Effects of soil bund on soil physical and chemical properties in Arsi Negelle woreda, Central Ethiopia

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This study was conducted in Arsi Negelle woreda of West Arsi Zone, Oromia regional state. The main objective of the study was to investigate the impacts of soil bund on soil physical and chemical properties in Arsi Negelle woreda. The soil data was collected from sites namely: lowland, midland and highland and from soil bunds aged >4 years, <4 years and control of farmland. Three representative sites were selected purposively for soil sample collection. Stratified random sampling techniques were used for soil samples collection. Fifty-four disturbed and undisturbed soil samples were collected for soil properties analysis from two soil depths (10 and 20 cm). Statistical analysis was done following a completely randomized design (CRD) with factorial experiments and treatments as fixed effect and location of sampling as a random effects. The analysis was carried using R software. Regression analysis was used to relate physical properties of soil with each other. Tukey test was used for comparison of means of treatments when statistical significance is found at P ≤ 0.05. Bulk density (BD) and air-filled porosity (AFP) showed significance difference on treated and non-treated site, respectively. The mean of electric conductivity (EC), total nitrogen (TN), available phosphorous (AP) and organic carbon contents were recorded to be significantly higher (p≤ 0.05) on soil bund ages greater than 4 years (>4years) at both soil sampling depths. Aged soil bunds (treated plots) showed a significant changes on soil physical and chemical properties than control plots. The mean of total nitrogen (TN), available phosphorous (AP) and organic carbon contents were recorded significantly higher (p≤ 0.05) in lowland than highland at both soil sampling depths. In generally, ages of soil bunds and sites had significant effect on many soil physical and chemical properties. The sites and ages interaction had significant effect on bulk density (BD) at both depths at P ≤ 0.05. In conclusion, this study showed that soil bunds had significant effect on many physical and chemical properties of soil in the study area.

Key words: Soil bund, bulk density, saturated hydraulic conductivity, electrical conductivity, total nitrogen, organic carbon.

INTRODUCTION

Natural resource degradation and land degradation in particular has negative impact on the economy of developing countries including Ethiopia. This is because, the country heavily depends on their natural resource for...
food self-sufficient, food security and economic development. Soil erosion and nutrient depletion are the most important forms of land degradation in Ethiopia (Tekle, 1999). The effects of soil erosion vary by management (conservation) and location. In general, it deteriorates chemical properties of soil by loss of organic and minerals containing plant nutrients that are necessary for life support system of soil resource (Zoumoge, 2009).

Soil erosion also brings changes in physical properties such as texture, infiltration rate, bulk density, available water holding capacity and depth of favorable root growth. These changes have negative effect on most of the soil ecological function and services (Schjonning et al., 2009). The contributing factors for soil erosion in most parts of the country are poor agriculture activities (including intensive tillage, complete removal of crop residues, low levels of fertilizer application), lack of appropriate soil conservation measures and cropping practice (Abebayehu and Eyassu, 2011).

In central rift valley of Ethiopia, soil erosion is a serious problem because of fragile and easily erodible soil. The land of Arsi Negelle is well known for the devastating soil erosion problem that has resulted in a decline in agricultural productivity in the region (Titola, 2008). Arsi Negelle is located in central rift valley, where the ecosystem is fragile. Continuous cultivation with little protection measures exacerbated the level of soil erosion, and hence land productivity had declined significantly and farmers were cultivating the land without giving more attention to soil maintenances in the area. This caused the loss of top soil and reduced productivity capacity of the land and economy of the country. Physical soil and water conservation (SWC) measures such as soil bunds have been practiced in Arsi Negelle woreda for decades (from elders interviewed) as amelioration measures for soil erosion. Soil bunds are a common practice for physical soil and water conservation measures and many studies were conducted to address issues of its adoption and reduction in soil loss due to construction of the structure.

Most soil research focused on empirical soil loss, crop yield and largely based on study of perception of farmers to adaptation of soil and water conservation structures. Some of the key processes important for potential restoration of degraded soil have been studied, but largely in the study of farmers’ perception. Limited knowledge of soil regeneration due to soil and water conservation structures, limits quantitative measures of severity of soil degradation. Thus, this research work focused on identifying the benefits of this structures and its impact on soil physical and chemical properties in the study area. Specific objectives are as follows:

1. To analyze the impacts of ages of soil bunds on soil physical and chemical properties
2. To analyze the impacts of sites on physical and chemical properties.

**MATERIALS AND METHODS**

**Description of the study area**

The study was conducted in Arsi Negelle woreda, which is located at 225 km south of the Addis Ababa. Geographically, it is situated in the central rift valley system between 7° 09’-7° 41’ N longitude and 38°25’-38° 54’ E latitude (Figure 1). Average annual temperature varies from 10 to 25°C, while the annual rainfall varies between 800 and 1200 mm (ORS, 2004). The altitude of the study area ranges from 1500 to 2300 m above sea level and falls in Weyna Dega Agro-ecological Zone. The Woreda has 43 rural and 3 urban kebeles. The study area is classified into three sites (lowland, midland and highland) based on temperature, rainfall, altitude and vegetation covers.

**Experimental design and sampling**

The three representative kebeles were selected purposively for each site (lowland, midland and highland) based on recommendation by woreda agricultural Expert and Development agent (DA) for soil sample collection. Stratified random sampling techniques were used for soil samples collection. In each selected kebele, three replicate field plots with two age groups (<4 years and >4 years) and control were identified within the similar slope. At each sampling plot, two undisturbed soil samples were collected at the center from 10 to 20 cm soil depths by using core samplers. Whereas, at each sampling plot, two disturbed soil samples were collected from four corners and one from the center by using auger from 10 to 20 cm soil depths, respectively. The collected soil samples were mixed to obtain representative composite samples approximately 1 kg of disturbed soil samples. From ages of soil bunds >4 years, <4 years and control, six soil samples were collected from each plots and 18 soil samples were collected from each site. A total of samples include 54 undisturbed (three sites × three treatments (two age groups of soil bund + without soil bund (control)) × three replications × two soil depths) and 54 disturbed soil samples were collected respectively.

**Laboratory analysis**

Before the actual measurement, excess soil was removed by spatula in field. The core soil samples were used for determinations of volumetric moisture content, bulk density, saturated hydraulic conductivity and air-filled porosity, whereas the disturbed soil samples were used for the analysis of soil texture and soil chemical properties. Standard methods were used for analyses of soil

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The cores samplers were covered with nylon cloth from the bottom, and saturated step-wise with capillary water from beneath. Then, the samples were used for measurement of saturated hydraulic conductivity, $K_{sat}$ using constant head method as described in Klute and Dirksen (1986). The measurements of average value of water discharge ($Q$) (unit: $L^3T^{-1}$) collected after it reached steady state, soil length ($L$), cross-sectional area of the soil sample ($A$) (unit: $L^2$), and hydraulic head ($H$) [L], were used to determine the $K_{sat}$ ($LT^{-1}$) using Darcy’s equation, which is given by:

$$K_{sat} = \frac{QL}{AH}.$$ 

Statistical analysis

Prior to statistical analysis, the normality of datasets (data sets) was checked. Statistical analysis followed a completely randomized design (CRD) with factorial experiments. A linear mixed model with treatments (site and age) as fixed effect and location of sampling as a random effect was fitted for each sampling depths. A mixed model in R software was employed. Tukey test was used for comparison of means of treatments when statistical significance is at $P \leq 0.05$. Regression analysis was used to relate soil physical properties with each other.

RESULTS AND DISCUSSION

Impact of soil bund on selected soil physical properties

Soils were collected from three different sites (lowland, midland and highland) and three treatments (age>4 years, <4 years and control) and along with the interaction effect of treatments of both soils collected at
Table 1. Effects of soil bund ages and sites on selected soil physical properties.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Soil parameter</th>
<th>Age effect</th>
<th>Site effect</th>
<th>Site x age</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>BD (g cm⁻³)</td>
<td>1.317c, 1.324b, 1.333a, 1.32b, 1.323b, 1.33a</td>
<td>1.321c, 1.326b, 1.334a, 1.323c, 1.328b, 1.33a</td>
<td>0.0039</td>
</tr>
<tr>
<td></td>
<td>Θₑ (cm³ cm⁻³)</td>
<td>0.38a, 0.36b, 0.36a, 0.404a, 0.381a, 0.32b</td>
<td>0.417a, 0.353b, 0.38b, 0.41a, 0.39b, 0.303b</td>
<td>Ns</td>
</tr>
<tr>
<td></td>
<td>εₛ (cm³ cm⁻³)</td>
<td>0.121a, 0.141a, 0.14a, 0.097b, 0.121b, 0.183a</td>
<td>0.084c, 0.15a, 0.114b, 0.090b, 0.1065b, 0.148a</td>
<td>Ns</td>
</tr>
<tr>
<td></td>
<td>Kₑ (mm hr⁻¹)</td>
<td>37.69a, 39.26b, 35.94a, 39.3a, 38.7b, 34.9b</td>
<td>37.75a, 39.1a, 36.5a, 41.3a, 40.37a, 31.63b</td>
<td>Ns</td>
</tr>
</tbody>
</table>

Means with same letter in each row are not statistically significant at P<0.05, Ns = not significant. Site x age refers to the interaction between site and age.

10 and 20 cm soil sampling depth shown in Table 1.

Ages effects on selected soil physical properties

Bulk density (BD) was significantly difference at p < 0.05 among ages of structures. The untreated plots were found to exhibit significantly higher mean value of BD than treated plots at both depths (Table 1). Soil bund construction reduced loss of fertile soil and crop residues. Similar results were reported elsewhere, for instance Mulugeta and Karl (2010) conducted study on impact of conservation structures on key soil properties in south Gondar, and reported significantly higher mean value of BD in non-conserved plots than in the plot treated with soil and water conservation measures.

Volumetric moisture content (Θₑ) at sampling did not show significantly difference at p<0.05 among ages of structures at 10 cm soil depth, whereas significant impact for soil at 20 cm depth. The non-significant result at upper depth could be due to sampling condition.

Air-filled porosity (εₛ) in almost all cases higher in the soil bund conserved less than 4 years and non-conserved plot, although this was significantly difference at p<0.05 at 20 cm soil sampling depth among ages of structures, but not at 10 cm sampling depth. This might be due do to more moisture in conserved farm plot. The high values of air-filled porosity observed both in treated and non-treated soils indicate that the soil in the study area was generally suitable for plant growth even prior to the introduction of soil conservation measures.

For most combinations of depth and experimental treatments, the saturated hydraulic conductivity values of the soil considered under this study were considerably higher than 8.6 cm day⁻¹, which was established by McQueen and Shepherd (2002) as the critical limit for adequate hydraulic conductivity. However, the observed value of saturated hydraulic conductivity was rather low when compared with the extreme precipitation events in the study area. This situation inevitably increases the risk of surface runoff and eventually soil erosion, which was evidently observed in year 2016.

Sites effects on selected soil physical properties

Bulk density was significantly difference at p < 0.05 among sites of structures. The mean of bulk density was highest at highland and lowest at lowland. This might be due to maintenance problem of structures in highlands that washed away fertile and light soil and thereby exposed slightly heavier soil. The deposition of this washed away soil could occur at lowland and thereby reduced the bulk density of soil at the destination. In another study, Tan (1996) categorized the bulk density values, 1.0 to 1.5 g cm⁻³ as a favorable physical condition of soils for plant growth.

Volumetric moisture content (Θₑ) was significantly different at p < 0.05 among sites for both soil-sampling depths (Table 1). The mean of volumetric moisture content did not show significant differences at midland and lowland for both soil-sampling depths, because soil bunds at these locations were well maintained and promoted more water retention than in highlands.

The mean of air-filled porosity (εₛ) at sampling was higher at highland than midland and lowland for both soil-sampling depths. Soil conservation structure could have been expected to improve aeration condition of the soil, whereas, the condition observed here was contrary. This could be explained by high moisture holding capacity of deposited soil at these two locations and the samples were collected during rainy season at the time of high moisture content in the soil.

As expected, the mean of saturated hydraulic conductivity (Kₑ) was higher at lowland and midland than highland for both soil-sampling depths. However, no
Significant differences were observed in saturated hydraulic conductivity between soils collected from midland and lowland. One reason for higher saturated hydraulic conductivity at midland and lowland could be proper maintenance of structures at these two sites than highland.

**Ages interaction sites effects**

In this study, for soil sampled at 20 cm depth, there was significant interaction between ages of structures and sites for bulk density, volumetric moisture content and air-filled porosity (Table 1). This trend was not true for soil collected from 10 cm soil depth except for bulk density. As can be seen from Figure 2, the two lines (one for age and the other for site) cross each other, this implies interaction.

**Impact of soil bund on selected soil chemical properties**

Soils were collected from three different sites (lowland, midland and highland) and three treatments (>4 year, <4 year and control) and along with the interaction effect of treatments of both soils collected at 10 and 20 cm soil sampling depth as shown in Table 2.

**Ages effects on selected soil chemical properties**

The mean of pH were not significantly different at P<0.05 for both soil sampling depth. In general, the mean of pH value of soil in the study area ranges from neutral to slightly alkaline (6.75 to 7.5) according to classification by SSSA (1996). The mean value of electric conductivity (EC) was significant difference at P<0.05 among ages of structures for both soil sampling depth.

Total nitrogen (TN) contents were significantly different at P<0.05 among the ages of soil bund for both soil sampling depths (Table 2). The treated farmland had also higher TN as compared to the non-treated farmland for both soil-sampling depths. Similar results were reported by Mulugeta and Karl (2010), who stated that physical soil and water conservation measures stabilizes the nitrogen fixing plants and thereby increase TN in conserved plot. In general, the total nitrogen content of the soil in the study area lies within very low to medium class according to Barber (1984). The low value of total nitrogen was observed both in the conserved and non-conserved plot; this indicates that the soil in the study
area was generally poor in total nitrogen content. Moreover, the crop residue have impact on replenishing of total nitrogen content which was used as source of firewood.

Available phosphorous (AP) was significantly different at P<0.05 among the ages of soil bund for both soil sampling depths (Table 2). The mean of AP for treated farm land is greater than untreated farm land. The result agrees with the finding of Mulugeta and Karl (2010)who reported that AP was observed to be significantly different between the conserved and non-conserved fields. The variation is due to the soil organic matter content difference.

In general, according to Barber (1984), AP content of the cultivated land both for treated and untreated land is low. This could be one of the reasons why the yield in the area was very small as compared to yield reported in the media, although farmers use extension packages. Therefore, more has to be done in conserving macronutrients on cultivated land by using extension package.

There was significant difference at p<0.05 in mean value of organic carbon (OC) contents among treated and untreated farmland at both soil sampling depth (Table 2). This might show that the soil bund construction has played a positive role in conserving the soil organic carbon. The result agrees with the finding of Tadele (2011), who reported higher organic carbon in treated farmland and lower in untreated farmland. Even though, the soil bunds construction increased organic carbon, the mean of organic carbon on treated and untreated plot is almost equal or below the critical value of organic carbon. Loveland and Webb (2003) reported that a 2% of OC is a critical level for crop production and soil aggregate stability. In generally, more has to be done to conserve organic carbon, organic matter and others micronutrients.

Site effects on selected soil chemical properties

In general, pH, AP, TN and OC shows that there were significant differences at P<0.05 among sites at both soil sampling depths (Table 2). Whereas, the EC was not significantly different at p<0.05 in 10 cm soil sampling depth and significant difference at p<0.05 in 20 cm soil sampling depth (Table 2). In all the cases, the numeric values were highest at lowland except for pH and EC. During erosion, it can be hypothesized that top soil is washed away progressively with nutrients and the remaining soil become infertile. In addition, at site of deposition, the soil could have been fertile and contain more nutrients. The result of this study supports this hypothesis that soil bund constructed at lowland is well maintained. For chemical properties, the interaction effects between site and age were not significant difference at p<0.05, except for the case of EC at 10 cm soil depth and TN at 20 cm soil depth (Table 2).

Relationship between soil physical properties

Bulk density is one of the common parameters used to quantify this change. This is because of the ease of measurement of bulk density. They also used the changes in bulk density to quantify changes in other physical properties of soil. The only few field studies address the quantitative relationships between bulk density and saturated hydraulic conductivity. Exceptions are the work of Dexter (2004) who predicted changes into hydraulic conductivity due to increase in bulk density following passage of heavy agricultural machinery on soil. In this study, strong and significant relationship between saturated hydraulic conductivity and bulk density was

Table 2. Effects of soil bund age and site on selected soil chemical properties.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Soil parameter</th>
<th>Age effect</th>
<th>Site effect</th>
<th>Site x age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EC (mmhos/cm)</td>
<td>&gt;4year</td>
<td>Low land</td>
<td>Control</td>
</tr>
<tr>
<td>10</td>
<td>0.24&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.203&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>7.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>T N(%)</td>
<td>0.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.114&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>A P(ppm)</td>
<td>10.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>OC (%)</td>
<td>3.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.23&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.05&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>EC (mmhos/cm)</td>
<td>0.182&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.154&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.127&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>7.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.75&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>T N (%)</td>
<td>0.155&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.122&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.07&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>A P (ppm)</td>
<td>8.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>OC (%)</td>
<td>2.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.24&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1.62&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means with same letter in each row are not statistically significant at P<0.05, Ns = Not significant. Site x age is refers to the interaction between site and age.
Figure 3. Saturated hydraulic conductivity versus BD. Measured values of the saturated hydraulic conductivity, $K_{sat}$, for soils collected from 10 and 20 cm depth.

Remarkably, the regression equation in this investigation was almost identical to the relationship found by Dexter (2004) for Polish soils that were collected from different sites of agricultural fields from 10 to 16 cm depths.

$$K_{sat} = -736.91 \text{ BD (± 244.22 )} + 1013.72 (±323.65)$$

$$R^2 = 0.86; \quad p < 0.05$$

Conclusions and recommendations

The mechanisms in natural amelioration as well as artificial supplements to erode are nearly absent in subsoil layers. The results need efforts to minimize soil erosion. Hence, soil bund construction reduced soil erosion and increased production and productivity of soil unless soil erosion increased from time to time and reduced soil production potential. Thus, soil bund construction improved soil properties. Development strategy and program interventions designed to enhance agricultural productivity by promoting soil bund in land management in the study area need to take into account. There is an urgent need to restrict further increase in soil erosion risk. To have a whole picture of soil erosion (cause-and-effect chains), further studies are needed to link changes in physical properties to soil functions relevant for biomass production and environmental quality. In generally, the soil bund construction is mandatory to obtain sustainable development unless the fertility of soil is eroded and the land becomes degraded (out of production).

Acknowledgements

The authors acknowledge Oromia Agricultural Research Institute for granting MSc program.

References