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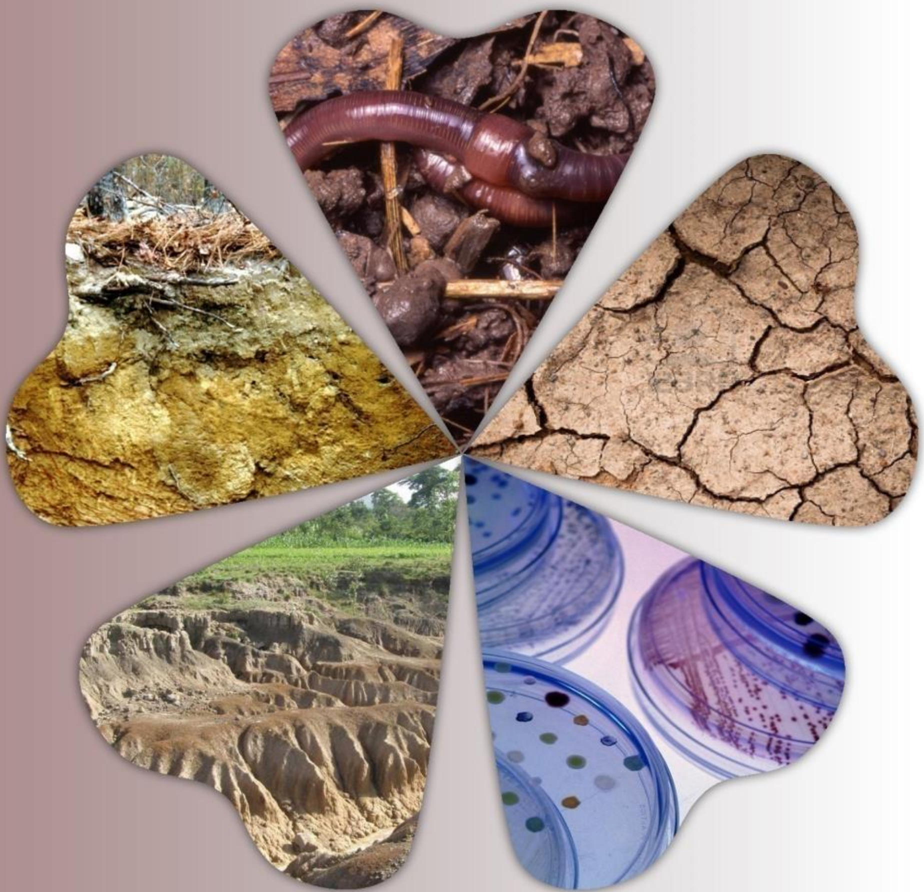

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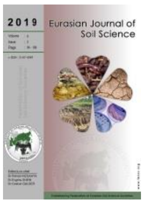

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Effects of land use types on selected soil physical and chemical properties: The case of Kuyu District, Ethiopia

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Abstract

Information about effects of land use types on selected soil physical and chemical properties is essential in sustainable utilization of soil resources. Therefore, this study was conducted to evaluate effects of land use types on selected soil physical and chemical properties on Kuyu district, Ethiopia. Totally, 24 composite soil samples were collected from grass, cultivated, forest and grazing lands by two soil depths (0-20 cm and 20-40 cm) with three replications. The two way analysis of variance was used to test the mean differences of the soil physical and chemical properties. The highest mean values of sand and clay were recorded in cultivated and grasslands, respectively. The mean bulk density of the soils ranged from 1.10 and 1.37 g cm^{-3} and the mean total porosity ranged from 48.2 to 58.7%, which indicated the less soil compaction. The pH ranged from 7.68 to 8.00 while the mean values of OM ranged from 3.15 to 5.02%. However, the mean values of total N ranged from 0.18 to 0.26%. The mean value of available P ranged from 1.26 to 5.37 mg kg^{-1}, which implies that high deficiency of available P in the study area. The exchangeable basic cations and CEC values were within high to very high ranges in all land use types. Conversion of land use types from one to another has adverse effects on soil properties, especially overgrazing and cultivation of deforested land. Therefore, the proper soil and water conservation practice are important in the study area to enhance soil fertility and crop productivity.

Keywords: Cultivated land, forest land, grazing land, soil depth, soil fertility.

Introduction

Land use is defined as the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (Ufot et al., 2016). Successful agriculture requires the sustainable use of soil resource, because soil can easily lose its quality and quantity within a short period of time for different reasons such as intensive cultivation, leaching and soil erosion (Kiflu and Beyene, 2013). Agricultural practice, therefore, requires basic knowledge of sustainable use of the land (Takele et al., 2014). A success in soil management to maintain the soil quality depends on the understanding of how the soil responds to agricultural practices over time (Duguma et al., 2010). However, the basis of this sustainable agricultural development is good quality of the soil, since maintenance of soil quality is an integral part of sustainable agriculture and the convenient witness to enhance the crop productivities (Liu et al., 2010). Soil resource has also provided a great contribution in the production of food and fiber, in the maintenance of local, regional, and worldwide environmental quality (Bore and Bedadi, 2015).

On the other hand, the ever-increasing human population is most challenging in areas like central Ethiopia, where there is a very high population density and heavy dependence on land resources. This is the atrocious threat in, which soil properties are adversely damaged thereby leads to land degradation and hampered the sustainability of soil resources (Yimer and Abdulkadir, 2011). The major causes of land degradation, natural

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resources depletion and environmental deterioration in Ethiopia are: cultivation on steep soil with inadequate management in soil conservation or vegetation cover, erratic and torrential rainfall patterns, deforestation and overgrazing (Aytenew and Kibret, 2016). In addition, the topography of the land has also a great impact on the soil quality and soil depth due to the interaction impact of cultivation practices and slope (Pavlu et al., 2007). Therefore, reducing resource degradation, increasing agricultural productivity, reducing poverty, and achieving food security are major challenges of the countries in tropical Africa (Qadir et al., 2014). Thus, possible effort should be focused on the maintenance of the physical, biological and socio-economic environment for production of food crops, livestock, wood and other products through sustainable use of natural resources (Adeyemo and Agele, 2010).

With the increment of human and livestock population, temporary intensively expansion of farmland and grazing areas has begun to influence the soil properties (Mustapha, 2007). This resulted, as the expansion of land use conversion is based on the conversion of the existing forest lands into cultivated lands and grazing lands (Chemada et al., 2017). However, when the intensification limit is reached, for example, in countries like Ethiopia, where the forest land area dropped from 40% to below 3% of the land cover and the human population is rapidly growing (MOFED, 2007) (almost doubling every 26 years), intensification i.e. the frequent and continuous utilization of the available land has continued. However, the current studies indicated that the forest coverage area is becoming 15% by afforestation and plantation systems (FAO, 1998). Various studies have been conducted to assess the effect of land use types on soil physical and chemical properties in Ethiopia (Lemenih et al., 2005; Lemma et al., 2006; Yimer et al., 2008). Lemma et al. (2006) showed that afforestation of farmland with various trees specious increased total nitrogen (N), exchangeable potassium (K), and exchangeable calcium (Ca) on the surface soil layer than subsurface soil layer. Yimer et al. (2008) also compared croplands, forest lands and grazing lands and found that soil organic carbon (OC) and total N decreased in croplands as compared to forest lands. He also suggested that the OC was abundant of surface soil layer compared to the lower soil horizon.

Currently, the forest land was drastically degraded in the study area because of the timber production, firewood, expansion of cultivated and grazing lands, which may results in the decline of soil fertility and limit crop productivity, which in turns affect the livelihood of local communities. Additionally, the grassland has been converted into grazing lands in the study area. This is because of the increment of livestock, which leads to soil compaction by removing the palatable shrubs and bush trees, and expose the surface soil for the erosion problems. In order to put the proper recommendations for sustainable utilizations of soil resources and improve crop productivity, the information about effects of land use types on soil physical and chemical properties are essential. Therefore, the objective of this study was to evaluate effects of land use types on selected soil physical and chemical properties on Jila Kerensa kebele, Kuyu district.

Material and Methods

Description of the study area

The study was conducted on Jila Kerensa kebele, Kuyu district, north Shewa zone, Oromia National Regional State, Ethiopia. It's located on the 150 km in north direction from Addis Ababa. Geographically, it is located at about 9°6'34" N latitude and 38°05'00" E longitude with an altitudinal range of 1200-2600 meters above sea level (masl) (KWAO, 2017).

Climate

The vast majority part of the study area is *badda daree* (*woinadega*) (1500-2500 masl) which accounts 75%, followed by *gammoojjii* (*kolla*) (below 1500 masl) (20%). The rest 5% of the area is constituted by *baddaa* (*dega)* (above 2500 masl) agro-climatic zone. The average annual rainfall of the study area was 1475.3 mm per year, where the maximum is obtained during summer (*kremt*) season from June to September and the minimum is obtained during spring (*belg*) season from March to June. The mean monthly minimum and mean maximum air temperature of the study area were 8.0 and 20.0 °C, respectively (KWAO, 2017).

Soils, geology and topography

According to FAO/UNDP (1984), the dominant soil type of the study area is Vertisols. Its vernacular or local name is "Biyyee Gurraacha" meaning black soil and clay is the dominant soil texture. According to (KWAO, 2017), the most soils of the study area have been weathered from basaltic bedrock formed during the tertiary era. The geology or parent material of the soil the study area is alluvial and colluvial which deposits and derived from the basaltic rocks. The topography of the study area is plain with the flat slopes (64%), undulating slopes (21%) and valleys parts which covered (15%). Most (90%) of study areas are in ranges of 0-10% slope level and the remaining area is more than this slope (KWAO, 2017).

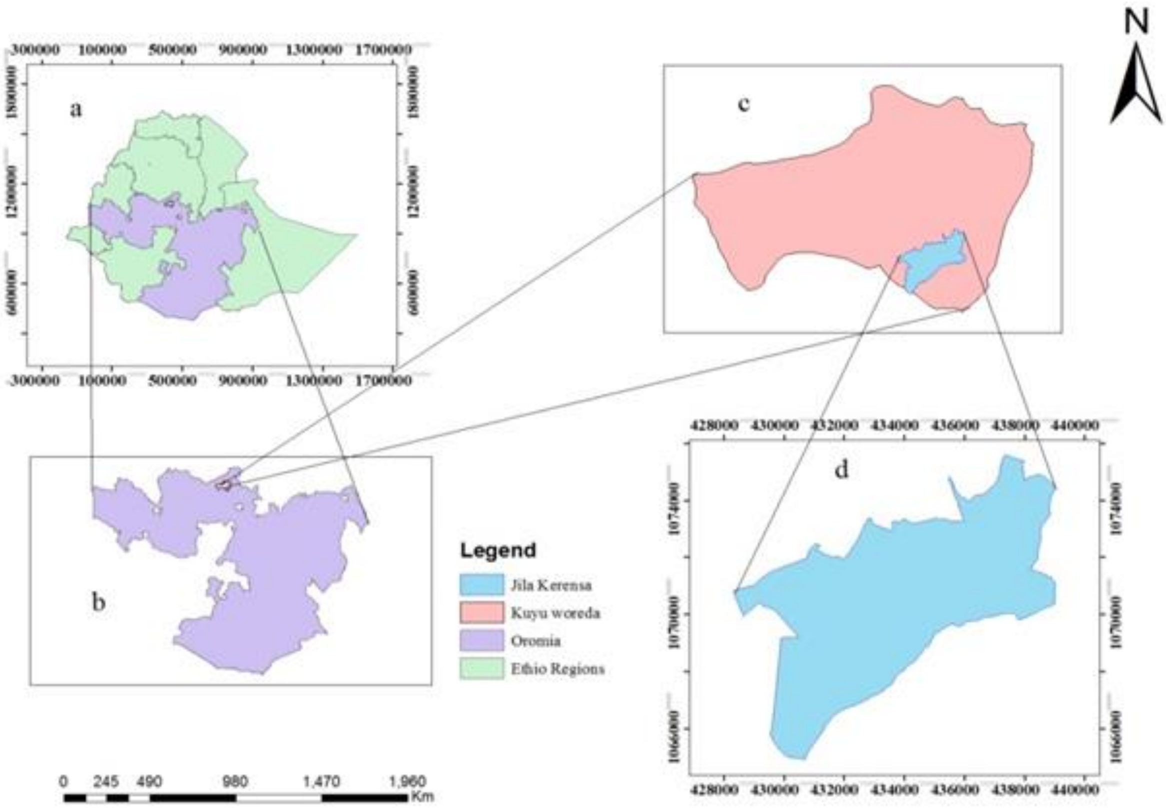

Figure 1. Location map of the study area: (a) Map of Ethiopia showing Oromia Regional State, (b) Oromia Regional State showing Kuyu woreda, (c) Kuyu woreda and (d) Jila Kerensa kebele.

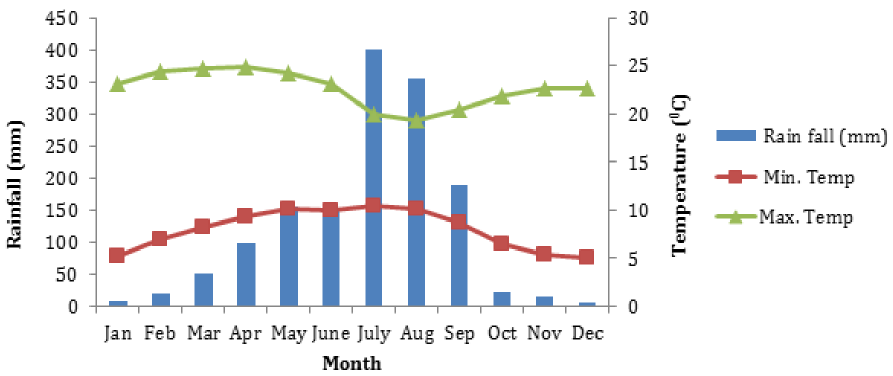

Figure 2. Mean monthly rainfall and mean monthly minimum and maximum temperatures of the study area for eight years (2010-2017)

Vegetation

According to KWAO (2017), the study area has the scarcity of natural forest in different land use types. However, plantation forests such as eucalyptus trees are found in *dega* and *woinadega* regions of the study area. As it is true for most areas of Ethiopia deforestation has been one of the serious problems in the study area. Vegetation has been cleared for the purpose of timber production, firewood, construction materials and for expansion of cultivation lands. As a result, the fertile soils have been lost and the wild animals have been endangered. Almost all flat land of the study area has small form of natural vegetation, whereas the valleys and sloppy lands are covered with scattered bushes and shrubs (KWAO, 2017).

The study area contained both native and exotic plant species. There are the several diversity of native plant species such as, *Birbirsa* (*Zigba)* (*Podocarpus talacta*), *Waddeessa* (*Wanza*) (*Cordia africana*), *Ejersa* (*Weira)* (*Olean africana*), *Sombo* (*Ekebcrgia capensis*) and *Laaftoo* (*girar*) (*Acacia's*) species are commonly found in most parts of the study area. Additionally, there are some exotic species such as *Gravillia*, *Juniperusprocera* and *Eucalyptus* species. *Eucalyptus* species such as *globulus* and *camaldulensis* are the major species planted in the study area. *Gravillia* species are only planted and found around the homestead area while *Juniperusprocera* are sparsely found in large areas (KWAO, 2017).

Land use and farming system

According to KWAO (2017), in the study area there are different land use types: cultivated lands, forest lands, bush and shrubs, grasslands, and grazing lands. The total land coverage areas of Jila Kerensa kebele is 4973.341 ha, where cultivated land is (3673.077 ha), grazing land (362.46 ha), grassland (308.23 ha), forest land (274.68 ha), settlement (228.059 ha), bush and shrubs (114.84 ha), institution (6.275 ha) and urban area was (5.72 ha) (KWAO, 2017).

The agricultural activities of the study area is mixed farming system that is sowing and producing a variety of crops as well as rearing animals that improve the livelihoods of local communities and their income. All crops are annual and rain feed crops, such as teff (*Eragrostis tef*), maize (*Zea mays* L.), wheat (*Triticum spp*), sorghum (*Sorghum bicolor*), barley (*Hordeum spp*), chickpea (*Cicer arietinum*), grass pea (*Lathyrus sativus*), lentil (*Lens culinaris*), bean (*Fabaceae spp*), pea (*Pisum sativum*), niger seed (*Guizotia abyssinica*), linseed (*Linus usitatissiumum*), and sunflower (*Helianthus annus*) are the common one. From the fruit, sugar cane (*Saccharum officinarum* L.), banana (*Musa spp*.) and orange (*Citrus aurantium*) are found in some specific study area of the small scale level. The livestock of study area includes cattle, sheep, goats and equine (donkeys, mules and horses) (KWAO, 2017).

Site Selection

For this study, Jila Kerensa kebele was purposively selected from Kuyu district because higher land degradation and soil erosion problems are commonly observed in this area which has a deleterious impact on soil physical and chemical properties under different land use types. Prior to the collection of soil samples, discussions was made with the woreda agricultural office expertise in order to get the prehistory and current information about the utilization of land use types and lifestyle of the local community in the study area.

Thenafter, a reconnaissance field survey was carried out in order to have a general view of land use types in the study area. Throughout the visual observation of the study area its geographic coordination (latitudes and longitudes) and elevation were recorded by global positioning system (GPS). Thenafter, for addressing the intended objective, the treatments were stratified in to four land use types viz: cultivated, grazing, forest and grasslands.

Soil Sampling

Composite soil samples were collected from the four land use types (cultivated, grazing, forest and grasslands) by two soil depths (0-20 cm and 20-40 cm) with three replications. The whole factors were situated on the same slope, geologic and topography. Both undisturbed and disturbed soil samples were taken from two soil depths from ten to fifteen sampling point based on the heterogeneity of land unit in a zigzag manner. Undisturbed soil samples were taken by core sampler to measure the soil bulk density, whereas the disturbed soil samples were taken by using an auger to measure the rest selected soil physical and chemical properties.

During the collection of soil samples, gravel materials, dead plants, old manures, areas near trees and compost pits were excluded. This is to minimize the differences variation, which may arise because of the dilution of soil OM due to mixing through cultivation and other factors. After these materials and areas were separated, 24 composite soil samples were collected from representative land use types. Thenafter, about one kilogram of the soil samples from 24 composite soil samples were sub-sampled and packed by plastic bags. After the composite soil sub-samples were taken and packed, it was air dried and finally ground and sieved by 2 mm sieve to the analysis of physical and chemical properties of soil. However, organic carbon (OC) and total nitrogen (N) analyses were ground to pass 0.5 mm size sieve and then brought to the laboratory for the analysis of selected soil physical and chemical properties.

Analysis of soil physical and chemical properties

Soil texture was analyzed by the Bouyoucous hydrometer method (Bouyoucous, 1962), after OM was destroyed or burned by using hydrogen peroxide (H_2O_2), soil particles dispersed and disintegrated by sodium carbonate (Na_2CO_3) and sodium hexametaphosphate ($NaPO_3$) in distilled water and finally using amyl alcohol to destroy the soil solution foam. After the particle size distributions were determined in percent, the textural class of the soil could obtained by using USDA soil textural triangle classification system (USDA, 2008).

The bulk density (BD) of the soil was measured from undisturbed soil samples collected using a core sampler after drying the core samples in an oven at 105 °C (Black, 1965). The total porosity of soil samples was estimated from the values of bulk density (BD) and particle density (PD) (assuming an average particle density of mineral soil is 2.65 g cm^{-3}). Then the total porosity (TP) was calculated as,

$$TP (\%) = (1\text{-Bulk density/Particle density}) * (100).$$

The pH of the soils was measured in water (H_2O) suspension in a 1:2.5 (soil: liquid) by pH meter, whereas electrical conductivity was measured by a conductivity meter (Van Reeuwijk, 1992). Calcium carbonate content of the soil was determined by an acid neutralization method in, which the soil carbonate was neutralize by standard 0.1M HCl solution and back titrated with standard NaOH (Van Reeuwijk, 1992).

To determine organic carbon, the Walkley and Black (1934) method was used in which the carbon was oxidized under standard conditions with potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid solution. Finally, the organic matter content of the soil was calculated by multiplying the organic carbon percentage by 1.724 following the assumptions that OM is composed of 58% carbon. The total nitrogen content in soils was determined using the Kjeldahl digestion, distillation and titration method by oxidizing the OM in concentrated sulfuric acid solution (0.1N H_2SO_4) as described by Black (1965). Thenafter, C:N was calculated by dividing organic carbon to total nitrogen. The available P was calculated by the Olsen method using sodium bicarbonate (0.5M$NaHCO_3$) as an extraction solution (Olsen et al., 1954).

Exchangeable bases (Na, K, Mg and Ca) were determined after extracting the soil samples by ammonium acetate (1N NH_4OAc) at pH 7.0. Exchangeable Na and K were analyzed by flame photometer while Ca and Mg in the extracts were analyzed using atomic absorption spectrophotometer (AAS) as described by Rowell (1994). Cation exchange capacity was estimated titrimetrically by distillation of ammonium that could be displaced by sodium from NaCl solution (Chapman, 1965). Percent base saturation was calculated by dividing the sum of the charge equivalents of the base forming cations (Na, K, Mg and Ca) by the CEC of the soil and multiplying by 100.

Statistical Analysis

The two way analysis of variance (ANOVA) was used to test differences in soil physical and chemical properties across land use types and soil depths. For statistically different parameters at probability 5% ($p \leq 0.05$), means were separated by the Duncan's Multiple Range Test (DMRT) using SAS software version 9.4 (SAS, 2013).

Results and Discussion

Selected soil physical properties under different land use types

Soil texture

According to the results of analysis of variance (ANOVA) revealed that there was no significant different on the sand particle under land use types, soil depths and in the interaction of the land use types with the soil depth. But, silt and clay particles were significantly ($P \leq 0.05$) affected by land use types (Tables 1 and 2). Although there was no statistical disparity on soil sand particles amongst land use types, there was the numerical variation across the land use types.

Table 1. Interaction effects of land use types and soil depth on selected soil physical properties on Jila Kerensa kebele

	Sand (%)		Silt (%)		Clay (%)		BD (g cm^{-3})		TP (%)	
	Soil depth (cm)		Soil depth (cm)		Soil depth (cm)		Soil depth (cm)		Soil depth (cm)	
Land use types	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
Grass	25.0	24.7	26.0	25.0^{b}	49.0	50.3^{a}	1.09^{c}	1.1^{d}	58.8^{a}	58.5^{a}
Cultivated	34.3	26.3	26.7	22.7^{b}	39.1	51.0^{a}	1.38^{a}	1.36^{a}	47.8^{c}	48.56^{d}
Forest	21.3	25.3	32.7	38.0^{a}	46.0	36.7^{b}	1.15^{b}	1.16^{c}	56.5^{b}	55.9^{b}
Grazing	27.7	25.0	28.7	30.7^{ab}	43.7	44.3^{ab}	1.39^{a}	1.34^{b}	47.6^{c}	49.4^{c}
CV (%)	19.62	18.24	20.55	16.05	17.05	12.51	0.64	0.67	0.61	0.55
p-values	ns	ns	ns	*	ns	*	***	***	***	***

Interaction means within a columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns = not significant; * = significant at $P \leq 0.05$; *** = significant at $P \leq 0.001$; BD = Bulk density; TP = Total porosity; CV = Coefficient of variation.

Considering the interaction of land use types with soil depth, the highest (34.3%) and the lowest (21.3%) value of sand was found on the surface (0-20 cm) soil layer of cultivated and forest lands, respectively. Whereas the highest (51.0%) and lowest (36.7%) values of clay content were found in the subsurface (20-40 cm) soil layer of the cultivated and forest lands, respectively (Table 1). In the case of soil depth, the higher sand content was obtained at the surface (0-20 cm) soil layer, whereas the higher silt and clay were recorded in the subsurface (20-40 cm) of soil layer (Table 2). Generally, the clay content was higher in the subsurface layer of cultivated land as compared to the adjacent forest, grass and grazing lands. The reason might be due to the preferential removal of clay particles and its downward movement into the subsurface soil layer through the process of clay migration.

Similarly, Chemada et al. (2017) stated that the clay content of cultivated land was increased from the surface to subsurface soil layer due to the long period of cultivation. Additionally, Gebrelibanos and Assen (2013) reported that lower clay and higher sand content was found in the surface layer and higher clay contents was found in the subsurface layer of cultivated land than the others adjacent natural forest, plantation forest and grazing lands. Generally, the variation of soil texture amongst land use types is implies that the effects of land use types on soil propertie which triggered from different utilization and management system of land use types (Abbasi et al., 2007).

Table 2. Main effect of land use types and soil depth on selected physical properties of soil on Jila Kerensa kebele

Treatments	Sand (%)	Silt (%)	Clay (%)	BD (g cm^{-3})	TP (%)
			Land use types		
Grass	23.30	25.33^{b}	51.33^{a}	1.10^{d}	58.70^{a}
Cultivated	30.30	24.70^{b}	45.00^{ab}	1.37^{a}	48.20^{c}
Forest	23.30	35.33^{a}	41.33^{b}	1.16^{c}	56.20^{b}
Grazing	26.30	29.70^{ab}	44.00^{ab}	1.36^{b}	48.50^{c}
			Soil depth (cm)		
0-20	27.60	28.50	43.92	1.25^{a}	52.70^{b}
20-40	24.10	29.00	46.90	1.24^{b}	53.11^{a}
Land use	ns	*	*	***	***
Depth	ns	ns	ns	**	**
Land use * depth	ns	ns	ns	***	***
CV (%)	22.40	22.54	14.32	0.62	0.54

Main effect means within a columns followed by the different letter(s) are significantly different from each other at P ≤ 0.05; ns = not significant; * = significant at P ≤ 0.05; ** = significant at P ≤ 0.01; *** = significant at P ≤ 0.001.

Bulk densities

The soil bulk density value was significantly (P ≤ 0.001) affected by land use and by their interaction effects, whereas it was significantly affected by soil depth at P ≤ 0.01 (Tables 1 and 2). Considering the main effects, the highest (1.37 g cm^{-3}) mean value of bulk density was recorded on the cultivated land and the lowest (1.10 g cm^{-3}) mean value was found under the grassland (Table 2). The reason for the lowest soil bulk density of the grassland could be due to the higher clay content and less disturbance of the soil under grassland. The higher bulk density of soil in cultivated land might be due to the practice of ploughing in cultivated soil, which tends to lower the quantity of OM of that soil through animal trafficking and expose the soil surface to direct strike by rain drops. This finding is in agreement with Yitbarek et al. (2013) who found the highest bulk density under cultivated land compared to the adjacent grazing and forest lands at a soil depth of 0-20 cm. Additionally, Takele et al. (2014) and Abad et al. (2014) suggested that the bulk density of cultivated land was higher than that of adjacent grazing land and forest lands at soil depth of 0-30 cm. Paradoxically, Lelisa and Abebaw (2016) found that the higher bulk density in the grassland compared to the adjacent bare land and rehabilitated land at a soil depth of 0-10 cm, 20-30 cm and 30-40 cm. Generally, the ranges of bulk density values observed in this study are within the ranges expected value (1.1 to 1.4 g cm^{-3}) in most mineral soils as indicated by Gupta (2004). Since the bulk density of this study area was within the expected values the aeration and water movement within the soil structure is in conducive situation that attain plant growth and determine the numbers and diversity of soil microbes thereby they furnish the versatile function in agrarian activities.

The bulk density of the soil was insignificantly and negatively correlated with silt and clay particles values at r = -0.13, -0.21, respectively. But it was significantly and negatively (r = -0.99***) correlated with the total porosity (Table 8). This might be due to the reciprocal relationship between soil bulk density and total porosity, which shows the degree of soil compaction.

Total porosity

The result of the analysis of variance (ANOVA) showed that the total porosity of soil was significantly (P ≤ 0.001) affected by land use types and by their interaction. But it was significantly affected by soil depth at P≤ 0.01 (Tables 1 and 2). Considering the interaction of land use types with soil depth, the highest (58.8%) and the lowest (47.6%) values of total porosity was recorded on the surface soil layer of grass and grazing lands, respectively (Table 1). The higher value of soil total porosity in grassland was implied that the low bulk density of grassland.

Regarding to the mean values of total porosity under different land use types, the mean total porosity of grass, cultivated, forest and grazing lands were 58.7, 48.2, 56.2 and 48.5%, respectively (Table 2). In the case of both soil depths, the higher value of total porosity was recorded at the subsurface soil layer. The higher and lower of total porosity across the adjacent land use types was implies the lower and higher bulk density values of that soil, respectively.

The soil total porosity was insignificantly and positively correlated with soil OM and clay at r = 0.04 and at r = 0.22, respectively. This is because of the soil contained OM and clay particles have meso or microspores, which has low soil aeration and water percolation. But it was significantly and positively correlated with $CaCO_3$ and CEC of the soil at r = 0.76*** and at r = 0.75***, respectively (Table 8).

According to Landon (1991) the favorable total porosity of sand particles was about 40% whereas that of clay content soil is about 50% and above to sustain and regulate the activities of soil biota. Therefore, having this as departure the findings of this study is in agreement with these ideas and confirms no problems of soil properties via water infiltration and soil aeration under adjacent different land use types in the study area. Moreover, the high total porosity of the soil implies that the less problem of water logging and surface runoff.

Selected soil chemical properties under different land use types

Soil reaction (pH), electrical conductivity and calcium carbonate

The analysis of variance results indicated that the soils pH-H_2O was not significantly affected by land use types, soil depth and their interaction (Tables 3 and 5). Even though there was no statistical variation of soil reaction under different land use types and in their interaction effects, there was a numerical variation on its values. Considering the interaction of land use types with soil depth, the highest (8.1) and the lowest (7.6) values of soil reaction were recorded on the surface (0-20 cm) soil layer of grass and cultivated lands, respectively (Table 3). The higher pH value was recorded at the surface soil layer than the subsurface soil layer (Table 5).

Table 3. Interaction effects of land use types and soil depth on soil pH, EC and $CaCO_3$ on Jila Kerensa kebele

	pH-H_2O (1:2.5)		EC (dS m^{-1})		$CaCO_3$ (%)	
	Soil depth (cm)		Soil depth (cm)		Soil depth (cm)	
Land use types	0-20	20-40	0-20	20-40	0-20	20-40
Grass	8.1	7.9	0.32^{b}	0.24^{b}	8.13^{b}	9.13^{a}
Cultivated	7.6	7.7	0.31^{b}	0.33^{ab}	6.80^{c}	7.20^{b}
Forest	7.8	7.9	0.57^{a}	0.48^{a}	11.50^{a}	9.06^{a}
Grazing	7.7	7.7	0.30^{b}	0.35^{ab}	5.10^{d}	5.86^{c}
CV (%)	4.24	4.82	20.53	25.24	5.44	4.36
P - values	ns	ns	**	*	***	***

Interaction means within a columns followed by the different letter(s) are significantly different from each other at P ≤ 0.05; ns= not significant; * = significant at P ≤ 0.05; ** = significant at P ≤ 0.01; *** = significant at P ≤ 0.001; EC = Electrical conductivity; $CaCO_3$ = Calcium Carbonate.

Compared with the others adjacent land use types, the lowest mean value of soil reaction was observed under the cultivated land. This might be due to the depletion of basic cations through crop harvesting. Similarly, Bore and Bedadi (2015) also found that the lower soil reaction under cultivated land compared to the adjacent forest and grazing lands.

These results area also in agreement with the results of Takele et al. (2014) who suggested that the soil reaction was lower under cultivated land compared to forest and grazing lands at a soil depth of 0-20 cm and 20-40 cm. As per rating of soil pH by Tekalign (1991), the soil pH of the study area under grass and forest lands was rated as moderately alkaline whereas the pH values of cultivated and grazing lands were in the range of slightly alkaline. By and large, the result of high pH values of soil in the study area was indicated that the presence of calcareous soil, which is characterized by high contents of calcium carbonate ($CaCO_3$) compounds, which occupied the exchangeable complex site.

The electrical conductivity (EC) values of soils were significantly (P ≤ 0.01) affected by land use types, but not significantly affected by the soil depths and their interaction (Tables 3 and 5). Considering the main effects of land use types, the highest (0.53 dS m^{-1}) and the lowest (0.26 dS m^{-1}) EC of the soils were obtained in the forest and the grasslands, respectively (Table 5). The lowest EC value under the grassland could be associated with the loss of base forming cations through high water percolation since grassland had a low bulk density and higher total porosity.

Similarly, this result is in agreement with findings of Mesele et al. (2006) who found the lower electrical conductivity under grassland compared to the adjacent croplands, bush lands and bushed-grasslands at 0-20 cm of soil depth. The EC of soil was going increased with depth i.e. it increased from the surface (0-20 cm) layer to subsurface (20-40 cm) layer except in forest land in which it was decreased from surface (0.57 dSm^{-1}) to subsurface layer (0.48 dSm^{-1}).

According to the standard classification of EC values by Landon (1991), the EC values measured under all land use types in the study area indicated that the concentration of soluble salts is below the levels atwhich growth and productivity of most agricultural crops are affected. This implies that the presence of enough precipitation to evaporation ratio on the study area. Therefore, it is not the limiting factor regarding to plant growth and agricultural crop productivity.

The calcium carbonate ($CaCO_3$) of soils was significantly ($P \leq 0.001$) affected by land use types and by the interaction of land use types with soil depths, but not significantly affected by the soil depths (Tables 3 and 5). Considering the interaction of land use types by soil depths, the highest (11.50%) and the lowest (5.10%) $CaCO_3$ values were observed on the surface (0-20 cm) soil layer of forest and grazing lands, respectively. According to Landon (1991) classification, the soil classified as none calcareous soil when $CaCO_3$ contents are less than 0.5% and considered as calcareous soil when it is 0.5% and above. Based on this classification, the study area was characterized by high content of $CaCO_3$ in all land use types, which indicates that the presence of calcareous soil in the study area. This in turn causes for phosphorous precipitation in the form of Ca-phosphate and ultimately decreases the availability of P in the soil.

Soil organic matter

The analysis of variance results revealed that the soil OM contents were significantly ($P \leq 0.001$) affected by land use types, soil depth and the interaction of land use types with soil depth (Tables 4 and 5). Considering the interaction effects, the highest (5.60%) value of soil OM content was recorded on the surface (0-20 cm) soil layer of forest land and the lowest (2.73%) value of soil OM was found under the subsurface (20-40 cm) soil layer of grazing land (Table 4). The decline of soil OM content in the grazing land might be due to the overgrazing and the heavy compactness of the soil by livestock trampling. This could be in turns hamper an accumulation of soil OM at both surface and subsurface soil layer. Compared to the grazing lands, cultivated land had relatively higher soil OM at the surface and subsurface soil layer. This could be due to rooting systems in, which grazing lands have fine and short roots while cultivated land has large, and long roots of crops, which can play a great contribution in the enhancement of OM and soil microorganism function (Gebrelibanos and Assen, 2013).

Table 4. Interaction effects of land use and soil depth on total N, soil OM, C:N and Av. P of the soils on Jila Kerensa kebele

	Total N (%)		OM (%)		C:N		Av.P (mg kg^{-1})	
	Soil depth (cm)		Soil depth (cm)		Soil depth (cm)		Soil depth (cm)	
Land use types	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
Grass	0.26^{ab}	0.21^{ab}	4.6^{ab}	3.60^{b}	10.5^{b}	10.0	2.22^{bc}	0.88^{b}
Cultivated	0.21^{b}	0.20^{ab}	3.7^{b}	3.30^{b}	10.2^{b}	10.0	3.03^{b}	1.75^{ab}
Forest	0.28^{a}	0.22^{a}	5.6^{a}	4.30^{a}	11.6^{a}	11.3	7.70^{a}	3.05^{a}
Grazing	0.20^{b}	0.16^{b}	3.5^{b}	2.73^{b}	10.1^{b}	9.9	1.40^{c}	1.13^{b}
CV (%)	13.31	7.83	5.90	16.47	8.77	8.81	21.86	10.33
P - values	***	**	***	*	*	ns	***	*

Interaction means within a columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; Av.P = Available phosphorous; ns = not significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$.

However, the highest value of soil OM on the surface layer of forest land was attributed to the excessive amount of plant residues and biomass on surface land. The soil OM of the study area was going decreased while soil depth was going increased, i.e. the soil OM decreased from the surface (0-20 cm) to subsurface (20-40 cm) soil layer (Table 4). This implies that the soil OM was suffice on surface soil layer where both animal and plant residues are present to accommodate several diversity of soil organisms. This in turns play vital role in mineralization processes. Therefore, the analysis of variance results confirms that regarding to a soil depth of the study area, the soil OM value was higher (4.4%) on the surface soil layer than that of subsurface (3.5%) soil layer (Table 5).

This finding is in agreement with different individuals' findings Chibsa and Ta'a (2009), Duguma et al. (2010), Iqbal et al. (2012) and Takele et al. (2014) inwhich they reported that the soil OM decrease with increasing soil depth, with more accumulation on the upper surface soil layer. Similarly, it is in line with the other authors Kiflu and Beyene (2013), in their results they found that soil OM become decreasing with increasing soil depth and it was higher in grassland compared with adjacent maize and enset land at the soil depth of 0-10 cm and 15-30 cm. This might be due to roots of the grass and fungal hyphae in the grassland soils are probably responsible for the higher amount of soil OM. Generally, based on classification clue cited by Tekalign (1991), soil OM of study area was belonged to medium rate in all land use types except in forest land, which is in the high rate. Soil OM was insignificantly and positively correlated with the soil total porosity, silt and clay at r =0.40, at r =0.29 and at r =0.03, respectively, while it was significantly and positively correlated with the soil total N and CEC at r =0.95*** and at r =0.68***, respectively (Table 8). This positive relationship between soil OM and CEC confirm that the more soil OM, the more potential of the nutrient reservoir of the soil and exchangeable basic cations on soil complex site.

Total nitrogen and carbon to nitrogen ratio (C:N)

The total nitrogen (N) content of soils was significantly ($P \leq 0.001$) affected by land use types. However, it was significantly affected by soil depth at $P \leq 0.01$ and by the interaction of land use with soil depth at $P \leq 0.05$ (Tables 4 and 5). Regarding to the main effects of land use types and soil depths, the average value of total N was highest (0.26%) on the forest land and lowest (0.18%) on the grazing land (Table 5). The variations of total N content among different land use types are parallel with that of OM content, which is decreasing while soil depth was increased (Table 4). The higher total N content in soils of the forest land could be associated with the high OM contents of the soils, whereas the low content of total N in grazing land might be due to the house consumption of animal dung as fuel instead of leaving in the field. Further, removal of vegetation by livestock grazing and expose the surface layer of grazing land to direct rain drop could be generating more surface runoff, which can remove the animal and plant residues from the surface soil layer thereby cause for total N depletion.

Similarly, Nigussie and Kissi (2012), Ufot et al. (2016) and Chemada et al. (2017) stated that the higher total N was obtained under forest land compared to the adjacent grazing and cultivated lands. Regarding to the interaction of land use types with the soil depths, the highest (0.28%) total N was recorded on the surface (0-20 cm) soil layer of forest land while the lowest (0.16%) total N was recorded at the subsurface (20-40 cm) soil layer of grazing land (Table 4). According to the rating of total N by Tekalign (1991), the total N in the study area was in a medium rate under grazing and cultivated lands while it was rated as high in the grass and forest lands.

Table 5. Main effect of land use types and soil depth on selected chemical properties of soil on Jila Kerensa kebele

Treatments	pH-H_2O (1:2.5)	EC (dS m^{-1})	$CaCO_3$ (%)	Total N (%)	OM (%)	C:N	Av. P (mg kg^{-1})
			Land use types				
Grass	8.00	0.26^{b}	8.73^{b}	0.24^{b}	4.12^{b}	10.30^{b}	1.55^{bc}
Cultivated	7.68	0.32^{b}	7.00^{c}	0.21^{b}	3.51^{b}	10.10^{b}	2.40^{b}
Forest	7.90	0.53^{a}	10.45^{a}	0.26^{a}	5.02^{a}	11.50^{a}	5.37^{a}
Grazing	7.70	0.36^{b}	5.36^{d}	0.18^{b}	3.15^{b}	10.00^{b}	1.26^{c}
			Soil depth (cm)				
0-20	7.82	0.38	7.80	0.24^{a}	4.4^{a}	10.5	3.58^{a}
20-40	7.81	0.36	7.96	0.20^{b}	3.5^{b}	10.3	1.71^{b}
Land use	ns	**	***	***	***	*	***
Depth	ns	ns	ns	**	**	ns	***
Land use * depth	ns	ns	***	**	**	ns	***
CV (%)	4.22	21.30	4.95	9.47	10.03	8.73	28.10

Main effect means within a columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns= not significant; *= significant at $P \leq 0.05$; **= significant at $P \leq 0.01$; ***= significant at $P \leq 0.001$.

According to the analysis of variance results indicated that the carbon to nitrogen ratio (C:N) of the soils in study area was significantly ($P \leq 0.05$) affected by land use types. However, it was not significantly affected by soil depth and the interaction effects (Tables 4 and 5). Considering the main effects of soil depth, the higher (10.5) mean value of C:N was found on the surface (0-20 cm) soil layer. This indicates that the rate at, which total N decreased with soil depth was much higher than the reduction in carbon.

In fact, the C:N of the soil is decreasing while the soil depth going increase. Occasionally it can increase with the increment of soil depth in some exceptional cases, which might be due the alluvial soil that contain more C:N in subsurface soil layer than surface soil layer through sedimentation processes. However, the finding of this study was indicated the C:N was decreased when the soil depth increased. Considering the interaction effects, the highest (11.6) and the lowest (9.9) C:N values were recorded at the surface soil layers of the forest and grazing lands, respectively (Table 4). The higher C:N in forest soil indicates the prevalence of optimum biological activities, whereas the lower C:N in the surface soil of grazing and cultivated lands might be due to higher microbial activity and more CO_2 evolution and its loss to the atmosphere at the surface (0-20 cm) soil layer than in the subsurface (20-40 cm) soil layer.

The current result is in agreement with the findings of Gebrelibanos and Assen (2013) who found that the higher C:N in forest land compared to the adjacent plantation, grazing and cultivated lands. Additionally, Selassie and Ayanna (2013) found that the higher C:N in natural forest than the adjacent eucalyptus plantation, grazing and cultivated lands. They also suggested that the optimum range of the C:N is about 10:1 to 12:1 that provides nitrogen in excess of microbial activities. Accordingly, the C:N of the soil across the land use types under the study area were considered to be within the optimum range in all land use types. This indicates that the presence of suitable mineralization processes of soil organisms.

The soil total N and C:N were insignificantly and negatively correlated with the soil bulk density at r = -0.38 and r = -0.28, respectively. The soil total N was significantly and positively ($r = 0.92^{***}$) correlated with the availability P. Similarly, the C: N was significantly and positively ($r = 0.66^{***}$) correlated with the soil OM (Table 8).

Available phosphorus

According the analysis of variance results indicated that the available P of the study area was significantly ($P \leq 0.001$) affected by land use types, soil depth and the interaction of land use type with soil depth (Tables 4 and 5). The available P was higher in the surface soil layer than in the subsurface soil layer (Table 5). Generally, variations in available P contents in soils could be related to the intensity of soil weathering or soil disturbance under different land use types. Considering the main effects of land use types, the highest (5.37 mg kg^{-1}) available P was recorded on the forest land and the lowest (1.26 mg kg^{-1}) was recorded on the grazing land (Table 5).

Considering the interaction effect of land use types with soil depth, the highest (7.70 mg kg^{-1}) and the lowest (1.13 mg kg^{-1}) of available P contents was recorded at the surface soil layer of the forest and subsurface soil layer of the grazing lands, respectively (Table 4). Although Aytenew and Kibret (2016) and Chemada et al. (2017) reported that the higher available P was recorded in cultivated land than the adjacent grazing and forest lands, this finding reported that the higher available P was obtained in forest land at both surface and subsurface soil layer.

Relatively the high content of available P in the forest land could be due to the high content of soil OM resulting in the release of organic phosphorus thereby enhances available P under forest land. Similarly, this result is in agreement with the findings of Abad et al. (2014) who reported that the available P was high in forest land compared to pasture land and cultivated land at 0-30 cm soil depth. Additionally, it is in line with result of Takele et al. (2014) whose results revealed that available P was high in forest land than the adjacent cultivated and grazing lands at a soil depth of 0-10 cm, 10-20 cm and 20-30 cm. Compared with the rest of land use types in the study area, the higher available P was also recorded in the cultivated land next to the forest land. This might be due to the application of diammonium phosphate (DAP) and nitrogen phosphorous sulfur (NPS) fertilizers on the cultivated lands of the study area.

As per the ratings of available P by Olsen et al. (1954), the available P of the soil under this study was rated as very low in the grass, cultivated and grazing lands whereas it was rated as low in forest land. This deficiency of available P on the study area could be due to the high $CaCO_3$ content of the soil since the available P can precipitate in the form of calcium phosphate in calcareous soil. Similarly, Melese et al. (2015) reported that in calcareous soil, the available P was low due to the precipitation of P in the form of calcium phosphate.

Cation exchange capacity

The analysis of variance results revealed that the cation exchange capacity (CEC) of the soils in the study area was significantly ($P \leq 0.05$) affected by the land use types. The CEC means values under grass, cultivated, forest and grazing lands were 38.5, 33.2, 41.7 and, 30.1 $cmol_c\ kg^{-1}$, respectively (Table 7). The higher and lower of CEC in forest and grazing land might be due to the presence and absence of soil organic matter or high soil organic matter in forest land while it was less in grazing land. Besides, the amount and types of clay particles also the determinant factor on the CEC of soil under different land use types.

Table 6. Interaction effects of land use types and soil depth on Na, K, Mg, Ca, CEC and PBS on Jila Kerensa kebele

	Na^+		K^+		Mg^{2+}		Ca^{2+}		CEC		PBS	
	$cmol_c\ kg^{-1}$										%	
	Soil depth (cm)		Soil depth (cm)		Soil depth (cm)		Soil depth (cm)		Soil depth (cm)		Soil depth (cm)	
Land use types	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
Grass	0.43	0.45	0.62^b	0.65	5.4^b	5.50^b	23.2^b	24.0^a	36.60^b	38.60^a	81.6^a	79.2^a
Cultivated	0.42	0.47	0.64^b	0.78	5.8^b	5.68^{ab}	16.8^c	19.2^c	33.05^c	33.42^b	69.4^c	78.3^a
Forest	0.44	0.43	1.50^a	1.00	9.1^a	8.30^a	25.4^a	21.2^b	43.40^a	39.40^a	84.6^a	78.1^a
Grazing	0.42	0.43	0.35^b	0.36	5.4^b	5.20^b	15.2^c	15.4^d	27.13^d	28.90^b	77.0^b	73.7^b
CV (%)	17.61	15.40	23.4	14.4	18.8	21.8	3.62	5.45	3.89	6.98	1.88	3.10
P - values	ns	ns	**	ns	*	*	***	***	***	**	***	*

Interaction means within a columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns = not significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$.

This result is in agreement with the findings of Yitbarek et al. (2013) who suggested that the CEC of soil was higher in forest land compared to that of the adjacent grazing and cultivated lands. Considering the interaction effects, the CEC of the soil under the study area was significantly ($P < 0.05$) affected by interaction of land use types with the soil depth (Table 6). The highest (43.40 $cmol_c\ kg^{-1}$) value of CEC was recorded on the surface (0-20 cm) soil layer of forest land, whereas the lowest (27.13 $cmol_c\ kg^{-1}$) was recorded at the surface soil layer of grazing land. Considering the soil depth, like that of the interaction of land use types with soil depth, the CEC values of the soil under different land use types were not significantly affected by soil depth. But numerically, the higher CEC value was found in the subsurface (20-40 cm) soil layer (Table 7). Similarly, Kiflu and Beyene (2013) reported that the CEC of the soil was not significantly affected by soil depth at a soil depth of 0-15 cm and 15-30 cm under adjacent maize, enset and grasslands.

Moreover, Nigussie and Kissi (2012) reported that the CEC of soil was higher in the subsurface of soil layer under the adjacent forest, cultivated and grazing lands. As per the ratings CEC recommended by Hazelton and Murphy (2007), the CEC value of soil under the grass, cultivated and grazing land were in the range of high rate while it was rated as very high under the forest land. The CEC of the soil was significantly and positively correlated with the total porosity ($r = 0.75^{***}$), $CaCO_3$ ($r = 0.93^{***}$), total N ($r = 0.67^{***}$), soil OM ($r = 0.68^{***}$) , available P ($r = 0.63^{***}$) and PBS ($r = 0.61^{**}$) (Table 8).

Exchangeable bases

The analysis of variance results indicated that the exchangeable Ca was significantly ($P \leq 0.001$) affected by land use types, soil depths and the interaction of land use types with soil depth (Tables 6 and 7).The presence of such significant variation on exchangeable Ca could be triggered from different management practice, way of land utility, and the various imbalances proportional of soil texture and OM. Considering the main effect of land use types, the mean values of exchangeable Ca under grass, cultivated, forest and grazing lands were 23.6, 17.7, 24.1 and 16.2 $cmol_c\ kg^{-1}$, respectively (Table 7).

Table 7. Main effects of land use types and soil depth on selected chemical properties of soil on Jila Kerensa kebele

Treatments	Na^+	K^+	Mg^{2+}	Ca^{2+}	CEC	PBS
			$cmol_c\ kg^{-1}$			%
			Land use types			
Grass	0.45	0.63^{bc}	5.4^b	23.6^b	38.5^a	78.0^a
Cultivated	0.44	0.72^b	5.8^b	17.7^c	33.2^{ab}	74.3^b
Forest	0.46	1.30^a	8.7^a	24.1^a	41.7^a	82.9^a
Grazing	0.42	0.36^c	5.3^b	16.2^d	30.1^b	74.0^b
			Soil depth (cm)			
0-20	0.43	0.75	6.40	20.8^a	35.3	78.2^a
20-40	0.41	0.71	6.09	19.9^b	35.7	77.8^b
Land use	ns	**	**	***	*	***
Depth	ns	ns	ns	**	ns	*
Land use * depth	ns	ns	ns	***	ns	***
CV (%)	16.04	21.19	20.50	5.06	6.16	2.37

Main effect means within a columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns = not significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$.

Regarding to exchangeable Ca at both soil depths, the exchangeable Ca was higher at the surface soil depth than at the subsurface soil depth (Table 7). This could be the possibility of the high exchangeable Ca was available on surface soil layer with an abundance of animal and plant residues than beneath the soil layer. This is parallel with the work of Kiflu and Beyene (2013) in their results, they revealed that the exchangeable Ca contents of soil was higher on the surface soil layer than the subsurface soil layer due to the association of biological accumulation with biological activity and accumulation from plant residues.

However, Bore and Bedadi (2015) reported that the exchangeable Ca was increasing with increasing soil depth since it is susceptible and possibility of easily leach downward by runoff and water percolation. In terms of the interaction of land use types with the soil depth, the highest (25.4 $cmol_c\ kg^{-1}$) and the lowest (15.2 $cmol_c\ kg^{-1}$) exchangeable Ca was found in the surface soil layer of the forest and grazing lands, respectively (Table 6). As per the ratings of FAO (2006), the exchangeable Ca contents of study area soil was categorized as high rate under cultivated and grazing lands whereas categorized as very high rate under grass and forest lands. Therefore, by standing on this view of point, the study area was characterized by high contents of exchangeable Ca.

The analysis of variance result indicated the exchangeable Mg was significantly ($P \le 0.001$) affected by land use types while it was not significantly affected by soil depths and the interaction effects (Tables 6 and 7). Considering the main effect of land use types, the mean values of exchangeable Mg under grass, cultivated, forest and grazing lands were 5.4, 5.8, 8.7 and, 5.3 $cmol_c\ kg^{-1}$, respectively (Table 7). Considering the interaction effects, the highest (9.1 $cmol_c\ kg^{-1}$) exchangeable Mg was recorded on the surface soil layer of forest land while the lowest (5.2 $cmol_c\ kg^{-1}$) exchangeable Mg was obtained under the subsurface soil layer of grazing land (Table 6). As per the ratings of FAO (2006), the exchangeable Mg contents of the study area under grass, cultivated and grazing lands were in the range of high rate, whereas the exchangeable Mg contents under forest land was in the range of very high rate. The ratios of exchangeable Ca to Mg were within the critical values (3:1 to 5:1), which may not cause of the nutrient imbalance under different land use types of the study area.

The exchangeable K of soil under study area was significantly ($P \le 0.001$) affected by land use types. But it was not significantly affected by soil depths and the interaction of land use types with soil depth (Tables 6 and 7). Concerning to the main effect of land use types, the mean values of exchangeable K under grass, cultivated, forest and grazing lands were 0.63, 0.72, 1.30 and 0.36 $cmol_c\ kg^{-1}$, respectively (Table 7). Considering the soil depths of the study area, the higher exchangeable K was found on the surface (0-20 cm) soil layer (Table 7).

Considering the interaction effects, the highest (1.50 $cmol_c\ kg^{-1}$) and the lowest (0.35 $cmol_c\ kg^{-1}$) values of exchangeable K contents was recorded on the surface soil layer of forest and grazing lands, respectively (Table 6). The higher exchangeable K on the surface layer of forest land could be due to the availability of surface biomass through litter falling and little or no surface soil disturbance by rain drops, surface runoff and other severe erosion agents. The derivative of this phenomenon is the reasonable for lower exchangeable K in case of surface layer of grazing land in, which higher disturbance was severe and exacerbate soil erosion.

Similarly, this result is in agreement with the work of Yitbarek et al. (2013) and Duguma et al. (2014) whose findings was reported that the exchangeable K of soil is higher in the forest land than cultivated and grazing lands. According to the rate of exchangeable K cited by FAO (2006), the exchangeable K contents of grass and cultivated lands of the study area were rated as high, whereas that of grazing and forest lands were rated as medium and very high, respectively.

The analysis of variance results indicated the exchangeable Na of the study area was not significantly affected by land use types, soil depth and interaction of land use types with the soil depth (Tables 6 and 7). This finding is in agreement with that of Gebrelibanos and Assen (2013) who reported that, the exchangeable Na is not indicated the significant variation, neither under land use types nor across the soil depth by the time exchangeable Ca, Mg and K was showing significant variation under adjacent different land use types.

However, Selassie and Ayanna (2013), Aytenew and Kibret (2016) and Ufot et al. (2016) reported that like that of exchangeable Ca, Mg and K, exchangeable Na also affected by land use types. Although there was no statistical variation on exchangeable Na of the study area, more or less the numerical variation was remarkable on exchangeable Na under different land use types and on the interaction effects. Considering the mean values of exchangeable Na of the study area, 0.45, 0.44, 0.46 and 0.42 $cmol_c\ kg^{-1}$ were found under grass, cultivated, forest and grazing lands, respectively. The higher exchangeable Na was observed on the surface (0-20 cm) soil layer than the subsurface (20-40 cm) soil layer (Table 7).

Table 8. Pearson's correlation matrix for selected soil physical and chemical parameters

	Sand	Silt	Clay	BD	TP	pH	EC	$CaCO_3$	TN	OM	CN	Av. P	Na^+	K^+	Mg^{2+}	Ca^{2+}	CEC	PBS
Sand	1.00																	
Silt	-0.54**	1.00																
Clay	-0.63***	-0.31	1.00															
BD	0.29	-0.13	-0.21	1.00														
TP	-0.28	0.12	0.22	-0.99***	1.00													
pH	-0.58**	0.33	0.35	-0.37	0.37	1.00												
EC	-0.41*	0.52**	-0.02	-0.12	0.12	0.41*	1.00											
$CaCO_3$	-0.29	0.22	0.13	-0.76***	0.76***	0.19	0.41*	1.00										
TN	-0.29	0.28	0.07	-0.38	0.38	0.21	0.78***	0.71***	1.00									
OM	-0.21	0.29	0.03	-0.37	0.4	0.1	0.73***	0.74***	0.95***	1.00								
CN	0.17	0.23	-0.41*	-0.28	0.27	-0.13	0.29	0.56**	0.43	0.66**	1.00							
Av. P	-0.08	0.28	-0.16	-0.27	0.26	0.08	0.69**	0.66***	0.92***	0.95***	0.62**	1.00						
Na^+	-0.19	0.02	0.21	-0.06	0.06	-0.16	-0.27	0.03	-0.29	-0.22	0.06	-0.29	1.00					
K^+	-0.25	0.17	0.13	-0.39	0.39	0.27	0.67	0.77***	0.77***	0.77***	0.46*	0.75***	-0.22	1.00				
Mg^{2+}	-0.11	0.42	-0.27	-0.29	0.28	-0.22	0.54**	0.62**	0.72***	0.75***	0.48*	0.72***	-0.09	0.51*	1.00			
Ca^{2+}	-0.28	0.03	0.28	-0.88***	0.88***	0.2	0.18	0.88***	0.56**	0.57**	0.35	0.48*	0.02	0.58**	0.48*	1.00		
CEC	-0.15	0.18	0.01	-0.75***	0.75***	0.01	0.31	0.93***	0.67***	0.68***	0.45*	0.63***	-0.01	0.68***	0.7***	0.9***	1.00	
PBS	-0.31	0.03	0.32	-0.66***	0.66***	0.22	0.33	0.62**	0.53**	0.55**	0.36	0.45*	-0.04	0.49*	0.43*	0.78***	0.61**	1.00

*Significant at P ≤ 0.05; ** significant at P ≤ 0.01; *** significant at P ≤ 0.001; BD = Bulk density; TP = Total porosity; EC = Electrical conductivity; $CaCO_3$ = Calcium carbonate; TN = Total nitrogen; OM = Organic matter; Av.P = Available phosphorous; C:N =Carbon to nitrogen ratio; CEC = Cation exchange capacity; PBS = Percent base saturation.

Considering to the interaction of land use types with soil depth, the highest (0.47 $cmol_c$ kg^{-1}) exchangeable Na was obtained under the subsurface soil layer of forest land, whereas the lowest (0.42 $cmol_c$ kg^{-1}) exchangeable Na was obtained on the surface soil layer of both cultivated and grazing lands (Table 6). Though there was no statistical variation in its values, the higher exchangeable Na in the forest land might be due to the availability and accumulation of plant residues resulted from an abscissions of leaf trees and biological functions thereby enhance exchangeable Na in forest land. On the other hand, the lower exchangeable Na in cultivated and grazing lands attributed to the removal of crops residues on cultivated land through harvesting activities, whereas the removal of surface vegetation by livestock grazing may render the lower exchangeable Na on grazing land.

This result is also parallel with the results of Chemada et al. (2017) who found that the lower exchangeable Na under cultivated and grazing lands compared to the adjacent forest land. As per rating of FAO (2006), the exchangeable Na of the study area was in the range of medium rate under all land use types. Therefore, the exchangeable Na of soil under this study was not the limiting factor on crop productivity and not surplus that may trigger soil sodicity, which in turns hamper the agricultural practices.

Percent base saturation

The percent base saturation (PBS) of the study area was significantly ($P \leq 0.05$) affected by land use types and interaction of land use types with soil depth (Tables 6 and 7). Considering the interaction of land use types with soil depth, the highest (84.6%) and the lowest (69.4%) value of PBS was obtained in the surface (0-20 cm) soil layer of forest land and grazing land, respectively (Table 6).

Considering the main effects of land use types, the highest (82.9%) and the lowest (74.0%) values of PBS were recorded under the forest and grazing lands, respectively (Table 7). In general, processes that affect the extent of basic cations also affect percent base saturation of the soil. According to the rate of PBS cited by Hazelton and Murphy (2007), the PBS of the study area was rated as high in the grass, cultivated and grazing lands whereas it was rated as very high in the forest land. This implies that the soil under the study area was contained high exchangeable bases.

Conclusion

The objective of the this study was to evaluate the selected soil physical and chemical properties as affected by different land use types on Kuyu district, north Shewa zone, Central Highland of Ethiopia. The study area has low bulk density, which is indicating the higher soil OM and clay soil particles. The soil pH ranged in between 7.68 to 8.00 in cultivated and forest lands, respectively. The highest mean value EC ranged in between 0.53 to 0.26 dSm^{-1}.

The higher soil OM and total N were recorded in the forest land while the lower was found in the grazing land. Considering the main effect of soil depths, the higher soil OM was observed on the surface soil layer and it is decreasing with increasing soil depth. The average values of exchangeable basic cations (Ca, Mg, K and Na) ranged from 12.6 to 24.1, 5.3 to 8.7, 0.36 to 1.3 and 0.42 to 0.46 $cmol_c$ kg^{-1} in grazing and forest land, respectively. The CEC of soil under the study area was categorized in the high rate in grass, grazing and cultivated lands, whereas rated as very high in forest land. The mean values of PBS ranged between 74.0 to 82.9% in grazing and forest lands, respectively.

Generally, the study area has high pH, clay particles, total porosity, exchangeable basic cations, CEC and $CaCO_3$, but has low available P. The available P was the limited nutrient in the study area, which might be due to its fixation by $CaCO_3$. Therefore, the supply of high P fertilizers levels are important, which can increase crop productivity. To minimize the P fixation and increase its availability, band or localized application of P fertilizer is highly recommended in the study area.

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Spatial variability assessment of Nile alluvial soils using electrical resistivity technique

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Abstract

Spatial information about soils generally results from local observations which are destructive and time consuming. Geophysical techniques could help soil mapping since they are non-destructive and fast. Electrical resistivity is interesting for soil studies due to a wide range of values and as it depends on soil characteristics. This work aims to study soil spatial variability using electrical resistivity. GPS defined grid points of 40X40 m were installed in the experimental western farm (EWF) in the Faculty of Agriculture of Cairo University in Giza. Electrical resistivity was measured at 40 points using 4-electrodes Wenner array in a line perpendicular to the path direction. Soil resistivity data from 2-depths profiling mode was considered to produce two apparent resistivity maps and geostatistically tested. Soil resistivity taxa were sampled and analyzed for soil moisture, EC and bulk density. Krigged soil resistivity maps were produced for depths (i.e. 30 and 60 cm). Kriging and Semivariogram interpretation was conducted, and the spatial dependency of top and subsoil resistivity were moderate (48.4% and 68.6% respectively). Highly significant negative correlations were recorded in the topsoil between apparent or true resistivity and soil moisture, EC or bulk density. The obtained models were used to produce conjugated moisture and EC maps and geostatistically investigated. The spatial dependency of the top and subsoil moisture or salinity were moderate. Soil moisture and EC are the most significant factors for controlling soil electrical resistivity. The method used opens the way to the development of semi-automatic soil mapping from electrical resistivity data.

Keywords: Soil resistivity, Wenner profiling, soil moisture, soil salinity, mapping, spatial dependency.

Introduction

Because the huge number of soil sampling and laboratory analysis work required in ordinary survey methods cause waste of time and money, alternative methods to investigate spatial variability of soil properties are desirable. Soil electrical resistivity could be considered as a proxy for the spatial and temporal variability of soil physical and chemical properties (i.e. soil structure, water content, salinity or fluid composition). This non-destructive and sensitive method is a unique tool for assessing the soil subsurface properties without digging (Samouëlian et al., 2005). The electrical resistivity method was applied in different studies such as: groundwater exploration, landfill delineation and solute transfer, agronomical management of soil compaction or soil and water table depths and also soil moisture status assessment.

The electrical resistivity surveys, depending on the soil variability, can be made in 1-, 2- or 3-dimensions and also at different resolutions from small to regional scales. Soil electrical resistivity (ER) is increasingly used in near-surface soil applications because it is related to many soil characteristics and electrical survey

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information; it therefore, represents a rapid and flexible tool to predict spatial soil variability at the field or local scale (Panissod et al., 1998; Lund et al. 1999; Dabas et al., 2001). The soil bulk electrical resistivity technique offers the following advantages: (i) widely used to characterize soil physical and chemical properties, (ii) ER measurements can be taken quickly, (iii) low cost, (iv) two people can cover a large area, (v) monitoring of soil variability, (vi) exploring soil subsurface without digging and (vii) minimizing the number of soil samples. Soil bulk resistivity depends on multiple variables including soil texture and structure, porosity, soil moisture content (Besson et al., 2010), pore water salinity, temperature and sometimes the presence of root biomass. Several studies have been performed using this technique, with the aim of delineating field zones for managing specific crops in the context of digital agriculture (Heiniger et al., 2003; Kitchen et al., 2003; Corwin et al., 2006), mapping soil texture (Jung et al., 2005; McCutcheon et al., 2006) and describing the soil structure of different soil horizons (Tabbagh et al., 2000) and soil salinity variability (Rhoades, 1993; Omonode and Vyn, 2006).

The objectives of the present study were to: (i) survey the electrical resistivity of an alluvial soil farm using the Profiling Model in two depths to describe its spatial variability, (ii) correlate profiling resistivity values in the alluvial farm with its correspondent physical and chemical properties and (iii) produce the soil map of the studied farm by correlating ER units with their physical and chemical properties.

Material and Methods

Principals of electrical resistivity measurement

Electrical resistivity methods introduce an electrical current into the soil through current electrodes at the soil surface and measure the drop in current flow potential at inner electrodes. The Wenner array of electrode configuration was described by four electrodes placed at equal distances in a straight line. The outer two electrodes were working as the current or transmission and the inner two electrodes the potential or receiving ones (Figure 1).

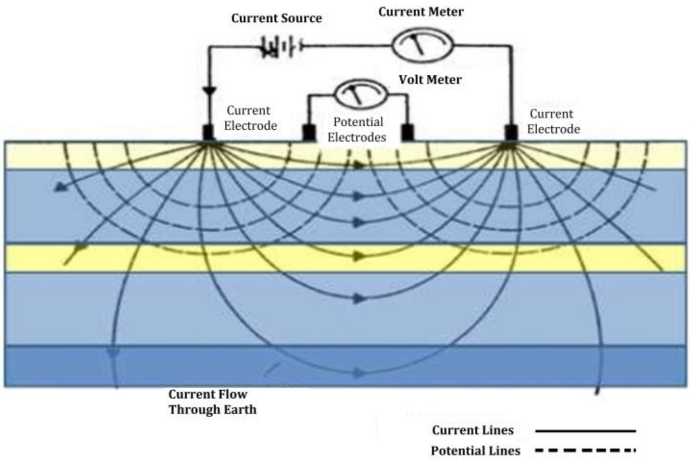

Figure 1. The flow of current and potential line in the measurement of soil electrical resistivity using the Wenner electrod arrayThe extent of electrical current penetration and the depth and volume of measurement depend on the inter electrode spacing. The larger the spacing the deeper the measurement and volume of measurement. The resistivity measured with the Wenner array (Burger, 1992) is:

$$\rho = 2\pi a \Delta V / i = 2\pi a R$$

One and two meters spacing between probes were chosen so as to detect metric contrasts in the soil properties at two depths (US-EPA, 2019). Soil resisitivity readings were converted to apparent resistivity using the relation:

$$\rho_a = k_i \frac{\Delta V}{I}$$

With i=1,2m for each array and where I=is the injected current in mA, ΔV is the electrical potential difference (Volt) measured between electrodes Mi and Ni and the geometrical parameter for each array is:

$$k_i = \frac{\pi}{\frac{1}{AM_i} - \frac{1}{AN_i}}$$

Site description

The experimental western farm (EWF) in the Faculty of Agriculture, Cairo University at Giza was chosen for the present study. The geo-referenced coordinates of the investigated rectangle area (@ 6.1 hectares) were shown in Figure 2.

Figure 2. Acquisition of the Resistivity Data

For the farm survey, GPS defined grid points of 40X40m were istalled. Data were acquired on the nodes of regular grids extended across an area of about 160 by 400m. At each point (40 nodes), resistivity was measured using 4-electrodes Wenner array in a line perpendicular to the path direction (Sudha et al., 2009). The readings were collected by a resistivity meter (KYORITSU-KEW-4106). All measurements (40 points) were geo-referenced using a Germin-550 differential GPS and recorded on a PC.

Data preprocessing

Data processing was simple and consisted of: i) Inversion of the apparent resistivity values (Ra) into true resistivity (Rt) using the IPI2win software, then ii) generating an iso-line distribution map of the inverted electrical resistivity data to report the spatial distribution of the true resistivity values. The maps were generated using the ArcGis Software (ESRI, 2011). The results were presented in the form of two maps corresponding to the two targeted depths of soil layers. These maps represent the contribution of the cumulative soil volume, from the surface down to the two depths of investigation, 0.3, and 0.6m for arrays 1 and 2m, respectively.

Determination of soil properties

Ten taxa were identified from the resistivity maps. Composite disturbed soil samples were collected at two depths (0-30 and 30-60cm) to represent each soil resistivity taxa. The collected samples were analyzed for soil moisture content (Gardner, 1986) and electrical conductivity EC at a 1:2.5 soil:water ratio (Rhoades, 1982). In addition, undisturbed soil samples for each resistivity taxa were collected to determine soil bulk density (Blake and Hartge, 1986).

Results and Discussion

Soil resistivity values for the surface layers (0-30cm) and (30-60cm) were mapped using the ArcGis software (ESRI, 2011) and presented in Figure 3. Kriging and Semivariogram Interpretation was conducted to find out the spatial dependency of the top soil (Nugget/sill, %), and the resultant output was presented in Table 1. The weighted least square method was used to estimate the auto- and cross-variogram parameters (i.e., nugget, sill and range).

Table 1. The Semivariogram Model interpretation of the surface and subsoil block krigged soil maps of electrical resistivity, moisture and salinity

Semivariogram properties	Soil map property					
	Electrical Resistivity		Soil Moisture		Soil Salinity	
	Layer depth		Layer depth		Layer depth	
	0-30cm	30-60cm	0-30cm	30-60cm	0-30cm	30-60cm
Semivariogram Model type	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
Nugget	8.889	15.013	12.899	6.163	0.038	0.071
Range (m)	137.250	137.37	138.19	159.13	86.04	151.61
Partial sill	8.35	6.88	14.24	4.039	0.017	0.043
Spatial dependency	48.4% (Moderate)	68.6 (Moderate)	47.53% (Moderate)	60.41 (Moderate)	48.4% (Moderate)	68.6 (Moderate)

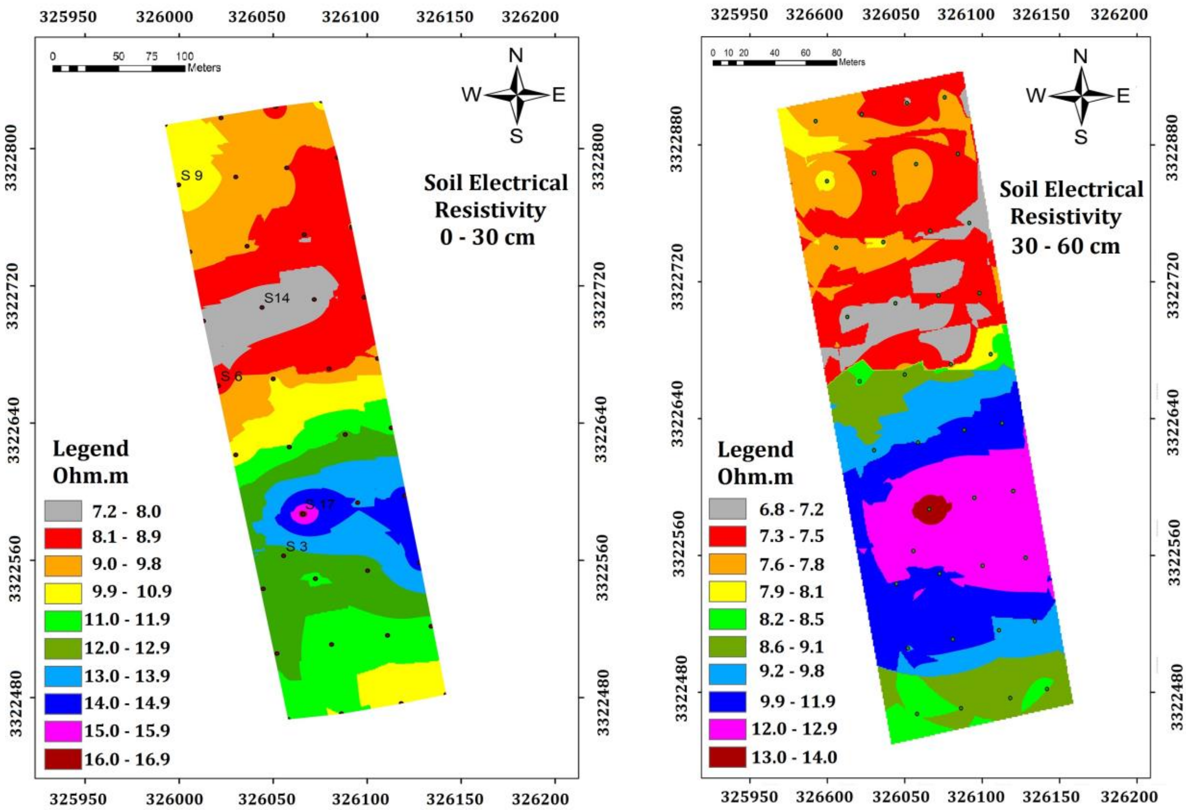

Figure 3. Topsoil (0-30 cm) and subsoil (30-60 cm) soil electrical resistivity krigged map

Any soil property has strong spatial dependency if the ratio of nugget/sill is equal to or less than 25%, moderate spatial dependency if between 25 and 75%, and weak spatial dependency if greater than 75% (Cambardella et al., 1994; Sun et al., 2003).

From figure 3 and Table 1, it is clear that the spatial dependency of both topsoil and subsoil resistivity is moderate (48.4% and 68.6%, respectively). Gülser et al. (2016) stated that strong spatial dependency of soil properties is related to structural intrinsic factors such as texture and mineralogy, while random extrinsic factors such as dynamic moisture and porosity properties showed moderate or weak spatial dependency.

Generally, a semi-variogram may reach its sill at a finite distance called the range. The range of the semivariogram represents the distance limit beyond which the data are no longer correlated, and it was found to be 137.3 m for the resistivity of the investigated topsoil. Eight soil taxa units were identified to cover the resistivity range between 4 and 24 Ohm.m were resulted from the krigged map.

The soil physical properties of the composite soil samples representing the resistivity taxa units of both topsoil and subsoil were shown in Table 1. The number of sampling sites represented 20% of the total grid points which were normally sampled in an ordinary soil survey. Simple regression analysis was developed between both apparent/true resistivities and each of the soil moisture content, EC and bulk density. Figure 4 represents the best fitting relationships for each property for both the top- and subsoils.

Highly significant negative correlations were recorded in the topsoil between apparent or true resistivity and soil moisture, EC or bulk density. The best fitting relationship models (Table 3) ranged between linear, power, logarithmic and exponential models. Weak or insignificant relationships were recorded in the subsoil. These findings indicated that the present array of soil resistivity measurement could be more useful for detecting topsoil variability efficiently. It is suggested future works could focus on the subsoil layer changing the array of soil resistivity measurement. Pandey (2015) observed that the resistivity of sandy soils decreased rapidly with an increase in the water/fluid content, but the rate of decrease dropped considerably for water contents over 10-12%.

Table 2. The apparent and true resistivities, soil moisture content, EC and bulk density of the main topsoil and subsoil resistivity taxa units

Taxa Unit	Apparent R (Ω m)	True R (Ω m)	θ % (w/w)	$EC_{2.5}$, dS/m	Bulk Density, $g.cm^{-3}$
		Topsoil (0-30 cm)			
I	12.90	17.59	25.0	1.09	1.35
II	9.20	10.76	26.0	0.63	1.17
III	6.20	6.36	33.7	1.48	1.24
IV	4.80	5.04	31.7	0.94	1.32
V	4.70	5.57	35.0	1.63	1.33
VI	18.00	18.16	23.5	1.33	1.18
VII	24.00	20.42	23.3	1.49	1.14
VIII	14.20	15.62	30.9	1.13	1.38
		Subsoil (30-60 cm)			
I	8.00	4.11	24.0	0.89	1.36
II	7.40	5.57	26.7	0.65	1.18
III	6.00	5.73	33.2	1.49	1.22
IV	4.50	4.11	30.8	1.13	1.32
V	3.70	2.72	32.2	1.61	1.30
VI	17.80	17.51	21.3	1.02	1.26
VII	29.10	41.17	23.3	1.20	1.31
VIII	12.50	10.53	26.3	0.86	1.45

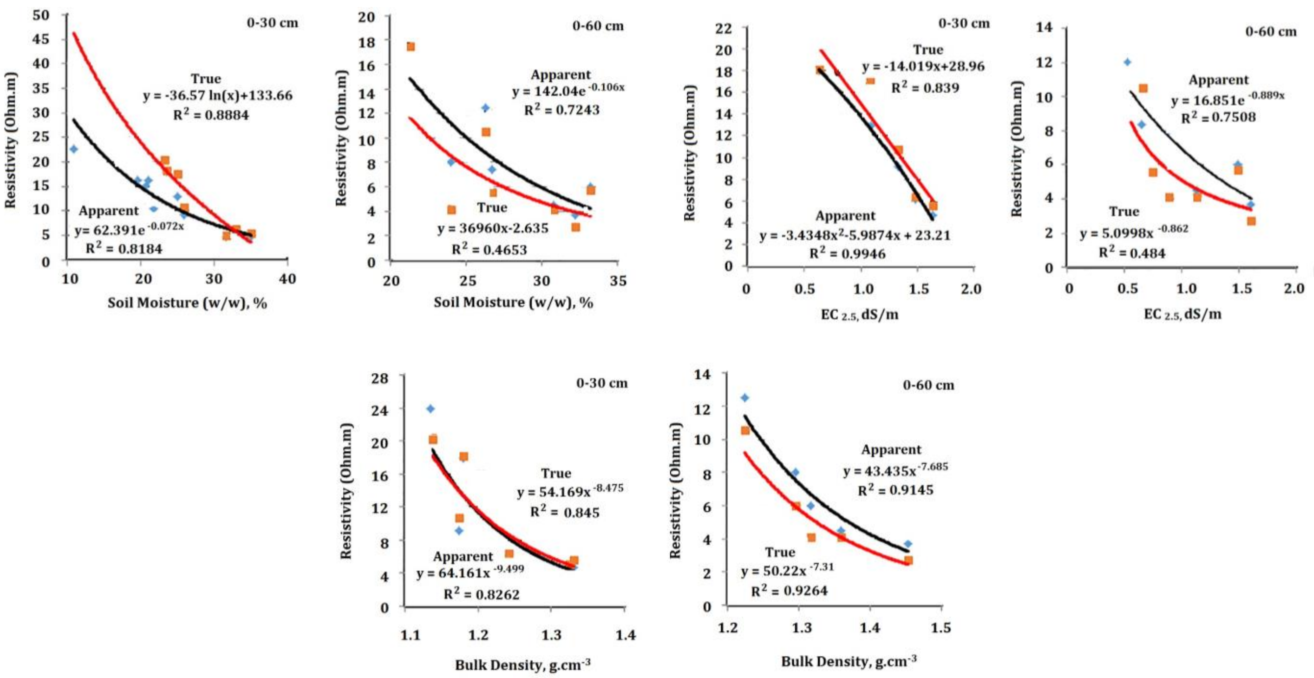

Figure 4. The best fitting relationships for each soil property and apparent or true resistivities for both top- and subsoils

The relationships shown in Table 3 were in good agreement with a great number of studies. In literature, various models were proposed to describe the relationships between electrical resistivity and soil water content, temperature or salt content. Relationships between soil water content and electrical resistivity were measured in field and laboratory conditions and mostly through curvilinear models (Abidin et al., 2013;

Ozcep et al., 2009, 2010). Kusim et al. (2013) showed that the electrical resistivity decreased significantly by increasing the salt content in the soil.

Table 3. The statistical relationship models between apparent or true resistivities with soil moisture, EC and bulk density for both top- and subsoils.

Soil Property	Apparent Resistivity	True Resistivity
	Topsoil	
Moisture	$y = 62.391e^{-0.072x}$ $R^2 = 0.8184$	$y = -36.57\ln(x) + 133.66$ $R^2 = 0.8884$
EC	$y = -3.4348x2 - 5.9874x + 23.21$ $R^2 = 0.9946$	$y = -14.019x + 28.96$ $R^2 = 0.839$
Bulk Density	$y = 64.161x^{-9.499}$ $R^2 = 0.8262$	$y = 54.169x^{-8.475}$ $R^2 = 0.845$
	Subsoil	
Moisture	$y = 142.04e^{-0.106x}$ $R^2 = 0.7243$	$y = 36960x^{-2.635}$ $R^2 = 0.4653$
EC	$y = 16.851e^{-0.889x}$ $R^2 = 0.7508$	$y = 5.0998x^{-0.862}$ $R^2 = 0.484$
Bulk Density	$y = 50.022x^{-7.31}$ $R^2 = 0.9264$	$y = 43.435x^{-7.685}$ $R^2 = 0.9145$

Production of maps for soil properties

The models obtained were used to produce conjugated moisture, EC and bulk density maps. The regression equations were used to calculate the value of the soil moisture and salinity for each resistivity value of the 40 points of the investigated grid. The calculated moisture and EC values were used to produce conjugate soil moisture and soil-EC maps (Figure 5 and 6).

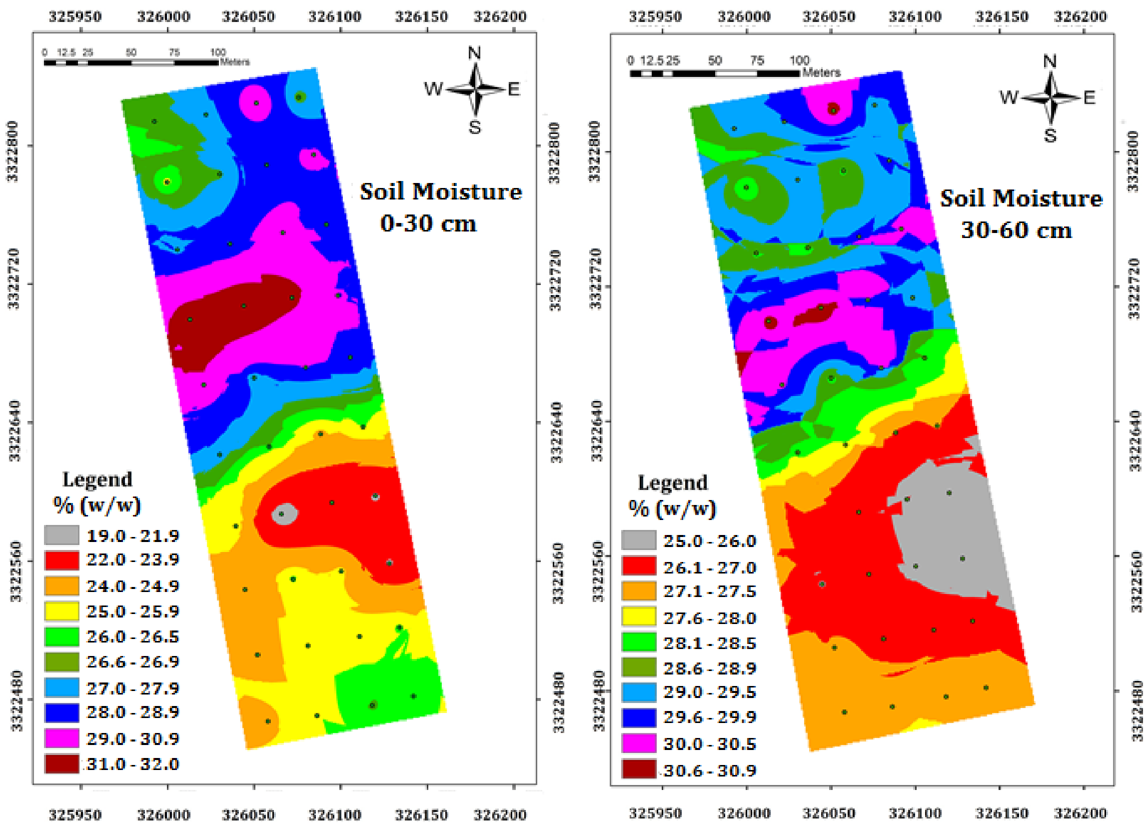

Figure 5. Soil moisture map of top- and subsoils as conjugated from their relevant soil resistivity maps

The spatial dependency of the top and subsoil moisture contents were moderate (47.5% and 60.4%, respectively), while it was for soil salinity 68.5% and 62.5%, respectively as shown in Table 1. These maps could be used for better management of the farm irrigation system to reduce the uneven distribution of both soil moisture and salinity. Al-Omran et al. (2013) showed in their study on soil spatial variability that only TDS, ESP and OM had weak spatial dependency while other properties had moderate or strong spatial dependencies. Huntley (1986) and Michot et al. (2003) concluded that as the resistivity of the pore fluid increased (low salinity) or the porosity decreased, the electrical resistivity of the soil increased.

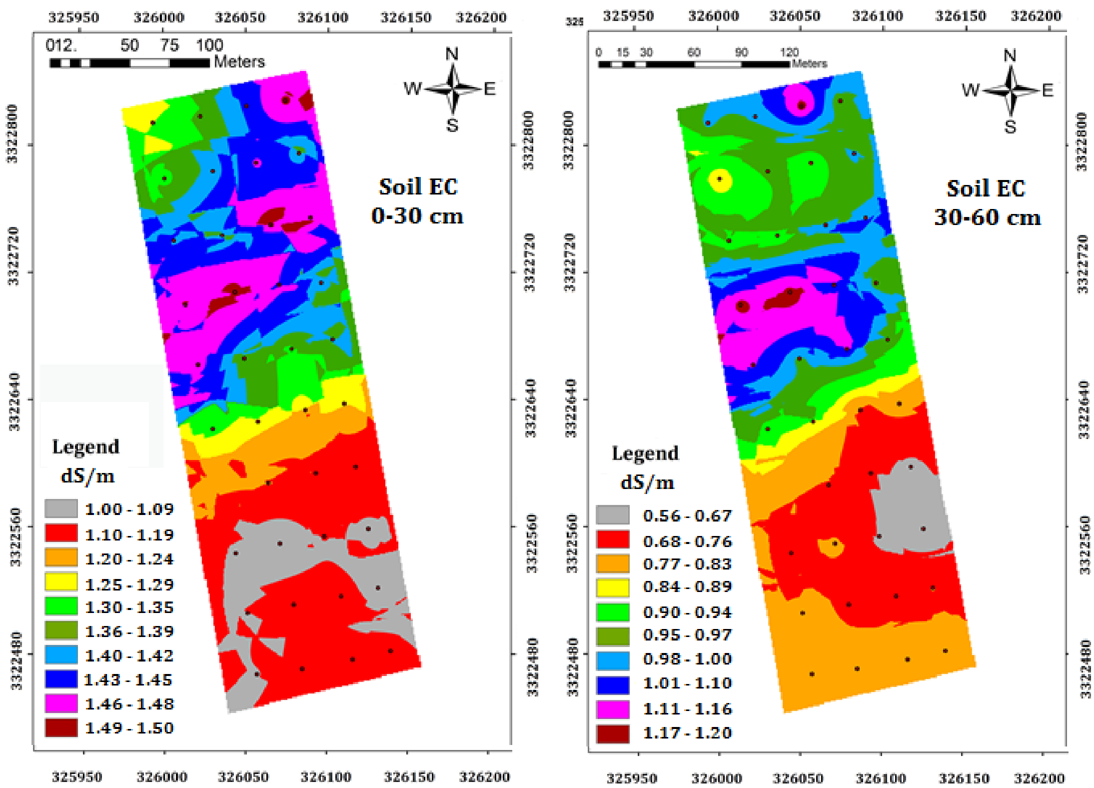

Figure 6. Soil salinity map of top- and subsoil as conjugated from their relevant soil resistivity maps

Conclusion

In conclusion, mapping of soil electrical resistivity for the surface layer (0-30 cm) could be used efficiently to express spatial variability of soil properties, especially moisture- salinity content and, to some extent, bulk density without digging. It saves time, effort and money for monitoring the variability of soil moisture and salinity. In addition, soil moisture and salinity maps could be easily produced from resistivity maps and used for soil irrigation management and soil salinity control. With the help of this electrical resistivity method for soil investigation, we can easily analyze the required properties of soil in agricultural fields without disturbing and removing soil samples from its natural condition. Therefore, it is recommended to use this easy mapping of soil electrical resistivity which can facilitate precision or digital agricultural practices, where the heterogeneity and variation of soil physical parameters in a field should be taken into consideration for a successful site specific management.

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Determination of physico-chemical properties and agricultural potentials of soils in Tembaro District, KembataTembaro Zone, Southern Ethiopia

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Abstract

The objectives of this study were to classify the soils of Tembaro district, and to identify its potentials for crop production. Five pits representing a pedon each were opened and profile in each pit was described for its morphological, physical and chemical characteristics according to standard procedures. A total of 20 disturbed soil samples and 16 core ring samples were collected from five representative profiles. The samples were analyzed in the laboratory for texture, BD, FC, PWP, Soil pH, EC, OC, TN, av.P, av.K, exchangeable bases, free and active iron and CEC. The results showed that the proportions of soil separates varied among profile and depth however, soils were all in clay textural class. The BD varied from 1.02 in the surface profile 1 to 1.25 g.cm^{-3} in the profile 3. Soil pH ranged from 6.8 to 5.4 in the surface horizons of all profiles with further decrease with depth indicating that the soils in the watershed are slightly acidic to moderately acidic. The OM and TN contents ranged from 2.90 to 5.43 and 0.23 to 0.45% in the surface horizon and they were in the low, low to medium and high categories respectively. The corresponding values for the remaining subsoil horizons were in the low categories. In all cases the contents of these parameters decreased considerably with depths. Available P was below critical values for all profiles and depths except for profiles 1 and 4. Exchangeable K was above critical value in all profiles with increasing trend along with depth of all profiles. Exchangeable Mg varied from 2.47 in surface horizon of profile 3 to 3.98 cmolc kg^{-1} in the surface horizons of profile 4 and increased with depth in all profiles except in profile 1. The observation with exchangeable K and Mg implies that there is leaching phenomenon in the study area. Ca ranged from 4. 35 cmolc kg $^{-1}$ in profile 5 to 16.50 cmolc kg $^{-1}$ in profile 1 with inconsistent trend with depth. The CEC from 18.22 cmolc kg $^{-1}$ soil in surface horizon of profile 5 to 27.43 cmolc kg-1 soil in the surface horizons of profile 1 indicating they are in the medium to high ranges. But inconsistent trend in CEC distribution was observed with depth in all profiles. Based on the data collected from profile description study and soil physicochemical analytical data and according to FAO-WRD soil classification legend, the soil at Ambukuna watershed were classified as Haplic Nitisols (Endoeutric, humic), Haplic Nitisols (Hypereutric, humic), Haplic Nitisols (Endoeutric) and Haplic Nitisols (Epidystric, Humic). Most of the soil physical and some of the chemical characteristics studied could be ranked as good indicating that the area has high potential for agricultural production.

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Introduction

Sustainable agricultural productivity aims to produce components that are directly consumed by human beings and contribute to the satisfaction of human needs by producing quantity and quality products with little damage to the environment, such as soils. Thus the overall productivity and sustainability of a given

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agricultural sector are functions of fertile soils and productive lands. However, soil fertility depletion is the fundamental biophysical cause for declining per capita food production in sub- Saharan African countries in general (Sanchez et al., 1997, Sanginga and Woomer, 2009) and in southern Ethiopia in particular. The study and understanding of soil properties and their distribution over an area has proved to be useful for the development of soil management plan for efficient utilization of limited land resources. Moreover, it is very important for agrotechnology transfer (Buol et al., 2003).

Ethiopian agriculture accounted for 39% of GDP, 83.9% of export earrings and 80% of total employment in 2015/2016, compared to 44.9%, 76.9%, and 80%, respectively in 2002/2003 (CSA, 2017). As a result, agriculture remains to be Ethiopian economy's most important sector.

Ethiopia has great agricultural potential because of its vast areas of fertile land, diverse climate,

generally adequate rainfall, and large labour pool (CSA, 2017). The country has a total surface area of 111.8 million ha (Mabbutt, 1984); of which 62.81million ha are estimated agriculturally productive (Mishra et al., 2004). However, Ethiopia's agriculture is characterized by low production per unit area. Although the country has enormous potential for agricultural production (such as in terms of land, climate and water resources), it is not uncommon facing a serious and chronic problem of food crop shortage in the country (Yohannes, 1989). Ethiopia with its immense potential soil resource base suffers from food insecurity (Mishra et al., 2004). This is a paradox, which invites researchers to investigate the causes of the problem and suggest feasible solutions.

There is no adequate information on soil resources of Ethiopia mainly at catchment levels, whereas such information is important in providing base line data for wise use of the agricultural resources in general. As a result, decision makers and development workers usually give a blanket recommendation of agricultural technologies on agro-climatic basis in the effort of increasing crop productivity. The objectives of the present study were to investigate the major morphological, physical and chemical properties and classification of the soils and, to determine agricultural potentials and constraints for crop production of the soils of Ambukuna catchment.

Material and Methods

Description of the study area

The study area, Ambukuna catchment, is located at about 8 km south east of Mudulla town in the Kembata-Tembaro zone, Tembaro woreda, Southern Ethiopia. It is located just 392 km south of Addis Ababa and 172 km west of Hawassa town. Geographically, the catchment is located between latitude 79o83'79" and 80o09'79" N and longitude 34o32'70'' and 34o20'96" E (Figure 1). The total area of the Tembaro woreda and Ambukuna catchment is about 27.917 ha and 341 ha, respectively (WAO, 2011). Land degradation and soil erosion are the main problems due to the prevailing landscape and high altitude in the study area. It is divided into three agro-ecological zones, namely highland (*dega*), mid highland (*woina dega*) and lowland (*kolla*). The recent ten years (2006–2018) mean annual precipitation of the study area was about 1095.6mm. The area has a bimodal rainfall pattern and about 30 and 40% fall during autumn (March-May) and summer (June-August) seasons, respectively. The mean monthly temperature for the last ten years (2005-2015) ranges from 18.95–21.75 °C with an average of 20.59 °C.

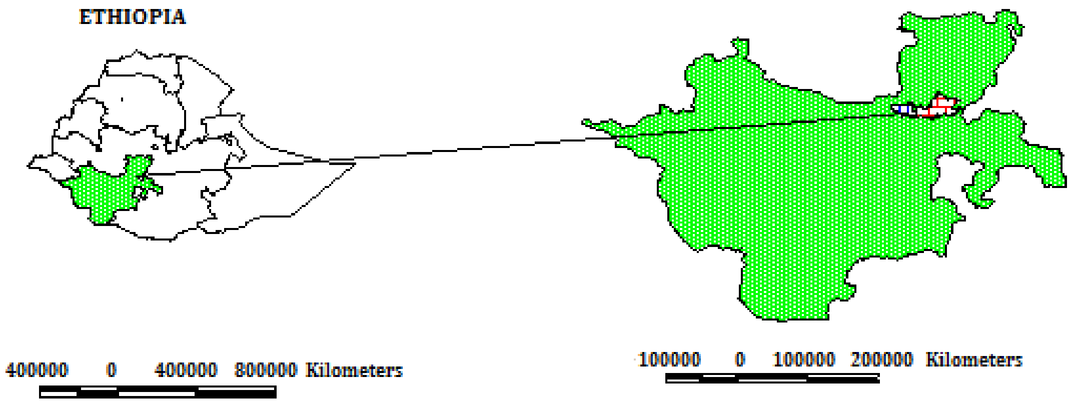

Figure 1. Ambukuna catchment map

Data Collection and Analysis

Two phases of field surveys were accomplished in studying the soil of the watershed. First, a preliminary or reconnaissance survey was performed with the help of 1:50,000 topo-sheet (EMLS, 1976) to acquire general information on soils and environment of the proposed study area. At this level tentative soil units and map were prepared on the same map based on landscape vegetation relationships and surface soil characteristics (e.g. colour, structure, texture) as field guide. Survey was conducted during the second phase. Using the tentative soil map as supplementary, soils were studied from auger holes, gully cuts and site observations. A number of auger holes observations were made and site characteristics and land use patterns were recorded on standard form. Then with this information, the tentative soil units were adjusted through manipulations of tentative soil boundaries. The final soil field boundaries were then delineated on the 1:50000 topo-sheet. In delineation of boundaries topographic factors, vegetation characteristics, surface colour and land use patterns were used in addition to auger hole and other observation points. A toposequence was selected along east-west facing slopes encompassing landform components from upper slope to bottom slope of the watershed. After a proper identification of soil mapping units, five soil pits were opened and profiles described according to procedures and criteria indicated in FAO (2006), for their environmental and morphological characteristics. Colours of the soils were determined using Munsell soil colour chart (Munsell colour company, 1975). The FAO (2014) classification legend was followed in the classification of the soils. Profile observation points were geo-referenced with the help of geographical positioning system (GPS) and located on the 1:50,000 scale base and then finally in the soil map. Total 20 disturbed and 16 undisturbed soil samples were collected from recognized genetic horizons of the 5 representative pits. From each recognized genetic horizon, disturbed soil samples using bag were taken, and from which 1 kg of soil was transferred into plastic bag and labeled. Then the soil samples were transported to National Soil Testing Center (NSTC), where they were analyzed for their physical and chemical characteristics.

The undisturbed core samples were used for the determination of bulk density and soil moisture contents at field capacity (FC at -0.33 bar) and permanent wilting point (PWP at -15 bars). The disturbed soil samples were air-dried, ground and passed through a 2 mm sieve and analyzed for physical and chemical parameters. The bulk density of undisturbed soil was determined by the core method as described by Gupta (2000). Total porosity was estimated using the following formula: Total Porosity (%) = 100-[(BD/Pd) x100] (Brady and Weil, 2002). The soil moisture contents at field capacity and at permanent wilting point were measured by the pressure plate apparatus. Finally, the available water holding capacity was determined from the difference between water content at FC and PWP (Hillel, 1980). The particle size distribution was determined by the hydrometer method (Van Reeuwijk, 2002). Electrical conductivity was measured by conductivity meter in 1:2.5 soil-water ratio (Okalebo et al., 2002). Soil pH was determined using pH meter with combined glass electrode at 1:2.5 (soil: water) ratio as described by Carter (1993). The organic carbon was determined by the Walkley and Black (1934) method and organic matter content was obtained by multiplying the OC content by a factor of 1.724. The total N content in soil was determined by using the Kjeldahl procedure (Gupta, 2000) and available P was determined by the Mehlich-III method (Mehlich, 1984). To determine available K in the soil, the soil samples were extracted with Morgan's solution and K was read by flame photometer (Morgan, 1941). Exchangeable bases (Ca, Mg, K and Na) and CEC in the soil were estimated by the ammonium acetate (1N NH_4OAc at pH 7.0) extraction method. Then, Ca and Mg were measured with the help of atomic absorption spectrophotometer (AAS), and K and Na by flame photometer in the ammonium acetate extract. Cation exchange capacity was determined through distillation and titration after leaching the ammonium saturated soil with 10% NaCl (Van Reeuwijk, 2002). Percent base saturation (PBS) was calculated by dividing the sum of exchangeable bases by the CEC of the soil and multiplied by 100. The CEC clay was obtained by dividing CEC of the soil by amount of clay of each horizon and expressed on the bases of percentage. The relative proportion of each exchangeable base was calculated by dividing the amount of respective cation by the CEC of the soil and multiplying by 100 for each horizon (Buol et al., 2003). The sample was shaken with a complexing acid ammonium oxalate solution dissolving the "active" or "short range-order" ("amorphous") compounds of Fe which were determined in the extract by AAS (Blakemore et al., 1987). The sample was heated in a complexing buffer of sodium citrate/bicarbonate to which solid sodium dithionite was added as a reducing agent and free iron was measured in the extract by AAS (Mehra and Jackson, 1960). Active Fe to free Fe ratio was calculated from Fe active and free iron data.

Statistical analysis

Simple linear correlation analysis was carried out to reveal the relationships between and among selected physicochemical properties of the soils according to the procedures described by Gomez and Gomez (1984) and used in the interpretations of data. Statistical Package for Social Science (SPSS) software model was employed in the statistical analysis procedure.

Results and Discussion

Site and morphological characteristics

Profiles had a depth of over 100 cm, which can be generally described as deep to very deep soils. The relatively less deep soil depth (124 cm) was recorded in profile 5, whereas all others have a depth of 200 cm. In the study area, surface soil colour patterns showed great variability. This may be related to position in the landscape, slope gradient and organic matter contents (Abate et al., 2014; Hailu et al., 2015, Fekadu et al., 2018). The soil colour patterns of the described profiles (profiles 1, 2, 3, 4 and 5) have become uniformly redder with depth. It changed from dark brown with moist hues of 7.5 YR in surface to dark reddish brown hues (5YR or 2.5YR, moist) in subsoil horizons (Table 1). The relatively dark brown surface soil colour could be attributed to a relatively high content of organic matter of the surface horizons. The redder hues (5 YR or 2.5 YR, moist) in subsoil horizons indicated the well drainage conditions of the profiles (hence described as well drained class soils) as well as organic matter decreased in subsoil suggesting the release of free iron to pigment the soils' reddish patterns. According to Foth (2003), reddish color is due to the presence of iron compounds in various states of oxidation.

Table 1. Selected morphological characteristics and classification

Depth (cm)	Horizon	Colour		Consistence	Structure	Boundary	Root	Cutanic
		Dry	moist	dry/moist/wet	grade/size/type	Distinctness/Topography	Abundance/Size	Feature
Profile 1: Haplic Nitisols (Endoeutric, humic)								
0-20	Ap	7.5YR4/4	7.5YR2.5/3	SHA/FI/SST/SPL	MO/ME/SB	G/S	M/M-C	None
20-75	Bt1	2.5YR3/6	2.5YR3/4	HA/FI/ST/PL	MO/ME/SB	D/S	C/F	Nitic
75-120	Bt2	2.5YR4/6	2.5YR3/6	HA/FI/ST/PL	MO/ME/SB	D/S	V/FV	Nitic
120-200	Bt3	2.5YR4/6	2.5YR3/6	HA/FI/ST/PL	MO/ME/SB	D	None	Nitic
Profile 2: Haplic Nitisols (Hypereutric, humic)								
0-24	Ap	7.5YR3/3	7.5YR2.5/3	SHA/FR/SST/SPL	MO/ME/SB	C/S	C/F-M	None
24-78	Bt1	7.5YR3/4	5YR3/4	HA/FI/ST/PL	MO/ME/SB	G/S	F/VF	Nitic
78-118	Bt2	2.5YR3/4	2.5YR3/4	HA/FI/VST/PL	MO/ME/SB	D/S	V/VF	Nitic
118-200	Bt3	2.5YR3/4	2.5YR3/6	HA/FI/LVST/PL	MO/ME/SB	D	None	Nitic
Profile 3: Haplic Nitisols (Endoeutric, humic)								
0-20	Ap	5YR4/4	5YR3/2	HA/FR/SST/SPL	MO/F/SB	C/S	C/M	None
20-50	Bt1	5YR4/6	5YR3/3	SHA/FI/ST/SPL	MO/F/SB	G/S	F/VF	Nitic
50-90	Bt2	5YR4/4	5YR3/2	SHA/FI/ST/PL	MO/F/SB	D/S	V/VF	Nitic
90-200	Bt3	2.5YR4/4	5YR3/3	SHA/FI/ST/PL	MO/F/SB	D	None	Nitic
Profile 4: Haplic Nitisols (Endoeutric								
0-15	Ap	5YR4/4	5YR3/2	SHA/FR/SST/SPL	ST/FI-ME/SB	C/S	M/F-M	None
15-58	Bt1	5YR3/3	5YR3/3	HA/FI/ST/PL	MO/ME/SB	G/S	F/F	Nitic
58-105	Bt2	5YR4/4	5YR3/2	HA/FI/ST/PL	MO/ME/SB	D/S	V/VF	Nitic
105-200	Bt3	2.5YR4/4	2.5YR3/2	HA/FI/ST/PL	MO/ME/SB	D	None	Nitic
Profile 5: Haplic Nitisols (Epidystric, Humic)								
0-21	Ap	7.5YR4/6	7.5YR3/3	SHA/FI/SST/PL	MO/FI-ME/SB	C/S	M/M	None
21-53	Bt1	5YR4/3	5YR3/3	HA/FI/ST/PL	MO/FI-ME/SB	G/S	C/VF	Nitic
53-97	Bt2	5YR4/6	2.5YR4/4	HA/FI/ST/PL	MO/FI-ME/SB	G/S	V/VF	Nitic
97-124	Bt3	2.5YR4/6	2.5YR3/6	HA/FI/ST/PL	MO/FI-ME/SB	G	None	Nitic

Abbreviations are as per FAO-WRB (2006).

Different degrees of nitic properties were observed in all of the subsoil horizons within 100 cm from the surface. This revealed a presence of nitic horizons as described in FAO (2014). The type, size and grade of structure in the surface horizons were uniformly described to have sub angular blocky, fine to medium and moderate, respectively. The development of blocky structure types could be related to the low level of organic matter, reduction in abundance of plant roots and higher clay percentage of subsoil horizons (Dengiz et al, 2013).

The change in consistence characteristics from surface to subsoil horizons reflects the high contents of clay and low contents of organic matter of subsoil horizons. Horizon boundary characteristics showed slight variations both among and within studied profiles. This is a typical characteristic of most tropical soils (Young, 1976).

Physical characteristics

Selected soil physical characteristics for representative profiles were described in Table 2. Clay content varied between 54% (profile 3) and 38% (profile 2) in surface soil and 84% (profile 1) to 42% (profile 3) in subsoil. This increasing pattern of clay content and a decreasing pattern in sand and silt contents with depth of profiles identify most subsoil horizons as argillic (Bt) (FAO, 2014). According to Boul et al. (2003), the accumulation of clay in the subsurface horizon could be due to the in situ synthesis of secondary clays and the weathering of primary minerals in the B horizon (Sekhar et al., 2014). However, most horizons have silt-clay ratio of below 0.15, as typical properties of tropical soils (Abayneh , 2005).

The bulk densities of the studied soils showed great variability with respect to contents of organic matter and position of horizons in a profile (Table 4). In most of the profiles, bulk density values were lower in the surface than in the underlying horizons. Bulk density varied from 1.02 g cm^{-3} (profile 1) to 1.23 g cm^{-3} (profile 3) in surface soil and 1.10 g cm^{-3} (profile 3) to 1.35 g cm^{-3} (profile 2) in subsoil horizons. This reveals that the high amount of organic matter and well structure characteristics of profile 1 resulted in low value of bulk density of surface soils. Hence, the unsystematic increasing pattern in bulk densities with depth of profiles could be related to a decrease in contents of organic matter and a presence of blocky type of soil structure. Higher OM content in the A horizon makes soils loose, porous and well aggregated, thereby reducing bulk density and bulk densities range for agricultural soils from values of the order of 1.0 g cm^{-3} to 1.7g cm^{-3} (Hillel, 1980). This implies that no excessive compaction and no restriction to root development (Werner, 1997). The bulk density of the study area was within the average range for good agricultural soils. According to Brady and Weil (2002), ideal total pore space values, which are acceptable for crop production, are around 50%. Hence, the soils of Ambukuna district have an acceptable range of total porosity values for crop production. According to rating Beernaert (1990), available water content values in the Ambukuna catchment were rated very low due to low organic matter in the study profiles.

Table 2. Some physical properties of the soils of Ambukuna catchment.

Depth (cm)	Particle size distribution			Textural Class	silt/clay	Water content			Bulk density (g cm^{-3})	Porosiy (%)
	Sand (%)	Silt (%)	Clay (%)			FC (%)	PWP (%)	AWC (%)		
Profile 1: Haplic Nitisols (Endoeutric, humic)										
0-20	23	37	40	C	0.93	27	25	2	1.02	62
20-75	19	15	66	C	0.23	33	28	5	1.24	47
75-120	7	11	82	C	0.13	33	28	5	1.23	46
120-200	5	11	84	C	0.13	31	29	2	1.28	48
Profile 2: Haplic Nitisols (Hypereutric, humic)										
0-24	33	29	38	CL	0.76	30	26	4	1.16	44
24-78	21	19	60	C	0.32	31	28	3	1.28	48
78-118	15	11	74	C	0.15	29	27	2	1.14	43
118-200	13	9	78	C	0.12	31	30	1	1.35	51
Profile 3: Haplic Nitisols (Endoeutric, humic)										
0-20	27	19	54	C	0.35	29	24	5	1.23	46
20-50	31	23	46	C	0.5	29	24	5	1.27	48
50-90	31	25	44	C	0.57	30	24	6	1.10	42
90-200	25	33	42	C	0.79	29	24	5	1.23	46
Profile 4: Haplic Nitisols (Endoeutric										
0-15	25	27	48	C	0.56	28	23	5	1.20	45
15-58	15	17	68	C	0.25	31	26	5	1.11	42
58-105	11	13	76	C	0.17	36	31	6	-	-
105200	9	9	82	C	0.11	37	33	3	-	-
Profile 5: Haplic Nitisols (Epidystric, Humic)										
0-21	29	25	46	C	0.54	-	-	-	-	-
21-53	29	25	46	C	0.54	-	-	-	-	-
53-97	15	15	70	C	0.21	-	-	-	-	-
97-124	19	7	74	C	0.09	-	-	-	-	-

C=Clay, CL= Clay loam, "-" not determined, FC=field capacity, PWP=permanent wilting point, AWC=Available water content

Chemical characteristics

Selected soil chemical characteristics of representative profiles are presented in Table 5. According to Churchman et al. (1983), these values reveal the absence of calcium carbonate in the study area, where values of pH-H_2O less than 6.5 are generally considered as non-calcareous. According to Brook (1983), the studied soils can be rated to range from moderately acidic to slightly acidic in reaction. Currently, it is estimated that about 40% of arable lands of Ethiopia are affected by soil acidity/Al^{3+} toxicity (Taye, 2007). According to Jones (2003), the soils of Ambukuna district of surface and subsoil horizons were rated as very low which considered as non-saline, mainly as a result of high rainfall of the area leaching much of salts in the profiles (Table 3).

According to Brook (1983), rating for soils of tropical and subtropical regions, organic matter content of the surface soils in the study area of profiles 1 and 2 was in medium level and profiles of 3, 4 and 5 was low class which is due to differing intensity of erosion, addition of organic material and level of the mineralization/decomposition of organic matter. According to Landon (1991), rating organic carbon content of the soils were low in all study profiles. According to Havlin et al. (1999), TN content of study area soils were categorized under the medium to high category. The results are in accordance with the findings of Wakene and Heluf (2003) and Tuma (2007) who reported that intensive and continuous cultivation forced oxidation of OC and thus resulted in reduction of TN. Moreover, a result from simple correlation analysis indicated that total nitrogen and organic matter are positively and significantly correlated (r =0.54*) and organic matter and clay content, water field capacity and permanent wilting point are negatively correlated r= -0.74**, -0.57* and -0.60, respectively.

Table 3. Some chemical properties of Ambukuna catchment

Depth (cm)	pH–H_2O	EC(ds/m)	OC (%)	OM (%)	TN (%)	C/ N	av. P (ppm)	av. K (ppm)
Profile 1: Haplic Nitisols (Endoeutric, humic)								
0-20	6.1	0 .11	3.17	5.46	0.41	8	6.52	383.18
20-75	6.0	0.04	1.09	1.88	0.10	11	1.46	668.61
75-120	5.4	0.03	0.87	1.50	0.13	7	1.54	383.18
120-200	5.0	0.04	0.46	0.79	0.06	8	1.00	465.29
Profile 2: Haplic Nitisols (Hypereutric, humic)								
0-24	6.2	0.04	2.77	4.77	0.30	9	3.58	559.13
24-78	6.4	0.04	1.44	2.48	0.25	6	2.24	574.77
78-118	6.0	0.03	0.87	0.50	0.15	6	1.80	430.10
118-200	5.9	0.03	0.63	1.10	0.13	5	0.90	484.84
Profile 3: Haplic Nitisols (Endoeutric, humic)								
0-20	5.6	0.03	1.72	2.96	0.30	6	4.58	359.72
20-50	5.6	0.03	1.34	2.31	0.25	5	2.64	164.22
50-90	5.8	0.02	1.49	2.57	0.16	10	3.04	160.31
90-200	5.9	0.03	1.48	2.55	0.29	5	3.50	168.13
Profile 4: Haplic Nitisols (Endoeutric)								
0-15	5.7	0.03	1.82	3.14	0.27	7	13.72	320.62
15-58	6.0	0.03	0.75	1.29	0.16	5	24.52	355.81
58-105	5.9	0.02	0.59	1.02	0.08	8	11.22	391.00
105-200	5.9	0.02	0.39	0.67	0.06	7	2.36	441.83
Profile 5: Haplic Nitisols (Epidystric, Humic)								
0-21	5.5	0.03	1.74	3.00	0.22	8	3.72	324.44
21-53	5.6	0.02	1.94	3.34	0.25	8	0.70	238.51
53- 97	5.5	0.19	1.01	1.72	0.13	8	0.68	301.07
97-124	5.1	0.03	0.67	1.16	0.11	6	0.56	340.00

EC = electrical conductivity, OC = Organic carbon, OM = organic matter, TN = total nitrogen, C/N = carbon/nitrogen, av .P = available phosphorus, av.K = available potassium

In general, a C/N ratio of about 10 suggests relatively better decomposition rate and indicates improved availability of nitrogen to plants and there will be possibilities to incorporate crop residues to the soil without adverse effect of nitrogen immobilization (Yerima, 1993). According to Yihenew (2002), optimum range of the C:N ratio is about 10:1 to 12:1 that provides nitrogen in excess of microbial needs. Accordingly, the C:N ratio of the surface soils across the sites may be considered to be below the optimum range in all soils for microbial needs.

According to the ratings for some tropical soils (Mehlich, 1984; Brook, 1983; Havlin et al., 1999), available P contents in the study Ambukuna district were low (soil indicates a crop response to P fertilizers) in the profiles of 2, 3 and 5, medium (indicates a probable response) in profile 1 and high (indicates a crop response is unlikely) in profile of 4 of the topsoils. Topsoil phosphorus is usually greater than that in subsoil due to sorption of the added phosphorus and greater biological activity and accumulation of organic material in the former. Moreover, Wakene and Heluf (2003) have suggested that the existence of low contents of available phosphorus is a common characteristic of most Ethiopian soils. The greater the proportion of clay minerals high in potassium, the greater will be the potential potassium availability in a soil (Tisdale et al., 2002). As Jones (2003) has suggested the index values for available potassium (K) in Morgan method, values of K in the study area was adequate. In most profiles, the available potassium content followed unsystematic variation with depth.

According to Brook (1983), rating of exchangeable Ca (in cmol(+) kg^{-1}), Ambukuna district was rated low in profile 5 and medium to high in profiles 1, 2, 3 and 4 in both surface and subsoil horizons. In the subsoil horizons, contents of exchangeable Ca showed an unsystematic decreasing trend in the other profiles, and varied from 2.90 cmol(+) kg^{-1} soil (profile 1) to 16.80 cmol(+) kg^{-1} soil (profile 2). In these subsoil horizons exchangeable Ca constituted 48 to 77 % of the exchange site of the soils. This revealed relatively low levels of exchangeable Ca in the profiles may suggest relatively advanced developed soils. According to Sims (2000), the range of critical values for optimum crop production for Ca are from 1.25 - 2.5 cmol (+) kg^{-1} soil and the exchangeable Ca content of the soils Ambukuna district were above the critical values. As Brook (1983) has suggested, exchangeable Mg (cmol(+) kg^{-1}) was rated medium to high in both surface and subsoil of the studied profiles of Ambukuna microcachment. A continuous cultivation and inorganic fertilizers application resulted in declining of soil pH that caused loss of basic cations and especially under intensive cropping of inherently poor soils, the deficiencies of calcium and magnesium are common (Wakene, 2001).

As Brook (1983) rating of exchangeable potassium (cmol(+) kg^{-1} soil), Ambukuna catchment exchangeable K was medium to high in both surface horizons and most of the subsoil horizons for crop cultivation. According to the same uother rating of sodium for tropical soil, amount of exchangeable sodium was very low to low or trace amount throughout the profiles and surface and subsoil horizons of the study watershed soils. In general, magnitude of exchangeable cations was in the order of Ca> Mg> K> Na. The ratios of K/Mg and Ca/Mg varied from 0.21 to 0.46 and 1.22-5.98 in the surface soil, respectively (Table 4).

According to Brook (1983), the CEC of Ambukuna catchment was rated as medium in the profiles 2, 4 and 5 to high in profiles 1 and 3 for surface horizons. In the subsoil horizons, CEC values varied between 13.38 cmol(+) kg^{-1} soil in profile 1 and 40.00 cmol(+) kg^{-1} soil in profile 2. There exists a strong relationship (r=0.81**) between CEC and sum of exchangeable cations and (r=0.76**) between CEC and available P of the soil profiles but sum of exchangeable bases and water field capacity have negative correlation (r=-0.71**) (Table 7). Accordingly, the increase in clay contents with depth of the profiles did not match with increase in CEC. The CEC/clay values were also found to be higher for the surface horizons than the subsoil horizons of the studied profile. Except for some profiles (profiles 1 and 4), CEC/clay showed an unsystematic decrease with depth of the profiles.

Table 4. Exchangeable bases, CEC and percent base saturation of soils of Ambukuna catchment

Depth (cm)	Exchangeable bases (cmol(+)/kg soil)				K/Mg	Ca/Mg	CEC (cmol(+)/kg soil)	PBS (%)	CEC/clay (%)
	Na	K	Ca	Mg					
Profile 1: Haplic Nitisols (Endoeutric, humic)									
0-20	0.00	0.98	15.59	3.35	0.29	4.65	26.35	76	66
20-75	0.00	1.71	8.75	3.40	0.50	2.57	18.72	74	28
75-120	0.00	0.98	5.14	3.24	0.30	1.59	17.47	54	21
120-200	0.00	1.19	2.90	1.96	0.61	1.48	13.38	45	16
Profile 2: Haplic Nitisols (Hypereutric, humic)									
0-24	0.00	1.43	15.30	3.12	0.46	4.90	23.13	86	61
24-78	0.00	1.47	16.80	3.53	0.42	4.76	40.00	55	67
78-118	0.00	1.10	13.09	3.75	0.29	4.49	22.35	80	30
118-200	0.04	1.24	10.55	3.20	0.39	3.30	20.88	72	27
Profile 3: Haplic Nitisols (Endoeutric, humic)									
0-20	0.00	0.92	14.76	2.47	0.37	5.98	25.70	71	48
20-50	0.00	0.42	4.01	3.50	0.12	1.15	19.02	42	41
50-90	0.00	0.41	7.63	4.05	0.10	1.88	20.27	60	46
90-200	0.00	0.43	11.41	4.47	0.10	2.55	23.57	69	56
Profile 4: Haplic Nitisols (Endoeutric									
0-15	0.00	0.82	11.50	3.98	0.21	2.89	21.08	77	44
15-58	0.00	0.91	10.04	4.70	0.19	2.24	24.28	64	36
58-105	0.13	1.00	8.47	4.02	0.25	2.11	23.46	56	31
105-200	0.13	1.13	7.36	4.77	0.24	1.54	22.40	60	27
Profile 5: Haplic Nitisols (Epidystric, Humic)									
0-21	0.00	0.84	3.37	2.77	0.30	1.22	17.16	41	37
21-53	0.00	0.61	3.88	3.82	0.16	1.02	17.64	47	38
53-97	0.00	0.77	6.49	4.17	0.18	1.56	21.48	53	31
97-124	0.00	0.87	5.63	3.09	0.28	1.82	16.84	57	23

Na=sodium, K=potassium, Ca=calcium, Mg=magnesium, CEC=cation exchangeable capacity, PBS=percentage saturation, EA=Exchangeable Acidity, K/Mg= ratio of potassium to magnesium, Ca/Mg=ratio of calcium to magnesium

The decline in total CEC or CEC/clay with depth of profiles reflects the role of clay mineralogy. The measured values of CEC from profile1, 2, 3, 4 and 5 may indicate presence of mixed clay mineralogy. These facts indicate that CEC could also be explained by stages of soil development. The percentage base saturation (PBS) was generally above 50% in most of the horizons and profiles. Although it still remained high, PBS showed a slight decreasing pattern with depth of almost all profiles, suggesting an existence of movement of bases from topsoil to subsoil horizons was unsystematic pattern probably due to differences in clay content in the subsoil horizons. PBS varied from 86 % of profile 2 to 41 % of profile 5 in the surface horizon. In the subsoil, PBS varied between 80 % of profile 2 and 42 % of profile 3 (Table 6). According to Brook (1983) suggestion for tropical soils (PBS %) of the Bejjo watershed has medium PBS for profile 5 and high PBS for profiles 1, 2, 3 and 4. PBS showed a slight increase in profile 5 with depth, suggesting an existence of movement of bases from topsoil to subsoil horizons. This variability in PBS is an indication of presence of variable levels of soil development in the study area.

Soil Classification

The studied morphological and physico-chemical characteristics were used in the classification of the soils of *Ambukuna* watershed. As described earlier, all profiles have variable degrees of shining faces in their subsoil horizons; indicating the presence of nitic properties and qualifying for nitic horizon as well.

According to FAO (2014), a nitic horizon needs to satisfy:

1. less than 20 percent change (relative) in clay content over 12 cm to layers immediately above and below; and
2. all of the following:
   a. 30 percent or more clay; and
   b. a water-dispersible clay to total clay ratio less than 0.10; and
   c. a silt to clay ratio less than 0.40; and
3. moderate to strong, angular blocky structure breaking to flat-edged or nut-shaped elements with shiny ped faces. The shiny faces are not, or are only partially, associated with clay coatings; and
4. all of the following:
   a. 4.0 percent or more citrate-dithionite extractable Fe (free iron) in the fine earth fraction; and
   b. 0.20 percent or more acid oxalate (pH 3) extractable Fe (active iron) in the fine earth fraction; and
   c. a ratio of active to free iron of 0.05 or more; and
5. a thickness of 30 cm or more.

Table 5. Free iron, Active iron and Active Fe/Free Fe Ratio for soils of Ambukuna Catchment

Depth (cm)	Free Fe (%)	Fe_2O_3 (%)	Active Fe (%)	Fe_2O_3 (%)	Active Fe/Free Fe
Profile 1: Haplic Nitisols (Endoeutric, Humic)					
0-20	6.90	9.90	1.41	2.01	0 .20
20-75	7.00	10.00	1.26	1.80	0.18
75-120	7.20	10.30	0.98	1.39	0.14
120-200	7.20	10.30	0.99	1.41	0.14
Profile 2: Haplic Nitisols (Hypereutric, humic)					
0-24	6.20	8.90	1.26	1.81	`0.20
24-78	6.70	9.60	1.18	1.69	0.18
78-118	7.40	10.50	1.14	1.63	0.15
118-200	6.90	9.90	0.96	1.38	0.14
Profile 3: Haplic Nitisols (Endoeutric, humic)					
0-20	8.40	12.00	1.43	2.04	0.17
20-50	6.60	9.50	1.51	2.15	0.23
50-90	4.80	6.80	1.28	1.83	0.27
90-200	5.10	7.20	1.39	1.98	0.27
Profile 4: Haplic Nitisols (Endoeutric)					
0-15	6.30	9.00	0.95	1.35	0.15
15-58	7.10	10.20	0.76	1.09	0.11
58-105	7.30	10.40	0.80	1.14	0.11
105-200	6.90	9.80	0.68	0.98	0.10
Profile 5: Haplic Nitisols (Epidystric, Humic)					
0-21	4.30	6.10	0.92	1.31	0.21
21-53	4.20	6.00	0.88	1.26	0.21
53-97	4.90	7.00	0.70	1.00	0.14
97-124	5.00	7.20	0.53	0.76	0.11

Many of these criteria are observed and measured in the field as well as determined in the laboratory. The subsoil horizon of all studied profiles have subangular to nutty structure and shiny faces, less than 20% clay content change, over 30% clay content with silt-clay ratio of less than 0.4 (except in nitic horizon profile 3), over 4% free iron and over 0.2% active iron with active to free iron ratio of >0.05 and a thickness of over 30 cm (Tables 3, 4 and 8). The surface horizon of these soils uniformly met the requirements for an ochric A horizon (FAO, 2006). Hence all the studied soils are classified as Nitisols, following the classification legend of FAO (2006). However, nitic horizon of profile 3 has silt/clay ratios of over 0.40 but clearly exhibited nitic properties as described by its shining faces in the field. The high silt content of profile 3 is related to the deposition of silty materials as it is located in the gentler lower slope position. Regardless of this, it is classified as Nitisols. In this study, none of the soils could qualify for prefix (2nd level) qualifier other than Haplic as suggested in the employed classification legend (FAO, 2006); thus, all the soils are classified as Haplic Nitisols. The present Nitisols were further mapped into detail mapping units on the basis of recognized unique suffix qualifiers depending on their specific morphological and physicochemical properties.

Accordingly, profile 1 and 3 had high base saturation status (greater than 50 percent) in all of its parts between 50 and 100 cm from the soil surface and qualified for endoeutric concept at the 3rd level. They also had a humic soil property which is having organic carbon content of greater than 1.4 percent as weighted average over a depth of 100cm from the soil surface and recognized meeting a humic qualifier at 4th unit level of classification. Therefore, soils represented by this profile (profile 1) were classified as Haplic Nitisols (Endoeutric, Humic) (FAO–WRB, 2006).

They are mapped as NT ha–ne, hu. Haplic Nitisols (Endoeutric, Humic) cover 3.5 % (12 ha) of the total area of the study watershed (Figure 2; Table 2,3,6).

Profile 2 experiencing high base saturation status (greater than 50 percent) between 20 and 100 cm from the soil surface and 80 percent or more in some layer within 100 cm of the soil surface qualified for hypereutric at the 3rd level. It also show a humic soil property as defined above and was a humic qualifier at 4th level. Accordingly, soils represented by profile 2 were classified as Haplic Nitisols (Hypereutric, humic) (FAO, 2006). They are mapped as NTha-he, hu. These soils covered about 18 % (61 ha) of the total area of the watershed (Figure 2; Table 2,3,6).

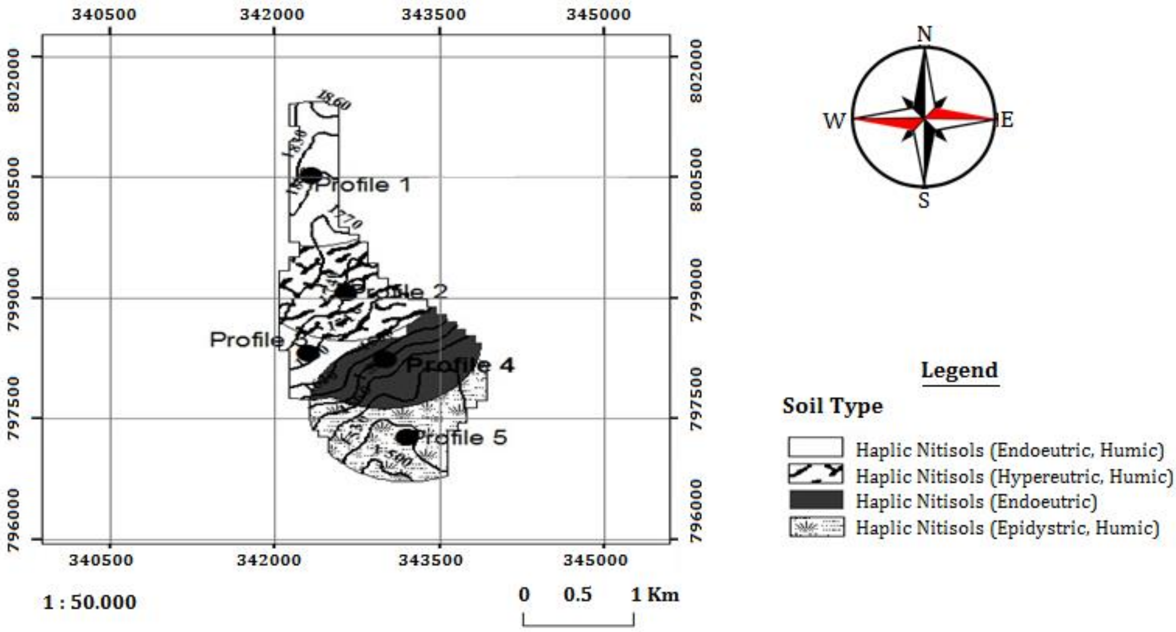

Figure 2. Soil map of Ambukuna catchment

Profile 4 showed high base saturation (greater than 50 percent) between 50 cm and 100 cm from the soil surface and qualified for endoeutric at 3rd level and as well does not qualify for humic as the others. It is mapped as Haplic Nitisols (Endoeutric) and (NT ha-ne) (FAO, 2006). The total area of these soils in the catchment is 141hectares i.e. 41.3 % of the total area of the study watershed (Figure 2; Table 2,3,6).

Profile 5 having medium base saturation (less than 50 percent) between 20 cm and 50cm from the soil surface qualified for Epidystric at 3rd unit level. It also showed a humic soil property as defined above and qualified for a humic qualifier. Accordingly, soils represented by profile 5 were classified as Haplic Nitisols (Epidystric, Humic) (FAO, 2006). They are mapped as NTha-ed, hu. The total area of these soils in the catchment is 127 hectare i.e. 37.2 % of the total area of the study watershed (Figure 2; Table 2,3,6).

Table 6. Description of soil mapping units and representative soil profile sites

Profile No.	Soil mapping units	Mapping units Symbol	Area	
			Ha	%
1 and 3	Haplic Nitisols (Endoeutric, humic)	NTha-ne, -hu	12	3.5
2	Haplic Nitisols (Hypereutric, humic)	NTha-he, -hu	61	18
4	Haplic Nitisols (Endoeutric)	NTha-ne	141	41.3
5	Haplic Nitisols (Epidystric, Humic)	NTha-ed, -hu	127	37.2
	Total		341	100

Agricultural constraints and potentials of the soils

Nitisols are among the most productive soils of the humid tropics and sub tropics (FAO, 2006). Nitisols are the extensively cultivated soils in the study area. Almost all identified units of the Nitisols had uniform characteristics with slight variation in physical properties (structure, texture, water holding, consistence, bulk density, colour); thus could have similar potentials and constraints for crop cultivation. The very deep solum, well drained condition, clay loam to clay texture, moderate - strong granular structure and relatively low bulk density values could form favourable soil conditions for agriculture. These properties allow free drainage, proper aeration, and ready infiltration of water and resist erosion- runoff processes. Furthermore, the friable to firm consistence, absence of a hard pan and/or of rock fragments imply that the soils are good for agriculture, as it is easy to cultivate and for penetration and development of plant roots.

Nitisols of the present study area are marked by low pH value (5.5 to 6.2) for surface soils. These values imply that the soil is moderately acidic to slightly acidic in reaction. According to Brook (1983) the most favourable pH for availability of most nutrients correspond roughly with the optimum range of 6-7 for most of the crop plants. This level of soil reaction of the soils may limit crop production and productivity by influencing availability of important nutrients as discussed above. Therefore, crops that are highly sensitive to acidity either cannot grow or their yield would be markedly reduced. Based on Table 10, profiles 1, 2, 3, 4 and 5 are commonly suitable for Carrot, Citrus-Lemon, Citrus-Orange, Coffee, Potato (sweet), Pumpkin and Sorghum. Soil acidity limits or reduces crop production primarily by impairing root growth there by reducing nutrient and water uptake (Marschner, 1995). Moreover, low pH or soil acidity converts some available soil nutrients in to unavailable form and also acidic soils are poor in their basic cations such as Ca, K, Mg and some micronutrients (e.g. Mo) which are as essential to crop growth and development (Wang et al., 2006).

According to the rating of Landon (1991), CEC of the surface horizons of Nitisols of the area can be rated as medium to high. Furthermore, such high CEC value provides the soil with high buffering capacity so that one can apply the required amount of fertilizer dosage without any immediate negative effects on the soils. On the other hand, the medium CEC values in the surface and subsoil horizons show the potential danger of nutrient losses due to leaching.

The percentage base saturation is frequently considered to be an indication of soil fertility. Soils with percentage base saturation of <20%, 20-60% and >60% are considered as low, medium, and high in fertility quality (Landon, 1991). Thus, the Nitisols of the present study area exhibited medium to high percentage base saturation levels (Table 6) which implies that basic cations were lost from the soil through the processes of leaching due to the high rainfall. Thus, as mentioned above low potential levels of basic cations could be the other major constraints of these soils. However, for profile 4 and 5, Mg may limit crop production predominantly as the Ca: Mg ratios between 4 and 6 are higher values that profiles 1, 2 and 3 are found in optimum range for agricultural production (Table 6; Brook, 1983). The exchange complex of the soils is dominated by Ca followed by Mg, K and Na (Table 6). According to Havlin and Tisdale (1999), the prevalence of Ca followed by Mg, K, and Na in the exchange site of soils is favourable for crop production. The exchangeable Na content of the soils is low and the exchangeable sodium percentage (ESP) of the soils was also less than 2%. This indicates that there is no sodicity problem in these soils. According to Brady and Weil (2002), ESP of 15% is considered as critical for most crops. According to Sims (2000), the range of critical values for optimum crop production for K, Ca and Mg are from 0.28 - 0.51, 1.25 - 2.5, and 0.25 - 0.5 cmol (+) kg^{-1} soil, respectively. Accordingly, the exchangeable K, Ca and Mg content of the soils are above the critical values. However, this does not prove a balanced proportion of the exchangeable bases. Potassium uptake would be reduced as Ca and Mg are increased; conversely uptake of these two cations would be reduced as the available supply of K is increased (Havlin and Tisdale, 1999). In addition, the ratio of exchangeable Ca/Mg should not exceed 10/1 to 15/1 to prevent Mg deficiency and also the recommended K/Mg are < 5/1 for field crops, < 3/1 for vegetables and sugar beets and < 2/1 for fruit and greenhouse crops (Havlin and Tisdale, 1999). The Ca/Mg ratio of the studied soils was in the range of 1.22 – 5.98 indicating that the response of crops to Mg is not likely. The K/Mg ratio of the studied soils varied from 0.21 to 0.46 and hence it is within the acceptable range for crop production.

Potassium (K) is one of the essential elements required by plants for their growth and development. It plays a very important role in activation of enzymes, photosynthesis, starch synthesis, nitrate reduction and sugar degradation (Askegaard et al., 2004). K availability would not be a limiting factor for crop production as the Nitisols of the present study area were rich according to the classification set by Landon (1991) and Jones (2003). Kapkiyai et al. (1998) indicated that soil organic matter (OM) content is a critical component of soil productivity and its maintenance is a sound approach to maintaining productivity of continuously cropped soils. The same publication showed that changes in soil OM results from imbalances between organic inputs and losses, and declining soil OM are frequently observed when lands are converted from natural vegetation to agriculture. The status of organic matter and total nitrogen of the Nitisols of the study area were low to medium and medium for agricultural use respectively (Landon, 1991).

In general terms, the available P content of Nitisols is below the critical limit for the growth of most crops based on Landon (1991) classification. According to Jones (2003) rating the available P content of the study area soil indicated low in profiles 2, 3 and 4 which indicates a crop response to P fertilizers; medium in profile 1 which indicates a probable response and high in profile 4 which indicates a crop response is unlikely. Thus, the available P content of most of these Nitisols appears to be the most limiting nutrient for crop production. According to Mishra et al. (2004), P in the Ethiopian soils poses different scenario wherein only a very low fraction of total P is available to plants. Phosphorus in soils of the highlands of Ethiopia is the limiting element in crop production, as a result 70 to 75% of the agricultural soils of the highland regions of the country are P deficient (Shiferaw, 2004). According to Anetor and Akinrinde (2006) report, with high rate of P fertilizer additions, soil sorption sites are satisfied and P level increases to sufficiency for crop production.

Conclusion

As Ethiopia is an agricultural country, its development is strongly linked with the agricultural resource base. The soil as one component is the basic resource that provides opportunities and constraints for agricultural development. Therefore, knowledge about the soils of the country is important for technology transfer, decision making and planning and policy formulation. However, the soil information currently available is very limited and derived from small scale studies. As a consequence, it is not possible to give site specific appropriate recommendation for agricultural problems based on spatial variability of soil properties. Hence, there is a need to conduct soil research that includes characterization and classification of soil at a watershed level, which is useful to determine the full production potentials of the country together with the identification of the factors, which are likely to limit production. The present soil study performed a field survey guided by 1: 50,000 topographic maps.

The soils showed variations in morphological, physical and chemical characteristics and one major soil unit namely, Nitisols were identified. Soil colour showed variability due to variations in elevation and topographic position. The colour of the soils in the gently sloping to moderately sloping land were dark brown (7.5YR, moist) in the surface and dark reddish (5YR to 2.5YR) in the subsurface. Surface soils structure was very similar in all the studied profiles but showed variations among the surface and subsurface soils of study profiles. The drainage condition in all profiles of study area was relatively the same and well drained. The texture of the soils in the surface horizons exhibited to be clayey in all the studied profiles. Bulk densities of the soil showed spatial variability among the soils in accordance with the level of organic matter.

Generally, the reactions of the soils were acidic in the studied profiles irrespective of their position in the landscape. Distribution of organic matter and total nitrogen varied among the studied profiles in response to differences in landscape position, elevation and management history. It was observed that the level of organic matter increases with increase in elevation and decreases with depth in the profiles. Distribution pattern of total nitrogen nearly resembled that of organic matter implying the major source of nitrogen for the soil system is organic matter. Therefore, preservation and maintenance of organic matter is essential for successful crop production. Available phosphorus shows irregular variability implying phosphorus availability is governed by complex processes. Besides, the level of available phosphorus was ranged from low (profile 1) to high (profile 4) in topsoil of the study soil; it is one of the major limiting nutrient elements in the study area. Therefore, management of phosphorus is essential to fully exploit the potential of the soils for crop production.

The concentration of exchangeable basic cations (Ca, Mg, K, Na) showed great variability among the soil profiles both in the surface and subsurface horizons. The contents of exchangeable and available K in the surface horizons of all soils was very high. Thus, K fertilization may not be needed for the presently grown crops of the study area. Exchangeable Na was low throughout the profiles and horizons of the studied soils. As a result, adverse effect of Na would not be expected in the study area. Generally, exchangeable cations increased downward with depth in most of the profiles. However, in a few cases it was observed that topsoil (A-horizon) contained higher exchangeable base than the upper B-horizon. The ratios of Ca/Mg in most cases were higher than 6:1 indicating the probable occurrence of an imbalance of Ca and Mg. In most of the cases, CEC of surface horizons was higher than that of subsoil horizons and generally decreased with depth of profiles. Accordingly, the increase in clay contents with depth of the profile did not parallel with increase in CEC. These suggest that CEC variations could not be explained by amount of clay and OM. The percentage base saturation was generally high in most of the soils in the studied profiles in the A-horizons.Based on this study finding, some specific recommendations are forwarded as follows:

- Organic matter was rated from low to medium in the soil of the watershed and these should be managed by application of crop residue, compost, green manure and farmyard manure in order to improve agricultural potential of soils of the watershed.

- The soil test of Bejjo watershed of P content was rated low which should be improved by applying organic materials and P-fertilizers (rock phosphate) to maximize agricultural production.
- There was less soil water conservation practice in the watershed. The soil water conservation practice should be improved by applying different farmer participatory SWC structure practice.

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Assessing aggregate stability of soils under various land use/land cover in a watershed of Mid-Himalayan Landscape

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Abstract

Soil aggregate stability is considered as an important indicator of soil quality in the landscapes witnessing land degradation due to soil erosion by water. An increase in anthropogenic activities over the period of time has accelerated soil erosion that necessitated need to assess soil aggregate stability in various land use/land cover in the hilly and mountainous landscape. The study investigated the soil aggregate stability of surface soils in different land use/ land cover classes, hillslope unites as well as in respect to terrain parameters in the watershed. The watershed located in mid- Himalayan region of Tehri Garhwal district, Uttarakhand, India covering an area of 196 ha. The elevation of the watershed ranges from 1200 m to 1927 m. CartoDEM was used to derive terrain parameters i.e., aspect, slope and terrain indices like Terrain Wetness Index (TWI) and Stream Power Index (SPI) of the watershed. Among the various land use /land cover classes, aggregate stability in crop land was found to be in the range of 0.16 (lower hillslope) to 0.28 (mid hillslope), in forest ranged from 0.18 (mid hillslope) to 0.28 (upper hillslope) and in dense scrub ranged from 0.16 (middle slope) to 0.32 (upper/lower hillslope). The aggregate stability was further analyzed in relation with various soil (carbon, nitrogen, sand, silt, clay and pH) and terrain (slope, elevation, TWI and SPI) variables. Among these variables soil carbon, nitrogen, elevation, TWI and SPI were found to have moderate to high degree of correlation with soil aggregate stability. Prediction model developed by using the various significant soil and terrain parameters were found to be more effective (r2 = 0.50) than the models developed using only soil parameters (r2= 0.36) or only terrain parameters (r2= 0.37).

Keywords: Land Use/ land cover, Mid-Himalaya, soil aggregate stability, terrain parameters.

Introduction

Aggregate stability of a soil is the measure of the resistance of soil structure against mechanical or physico-chemical destructive forces. Soil structure is closely associated with soil characteristics like soil water regime, soil nutrient availability and soil erodibilty (Shaver et al., 2002). Aggregate stability is considered to be one of the main soil properties controlling soil erodibility (Cerdá, 1996). It is one of the major factors influencing plant growth by its adverse impact on root penetration, soil temperature and gas diffusion, water transport and seedling emergence. Increase in aggregate stability reduces the soil loss and ingresses the quality of macro-aggregates and total and effective porosity. It also helps in reducing the loss of carbon, nitrogen and phosphorous (Kasper et al., 2009).

Gülser (2006) observed decrease in the proportion of micro aggregates in the fractions 0.5 mm in size and increased the proportion of macro aggregates in the fractions 1.00 mm in size in various forage cropping treatments. He found significant increase in organic carbon (OC) content and aggregate stability in various

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forage cropping treatments in comparison to the fallow control treatment. Zhu et al. (2017) reported positive correlation of soil organic carbon (SOC) with soil aggregate stability index in natural restoration grassland whereas opposite in Chinese red pine forest.

Erosion primarily hinders the development of soil structure. Since aggregates can only be made when there is limited loss of finer particles and cementing agents (Shi et al., 2010). Several studies had described the relationship between the aggregate stability indices and soil erosion (Le Bissonnais, 1996; Cantón et al., 2009). It is a vital and critical component of soil erodibility as it regulates the soil dispersion and surface seal development. Soil aggregate stability directly or indirectly related to soil erosion and degradation (Barthès et al., 1999; Tejada and Gonzalez, 2006; Mataix-Solera et al., 2011) performed a study on amended soils and suggested to adopt both erodibility and structural stability as a measure of soil vulnerability. Field investigation of soil susceptibility to water erosion is generally an expensive and time taking process (Barthès and Roose, 2000). Therefore, determining its relationship with soil aggregate stability is rather cheaper and easier approach to enable characterizing soil aggregation which can further be extended to investigate its susceptibility (Poch and Antúnez, 2010).

Several studies had focused on establishing relationship between organic carbon, soil erosion and the role of soil aggregation in organic carbon protection in different landscapes (Six et al., 2004; Berhe et al., 2007; Yadav and Malanson, 2007). Certain factors like temporal and spatial heterogeneity and complexity in soil continuum make it really difficult to measure aggregation and carbon storage in soil (Bronick and Lal, 2005). Water test of aggregate is discrete and indirect method to estimate aggregation which is a simple and fast way to understand the management effect on aggregation and carbon storage. (Shrestha et al., 2007) studied the relationship between soil aggregate stability and land use systems. The study showed that different land use systems and management practices have a significant impact on the soil's properties, especially organic carbon and soil aggregation. Soil aggregate stability can be substantially enhanced by increasing the organic carbon content which is more profound in soils having higher clay content. Soils with high organic matter and clay content develop better soil structure that ultimately provides high resistance to water erosion (Emadodin et al., 2009).

Topography is the key soil forming factor in climatically and geologically homogenous areas. It plays a significant influence on a wide range of soil physical and chemical properties (Gerrard, 1981). Quantitative topographic data are widely applied in studies to understand how topography influences the soil properties (Kumar and Singh, 2016). Digital Elevation Models (DEMs) are commonly being used for extracting terrain parameters of the landscape. Currently, global DEMs such as Shuttle Radar Topography Mission (SRTM) (version 4, C-Band DEM of 3 arc-second, 90 m resolution) and the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) (version 2, 30 m resolution) are available to the global users. However, CartoDEM (30 m resolution) is available for Indian Peninsula (Jain et al., 2017). High resolution provides improved estimation of terrain variables and help in better characterization of morphometric parameters of watershed and soil properties (Case et al., 2005; Hancock et al., 2006; Smith et al., 2006; Anornuet al., 2012; Das et al., 2016). Several studies have used ASTER, SRTM and Cartosat DEM with 30 to 90 m resolution in predicting soil parameters for small and large area (Saran et al., 2010; Ballabio et al., 2016). Terrain attributes are usually used regardless of the study scale or DEM resolution and are associated with the mathematical sense of particular variables (Florinsky, 2012). Kienzle (2004) compared terrain variables on 100 m elevation points with high resolution DEM and reported that elevation and slope has strong positive relationship while other terrain derivatives were not represented very well when derived from a coarse DEM.

Terrain attributes such as slope, aspect, Terrain Wetness Index (TWI) and Stream Power Index (SPI) are closely associated with the spatial heterogeneity of aggregate stability through their impact on various soil properties (Rhoton and Duiker, 2008). TWI is a study state wetness index its higher values represent drainage depressions, lower values represent crests and ridges and SPI used to describe potential flow erosion at the given point of the topographic surface. However, there are few studies concentrating on the soil aggregate stability and its relationship with terrain attributes. There are few studies conducted on the assessment of soil aggregate stability in various parts of the hill landscape systems (Rhoton et al., 2006; Tang et al., 2010) considering their direct relationship with topographic derivatives (Cantón et al., 2009). However studies exploring such relationships are rarely been conducted and reported from the fragile ecosystems of North West Himalayan region. Soils of the Himalayan region are very young and very prone to erosion. These soils have poor structural development. The present study was aimed to investigate the soil aggregate stability in different land use/ land cover as well as to assess the soil aggregate stability in relation to soil properties and terrain attributes of the watershed.

Material and Methods

Description of the study area

The study was carried out to study soil aggregate stability under various land use/land cover in a watershed represent mid-Himalayan region of Tehri Garhwal district of Uttarakhand state in India (Figure 1). The watershed is located at longitude of 78°25'2.556"E to 78°24'1.2"E and Latitude of 30°21'31.87"N to 30°21'21.51"N covering an area of 196 ha. The elevation in the watershed ranges from 1200 to 1927 m. The region is characterized as humid sub-tropical. The minimum and maximum mean temperatures in the region are 4.6° C in winter and 33.5° C in summer, respectively. The average annual rainfall is 1400 mm. The entire watershed consists of high hills and ridges which are deeply incised by the streams. The hilly landform of the watershed has been divided into upper, middle and lower hillslopes (Figure 2). The soils of the watershed is characterized as excessively drained to well drained and containing slight to moderate coarse fragment in the surface layer. Soils are shallow to moderately deep and sandy loam to loam in texture (Table 1, Figure 3).

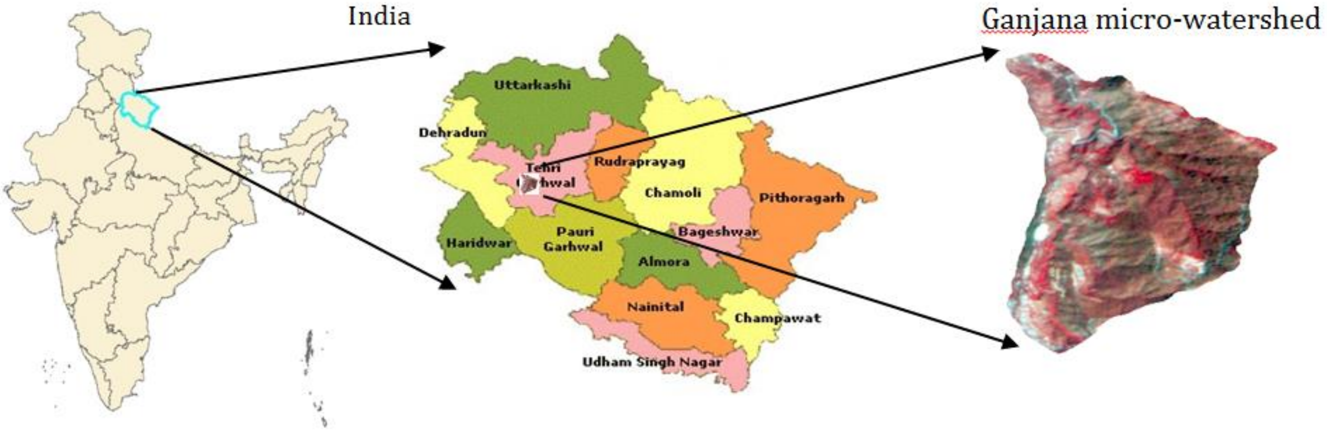

Figure 1. Location of the study area

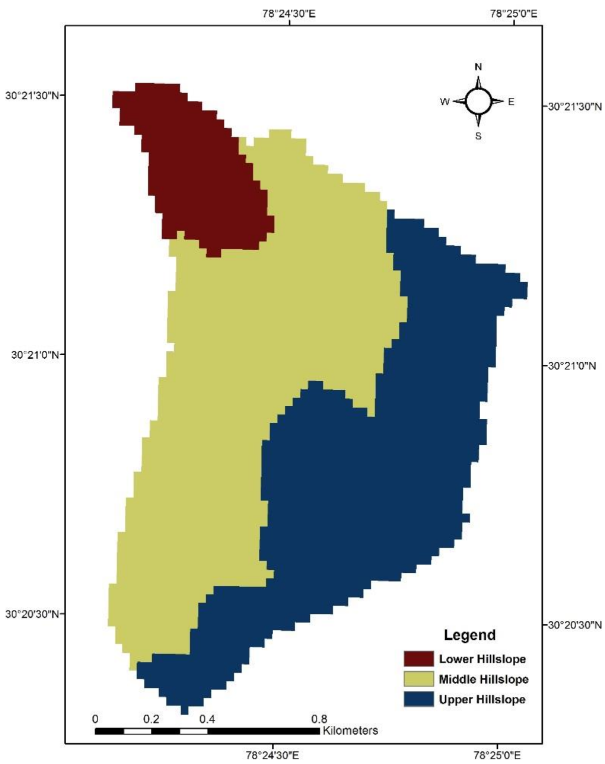

Figure 2. Landform map showing various hillslope units in the watershed

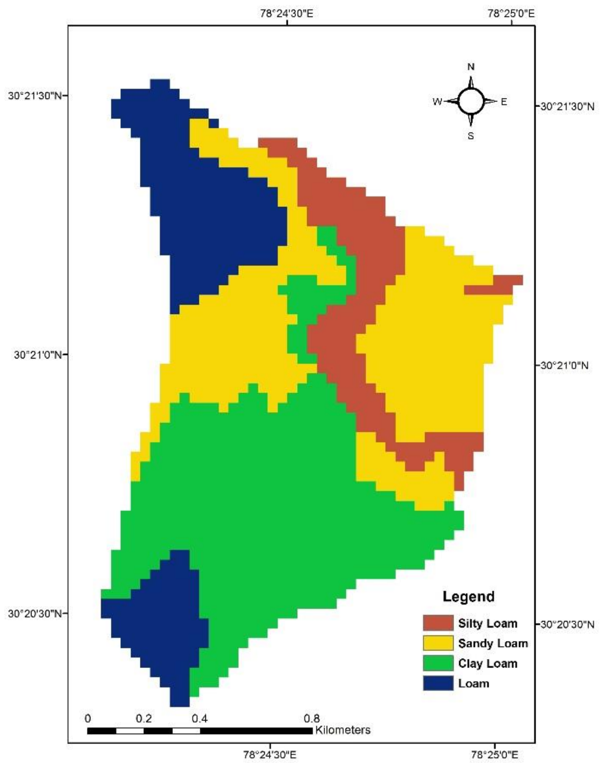

Figure 3. Soil textural class map of the watershed

Table 1. Site characteristics and physico-chemical properties of soils in the study area

S. no.	Variables	Range of Characteristics
1	Elevation (MSL)	1200-1927 m
2	Slope class	Undulating to very steep
3	Soil Texture Class	Sandy Loam to Loam
4	Soil Depth class	Shallow to moderate deep
5	Drainage class	Well to Excessive
6	Erosion class	Moderate to severe
7	pH	5.3-7
8	EC	0.02-0.66 dS/m
9	Total soil Carbon	1.2-3.28 %
10	Total soil Nitrogen	0.05-0.55 %

Data Used

Resourcesat-1 LISS-IV data was used to prepare land use land cover of the watershed by on screen visual interpretation at 1:25,000 scale. CartoDEM derived from Cartosat-1 satellite having a spatial resolution of 10 m was used to generate terrain indices like Stream Power Index (SPI), Terrain Wetness Index (TWI) and terrain parameters like aspect and slope. The CartoDEM was downloaded from website http://bhuvan.nrsc.gov.in/data/download/index.php. The DEM has vertical accuracy of 8 meter (Santillana et al. 2016). The salient characteristics of satellite data and DEM used in the study are given in (Table 2). The google earth image of the study area used for detailed understanding and preparation of the field plans.

Table 2. Salient characteristics of satellite data and DEM used in the study

Satellite data	Used for	Date of acquisition	Resolution			Source
			Spatial (m)	Radiometric	Temporal	
Resourcesat-2 LISS-IV	Land use/land cover	18/5/2016	5.8	10	5	NRSC data center
Carto-DEM	Terrain characterization	27/5/2016		10		bhuvan.nrsc.gov.in /data/download/

Methodology

Soil sampling

The watershed was classified into upper, middle and lower hillslopes based on elevations. Three number of transects were selected for soil sampling corresponding lower to upper hillslope positions with various land use/ land cover. Field sites were identified to collect soil sample in each hillslope of 0-20 cm depth (Figure 4). There were 15 no. of soil sample were collected from each hillslope unit accounting total 45 no. of soil samples in July 2016. The geographic coordinates were recorded using GPS. Soil sample were analyzed for soil aggregate stability and their physico-chemical properties. The soil samples were processed and soil texture (sand, silt and clay contents) was estimated by using Bouyoucos hydrometer method (Kroetsch and Wang, 2007). The total soil carbon (TC) and total nitrogen (TN) were estimated using CHNS elemental analyzer (Vario MICRO cube, Elementar Inc., Germany). Soil pH (1:2) was measured using a pH-meter.

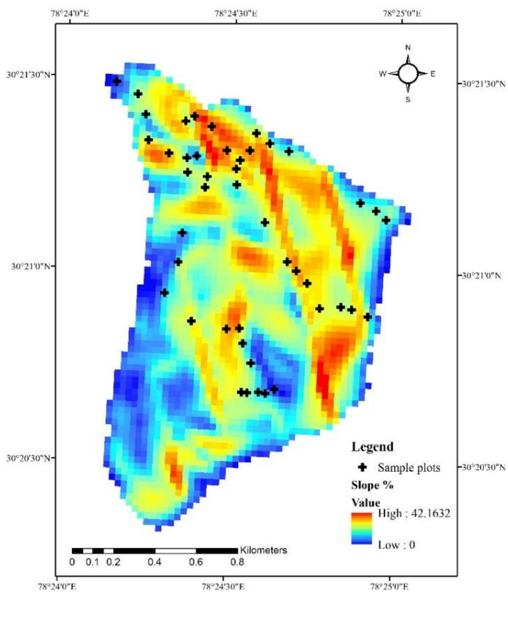

Figure 4. Slope map of the study area showing the field sample point

Soil aggregate stability analysis

The aggregate stability was analyzed using Wet Sieving Apparatus following the procedure described by (Nimmo and Perkins, 2002). Aggregates were determined on 2-mm sieved, air dried soil samples of 4 g, premoistened the aggregates for 5-10 minutes. The sample was then wet-sieved using a motor –driven holder lowering and raising 0.25-mm sieves in containers of deionized water, the stroke length was 1.3 cm and sieving frequency was 34 cycles min^{-1} for 3 minutes. The fraction < 0.25 mm was collected to determine fraction < 0.25 mm by sedimentation, the fraction > 0.25 mm was dried at 105°C and then weighed. The aggregates remained on the sieve were next sieved in the solution of sodium hexameta phosphate (0.05M) until only sand particles remained on the sieve using the same device. Then it was dried at 105° C and weighed. The index of water stable aggregates, (WSA), was then determined as:

$$WSA = \frac{WDS}{WDS+WDW} \tag{1}$$

where;
WDS – weight of aggregates dispersed in the dispersing solution (M)
WDW – weight of aggregates dispersed in distilled water (M)

Terrain analysis

Terrain parameters of watershed were extracted using CartoDEM. Integrated algorithms were utilized to compute terrain parameters such as slope, aspect, flow direction, flow accumulation. The following terrain parameters such as slope, Terrain Wetness Index (TWI) and Stream Power Index (SPI) the average value 3x3 pixels of the samples sites was computed using ArcGIS 10.2.2

Slope

It is primary terrain attribute used to describe the steepness of the area. Mathematically it is the rise over run. The range of slope values in the watershed varies from 0 to 90 degrees.

Terrain wetness index (TWI)

It is one of the secondary terrain parameters also known as CTI (Compound Topographic Index), it quantifies the contribution of topography on the soil erosion generated at a particular sites. The terrain wetness index was computed as (Beven and Kirkby, 1993):

$$TWI = \ln (As/\tan\beta) \tag{2}$$

where,
A = Upstream contributing area (m^2)
β = Local slope gradient

Stream power index (SPI)

It is the secondary terrain parameter. It represent the rate of depletion of energy by the flowing stream of water on the channel bed and basins, which determines the strength of the flowing water body to carry soil particles and sediments.

$$SPI = \ln (As * \tan\beta) \tag{3}$$

where,
A = Upstream contributing area (m^2)
β = Local slope gradient

ArcGIS 10.2 used for creating and using maps, compiling geographic data and managing geographic information in a database.

Statistical analysis

The multiple linear regression analysis was used to evaluate the relationships between the soil aggregation stability with soil properties and terrain variables. The simple correlation between the variables was assessed using Pearson correlation coefficient. Two factors with replication analyses of variance ANOVA procedures was computed to establish relationship between aggregate stability under various land use/land cover using statistical package (SPSS) version 16.0. (R Studio) was used for statistical and graphical techniques, that includes linear and multiple linear modeling, classical statistical tests.

Results and Discussion

Land use/ land cover and terrain characteristics of the watershed

Land use/land cover type map of the study area was prepared by visually interpreting the standard FCC of satellite data by onscreen digitization. The major land use/land cover types interpreted in the watershed were crop land, open forest, dense scrub, open scrub and settlement.

Dense scrub (45.07 %) formed the predominant land use/land cover type followed by agriculture (36.90%) (Table 5; Figure 5). Analysis of soil aggregate stability data in the present study revealed that highest aggregate stability was found in dense scrub land with a mean value of 0.26, followed by forest land (mean value of 0.23) and cropland (mean value of 0.22) respectively (Table 4). Lower soil aggregate stability in cropland may be attributed to frequent disturbances caused by human activities such as plowing as well as other inter cultural operations, which are very minimal or absent in case of scrub and forest lands. The elevation within the watershed varied from 1200 to 1927 m above MSL. Elevation range in the watershed of >1713m was categorized as upper hillslope and < 1489m as lower and 1489 To 1713 m as mid-hillslope area. Within the entire study are TWI and SPI value ranges from 3.52-15.14 and 4.03-18.1 respectively (Figure 6 & 7). The watershed was characterized by highly rugged terrain with steep slope. Larger area (>85%) of the watershed was characterized with slope of more than 25 percent, whereas 17 percent of the area had slope values greater than 60 percent (Table 6).

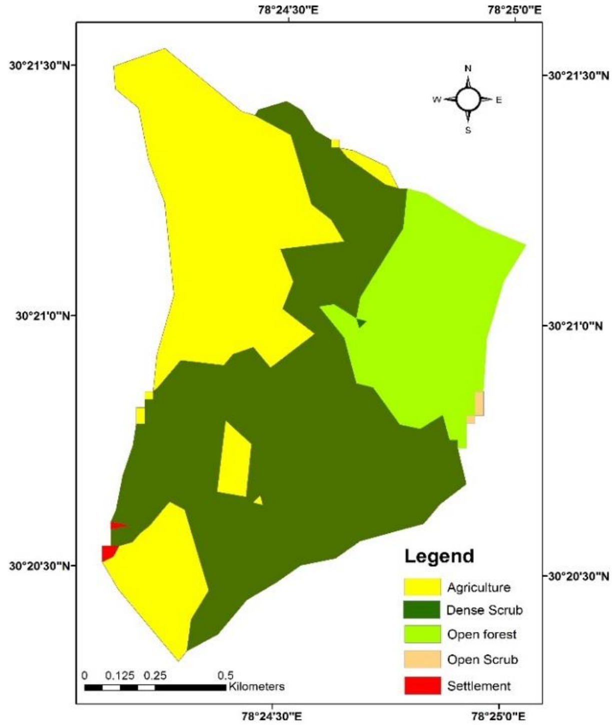

Figure 5. Land use land cover map showing various LU/LC units in the watershed

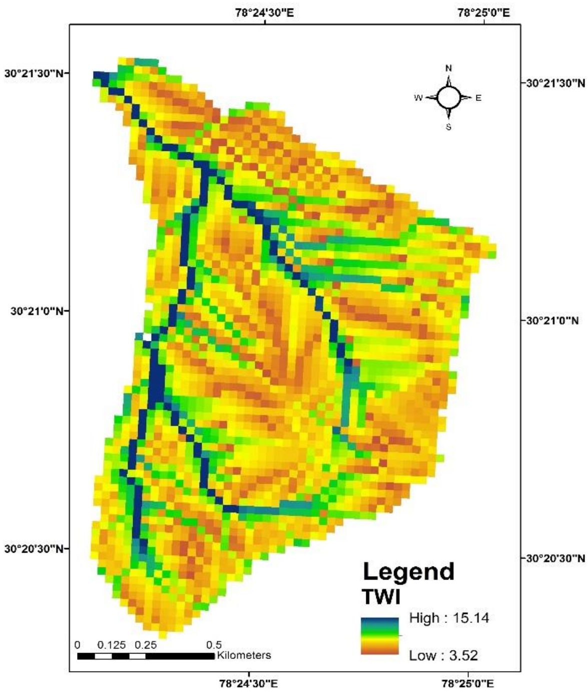

Figure 6. Terrain Wetness Index (TWI) map of the watershed

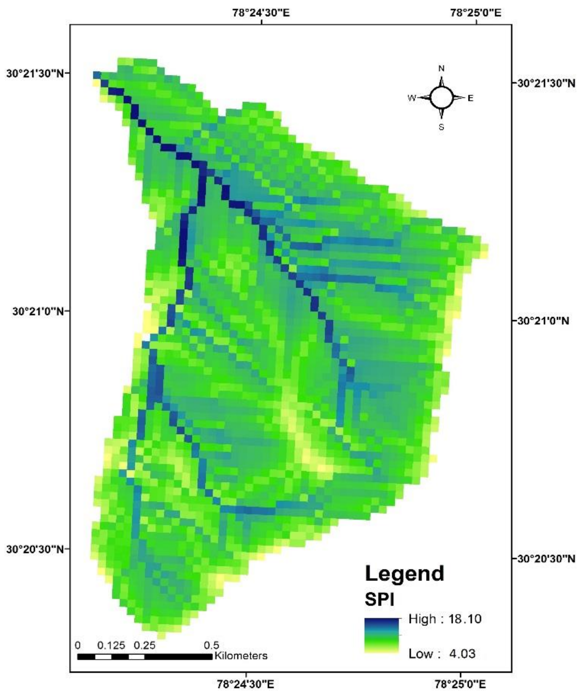

Figure 7. Stream Power Index (SPI) map of the watershed

Table 4. Distribution of aggregate stability in different land use with respect to hillslope units

Land use/land cover	Hillslope Units						Aggregate Stability Value with in study area
	Upper		Middle		Lower		
	Mean	SD	Mean	SD	Mean	SD	Mean
Crop land (12)	-	-	0.28	0.18	0.16	0.09	0.22
Forest land (18)	0.28	0.09	0.18	0.06	-	-	0.23
Dense Scrub (15)	0.32	0.04	0.16	0.17	0.32	0.13	0.26

Table 5. Watershed area under various land use / land cover classes

Land use/land cover	Area in (Ha)	Area in (%)
Agriculture	72.18	36.9
Dense Scrub	88.89	45.07
Open Forest	35.34	17.61
Open Scrub	0.36	0.14
Settlement	0.33	0.27

Table 6. Watershed area under various slope classes

Slope Class	Slope Value %	Area in (%)
Nearly Level	0-10	1.49
Gentle Sloping	10-25	12.98
Moderate Slope	25-40	29.35
Steep	40-60	39.16
Very Steep	>60	17

Physico-chemical characteristics of soils

The soil analysis revealed that the soils of the watershed are slightly acidic with a mean pH value of 6.01. It containing high amount of soil carbon with an average value of 2.26 percent and nitrogen with a mean value of 0.18 percent (Table 3). The predominant soil textural class in the watershed was sandy loam to loam.

Table 3. Distribution of SOC, N, Sand, silt, clay and pH in different hillslope units

Soil Variables	Hillslope Units						Value with in entire study area
	Upper		Middle		Lower		
	Mean	SD	Mean	SD	Mean	SD	Mean
Carbon	2.44	0.50	2.25	0.61	2.11	0.59	2.27
Nitrogen	0.20	0.06	0.19	0.13	0.16	0.03	0.18
Sand	35.38	12.45	45.48	14.07	38.64	6.91	39.83
Silt	41.10	11.27	35.1	9.69	39.37	6.04	38.52
Clay	23.63	3.52	19.41	5.65	22.65	3.16	21.89
pH	6.06	0.30	6.01	0.30	5.97	0.38	6.01

Aggregate stability of soil

Aggregate stability in various Land use/land cover

Several studies have been carried out to determine the influence of the land use of the soil, topographical position, and management practices on the soil organic matter (SOM) content and stability of soil aggregates (Lyneh, 1984; Cambardella et al., 1994; Bricchiet al., 2004; Annabie et al.,2017; Ouet al., 2017). Analysis of soil aggregate stability data in the present study revealed that highest aggregate stability was found in dense scrub land with a mean value of 0.26, followed by forest land (mean value of 0.23) and cropland (mean value of 0.22) (Table 4). It has been observed that cropland soils had significantly lower soil aggregates stability than that of other land use types (Zhao et al., 2016). Zhang (2012) reported soil organic matter (SOM) contents in surface soils followed in a descending order of scrubland, grassland, woodland and cropland, respectively. Lower soil aggregate stability in cropland may be attributed to human activities such as plowing**.** Plowing can destroy the natural soil structure (Reicoskyet al., 1995) and the decomposition of SOC (Rovira and Greacen, 1957; Davidson and Ackerman, 1993). High soil organic carbon will bind the soil particles through the formation of various organo-mineral as well as organo-clay complexes thus resulting in soil aggregate high stability. SOM serves as a cementing in the soil aggregates development (Six et al. 2002). These complexes provide high aggregate stability because of their strong ability to withstand action of erosion causing forces mainly water, due to their strong binding action. The positive effect of high organic matter on aggregate stability are much prominent and distinct in soils with higher clay content, because of their synergistic effect in binding of molecules by formation of chemical bonds. Soil aggregation increases with an increase in SOM content and clay mineral in the soil (Bronick and Lal, 2005; Fernández-Ugalde et al., 2013). Several studies revealed a linear relationship between organic carbon content and water stable aggregates for various soils (Angers, 1992; Carter,1992).

Among the various hillslope positions, upper hillslope has no agricultural area. It is covered with natural pine forest and dense scrub. Soil of dense scrub land showed higher aggregate stability ranged from 0.16 (middle slope) to 0.32 (upper/lower hillslope) followed by soil in forest cover ranged from 0.18 (mid hillslope) to 0.28 (upper hillslope). In mid hillslope area of the watershed cropland showed the highest stability (0.28) followed by forest and dense scrub cover (Table 4). Agriculture is major land use in lower hillslope with dense scrub land in patches, where no forest cover was observed. In lower hillslope scrub land showed the highest values for soil aggregate stability followed by cropland (Amézketa, 1999) studied macro aggregation at various hillslope positions and observed higher aggregation in surface soil at the lower slope position as well as an increase in soil organic carbon (Stanchi et al., 2015) found higher aggregates stability in the soils due to lower erosion rate at lower hillslopes.

Land use / land cover types strongly influences distribution of soil organic carbon (SOC) contents in the soil (White et al., 2009; Fang et al., 2011). Soils under forest cover had high soil organic carbon than the soils of cropland. (Sreenivas et al., 2016) showed highest SOC density in forest soils than the agricultural land in India. SOC accumulation from vegetation biomass contributes to the enhancement of soil aggregation and vice versa (Six et al., 2000). In cropland soils, soil disturbance from tillage destabilizes aggregates, releasing intra-aggregate organic matter and increasing decomposition of soil carbon (Grandyand Robertson, 2006; Six et al., 1999, Six et al., 2000). It results decline in SOC in cropland and therefore poor aggregate stability in the soils of cropland. Besides this, SOC accumulation is also strongly influenced by soil erosion and deposition that differs at slope position in the watershed. Organic matter acts as major binding agent and stabilizer to natural soil aggregates (Greenland et al., 1962; Six et al., 2004).

In the present study, scrub land located in upper hillslope showed highest aggregate stability in the watershed. Forest soils had higher soil aggregate stability than the crop land attributed to the high SOC contents in the forest land. Forest land in upper hillslope had higher aggregate stability as these soils witnesses less surface runoff and eventually low soil erosion. Soils of crop land of mid-hillslope had high aggregate stability than the lower hillslope as it receive higher surface runoff water from upper hillslope area resulting removal of SOC from soil and these soils witness higher soil erosion rate. (Zhang et al., 2015) showed decrease in the surface runoff and soil erosion in forest land compared to crop land and fallow land in the Hilly Watershed of Southern China. Similarly, (Zhang et al., 2006) reported less SOC contents in toe-slope (lower- slope) portions than those above the toe-slope (i.e. upper- and mid-slope portions) in the watershed. Soil aggregation and soil carbon accumulation differed between slope positions (Tang et al., 2010). (Liu et al. 2003) pointed out that terrain characteristics have significant impacts on soil C dynamics. Further, topographical influences on soil C can interact with management, resulting in altered responses to management such as tillage (Senthilkumar et al., 2009) and land use (Tan et al., 2004) depending on slope positions in the landscape.

Aggregate stability relation with soil and terrain variables

Topography significantly influences physical and chemical properties of soils. Terrain attributes derived from digital elevation models (DEMs) have been widely used in predicting soil properties (Camplig et al., 2002; Lai et al., 2006; Wang et al., 2007, Kumar and Singh, 2016). Spatial variation in SOC strongly influenced by the topography (McBratney et al., 2003; Schwanghart and Jarmer, 2011) and local terrain attribute algorithm better capture the spatial variation of SOC in the landscape (Behrens et al., 2010). In the study, Multiple Linear Regression Analysis was performed considering soil aggregate as dependent variable and all other factors as independent variable. Here, the correlation coefficient quantifies the linear association between the dependent and independent variable. The value of the coefficient (ß1) shows the affect independent variable on the dependent variable. The P-value is used as a measure to reject null hypothesis, P-value of 5% ($p < 0.05$) or less is the generally accepted point at which to reject the null hypothesis. The coefficient (ß1) and P-value are calculated to identify the best factors that can be used to model the change in soil aggregation. Regression analysis for AS prediction of different land use land cover types revealed varying influences of soil and terrain variables for prediction. Among the different land use type's regression models were able to predict AS prediction, with varying accuracy levels. (R^2 values (r^2=0.27), (r^2=0.75) and (r^2=0.95) respectively. higher soil aggregate stability found in scrub lands may be minimal or absent frequent disturbances caused by human activities such as plowing as well as other inter cultural operations, which are very common in crop land. The Prediction variables were found to be the same. But the level of significance varied much among the different land use land cover types with respect to AS.

An attempt was also made to study the relationship between various soil variables and the soil aggregate stability. Various soil properties like total soil carbon, total nitrogen, pH, clay and silt were estimated by the laboratory analysis of soil samples. Among these variables, carbon and nitrogen were found to exhibit statistically significant ($p < 0.05$) correlation with soil aggregate stability. Multiple linear regression model (r2=0.36) was developed using the various soil properties for the prediction of soil aggregate stability (Table

7). Gulser (2018) analyzed water stable aggregates of surface cultivated soils and found clay, sand, pH and organic matter (OM) contents as the most effective variables in predicting soil aggregate stability.

Table 7. Relationship between soil aggregate stability and different soil variables

Soil variables	Aggregate stability Vs Soil Variables			
	R2	Intercept	β1	P-Value
Carbon (C)			-0.079	0.01
Nitrogen (N)			-0.609	0.009
Clay (%)	0.36	0.69	-0.0051	0.223
Silt (%)			-0.001	0.559

Various soil and terrain parameters had significant relationship with soil aggregate stability and were further used for developing statistical model for predicting soil aggregate stability. Among the terrain variables slope gradient, curvature (profile and plan), topographic wetness index (TWI) and stream power index (SPI) are the most important variables influencing aggregate stability of soils (Walock and McCabe, 1995; Pennock, 2003). An analysis was attempted to study relationship between soil aggregate stability and terrain variables. Among the different terrain variables, elevation, TWI and SPI were found to have significant relationship with the soil aggregate stability. Regression model for the prediction of soil aggregate stability was also developed using these terrain variable (r^2=0.37) (Table 8). Several studies described significant relationship between the terrain variables and soil aggregates stability (Rhoton and Duiker, 2008; Canton et al., 2009). Aggregate stability varies in different parts of the slope position and had a direct relationship with topographic derivatives (Rhoton et al., 2006; Canton et al., 2009; Tang et al., 2010). Zádorová et al. (2011) identified the plan curvature as the main variable influencing spatial distribution of soil organic carbon.

Table 8. Relationship between soil aggregate stability and different terrain variables

Terrain variables	Aggregate stability Vs Soil/Terrain Variables			
	R2	Intercept	β1	P-Value
Elevation			0.002	0.018
Slope			0.080	0.578
TWI	0.37	-0.64	-0.051	0.013
SPI			0.0003	0.034

The variables carbon, nitrogen, elevation, TWI and SPI having high correlation coefficient were selected. Multiple linear regression analysis using these variables yielded more accurate prediction model (r^2= 0.50) compared to the models developed using the soil and terrain parameters separately (Table 9).

Table 9. Relationship between the aggregate stability and selected soil and terrain variables

Soil and Terrain variables	Aggregate stability Vs Soil/Terrain Variables			
	R2	Intercept	β1	P-Value
Nitrogen			-0.154	0.434
Carbon			-0.082	0.009
Elevation	0.50	-0.266	0.0003	0.022
TWI			0.051	0.001
SPI			-0.019	0.246

The following plots obtained after performing regression analysis clearly revealed the existence of linear relationship between Soil aggregation, carbon, nitrogen, elevation, TWI and SPI as well as the normal distribution of the variables in the watershed (Table 10). Multiple linear regression equation to model soil aggregate stability and residual vs fitted plot and normal Q-Q plot revealed that error is comparatively lesser than the previous models developed using all the soil properties as well as terrain parameters (Figure 8, 9, 10). Normal Q-Q plot analysis was carried out to estimate the error in statistical model analysis revealed lesser error values of model developed with soil and terrain variables.

Table 10. Multiple Linear Regression equations to predict soil aggregate stability

Variables	Multiple Linear Regression	R^2
Soil	YAS=0.698-0.0795*Carbon-0.6097*Nitrogen-0.005*Clay-0.001*Silt	0.368
Terrain	YAS=-0.641+0.002*Elevation+0.080*Slop-0.051*TWI+0.0003*SPI	0.372
Soil + Terrain	YAS=-0.266-0.154*Nitrogen-0.082*Carbon+0.051*TWI-0.019*SPI+0.0003*Elevation	0.504

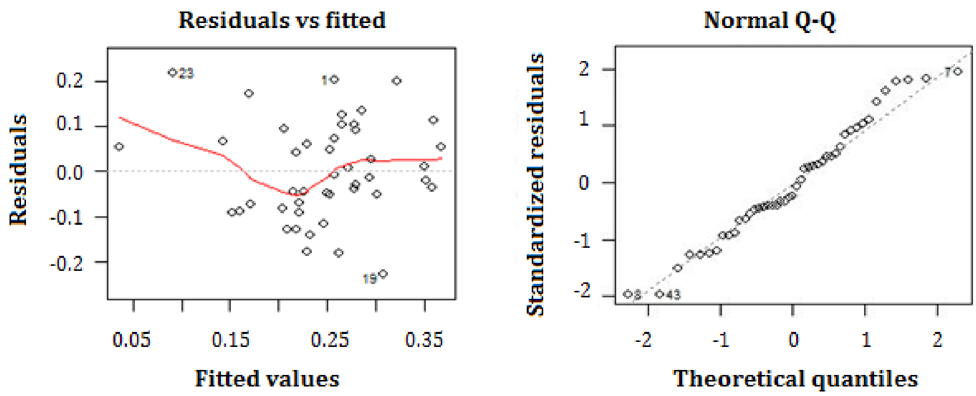

Figure 8. Soil aggregate stability with carbon, nitrogen, clay and silt as explanatory variable and the scatter plot and QQ plot were analyzed

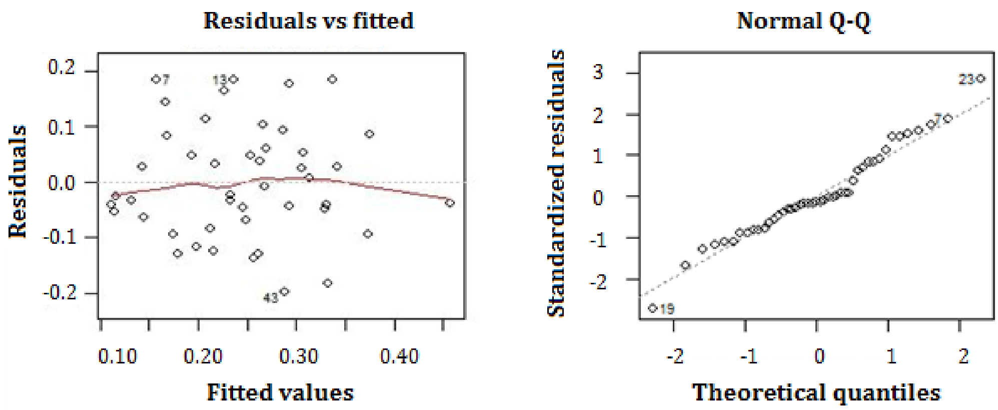

Figure 9. Soil aggregation with Elevation, slope, TWI and SPI as explanatory variable and the scatter plot and QQ plot were analyzed

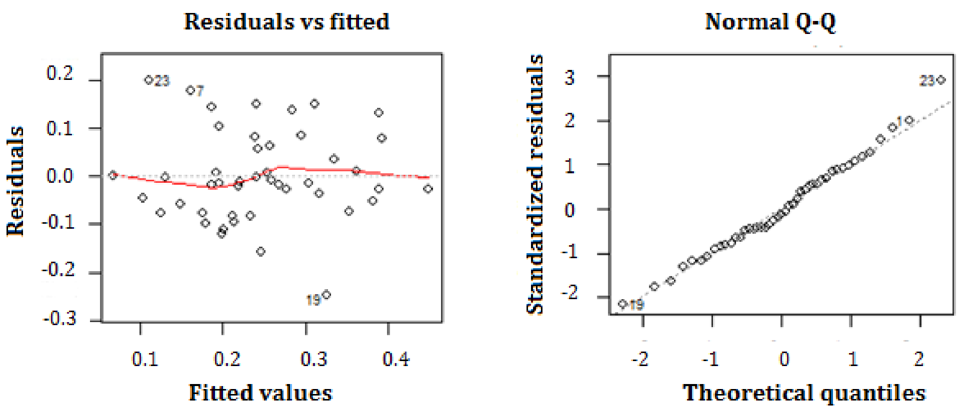

Figure 10. Soil aggregation with carbon, nitrogen, elevation TWI and SPI as explanatory variable and the scatter plot and QQ plot were analyzed

Conclusion

Aggregate stability of surface soil denote its resistance to susceptibility of soils. Changes in soil aggregate stability with respect to land use and topographic positons were investigated in Tehri Garhwal district of Uttarakhand state, India. Analysis revealed that the land use type had significant impact on the soil aggregate stability. Among the various land use /land cover classes, aggregate stability was found highest in dense scrub land with a mean vale of 0.26 ranged from 0.16 (middle slope) to 0.32 (upper/lower hillslope) followed by forest land (mean value of 0.23) ranged from 0.18 (mid hillslope) to 0.28 (upper hillslope) and lowest in crop land (mean value of 0.22) was found to be in the range of 0.16 (lower hillslope) to 0.28 (mid hillslope). Soil aggregate stability was found to be highest in dense scrub and lowest in crop land. This may be due to the high organic carbon rooting and proportion of vegetative cover in dense scrub, which limits/restricts the deteriorating impact of raindrops and runoff water on soil aggregates. 15 Aggregate stability was also correlated with soil and terrain variables, of which, carbon and nitrogen among soil variables and elevation, TWI and SPI among the terrain variables showed highest correlations, significant p-values and less error. Multiple linear regression analysis using soils and terrain variables resulted much better prediction model (r^2= 0.50) in comparison to the models developed using the soil and terrain parameters separately. The knowledge generated from this study will help us in identifying areas which are vulnerable to soil loss as well as nutrient due to the lower stability of aggregates. The relationships established between aggregate stability and terrain parameters will help us in spatial mapping of aggregate stability status with optimum number of sampling thus avoiding extensive sampling in these hilly mountainous terrains where inaccessibility is an issue due to terrain characteristics.

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Empirical model and variability of soil salinity in the coastal zone of Bangladesh

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Abstract

Soil salinity expressed by electrical conductivity is a threat to crop production. The study aims were to establish relationships of electrical conductivity with its relevant soil properties, and analyze variability of soil salinity in the coastal zone of Bangladesh. A total of 150 geo-referenced saline soil samples from three coastal districts (Khulna, Satkhira and Bhola) of Bangladesh were analyzed for electrical conductivity of saturated paste extract (ECe), salt cations and other soil properties related to salinity. Statistical and geostatistical analyses were done as required. Moderate to strong significant regression relationships (R^2=0.42 to 0.94) were found between ECe and salt cations (ECe=43.12*Na^2-46.36*Na+13.97; ECe=12.26*K-2.5;ECe=1.16*Ca-1.97; ECe=0.32*Mg^2-1.60*Mg+3.53) of the soils. On the contrary, weak relationships (R^2=0.05 to 0.21) were found between ECe and other soil properties (ECe=4.41*organic carbon-0.56; ECe=-1.71*Txw (soil texture)+3.98;ECe=0.35*cation exchange capacity-1.98; ECe=0.06*specific surface area-0.55). Khulna soils (CV=65.99%) showed lower statistical variations while Satkhira (CV=97%) and Bhola (CV=105%) soils showed higher statistical variations for ECe. In contrast, Khulna, Satkhira and Bhola soils showed strong, moderate and weak spatial dependency for ECe, respectively. Interpolated spatial distribution maps of ECe showed variations in individual districts of study areas. The findings would assist soil scientists or farm managers to understand and/or manage saline soils, specially the soils of coastal zone of Bangladesh.

Keywords: Geostatistics, electrical conductivity, map, relationship, soil property.

Introduction

Soil salinity is a serious environmental concern in agriculture. It has been predicted that globally 20% of cultivated and 33% of irrigated arable lands are affected by high salinity (Shrivastava and Kumar, 2015). A projection made by Jamil et al. (2011) stated that more than 50% of cultivable land would be salinized by 2050. Coastal lands are salanized because of intrusion of salty water from adjacent sea (Ravindran et al., 2007). These types of saline lands are important natural resource for the community of many geographic regions (Mondol et al., 2001). In Bangladesh more than 30% cultivable lands are salt affected (SRDI, 2012) which are located in the coastal belts nearby the Bay of Bengal. Soil salinity is a function of soil property, degree of inundation by salt water, management (e.g., shrimp culture) practices, the level and nature of ground water etc. By affecting drainage and retaining or mobilizing salt ions, the intrinsic property of soil regulates its salinity which is perceived universally by electrical conductivity of saturated paste extract of soil (ECe).

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Various empirical models have become important tools in research related to the quantification and integration of the most important properties and processes within soils. Wösten et al. (2001) stated that the use of models for research and management necessitate input parameters regulating retention and transport of water and chemicals in soils. Models like regression equations expressing inter-conversion relationship between soil properties were named as 'pedotransfer functions' (Bouma, 1989; Hamblin, 1991). The pedotransfer functions developed so far could not fill up the regional knowledge gaps and very little effort has been given to derive pedotransfer functions for problem soils including saline soils (Vereecken et al., 2016).

Past studies (e.g., Zhang et al., 2005; Sonmez et al., 2008) focused on deriving empirical regression equations to express relationships among respective salt ions in the extractions of different soil-water ratios. There are still research gaps on the regression relationships of ECe with the salt ions present in soil. Moreover, the regression relationships of ECe with other soil properties (other than salt ions) got little attention. In addition, a comparison on those regression relationships in a particular soil is still rare. Like other soil property, electrical conductivity of soil varies with the distance (or space) which is known as spatial variability that depends on the spatial resolution and the site-specific nature and property of soils. Understanding and estimating of spatial nature of soil salinity help its risk assessment (Florinsky et al., 2000) and the spatial correlation as well as its prediction can help making policy concerning environmental monitoring, remediation and land management (Juan et al., 2011). Little information is available regarding the extent of spatial variations of electrical conductivity in the coastal saline soils of Bangladesh. Moreover, with a specific scale and spatial resolution, a comparison between geostatistical and statistical variations of soil salinity in a particular soil is still unknown. Considering the above issues, the study was designed with the aim to (i) establish functional relationships of ECe with its relevant soil properties, and (ii) observe and compare the extent of statistical and geostatistical variability of soil salinity in the coastal zone of Bangladesh.

Material and Methods

Study areas and soil sample collection

One hundred and fifty geo-referenced soil (0-20cm) samples were collected from three salt affected districts (Khulna, Satkhira and Bhola) located in the coastal region of Bangladesh (Figure 1). The average annual temperatures of Khulna, Satkhira and Bhola districts are 26.1, 26.2 and 25.8 ^{O}C, respectively. Corresponding values for the average annual rainfall are 1736, 1655 and 2424 mm. And the districts are situated at 2.1, 3.96 and 4.3 m above sea level, respectively. The samples were collected during dry season (January 2015) and the dry seasonal evapotranspiration exceeds the seasonal precipitation in the areas. In the wet season, the areas remain predominately covered by paddy whereas in the dry, the land remains mostly fallow and vegetables/winter crops are grown in some upland. Being a coastal zone, the tidal salt water intrusion is the natural cause while the use of saline irrigation water and shrimp cultivation are the anthropogenic causes for salt build up in the areas.

Laboratory analyses of soil samples

Collected soil samples were dried in the air, ground in a mill (TI-200, HEIKO), and sieved in 2 mm mesh sieve. Exchangeable cations (Na, K, Ca and Mg) were determined by 1N ammonium acetate extraction methods (Soil Survey Staff, 2011). Particle size analysis was done by hydrometer method (Bouyoucos, 1962). Determination of organic carbon (OC) and cation exchange capacity (CEC) were done following wet digestion (Nelson and Sommers, 1982) and 1N ammonium acetate extraction (Jackson, 1973) methods, respectively. Specific surface area (SSA) of soil was determined using ethylene glycol monoethyl ether (EGME) as per procedure described by Cerato and Lutenegger (2002). Electrical conductivity of saturated paste extract (ECe) was determined by the slightly modified procedure of Rhoades et al. (1999). A saturated soil-paste was prepared by adding distilled water into a soil sample amounting 200g while stirring with a glass rod. The mixture was then allowed to rest for three hours so that salts could be dissolved and attained a uniformly saturated paste of soil-water. The saturated extract was collected by suction via a Buckner funnel and a filter paper (Whatmann no. 42) with a suction of 650 mm Hg with the help of a vaccum pump. Corrections on the readings were made considering cell constant of the conductivity meter and temperature of extract at 25°C.

Use of soil textural index (Txw)

Soil textural index Txw (Hossain et al., 2018) was used to represent soil texture. Txw indicates that soil fineness increases with decreasing the values of Txw.

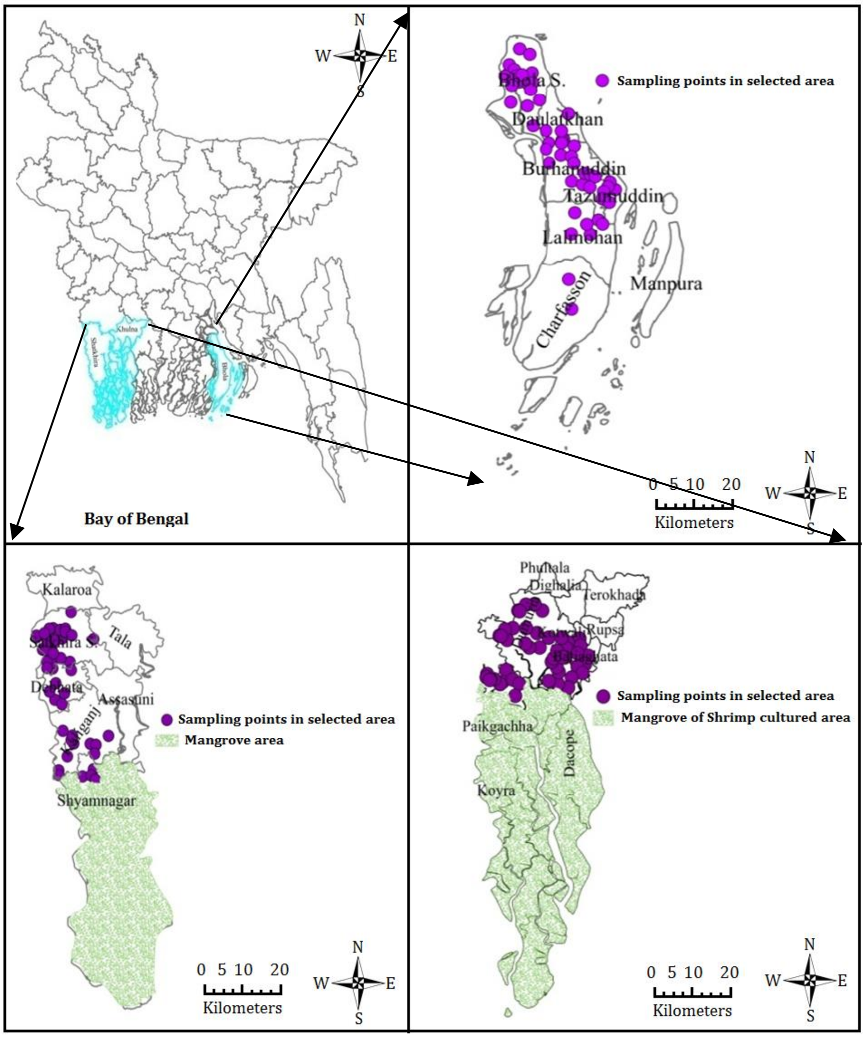

Figure 1. Sampling points in the districts of Satkhira (bottom left), Khulna (bottom right) and Bhola (top right) in Bangladesh

Statistical and geostatistical analyses

Statistical analyses were performed by Excel and SPSS (version 16.0) software. Derived regression equations were evaluated based on coefficient of determination (R^2) and significance of regression (P) (Kleinbaum et al., 1988). Kriging (Weisz et al., 1995; Ardahanlioglu et al., 2003) interpolation was performed using GIS software to get values of ECe in the un sampled or unvisited locations. Frequency histogram was viewed to judge data distribution. When data were not normally distributed, log-transformation and Box-Cox transformation of the original data were done to have better estimations using kriging method. Semivarigram model was used to estimate the spatial autocorrelation or spatial dependence of ECe. Any one of the spherical, stable, exponential or Gaussian model was chosen for best fitting to the experimental semivariogram of the concerned parameter (Isaak et al., 1989). The best fitting was judged depending on visual fitting and corresponding error component. The degree of spatial dependence was calculated as follows (De Benedetto et al., 2012; Hu et al., 2014):

$$\text{Degree of spatial dependance} = \frac{\text{Co (Nugget)}}{\text{C0+C1 (Sill)}} * 100$$

Results and Discussion

The relationships of ECe with exchangeable cations

The summary statistics of electrical conductivity, Na, K, Ca and Mg concentration in the study soils are shown in the Table 1. The ECe, Na, K, Ca and Mg values ranged from 0.24 to 16.17 dSm^{-1}, 0.38 to 1.02 $cmol_c kg^{-1}$, 0.15 to 1.5 $cmol_c kg^{-1}$, 0.50 to 12.51 $cmol_c kg^{-1}$, and 1.50 to 7.88 $cmol_c kg^{-1}$, respectively. The highest variability of ECe value was found in the area as indicated by the coefficient of variation (CV) value figuring 91.83% which was followed by the CV values of K, Ca, Mg and Na (Table 1).

Table 1. Descriptive statistics of the ECe and major salt cations in the entire study areas

Statistics	Ece (dS m^{-1})	Na ($cmol_c$ kg^{-1})	K ($cmol_c$ kg^{-1})	Ca ($cmol_c$ kg^{-1})	Mg ($cmol_c$ kg^{-1})
Mean	3.55	0.68	0.49	4.78	4.56
Standard Deviation	3.26	0.16	0.26	2.19	1.51
Minimum	0.24	0.38	0.15	0.50	1.50
Maximum	16.17	1.02	1.50	12.51	7.88
CV	91.83	23.53	53.06	45.82	33.11

CV: Coefficient of variation, ECe: Electrical conductivity of saturated paste extract

From the dataset as presented in Table 1, the regression equations of electrical conductivity of saturated paste of soil (ECe) on exchangeable cations (Na, K, Ca and Mg) were derived which are given in Table 2. It was found that the relationships of ECe with K and Ca follow linear regression model while the relationships of ECe with Na and Mg fitted well by second order polynomial regression models. The slopes of the line of ECe with Ca was very close to the unity indicating that the unit change of this cation can change the ECe value by about one unit. The slope for the line for K was around 10 times higher than that of Ca which denotes that unit change of K results in the tenfold change of ECe value.

Table 2. Regression equations of ECe with major dissociative salt cations and corresponding coefficient of determinations

***Equation with intercept	r^2	***Equation without intercept	r^2
$ECe=1.16*Ca-1.97$	0.61	$ECe=0.82*Ca$	0.54
$ECe=12.26*K-2.5$	0.94	$ECe=8.28*K$	0.81
$ECe=43.12*Na^2-46.36*Na+13.97$	0.57	$ECe=43.12*Na^2-4.85*Na$	0.51
$ECe=0.32*Mg^2-1.60*Mg+3.53$	0.42	$ECe=0.32*Mg^2-0.03*Mg$	0.40

ECe: Electrical conductivity of saturated paste extract; ***Regression equations (regression coefficients) are significant at $p<0.001$

Out of the two polynomial equations of ECe with Na and Mg, Na got very sharp slope (~43) that means it can change ECe more than all other cations. Higher slope for Na might be due to more hydrating capacity of Na. The coefficient of determination (r^2) was higher in case of K which was 0.94 meaning that 94% of the variability of ECe value is controlled or explained by K concentration. The values of coefficient of determinations were followed by the lines of Ca, Na and Mg amounting 61, 57 and 42%, respectively. When the intercept was deliberately set to zero, the equation was passed through the origin of the graph and the coefficient of determinations (R^2) were slightly decreased (Table 2). These types of equations (without intercept) are advantageous or useful when the values of independent variables are very small.

The relationships of ECe with soil properties other than salt ions

The summary statistics of the electrical conductivity relevant soil properties excluding salt ions are presented in the Table 3. The cation exchange capacity (CEC), organic carbon (OC), soil textural index (Txw) and specific surface area (SSA) ranged from 9.0 to 30.21 $cmol_c kg^{-1}$, 0.42 to 1.5%, -1.6 to 1.6 and 31.75 to 146.75 m^2g^{-1}, respectively. The coefficient of variations of CEC, OC, and SSA were found as 23.65, 18.28, and 33.50%, respectively.

Table 3. Descriptive statistics of EC related soil properties other than exchangeable cations

Statistics	CEC ($cmol_c$ kg^{-1})	OC (%)	Txw	SSA (m^2 g^{-1})
Mean	15.77	0.93	0.25	67.64
Standard Deviation	3.73	0.17	0.88	22.66
Minimum	9.00	0.42	-1.60	31.75
Maximum	30.21	1.50	1.60	146.75
CV (%)	23.65	18.28	-	33.50

CEC: cation exchange capacity, OC: organic carbon, Txw: Soil textural index simulating soil texture, SSA: Specific surface area, CV: coefficient of variation.

From the dataset as presented in Table 3, the regression equations of ECe with CEC, OC, Txw and SSA were derived which are given in Table 4. It was found that the relationships of ECe with all of these soil properties follow linear regression equations. Among the equations, the slope for the equation of OC was higher (~4.0) which was followed by the slope for the equation of Txw. The mineralization of the labile organic matter contributes to the increase of soil electrical conductivity as indicated by the OC dependent regression equation. Regarding soil texture, EC value increased with the decrease of the Txw value (the increase of soil fineness) at a rate of 1.71 due to more retention ability of salt cations by fine textured soils and less hydraulic conductivity of heavy soils. In case of CEC, the slope was smaller than the unity (0.35) and for the SSA, it was the lowest (0.05).

Table 4. Regression equations of ECe on relevant soil properties other than salt ions and corresponding coefficient of determination (R^2)

Equations with intercept	r^2	Equations without intercept	r^2
***ECe=0.06*SSA-0.55	0.18	***ECe=0.05*SSA	0.18
**ECe=4.41*OC-0.56	0.05	**ECe=3.83*OC	0.05
***ECe=0.35*CEC-1.98	0.16	***ECe=0.23*CEC	0.14
***ECe=-1.71*Txw+3.98	0.21	……………	….

SSA: Specific surface area, OC: organic carbon, CEC: Cation exchange capacity, Txw: Soil textural index representing soil texture, ECe: Electrical conductivity of saturated paste extract. ***Regression equations (regression coefficients) are significant at $p<0.001$; ** Regression equations (regression coefficients) are significant at $p<0.01$

By making comparison of the equations (coefficients of regression) as well as coefficients of determination (r^2) of ECe with salt cations (Table 2) and those with other soil properties (Table 4), we can note that the associations of salt cations to ECe values were much higher than those of other soil properties. In case of SSA, Manikandan (2016) found an elevated EC value in fine black soil (higher SSA) compared to coarse river sand (low SSA). Although his research did not measure the relationship, his positive finding supported our findings. Sultan (2006) observed that the correlation (r) of EC with silt and clay fractions of an Australian soil were 0.41 and 0.46 respectively. He also found that the correlation (r) between EC and organic matter in the soils of Creswick in Australia was 0.52. Valente et al. (2012) found that the correlation coefficient between CEC and EC was 0.35. Although these findings did not provide information on regression relationships, these supported our findings in relation to the coefficients of determination (R^2) in linear relationships.

Variability of electrical conductivity of saturated paste extracts of soil in the study area

In every district under study, summary statistics of the electrical conductivity of saturated paste extract (ECe) are given in Table 5. The average value of ECe for the district of Satkhira and Bhola were found as 2.71 and 2.5 dSm^{-1} respectively which are below the general threshold value for the rice crop generally called non-saline soil. But the ECe value of the soil of these districts varied from 0.24 to 12.30 dSm^{-1} and 0.26 to 15 dSm^{-1}, respectively. Also the coefficients of variations (CV) of ECe of these two districts were found higher amounting 105 and 97% for Bhola and Satkhira districts, respectively.

Table 5. Descriptive statistics of ECe in the individual district under study

Statistics	Khulna	Satkhira	Bhola
Mean	5.44	2.71	2.51
Standard Deviation	3.59	2.63	2.64
Minimum	0.62	0.24	0.26
Maximum	16.17	12.30	15
CV (%)	65.99	97.05	105

ECe: Electrical conductivity of saturated paste extract in $dS\ m^{-1}$

The mean value of ECe in the soils of Khulna was found 5.44 dSm^{-1} which is generally called slightly saline, although the ECe ranged from 0.62 to 16.17 dSm^{-1}. The CV value of ECe of the soils of this district was found least figuring 65.99%.

The degree of spatial variability was found out by the analysis of the components of the fitted semivariogram as shown in Table 6. The degree of spatial variability was expressed by the ratio of nugget to sill (expressed as percentage) known as nugget effect. De Benedetto et al. (2012) mentioned that at a regional scale low nugget effect (<25%) implies strong spatial autocorrelation (spatial dependency), high nugget effect (>75%) indicates a weak spatial autocorrelation of the variable, and otherwise a moderate spatial autocorrelation. As indicated by the ratio (Nugget/Sill) values (Table 6), the ECe of the soil of Bhola has very weak spatial dependency (nugget effect 80%) while the ECe of Khulna soil has strong spatial dependency (nugget effect 0%) and ECe of Satkhira soil has moderate spatial dependency (nugget effect 53%).

Table 6. Components of fitted semivariogram model for ECe & and model type used in individual district obtained by ordinary kriging

District	Transformation	Model type used	Nugget	Sill	(Nugget /Sill) %	RMSS
Khulna	Normal score	Stable	0.0	18.22971	0	0.85519
Satkhira	Box-Cox (ECe)	Exponential	1.58634	2.99216	53	1.06726
Bhola	Log (ECe)	Gaussian	4.99022	7.38175	80	0.87221

RMSS: Root mean square standardized

Hu et al. (2014) investigated the spatial variability of ECe in a watershed in China and found that ECe showed moderate and weak spatial dependency in the top and subsoil, respectively.

On the contrary, variations of the ECe of the soils of these districts were highest (CV=105%) for Bhola, moderate (CV=97%) for Satkhira and lowest (CV=65.99%) for Khulna (Table 5). Therefore, the extent of variability of ECe was found different between geostatistical spatial variability and statistical variability.

Spatial variability of ECe in the individual district under study

The nature of spatial variability of electrical conductivity (ECe) is visually observable in the interpolated map obtained by ordinary kriging. The spatial distribution map of ECe and corresponding standard error are shown in Figure 2, 3 and 4. Soil salinity classification (ECe: 0-2 dSm^{-1}: non saline; 2-4 dSm^{-1}: low salinity; 4-8 dSm^{-1}: mild salinity; 8-16 dSm^{-1}: high salinity and more than 16 dSm^{-1}: severe salinity) given by FAO (USDA) cited by Shirokova et al. (2000) was used only to discuss the spatial distribution of salinity.

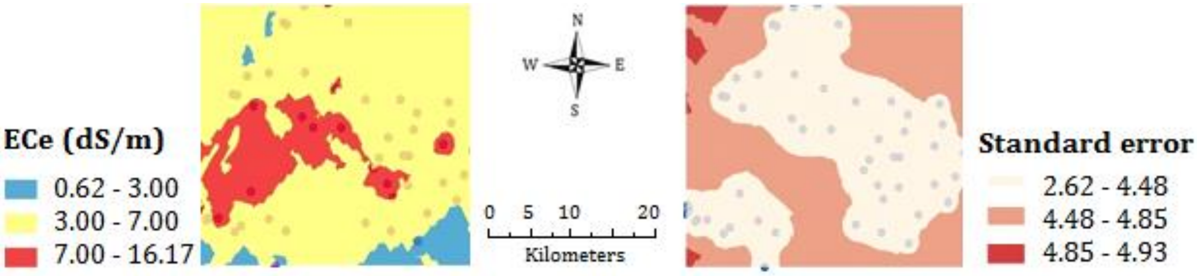

Figure 2. The spatial distribution of ECe obtained by ordinary kriging (left) and corresponding distribution of standard error (right) in the study area of Khulna

In Khulna, with the scale as shown in Figure 2, the area was dominated by the salinity soils ranging from low to mild saline soil (ECe=3.0 to 7.0 dSm^{-1}) which was followed by the area having salinity level mild to high (ECe=7.0 to 16.17 dSm^{-1}). A little area was fall under non to low salinity (ECe=0.62 to 3.0 dSm^{-1}). In case of Satkhira district (Figure 3), the southern part was saline soil (ECe=4.0 to 12.0dSm^{-1}) while the northern part under study was non saline (ECe=0.24 to 2 dSm^{-1}) and some portion was mild saline (ECe= 2.0 to 4.0 dSm^{-1}).

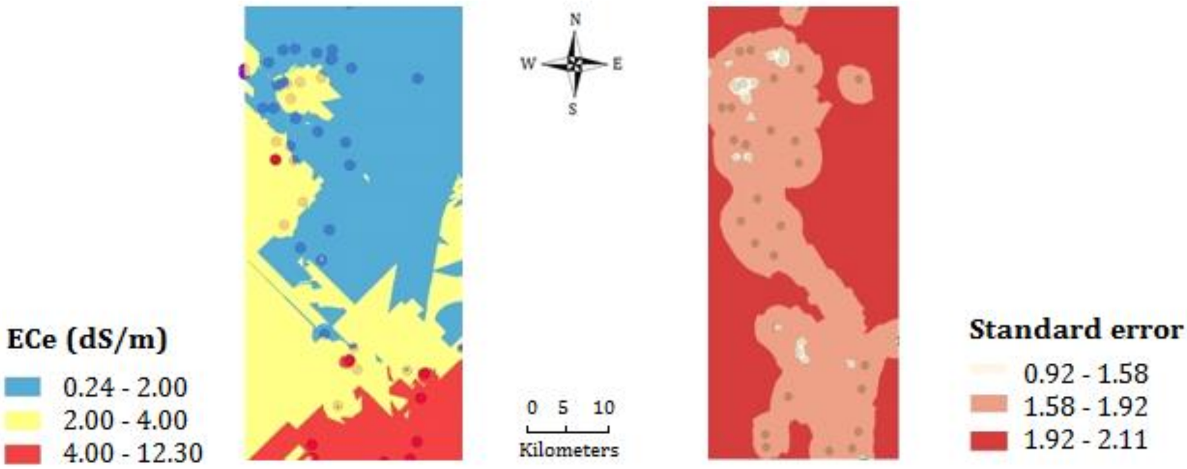

Figure 3. The spatial distribution of ECe obtained by ordinary kriging (left) and corresponding distribution of standard error (right) in the study area of Satkhira

In the district of Bhola (Figure 4), a little northern side was characterized by saline soils (ECe=4.0 to 15.0 dSm^{-1}) while remaining part was characterized by non-saline to low saline soils (ECe=0.26 to 4.0 dSm^{-1}).

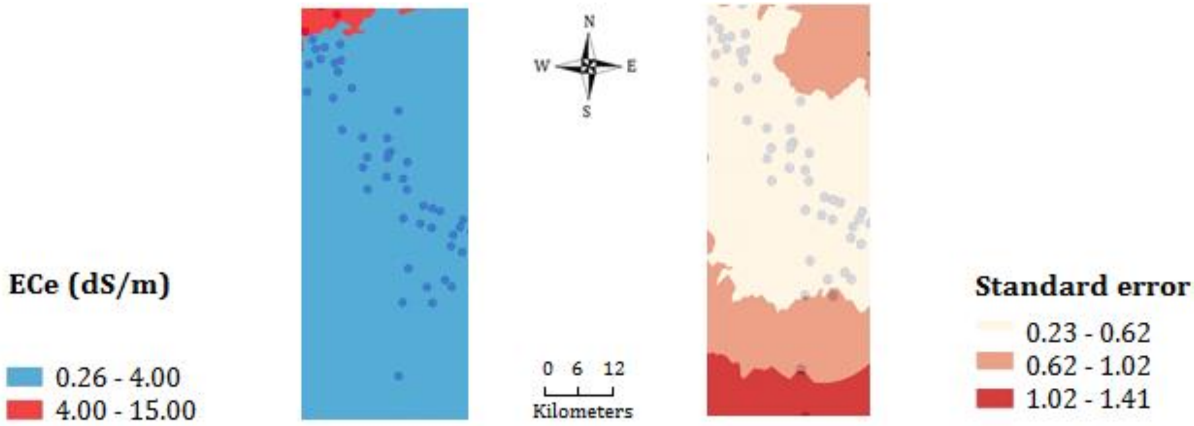

Figure 4. The spatial distribution of ECe obtained by ordinary kriging (left) and corresponding distribution of standard error (right) in Bhola

With the specific scale and spatial resolution of sampling, the variation of ECe across the distance was highest in Khulna which was followed by that of Satlkira and Bhola. The high salinity areas are more exposed to the salty tidal water that comes from the ocean (Bay of Bengal) located in the southern side. Some of these areas are used for shrimp culture ponding the salty water. The underlying soils become salty when these lands are dried up. In case of Bhola district, the flowing of fresh stream water in and around all sides except the south and washing the areas by its water may be a cause for non or less salinity characteristic in the majority part of the district. Geogenic nature of the soils might be a cause of saltiness in the northern part of the district. It was found that the corresponding standard errors (of spatial variations) in each district were the lowest in the area dominated or covered by sampling points.

Conclusion

The regression relationships of ECe with salt cations (Na, K, Ca and Mg) showed much higher association than those with other soil properties (organic carbon, soil texture, cation exchange capacity and specific surface area). The differential spatial variability of ECe was found in the three districts (Khulna, Satkhira and Bhola) under study. The study revealed that the extent of geostatistical spatial variability was not similar with that of the statistical variability of soil electrical conductivity. Depending on the salt tolerance, crops should be selected to grow in the various levels of salt affected areas. Shrimp culturing should be discouraged and intrusion of salty sea water should be controlled (e.g., by constructing dam) to prevent non-to-less salinity areas from further salt build up. Also, strategies should be undertaken globally to check global warming so as to curtail the rise of sea water and its consequent flooding into nearby upland.

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Pedogenetic characterization and classification of forest soils in the Central Middle Atlas (Morocco)

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Abstract

The study was carried out in the forests of the Central Middle Atlas where the soils have a Mediterranean character. The forest formations found include resinous species such as on Atlas cedar (*Cedrus atlantica*) and maritime mountain pine (*Pinus pinaster*), and deciduous species of green oak (*Quercus rotundifolia*) and zeen oak *(Quercus canariensis).* The morphological description of soils' genetic horizons was based on the opening of soil pedons in the forest formations composing the studied area. Then, physical and chemical characterization of the studied soils was analyzed. According to the Commission of Pedology and Soil Mapping (CPCS, 1967) principles and those of the international system of classification, nomenclature and soil mapping used by FAO (2015), three types of soils were identified as dominant in these forests, namely, the class of browned soils, iron sesquioxide soils and calcimagnesic soils. As a result, they differ in their responses to management practices, their inherent ability to deliver ecosystem services, as well as their resilience to disturbance and vulnerability to degradation.

Keywords: Browned soils, Calcimagnesics, Middle Central Atlas, iron sesquioxide.

Introduction

Forests and forest soils have been performing essential, complex and interactive functions in the environment for millions of years, soils support trees and forests. Soils are a major component of forests and forest ecosystems because they help to regulate important ecosystem processes, such as the absorption of nutrients, the decomposition of organic matter and the availability of water. They provide trees with anchorage, water and nutrients (FAO, 2015). On the other hand, forest soils can become an important source of CO_2 as a result of global warming, as the latter could lead to mineralization of organic matter higher than the net primary production of vegetation (Bernoux et al., 2005). Even small changes in the organic carbon reservoir in the soil can significantly affect the concentration of CO_2 in the atmosphere, since the soil contains twice as much carbon as the atmosphere (Schlesinger, 1977; Post et al. 1982; Watson et al., 1990).

Soil characterization studies are major building block for understanding the soil, classifying it and getting the best understanding of the environment (Onyekanne et al., 2012). Soil characterization provides the information for our understanding of the physical, chemical, and genetic properties of soil. It also helps to organize our knowledge, facilitates the transferring of experience and technology from one place to another (Chekol and Mnalku, 2012; Adhanom and Toshome, 2016). The Characterization and classification of these soils have therefore paramount importance in using those resources based on their capability and to manage them in sustainable manner. The soils of the forests of the Central Middle Atlas are of great importance and

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present a variability in their physical and chemical characteristics as well as in the genetic profiles. As a result, they differ in their responses to management practices, their inherent ability to deliver ecosystem services, as well as their resilience to disturbance and vulnerability to degradation (FAO, 2017). The objective of this study is to determine the physical and chemical properties of the genetic horizons of these soils while identifying the dominant soil types in this area.

Material and Methods

Presentation of the studied area

This study was carried out in three forests in the Central Middle Atlas, including the forest of Azrou, the forest of Jaaba and the forest of the south of Jbel Aoua (Figure 1). These forests are considered the most important in terms of area and have a diversity of forest composition and lithological material. The Middle Atlas is an intracontinental mountain range oriented NE-SW and extended over about 350 km that is part of the Atlas domain (Michard, 1976). These forests receive annual rainfall ranging from 800 to 1100 mm. Snowfall occurs sporadically from December to April with variable heights ranging from 20 to 60 cm. The climate in this area is Mediterranean with a bioclimatic atmosphere ranging from sub-humid to cool, to wet and to very cold (HCEFLCD, 2007).

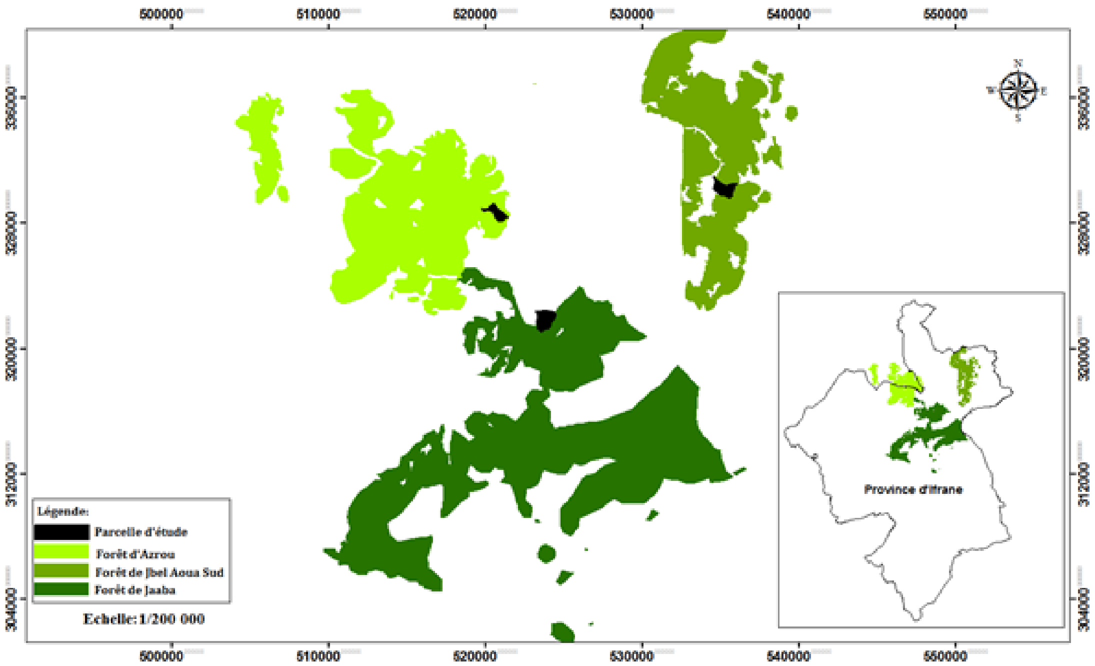

Figure 1. The map of the studied area

Methodological approach

At the level of each forest, a plot representative of the topoclimatic plan and the type of forest cover occupying the region was chosen to open soil pits. The number of soil profiles prepared at the level of each plot was based on its area and the forest composition present. This approach allowed us to identify nine sites, each of which is the subject of a soil pit (Table 1).

The description of the studied sites focused on the distinction of genetic horizons and their depth, color, texture, structure, consistency, rooting, pH and transition between horizons.

A 200 g soil sample was taken from each horizon. After sieving the soil through 2 mm meshes, physical and chemical analyses were carried out at the Soil Microbiology and Environment Laboratory of the Faculty of Science in Meknes to determine the granulometric composition of the fine soil (< 2mm), pH, organic matter (Organic carbon), total nitrogen, assimilable phosphorus, total limestone, cation exchange capacity and base saturation rate. Soil pH was measured in the supernatant suspension of soil using pH meter. Soil organic carbon was determined using the Walkley and Black wet oxidation method (Walkley and Black, 1934). The organic matter is obtained by multiplying the organic carbon rate by the coefficient of 1.724 (Dabin, 1970). Total nitrogen was determined using the Kjeldahl procedure (Wilke, 2005). Available phosphorus was determined using Olsen method (Olsen and Sommers, 1982).

Table 1. Description of the identified sites

Number of site	Localisation	Coordinates	Exposition	Slope (%)	Altitude (m)	Parent rock	Forest vegetation
1	Jaaba forest	33°33'7"N -5°10'28"W	NW	14	1593	Basalt	Mixture of an adult forest of zeen oak and green oak
2	Jaaba forest	33°33'16"N -5°10'38"W	N	10	1562	Basalt	Mature zen oak forest
3	South Jbel Aoua forest	33°34'26"N -5°01'33"W	NE	13	1745	Sandy dolomite	Mature green oak forest
4	South Jbel Aoua forest	33°34'21"N -5°01'26"W	NE	15	1750	Sandy dolomite	Young cedar forest
5	South Jbel Aoua forest	33°34'10"N -5°00'54"W	NE	18	1740	Sandy dolomite	Mature maritime pine forest
6	South Jbel Aoua forest	33°34'03"N -5°00'51"W	NE	20	1768	Sandy dolomite	Mixture of a young green oak forest and a mature cedar forest
7	Azrou forest	33°29'57"N -5°08'31"W	NE	20	1690	Basalt	Pure cedar forest
8	Azrou forest	33°29'34"N -5°08'39"W	SW	10	1720	Basalt	Mature zeen oak forest
9	Azrou forest	33°29'30"N -5°08'43"W	SW	25	1710	Basalt	Mature green oak forest

Results and Discussion

Morphological characteristics

Table 2 shows the morphological characteristics of the studied soils. They show a fairly homogeneous character of these soils, with the exception of the depth of the horizons which shows some differentiation. The color is a property that is easy to observe and measure, but its interpretation must be made in interference with soil mineralogy, alteration stage, organic matter content, seasonal fluctuations in water and several other aspects of land use and performance (Olson, 1981). This is a very important criterion to study because it provides information on the properties and behaviour of the soil. Indeed, apart from the soil at site no 8 where the red coloration appears from the surface, all other soils have a dark brown coloration in the surface horizons and more reddish at depth. Concerning the structure, it is defined by Plaisance and Cailleux (1958) as the way in which the aggregates are arranged in the ground building. The structure of the studied soils is lumpy everywhere. This fairly stable structure plays an essential role because it maintains the favorable physical properties of the forest soil (aeration and drainage) and also because it prevents any unfavorable pedological evolution of the profile (Duchaufour, 1953).

Table 2. Morphological characteristics of the studied soils

Number of site	Depth of the litter L+F (cm)	Horizon	Depth (cm)	Moist color	Structure
1	0-4	A	0-37	10 YR 2/2, Very dark brown	Lumpy
		B_1	37-47	7,5 YR 4/6, Intense brown	Irregular lumpy
		B_2	47-86	7,5 YR 4/6, Intense brown	Regular lumpy and prismatic
2	0-4	A_H	0-47	7,5 YR 4/6, Intense brown	Irregular lumpy
		B	47-85	10 YR 3/6, Dark red	Irregular lumpy
3	0-2	A	0-60	10 YR 2/2, Very dark brown	Lumpy
		C_R	>60	-	-
4	Same as site no. 3				
5	0-10	A	0-50	7,5 YR 3/4, Dark brown	Lumpy
		C_R	>50	-	-
6	Same as site no.5				
7	0-1	A	A-60	10 YR 2/2, Very dark brown	Lumpy
		(B)	60-100	2,5 YR 3/4, Dark reddish brown	Lumpy
8	0-7	A	0-51	5 YR 3/2, Dark reddish brown	Lumpy
		B_t	51-80 and over	2,5 YR 3/6, Dark red	Lumpy to prismatic
9	0-6	A	0-60	10 YR 2/2, Very dark brown	Lumpy
		(B)	60-80 and over	2,5 YR 3/4, Dark red	Particulate

In general, the main soil genetic processes in these soils are: Brunification, Rubefaction and Rendzinification. The brunification is the process by which soil particulates take on a brownish coloring by goethite. During the process of the brunification, iron is released by altering the minerals. When this iron undergoes hydration in contact with water (H_2O), this results in the formation of goethite (FeO-OH) (Benjelloun, 2017). The latter, by attaching itself to the soil particulates, gives them a brownish coloration (S1). This phenomenon occurs in temperate, Atlantic or semi-continental climates, distinguishing the class of browned soils under deciduous vegetation (Duchaufour, 1977) characterizing S1 where there is a mixed stand of zeen oak and green oak. The rubefaction is the phenomenon by which soil particulates take a reddish coloring by hematite (Fe_2O_3) (Vandour, 1972). These are dehydration and oxidation of iron following evaporation in hot and dry Mediterranean-type climates (Duchafour, 1965). This is a characteristic of the soil class of iron sesquioxides (S2, S7, S8 and S9) (Table 3). The rendzinification is a set of processes leading to the formation of rendzina soil, a group of the calcimagnesic soil class. It consists in the formation of a stable complex between organic matter and calcium (Ca^{2+}) or a mantle out of this matter with active limestone ($CaCO_3$) which blocks any further evolution of organic matter and prevents its migration to depth, and consequently, we are witnessing the development of a soil with an organic horizon resting directly on the parent rock (Profile type A/CR) (Benjelloun, 2017). This is the case for S3, S4, S5 and S6 (Table 3).

Using the classification system adopted by the Commission of Pedology and Soil Mapping (CPCS, 1967), as well as the international system of classification, nomenclature and soil mapping used by FAO (2015), and based on the above data, the soils studied are classified as follows (Table 3, Figure2,3 and 4).

Table 3. Classification of the studied soils

Classification Number of site	Commission on Pedology and Soil Mapping (1967)				FAO - Word Reference Base for soil ressources (WRB) (2015)
	Class	Under class	Group	Under group	
1	Browned	Moist temperate	Brown	Andic brown	Cambisols
2	Iron sesquioxide	Fersialitic	Without calcic reserve and leached out	With an andic character	Nitisols-Alisols
3, 4, 5, 6	Calcimagnesic	Carbonated	Rendzina	Modal	Leptosols
7	Iron sesquioxide	Fersialitic	Without calcic reserve and leached out	With an andic character	
8	Iron sesquioxide	Fersialitic	Without calcic reserve and leached out	With an andic character	Nitisols-Alisols
9	Iron sesquioxide	Fersialitic	Without calcic reserve and leached out	With an andic character	

Figure 2. A profile of a browned soil

Figure 3. A profile of an iron sesquioxide soil

Figure 4. A profile of a calcimagnesic soil

Physical and chemical characteristics

Granulometric composition and texture

The granulometric analysis makes it possible to know (in weight form) the distribution of mineral soil particulates less than 2 mm according to size classes. A distinction is made between clays ($Ø \le 2$ µm), fine silts (2 µm $\le Ø \le$ 20 µm), coarse silts (20 µm $\le Ø \le$ 50 µm), fine sands (50 µm $\le Ø \le$ 200 µm) and coarse sands (200 µm $\le Ø \le$ 2000 µm). Texture plays an important role in porosity, drainage and especially carbon stocks in soils. It conditions soil structure and remains a reliable variable since it is stable and modified only according to long-term soil evolution (Gobat et al., 2003). By analyzing Table 4, the fractions of the studied soils (Sand, silt and clay) show some fluctuations within or across the same profile, with a dominance of the silt fraction, which has characterized the texture of these soils as determined from the textural triangle. The most represented textures are silty fine, silty clay and silty sandy.

The granulometric composition, an intrinsic characteristic of the soil, is little influenced by the vegetation cover (Benjelloun et al., 1997). As a result, the effect of different types of forest is not felt at this level. The effect of forest vegetation types is perceived in terms of chemical characteristics such as pH, organic matter, nitrogen, P_2O_5 and exchangeable bases.

Table 4. The granulometric composition of the studied soils

Number of site	Horizon	Thin sand (%)	Coarse sand (%)	Thin silt (%)	Coarse silt (%)	Clay (%)	Texture
1	A	10,20	6,66	35,22	14,65	25,82	Silty thin
	B_1	10,53	6,92	29,37	13,10	35,87	Clay silt
	B_2	7,08	6,12	29,25	9,10	42,75	Clay
2	A_H	10,10	6,00	32,92	10,80	33,22	Clay silt
	B	4,27	3,11	10,42	5,95	72,62	Clay
3	A	18,91	11,99	44,53	7,22	10,65	Sandy silt
4	Same as site no 3						
5	A	24,68	4,75	30,02	10,36	26,62	Sandy clay silt
6	Same as site no 5						Sandy silt
7	A	24,88	13,59	22,20	17,10	18,22	Silty
	(B)	20,62	17,80	18,92	14,85	23,17	Silty
8	A	12,57	13,14	31,27	11,67	23,12	Silty
	B_t	9,30	10,53	20,62	9,35	41,92	Clay silt
9	A	10,52	14,98	22,22	18,80	28,07	Clay silt
	(B)	15,26	22,94	16,95	14,22	18,85	Sandy silt

Soil chemical characteristics

The results of the analyses are grouped in Tables 5 and 6.

Table 5. The chemical characteristics of the studied soils

Number of site	Horizon	pH_{H2O}	pH_{KCl}	Organic matter (%)	Carbon (%)	Total Nitrogen (%)	C/N	P_2O_5 (mg/kg)	$CaCO_3$ (%)
1	A	6,68	6,00	8,10	4,70	0,75	6,27	120,00	1,50
	B_1	6,77	6,11	4,20	2,44	0,38	6,42	31,60	2,73
	B_2	6,58	5,74	5,70	3,31	0,21	15,76	55,64	1,92
2	A_H	6,82	6,10	7,00	4,06	0,17	23,88	52,22	0,60
	B	6,56	6,54	4,00	2,32	0,05	46,40	17,86	0,70
3	A	7,32	6,77	7,70	4,47	0,57	7,84	14,65	1,81
4	Same as site no 3								
5	A	7,04	6,56	5,10	2,96	0,43	6,88	11,00	4,16
6	A	7,24	6,79	3,50	2,03	0,02	101,50	109,00	1,10
7	A	6,46	5,21	4,50	2,61	1,15	2,27	21,52	1,32
	(B)	6,29	4,90	4,60	2,67	0,14	19,07	19,22	1,10
8	A	6,41	5,33	8,20	4,76	1,07	4,45	53,58	1,48
	B_t	6,33	4,74	6,00	3,48	0,05	69,60	38,47	2,57
9	A	6,41	5,43	7,40	4,29	1,62	2,65	174,00	1,97
	(B)	6,33	4,8	4,40	2,55	0,37	6,89	18,77	1,36

pH

The pH_{H2O} analysis results (Table 5) show that the soils studied have pH values ranging from 6.3 to 7.3 (very weakly acidic to neutral). The pH_{KCl} is always 11% to 33% lower than the pH_{H2O}. Indeed, the pH_{KCl} indicates the quantity of H^+ protons in the soil solution as well as some or all of the H^+ ions on the adsorbent complex (acidity in reserve). The studied sites are divided into two groups, a first group where the soils are not very basic represented by the sites: S3, S4, S5 and S6. This can be explained on the one hand by the nature of the vegetation based on hardwood species (Green oak) for S3 and S6 (Duchaufour, 1977) and on the other hand by the presence of total limestone ($CaCO_3$) and the nature of the substrate which can explain the increase in pH in S4 and S5 despite the acidifying or low acidifying nature of the vegetation cover (cedar, maritime pine) (Duchaufour, 1965). Indeed, the presence of $CaCO_3$ in addition to the exchangeable bases contributes to a saturation of the adsorbent complex and subsequently an increase in pH. On the other hand, the soils of the second group tend to have lower pH: S1, S2, S7, S8 and S9. The acidification observed in this group is mainly due to the acidifying or slightly acidifying nature of the vegetation represented by resinous essences in their natural state (Duchaufour, 1977).

Organic matter, carbon and nitrogen

The chemical composition of soil organic matter (OM) influences carbon and nutrient dynamics through the rapid degradation of its constituent substances (Banville, 2009). Plant composition is therefore the main factor responsible for differentiating the chemical properties of organic matter in soils (Banville, 2009). Good quality MO is more quickly eliminated by microorganisms and has a higher rate of decomposition. In general, the Mediterranean climate is not favorable for the accumulation of organic matter (Benjelloun et al., 1997). Generally, we perceive a drop in organic matter, carbon and nitrogen in the B horizon since the latter has a lower root density than the surface organic horizon where microbial activity is higher. In terms of fertility, and following these recorded values (Table 5), all sites are considered to be very rich in total nitrogen, values higher than 0.15% announced by Dabin (1963). The C/N ratio can be used as an indicator of the organic matter decomposition rate and provides information on microbial activity in the soil. A high C/N ratio represents a low rate of carbon decomposition since decomposing organisms use nitrogen which quickly becomes limiting (Benjelloun, 2002). Thus, for the surface horizons, and based on the soil reference frame (1995) cited in Ambassa (2005), the soils of the studied sites have active mineralization of organic compounds and present significant quantities of nitrogen allowing intense microbial activity and rapid decomposition of organic matter with the exception of S2 (Mix zen oak forest) whose C/N ratio is higher (23.88%), which indicates that the process of immobilization of nitrogen by microorganisms prevails over the process of mineralization.

Table 6. The chemical characteristics of the soils studied

Number of site	Horizon	Ca (meq/100g)	Mg (meq/100g)	K (meq/100g)	Na (meq/100g)	SEB (meq/100g)	CEC (meq/100g)	Saturation rate (%)
1	A	12,00	3,34	0,77	0,55	16,66	36,31	45,88
	B_1	8,70	0,90	0,71	0,35	10,66	34,43	30,96
	B_2	17,80	1,05	0,72	0,42	19,99	29,56	7,63
2	A_H	20,60	2,67	1,07	0,13	24,47	34,78	70,36
	B	5,40	3,22	0,30	0,23	9,15	28,00	32,68
3	A	10,60	3,08	0,71	0,48	14,87	63,69	23,35
4	Same as site no. 3							
5	A	14,00	5,43	0,70	0,14	20,27	27,82	72,86
6	A	25,20	1,40	0,71	0,28	27,59	44,65	61,79
7	A	5,40	1,14	0,10	0,20	6,84	45,47	15,04
	(B)	1,53	0,84	0,10	0,51	2,98	22,47	13,26
8	A	14,00	2,76	0,35	0,17	17,28	40,43	42,74
	B_t	5,43	4,69	0,12	0,17	10,41	25,86	40,26
9	A	19,75	1,68	1,38	0,42	23,23	56,95	40,79
	(B)	4,00	0,41	0,71	0,61	5,73	23,08	24,83

SEB: Sum of the exchangeable bases, CEC: cation exchange capacity

The assimilable phosphorus P_2O_5

The phosphorus cycle in the soil is a dynamic involving the soil, the plant, and the microorganisms. In soil, phosphorus can come either from carbonate rocks containing apatite or from acidic rocks containing variscite or strengite (Benjelloun et al., 1997). The values of assimilable posphorus in the studied areas show a poor to medium fertility level compared to the norms used by Bonneau (2001) in horizon A and shows a diminution with depth.

Exchanged bases

These are calcium, magnesium, potassium and sodium. Among these bases, calcium is the most important element in the studied soils (Table 6). In descending order, we find magnesium, then potassium and sodium. At the surface horizon, the sum of the exchanged bases (SEB) has the highest values under hardwood (green oak and zeen oak). The lowest value is found in S7 (pure Cedar). This is due to the great variability of the substrate but also to the acidity of the soils from the resinous species. Indeed, the reserves of nutrients present in soil minerals are depleted relatively faster under resinous species than under deciduous species (Augusto et al., 2000).

Cation exchange capacity (CEC)

The cation exchange capacity (CEC) of a soil is the maximum amount of cations that a soil can adsorb, in other words, this measure represents the total negative soil charges available for fixing H^+ and Al^{3+} ions and exchangeable bases. This parameter depends on colloids and soil pH. Most of the studied soils have a high to very high CEC content due to the dominance of deciduous vegetation that improves the soil (Augusto et al., 2000) in the studied area.

Conclusion

The studied area is characterized by a sub-humid to humid climate with a very cold variant, a basaltic parent rock and sandy dolomite with an altitude varying between 1562 and 1768 m. The forest formations encountered include resinous species based on cedar and maritime mountain pine, and other deciduous species as green oak and zeen oak. The morphological study and description of the genetic horizons of the studied soils allowed us to identify three types of soil characterizing the area, namely, the browned soil class, the iron sesquioxide soil class and the calcimagnesic soil class. This work shows that the chemical characteristics of the soils under study are influenced by the type of vegetation, in contrast to their intrinsic fertility properties.

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Relative potential of rhizobium species to enhance the growth and yield attributes of cotton (*Gossypium hirsutum* L.)

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Abstract

Legumes compensate mineral fertilizer by fixing nitrogen due to the specialized structures i.e. nodules by *Rhizobium* species. Literature revealed that legumes fixed nitrogen due to *Rhizobium* inoculation from 50-300 kg NPK ha^{-1} $year^{-1}$. *Rhizobium* besides nitrogen fixation, solubilized phosphates, produced growth hormones and due to its root colonizing ability improved the growth and yield of non-legumes also and performed as plant growth promoting rhizobacteria (PGPR). Study was conducted to assess the relative efficiency of *Rhizobium* species for the growth and yield of cotton. Different isolates of five species of *Rhizobium* species responsible for different nodule formation in legumes were assessed for the auxin biosynthesis potential as IAA equivalents and isolates having higher values for IAA equivalents were used for experimentation. Results revealed that isolates of *Rhizobium* species improved the growth and physiological parameters of cotton. Higher values were root/shoot length and mass were observed with *Rhizobium* species of berseem (Br_5). Bacterial inoculation with isolate (Br_5) produced 60.94, 64.40 g shoot/root mass that is 16.70 and 23.80 % higher than control and percent increase improvements of cotton shoot/root length with Br_5 i.e. 18.3, 24.8 % higher than that of control. Higher values of IAA equivalents were observed in root/shoot content of cotton with isolate of Br_5. Bacterial inoculation improved the plant height, boll weight, number of bolls $plant^{-1}$ and seed cotton yield with Br_5 inoculation. The chlorophyll content, photosynthetic rate, transpiration rate and photo active radiation were also higher in the inoculated treatments. Results of present study clearly demonstrated that different isolates of *Rhizobium* species improved the growth and yield parameters of cotton and thus *Rhizobium* sp can be effectively utilized as bacterial inoculants in non-legumes.

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Introduction

Cotton is the major cash crop of the country. It requires balanced amount of nutrients for proper growth and development. Microbial inoculants have the potential to compensate the mineral fertilizer and to provide a balanced diet to cotton. Biofertilizer technology has taken a part to minimize production costs and at the same time, avoid the environmental hazards (Galal et al., 2001).

The microbe responsible for formulations of nodules i.e. mini factories of nitrogen is *Rhizobium*. Different species of *Rhizobium* forms nodules on different legumes. More than 20,000 members of family Fabaceae form nodules with *Rhizobium* (Gepts et al., 2005). Specificity of *Rhizobium* species is due to the chemical

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signaling between host legume and *Rhizobium* sp. *Rhizobium*-legume symbiosis is a well distinguished feature of legumes. Legumes fulfill most of its nitrogen by these symbiotic relationships. *Rhizobium* inoculation has been carried out in our agricultural systems for more than a century. Rhizobium besides nitrogen fixation in legumes also involved in variety of functions like P-solubilization due to production of organic acids, growth hormone production like auxins, gibberellins etc. and antibiotics (Sessitsch et al., 2002; Cassán et al., 2009; Mehboob et al., 2009; Ullah et al., 2017a). Literature reported that rhizobium strains influenced the roots of cotton due to the production of auxins resulted in efficient nutrient uptake (Hafeez et al., 2004; Hossain and Mårtensson, 2008; Gopalakrishnan et al., 2015).

Interactions between plants and microorganisms in the rhizosphere can clearly affect crop yields. Rhizobacteria that benefit plant growth and development are called PGPR. PGPR can directly stimulate plant growth by producing phytohormones and by increasing nutrient uptake (Lippmann et al., 1995; Egamberdieva et al., 2008; Cassán et al., 2009) or by inducing systemic plant resistance towards pathogenic micro-organisms (Mehboob et al., 2009; Noreen et al., 2012; Kumar and Jagadeesh, 2016). PGPR can stimulate plant growth indirectly by inhibiting the root pathogens (Gopalakrishnan et al., 2015; Habig et al., 2015). Rhizobia as a PGPR should be able to colonize and survive in the rhizosphere of non-legume plants because root colonization is an important first step in the interaction of beneficial bacteria with plants (Kloepper and Beauchamp, 1992; Mehboob et al., 2009; Egamberdieva, 2011; Habig et al., 2015; Kumar and Jagadeesh, 2016; Ullah et al., 2017a). Root colonization is the most crucial step for successful use of PGPR (Lugtenberg et al., 2001). PGPR facilitated the plants to uptake nutrients present in soil environment (Glick, 1995; Mehboob et al., 2009; Habig et al., 2015). Microbial inoculants only exhibited marginal increase in yield when tested under ideal conditions due to inconsistent response of crops (Mehboob et al., 2009). Researchers reported that crops inoculated with rhizobia exhibited increased amount of nutrients than un-inoculated control (Biswas et al., 2000; Egamberdieva, 2011). Rhizobia having the potential of P-solubilization also enhance plant growth by increasing the nutrient mobilization, enhancing the availability of other trace elements and by production of plant growth promoting substances (Gyaneshwar et al., 1998; Gepts et al., 2005; Mehboob et al., 2009; Egamberdieva, 2011; Kumar and Jagadeesh, 2016). Present study was conducted to assess the comparative potential of *Rhizobium* species (berseem, chickpea, lentil, vegetable pea and mung bean) on growth and yield of cotton.

Material and Methods

Isolation and purification of rhizobia of different crops

Yeast Extract Mannitol Agar (YMA) medium is used for the isolation of the *Rhizobium spp.* having composition per liter (5% K_2HPO_4:10ml; 2% $MgSO_4.7H_2O$: 10ml; 1% NaCl: 10ml; mannitol: 10 g; yeast extract: 1 g; agar: 15.0 g) (Vincent, 1970). For the preparation of the medium, the salts specified above were weighed and dissolved in water in pan and heated to dissolve the contents then it is shifted to conical flask and sterilized by autoclaving for 15-30 minutes at 15-20 lb inch^{-2} pressure and 121^{0}C. After sterilization the media was poured on Petri plates aseptically in a laminar air flowcabinet and allow to solidify. Then this media is further surface sterilized by putting these plates in laminar flow cabinet under UV light.

Plants of berseem, chickpea, lentil, vegetable pea and mung bean are uprooted at nodulation stage. The roots are thoroughly washed with tap water to remove soil particles from roots. Now collect the healthy nodules from roots of each crop plant without damaging the nodule. Now these undamaged nodules are immersed in 95% ethanol for 4-5 minutes. Then rinse them with sterilized distilled water. Now nodules are surface sterilized with 0.1% $HgCl_2$ followed by washing with sterilized distilled water. Now punctured the nodule with needle or crushed it with sterilized forceps. Immediately streak the juice of punctured nodule on solidified YMA media in Petri plates in air flow cabinet by surface sterilized streaking needle. Incubate the inoculated media for 48-72 hours. The prolific colonies can be seen on the plate media after 2 days as they don't attained congored color. These colonies are then further multiplied on fresh prepared Petri plates as well as purified in slants and kept at 5±1 ^{0}C for further experimentation.

Determination of auxin biosynthesis status of these Rhizobia spp.

Isolates of *Rhizobium sp* berseem (Br_1, Br_2, Br_3, Br_4, Br_5), chickpea(CP_1, CP_2, CP_3, CP_4, CP_5), lentil (L_1, L_2, L_3, L_4, L_5) mung (M_1, M_2, M_3, M_4, M_5) and Vegetablepea (Vp_1, Vp_2, Vp_3)werescreened for their auxin biosynthesis potential colorometrically. For this purpose the isolates were cultured on the autoclavedGPM broth in test tubes with and without L-Tryptophan. The test tubes were covered and incubated at 28±2°C for one week and well shaken regularly throughout the week. The Un- inoculated control was kept for comparison. After incubation the contents were centrifuged @1000 rpm for 10 minutes and filtered through whatman filter paper No.2. The auxin biosynthesis potential was determined as Indole-3-acetic acid (IAA) equivalents by spectrophotometer at 535 nm using Salkowski's reagent (2 mL of 0.5M $FeCl_3$ +98 mL of 35% $HClO_4$) as reported by Sarwar et al. (1992). Isolates exhibited the highest auxin biosynthesis (Br_5, Cp_5, L_3, Vp_2 and M_3) were selected for the study as mentioned in the Table 1.

Table 1. Some different traits of microbes under study

Rhizobium spp.	Isolates	IAA equivalents (μg mL^{-1})		Congo-red test	Bromo-thymol Blue test	Gram Reaction
		L-TRP [-]	L-TRP [+]			
Berseem	Br_1	3.91	4.98	+	+	-
	Br_2	4.33	5.37	+	-	-
	Br_3	3.77	5.26	+	+	-
	Br_4	4.12	5.68	+	+	-
	Br_5	4.48	6.54	+	+	-
Chickpea	Cp_1	3.05	4.40	+	+	-
	Cp_2	4.15	5.23	+	+	-
	Cp_3	3.38	4.37	+	+	-
	Cp_4	3.97	5.12	+	-	-
	Cp_5	3.81	5.95	+	+	-
Lentil	L_1	4.05	5.10	+	-	-
	L_2	4.39	5.28	+	-	-
	L_3	4.47	5.39	+	+	-
	L_4	3.55	4.20	+	+	-
	L_5	3.33	4.51	+	-	-
Vegetable Pea	Vp_1	3.22	4.25	+	+	-
	Vp_2	3.67	4.76	+	+	-
	Vp_3	3.12	4.19	+	+	-
Mung bean	M_1	3.96	4.02	+	-	-
	M_2	3.71	4.11	+	+	-
	M_3	4.24	4.91	+	+	-
	M_4	3.95	4.64	+	-	-
	M_5	3.77	4.98	+	+	-

Preparation of inoculum

Now YMB broth with composition per liter (Mannite: 10g; Yeast extract: 1g; K_2HPO_4 (5%):10mL; $MgSO_4.7H_2O$ (2%):10mL; NaCl (1%):10mL) is prepared and autoclaved at 121^{0}C temperature and 15-20 lb / inch^{2}pressure. This autoclaved broth is then inoculated with purified and high biosynthetically auxins producing colonies of *Rhizobium sp* (CP_5, Br_2, L_4, M_2 and Vp_2) in laminar flow and incubated at 25^{o}C for 48 hours. When we see the maximum growth of rhizobium in broth then the seeds of Cotton are soaked in the prepared inoculum.

Pot experiment

A pot study was conducted in medium textured soil having pH 7.88, EC 1.47 dSm^{-1},N 0.043 % and available P 7.35 mg kg^{-1} at Soil Bacteriology Section, AARI, Faisalabad. Experiment comprised of the following treatments included Control, *Rhizobium sp* (Berseem), *Rhizobium sp* (Chickpea), *Rhizobium sp* (Lentil), *Rhizobium sp* (Mungbean), *Rhizobium sp* (Vegetablepea). Fertilizer @ 100-60 kg NP $ha^{-1}$was applied to all treatments. Experiment was laid out in completely randomized design (CRD) with five replications. All phosphorus andhalf nitrogen were applied as basal and half nitrogen was applied after 30 days of sowing. The photosynthetic rate, transpiration rate and photoactive radiation were determined by using IRGA (CI-340). Two repeats of cotton were uprooted after 45 days by irrigating the pots to record root / shoot length and mass. Then after 30 minutes when the soil became soft water from pipe was poured on to the pot as soil is removed and plant of cotton along with roots without any damage are obtained. The remaining three repeats were kept until maturity and growth / yield parameters were recorded. Data were subjected to statistical analysis by analysis of variance following completely randomized design (CRD) (Steel et al., 1997) and differences among the means were compared by the Duncan's multiple range test (Duncan, 1955).

Lab analysis

Chlorophyll content of leaf of each replication is determined colorimetrically by crushing the leaves in acetone and by centrifuging @ 1000 rpm for 10 minutes then run on spectrophotometer (Arnon, 1949). After uprooting the plants physical parameters like root and shoot length is measured by measuring scale in centimeters while root and shoot mass is determined by using digital balance. Then two gram of each of the root and shoot of each repeat is taken that is dipped and ground in autoclaved 10mL GPM in test tube and covered with cork. Two GPM containing test tubes are kept as control. This is kept for one week and shaken well three times a day regularly. Then the contents are centrifuged @ 1000 rpm for 20 minutes. 5 standards of auxin (1, 2, 3, 4 and 5) ppm were made from 1000 ppm auxin stock solution. Three mL of supernatant and auxin standards are taken in test tubes and added 2 mL of Salkowski's reagent (98mL 35% $HClO_4$+ 2mL0.5M $FeCl_3$) to each tube. After 30 minutes a pink color ring is formed on top of GPM supernatant that indicated presence of auxin. The samples were run these samples on spectrophotometer @535nm spectrum and check the biosynthesis of auxin as IAA equivalents by plant shoot and root by comparing it with control.

Results and Discussion

Data regarding IAA production by different strain of *Rhizobium* isolated from root nodules of crops under study is presented in Table 1. Keeping in view the above data it can be observed that *Rhizobium* species isolated from nodules of berseem, chickpea, lentil, vegetable pea, mungbean (Br_5, Cp_5, L_3, Vp_2 and M_3) produced higher auxin values in order of 4.48, 3.81, 4.47, 3.67 and 4.24 µg ml^{-1} and the values were more enhanced with the supplement of L-tryptophan i.e. 6.54, 5.95, 5.39, 4.76 and 4.91, respectively. It was observed that all tested isolates produced IAA equivalents and effect was more pronounced with the application of L-tryptophan. The biochemical tests such as Congo red test, bromothymol and gram reaction showed the characteristic features of the tested isolates.

Use of beneficial rhizobacteria to attain sustainable agriculture and nutrient availability for crop plants has been becoming an emerging approach in conservation of agriculture (Habig et al., 2015). Moreover, Rhizobia are potential partner of legumes crops but also act as beneficial rhizobacteria for non-legume or cereals (rice, maize, wheat) without forming nodules through different plant growth mechanisms such as nutrient availability, release of growth hormone, production of siderophores and lumichrome, improved root morphology, more root adhering soil and defense action (biocontrol, induced systemic resistance) (Mehboob et al., 2009; Kumar and Jagadeesh, 2016). Among the phytohormones (auxins, gibberellins, abscisic acid, ethylene), auxins play major role in plant-microbe interaction, and growth and development of plants (Boivin et al., 2016). In this experiment rhizobial species isolated from five different legumes were assayed for their IAA-producing efficiency then verified to affect the growth and yield attributes of cotton. In results, rhizobial isolates Br_5 showed maximum IAA-potential hence better impact on cotton growth and yield than other isolates. Our observation regarding auxin production related to different studies which were conducted to investigate the potential of IAA-producing rhizobial species to enhance plant growth (Hussain et al., 2014; Parthiban et al., 2016).

Data regarding shoot/root mass is presented in Figure 1 showed that isolates of *rhizobium* species enhanced the shoot/root mass considerably. Inoculation with isolate Br_5 produced 60.94, 64.40 g shoot/root mass that is 16.70 and 23.80 % higher than control while other isolates showed percent increase compared to control viz. Cp_5 (8.1, 20.3%), L_3 (8, 18.0%), Vp_2 (4.3, 12.6%), M_3 (4.7, 9.4%), respectively.

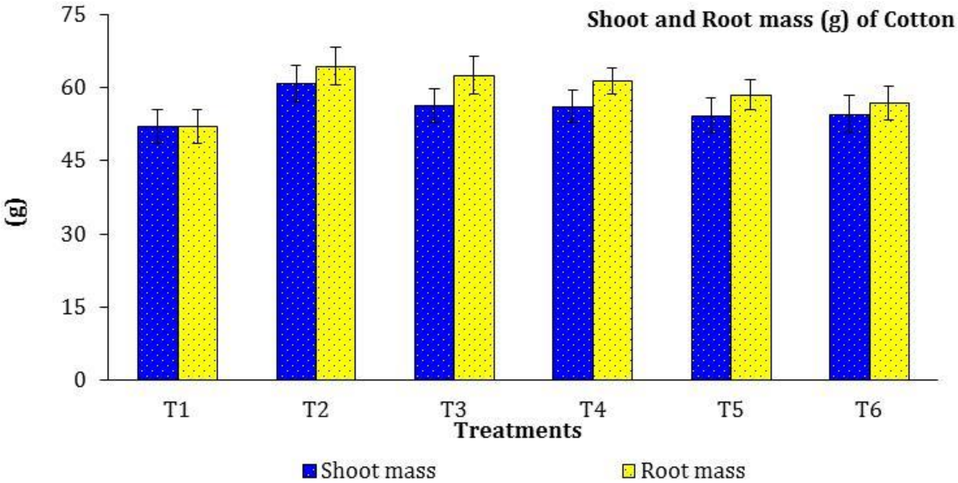

Figure 1. Comparative effect of rhizobium sp on shoot / root mass of cotton

Data regarding shoot / root length is presented in Figure 2 that showed that all isolates have improved the shoot/root length. *Rhizibium* isolates of Br_5, Cp_5, L_3, Vp_2 and M_3improved the shoot/root length of cotton seedlings i.e. (27.8, 49.3 cm), (25.8, 46.0 cm), (27.0, 44.5 cm), (23.5, 47 cm) and (24.8, 48.0 cm) as compared to control (23.5, 39.5 cm), respectively. The percent increase improvements of cotton shoot/root length with

Br_5 i.e.18.3, 24.8 % higher than that of control while Cp_5 (9.8, 16.5%), L_3 (14.9, 12.7%) and M_3 (5.53, 21.5%) and isolate of Vp_2 has no impact regarding shoot length of cotton while improved root length 19%.

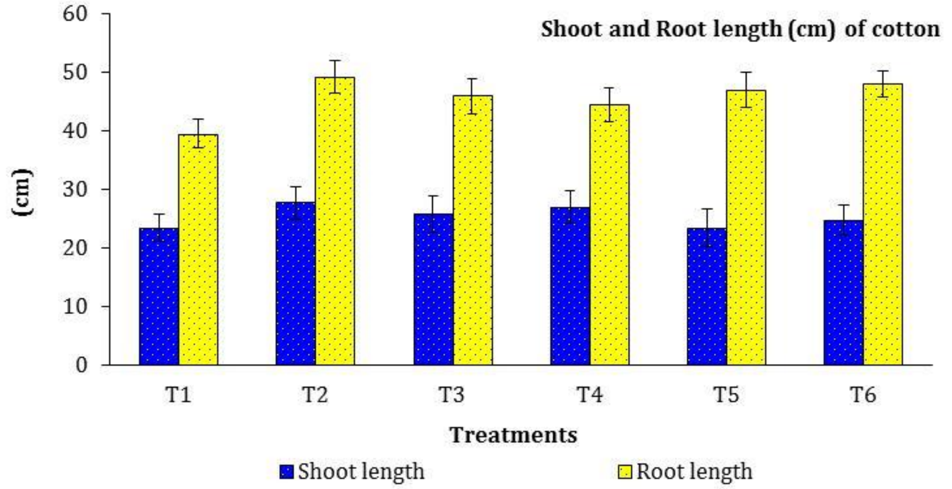

Figure 2. Comparative effect of rhizobium sp on shoot / root length of cotton

The IAA equivalents in shoot/root content of cotton seedlings are presented in Figure 3. Results clearly demonstrated that bacterial inoculation improved the IAA content in shoot/root content of cotton seedlings as compared to control and isolates showed variable response regarding shoot/root IAA content. Results showed that the highest value of shoot/root IAA content was obtained with Br5 i.e. 4.41 and 3.65 µg g^{-1} followed by Cp_5 i.e. 4.41 and 3.49 as compared to control i.e. 2.35 and 1.95, respectively.

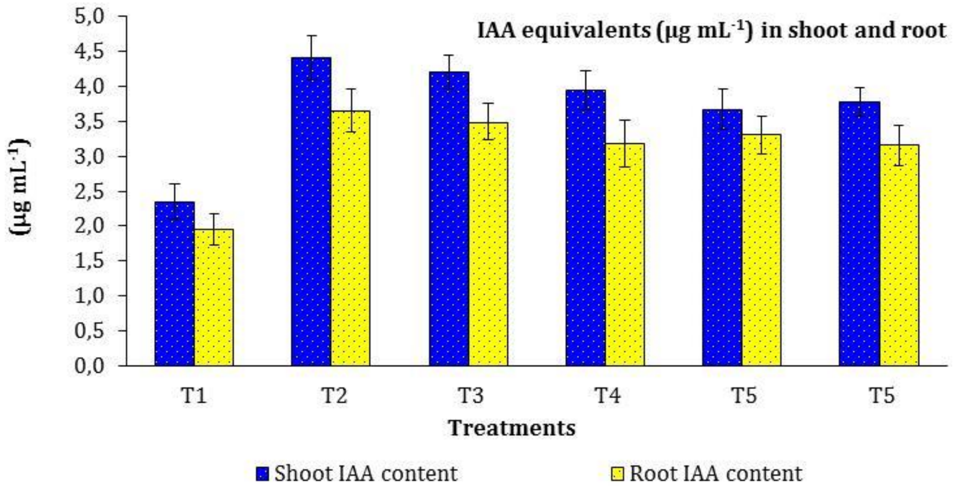

Figure 3. IAA equivalents in shoot / root content of cotton

Inoculation of cotton seeds with rhizobial isolate caused maximum increase in length and mass of root and shoot which might be due to production of lumichromes that help in CO_2 assimilation by roots (Dakora, 2003), riboflavin which stimulate root respiration (Dakora et al., 2002) and auxins to promote cell elongation through their expansion action (Pacheco-Villalobos et al., 2016). Beneficial rhizobacteria also influence the cell division and differentiation of plant roots which caused improved growth of shoot system (Verbon et al., 2016). These improvements are in lined with the study of (Noreen et al., 2012) who observed 54, 45 and 185% increase in root, shoot length and seedling fresh weight of *Vignamungo* (L.) when inoculated with IAA-generating strain *Pseudomonas aeruginosa* As-17. (Asghar et al., 2015) also noted a significant improvement in weight and length of root and shoots of wheat plants due to inoculation with different rhizobial isolates.

Data regarding physical parameters i.e. plant height, boll weight, boll $plant^{-1}$, cotton leaf curl virus percentage (CLCV) and seed cotton yield from remaining repeats is presented in Table 2. Results regarding physical parameters demonstrated the positive response of *Rhizobium* species (Br_5, Cp_5, L_3, Vp_2 and M_3). The maximum plant height i.e. 79.5 with Br_5 followed by Cp_5 i.e. 76.0 cm compared to control i.e. 72.0 cm. The maximum boll weight was obtained with Br_5 i.e. 2.87 g followed by 2.79 g with Cp_5 inoculation compared to control i.e. 2.65 g. The maximum number of bolls was obtained with the isolate Br_5 i.e. 15 followed by Cp5 i.e. 13.5 and the least number of bolls was obtained with M3 that is at par with control i.e. 10.5. Results regarding CLCV percentage, it was observed that the highest CLCV percentage was observed with control and the least was observed by inoculation with Br_5. Results regarding seed cotton yield clearly demonstrated that bacterial inoculation improved the seed cotton yield (47.0 g) as compared to control (34.50), respectively. Increase in seed cotton yield due to bacterial inoculation (36, 27.5, 18.8, 12.3, and 5.8%) due to application of *Rhizobium* species i.e. Br_5, Cp_5, L_3, Vp_2 and M_3 was observed, respectively.

Table 2. Effect of bacterial inoculation on yield components of cotton and parameters recorded by the IRGA (CI-340).

Treatments	Plant Height (cm)	Boll weight (g)	Bolls plant^{-1}	CLCV (%)	Seed cotton yield (g pot^{-1})	Photosynthetic rate (μ mole m^{-2}s^{-1})	Transpiration rate (mmole.m^{-2}s^{-1})	Photo Active Radiation (μmole m^{-2}s^{-1})	Total Chlorophyll content (mg g^{-1})
Control	72.0^{*bc}	2.65^{d}	10.5^{b}	36.0^{a}	34.50^{e}	78.0	7.80	841.0	1.35
Rhizobium sp (Berseem)	79.5^{a}	2.87^{a}	15.0^{a}	31.5^{b}	47.00^{a}	89.0	8.20	863.0	1.40
Rhizobium sp (Chickpea)	76.0^{ab}	2.79^{b}	13.5^{ab}	33.5^{ab}	44.00^{ab}	84.5	7.70	859.0	1.38
Rhizobium sp (Lentil)	73.0^{bc}	2.76^{bc}	13.0^{ab}	35.0^{a}	41.00^{bc}	86.0	7.75	857.0	1.39
Rhizobium sp (Vegetable pea)	73.0^{bc}	2.73^{bc}	12.0^{ab}	34.0^{ab}	38.75^{cd}	84.0	7.60	854.0	1.36
Rhizobium sp (Mung bean)	69.0^{c}	2.71^{cd}	10.5^{b}	34.5^{a}	36.50^{de}	85.5	7.80	853.5	1.37
LSD	5.142	0.0696	3.670	2.736	3.619	14.37	1.372	127.08	0.052

*Means sharing the same letter(s) in a column do not differ significantly at $p<0.05$ according to Duncan's Multiple Range Test

Rhizobial inoculum left potential impact on cotton plants and increased the biomass and yield parameters of cotton crop including number of bolls per plant, boll weight and seed cotton yield. It might be attributed to different rhizospheric-synergistic effects of rhizobia such as biocontrol against pathogens (Hossain and Mårtensson, 2008), cyanide production (Adnan et al., 2016), production of exopolysacharides, antioxidants, better colonization ability (Hussain et al., 2014), growth hormones (Qureshi et al., 2013) like IAA in the cotton rhizosphere which improved root morphology, root proliferation (Hussain et al., 2009) thus better root system for acquisition and uptake of mineral nutrients (N, P and K) as seen in case of rice seed and seedling inoculation with different *Rhizobium* spp (i.e. *Bradyrhizobium* sp IRBG271, *R. leguminosarum* bv. trifolii E11 and *Rhizobium* sp. IRBG74,) (Biswas et al., 2000) ultimately improving cotton yield. Our results relevant to a recent study conducted by (Arshad et al., 2016) who found a substantial increment (13%) in lint and seed yield of transgenic and non-transgenic cotton plants upon inoculation with IAA-producing rhizobacterial strain*Brevibacillus* spp. TN4-3NF in comparison to un-inoculated control plants.

Results regarding different parameters obtained with IRGA (CI340) like Photosynthetic rate, Transpiration rate, Photo active radiation (PAR) and total chlorophyll content obtained by spectrophotometer are presented in Table 2. Results showed that the maximum photosynthetic, transpiration and PAR values were observed with *Rhizobium* sp (Br_5) i.e. 89.0 μmole m^{-2} s^{-1}, 8.2 mmole m^{-2} s^{-1} and 863 μmole m^{-2} s^{-1} and total chlorophyll content 1.40 mg g^{-1}, respectively.

Seed inoculation of cotton with rhizobial isolates put positive influence on physiology of cotton plants, thus, enhancing the photosynthetic activity and transpiration rate. This improvement by rhizobia may be due to the production of siderophoresenhancing iron (part of chlorophyll) supply, growth hormones (Adnan et al., 2016) and exopolysaccharide which facilitate water and mineral supply throughimproved root system (Egamberdieva and Kucharova, 2009; Hussain et al., 2014) ensuring better plant physiology for normal growth and development of cotton plants. These finding of our experiment according to an experiment in which inoculation of maize seeds with two PGPR strains (*B.phytofirmans* PsJN and *Enterobacter*sp. FD17) caused significant increase in physiological parameters (photosynthetic rate 75%, stomatal conductance 87%, transpiration rate 84%, chlorophyll contents 22% of plants (Naveed et al., 2014).

Study results concluded that *Rhizobium* species are effective PGPR if screened thoroughly and by determining its growth hormone production potential. Present study also predicted that *Rhizobium* species have specific response on different crops also study concluded that *Rhizobium* species having growth hormone production potential should have root colonizing ability for successful utilization in non-legumes.

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Imbalance of nutritional substances of the soil at the modern stage of development of agricultural production in Russia

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Abstract

The paper is devoted to the analysis of changes in the gross harvest of crops from 2008 to 2017. Nutrient removal volumes according to their types with the yield of main commercial crops, including 1 hectare of each crop area are calculated. Volumes of removal by type of nutrients are established. The removal of nutrients with the yield and the application of mineral and organic fertilizers when growing major crops are compared. The size of the nutrient removal over their application in general, including the main crops and types of nutrients is estimated. Proposals to improve the effective soil fertility by increasing the use of fertilizers are formulated. The authors consider ways of these proposals implementation.

Keywords: Gross yield, arable area, productivity of land, nutrients, fertilizers, nutrient balance, natural fertility, export of mineral fertilizers, grain exports.

Introduction

From a comparison of data for two five-year periods (2008-2012) and (2013-2017) it is clear that the gross harvest of most agricultural crops in Russia has increased significantly (Table 1).

More noticeable is the growth in gross yield for sunflower, cereal crops, primarily for corn, and also for sugar beet. The growth rates for vegetables and potatoes are much lower, presumably, because the bulk of the production of these crops is in the households, where the increase in gross harvest was less intense than in the other categories of farms.

The direct components of the gross harvest are the acreage in which crops were cultivated, and their productivity. Let's turn first to the acreage. The acreage of corn and sunflower expanded to the greatest extent in the second five-year period. However, the acreage of these crops has expanded to a much lesser extent than the growth of gross harvests for these crops. For the main grain crops (wheat and barley), the size of the acreage has increased by no more than 2.5%. For sugar beet, the arable area has even decreased. At the same time, as can be seen from table 1, gross harvest increased: by 14.3% for barley, by 27.6% for wheat, by 27.2% for sugar beet. As for the potato, the area of planting of this crop has decreased, due to its reduction in the household farms; the area for vegetables slightly increased with their stable sizes in household farms, at the same time, the gross harvest of potatoes increased by 8.7%, vegetables by 17.0%. At the same time, as can be seen from table 1, the gross yield increased: by 14.3 % for barley, by 27.6% for wheat, by 27.2% for sugar beet.

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A comparative analysis of the dynamics of gross yields and acreage makes it possible to make a univocal conclusion: the increase in gross yields in the second five-year period is primarily due to the increase in crop yields. Due to the increase in crop yields, the gross yield of sugar beet, potatoes, wheat and barley is fully or almost completely increased, and for sunflower and corn by more than 2/3. In connection with the revealed circumstances, the question naturally arises: What are the reasons of the growth of yield increase in Russia over the past five years? At first sight, there are numerous yield factors of various agricultural crops, given the extremely wide variety of conditions for their growth in Russia. However, in any conditions, the leading factor is the availability of nutrients for plants, which is ensured by the natural fertility of the soil and fertilization. Of course, it is impossible to discount the improvement of cultivation technology, which is reflected in the introduction of new varieties and hybrids, in higher quality tillage, in shortening the duration of the main technological operations (sowing, harvesting), in using more efficient methods and means of controlling weeds and pests. However, in our opinion, the improvement of technology in general is aimed at increasing the ability of plants to absorb nutrients, as well as other important components of the crop - water and solar energy. Comparison of the obtained volumes of crop production and the nutrients used for this is done through the construction of nutrient balances.

Table1. Gross yields, arable area and crop productivity in the Russian Federation from 2008 to 2017 by periods (Anonymous, 2018a)*

Indicators	Cereals and legumes	Including			Sugar beet	Sunflower	Potatoes		Vegetables	
		wheat	barley	corn			total	in households	total	in households
Gross yield (million tons)										
2008-2012	86.3	52.2	16.1	5.8	33.8	7.4	28.7	23.3	13.6	9.5
2013-2017	111.8	66.6	18.4	12.9	43.0	10.1	31.2	24.7	15.9	10.6
The second period to the first period, %	129.5	127.6	114.3	222.4	127.2	136.5	108.7	106.0	117.0	111.6
Arable area (ths. hectars)										
2008-2012	45100	26442	8514	1633	1047	6738	2194	1853	667	497
2013-2017	46694	27046	8728	2766	1030	7354	2067	1736	681	501
The second period to the first period, %	103.5	102.3	102.5	169.4	98.4	109.1	94.2	93.8	102.1	100.8
Crop productivity (per hectar)										
2008-2012	19.4	19.7	18.8	35.5	322.8	11.0	132.6	126.2	203.2	190.7
2013-2017	23.9	24.6	21.0	46.7	417.5	13.7	150.9	142.1	233.9	211.1
The second period to the first period, %	123.2	124.9	111.7	131.5	129.3	124.5	113.8	112.6	115.1	110.7

* Calculated by authors based on official data (Agriculture, hunting and forestry in Russia. Federal State Statistics Service (FSSS). Statistical collection (SC). Electronic versions 2009, 2011, 2013, 2015; Russian statistical yearbook. FSSS-SC. Electronic versions 2008-2018)

The study of the balance of nutrients in the conditions of modern Russia is devoted to numerous studies. Sychev and Saffran (2017) exploring the balance of nutrients in agriculture in Russia for the period from 1966 to 2015. in particular, they note that since the 1990s, the use of mineral fertilizers has sharply decreased, as a result of which the balance of nutrients began to take shape with a significant excess of the removal over their input into the soil. Sychev et al. (2016) expressed the opinion that, the annual decline in the yield of winter wheat and spring barley is within 1 centner/ha is the result of the imbalance of nutrients that had arisen since the 1990s in favor of their removal throughout the country. Further, these authors note that if the situation does not change, the crop shortage will increase. Monastyrsky et al. (2016) emphasizes that the immediate restoration of scientifically-based doses of the use of mineral fertilizers and plant protection products is a crucial condition for food safety. The nature of the current imbalance in favor of the removal of nutrients, including particular regions of Russia, is also reflected in (Shafran, 2016; Krasnitsky et al., 2018; Chekmarev, 2018; Yakovlev et al., 2018).

This article aims to construct and analyze the balance of the main nutrients in Russia in the context of crops over the past 10 years. Constructing balances over five-year periods, on the one hand, helps eliminate the effect on the meteorological conditions of individual years on production volumes, and on the other, allows comparing balances over two periods, including major crops and nutrient types. In addition, the aim of the work is to establish the causes of the imbalance of nutrients and to propose an organizational and financial mechanism for its elimination by increasing the volume of applied fertilizers.

Material and Methods

The object of the study is the balance of nutrients for main crops, the cultivation of which took place in Russia from 2008 to 2017. As an information base we used data from the official statistical compilations of Federal State Statistical Service, as well as the standards for the removal of nutrients from the harvested crop, as indicated in the relevant educational and scientific literature. The research methodology includes the analysis of time series through a system of absolute and relative indicators, as well as constructive calculations. In particular:

The absolute increase shows by how many units of measure the value of the indicator has changed in the current period compared to the previous one

$$A_i = y_i - y_{i-1}$$

The growth coefficient shows how many times the value of the indicator has changed in the current period compared to the previous one

$$K_i = \frac{y_i}{y_{i-1}}$$

The percentage growth rate shows how many percent the value of the indicator has changed in the current period compared to the previous one.

$$T_i = \frac{A_i}{y_{i-1}} \times 100$$

where;

y_i - value of the studied indicator in the current period

y_{i-1} - value of the studied indicator in the previous period

The use of the computational-constructive method made it possible to calculate the predictable amount of a fund of deductions from the sale of grain crops for export, aimed at restoring effective soil fertility:

$$F=P\times N\times Q$$

P – average price of exported grain, USD per ton (in the proposed calculations - $ 200)

N – a standard proposed by the authors of contributions to the fund for the restoration of natural soil fertility in the amount of 5%

Q – the amount of exported grain (in the example - 30 million tons)

Results and Discussion

On the basis of data on the gross yield of main crops (Table 1) and the standards for the removal of nutrients with the unit of the harvested crops (Kidin and Torshin, 2015) the calculated volume of the annual production removal of nutrients and their removal with the main products is presented in Table 2. About 60 - 70% of the total production removal of nutrients accounted for wheat and barley sowing, about 20% for sunflower sowing. With the harvest of corn and sugar beet, 7-10% of the total production removal was made. Plantingof potatoes and vegetables account for an insignificant proportion of the removal, due to the fact that the calculation was made only for sowing in agricultural organizations and farms. As for the structure of the removal of nutrients with the main products, by crops it generally corresponds to the structure of production removal, with the exception of the share of sunflower, which decreases to 10-12%.

It should also be especially emphasized that the volume of both production removal and removal with the main crops in the second period increased in proportion to the growth of their gross harvests. For individual nutrients, calculations of the volumes of production removal and removal with the main products are presented in Table 3.

In the structure of production removal of nutrients, about 50% is potassium, nitrogen is about 35%, and the remaining 15% is phosphorus. The structure of removal with the final products is different: up to 58% is nitrogen, about 25% is phosphorus and the remaining 16-17% is potassium.

Table 2. Average removal of nutrients with crop yields in Russia per year by periods (th. tonnes of active substance)

Group of crops and crops	Period (five years)		The second period to the first period, %
	2008-2012	2013-2017	
Wheat + Barley *			
production removal	4888	5756	117.8
grain removal	2352	2916	124.0
Corn			
production removal	485	1048	216.1
grain removal	171	374	218.7
Sugar beet			
production removal	510	635	124.5
root vegetable removal	218	275	126.1
Sunflower			
production removal	1543	2090	135.4
seed removal	391	536	137.1
Potatoes **			
production removal	82	97	118.3
tuber removal	51	62	121.6
Vegetables ***			
production removal	43	56	130.2
For all crops			
production removal	7551	9682	128.2
removal with the main products (without vegetables)	3183	4064	127.7

* crops are combined, because according to them the removal from a unit of production is approximately the same; ** for potatoes and vegetables, the calculation was made only for agricultural organizations and farms; *** for vegetables, the calculation for the final product was not made, due to the large variation of this indicator for individual vegetable crops

Table 3. Average production removal of nutrients and removal with the main crops for the year (ths tons of active substance)

Nutrients	Period		The second period to the first period, %
	2008-2012	2013-2017	
Production removal			
Nitrogen	2500	3643	130.1
Phosphorus	1208	1443	119.4
Potassium	3543	4596	129.7
Total	7551	9682	128.2
Removal with the main crops			
Nitrogen	1750	2434	139.1
Phosphorus	862	1088	126.2
Potassium	571	642	112.4
Total	3183	4164	130.8

During the second five-year, the production removal of nitrogen and potassium increased most intensely, and with the main products nitrogen and phosphorus increased. Based on the average yield obtained by periods, the removal of nutrients per 1 hectare of sowing of the respective crops is presented in Table 4.

The largest volume of production removal from 1 hectare of sowing in both periods occurred in sugar beet, corn and vegetables, the smallest in wheat and barley. In the same approximate ratio are cultures for the removal of the direct products. The increase in yields for all crops in the second five-year period led to an annual increase in nutrient removal in the same proportion.

Table 5 presents data on the application in the studied periods of mineral and organic fertilizers, as well as other measures aimed at improving the effective fertility of the soil. The materials of this table show, first of all, that despite the slight increase in the number of mineral fertilizers introduced in the second period (with the exception of potash fertilizers), more than half of the arable areas are still not fertilized.

Table 4. The total removal of nutrients from 1 hectare of crops sowing (kilograms of active substance)

Group of crops and crops	On average per year by period		The second period to the first period, %
	2008-2012	2013-2017	
Wheat + Barley *			
production removal	140	161	115.0
grain removal	67	82	122.4
Corn			
production removal	297	379	127.6
grain removal	105	135	128.6
Sugar beet			
production removal	487	617	126.7
root vegetable removal	209	267	127.8
Sunflower			
production removal	229	284	124.0
seed removal	58	73	125.9
Potatoes **			
production removal	240	294	122.5
tuber removal	151	188	124.5
Vegetables ***			
production removal	255	312	122.4

* crops are combined, because according to them the removal from a unit of production is approximately the same; ** for potatoes and vegetables, the calculation was made only for agricultural organizations and farms; *** for vegetables, the calculation for the final product was not made, due to the large variation of this indicator for individual vegetable crops

Table 5. Indicators of measures to improve the effective fertility of land in Russia from 2008 to 2017 over five years (on average per year)

Indicators	Period (five years)		The second period to the first period, %
	2008-2017	2013-2017	
Mineral fertilizers (million tons of active substance)			
Total	2.42	2.66	109.9
including:			
Nitrogen	1.52	1.66	109.2
Phosphorus	0.50	0.61	122.0
Potassium	0.40	0.39	97.5
Mineral fertilizers applied per 1 hectare (kg of active substance):			
the total sowing area	37	45	121.6
cereal sowing	41	47	114.6
sugar beet sowing	270	277	102.6
Sunflower sowing	24	30	125.0
planting of potatoes	257	316	123.0
planting of vegetables	156	181	116.0
Organic fertilizer applied			
total			
in physical weight (mln tons)	53.0	62.7	118.3
in active substance (ths tons)	715	847	118.3
on 1 ha of sowing of all crops			
in physical weight (tones)	1.0	1.2	120.0
in active substance (kg)	9.4	10.7	113.8
The proportion of the fertilized area (%)			
by mineral fertilizers	44.4	48.4	+4.0
by organic fertilizer	7.1	8.2	+1.4
Liming acid soils (mln. ha)	0.24	0.22	91.6
Lime flour applied			
total (mln tons)	2.06	2.10	101.9
Per 1 ha (tons)	8.3	8.9	107.2
Phosphoritization of acidic soils produced (thousand hectares)	8.7	16.8	224.0

The volume of work on soil deoxidation, which occupy tens of millions of hectares in Russia, is absolutely insufficient and not changing in dynamics. Let’s compare the removal of nutrients from 1 hectare of crops

(Table 4) and fertilization to this area (Table 5) by crops over five years. We present this comparison in Table 6.

Table 6. Removal with a harvest and application of nutrients per 1 hectare of sowing on average per year over five years (kg of active substance)

Group of crops and crops	Period					
	2008-2012			2013-2017		
	Removal	Application	Application to removal, %	Removal	Application	Application to removal, %
Wheat + Barley						
production removal	140	41	29.3	161	47	29.2
grain removal	67			82		
Corn*						
production removal	297	60*	20.2	379	60*	15.8
grain removal	105			135		
Sugar beet						
production removal	487	270	55.4	617	277	44.9
root vegetable removal	209			267		
Sunflower						
production removal	229	24	10.5	284	30	10.6
seed removal	58			73		
Potatoes						
production removal	240	257	107.1	294	316	107.5
tuber removal	151			188		
Vegetables						
production removal	255	156	61.2	312	181	58.0

* approximate value, obtained from literary sources for the Southern and North Caucasian federal districts, which account for about 60% of planting of crops

Only one tenth of the nutrients removed with the sunflower crop is compensated by the mineral fertilizers applied. For corn, the sixth-fifth part is compensated, for wheat and barley no more than 30%, for sugar beet and vegetables about a half. Only for potatoes with its very low productivity, fertilizers compensate for the entire removal of nutrients. It should be emphasized that in the second five-year period, the proportion of nutrients compensated by fertilizers for most crops decreases and only the sunflower remains the same, about 10%.

This leads to a fundamental conclusion: The growth of gross harvest of agricultural crops achieved in recent years is ensured, above all, by the use of natural soil fertility. Therefore, with the continued decrease in compensation of natural fertility by fertilizers, in the long term there will inevitably be a decrease in the natural and, consequently, effective soil fertility and, as a result, a decrease in the volume of crop production.

Comparison of the volumes of nutrients removed with the crop and applied with mineral fertilizers according to their types is presented in Table 7.

Table 7. Annual removal and application of nutrients by their types in Russia, as a whole (ths. tons of active substance)

Nutrients	Period					
	2008-2012			2013-2017		
	Production removal	Removal with direct products	Application	Production removal	Removal with direct products	Application
Nitrogen	2800	1750	1520	3643	2434	1660
Phosphorus	1208	862	500	1443	1088	610
Potassium	3543	571	400	4596	642	390
Total	7551	3183	2420	9682	4164	2660

The largest difference between the production removal and nutrients applied is in potassium: about 3 million tons in the first five years and 4 million tons in the second. For nitrogen the deficit was about 1.3 mln. tons of active substance in the first five years and 1.8 mln. tons of active substance in the second. For phosphorus, the difference between removal and application is the lowest: 700 thousand tons in the first five years, and about 800 thousand tons in the second. It is worth emphasizing that in the second five-year period, the difference in favor of the removal of all nutrients increased.

After what has been said, the question is naturally: does the Russian industry have the ability to eliminate as quickly as possible the difference between the removal and application of nutrients and, therefore, prevent the degradation of Russian soils? Table 8 presents data on the annual production of mineral fertilizers in

Russia over the past 10 years. This table also compares the amounts of mineral fertilizers applied and produced. The production of mineral fertilizers in the last 5 years has increased in all types of fertilizers, but only the seventh part of fertilizers produced in Russia were applied, and nitrogen and phosphorus, is one fifth and one sixth. We have a paradoxical picture that is absolutely unacceptable for common sense: we produce fertilizers, but do not apply them, constantly worsening the natural fertility of the soil.

Mineral fertilizers produced in Russia at the expense of irreplaceable resources are exported. According to our calculations, in the last 5 years, on average, 14.8 million tons of mineral fertilizers were exported per year, including 4.7 million tons of nitrogen fertilizers, 4.3 million tons of mixed fertilizers and 5.8 million tons of potash fertilize. If the exported fertilizers were applied in Russia, then each hectare of arable land would receive an additional 186 kg of active substance of fertilizer. This is in principle (additional calculations are necessary, of course) would be enough to cover the removal of nutrients at the level of crop productivity achieved. Higher productivity levels will require higher doses of fertilizer.

Table 8. Production of mineral fertilizers in Russia on average for the year, the share of the volume of applied mineral fertilizers of the produced

Type of fertilizers	Period		The second period to the first period, %
	2008-2012	2013-2017	
Produced (million tons of active substance)			
Nitrogen	7.56	8.90	117.7
Phosphorus	2.92	3.40	116.4
Potassium	6.60	8.00	121.2
Total	17.08	20.03	117.3
Application to production of fertilizers (Table 7), %			
Nitrogen	20.1	18.6	-1.5
Phosphorus	17.1	17.9	-0.8
Potassium	6.1	4.9	-1.2
Total	14.2	13.3	-0.9

It is logical to assume that the reason that the produced mineral fertilizers are sent for export is the difference in prices (export and domestic), in the substantial benefit of export. Due to the lack of systematic data for comparing these prices, we present calculations for 2010 and 2014. Export prices: (in terms of rubles at the average annual exchange rate) generally refer to nitrogen, potash and mixed fertilizers, and domestic - to certain types of fertilizers with their classification into nitrogen, potash, mixed (Table 9).

Table 9. Export and domestic prices for mineral fertilizers (rubles per ton in physical weight) (Anonymous, 2018b)*

Type of the price	Types of the fertilizers	2010	2014
Export	Nitrogen	6070	9612
	Potassium	8632	9288
	Mixed	10462	13212
Domestic	Nitrogen		
	Ammonium nitrate	7297	-
	Ammonium sulphate	5142	-
	Liquid ammonia	4908	11500
	Carbamide	9139	14299
	Potassium		
	Potassium chloride	7986	10434
	Mixed		
	Nitro Ammophos	8652	17750
	Ammophos	14364	18992
	Azofoska	11627	15209
	Sulfa Ammophos	10200	14925
	Diammophos	14268	18275
	Diammofoska	14024	18041

* Calculated by authors based on official data (Trade in Russia. Federal State Statistics Service. Statistical collection. Electronic versions 2009,2011,2013,2015

From the data of this table 9, it follows that both export and domestic prices have increased over four years, for some types of fertilizers by 1.5 times, but the main conclusion is that export prices are not higher than domestic ones, and even lower for nitrogen and potash. Consequently, the difference in prices in favor of export should not be considered as a factor of its advantage. Obviously, the question is either in the absence of Russia's agricultural producers of financial resources for the purchase of fertilizers or in their dismissive, selfish attitude to such an important resource as soil fertility.

According to our calculations, the average annual revenue of exporters of fertilizers for 2012-2016 amounted to 9010.6 million USD. In terms of rubles at an average rate of 60 rubles. per dollar annual revenue amounted to 540.636 billion rubles. If the state withdraw 10% from this revenue for the replenishment the fund for the conservation of natural fertility offered in this article, the amount of its annual replenishment will be 54.064 billion rubles. Then, even at the maximum price of 20,000 rubles per ton, the farmers will additionally get 2,730.3 million tons of mineral fertilizers, or, in terms of 1 ha of the entire arable area, about 35 kg.

Along with the export of mineral fertilizers, in recent years, exports of agricultural products, primarily grain, have been growing rapidly. But, since it was established that the growth of gross grain harvest in modern Russia occurs primarily due to a decrease in natural soil fertility, an increase in grain exports actually means the alienation of the country's not replenished natural resources in the form of soil fertility elements. Table 10, based on the amount of nutrients that are not replenished by the application of mineral fertilizers, presents the calculation of the volumes of their alienation abroad.

Table 10. Exports of grain and nutrients from Russia over five years (on average per year)

Indicators	On average per year for five years (period)		The second period to the first period, %
Exported grain (thousand tons)	2008-2012	2013-2017	
Wheat	14345	22971	160.1
Barley	2414	3612	149.6
Corn	943	4059	by 4.3 times
Alienated overseas elements of natural fertility by 1 ton of exported products (kg of active substance)			
Wheat	50.2	46.3	92.2
Barley	52.6	54.3	103.2
Corn	66.8	68.3	102.2
Alienated overseas elements of natural fertility from the entire export (tons of active substance)			
Wheat	720119	1063557	147.7
Barley	126976	196132	154.5
Corn	62992	277230	by 4.4 times
Total	910087	1536919	168.9

With the alienation of nutrients from 1 ton of exported products remaining in general in the second period, due to the growth of grain exports, the overall increase in the volumes of nutrients alienated for abroad increased almost 1.69 times and reached 1.537 million tons of active substance, that is about 70 % of the amount of fertilizer applied for grain. In our opinion, export supplies of grain should be another source of preserving the natural fertility of the land in Russia. Such a proposal is logical, including from the point of view of export: exporters should think not only about the present profit, but also about the possibility of its stable receipt in the future, which is excluded when effective soil fertility is reduced. With a modern export price of 1 ton of grain not lower than USD 200 per ton, exporters should, in our opinion, transfer at least $ 10 to the fund to support natural soil fertility. If we proceed from the average annual volume of grain exports in recent years in the amount of at least 30 million tons, the amount of deductions will be 300 million USD, and at the rate of 60 rubles for dollar it will be about 18 billion rubles. The use of these deductions, according to our approximate calculations, will allow increasing the doses of fertilizer application for cereals by at least 30 -40 kg of active substance per 1 hectare of the arable area.

Conclusion

The growth of gross harvests of major crops in Russia in recent years has been accompanied by a growing imbalance between the removal of nutrients from the crop and their application with fertilizers. Thus, there is an intensive decrease in the effective fertility of the soil, which, can develop into their degradation while maintaining this process. Instead of all the expected growth in crop production, the result will be an accelerated fall. Of course, this conclusion should be supported and differentiated by regional studies, including agrochemical soil monitoring.

To reduce, and in the future complete elimination of imbalance of nutrients in the soil, along with state support for the application of mineral fertilizers by economic entities, in our opinion, the immediate creation of a special fund for the conservation of soil fertility should be relevant. The main sources of replenishment of this fund can be deductions from export earnings from the supply of mineral fertilizers and grain abroad.

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Assessment of soil quality for vineyard fields: A case study in Menderes District of Izmir, Turkey

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Abstract

This study was carried out to determine the suitable classification of soil quality for vineyard fields of Akçaköy, Çatalca, Efemçukuru, Görece and Yeniköy villages in Menderes district of Izmir-Turkey. In vineyard fields, soil pH gave a positive relation with Ca and significant negative relations with P, Fe, Mn and Zn contents. Soil organic matter (OM) content had significant positive relations with EC, P, Fe, Mn and Zn and significant negative relations with bulk density and $CaCO_3$ content. Soil quality index values for the vineyard fields varied between 0.38 and 0.85 with a mean of 0.57. Only one of the 28 soil samples taken from different vineyard fields was found in very suitable (S_1:1.00-0.75) class, 8 in suitable (S_2:0.75-060), 12 in marginal suitable (S_3:0.60-0.50) and 7 in non-suitable (N:<0.50) class according to the soil quality index (SQI). Restricting soil factors for vine growth in the fields classified in S_2 and S_3 classes generally became low pH, low organic matter (OM), P, Fe, Mn, Cu, Mg and K contents than that of suggested levels. In addition to restring factors in S_2 and S_3 classes, physical properties in soils classified in N class were lower than suggested levels. The SQI values showed significant positive relations with grape yield, soil OM, P, K, Fe, Cu, Mn, Zn contents and significant negative relations with soil pH, exch. Ca and $CaCO_3$ contents. The grape yields had also positive relations with soil OM, Fe, Mn, Zn contents and negative correlations with soil pH and $CaCO_3$ content. Soil quality in a vineyard field should be assessed to reach successful sustainable and precision agricultural practices for high crop production.

Keywords: Soil quality, grape, yield, soil properties.

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Introduction

Soil quality is defined as ‘‘the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation’’ (Karlen et al., 1997). These functions of soils in many soil quality definitions include a soil's role in plant growth, hydrology, biological transformations, and degradation of organic materials. The sustainability and productivity of field use can be affected by the quality of soil which is controlled by chemical, physical, and biological components of a soil and their interactions (Papendick and Parr, 1992). While physical soil quality indicators are generally related to aeration, water storage and movement, chemical soil quality indicators are related to nutrient availability, phytotoxicity of trace metals, and pesticide mobility in soils (Doran and Parkin, 1994). The soil properties interact each other are generally related with topography, land use and management practices (Ekberli and Kerimova, 2005; Karaca and Gülser, 2015; Karaca et al., 2018; Kars and Ekberli, 2019).

The vine can grow in most soil types where many crop fields cannot grow. However, the soils including very heavy texture, poor drainage, salty and toxic substances is not appropriate for vine production. In heavy textural and moist soil conditions, the roots of vine die due to low aeration and crop production decreases.

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Loamy soils including high organic matter, low water holding capacity and well drainage characteristics are generally suitable for good quality grape production (Gücüyen, 2007).

Adverse effects of intensive agricultural practices on microbial activity and modification of soil organic matter are evident in vineyards. Soils in vineyards are usually sensitive to degradation and organic matter loss due to their intrinsic properties such as; limited soil development, coarse texture, and low capacity to protect organic matter binding to soil minerals (Le Bissonnais et al., 2007; Martínez-Casasnovas and Ramos, 2009). Belmonte et al. (2018) reported that soil tillage in a vineyard reduces soil organic matter accumulation and aggregate stability while permanent vegetation cover about 20-30 % of the vineyard floor improves vineyard soil conservation. Monga et al. (1990) determined that the application of N, P, K (500:750:500 g per vine per year) produced significantly more number of bunches (167), fruit yield (53.21 kg/vine) than the other treatments. Mackenzie and Christy (2005), studied on the soil chemical composition effects on the composition and quality of wine grapes in two vineyards of South Australia. They found that grape juice properties such as Baumé and titratable acidity were clearly correlated with micro elements in the soil such as; Ca, Sr, Ba, Pb and Si. Arnó et al. (2012) reported that soil fertility, physical and chemical soil properties have a great importance on grape quality. They found that the soil carbonates had a great effect on grape quality probably due to the reduced availability of manganese in calcareous soils.

Aegean Region having 33.0% of Turkey's vineyard area is ranked in the first place with 43.3% of grape production. Seedless dried grape production is done only in this region, again seedless raisins export in our country in the world ranking is also taken into account when the vineyard is indispensable for our country and our region. This region is followed by the Mediterranean Region with 19.5% of the vineyard area and the Middle South agricultural region with 18.2% of the vineyard area in Turkey (Çelik et al., 2000). Generally crop fields, fruits and vegetables cannot be cultivated on the ridge areas due to high slope. This type of field is available for vineyard growth and an important source of income for the people living in these areas (Aktaş, 2002). The objective of this study was to assessment of soil quality of vine yard fields located in Akçaköy, Çatalca, Efemçukuru, Görece and Yeniköy villages of Menderes district, Izmir-Turkey.

Material and Methods

In the study, surface soil samples (0-20 cm depth) of 28 vineyard fields were taken from Akçaköy (3), Çatalca (4), Görece (3), Efemçukuru (9) and Yeniköy (9) villages in Menderes districts of Izmir, Turkey. Locations of the vineyard fields are given in Table 1.

Table 1. Locations of soil samples taken from 28 vineyard orchards

Location	Coordinates		Elevation	Location	Coordinates		Elevation
	North 'N'	East 'E'	(m)		North 'N'	East 'E'	(m)
Akçaköy-1	38°15.045'	27°05.827'	154	Görece-1	38°16.352'	27°07.579'	143
Akçaköy-2	38°15.055'	27°05.832'	153	Görece-2	38°16.159'	27°07.087'	139
Akçaköy-3	38°14.730'	27°05.653'	153	Görece-3	38°16.381'	27°07.612'	142
Çatalca-1	38°15.782'	27°04.378'	196	Çatalca-3	38°14.006'	27°03.933'	174
Çatalca-2	38°15.879'	27°04.513	201	Çatalca-4	38°15.247'	27°04.769'	176
Efemçukuru-1	38°16.443'	26°59.251'	684	Yeniköy-1	38°12.514'	27°01.877'	196
Efemçukuru-2	38°16.600'	26°57.995'	636	Yeniköy-2	38°12.805'	27°02.529'	154
Efemçukuru-3	38°16.630'	26°57.958'	626	Yeniköy-3	38°14.046'	27°03.794'	179
Efemçukuru-4	38°16.714'	26°57.920'	619	Yeniköy-4	38°12.514'	27°01.877'	196
Efemçukuru-5	38°16.712'	26°57.962'	614	Yeniköy-5	38°12.302'	27°01.803'	219
Efemçukuru-6	38°16.713'	26°57.934'	617	Yeniköy-6	38°12.637'	27°02.265'	199
Efemçukuru-7	38°16.398'	26°59.240'	686	Yeniköy-7	38°12.328'	27°01.758'	219
Efemçukuru-8	38°16.678'	26°58.003'	608	Yeniköy-8	38°14.037'	27°03.791'	175
Efemçukuru-9	38°16.615'	26°57.980'	630	Yeniköy-9	38°12.805'	27°02.529'	154

The soil properties of the fields were determined as follows: particle size distribution by the hydrometer method (Day, 1965); bulk density (BD) by soil core method (Demiralay, 1993), soil reaction (pH) in 1:1 (w:v) soil water suspension by pH meter; electrical conductivity (EC_{25}ºC) in the same suspension by EC meter; and exchangeable cations (Ca, Mg, K, Na) by ammonium acetate extraction (Kacar, 1994), available phosphorus by Olsen's method (Olsen et al., 1954), DTPA extractable heavy metals (Fe, Mn, Zn, Cu) according to Lindsay and Norvel (1978). The organic matter content was determined using the modified Walkley-Black method (Kacar, 1994). The lime content was determined by Scheibler Calcimeter (Nelson, 1982). Exchangeable Ca, Mg and K percentages (ECaP, EMgP, EKP) were calculated with dividing exc. cation by sum of exc. cations.

Grape yield (ton/ha) and yield per vinestock (kg/vinestock) were obtained after the harvest season completed from each vineyard field in 2011.

The following geometric mean equation was used to determine for soil quality index values for each vineyard field.

$$\mathrm{SQI} = \sqrt[n]{a_1 . a_2 . a_3 \ldots a_n}$$

where;

SQI: soil quality index; a: score of each soil parameter between 1.0 and 0.2 given in Table 2, n is number of soil parameter.

SQI values for vineyard fields were classified as;

S_1: between 1.00 – 0.75 as very suitable

S_2: between 0.75 – 0.60 as suitable

S_3: between 0.60–0.50 as marginal suitable and

N:< 0.50 as non-suitable for vineyard growth.

The relationships among the experimental data were performed using the SPSS 17 software package programme.

Results and Discussion

Soil properties of vineyard fields

Descriptive statistics of some physical and chemical soil properties are given in Table 2. Clay content of vineyard fields varied between 9.99 and 37.48% with a mean of 19.96%. Soil texture of the vineyard fields was classified as sandy loam (SL) in 15, sandy clay loam in 10 and clay loam (CL) in 3 fields. Kurtural (2011) reported that soils having less than 5% of stone by volume and clay loam to light clay texture have high potential for vineyard growth while sandy to sandy loam textural soils have low potential. In this study, 13 fields were found as suitable for vineyard growth according to their textural classes, but 15 fields were not suitable. The bulk density (Db) of the soils varied between 1.07 g/cm^3 and 1.75 g/cm^3. Leake (1999) reported that the ideal Db values in the vineyard soils should be less than 1.4 g/cm^3. While the Db values of 15 vineyard fields were below this critical value, the values of 13 fields were found to be higher than this value. The soil pH values ranged from 4.85 to 8.16 were classified as neutral in 12, slightly alkaline in 5, slightly acid in 3, moderately alkaline in 3, very strongly acid in 3 and moderately acid in 2 vineyard fields. Çelik (1998) reported that the pH values of the vineyard soils varied between 5.5 and 8.5. The most suitable soil pH in terms of vine cultivation is neutral (Leake, 1999), 12 soil samples were found to be ideal in this study. The electrical conductivity of the soils in the vine fields varied between 0.11 dS/m and 0.70 dS/m. Lanyon et al. (2004) reported that the EC values of vine growing soils should be less than 2 dS/m. According to the classification of Soil Quality Lab. Staff (1999), all of the soils were found in non-salty class. The lime contents of the soils ranged between 0.38 and 15.19% and were generally classified as low.

The organic matter contents of the vineyard fields ranged from 0.48 to 2.57% (Table 2). Kurutural (2011) reported that organic matter content of vine growing soils should be between 2 and 3%. While the organic matter contents of 24 vineyard fields were found as low, OM contents of the 4 fields were found as suitable for vine growth. The available phosphorus contents of soils were between 1.92 and 29.55 mg/kg. Lanyon et al. (2004) classified the available phosphorus content of the vineyard fields as deficient less than 25 mg/kg, marginal between 25 and 35 mg/kg, sufficient between 35 and 80 mg/kg, and high higher than 80 mg/kg. In this study, the available P content of 24 soil samples was found less than 25 mg/kg and classified as deficient.

The Ca contents and exch. Ca percentage (ECaP) values of the soil samples were between 1.85 and 31.39 cmol/kg, and between 44.33 and 91.78%, respectively (Table 2). The researchers reported that the ECaP of vine grown soils should be between 60-80% (Leake 1999; Lanyon et al., 2004). ECaP values of 6 soil samples were found less than 60% and the others were higher than this critical value. The Mg contents and exch. Mg percentage (EMgP) of the soils were between 1.01 and 5.97 cmol/kg, and 5.99 and 42.32%, respectively. Lanyon et al. (2004) reported that EMgP of the vineyard soils should be between 15-30%. In this study, the EMgP values of 8 soil samples were found to be less than 15%, 13 of them were between 15-30% and 7 of them were higher than 30%. The K contents and exch. K percentage of the soil samples were between 0.11 and 0.67 cmol/kg. Researchers reported that the EKP of vineyard soils should be between 5-10% (Leake, 1999; Lanyon et al., 2004). The EKP values of 4 soil samples were more than 5% and the others were lower than this value.

Table 2. Descriptive statistics for some soil properties, soil quality index values and yields of vineyard fields (n=28).

	Minimum	Maximum	Mean	Std. Dev.	Skewness	Kurtosis
Clay, %	9.99	37.48	19.96	7.34	0.86	0.34
Silt, %	12.33	29.98	20.86	4.77	-0.03	-1.02
Sand, %	38.31	74.54	59.17	9.08	-0.59	0.51
Bulk density, g/cm^3	1.07	1.75	1.43	0.18	-0.03	-0.64
pH (1:1)	4.85	8.16	6.84	0.93	-0.75	0.01
EC, dS/m	0.11	0.70	0.32	0.16	0.90	0.17
Organic Matter, %	0.48	2.57	1.28	0.58	0.74	-0.20
Av. P, mg/kg	1.92	29.55	11.57	8.88	0.70	-0.81
K, cmol/kg	0.11	0.67	0.28	0.12	1.35	2.91
Ca, cmol/kg	1.85	31.39	10.57	7.12	0.99	0.98
Mg, cmol/kg	1.01	5.97	2.51	1.20	1.22	1.56
Na, cmol/kg	0.24	0.44	0.28	0.05	1.98	4.13
Exc. K (EKP), %	0.64	7.83	2.81	1.91	0.87	0.12
Exc. Ca (ECaP), %	44.33	91.78	72.54	13.17	-0.57	-0.57
Exc. Mg (EMgP), %	5.99	42.32	21.94	10.36	0.53	-0.50
Exc. Na (ESP), %	0.92	8.46	2.71	1.64	1.85	4.50
$CaCO_3$, %	0.38	15.19	2.81	4.09	1.79	2.21
Fe, mg/kg	3.30	55.70	14.28	13.60	1.86	2.97
Cu, mg/kg	0.58	2.46	1.38	0.49	0.48	-0.56
Mn, mg/kg	7.70	270.36	49.50	62.45	2.59	6.39
Zn, mg/kg	0.71	6.97	1.91	1.58	2.46	5.75
Soil quality index (SQI)	0.38	0.85	0.57	0.10	0.33	0.68
Grape yield, ton/ha	2.50	25.00	9.69	6.17	1.03	0.19
Yield per vinestock, kg	1.00	11.90	4.35	2.74	1.17	0.87

The mean values of available Fe, Cu, Mn, and Zn contents of the vineyard soils were 14.28, 1.38, 49.50 and 1.91 mg/kg, respectively (Table 2). While Lanyon et al. (2004) reported that available Fe contents of vineyard soils should be more than 4.5 mg/kg, Holzapfel et al. (2009) reported that Fe content in vineyard soils varies between 4 and 200 mg/kg. In this study, only Fe content of 2 soil samples was less 4 mg / kg and the others were higher. Lanyon et al. (2004), reported that available Zn content of the vineyard soils is classified as deficient less than 0.5 mg/kg, marginal between 0.5-1.0 mg/kg, sufficient between 1.0-2.0 mg/kg and high between 2.0 and 20.0 mg/kg. In this study, Zn contents of the most soil samples were found as sufficient for vineyard growth. Lanyon et al. (2004) reported that Mn contents of the vine-grown soils are classified as marginal less than 2.0 mg/kg and sufficient between 2.0 and 4.0 mg/kg. On the other hand, Holzapfel et al. (2009) stated that for ideal viticulture, soils should contain between 15 and 70 mg/kg Mn. In the study, Mn contents of 6 soil samples were less than 15 mg/kg, Mn contents of 22 soil samples were higher than 15 mg/kg. Lanyon et al. (2004) classified the useful Cu contents of grapevine-grown soils as deficient less than 0.1 mg/kg, marginal between 0.1-0.2 mg/kg, sufficient between 0.2-0.4 mg/kg, and high more than 0.4 mg/kg.

Soil quality classification in vineyard fields

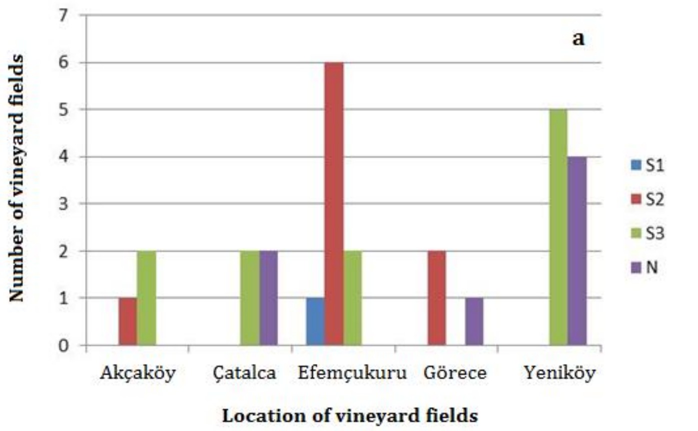
The selected soil physical and chemical quality parameters were classified between 1.00 (ideal) and 0.20 (poor) according to the soil requirements of vineyard given in the literatures (Leake, 1999; Lanyon et al. 2004; Holzapfel, 2009; Kurtural, 2011) and given in Table 3.

Estimated soil quality index values for the vineyard fields varied between 0.38 and 0.85 with a mean of 0.57 (Table 2). The fields chosen in Akçaköy and Efemçukuru villages were generally found to be suitable vineyard cultivation and did not have a non-suitable class in soil quality assessment (Figure 1a). The fields chosen in Çatalca and Yeniköy villages were generally found to be non-suitable for vineyard cultivation and classified in N class. According to the frequency distribution of soil quality classes given in Figure 1b, only one (3.5%) of the 28 vineyard fields was determined in very suitable (S1) class, and the other fields were classified as; 9 fields (28.6%) in suitable (S2), 11 fields (42.9%) in marginal suitable (S3) and 7 fields (25%) in non-suitable (N) class.

Table 3. Suitable classes of some soil properties for vineyard growth.

Suitable classes	Ideal	Good	Moderate	Poor
Score	1.0	0.8	0.5	0.2
Soil texture*	L, SiCL, CL	SiL, SCL,	SL, SiC, SC	C, Si, S, LS
Bulk density, g/cm^3	<1.2	1.2-1.4	1.4-1.6	>1.6
pH (1:1)	6.7-7.3	6.1-6.6 & 7.4-7.7	5.5-6.6 & 7.7-8.0	<5.5 & >8.0
EC, dS/m	<1.5	1.5-2.5	2.5-4.0	>4.0
Organic matter, %	3.5	2.5-3.5	2.5-1.5	<1.5
Phosphorus, mg/kg	80-50	50-30	30-20	<20
ECaP, %	>65	65-55	55-40	<45
EMgP, %	>30	30-20	20-10	<10
EKP, %	>8	8-5	5-3	<3
$CaCO_3$, %	<2	2-4	4-8	>8
Zn, mg/kg	>2.0	2.0-1.0	1.0-0.5	<0.5
Mn, mg/kg	70-50	50-30	30-15	<15
Cu, mg/kg	>0.4	0.4-0.2	0.2-0.1	<0.1
Fe, mg/kg	35-25	25-15	15-4	<4

*L: loam, Si: silt, C: clay, S: sand



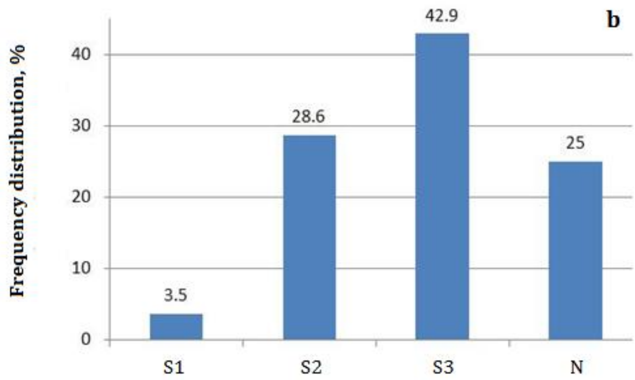


Figure 1 a) Soil quality classification of vineyard fields in different locations; b) Frequency distribution of soil quality classes in 28 vineyard fields (S_1:very suitable S_2: suitable, S_3:marginal suitable, N:non-suitable).

Restricting soil factors for vine growth in the fields classified as S_2 and S_3 generally became lower pH, OM, P, Fe, Mn, Cu, Mg and K contents than that of the suggested levels. In addition to these restring factors in S2 and S3 classes, the physical soil properties of the vineyard fields classified as non-suitable (N) were lower than that of the suggested levels. Arnó et al. (2012) determined that mineral concentration (basically N, Ca, Mg, Fe, S, Zn, Mn and B) of leaves played an important role in differentiating vineyard areas of low and high production.

According to the correlation matrix among the soil properties given in Table 4, soil reaction (pH) had positive relation with exch. Ca, significant negative correlations with available P, Fe, Mn and Zn contents. Organic matter (OM) content had significant positive correlations with EC, P, Fe, Mn and Zn and significant negative correlations with Db and $CaCO_3$ content. Electrical conductivity values gave significant positive correlations with clay, K, Ca and Mg contents. There were also significant positive correlations among the micro nutrient contents of soils. Gülser et al. (2015) found that addition of compost and organic residue into soil increased plant available nutrient contents of the soil in a hazelnut orchard and soil organic matter content showed significant positive correlations with EC, Ca, and sum of exchangeable cations. In another study, Candemir and Gülser (2011) reported that soil bulk density reduced with organic waste application and generally gave significant negative correlations with organic matter and other soil properties. They concluded that the soil quality parameters of clay and loamy sand soils increased by the application of different agricultural wastes.

Table 4. Correlation matrix among the soil properties of vineyard fields.

	Si	S	Db	pH	EC	OM	P	K	Ca	Mg	Na	$CaCO_3$	Fe	Cu	Mn	Zn
C	0.08	-0.85**	-0.66**	0.35	0.68**	-0.06	-0.32	0.19	0.76**	0.63**	0.55**	0.39*	-0.33	-0.36	-0.27	-0.13
Si		-0.59**	0.10	-0.02	-0.02	0.09	0.18	-0.05	-0.04	0.06	0.01	0.35	0.20	-0.04	0.08	-0.05
S			0.48**	-0.27	-0.54**	-0.01	0.17	-0.13	-0.60**	-0.54**	-0.45*	-0.50**	0.16	0.31	0.17	0.13
Db				-0.30	-0.72**	-0.49**	0.12	-0.35	-0.64**	-0.67**	-0.24	0.15	0.03	0.05	-0.10	-0.22
pH					0.35	-0.27	-0.63**	-0.22	0.67**	0.20	0.18	0.24	-0.72**	-0.21	-0.53**	-0.37*
EC						0.38*	0.03	0.42*	0.62**	0.56**	0.33	0.05	-0.04	-0.11	0.16	0.11
OM							0.40*	0.25	-0.09	0.15	-0.22	-0.45*	0.68**	0.27	0.71**	0.57**
P								0.15	-0.36	-0.17	-0.21	-0.05	0.69**	0.36	0.65**	0.33
K									-0.01	0.54**	0.32	-0.42*	0.30	0.21	0.23	0.07
Ca										0.47*	0.47*	0.33	-0.54**	-0.22	-0.40*	-0.21
Mg											0.39*	-0.01	-0.06	0.06	0.02	0.03
Na												0.13	-0.29	-0.18	-0.27	-0.16
$CaCO_3$													-0.28	-0.36	-0.24	-0.29
Fe														0.50**	0.87**	0.53**
Cu															0.51**	0.39*
Mn																0.70**

The correlation matrix among the SQI, grape yield and soil properties are given in Table 5. The SQI values of the vineyard fields showed significant positive correlations with OM, P, K, Fe, Cu, Mn, Zn contents and significant negative correlations with soil pH, exch. Ca and $CaCO_3$ contents. Soil quality index (SQI) values of the vineyard fields had also significant positive relationships with grape yields at 1 % level (Figure 2a,b).

Table 5. Relationships among the soil quality index (SQI) values, grape yield and soil properties.

	G. Yield	S	Si	C	Db	pH	EC	OM	P
SQI	0.747**	0.286	-0.078	-0.304	-0.196	-0.485**	0.191	0.728**	0.488**
Grape Yield	1	0.248	-0.143	-0.214	-0.210	-0.386*	0.238	0.740**	0.332
	K	Ca	Mg	Na	$CaCO_3$	Fe	Cu	Mn	Zn
SQI	0.554**	-0.447*	0.156	-0.360	-0.657**	0.728**	0.424*	0.664**	0.466*
Grape Yield	0.200	-0.301	0.002	-0.311	-0.420*	0.658**	0.179	0.739**	0.698**

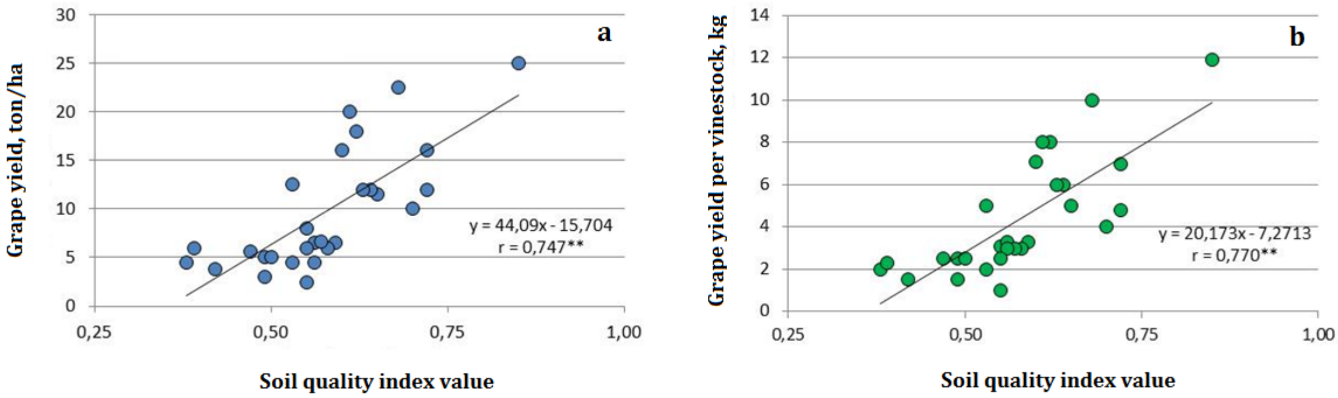


Figure 2.a) Relationship between soil quality index values and grape yields of vineyard fields,
b) Relationship between soil quality index values and grape yields per vinestock.

The grape yields of vineyard fields had positive correlations with soil OM, Fe, Mn, Zn contents and negative correlations with soil pH and $CaCO_3$ content (Table 5). Arnó et al. (2012) reported that soil physical and chemical properties are great of importance with regard to grape yield and quality attributes, especially soil carbonate content leading to deficiency of some mineral nutrients in soil. A major threshold for soil OM is 3.5%, below which a potentially serious decline in soil quality will occur (Loveland and Webb, 2003). In this study, soil OM contents generally were lower than this critical value. While the nutrient contents, grape yield and SQI values in vineyard fields increased with increasing soil OM content, the bulk density of soils decreased with increasing soil OM content. Aggregates are the main units of soil structure and addition of organic matter to soils improves physical quality of soil by increasing aggregate stability and decreasing bulk density (Gülser 2006; Candemir and Gülser 2011). Le Bissonnais et al. (2007) found that organic carbon content was strongly correlated with aggregate stability in 68 soil samples and it is a predominant indicator of aggregate stability of vineyard soils. It is known that there are functional relationships between plant nutrition, fertility and soil properties (Ekberli and Kerimova, 2008; Bayram and Gülser, 2018). In this study, the grape yields in vineyard fields increased with increasing SQI values due to high OM, nutrient contents and low Db and $CaCO_3$ content. Demir and Gülser (2015) reported that the compost application improved soil quality with increasing the water holding capacity, EC, OM content, exch. Mg, K and available P contents and decreasing bulk density, pH, Na and Ca contents, and increased tomato yield under greenhouse conditions.

Conclusion

In this study, evaluation of soil quality of 28 different vineyard fields located in Menderes district of İzmir-Turkey were done according to the physical and chemical soil indicators. While the most of vineyard fields (67.9%) classified in marginal suitable (S3) and non-suitable (N) class for vineyard growth, 32.1% of the fields were classified in very suitable (S1) and suitable (S2) class. Restricting soil factors for vine growth were generally low pH, OM, P, Fe, Mn, Cu, Mg and K contents and high bulk density in the fields. Generally low OM content and high pH and $CaCO_3$ content in the soils decreased soil quality for vine growth by decreasing the availability of nutrients and restricting soil physical properties. The grape yields of the fields had significant positive correlations with SQI values which increased by increasing the suitable soil physical and chemical characteristics in the fields for vineyard growth. It can be suggested that assessment of soil quality of the vineyard fields could play an important role for high grape productivity in precision agricultural practices.

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Nutritional quality evaluation of different varieties of pomegranate under climatic conditions of Faisalabad

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Abstract

The nutritional value of different pomegranate verities was determined in the laboratory of Biochemistry, Ayub Agricultural Research Institute (AARI), Faisalabad Pakistan to study the effectiveness of pomegranate juice as health responsive. The results showed that tested pomegranate varieties contained peels and seed percentage range from 34-40% and 28-39% respectively. Juice contained a much higher remarkable content of total soluble solids ranged from (15-19%), reducing sugar (10 to 14%), non-reducing sugars (2.8 to 5%), total invert sugars (13.8 to 18%), Vitamin-C (10.5 to12.6 mg/100 mL) and acidity (0.9 to 1.7%). Total phenols and antioxidants were higher in Sultan (1101µg GAE L^{-1} (gallic acid equivalants) and 41.5% DPPH (2,2-diphenyl-1-picrylhydrazyl) inhibition respectively) and lowest in NARC-1(1012 – 1101 µg GAE L^{-1} and 25.7% respectively). Therefore, the current results suggest that nutritional status of pomegranate variety, Sultan was better than Turnab Ghulabi, NARC-1, NARC-2 and Kandhari. It can be directed to incorporate Sultan (pomegranate) fruit juice for better nutritional status.

Keywords: Antioxidants, phenols, physico-chemical properties, pomegranate.

Introduction

Pomegranate juice is the best source of antioxidants among all the fruit juices (Seeram et al., 2008). It contains vitamin C and Flavonoid (plant based antioxidants) which help to reduce the risk of heart diseases and some kind of cancer. It also contains minerals. Prevention and treatments of diseases on the part of consumers, researchers and the food industry by using food products has become widely accepted (Viuda-Martos et al., 2010 a,b). Functional foods find primary importance due to their role in physiological benefits and disease prevention or slow the progress of chronic diseases. Pomegranate is a functional food as it has multi functions relating to medicinal and nutritional benefits (Rowayshed et al., 2013).

It has great importance in human diet because of having several groups of substances, useful in disease risk reduction (Jaiswal et al., 2010). The pomegranate (*Punica granatum*) is a nutrient rich food source having phytochemical compounds. Phytochemical have been identified from various parts of the pomegranate tree and from pomegranate fruit: peel, juice and seeds. Pomegranates are prevalently consumed as fresh fruit, juice, beverages, jams, jellies and extracts. It is also used as botanical ingredients in herbal medicines and dietary supplements (Elfalleh et al., 2011). Bioactive compounds are preferably present in pomegranate and have been used in herbal medicine from ancient times. Many parts of pomegranate fruit possess colossal antioxidant activity. Its juice has high antioxidant activity and effectively prevents many diseases, such as atherosclerosis, low-density lipoprotein oxidation, prostate cancer, platelet aggregation and various cardiovascular diseases (Adhami and Mukhtar, 2006).

All parts of pomegranate (*Punica granatum* L.), leaf, seed, juice, husk and peel grab attention to study their role in bioactivities (Lansky and Newman, 2007). Pomegranate seed contains a range of nutraceutical components such as sterols, γ-tocopherol, punicic acid and hydroxyl benzoic acids (Liu et al., 2009).

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Pomegranate seed is more valuable in food industries as it has great role in by-product of juice and concentrates production plants, valuable pharmaceutical and nutritional compounds (unsaturated fatty acids and phenolic compounds) in the seed and their antioxidant properties (Rowayshed et al., 2013). The objective of this study was to assess and compare the quality of various varieties of pomegranate under climatic conditions of Faisalabad Pakistan.

Material and Methods

The present study was conducted at Biochemistry Section, Ayub Agricultural Research Institute, Faisalabad in collaboration with Horticultural Research institute AARI, Faisalabad Pakistan during the month of August and September in year 2017-18 to assess the nutritional quality of different varieties of pomegranate under climatic conditions of Faisalabad. Metrological data during the months of August and September 2017 and 2018 is given in Table 1. Soil properties of the field area of Horticulture Research Institute are given in Table 2. Five pomegranate varieties i.e. Tarnab Gulabi, NARC-1, NARC-2, Sultan and Kandhari were collected from Horticultural Research Institute AARI Faisalabad at maturity. The fruits were washed with water and wiped to completely dry. Fruits were peeled manually, separating the seeds and juice was extracted mechanically by using mechanical juicer blender. Then the juice was filtered through muslin cloth. The juices were immediately stored at 4°C in the refrigerator for further analysis. Data was collected about peel and seed percentage and juice was analyzed for TSS, acidity, vitamin C, reducing sugar, non-reducing sugar, total invert sugar, total antioxidant and total phenols.

Table 1. Summarized Meteorological data for the growing season 2017-18 (Source: Meteorological data, recorded at the observatory of Plant Physiology Section Agronomic Research Institute, Faisalabad Pakistan)

Parameters	August 2017	September 2017	August 2018	September 2018
Max. Temperature °C				
Mean max. Temp.	37.4	36.9	36.5	37.7
Highest Max. Temp	40.0	39.5	39.5	40.5
Lowest Max. Temp.	30.6	32.5	30.0	34.5
Minimum Temperature °C				
Mean Min. Temp.	26.9	23.4	24.6	28.1
Highest Min. Temp	29.6	26.7	28.0	30.3
Lowest Min. Temp.	21.0	20.0	19.0	25.5
Relative Humidity (%)				
Mean Rela Humi 8 am	73.1	69.9	73.2	72.4
Mean Rela Humi 8 am	54.9	51.2	53.5	56.7
Lowest Rela Humi	41.0	33.0	38.0	44.0
Highest Rela Humi	92.0	91.0	87.0	92.0
Sun Shine (Hours)				
Mean daily sunshine (hrs)	8-15	9-05	8-13	7-54
Total Sunshine (hrs)	255-40	272-20	246-15	245-10
Rain fall (mm)	65.7	19.0	85.4	15.2
Cloudy Nights	5.0	3.0	2.0	1.0

Titratable Acidity, pH, total soluble solids content

Titratable acidity (TA) was determined by titration to pH 8.1 with 0.1M NaOH solution and expressed as g of citric acid per 100 g of juice (AOAC, 2005). The pH and soluble solids content of the juice were measured immediately after extraction using pH meter and digital refractometer, respectively. The pH meter was calibrated with standards having pH 4 and 9. The refractometer was calibrated using distilled water and measurement was done with the temperature compensated mode. All measurements were made in triplicate and average results were reported. The total sugars were estimated according to the method described by Ranganna (2001). Ascorbic acid contents (g/100 mL juice) of samples were determined according to the titration method using 2, 6-dichlorophenol indophenol as was reported by AOAC (AOAC, 2005).

Total phenols and total antioxidants

Pomegranate juice was extracted with mixture of methanol, acetone and HCl. Extraction mixture was prepared with methanol, acetone and HCl in the ratio of 90:8:2 respectively. Extraction was carried out by taking 1mL of pomegranate juice vertexed with 5 mL of extraction mixture and centrifuged at 400 rpm for 5 minutes. Took the supernatant and stored for phenols and antioxidant determination. The measurement of the antioxidants was carried out as radical scavenging activity of DPPH (2,2-diphenyl-1-picrylhydrazyl) according to method describe by Brand-Williams et al. (1995) and Sánchez-Moreno et al. (1998). DPPH was diluted methanol and 0.004% DPPH methanol solution was prepared. Took 0.5 mL of supernatant and mixed with 3 mL 0.004% DPPH solution. The mixtures were incubated in the dark for 30 min. Absorbance of the resulting solution was measured at 517 nm by a UV–Visible spectrophotometer. The reading with 0.004% DPPH was used as blank (A_0) along with samples reading as 'A'. The results were expressed as the percentage of inhibition of the DPPH. Total antioxidants are determined by following equation:

$$\text{Total antioxidant [\% of DPPH reducing activity]} = [(A_0\text{-}A) / A_0] \times 100$$

Total phenolic contents were determined using a Folin-Ciocaltau colometric method and expressing the result as gallic acid equivalents (GAE). Supernatant sample (0.2 ml) was mixed with 0.1 ml of ten-fold diluted Folin-Ciocalteu reagents and 0.8 ml of 7.5% sodium carbonate solution. Gallic acid was used as standards and results were expressed as gallic acid equivalents (GAE) per 100 mL. After standing the prepared samples for 30 min at room temperature, the absorbance was measured at 765 nm using spectrophotometer (Singleton and Rossi, 1999)**.** Graph was prepared with standard values and calculated the total phenols as Gallic acid equalants

Table 2. Physico-chemical prperties of the soils

Sand, %	50.3
Silt, %	27.7
Clay, %	22.0
Texture type	Sandy clay loam
Saturation percentage, %	39.0
pH	7.9
EC, dSm^{-1}	1.4
Organic matter, %	0.76
Nitrogen, %	0.030
Available phosphorus (P), mg kg^{-1}	7.2
Extractable potassium (K), mg kg^{-1}	120

Statistical analysis

Data was arranged over the year and varieties were compared statistically. Means and standard deviations were calculated for three independent determinations for each variable. Correlation matrix was done using MS Excel 2003 version. Standard errors of means of the data were computed (Steel et al., 1997) whilst means were compared by Duncan's Multiple Range Test (Duncan, 1955).

Results

The results regarding physical and nutritional parameters of pomegranate are given in Table 3, 4 and 5 respectively. Juice percentage in different pomegranate varieties ranged from 22.7 to 33.1%. Maximum juice percentage was recorded in NARC-1 (33.1%) while minimum was recorded in Kandhari (22.7%). TSS of pomegranate juice samples ranged from 15.6 to18.6% as maximum TSS (18.6%) was recorded in Sultan while minimum was recorded in NARC-2 and Kandhari (15.6 %). Maximum peel percentage was recorded in NARC-1 (42%) while minimum peel was recorded in Sultan (35.1%). Seed percentage in pomegranate samples ranged from 32.1 to 36%. Ascorbic acid contents of juice of different pomegranate samples was found maximum in Kandhari and Tarnab Gulabi (12.7 mg/100g) and minimum was recorded in NARC-2 (10.6 mg/100g). Data regarding reducing sugar ranged from 10.4 to 12.1% such that maximum reducing sugar (12%) was recorded in Sultan while minimum reducing sugar (10.4%) was recorded in NARC-2. Regarding non reducing sugar, maximum was recorded in Sultan (5.7%) which is statistically at par with Tarnab Gulabi (5.3%) while minimum non-reducing sugar was present in NARC-I (3.6%). Total invert sugar recorded in juice of pomegranate samples ranged from 14.4 to18.1%. Similar trend was observed regarding total invert sugar having maximum in Sultan (18.1%) while minimum total invert sugar (14.4%) was recorded in NARC-1 and Kandhari.

Table 3. Comparison of physical parameters of different pomegranate varieties

Variety	Fruit wt, (g/fruit)	Juice (%)	TSS (%)	Peel (%)	Seed (%)
TarnabGulabi	147.7 ± 3.1	30.9 ± 1.8	16.9 ± 0.50	36.0 ± 1.9	33.1 ± 1.7
NARC -1	235.0 ± 2.6	32.9 ± 0.7	15.4 ± 0.26	39.0 ± 2.7	27.7 ± 2.5
NARC-2	213.4 ± 23	30.0 ± 1.7	15.2 ± 0.74	34.0 ± 3.5	35.9 ± 3.8
Kandhari	160.2 ± 3.6	20.6 ± 2.8	15.9 ± 0.67	40.0 ± 1.3	38.9 ± 3.4
Sultan	186.4 ± 2.3	32.4 ± 1.6	19.2 ± 0.53	36.0 ± 2.4	31.1 ± 2.8

Total antioxidant and total phenols of different varieties of pomegranate are given in Table 5.The DPPH radical scavenging assay is commonly employed to evaluate the ability of antioxidant to scavenge free radicals. The degree of discoloration indicates the scavenging potentials of the antioxidant extract. In this study, the differences in antioxidant capacity among the pomegranate cultivars were statistically significant and the values ranged from 25.7 (NARC-1) to 41.5% (Sultan). Total phenols were found higher in Sultan (1101 µg GAE L^{-1}) followed by Kandhari (1075 µg GAE L^{-1}) while minimum was observed in NARC-1 (1012 µg GAE L^{-1}).

Table 4. Comparison of nutritional quality parameters of pomegranate varieties

Variety	Reducing sugar (%)	Non-reducing sugars (%)	Total invert sugars (%)	Vitamin C (mg/100mL)	Acidity (%)
Tarnab Gulabi	10.6 ± 0.38	5.0 ± 0.66	15.9 ± 0.66	12.4 ± 0.81	1.6 ± 0.018
NARC -1	11.2 ± 0.84	2.8 ± 0.95	14.1 ±0.43	12.0 ± 0.48	1.7 ± 0.022
NARC-2	10.3 ± 0.38	3.4 ± 0.58	13.8 ± 0.54	10.5 ± 0.82	1.6 ± 0.017
Kandhari	11.4 ± 0.94	3.2 ± 0.67	14.7 ± 0.39	12.6 ± 0.62	1.2 ± 0.019
Sultan	14.2 ± 1.90	3.9 ± 1.36	18.3 ± 0.59	11.7 ± 0.52	0.9 ± 0.192

Table 5. Comparison of antioxidants and total phenols of pomegranate varieties

Variety	Antioxidant capacity (DPPH inhibition %age)	Total Phenols (µg GAE L^{-1})
Tarnab Gulabi	30.9 ± 6.90	1021 ± 12.20
NARC -1	25.7 ± 0.53	1012 ± 12.40
NARC-2	36.2 ± 8.90	1037 ± 13.31
Kandhari	39.4 ± 7.30	1075 ± 12.71
Sultan	41.5 ± 8.20	1101 ± 13.35

Discussion

Among the fruit juices, pomegranate juice is considered as one of the superlative sources of antioxidants. Although it is not a rich source of well-known antioxidants such as vitamin C, however it contains plant-based antioxidants such as flavonoids (Elfalleh et al., 2011). These antioxidants may help to reduce the peril of cardiac disease and avoid some types of cancer (Afaq et al., 2005; Khan et al., 2007; Malik and Mukhtar, 2006). Pomegranate juice is also a good source of mineral (Opara et al., 2009; Melgarejo et al., 2011). TSS contents in pomegranate juice of Sultan was higher than other varieties and the obtained results are similar to those reported by Martinez et al. (2006) and Tehranifar et al. (2010).

The difference in fruit weight of different varieties is due to environmental conditions as explained previously by Zaouay et al. (2012) who determined that difference in fruit weight depended on the variety and environmental condition. The varieties, NARC-1 and Sultan with higher percentage of juice (32.9 and 32.4 respectively), could be more promising than other varieties because juice percentage is highly desirable property in the food processing and beverage industry (Rajasekar et al., 2012).

The differences among varieties were detected in pH and total acidity values might be due to the phenolic pattern of the juice obtained from different varieties of pomegranate seeds (Gil et al., 2000). Pomegranates, like most other fruits are impartially higher in natural sugar. The total sugars contents in different varieties of pomegranate are in line with those observed by Poyrazoglu et al. (2002) and Aviram et al. (2000). Results of Youssef et al. (2007) regarding vitamin C, supported the results of this study. The results depicted that the juice composition of pomegranate and its bioactive compounds depends on variety and maturity index as determined by Miguel et al. (2004). Antioxidants and total phenols content of the juices of five tested varieties varies considerably and similar to the results obtained by Faria and Calhau (2010). However all the varieties contained antioxidants which make them favourable for healthy consumption.

Conclusion

It was concluded that different varieties of pomegranate contained different values of Antioxidants, total phenols, total invert sugar, reducing sugar, pH and TSS. However, overall performance of pomegranate variety, Sultan regarding various quality parameters was found better.

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