Characterization of Soil of Jijiga Plain in the Somali Regional State of Ethiopia

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Abstract: Low soil fertility and poor soil fertility management practices constrain crop production in Ethiopia. Diagnosing soil fertility problems and characterizing soils are a prerequisite for formulating appropriate soil fertility management practices. However, most soil fertility problems in Ethiopia are not diagnosed, and the soils are not characterized. This invariably leads to lack of documented information for judicious application of soil ameliorative measures to increase crop yields. This study was, therefore, aimed at characterizing soil of Jijiga Plain in the Somali Regional State of Ethiopia on which wheat is commonly grown. The study was conducted during the main cropping season of 2012/2013. The study area was stratified in to three altitude categories 1650 - 1700, 1750 - 1800, 1850 - 1900 meters above sea level prior to sampling. Then, a total of 3 x 2 x 30 x 3 = 540 disturbed soil samples were collected from the surface (0-15 cm) and subsurface (15-30 cm) layers across the altitude categories. The samples were composited treatment-wise to 3 x 6 = 18 sub-samples. The composite soil sub-samples were analyzed for selected soil physico-chemical properties. The data were analyzed using descriptive statistics. The results indicated that both the surface and subsurface soils are clayey in texture. The pH of the soil at the layer of 0 - 30 cm ranged from 8.37 to 8.82 and is rated as strongly alkaline. The exchangeable Ca^{2+} contents of the soil at the surface and subsurface soil layers were 24.52 and 30.52 $cmol_+/kg$, respectively, which is rated as very high in both soil layers; the exchangeable Mg^{2+} content is 7.36 $cmol_+/kg$ in the surface soil layer, which is rated as high, but 10.21 $cmol_+/kg$ in the sub-surface soil layers, which is rated as very high. The exchangeable Na^+ content of the soil ranges from 0.33 to 2.16 $cmol_+/kg$, which is rated as medium to high. The exchangeable K^+ contents of the surface and subsurface soil layers are 1.1 and 1.4 $cmol_+/kg$, respectively, which are rated as high and very high in the surface and sub-surface soil layers. The cation exchange capacity of the soil ranges from 37.17 to 40.49 $cmol_+/kg$, which is rated as high to very high. The percent base saturation in the surface soil is 89.63% whereas that in the sub-surface soil is 109.23%, which is rated as very high. The contents of soil organic carbon (1.81%) and total nitrogen (0.13%) in the surface soil layer were found to be medium whereas those of the sub-surface soil layer were found to be low. However, the available phosphorus contents of both the surface (2.4 mg kg^{-1} soil) and sub-surface (1.87 mg kg^{-1} soil) soil layers were found to be very low. It could, thus, be concluded that, the soil of the study area is characterized by strong alkalinity with high contents soluble calcium carbonate, very low content of plant-available phosphorus, and medium contents of soil organic matter as well as total nitrogen. However, the texture and other chemical properties of the soil do not appear to limit crop production. Therefore, there is a need to take ameliorative measures aimed at lowering the pH and increasing availability of soil phosphorus, soil organic carbon, and total nitrogen to improve wheat and other crop yields in the study area.

Keywords: Available phosphorus; Cation exchange capacity; Soil organic carbon; Soil organic matter; Soil texture; Soil pH

1. Introduction

Agriculture is the mainstay of the national economy of Ethiopia, contributing over 90% of export, 85% of employment and 55% of GDP; the country has great potential for agricultural development with a total area of 113 million ha, of which 65% is estimated to be arable (Getinet *et al.,* 2001). Despite the fact that agriculture plays an important role in the economy of the country, it is characterized by low technology and low productivity (Getinet *et al.,* 2001), as a result of which the country suffers from food insecurity (Mishra *et al*., 2004). This is a paradox, which would invite researchers to investigate the causes of the problem and suggest feasible solutions. In addition, agriculture plays a great role in the growth of Ethiopia's economy and will command the lead in importance for many years to come (Rosell and Olvmo, 2014). Therefore, the country's development efforts must focus primarily on improving the sector (Mishra *et al*., 2004). Among the major causes for low agricultural productivity is the intensive exploitation of the agricultural resources by anthropogenic activities, which has put tremendous

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pressure on the country's natural resources in general and the soil in particular (Wakene, 2001).

The country's agriculture can be improved by developing appropriate national land management strategies. However, to suggest appropriate land management options to protect the soil for appropriate utilization requires sound information on its characteristics and dynamics (Mohammed, 2003). Therefore, so far and to date, efforts have been made by a number of researchers and governmental institutions to identify soil related problems and suggest remedies for further development of the agricultural sector (Mohammed, 2003). The drylands of Ethiopia consist of a wide range of agro-ecologies including the arid, semi arid, and dry sub-humid and cover about 75% of the total land mass, whereas the lowland dryland areas in Ethiopia, cover about 55% of the land mass of the country (MoARD, 2000). The dryland areas are inhabited by about one third of the Ethiopian population, and are the major source of its livelihood (Kidane *et al.,* 2003). However, similar to other agricultural ecologies, crop productivity is very low, and crop yields are principally limited by the low and highly variable rainfall amounts, both between and within seasons. In addition, crop production is limited by the progressive decline in soil fertility, as the farming practices do not adequately restore nutrients (FAO, 2010). Generally, in Ethiopia, information on present soil fertility status is not adequate to meet the requirement of agricultural development programs as a result of which rational fertilizer recommendations based on actual limiting nutrients of a soil for a given crop are lacking (IFPRI, 2010). Besides, the productivity of some soils is constrained by some inherent limiting factors even though they have high potential productivity or are naturally fertile (Gebreyes *et al.,* 2008). Therefore, the main problem in formulating appropriate intervention packages to address prevalent productivity constraints in any ecosystem is the lack of baseline data on land productivity, and identified soil-related constraints in the selected areas (Muya *et al.,* 2011). Thus, knowledge and understanding gained from characterizing soils of a certain agro-ecosystem would be essential for managing land, and this information could also help in formulating soil improvement strategies locally, nationally, and regionally (Debela *et al.,* 2011).

The agro-pastoralist farmers in Jijiga Plain in the Ethiopian Somali Regional State are producing cereal crops particularly wheat, which is the principal staple grain and ranks second to sorghum in terms of area and volume of production (CSA, 2013). However, in this area, compared to other wheat growing agro-ecologies in the country, the productivity of the crop is very low with an average grain yield of 1.0 ton ha^{-1}on farmers' fields (Somali Region LNCDB, 2015 annual report). This yield is much lower than the national average yield of 2.11 ton ha^{-1} (CSA, 2013). In general, the low average yield of the crop is primarily due to depleted soil fertility, low fertilizer usage, and lack of access to other improved crop management inputs (Asnakew *et al.,* 1991).

In many parts of Ethiopia, there is an increasing demand for information on soils as a means to produce food. This is because, to improve the productivity of a crop in the study area, there is a need to develop appropriate intervention packages to address soil problems that constrain crop growth and development. For this, documented information about the physico-chemical properties of the soil is required. However, the physico-chemical properties of soil of Jijiga Plain, which constrain crop production, have not yet been studied and documented well. This study was, therefore, conducted to diagnose and elucidate selected physico-chemical properties of soil of Jijiga Plain on which wheat is being grown and identify soil fertility problems that constrain production of the crop.

2. Materials and Methods

2.1. Description of the Study Area

The Jijiga Plain is located in the northern part of the Somali Regional State of Ethiopia. It covers 40,861 km^2, of which the rangelands extend over 36,629 km^2. It is bordered in the east by the Republic of Somalia, in the west by the Oromia Regional State, and in the South by Ogaden lowlands (Fig 1). The plain is a low lying, vast area, and most of its landmas is located in Fafen zone, previously Jijiga Zone, excluding Gursum and Babile districts. However, at micro-level, the physiographic feature is a rolling type of landmass, which forms a number of drainage channels that facilitate runoff towards the Jerer and Wabishebele river basins.

The climate is arid and semi-arid influenced by the Gulf of Aden and the Indian Ocean to the north and east and by the highlands of Ethiopia lying in north-west of the region. The Jijiga Plain is characterized by having a bimodal type of rainfall with an average annual precipitation of less than 200 mm in the southeast to some 600 - 700 mm in areas of the north and western parts of the Plain. However, the onset of the two rainfalls varies between areas within the Jijiga Plain. The northern and northwestern parts of the Plain are characterized by having two cropping seasons, the first rainy season comes as the *'dira'* rain which commences during mid-March and extends to the end of May and the second rainy season comes as *'Karan'* rain which starts during the mid of July and ends in late September. In this part of the plain, the 'Karan' rain is normally heavier than the 'dira' rain. Both sets of rain are equally important for cultivation and maturation of crops. However, the southern part of the Plain which includes some peripheral areas of the Ogaden lowlands also have two rainy seasons which are *'dira'* in which the rain starts during mid of March and stretches towards the end of May and *'deyr'* in which the rain starts in early October and ends at the end of November. The texture of the soils in most areas is almost clayey, except some exposed soils with steep slope gradients, which are sandy or gravely.

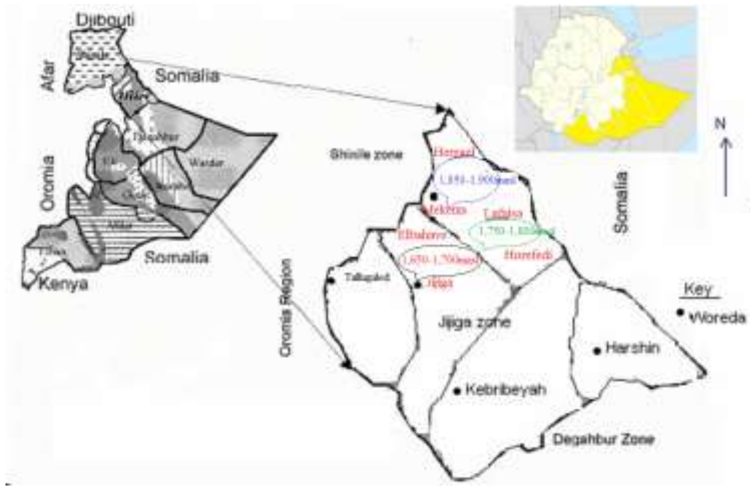

Figure 1. Map of the study area.

2.2 Sampling Methodology and Description of Soil Sample Collection Sites

A stratified sampling method was employed for sample collection through priory placement of sampling points into the relevant groups or strata. The delineation of sampling units or landscape based on altitude range was done before going to the field and was greatly facilitated by the use of Google earth software and Global Positioning System (GPS) receiver. Therefore, based on altitude category (landscape), the study area was classified into three sampling units. The first sampling unit was delineated as a landmass in altitude category of 1,650 -1,700 meters above sea level, which includes areas starting from Jijiga town (9^{0}22'00.32"N and 42^{0}48'07.81"E) extending east towards the catchment areas of Elbahaye dam (9^{0}24'08.52"N and 42^{0}51'09.69"E). The second sampling unit was delineated as a landmass in the altitude category of 1,750-1,800 meters above sea level, which includes areas extending from Horefedi village (9^{0}36'25.53"N and 42^{0}58'56.11"E) north towards Lafe Isa (9^{0}20'05.47"N and 43^{0}02'22.90"E). The third sampling sub-section of the field was delineated as a landmass in altitude range between 1,850-1,900 meters above sea level, and this includes an area which extends from East of Mekenis (9^{0}34'57.58"N and 42^{0}48'02.09"E) and stretches towards the northeast of Heregel (9^{0}29'55.63"N and 42^{0}43'52.64"E) (Fig 1).

A random selection of points were chosen to withdraw samples within each stratum to collect soil samples from the sampling depths of 0 - 15 cm and 15 - 30 cm which are considered as surface and sub-surface soils, respectively. However, in each of the sampling units, the sampling points were selected by using a zigzag sampling pattern. In addition, sample collection across the altitudinal category at each depth was done manually and typically by using an auger. Then about 30 soil samples were collected from each altitude range across each sampling depth. Sampling from each altitude range across the sampling depths was replicated three times. Therefore, a total of 3 x 2 x 30 x 3 = 540 disturbed soil samples were collected. The samples collected were composited treatment-wise to 3 x 6 = 18 representative composite soil samples. Finally, the composite soil samples were subjected to laboratory analysis for selected soil physical and chemical properties.

2.3. Sample Preparation and Laboratory Analysis

The representative composite soil samples collected from the wheat growing areas in Jijiga Plain were air-dried and ground to pass through a 2 mm size sieve in preparation for analysis of selected soil properties. For the analysis of soil total N, the soil samples were further passed through a 0.5 mm sieve. Finally, the composite soil samples were analyzed for selected agriculturally relevant soil physico-chemical properties at the soil laboratory of Ethiopian Somali Pastoral and Agro-pastoral Research Institute, following standard analytical procedures.

2.4. Analysis of Soil physical Properties

The soil physical property determined in the laboratory was soil texture (percent sand, silt and clay). Determination of particle size distribution was carried out by the hydrometer method as described by Okalebo *et al.* (2002). Once the sand, silt, and clay were separated, the soil in each sub-sections of the field was categorized based on landscape and assigned to a textural class based on the soil textural triangle described by Rowell (1994).

2.5. Analysis of Soil Chemical Properties

Similarly, the disturbed composite soil samples of each location were subjected to laboratory analysis to determine chemical properties: pH(1:2.5), exchangeable cations ($cmol_+/kg$) (Ca^{2+}, Mg^{2+}, Na^+, K^+), cation exchange capacity (CEC)($cmol_+/kg$), electrical conductivity (EC)(dS/m), $CaCO_3$ content (%), soil organic carbon content (OC)(%), total nitrogen content (TN)(%), available phosphorous content (mg P kg^{-1} soil) and Sodium Adsorption Ratio (SAR)(%).

Soil pH was determined as described by Carter (1993) using a pH meter with combined glass electrode in water (H_2O) at 1:2.5 soil: water ratio. Electrical conductivity was measured as described by Okalebo *et al.* (2002) by using a conductivity meter on saturated soil paste extracts obtained by applying suction. Calcium carbonate content of the soil was estimated by acid neutralization method in which the soil carbonate was decomposed by excess standard HCl solution and back titrated with standard NaOH after filtering. From the amount of acid (HCl) required to neutralize the carbonate, the $CaCO_3$ equivalent was estimated as described by Sahlemedhin and Taye (2000). To determine organic carbon content of the soils, the Walkley and Black (1934) method was employed in which the carbon was oxidized under standard conditions with potassium dichromate in a sulfuric acid solution. Also the total nitrogen content of the soils were determined as described by Sahlemedhin and Taye (2000) using the Kjeldahl procedure by oxidizing the organic matter with sulfuric acid and converting the nitrogen into NH_4^+ as ammonium sulfate. Determination of available phosphorous was carried out by the Olsen method using sodium bicarbonate (0.5M $NaHCO_3$) as an extraction solution as described by Olsen *et al.* (1954). The contents of basic exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) ($cmol_+/kg$) in soils were measured using the atomic absorption spectrophotometer (Hesse, 1972). The cation exchange capacity (CEC) was determined by the ammonium acetate method as described by Chapman (1965). Sodium Adsorption Ratio was determined based on the results obtained from the analysis of the major cations Ca, Mg and Na (in mmol L^{-1}) of the aqueous extracts and calculated as described by Richards *et al.* (1954). Finally, the percent base saturation (PBS) was computed as the percentage of the sum of the exchangeable bases to the CEC of the soil as:

$$PBS(\%) = \frac{\text{Sum of exchangeable bases (Ca, Mg, K, and Na)}}{\text{CEC of soil}} \times 100$$

2.6. Data Analysis

The data obtained from the laboratory analysis of the physico-chemical properties of the soil were subjected to descriptive statistics using MSTAT statistical Software package.

3. Results and Discussion

3.1. Particle Size Distribution

Averaged across three types of landscape, the results of the study revealed variations in sand, silt and clay proportion between surface and sub-surface soils (Table 1). The proportions of sand and silt decreased with increase in the sampling depth, but the clay proportion increased with the increase in sampling depth. Therefore, the proportions of sand and silt are higher in the surface soil layers than in the sub-surface soil. However, the clay proportion is higher in the subsurface soil layers. The removal and easy transport of sand and silt from steep slopes by wind and water erosion processes and deposition of these materials on surface soils of flat lands might have caused the variation observed in the proportion of sand, silt, and clay between the surface and sub-surface soil layers. In agreement with the results of the present study, Debela *et al.* (2011) concluded that slope differences and exposure to wind and water erosion caused variations in sand and silt proportions between soils of low lying and high lying areas. However, the increase in clay proportion in the sub-surface (15-30 cm) soils, compared to the surface (0-15 cm) soils, might be due to the nature of the parent material (limestone), coupled with variation in soil forming factors. Consistent with this suggestion, Mohamed and Mishra (2007) reported that the soil of Jijiga Plain was developed mainly from limestone parent materials in association with granite or sandstone as well as basalt and this may have contributed to the clayey texture of the soils.

According to the rating of Hazalton and Murphy (2007), the average proportion of sand and silt both in the surface and sub-surface soil layers are rated as low whereas the proportion of clay in both soil layers are rated as very high (Table 1). The very high clay proportion may be important as it describes the stability in soil aggregates, which exhibits less liability of the surface soil layers to wind and water erosion. The very high clay content may indicate better water and nutrient holding capacity of the soils of the study area. Therefore, this characteristic of the soil of the study area indicates high potential for crop production provided that other limitations are removed.

Table 1. Soil particle size distribution on surface (0-15 cm) and sub-surface (15 - 30 cm) soils of Jijiga Plain.

Variable	Mean		Range		St. Dev	
	0 -15 cm	15 - 30 cm	0 -15 cm	15 - 30 cm	0 - 15cm	15 - 30 cm
Sand (%)	20.28	17.28	16.28 - 23.28	17.28 - 17.28	3.61	0.000
Silt (%)	20.89	10.56	15.56 - 26.56	3.56 - 14.56	5.51	6.08
Clay (%)	58.86	68.83	50.16 - 68.26	68.16 - 69.16	9.07	0.577

3.2. Chemical Properties

3.2.1. Soil Reaction (pH)

Averaged across the three altitudinal categories, the results of the study revealed consistent variations in soil pH between the surface and sub-surface soil layers of the study area (Table 2). The average pH values of the surface and sub-surface soil layers across the three landscapes indicated that the pH value in the sub-surface soil layer is higher than that of the surface soil layer. The higher soil pH values of the subsurface soil layers could be attributed to high values of exchangeable Ca^{2+} in the subsurface soil layer as compared to the surface soil layer which can be from weathered carbonaceous (limestone) parent materials from which the soil in the study area originated. The current result is in agreement with the findings of Abayneh *et al.* (2006) who concluded that the increase in the pH of the soils of Jijiga Plain across sampling depth could be due to some leaching of carbonates from surface horizons and the carbonaceous substratum. Therefore, according to the classification of soil reaction by Tekalign (1991), the soils of the study area are strongly alkaline at both the surface (0-15 cm) and the sub-surface layers (15-30 cm depth) (Table 2).

Soil reaction is a very important property for crop production since it determines the availability of nutrients, microbial activity, and physical condition of the soil (Gupta, 2000). Although the pH tolerance limits of different plants vary greatly, a neutral range, with pH values (in a 1:2.5 soil: water suspension) between about 6.3 and 7.5 is most suitable for most crops (Landon, 1991). On the other hand, Fageria *et al.* (2009) indicates that the optimum soil pH for the growth of most crop plants in the tropical soils is determined by crop species; however, a pH value of about 6.5 determined in water is adequate for the growth of most crop species. Optimum pH range for wheat is 5.5 to 7.0 (Hazelton and Murphy, 2007). However, the observed average range of pH values (in a 1:2.5 soil: water suspension), both in the surface and sub-surface soil layers across the three altitudinal categories in the study area are far beyond this optimum ranges (Table 2).

Therefore, both the surface and sub-surface soil layers in the study area limit productivity of wheat and most other crops. In agreement with this suggestion, Slattery *et al.* (1999) concluded that on soils with a pH range of 7.5 to 8.5, crop growth can be limited because this range of pH significantly affects plant growth, primarily as a result of reduced availability of essential elements such as phosphorus, and most of the micronutrients, Cu, Fe, Mn, Mo, and Zn. This suggestion is substantiated by Mekuria *et al.* (2007) who reported that alkaline soils were less productive for wheat than soils within neutral pH range.

3.2.2. Exchangeable Cations and Cation Exchange Capacity (CEC)

Similarly, averaged across the three altitudinal categories, contents of exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and the cation exchange capacity (cmolc $_{(+)}$ kg^{-1}) of the soil of the study area varied between the surface and sub-surface soil layers (Table 2). Exchangeable Ca^{2+} followed by Mg^{2+} is the predominant cation in the exchange sites of both the surface and sub-surface soil layers. On the other hand, the exchangeable cations and the CEC increased with soil depth in exactly the same pattern as observed in soil pH. This shows that the soil parent material primarily releases divalent cations. Relatively high contents of Ca^{2+} and Mg^{2+} in surface and sub-surface soil layers were earlier reported for soils of Jijiga Agricultural Research Station by Abayneh *et al.* (2006) and for soils of Jelo micro-catchment by Mohammed *et al.* (2005). The increase in exchangeable cation content and cation exchange capacity in the sub-surface soil layer could be attributed to possible upward movement of exchangeable bases from the sub-soil stratum to the sub-surface soil layers, which might have been derived from inherited carbonate rich parent materials (limestone). In agreement with this suggestion, Debela *et al.* (2011) reported values of the similar magnitude for exchangeable bases in sub-surface soils semi-arid lowlands of eastern Shoa, central Ethiopia, and postulated that the limestone nature of the parent materials from which the soils were formed may have contributed to the increase in the exchangeable cations in the sub-surface soils. Consistent with the above suggestion, Curi and Franzmeier (1987) concluded that a soil weathered from an alkaline parent material can experience upward transfer of bases. In agreement with the results of the present study, Abayneh *et al.* (2006) reported increased cation exchange capacity in the sub-surface soil layers of Jijiga Agricultural Research Station, which could be attributed to increased concentration of exchangeable bases.

According to the rating of FAO (2006), the contents of Ca^{2+} in surface and sub-surface soil layers are rated as very high, respectively, whereas the contents of Mg^{2+} is rated as high in the surface soil layers and very high in the sub-surface soil layers (Table 2). Similarly, according to the same rating, the Na^{+} content in the surface soil layer is rated as high whereas it is rated as very high in the sub-surface soil layer. Also the contents of exchangeable K^{+} in the surface and subsurface soil layers are rated as high and very high, respectively (Table 2). The content of Ca^{2+} in the soil of Jijiga Plain is in excess of adequate level required for crop production (Table 2). This suggestion is evidenced by Fageria *et al.* (2008) who reported that for tropical soils, an adequate level of exchangeable Ca^{2+} for optimum growth of most crop plants in the range of only 2 to 3 ($cmol_{+}$/kg). Similarly, the level of Mg^{2+} in the soil of Jijiga Plain was found to be beyond the optimum range (Table 2). In agreement with this suggestion, Fageria *et al.* (1997) reported that the content of Mg^{2+} adequate for optimum plant growth varied from soil to soil, plant species to plant species, and even among cultivars within species. However, Mg^{2+} content in the range of 1.0 to 2.0 ($cmol_{+}$/kg) is sufficient to produce maximum economic yield of field crops (Fageria, 2002).

According to the rating of FAO (2006), the content of exchangeable potassium in both the surface and sub-surface soil layers is high to very high (Table 2), which means the nutrient is sufficiently available in the soil and its status would not limit crop growth and development. According to the same rating, the content of exchangeable sodium in the surface soil is low whereas that in the sub-surface soil is very high, which is above 2.0 ($cmol_+$/kg soil) (Table 2). This means that salinity or the possibility crop plant injury due to sodium salts could be ruled out in the short term, but in the long run, there may be potential for salinity especially if precipitation reduces and droughts recur. Therefore, it is important to take precautionary measures against possible build up of soluble salts in the soil of the study area. On the other hand, according to Hazelton and Murphy (2007), the CEC of the surface and subsurface soil layers could be rated as high and very high, respectively (Table 2). This means that the soil is resistant to changes in the soil chemical composition that are caused by land use systems (Hazelton and Murphy, 2007).

3.2.3. Calcium Carbonate Content, Sodium Adsorption Ratio (SAR), Electrical Conductivity (ECe) and Percent Base Saturation (PBS)

Averaged across the three altitudinal categories, the results have revealed consistent variations in $CaCO_3$ content (%) and sodium adsorption ratio (SAR) (%) between the surface (0-15 cm) and subsurface (15-30 cm) soil layers of the study area (Table 2). The average values of these soil chemical properties consistently increased across the sampling depths, and the parameters were higher in the sub-surface soils than in the surface soil layers. The possible reason for the increase in the calcium carbonate content of the sub-surface soils as compared to that of the surface soils could be due to increased upward translocation of calcium from the subsoil horizon which may be attributed to the nature of the parent materials (limestone) from which the soils of the study area evidently originated. In agreement with this suggestion, Mohamed and Mishra (2007) concluded that the soils of most areas of Jijiga Plain are developed on mixed types of rock species dominated by limestone (secondary/ precipitates). On the other hand, regarding the rating of calcium carbonate generally, there are no precise ratings for contents of free carbonates, but values of over 40% can be considered as extremely calcareous (Avery, 1964). However, according to the rating of FAO (1990), a soil horizon having a $CaCO_3$ content of > 15% within 100 cm from the soil surface qualifies for a calcic horizon and such a high carbonate content affects both the physical and the chemical properties of soils. Hence, in the current study, the level of $CaCO_3$ is > 15% and it showed an increasing trend with increasing depth but these depths are considered as a plow depth and rooting zone for most small cereal crops including wheat. Therefore, this problem could seriously affect crop production in the study area. This suggestion is in agreement with the calcium carbonate rating given by Carter (1981) that 11 to 30% total carbonate as the critical levels that adversely affect crop growth. Therefore, the calcium carbonate content of the soil of Jijga Plain is so high that it can seriously affect the production of wheat and other crops (Table 2).

Table 2. Chemical properties of surface (0-15 cm) and subsurface (15-30 cm) soils of Jijiga Plain.

Variable	Mean		Range		St. Dev	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0 - 15 cm	15-30cm
pH water (1:2.5)	8.37	8.82	8.33- 8.41	8.71-8.88	0.039	0.095
Ex. Ca^{2+}($cmol_+$/kg)	24.52	30.46	23.02-26.34	30.09-31.10	1.683	0.554
Ex. Mg^{2+}($cmol_+$/kg)	7.36	10.21	6.89- 7.63	8.72-11.10	0.410	1.296
Ex. Na^+($cmol_+$/kg)	0.33	2.16	0.21- 0.40	1.23-3.09	0.108	0.930
Ex. K^+($cmol_+$/kg)	1.1	1.4	1.01- 1.17	1.170- 1.65	0.081	0.253
CEC ($cmol_+$/kg)	37.17	40.49	36.5- 38.33	40.47- 40.5	1.011	0.017
EC (dS/m)	1.01	1.41	0.80- 1.120	1.204- 1.79	0.185	0.334
$CaCO_3$ (%)	16.05	18.66	15.94- 16.2	18.59- 18.7	0.133	0.064
Organic Carbon (%)	1.81	1.48	1.05- 2.46	1.33- 1.73	0.712	0.218
Total Nitrogen (%)	0.13	0.09	0.12-0.134	0.06- 0.12	0.007	0.029
Available P (mg kg^{-1})	2.36	1.87	1.76- 2.74	1.28- 2.4	0.525	0.557
SAR	5.67	7.33	4.0- 8.0	6.0- 9.0	2.08	1.528
PBS	89.63	109.23	66.01-107	98.23-127.6	14.19	9.56

Note: Ex. = Exchangeable

With regard to the Sodium Adsorption Ratio (SAR), it is higher in the sub-surface soil layer than in the surface soil layer, which is consistent with the increase in the content of soluble Na^+ because the SAR increased with soil depth in exactly the same pattern as observed in exchangeable Na^+ (Table 2). However, averaged across the three landscapes, the mean SAR values of both soil layers are below the critical SAR value of 13% of the US Salinity Laboratory Staff (1954) and soils in both layers are not sodic and this adverse soil chemical property (sodicity) may not be a limiting factor for wheat production in the study area (Table 2).

Similarly, averaged across the three landscapes, the Electrical Conductivity (ECe) of the soil increased with increase in the sampling depths, and the mean Ec_e value is higher in the sub-surface soil layer than in the surface soil layer (Table 2). The increase in the sub-surface soil layer may be ascribed to increased entry of soluble exchangeable cations to the sub-surface soil layer through upward capillary movement with water from the subsoil stratum originating from the weathering of the limestone parent material. In agreement with this suggestion, Curi and Franzmeier (1987) reported that a soil weathered from an alkaline parent material can experience a large transfer of bases. The accumulation of soluble salts in the soil profile curtails crop growth by increasing the osmotic potential of the soil solution and inducing specific ion toxicity or nutrient imbalances (Carter, 1993). These salts contain the cations Na^+, Ca^{2+}, and Mg^{2+} and the anions Cl^-, SO_4^{2-}, HCO_3^-, and CO_3^{2-} which can be weathered from minerals and accumulate in the soil solution in areas where precipitation is too low to provide leaching (Havlin *et al.*, 1997). This is common particularly in arid and semi-arid regions like Jijiga Plain. The electrical conductivity (ECe) measurement identifies soils which are potentially saline (Okalebo *et al.*, 2002). However, the mean EC_e values observed in both layers are not beyond the critical ECe value of 4 dS $m^{-1}$of the US Salinity Laboratory Staff (1954) and soils in both layers are non-saline and may not be a limiting factor for wheat production in the study area for now. In agreement with the result of the current study, Bernstein (1995) indicated that the ECe value which ranges from 0 to 2 dS m^{-1} has crop response which is negligible.

Averaged across the three landscapes, the percent base saturation (PBS) of the soil increased with increase in sampling depth, and the mean PBS value is higher in the sub-surface soil layers as compared to the surface soil layer and the increase showed a similar trend to that of the exchangeable cations (Table 2). Therefore, the increased mean value in the subsurface soil may be ascribed to increased soluble exchangeable cations especially Ca^{2+} and Mg^{2+} at the sub-surface soil layer. In agreement with this suggestion, Gebreyes (2008) also reported increased percent base saturation with increased sampling depth for soils of Enewari, Northeastern Ethiopia. According to Hazalton and Murphy (2007) the percent base saturation of soils of Jijiga plain is rated as very high. Similarly, as suggested by Landon (1991) soils having greater than 60% base saturation are rated as fertile soil.

3.2.4. Organic Carbon and Total Nitrogen

In contrast to other chemical properties of the surface and sub-surface soil layers whose values increased with increase in the sampling depths, the organic carbon and total nitrogen contents of the soils consistently decreased with the increase in sampling depths (Table 2). The decrease in organic carbon content of the soil across the sampling depths could be attributed to relatively higher organic matter content of the surface soil layers as a result of residual root debris, deposition from wind and water erosions, high biological activity and soil conditions suitable for decomposition of organic matter in the surface soil layer as compared to sub-surface soils. In agreement with the results of this study, Prasad and Power, (1997) indicated that nitrogen content in the sub-surface layer of any soil is generally less than that in the surface layer since most organic residues are deposited on the soil surface. According to the rating given by Tekalign (1991), the organic carbon content in the surface soil layer is medium whereas that in the sub-surface soil layer is low.

The total N content decreased across the soil layers in exactly the same pattern as the soil organic carbon content, suggesting a strong correlation between the contents of the two soil parameters. This suggestion is consistent with that of Murage *et al.* (2000) who reported that soil organic matter is the best surrogate of soil quality and mineralized nitrogen supply for improved crop production. According to the rating of Murphy (1968), the total nitrogen content of the surface soil layer is medium whereas that in the sub-surface soil layer is low. These values indicate only moderate potential of the soil to supply N to plants through mineralization as well as organic carbon as a source of energy for soil biota for enhanced soil water and nutrient holding capacity. Therefore, there is a need to provide external supply of nitrogen and organic carbon through application of mineral and organic fertilizers to enhance crop production in the study area.

The medium soil organic carbon and high total nitrogen contents of the surface soil layers in the study area could be attributed to the relatively customary practice of returning crop residues back to the soils by the farming communities. Thus, in the study area, almost all of the wheat growing farmers are using combine harvesters to harvest the crop and the chopped straw is returned to the soil on the spot. The decomposing is a source for soil biota, which in turn may increase the labile N in the soil through mineralization (Prasad and Power, 1997). The result of the present study is consistent with that of Abayneh *et al.* (2006) who reported medium total N content of about 0.14% in the surface layers of soils of Jijiga Agricultural Research Station.

3.2.5. Available Soil Phosphorus

The data revealed variations in the amount of available phosphorus between the surface and the sub-surface soils of the study area. The amount of plant available P in the surface soil layers was higher than that in the subsurface soil layers (Table 2). However, the available amounts of the nutrient in both surface and sub-surface soil layers are low based on rating shown by Cottenie (1980). The results are corroborated by Abayneh *et al.* (2006) who reported a decrease in the contents of available P with increase in the sampling soil depth. The low content of available phosphorus could be attributed to sorption and its precipitation by calcium and magnesium bicarbonates. In agreement with the results of this study, Mengel *et al.* (2001) state that the very low available phosphorus contents may be ascribed to high soil calcium contents, which lead to precipitation of phosphorus as Ca phosphates. On the other hand, Tekalign and Haque (1991) reported that 8 mg P kg^{-1} soil was the critical level of P for Ethiopian soils when assessed by the Olsen method. Except for the extreme layer, the content of available P showed a decreasing trend with soil depth. This is in agreement with the findings of Tekalign amd Haque (1988) who reported that topsoil P is usually greater than that in subsoil due to sorption of the added P, greater biological activity, and accumulation of organic material on the surface. Mulugeta (2000) also indicated decrease in P content with depth due to fixation by clay and precipitation by Ca, which were found to increase with depth. Similarly, Mohammed *et al.* (2005) observed low levels of available P in the surface horizons of the cultivated soils of the Chercher highlands in Eastern Ethiopia. Therefore, low contents of available P is a common characteristic of most soils in Ethiopia (Tekalign and Haque, 1991; Yihenew, 2002; Wakene and Heluf, 2003). Thus, it can be deduced that the very low amount of available P in soils is the most important factor constraining wheat production in soils of Jijiga Plain. This suggestion is in agreement with that of Page (1992), who stated that less than 4 mg plant-available P per kg soil indicates P-deficiency. This result is corroborated by Holford and Cullis (1985) who reported that lactate extractable P (mg P kg^{-1} soil), from a soil at the depth of 0–10 cm which is < 5 mg P kg^{-1}soil is very low for wheat production. Similarly, Fageria *et al.* (2009), suggested that soil P content below 12 mg kg^{-1} soil, is not optimum for plant growth and responses are likely to occur to the addition of the nutrients fertilizer.

Generally, in the study area, texture, pH, exchangeable cations, cations exchange capacity, electrical conductivity, calcium carbonate, and sodium adsorption ratios increased with increase in soil depth. However, the organic carbon, total nitrogen content, and available phosphorus contents decreased with increase in soil depth. The decrease could be attributed to the decline in soil organic matter content with increase in soil depth since these soil parameters are essential components of the former (Mohamed and Mishra, 2007).

4. Conclusions

This study has demonstrated that the soils of the study area are clayey in texture. The laboratory tests have also indicated that these soils contain a lot of soluble calcium carbonate which is responsible for the very high pH values (8.37 to 8.82) of the soil and its strong alkalinity. However, the soils are currently non-saline and non-sodic. The contents of soil organic carbon and total nitrogen are medium, which are moderately conducive for plant growth and development. The contents of exchangeable potassium, magnesium, calcium as well as the CEC of the soil were also found to be optimum for crop production. However, plant-available P content of the soil was found to be very low, which is attributable to the presence of high amounts of soluble calcium carbonates that react with the nutrient and renders it insoluble through precipitation. The strongly alkaline soil reaction and the very low content of available soil phosphorus are the major factors that constraint production of wheat and other crops in the study area. Thus, the soil of Jijiga plain requires ameliorative measures to reduce its pH and increase availability of phosphorus. Furthermore, the soil also needs improving its status of soil organic carbon and total nitrogen. Therefore, farmers need to use both mineral and organic fertilizers to mitigate the effect of high soil pH and enhance the availability of soil phosphorus, total nitrogen, and organic carbon for optimum crop growth and sustainably increased yields. Future research needs to focus on elucidating the effect of integrated soil fertility and water management options, formulation of site and crop specific fertilizer recommendations, and selection of crop species or varieties that are adapted to the low-P soil for enhancing production of wheat and other crops in the study area.

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