Unit Groups (SMUGs) at Wonji-Shoa and Metahara and; Luvisols and Vertisols at Finchaa were collected for laboratory analysis of selected soil properties. Results of the study indicated that soils under sugarcane cultivation had higher clay contents than uncultivated soils at all the soil management unit groups. The bulk density and total porosity values were out of ranges recommended for optimum sugarcane cultivation for most land uses of the estates. For all the sampled sites, soils under sugarcane had higher available water holding capacity than the uncultivated soils for all soil management unit groups. Available Water Holding Capacity (AWC) of the three estates is above the threshold AWC value ideal for sugarcane cultivation. Very close variations were observed in AWC among the cultivated soil management unit groups. The mean basic infiltration rate value of uncultivated land was greater than the cultivated lands in all the soil management unit groups. Interpretation of infiltration measurements in terms of suitability for furrow irrigation indicated that Finchaa soils are not suitable for furrow irrigation. From these findings one can conclude that long term cultivation of sugarcane induces soil compaction which decreased the total pore space of a soil mainly by increasing fineness of the soils and also number of meso and microspores in all the estates. The existing soil management based on pF2 classes of the three estates is poorly related with soil physical and hydraulic parameters. Thus, irrigation interval, frequency and the amount of water for irrigation presently in use in the three estates are in question. The gradual water releasing behaviors manifested by clay soils of Ethiopian Sugar Estates could be considered as an asset in increasing yield per fields of the estates if accompanied by good soil water managements. Hence, to maintain sustainability of sugarcane production in the three estates; soil management practices that can protect/ameliorate soil compaction and periodic revision of pF2 based soil management units classification are important. Nevertheless, to develop a concrete recommendation and to measure the long term effects of sugarcane cultivation on properties of state soils further research studies are needed.

Keywords: Cultivated soils; Degradation; Hydraulic property; Soil physical property

Introduction

Soil physical degradation due to long term sugarcane cultivation is one of the most significant constraints to increased production of sugarcane in Ethiopia. The use of heavy machinery, such as tractors for operations like cultivation, planting, fertilizer application, weed control and cane extraction during wet conditions and under low soil organic matter during sugarcane production have aggravated the situation. Moreover, sugarcane production in Ethiopia involves mechanized cultivation for increased cropping intensity, timeliness, higher work rates, and lower labor requirements in order to satisfy the local high demand for white sugar. Nevertheless, machinery overuse has been found to be the main cause for soil compaction.

Soil compaction is the main physical form of soil degradation which can alters soil structure, limits water infiltration, increase in bulk density and penetration resistance, reduces root penetration in the soil and have adverse effects upon sugarcane growth. Associated with these changes in physical properties of soil water, nutrients and

airflow towards the plant roots are also restricted. These restrictions may reduce the crop growth and yield.

Yield decline is an issue that has plagued sugarcane production systems in several sugar cane producing countries around the world for more than half a century. Despite, Ethiopia is one of the countries with the highest sugarcane yield in the world; sugar cane yield decline is currently becoming the major area of attention in the Ethiopian Sugar Estates. Studies in Ethiopian sugar estates also showed the declining productivity of the fields due to effects of soil compaction on soil physicochemical properties. Long-term annual yield data obtained from the three estates showed a decline in cane [1]. For instance, the cane yield per ha in Wonji-Shoa sugar cane plantation has declined by about 48.63% over the last 54 years (1954-2008), by 49.03% at Metahara (1969-2008) and by 26.63% decrease at Finchaa (1997-2008).

Research report by Alvarez et al. has shown that long-term monoculture and excessive tillage along with practices that deplete organic matter all contribute to yield decline. 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 indicated that long-term sugarcane cultivation under low soil organic matter condition altered soil properties.

Currently, there is dramatic increase in irrigated areas along with increased machinery uses in most monoculture sugarcane farms in the country. If not properly managed, this has a potential to induce land degradation and consequent decline in cane yield. Thus, sustainability of sugarcane agro-industry will be in question unless the main causes for yield decline could be addressed and solved [2]. Therefore, identifying and understanding the cause of the yield decline has paramount importance to design and recommend appropriate management strategies. Moreover, evidences on the impact of long-term mechanized cultivation for sugarcane production on soil physical properties are important inputs for planning soil and land management practices in large scale mechanized irrigated sugarcane farms in the sugar estates. Keeping in view the above facts, this study was conducted with objective of determining the effects of long term mechanized sugarcane production on soil physical and hydraulic properties at Wonji-Shoa, Metahara and Finchaa Sugar Estates taking uncultivated soils nearby the farms as references.

Materials and Methods

Description of the study areas

Location and area coverage: The study was conducted in 2017 at three climatically different commercial sugarcane production fields of Wonji-Shoa, Metahara and Finchaa Sugar Estates. The study areas, Wonji-Shoa, Metahara and Finchaa Sugar Estates, are located at a distance of 107, 200 and 374 km, respectively from Addis Ababa within the Oromia National Regional State (ONRS). Wonji-Shoa and Metahara Estates are located in the central part of the East African Rift Valley at 8° 21' 3.84" to 8° 27' 25.86" and 8° 45' 4.16" to 8° 53' 20.75" N latitude, 39° 12' 13.28" to 39° 18' 34.46" and 39° 49' 10.74" to 40° 0.21' 1.48" E longitude, respectively [3]. On the other hand, Finchaa Sugar Estate is located between 9° 21' 18.12" to 9° 25' 23.01" N and 39° 11' 8.85" to 39° 15' 3.2" E (Figure 1) in the valley of southwestern highlands of Ethiopia in the Abay River Basin. The total area of land under cultivation during the study period was about 7050, 10,248 and 9,000 ha, respectively, for Wonji-Shoa, Metahara and Finchaa Sugar Estates.

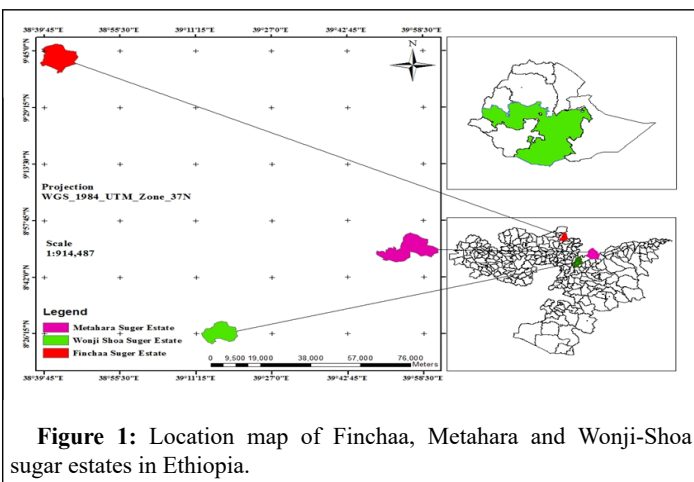


Figure 1: Location map of Finchaa, Metahara and Wonji-Shoa sugar estates in Ethiopia.

Climate: Ten years (2003-2013) climatic data (Figures 2a and 2b) of the Wonji-Shoa and Metahara Estates indicated that the areas have 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. Nevertheless, ten years (2003-2013) climatic data from Finchaa Meteorological Station showed unimodal rainfall pattern, in which majority of the annual rain falls between May to September (Figure 2c) [4]. The mean annual rainfall in the study areas is 831.47, 539.39, and 1399.72 mm for Wonji-Shoa, Metahara and Finchaa Estates, respectively. Moreover, average minimum and maximum temperatures of the three estates are about 15.19 and 27.57°C for Wonji-Shoa, 17.73 and 33.24°C for Metahara and 14.40 and 30.54°C for Finchaa.

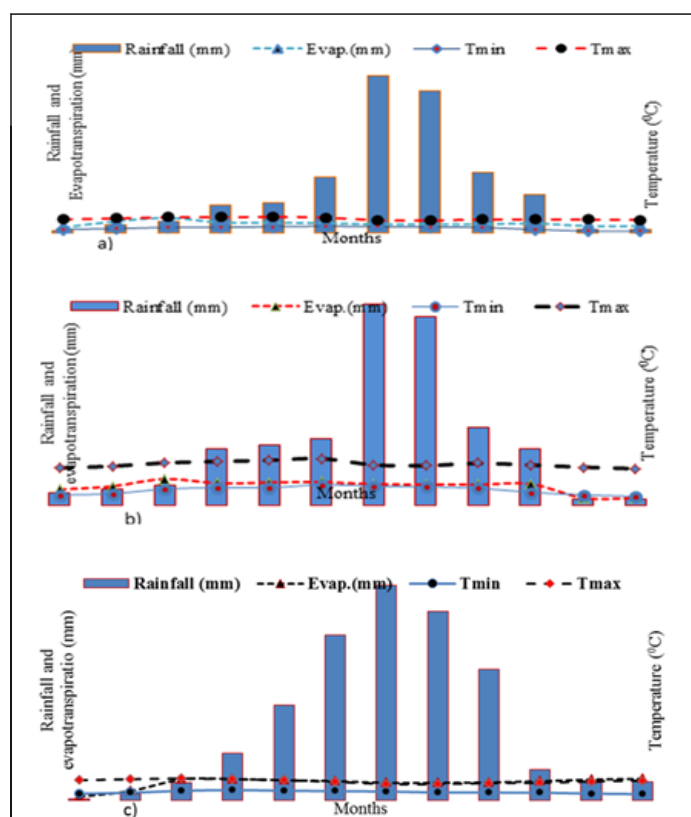


Figure 2: Ten years mean monthly rainfall, evapotranspiration (Evap), and monthly minimum (Min) and maximum (Max) temperatures of Wonji-Shoa (a), Metahara (b) and Finchaa Estates (c).

Physical features: The study areas are characterized by diverse physiogeographic features. At Wonji-Shoa and Metahara Estates, the slope of the field is generally very gentle and regular which makes them suitable for gravity irrigation. On the other hand, Finchaa Estate is dominated by a gently undulating surface with a general slope of 1 to 8 percent northwards with high and rugged mountains, valleys and plains [5]. Wonji-Shoa and Metahara Estates are found at altitude of 1540 and 950 meter above sea level, respectively, in the Awash River Basin. While, Finchaa Sugar Estate is found at an elevation of 1500 meters above sea level in the Abay River Basin.

Geology, soil types and soil management units: Majority of soils of Wonji-Shoa, Metahara and Finchaa Estates are 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 [6]. Vertisols and Fluvisols cover the major part of Wonji-Shoa, while Vertisols and Luvisols are dominant soils at Finchaa, and soils of Metahara Estate are classified as Calcaric Cambisols.

Moreover, the estates are grouped into a total of 13 soil management units where five, six and two of them belong to Wonji-Shoa, Metahara and Finchaa, respectively [7]. This grouping of soil management approach for Wonji-Shoa and Metahara was adopted from Kuipers though there is no documented information concerning depth of sampling, number of samples and methods of sampling for pF2.0 soil management classification of these estates. The first three soil groups (A1, A2, and BA2) of Wonji-Shoa and (Class-4, Class-5, and Class-6) of Metahara are heavy textured soils; while the last two soil types (B1.4 and C1) of Wonji-Shoa and (Class-1, Class-2 and Class-3) of Metahara are light textured soils. More than 95 percent of the cultivated and irrigated land soils in Finchaa are grouped in to Luvisols and Vertisols and in use for different agricultural field operations.

Agricultural production and management: In Wonji-Shoa plantation, the main crops cultivated are sugarcane, haricot bean and crotalaria. Moreover, fallowing is practiced using crotalaria as fallow crop for about nine months. In Metahara Estate, along with the cane plantation, the enterprise owns 140 ha of land covered with various types of fruits such as oranges, mangoes, lemons, grapefruits, etc. About 3,000 tonnes of fruits are produced annually at Metahara Estate [8]. Sugarcane is the principal crop in Finchaa Sugar Estate but sesame and horticultural crops are also cultivated in small areas of the estate. The average land productivity is about 155, 165 and 160 tonnes of cane per hectare, respectively, for Wonji-Shoa, Metahara and Finchaa Estates. These make the Ethiopian Sugarcane plantation farms one of the highest cane producing farms in the world.

Planting of seedlings and transplantation of sugarcane is done manually but cultivation and chemical spraying are accomplished mechanically. Tillage operations such as uprooting, subsoiling, plowing, harrowing, labeling, and furrowing are conducted before planting cane sets. Mechanization is also used for other farm operations like cane loading and cane haulage. Planting of sugarcane is usually practiced from mid-October to the end of June in a particular year. Sugarcane is planted at a rate of 16-18 t ha⁻¹ in the estates. At Wonji-Shoa nitrogen in form of urea (46%N) is applied to all fields depending on cutting but regardless of the soil type. The rate of application is 200, 400, 500 kg ha⁻¹, respectively, for first, second, third and above ratoons. Moreover, the most widely used fertilizer in Metahara Estate is ammonium sulfate nitrate (26%N) with the application rates of 300 kg ha⁻¹ for planting sugarcane, 500 kg ha⁻¹ for the second and third cuttings and 650 kg ha⁻¹ for the fourth and subsequent cuttings. While, at Finchaa Estate, 150-400 kg ha⁻¹ of urea and 250 kg ha⁻¹ of diammonium phosphate fertilizers are used.

Irrigation water source and management: The irrigation water source for Wonji-Shoa and Metahara plantations is the Awash River, while that of Finchaa plantation is the Finchaa River. Blocked-end furrow irrigation system and furrow irrigation using 425 mm plastic fluming (hydroflume) is used to irrigate sugarcane fields in the Wonji-Shoa and Metahara Estates, respectively. In Metahara water applied to each furrow is cutoff as it reaches the end of the furrow, which is blocked and ponds up within the furrow. In Finchaa plantation, movable sprinklers are employed for water application in the

sugarcane fields. In the sprinkler irrigation method the irrigation water is applied to the land in the form of spray, somewhat as an ordinary rain. This overhead irrigation manually move from place to place in the field based on the demand for irrigation. Each sprinkler serves 15 positions on an 18 m * 18 m grid. The laterals are spaced 90 meters and are designed to provide a gross application rate of 134.4 mm per irrigation cycle.

Irrigation application volume and intervals vary according to the type of the soil in the scheme. The gross irrigation depth ranges from 165 to 215 mm at Wonji-Shoa and at Metahara Estate. The application rates vary from less than 550 m³/ha for light to more than 1,500 m³/ha for heavy soils. Furthermore, the irrigation interval which depends on the soil types of the estates varies from 10 days for light soil to 28 days for heavy soils and 7 days for light to 22 days for heavy soils, respectively, for Wonji-Shoa and Metahara Plantations [9]. However, in Finchaa, independent of the soil type's irrigation application rate and interval for both soil types is the same and is applied every 15 days for length of 24 hrs. The feel method is used to recognize the need for irrigation. A test is conducted at two depths (30 and 60 cm) a few days before the expected date of irrigation, and irrigation is scheduled when the test results indicate dry soil.

Method of study

Site selection, soil sampling and sample preparation: The experiment was conducted on light and heavy soil management unit groups at Wonji-Shoa and Metahara, and on Luvisols and Vertisols at Finchaa. Three stages stratified random soil sampling method was used. In the first stage each 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 six 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 for both soil management units of each estate. 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 each estate, these soils have not been cultivated for about fifteen years, thirty years, and forty years, respectively, at Finchaa, Metahara, and Wonji-Shoa, respectively. 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 surface layer only. Composite and undisturbed (for bulk density) samples were collected from 0-30 cm soil depths using auger and core samplers, respectively. Twenty 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 108 composite and undisturbed samples were collected from plantation fields of the three estates.

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, Metahara, and Finchaa station soil laboratories. 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. After determining sand, silt, and clay separates; the soil was assigned to textural classes using the USDA soil textural triangle (Soil Survey Staff, 1999). Bulk density was determined using the core method as described by Jamison et al. Particle density (ρ_p) was determined using the pycnometer method following procedures described in Rao et al. Total porosity was calculated from the values of bulk density and particle density using the method described by Rowell.

To develop soil water retention characteristic curves, water retention was determined at 0, -5, -8, -10, -33, -60, -100, -300, and -1500 kPa matric potentials for the 36 soil samples collected only from the 0-30 cm layer. For the higher matric potentials ranging from 0 to -10 kPa, suction table (sand box apparatus) was used to apply the predetermined suctions. The same undisturbed samples were resaturated and used in a pressure plate extractor for measuring water content at -33, -60, -100, -300, and -1500 kPa matric potential. From these samples, disturbed subsamples were taken to determine water contents at -33, -60, -100, -300, and -1500 kPa. The equilibrium moisture content at -33, -60, -100, -300, and -1500 kPa matric potential points was determined gravimetrically as described in Reynolds. The gravimetric water content was converted into volume wetness by multiplying it with the ratio of dry bulk density to density of water (assumed to be 1 g cm⁻³). Available Water Holding Capacity (AWC) was computed as the difference between water retained at field capacity (θ_{fc}) and Permanent-Wilting Point (PWP). This difference was multiplied by 1000 mm/m to express it in equivalent depth of water per 1 m depth of soil.

The pH of the soils was measured in water (1:2.5 soil: water ratio) by glass electrode pH meter. Soil organic carbon was determined by the wet digestion method following the procedure of Walkley and Black. The total nitrogen was determined by the Kjeldal method as described by Jackson. 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 for all estate soils except Bray II for Finchaa (pH<6) extraction methods. The P extracted with different methods was measured by spectrophotometer following the procedures described by Murphy and Riley.

Field measured parameters: Infiltration rate was determined by using the double ring infiltrometer as outlined by Castellano and Valone at twelve representative field sites of the three estates with three replications per each land use. Mean value of tests was taken as infiltration rate value of the respective land uses per management units. About 36 tests including uncultivated fields were under taken for six management unit groups of soil types.

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 physical and

hydraulic parameters for each soil management unit group land uses were tested using the general linear model procedure of the SAS computer package. 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 uses on selected soil physical and hydraulic properties

Effects of land use on selected soil physical properties/particle size distribution: Particle size distribution is the amount of the various soil separates expressed as weight percentages in a soil sample. Data pertaining to the soil particle size distribution as influenced by land uses is presented. There were Particle size distribution variations among the soil management unit groups of cultivated soils as compared with the adjacent uncultivated soils of each soil management group with the exception that silt content was not significantly ($P<0.05$) affected by land uses of all soil management unit groups. The maximum value of clay percentage (57.15%) was recorded from heavy cultivated Wonji-Shoa Estate, while, minimum clay percentage (34.08%) was recorded from light uncultivated Wonji-Shoa Estate. 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 except in heavy soil management unit groups at Metahara.

Nevertheless, texture is typically permanent as well as an intrinsic attributes of the soil, the significant differences in individual separates modified the textural classes only in light uncultivated Wonji-Shoa Estate. The textural classes of the cultivated and uncultivated land uses in most of the estates is clay, but the texture of uncultivated light of Wonji-Shoa and Metahara soils are sandy clay loam and clay loam, respectively. The relatively increase in clay percentage of cultivated over the uncultivated land uses and the reverse for sand percentage could be attributed to mixing of the surface and subsurface horizon soils during tillage operations of sugarcane field soils and the difference in vulnerability of the land uses to eluviation and surface runoff. 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. In line with this Dang and Tesfaye et al, 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.

Bulk density and total porosity: Bulk density is a dynamic soil property, altered by cultivation, systems of land use, ameliorative measures such as subsoiling or soil mixing, and by loss of organic matter. Bulk density values were significantly ($P<0.05$) affected by land use for all soil management unit groups. Soil bulk density of three estates range from 1.22 to 1.54 g.cm⁻³. As per dry bulk density ratings suggested by Jones for different textured soils, the bulk density of Finchaa Luvisols (both cultivated and uncultivated) were within the range that causes restriction to root penetration (>1.40 g cm⁻³). While, the bulk density of the uncultivated light soils of Wonji-Shoa and cultivated Vertisols of Finchaa were in the range of close to the root restriction initiation bulk density values. On the other hand, the bulk

density values of all the other soils of three estates were within the normal range suggested for the respective textural class.

The dry bulk density values of the cultivated fields were significantly ($P < 0.05$) higher than the bulk density values of the adjacent uncultivated fields. This could be due to soil compaction induced in the soil due to long term cultivation of sugarcane at the same depth for long time under low soil organic matter content condition of cultivated fields. The negative and significant correlation between organic matter and bulk density in soils of the estates confirms the favorable effects of soil organic matter on bulk density in the cultivated soils. Similarly, Tesfaye et al. 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. 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 estates.

The different land uses showed significant ($P < 0.05$) effect on total porosity of soils except for Wonji-Shoa heavy and Metahara light soil management unit groups. The total porosity of soils of the estates ranges between 39.61 and 54.83%. The highest value of total porosity was obtained from uncultivated land and the lowest value was recorded from cultivated land for all soil management unit groups of estates. As suggested by Tesfaye et al. The optimum soil porosity for sugarcane growth is 50% and the total porosity of soils usually lies between 30% and 70%. Furthermore, according to Landon, in clay soils total porosity less than 50% can be taken as critical value for root restriction. As per these ratings, most of the total porosity values for the cultivated lands in these estates were less than the optimum value for sustainable sugarcane production and were in the range of root growth restriction.

The higher total porosity values in the uncultivated fields might be attributed to the higher amount of organic matter contents and lower bulk density values of uncultivated land uses. In line with this, Brady and Weil reported that the low total porosity was the reflection of the low organic matter content and the high bulk density. This is also supported by the negative and significant correlation between bulk density and total porosity in soils of the three estates. Furthermore, the positive correlation between total porosity and organic carbon also suggesting that maintaining higher soil organic matter in soils could result in higher total porosity.

Effects of land use on selected soil physical properties

Available water holding capacities: Available water holding capacity of greater or equal to 15% (15 cm per meter depth of soil) or more is considered to be ideal for sugarcane cultivation. As per this critical value, all the fields under sugarcane in the three estates have AWC that is well above this threshold value for sugarcane production. According to recommendation by Hazelton and Murphy Volumetric water content ranges from 10 to 50% and 2%-30% for agricultural soils, respectively, at field capacity and permanent wilting points depending on clay content and type. In this respect, the volumetric water content at FC and PWP of the three estates are within this range and it implies the potential sugarcane plantation fields have for better productivity of sugarcane.

For all the sampled sites, soils under sugarcane had higher available water holding capacity than the uncultivated soils for all soil management unit groups. The difference between cultivated land and uncultivated land in available water holding capacity might be due to higher bulk density of cultivated land use and the dominance of the clay fraction in affecting the available water holding capacity. This is in agreement with the findings of Hillel and Dang who stated that the water content can be affected by percentage of the clay present in the soil since they tightly hold large amount of water in their large surface area. Mehta and Wang also reported increase of available water holding capacity with increasing clay content.

Very slight variations in AWC among the cultivated soil management unit groups were observed. This may indicate that the existing soil management unit groups of the three estates are poorly related with soil physicochemical parameters including AWC. Similarly, different researchers verified the problems related to the soil management unit groups presently in use based on pF2 classes. Thus, irrigation interval, frequency and the amount of water for irrigation presently in use in the three estates are in question. This may call for periodic revision of the soil management groups based on their soil available water characteristics of the top 0.6 m where in most cane root populations exist.

Soil water retention characteristic curves: Soils at the three estates relatively high in clay content as well as silt plus clay, consequently, the release of water due to successive increment in matric potential points was very gradual in almost all the soil management unit groups. Nevertheless, in terms of their average volumetric water contents of each land use the presence of two distinct groups of soils were identified in each estate with respect to their water retention characteristic curves. At Wonji-Shoa Estate light cultivated, heavy cultivated, heavy uncultivated and light uncultivated; at Metahara Estate heavy cultivated, light uncultivated, light cultivated and heavy uncultivated; at Finchaa Estate vertisol cultivated, vertisol uncultivated and luvisol cultivated, luvisol uncultivated showed nearly identical water retention characteristic curves.

Beside this, at any suction point cultivated land use showed higher amount of water than uncultivated land use except in Metahara Estate greater for uncultivated heavy. The variation in water retention between cultivated and uncultivated land uses might be due to the differences in bulk density and clay contents. Moreover, this high retention of water of cultivated land use at the respective matric potential points could be related to good soil structure, which affects release of water in the wet range and the high specific surface of the clays which gives rise to high adsorptive forces at the dry range of the curve of cultivated land use. In agreement with this, Zeleke also reported dependence of water retained at respective matric potential points on bulk density and clay content.

Moreover, the two land uses under different soil management unit groups have distinct difference in shape of the soil water retention characteristic curve at low suction range and dry range of the curve might be due to difference in degree of compaction and clay percentage of soils, respectively. In line with this Tesfaye et al. reported the dependence of water retained at low suction range and dry range of the curve on dry bulk density and clay content, respectively. It is also supported by the finding of Zhang et al. which stated that clay percentage affects the shape of the soil water retention characteristic curve at lowest potential points (large negative tension values).

Long term cultivation of sugarcane induces soil compaction which decreases the total pore space of a soil mainly by increasing fineness of the soils and also number of meso and micropores in all the estates. As the fineness of texture increases, there is a general increase in the available moisture storage. This indicates that bulk density has a greater effect on water retention at low matric potential (matric potentials higher than -33 kPa).

The gradual releasing behaviors manifested by clay soils of Ethiopian Sugar Estates could be considered as an asset in cost benefit (by increasing the irrigation intervals) and to increase yield per fields of the estates if accompanied by good soil water managements. In line with this, Zeleke reported advantages of the estates clayey soils in increasing productivity of sugarcane under good management.

Infiltration characteristics: The rate of infiltration of water in the soil is important factor that limits the water economy of plant communities and the amount of surface runoff. The results of analysis of variance showed that infiltration rate was significantly ($P<0.05$) affected by the land use types at all the soil management unit groups. The basic infiltration rate showed a decreasing trend with increase in clay percentage except Metahara heavy soil management unit group. Finchaa uncultivated Luvisol soils had the highest basic infiltration rate (4.73 cm. hr⁻¹) followed by Finchaa Vertisol uncultivated soils (4.30 cm hr⁻¹), whereas, Wonji-Shoa heavy cultivated soils had the lowest basic infiltration rate (0.99 cm hr⁻¹).

Accordingly, the mean basic infiltration rate value of uncultivated land was significantly ($P<0.05$) greater than the mean infiltration rate of the cultivated lands in all the soil management unit groups. The results further indicated that long term cultivation decreased the basic infiltration rate by 56.06, 49.75, 19.21, 36.49, 45.67 and 48.14% as compared to the uncultivated sites, respectively, at light and heavy Wonji-Shoa, light and heavy Metahara, and Luvisols and Vertisols of Finchaa Estate. The lower basic infiltration rate recorded in the cultivated sites could possibly be due to subsoil compaction of the cultivated fields during sugarcane cultivation using heavy machinery. The highest infiltration rate in Finchaa land uses might be indicated the presence of more porous surface conditions in Finchaa Estate soil management units than the other soil management unit groups. This is in resonance with the finding by Tullberg and Freebairn who reported higher infiltration rate in uncultivated land than cultivated ones. Moreover, in a study of steady-state infiltration rates into alluvial soils in Botswana, Dikinya reported infiltration rate of 55.37% more for uncompacted relative to compacted soils.

For Metahara Estate, the results were contrary to what was recorded at Wonji-Shoa for light and heavy soil management units in that the basic infiltration rate increased from light to heavy. The relatively high infiltration rate recorded in the heavy soil management units of Metahara Estate could be attributed to the coarse pumic materials found in subsoil layer of most of the heavy soils in Metahara observed during soil sampling and field data collection as well as hidden subsurface cracks at the test sites, which is consistent with BAI and Tesfaye et al. who reported highest IR value due to hidden subsurface crack at Metahara Estate.

As per basis of basic infiltration ratings established by Landon, the land uses of soil management units in the three estates can be grouped in to two rating classes, thus moderate (uncultivated light Wonji-Shoa, Metahara heavy soil management unit group both land uses, Finchaa both soil management unit group land uses), while, moderately slow classes include (Wonji-Shoa light cultivated, Wonji-Shoa heavy soil

management unit group both land uses, Metahara heavy soil management unit group both land uses).

Moreover, interpretation of infiltration measurements for furrow irrigation as per ratings of El Ramlawi showed that all of the land uses in the three estates are in suitable class for furrow irrigation. Nevertheless, according to Hazelton and Murphy rule of thumb for surface irrigation (surface irrigation should be limited to soils having basic infiltration rates less than 3.6 cm hr⁻¹); Finchaa sugarcane plantation soil management unit groups basic infiltration values are out of this range which might indicate unsuitability of Finchaa soils for furrow irrigation.

The time required to reach the basic infiltration rate varied between the land uses of soil management unit groups. The difference in time required to reach basic infiltration between land uses might be due to difference in initial moisture content and clay content of the soil. Soils with relatively high initial water content was reached basic infiltration rate within short period and long time (>5 hrs) was taken for the soils with high clay percentage.

Conclusions

The results of the study indicated that soils under sugarcane cultivation had higher clay contents than uncultivated soils at all the soil management unit groups. The bulk density and total porosity values were out of ranges recommended for optimum sugarcane cultivation for most land uses of the estates. For all the sampled sites, soils under sugarcane had higher available water holding capacity than the uncultivated soils for all soil management unit groups. Available water holding capacity of the three estates is above the threshold AWC value ideal for sugarcane cultivation. Very close variations were observed in AWC among the cultivated soil management unit groups. The mean basic infiltration rate value of uncultivated land was greater than the cultivated lands in all the soil management unit groups. Subsoil compaction induced in cultivated fields increased bulk density and decreased basic infiltration rate. Interpretation of infiltration measurements in terms of suitability for furrow irrigation indicated that Finchaa soils are not suitable for furrow irrigation.

From these findings one can conclude that long term cultivation of sugarcane induced soil compaction which decreased the total pore space of a soil mainly by increasing fineness of the soils and also number of meso and micropores in all the estates. The existing soil management groups of the three estates are poorly related with soil physical and hydraulic parameters. The gradual water releasing behaviors manifested by clay soils of Ethiopian Sugar Estates could be considered as an asset in increasing yield per fields of the estates if accompanied by good soil water managements.

Based on the findings and conclusions of this study the following recommendations were given:

1. To maintain sustainability of sugarcane production in the three estates soil management practices that can protect/ameliorate soil compaction is important.
2. Periodic revision of the pF2 based soil management units classification is important as there may be altering of chemical, physical, and hydraulic properties of the estate soils due to long term tillage operation as well as application of organic and inorganic amendments.

3. Nevertheless, to develop a concrete recommendation and to measure the long term effects of sugarcane cultivation on properties of estate soils further research studies are needed.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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References

1. Barzegar AR, Mahmoodi SH, Hamed F, Abdolvahabi F (2005) Long term sugarcane cultivation effects on physical properties of fine textured soils. *J Agric Sci Technol* 7: 59-68.
2. Ahmad N, Hassan F, Qadir G (2007) Effect of subsurface soil compaction and improvement measures on soil properties. *Int J Agri Biol* 9: 509-513.
3. Usaborisut P, Niyamapa T (2010) Effects of machine induced soil compaction on growth and yield of sugarcane. *Am J Agric Biol Sci* 3: 269-273.
4. Wakgari T, Kibret K, Bedadi B, Temesgen M, Erikossa T (2019) Effects of Subsoiling and Organic Amendments on Selected Soil Physicochemical Properties and Sugar Yield in Metahara Sugar Estate. *American-Eurasian J Agric Environ Sci* 19: 312-325.
5. Wakgari T, Tsehai KK, Bedadi B, Temesgen M, Erkossa T (2018) Long Term Effects of Cultivation on Physicochemical Properties of Soils at Metahara Sugar Estate *Am Eurasian J Agric Res* 18: 246-257.
6. Alvarez CR, Taboada MA, Gutierrez FH, Fernandez PL, Prystupa P, et al. (2009) Topsoil properties as affected by tillage systems in the Rolling Pampa region of Argentina. *Soil Sci Soc Am J* 73: 1242-1250.
7. Hamza MA, Anderson WK (2005) Soil compaction in cropping systems. A review of the nature, causes and possible solutions. *Soil Tillage Res* 82: 121-145.
8. Kuipers H (1961) Water content at pF2.0 as a characteristics in soil-cultivation research in the Netherlands . *Neth J Agri Sci* 9: 1-33.
9. Dametie A, Fantaye A, Teshome Z (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.