EFFECT OF PHYSICAL SOIL AND WATER CONSERVATION MEASURES ON SELECTED SOIL PHYSICOCHEMICAL PROPERTIES IN UBALE MICRO WATERSHED, ARBA MINCH ZURIA WOREDA, SOUTHERN ETHIOPIA

M.Sc. THESIS

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HAWASSA UNIVERSITY,
HAWASSA, ETHIOPIA

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BY

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A THESIS SUBMITTED TO THE FACULTY OF
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REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN BIOSYSTEM ENGINEERING (SPECIALIZATION: SOIL AND WATER CONSERVATION ENGINEERING)

MAJOR ADVISOR: AWDENEGEST MOGES (PhD)
CO-ADVISOR: FISIHA GETACHEW (PhD)

May, 2019

APPROVAL SHEETI

This is to certify that the thesis entitled "Effect of Physical Soil and Water Conservation Measures on Selected Soil Physicochemical Properties in Ubale Micro Watershed, Arba Minch Zuria Woreda Southern Ethiopia" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Soil And Water Conservation Engineering, the Graduate Program of the Faculty of Biosystem Engineering, and has been carried out by Andarge Alaro Altaye, Id. No SWCE-R/003/09, under our supervision. Therefore we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the faculty.

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Awdenegest Moges (PhD) Signature__________________________

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Name of co-advisor Date _______________________

STATEMENT OF THE AUTHOR

I declare and affirm that this thesis is my own work. I have followed all ethical principles of scholarship in the preparation, data collection, data analysis and completion of this thesis. All scholarly matter that is included in the thesis has been given recognition through citation. I affirm that I have cited and referenced all sources used in this document. Every serious effort has been made to avoid any plagiarism in the preparation of this thesis.

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BIOGRAPHICAL SKETCH

The author was born on 11 of June 1992 G.C at Arba Minch town of Gamo Zone of Southern Nations Nationalities and People's Region, Ethiopia. He started and attended his elementary and junior schools at Arba Minch Elementary School, and Abaya Elementary and Secondary School respectively from 1998-2005 G.C. He continued his school from 2006-2010 G.C at Arba Minch Comprehensive Senior Secondary School. Following the 2010 G.C Ethiopian School Leaving Certificate Examination, he was able to join Mizan Tepi University where he studied and graduated with a B.Sc. degree in Natural Resource Management in 2013 G.C. He was employed by the Gamo Zone Bureau of Agriculture as an expert in Soil and Water Conservation at Geze Gofa Woreda for five months. Since March 29/2014 G.C, he has been serving in Arba Minch University as an assistance researcher in Soil and Water Conservation, in 2017 G.C. He was offered a chance to attend M.Sc. study in the field of Soil and Water Conservation Engineering at Hawassa University.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
AMZWAO	Arba Minch Zuria Wereda Agricultural Office
AMZW	Arba Minch Zuria Wereda
ANOVA	Analysis of Variance
FFW	Food for work
FAO	Food and Agricultural Organization
LSB	Level Soil Bund
LSTB	Level Stone Bund
MC	Moisture Content
MS	Micro Soft
NGO	Non-Governmental Organization
SCRP	Soil Conservation Research Project
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
PSNP	Productive Safety Net Program
SAS	Statistical Analysis System
SCRP	Soil Conservation Research Program
SNNPR	Southern Nations Nationalities Peoples Regional State
SWC	Soil and Water Conservation
TP	Total Porosity
WFP	World Food Program

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ABSTRACT

Following erosion-induced soil degradation tremendous efforts have been made in implementing different soil and water conservation measures (SWC) in Arba Minch Zuria Wereda. Apart from monitoring and evaluation reports no substantive studies were made and documented on the performances of SWC measures in soil properties so far. The aim of the study is examine the effects of different SWC measures on the selected physicochemical properties of soil among physical SWC measures and position of terrace and, its improvement on soil infiltration rate. Reconnaissance survey was carried out and convenient sampling method was used to select the sampling plot. In cultivated fields treated by level stone bund and level soil bund each with 5 years old age from 15-25% slope category were compared with control. 9 experimental plots were selected. A total of 21 composite soil samples, 18 from treated and 3 from control were collected from the top 15 cm soil depth using "W" sampling design method and analyzed for soil texture, pH [H_2O], electrical conductivity (EC), organic carbon (OC), organic matter (OM), total nitrogen (TN), available phosphorous (AP), zinc (Zn), exchangeable potassium (K^+), exchangeable calcium (Ca^{2+}) and exchangeable magnesium (Mg^{2+}) using standard laboratory procedures. 21 undisturbed core samples, 18 from treated and 3 from control plots were collected and analyzed for bulk density (BD), total porosity (TP) and moisture content (MC). Infiltration rate of the soil was measured using a double ring infiltrometer. Results of the experimental study showed that soil MC (%), EC (ds/m), SOC (%), SOM (%), TN (%) and Ca^{2+} (cmol (+)/kg) were significantly different between SWC measures and the three different position within terrace. % clay were significantly different between SWC measures and interaction effect. Except pH all soil properties were significantly different between SWC measures. Equilibrium infiltration rate was reached on each treatment after (120mins), the LSTB had the highest basic soil infiltration rate, while the control and the LSB received medium and lowest infiltration rate respectively. SOC, SOM and TN were better on the level stone bund and soil bund than the control plot, while the control plots was received the highest pH, EC, Zn, Ca^{2+} and silt fractions compared with treated plot. The middle position within terraces recorded the higher OC, OM and TN than upper and lower position. Interaction effect of soil and water conservation measures by positions, the level stone bund in the lower position was recorded the higher OC and TN followed by level soil bund on the middle position. The cumulative values of physical SWC measures without proper attention for technical characteristics of the bunds and the maintenance systems improved were decreasing the marginal status of soil nutrients. Biological measures could be integrated for better effect soil fertility. Thus, further research need to be conducted on the effectiveness of bunds in relation to functions relevant for biomass and environmental quality.

Key words: soil fertility, soil erosion, systematic sampling and convenient sampling

1. INTRODUCTION

1.1. Background of the Study

Land degradation, in the form of soil erosion and nutrient depletion, threatens food security and the sustainability of agricultural production in Sub-Saharan Africa (Menale Kassie, et al., 2007). The extent of soil degradation caused by deforestation, overgrazing, and poor soil management is the largest in Africa and Asia (Blanco and Lal, 2008).Poor and inappropriate land management is the main cause of physical chemical and biological degradation of cultivated land, pastures, rangelands and forest land especially in the Sub-Saharan Africa with continuous stress in the limited land resources (Eyasu, 2002). In Ethiopia, soil erosion by water constitutes the most widespread and damaging process of soil degradation (Woldeamlak, 2003). The erosion hazard particularly in the highland area is aggravated by nutrient mining by crops, extended farming to sloping areas, shortened fallow system, and decreased vegetative cover, depletion of soil organic matter and mismanagement of crop lands (Aklilu and Graaff, 2006; Tamene and Vlek, 2008). On average the annual rate of soil loss in Ethiopia is estimated to be 12 tons/hectare/year, and can be even higher on steep slopes with soil loss rates greater than 300 tons/hectare/year where vegetation cover is scant (USAID, 2000).

In the longer term soil erosion is harmful in removing the upper layer of soil which is generally the most nutrient rich and water retentive part of the soil profile (FAO, 1999). Physical degradation basically includes a negative impact on physical soil properties, such as structure, texture, aggregate stability, porosity, permeability and crusting (Mitiku et al., 2006). The poor soil quality in Ethiopia results in reduced crop productivity and greater vulnerability to famine (Hurni, 1983). Because, the livelihood of the vast majority of the population depends directly or indirectly on this sector, such dependence obviously leads to increased vulnerability of the economy to problems related to land degradation (Wegayehu, 2003).The excessive dependence of the Ethiopian rural population on natural resources, particularly land, as a means of livelihood is an underlying cause for land and other natural resources degradation (EPA, 2004). The rate of deforestation in Arba Minch Zuria Wereda have intensified due to increased population, expansion of agricultural land and unsustainable exploitation of forest resources which have led to land degradation and scarcity of forest products but accentuated the effect of climatic changes on the natural resources and peoples livelihood and negatively affected soil fertility and food security Habtamu et al. (2017).

Considering the background above on soil degradation in Ethiopia, proper soil conservation becomes imperative when considering issues regarding soil fertility improvement. To mitigate soil erosion the government of Ethiopia has taken different soil and water conservation measures. Nevertheless, the rate of adoption of the interventions is considerably low. Space occupied by SWC structures, impediment to traditional farming activity, water logging problems, weed and rodent problems and huge maintenance requirements are some of the reasons that cause farmers refrain from SWC works (Mitiku et al., 2006). In addition, lack of integrated bio-physical measures, poor conservation design, and improper land use, less maintenance, weak monitoring and evaluation of SWC practices are also the major constraints that determine the implementation of SWC measures in Ethiopia (Haregeweyn et al., 2015).

Soil conservation structures are designed to intercept and reduce runoff velocity, pond and store runoff water, convey runoff at non-erosive velocities, trap sediment and nutrients, promote formation of natural terraces over time, protect the land from erosion and improve water quality thereby enhancing biodiversity of downstream water (Blanco and Lal, 2008). For instance, Yonas et al. (2016) have reported that SWC measures improved the soil qualities such as soil pH, K^+, AP, SOC and TN compared to un-conserved land in the same sub-watershed. SWC practices could also contribute to maintain or enhance regulating ecosystem services by increasing water infiltration in the soil, which results in lower surface run-off and associated high levels of soil erosion and reducing floods and increasing low flows (Zenebe et al., 2017). Considerable progress has been made in developing conservation effective practices by adopting different soil and water conservation measures in Arba Minch Zuria Wereda and Ubale micro watershed in particular through community mobilization themselves and with the help of government. Thus, this study was designed to examine the effect of bunds on soil fertility.

1.2. Statement of the Problem

Soil degradation due to deforestation, overgrazing and cultivation of marginal and steep slope without adequate management and maintenances of constructed measures has been practiced in the Arba Minch Zuria Wereda highlands. In-order to control soil erosions, the government has been implemented different soil and water conservation measures in the degraded highland areas of the weredas for the last two decades by the help of World Food program (WFP), Employment Generation Schemes (EGS) and Productive Safety Net Programs (PSNP). Therefore, introduction of SWC technologies adopted and implemented by farmers with community participation and NGOs support especially Mercy corpus and PSNP have the main role to lead sustainable land rehabilitation in the Wereda (AZWAO, 2018). Level stone bund and level soil bund were practiced on the cultivated lands of Ubale micro watershed. However, apart from monitoring and evaluation reports no substantive studies made and documented on the performances of SWC measures in erosion control and soil productivity so far.

In addition, in Ethiopia level stone bund and soil bunds are the main soil and water conservation measures. Their beneficial effect can be attributed to a reduction in slope length and slope angle, which reduces the runoff velocity and the consequent soil loss, increase in infiltration rate and improving the soil properties. Studies were conducted so far by Vancampenhout et al. (2006); Gebremichael et al. (2005); Nyssen et al. (2010); Shimels (2012); Kebede et al. (2011) and Andreas et al. (2018) on the effectiveness of physical SWC measures on soil qualities in Ethiopia. However, few studies were addressed the variation observed within positions of terraces between different structures. Also these studies incorporated the effect of bunds on soil infiltration rate. Shimels (2012) suggested in that inadequate empirical evidence exists concerning the role of terracing on soil fertility despite various controversies on the merits and performance of terracing. Therefore, this study attempts to assess and draw conclusions on the effects of physical SWC measures on selected soil physicochemical properties and its improvement on soil infiltration rate in the Ubale Micro watershed of Arba Mich Zuria Woreda.

1.3. Objective

1.3.1. General objectives

The general objective of the study was to assess the effect of bunds on selected physical and chemical properties of soil at Ubale micro watershed.

1.3.2. Specific objective

- To examine the effect of level stone and soil bund on selected soil physical properties
- To examine the effect of level stone and soil bund on selected soil chemical properties

1.4. Significance of the Study

Studying the performance of physical soil and water conservation (SWC) measures on soil qualities is crucial for soil conservation planning and to draw conclusions that have contribute in future improvement of implementation of SWC measures for erosion control and to recommend for sustenance of bunds in controlling erosion and improving soil fertility in the studied micro watershed as well as in similar agro ecology in the country. The outcome of this study will also inform and assist government agencies, extension workers, researchers, policymakers, and NGOs which includes sustainable land management project and productive safety net program (PSNP) to have an insight on the implication of the ongoing SWC measures so as to inform them about the positive implication of SWC measures on soil qualities.

2. LITERATURE REVIEW

2.1. Soil Erosion in Ethiopia

The primary cause of soil degradation in Sub-Saharan Africa (SSA) is expansion and intensification of agriculture in efforts to feed its growing population (Tully et al., 2015). It is estimated that nutrient depletion accounts for about 7% of the agricultural share in the average Gross Domestic Product of SSA with national values ranging up to 25%, indicating soil nutrient mining as a significant basis of current economic performance (Drechsel et al., 2001). Ethiopia is one of the sub-Saharan countries where dangerous ecological process was observed particularly in the cultivated land in the form of sheet and rill erosion (MOA, 2016). The higher erosion rates being recorded in the high potential areas for cultivation (Lakew et al., 2005). Rapid population growth, cultivation on steep slopes, clearing of vegetation, and overgrazing are the main factors that accelerate soil erosion in Ethiopia (Tamene & Vlek, 2008).

The poor soil quality in Ethiopia results in reduced crop productivity and greater vulnerability to famine (Hurni, 1983). In some parts of Ethiopia like Welo highlands, within appropriate conservation measures soil erosion has in the past, and continues at present, to expose the soils to stress thereby accelerating the process of soil erosion due to crop cultivation (Belay, 1998). According to Defaru and Tuma (2013) most of the fertile land in Gamo Gofa Zone could be converted into cropland from 2005 base to 2012; this may induce reduction in fertile land or reducing the soil productivity. This conversion pattern is observed, where the resettlement programs are implemented. This means that farmers´ adaptation to climate change may increase the deforestation pressure in the resettlement programs implemented areas and therefore it contributes to an increase in greenhouse gas emission. Habtamu et al. (2017) also reported that the magnitude and rate of deforestation in Arba Minch Zuria Wereda (AMZW) have intensified due to increased human population, poverty, expansion of agricultural land and unsustainable exploitation of forest resources. This has not only led to land degradation and scarcity of forest products but has accentuated the effects of climatic changes on the natural resources and people's livelihoods in the area by reducing the productivity of the soil.

Soil erosion is a major environmental threat to the sustainability and productive capacity of agriculture (Pimental, 1995). Physical degradation basically includes a negative impact on physical soil properties, such as structure, texture, aggregate stability, porosity, permeability and crusting (Mitiku et al., 2006). When soil depth is substantially reduced by erosion from 30cm to less than 1cm plant root space is minimal, and plant production is significantly reduced (Pimeta, 2006). Cropland soils are, however, more susceptible to erosion because these soils are often left bare or with little residue cover between the cropping seasons (Blanco and Lal, 2008). The on-site consequences involve primarily the reduction in soil productivity, while the off-site consequences are mostly due to the sediment and chemicals transported away from the source into natural waters by streams and depositional sites by wind (Blanco and Lal, 2008).

2.1. Soil and Water Conservation in Ethiopia

The government of Ethiopia has taken different SWC measures to reduce land degradation. Nevertheless, the rate of adoption of the interventions is considerably low, space occupied by soil and water conservation (SWC) structures, impediment to traditional farming activity, water logging problems, weed and rodent problems and huge maintenance requirements are some of the reasons that cause farmers refrain from SWC works (Mitiku et al., 2006). The soil and water conservation activities have been carried out by the Ministry of Agriculture in the past forty years on a large scale on cultivated land with contour (level) bunds, on hillsides with afforestation terraces, and on degraded hills with hillside closures however, much more will have to be done in the future (MOA, 2016). Lack of integrated bio-physical measures, poor conservation design, and improper land use, less maintenance, weak monitoring and evaluation of SWC practices are also some of the major constraints that determine the implementation of SWC measures in Ethiopia (Haregeweyn et al., 2015).

In an attempt to address soil erosion problems, the Ethiopia Highland Reclamation Program was constituted under the Ministry of Agriculture in the 1980s. Important documents were produced focused more on physical structures than on matters related to sustainable land management. The Water Resources Ministry conducted studies and analyses on the rate of siltation on major river basins (Awash, Tekeze, Wabe, Shebele, Abay etc.) in the process of identifying potential dam sites. ILCA (now ILRI) was involved in soil and water conservation activities and studies in their attempt of pond construction using oxen power. Different forage sources were also screened for their role in stabilizing bunds and in the improvement of drainage systems mainly in Vertisol areas. NGOs were involved in the early 1970s on soil and water conservation activities particularly to mitigate drought and famine. These activities were in a form of technology transfer from other countries. Since the transfer was not commensurate with the socio-economic condition of the communities the impact was either lost or not documented at all (Mitikuet al., 2006).

The Soil Conservation Research Project (SCRP) was also initiated in Ethiopia in 1981 with main development objectives of providing the Ethiopian soil conservation efforts with necessary basic data for the proper implementation of soil conservation measures, testing the applied and planning adapted measures, and training local as well as international personnel in this field of study (SCRP, 2000). EthiOCAT was established with a vision of supporting conservation planning and implementation by providing information on land management: needed by planners, extension workers, researchers, educationists and policy makers by establishing a database and producing reports, overview books and maps (Dale, 2010).

Soil bunds are impermeable structures unless provided with spillways, intended to retain all rainfall, and hence, increase the moisture retention capacity of the soil profile and water availability to plants (Lakew et al., 2005). Review by Zenebe et al. (2016) have shown that physical SWC practices such as soil bunds and stone bunds were very effective in reducing run-off, soil erosion and nutrient depletion. Soil bund reduced losses of soil nutrients and organic carbon, however the absolute losses were still high (Zenebe et al., 2014).

The stone bund reduces and stops the velocity of runoff and consequently reduces soil erosion and the steady decline in fertility and crop yields. They are semi-permeable structures unless sealed with soil in their upper side (Lakew et al., 2005). Widespread implementation of stone bunds is an optimal solution to protect from onsite soil erosion and downstream siltation of reservoirs (Gebeyehu, 2013). Terracing alone does not improve soil fertility and cannot fully halt erosion (Shimels, 2012); it should be frequently connected with technical feasibility and adaptability, ecological soundness, economic viability, and social acceptance (Herwig and Ludi, 1999).

Several researcher for instance, Vancampenhout et al. (2006); Gebremichael et al. (2005); Nyssen et al. (2010); Shimels (2012) and Andreas et al. (2018) have conducted studies on the effects of soil or stone bunds on soil qualities in Ethiopia highlands. SWC measure conserves runoff and reduces soil loss by retaining moisture and enhances the accumulation of nutrients. Physical measures are essentially designed to reduce soil and water losses by reducing the length and the gradient of slopes and thus increasing water infiltration into the soil and making the soil on those slopes less vulnerable to erosion by the forces of rainfall and runoff (Lakew et al., 2005), while biological measures such as crop residues, using manure, and applying conditioners are in direct contact with the soil surface and thus serve as residues protecting the soil (Blanco and Lal, 2008). The main controlling factor of the unit soil transport rate is slope gradient (Nysen et al., 2000). Nyseen et al. (2007) observed changing of mean slope gradient from 14.1% to 11.2%, in 3–21 years, which made the land more suitable for cultivation than before bund building. The mean grain and biomass yields observed among the three slopes positions were decreased as one moved up the slope within the inter-terrace area (Alemayehu et al. 2007). In contrast Shimels (2012) have reported in that the topsoil fertility uniformity occurs as elevation differences within a terrace reduce to a minimum level.

In high rainfall areas of Anjeni nitrogen, phosphorus and soil organic matter are the main limiting factors for agricultural production have been significantly improved within the farm due to terraces, resulting better crop yield performances (Amare et al., 2013). Similarly, Shimels (2012) reported in his study on the effectiveness of soil and water conservation measures for land restoration in the Wello area, Northern Ethiopian Highlands in that SWC measures led to clear biophysical changes such as terrain modification improvement of soil depth, stability of active gullies and stream banks and development of bench terraces in Maybar Soil Conservation Research Site. Moreover, in the Wonago district, Southern Ethiopia SWC measures improved significantly the soil qualities such as soil pH, K^+, available AP, soil OC, TN, clay and CEC than in the adjacent without SWC treatment, in the same sub-watershed (Yonas et al., 2016).

2.2. Effects of Physical Soil and Water Conservation Measures on Soil Physical Properties

2.2.1. Soil texture

Soil texture determines physical and chemical properties of soil. It influences soil compaction through its effect on aggregation and porosity, absorption of water and other organic/inorganic compounds by altering surface area, water and nutrient storage through charge properties, transport of solute and gaseous exchange through porosity (Lal & Shukla, 2004). Soil texture has different capabilities of holding the aggregates together; among this sandy soils are less cohesive than clayey soils and thus aggregates with high sand content are more easily detached (Blanco and Lal, 2008). The high amount of silt may also lead to compaction and crusting of the soil surface unless it is supplemented by adequate amounts of sand, clay and organic matter (Brady and Weil, 2002). Soils high in silt, low in clay and in organic matter are the most erodible (Wischmeier and smith, 1994). The textural classes of soil horizons are not subject to easy modification in the field (Brady and Weil, 2002). Pedogenic processes such as erosion, deposition, elevation and weathering can alter the textures of various soil horizons (Foth, 1990; Ahmed, 2002).

Kebede et al. (2011) have found significantly greater clay content in the four year aged stone bund compared to non-terraced cropped land. In-contrast, Dejen (2017) have found non-significant difference between 8 year old stone bund structures and non-conserved farmland, the similarity of soil textural fraction between treatments could be happened due to the impact of erosion prior to terracing. Mengistu et al. (2015) have found higher silt content in the non-conserved rather than conserved land which is characterized with basaltic trapping series of volcanic eruptions parent material. Shimels (2012); Bobe (1997) have found non-significant differences between positions within terraces for soil texture. According to Bobe (1997) the percent clay decreases down terraces the highest being in the upper position and the lowest in the lower position; this could be due to erosion might have removed `more topsoil from the upper than the lower positions of the terraces whereby the lower horizons, with higher % clay had been exposed to the surface. Similarly, Million (2003) have reported the high clay content at the upper slope position of the inter-terrace area (i.e. below bund sampling plot) regardless of the width treatments considered in his study for the sites with 25% and 35% could be due to the impact of soil erosion occurred previously in the area. In contrast Mihiretu (2014) have reported high clay and low sand content in the lower positions.

2.2.2. Bulk density

Soil bulk density (BD) is ratio of the mass (oven-dry weight) of the soil to the bulk volume expressed in grams per cubic cm (g/cm^3), which includes the volume of both solids and pore space at a specified soil water content (Estefan et al., 2013). It also shows the influence of compaction on soil water retention, aeration, trafficability, and infiltration rate, and which is extremely sensible to soil management (Delgado & Gómez, 2016). Soils with a high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space (Brady and Weil, 2002). The solid particles of the fine-textured soils tend to be organized in porous grains or granules especially if adequate organic matter is present, this condition assures high total pore space and a low bulk density (Brady and Weil, 2002). The ideal soil bulk density for sandy clay loam, clay loam is <1.40gm/cm3 and for clay soil (<45% clay) is 1.39 which may not affect and restrict root growth (Soil Survey Staff, 2014).

The study results of Abay et al. (2016) revealed that the bulk density of non-conserved land soils was higher than the bulk density of six year graded stone bund; the higher soil bulk density on the non-conserved farmland could be due to low soil OM as a result of lack of soil conservation measures. Dullo et al. (2017) also found higher mean value of BD on the untreated plot than treated plots with >4 and <4 years old age soil bund. On the other hand Million (2003) observed the increased bulk density on the higher slopes/upper position and wider inter-terrace areas could be the presence of coarse textured soils due to the effect of water erosion, which is mainly influenced by the slope gradient and slope length of a given farm. On the other hand Shimels (2012) reported that the surface soil of the middle zone has a highest amount of soil BD while the two edges of terraces are nearly the same BD due to the uniform soil aggregate deposition resulted in packing of soil particles, the proportional soil aggregates received at the mid-terrace positions could enhance packing of soil voids and thereby increase BD. Andreas et al. (2018) also found higher soil bulk density below the stone bund, similar bulk density between middle zone and the lower position of the bunds (above the bunds). He claimed that mainly attributed to the fact that it was used as footpath for the farmers.

2.2.3. Total porosity

The total porosity of soil is important soil physical parameter which affects the soil water storage capacities and other soil properties, the characterization of the soil pore system gives essential indications about soil quality and vulnerability in relation to degradation events mainly connected with human activity. Such a characterization is especially useful in the study of the relationships between soil physical, chemical and biochemical properties and provides a realistic basis for understanding water retention and water movement in soil (Pagliail, 2002). It also governs the essence of biological processes that supports life and biochemical and physical processes that determine environment quality (Lal & Shukla, 2004).

Sandy surface soils show a range of 35-50% whereas medium to fine textured soils vary from 40 to 60%-even more in cases of high organic matter and marked granulation (Brady and Weil, 2002). The coarse-textured soils tend to be less porous than fine-textured soils, though the mean size of individual pores is greater in the coarse textured soil, however in clayey soils the porosity is highly variable because the soil alternately swells, shrinks, aggregates, disperses, compacts, and cracks (Hillel, 2003). If soil pores lay close together as in sands or compact sub soils the total porosity is low (Brady and Weil, 2002). The study results of Teramaj (2015) also revealed that the mean total pore volume of cropland provided with SWC treatments was higher than the total pore volume of control plots soil. Similarly, Mihiretu (2014) have found significantly ($p \leq 0.05$) higher pore volume on the stone bund and soil bund treated plots than untreated plot. The low amount in the control plot was due to structural degradation of the soil because of the removal of soil organic matter and exposure of the subsoil by erosion.

2.2.4. Soil moisture

The water content of a soil sample is the amount of water removed by drying at 105 ^{0}C; this can be expressed as the mass ratio of water to solid phase, commonly called wetness or gravimetric water content (Koorevaar et al., 1983). Quantitative measure of soil's moisture content is important to understanding soil behavior, plant growth, and soil's numerous other physical processes (Lal, 20104). Soil moisture and water retention capacity of soil may be affected by changes in SOC that occur because of both climate change and land management practices. Organic matter makes the soil more resilient to moisture loss and impacts on soil water conservation (Amooh & Bonsu, 2015). The size of a pore influences how strongly water is held and how readily water may be transmitted through the soil (FAO, 1999). The loss of vegetation due to overgrazing increases the rate of runoff and erosion and decreases the amount of water in the soil (Morgan, 2005).

Similarly, Andreas et al. (2018) noted that soil bunds increase soil water contents along the hill slope by interrupting hill slope hydrology and therefore increasing time for infiltration, especially near the soil bunds. On the other hand Imke and Erven (2017) have found non-significant differences in soil moisture content between the plots with soil bunds and the plots without soil bunds. Moreover, Beleay (2016) reported significantly higher soil moisture (%) on treated plots with stone faced soil bund with 33.5% than non-treated plots with mean value of 25.6%. Considering different positions within terraces, Amare et al. (2013); Nyssen et al. (2000) reported the higher moisture content on the soil or stone bunds above the bund (lower positions). Zenebe et al. (2017) also observed the higher soil moisture contents at 2 and 4 meters below the bunds (upper positions).

2.2.5. Infiltration characteristics of the soil

Infiltration is the process of water entering the soil at the ground surface (Raghunath, 2006). The rate of water flow through the soil surface is extremely sensitive to soil water content (Deldago and Gomez, 2016). Knowledge of water infiltration into soil is essential for soil and water conservation, and minimizing the risk of nonpoint source pollution (Lal, 2004). During a rainstorm, the spaces between the soil particles become filled with water and the capillary forces decrease so that the infiltration rate starts high at the beginning of a storm and declines to a level that represents the maximum sustained rate at which water can pass through the soil to lower levels (Morgan, 2005). As soils become wet, infiltration rate slows to a steady rate based on how fast water can move through the most restrictive layer, such as a compacted layer, or a layer of dense clay (Center, 2017).

Soil texture determines infiltration rate of soil (Delgado & Gómez, 2016). Increase in clay content increases surface area, swell-shrink capacity, absorption, water retention, plasticity, adhesion and total porosity, however, increase in clay content decreases water infiltration rate and soil bulk density (Lal, & Shukla, 2004). Coarse-textured soils such as sands and sandy loams have higher infiltration rates than clay soils because of the larger spaces between the pores (Morgan, 2005). Loamy soil has both sand and clay and so have macro pores and micro pores giving a more balanced supply of both air and water (in the macro pores and micro pores respectively) (Amooh & Bonsu, 2015).

Infiltration rate is restricted by poor management during this condition the water does not readily enter the soil and it moves downslope as runoff or ponds on the surface, where it evaporates and less water is stored in the soil for plant growth, and plant production decreases, resulting in less organic matter in the soil and weakened soil structure that can further decrease the infiltration rate (Haghnazari et al., 2015). Repeated tillage in the cultivated land and the low soil organic matter could lead to low aggregate stability, both of which consequently increase the detachment of soil particles and transport by generated runoff (Dessalegn et al., 2017).

The study results of Mulugeta and Karl (2010) revealed that organic matter was positively correlated with the infiltration rate while clay percentage was negatively correlated. Similarly, Yihenew et al. (2009) have reported in finding that the organic matter and percentage of clay soil separates in the treatments seemed to play the crucial role for the variation in mean basic infiltration rates. Gebeyehu et al. (2015) reported in their studies on the evaluation of the effectiveness of stone bunds and trenches in reducing runoff and soil loss in the semi-arid Ethiopian highlands showed all SWC structures are more effective in reducing soil loss than runoff. Combining soil bunds with biological measures enhanced the efficiency of soil bund (Amare et al., 2014).

2.3. Effects of Physical SWC Measures on Soil Chemical Properties

2.3.1. Soil pH [H_2O]

Soil pH is the chemical property of soil parameters that required for evaluating the soil quality. It is also an indispensable means for characterizing soil from the standpoints of nutrient availability and soil physical conditions like structure, permeability, workability (Mulugeta and Karl, 2010). The degree of acidity or alkalinity of a soil is a very relevant property affecting many other physicochemical and biological properties (Delgado & Gómez, 2016). Soil pH is influenced by the nature and type of inorganic and organic constituents that contribute to soil acidity (Margesine, 2005). The acidity of the soil gradually increases (i.e, low pH) as the exchangeable calcium and magnesium are lost by leaching (Brady and Weil, 2002). Soil pH <5.5 is deficient in Ca and Mg and should be limed and with this amount poor root growth due to low cation-exchange capacity (CEC) and possible Al^{3+} toxicity and phosphorus deficiency is likely (Soil Survey Staff, 2014). Low productive soils and sites were associated with low pH and corresponding low levels of exchangeable bases and organic matter (Mulugeta and Karl, 2010).

The study reported by Abay et al. (2016) and Kebede et al. (2011) revealed that the pH of non-conserved farmland soils was higher than the pH of conserved farmland soils. According Kebede et al. (2011) the low soil pH in level soil bund (LSB) aged 4 year, in stone bund aged 6 year and stone bund aged 8 year compared to the respective adjacent non-terraced cropland were probably due to loss of relatively more basic cation resulted from erosion before the structures built and did not restore yet after the structures. In-contrast Dejene (2017) found higher soil pH in farm land treated with 8 years aged stone bund than non-treated one. This could be due to the effect of removal of soluble bases and organic matter wash through erosion from non-treated farm lands because of the absence of SWC structure that trap soil as compared to the conserved one.

Soil pH increased in the terrace position from upper to lower position (i.e. upper < middle < lower positions) although this was not significantly different at 5 % probability level and the pH (H_2O) was found to be higher at the lower positions of a terrace (Bobe, 1997). Amare et al. (2013) and Shimeles (2012) have found non-significant variation for pH (H_2O) value at ($P \leq 0.05$) among position within terraces. Amare et al. (2013) have indicated relatively lower pH mean value for the loss zone due to relatively lower base saturation percentage and lower soil organic matter content while the highest pH value in the accumulation zone could be attributed to the presence of higher exchangeable cations due to reduced erosion. Continuous cultivation practices, excessive precipitation, steepness of the topography and application of inorganic fertilizer could have attributed as some of the factors which are responsible for the reduction of pH in the soil (Yihenew et al., 2015). Due to topographic influences the soil pH decreased toward the upslope terrain positions with low exchangeable bases, particularly there was higher acidity on the area 8-30% slope than on the 3-8% slopes (Shimels, 2012).

2.3.2. Electrical conductivity

Electrical conductivity (EC) of soil solution shows indirect measurement of salt content (Brady and Weil, 2002). Increasing concentration of electrolytes (salts) in soil water will dramatically increase soil EC (Seifi et al., 2010). Classification of saline soils and the assessment of the negative effects of salinity on crops are based on the electrical conductivity (EC) of the saturation extract of the soil (Delgado & Gómez, 2016). On the basis of a saturation extract, values of 0 to 2 ds/m are safe for all crops; yields of very sensitive crops are affected between 2 to 4 ds/m; many crops are affected between 4 and 8 dS/m; while only tolerant crops grow reasonably well above that level (Estefan et al., 2013). Worku et al. (2012) found that the electrical conductivity (EC) of the soil did not show significant variation between stone faced soil bund and control farm land. A higher EC were recorded on the conserved land (Mathewos et al, 2016).

2.3.3. Soil organic carbon

Soil organic carbon is the other important soil parameters which binds primary particles into aggregates physically, chemically, and biologically (Blanco and Lal, 2008). Soil compatibility, friability and soil erodibility were favorably improved by increasing the levels of soil organic carbon (Murphy, 2015). Cultivation and tillage can reduce soil SOC content and lead to soil deterioration (Liu et al., 2006). The low level of SOC on the control plots compared to conserved farmland was due to the practices such as intensive tillage, continuous cropping, removal of crop residues, and low organic carbon input in croplands (Kebede et al., 2011).Worku (2017) have reported highest soil organic carbon content on the cultivated land with stone faced soil bund and stone bund structures than under the control farm. Similarly, Worku et al. (2012) have found higher soil organic carbon in the cultivated land under 5 and 10 years of aged fanya juu structures than soil organic carbon content under the control farm.

Moreover, Dejene, (2017) have reported that the treated farm land demonstrated higher soil organic carbon content than the non-conserved farm land, this variation could be due to implementation of stone bund that reduce surface runoff and soil loss, retain water that enhances crop growth and contributes to SOC input.

Soil organic carbon was affected by position across terraces. Amare et al. (2013) found higher mean value of organic carbon at the deposition zone than the loss zone because soil nutrients transported from the upper parts of the terrace are trapped by the conservation structures at the lower sides of the terraces and maintained there. Similarly, Bobe (1997) found the higher organic carbon (%) content at the lower positions of a terrace. The large effect of management, possible fertility losses in the erosion zone can be compensated by adapted soil management and therefore pose no long term threat on stone bund sustainability (Vancampenhou et al., 2006).

2.3.4. Soil organic matter

Organic matter refers to all decomposed, partly decomposed and un-decomposed organic materials of plant and animal origin (Jahn, 2006). It represents an accumulation of partially decayed and partially synthesized plant and animal residues, which is continually being broken down as a result of the work of soil microorganisms (Brady and Weil, 2002). SOM also affects water-holding capacity and cation-exchange capacity and is a source of plant nutrients and energy for the soil population (Soil, 2014). Incorporating fresh organic residues such as green manure or crop residues, which can be readily, mineralized by microbes and result in greatly increased the microbial activity (Deldago and Gomez, 2016). The variations in mean value of organic matter could be attributed to the erosion reduction effects of soil and water conservation measures implemented and biomass accumulation (Amare et al., 2013). Field nutrient levels mainly depend on small scale soil and environmental features, plot history and management (Vancampenhout et al., 2006). Loss of SOM appeared to be a linear function of erosion (Stallings, 1957). Therefore, addition of organic materials to the soil must equal the loss due to decomposition for the sustainability of the system to be maintained (Evanylo & McGuinn, 2000).

Abay et al. (2016) have reported the higher soil organic matter content on plots with SWC measures, this could probably be attributed to accumulated and retained OM due to bund construction, whereas the lowest OM on the non-conserved farmland may be attributed to the due to lack of physical barriers that trap soil and water. Similarly, Zenebe et al. (2016) had observed higher organic matter content on soils treated with SWC practices when compared with soils that are not treated with SWC practices, improvements in organic matter (OM) ranged from 0.3% in soil bund to 0.7% in compost. Moreover, Yihenew et al. (2015) observed the higher mean value of OM on the treated land compared to non-conserved plots could have attributed to the effect of management practices implemented and biomass accumulated.

2.3.5. Total nitrogen

Total nitrogen is the other important soil parameters which is required for the growth of plants. It is an integral component of many compounds essential for plant growth processes including chlorophyll and many enzymes (Brady and Weil, 2002). Mineralization of soil organic matter by which nitrogen in soil organisms, plant material and soil organic matter is converted to mineral (nitrate and ammonium ions) and made available to plants is a major process for the provision of N (Murphy, 2015). Nitrogen is the most deficient element in the tropics for crop production (Mesfin, 1998).

The study results of Worku (2017) revealed that the overall total nitrogen content of soils under control farm plots was significantly lower than that of soils under stone bund and stone faced soil bund structures. Similarly, Dullo et al. (2017) observed the higher TN on the treated farmland with >4years and <4years old age soil bund than the non-treated farmland for both soil sampling depths from 0-20cm and 20-40cm. Moreover, Dejene (2017) reported that the farm lands treated with 10 years old age funyajuu bund have higher TN content than non-treated one. The low soil organic carbon content on the non-conserved farmland could be due to removal of soil organic carbon content through soil erosion.

The study results of Bobe (1997) showed that the total nitrogen (%) content of the soil was found to be higher at the lower positions of a terrace. Similarly, Amare et al. (2013) found a higher mean value of total nitrogen at the deposition zone than the loss zone because soil nutrients transported from the upper parts of the terrace are trapped by the conservation structures at the lower sides of the terraces and maintained there. Total nitrogen content was significantly different between deposition and loss zones and the highest was found from the deposition zone (Amare et al., 2013). In contrast, Mihiretu (2014) observed that total nitrogen and available phosphorus were not significantly different ($p \leq 0.05$) between the lower and the upper positions. Furthermore, Vancampenhout et al. (2006) have reported higher AP and TN and the high fertility were in the accumulation zone and a gradual lower fertility towards the erosion zone. According to Zenebe et al. (2014) the highest average losses in (kg ha^{-1} y^{-1}) of nitrogen (47.8), phosphorous (0.59), and potassium (0.39) were recorded in non-conserved plots, whereas the smallest losses of nitrogen (25), phosphorous (0.27), and potassium (0.21) were observed in the conserved soil bund plots, the variation in the nutrient losses is partly due to the variations in the fertility status of the soil and scales of measurement..

2.3.6. Available phosphorous

Available phosphorous is the most critical elements in influencing plant growth and production throughout the world next to nitrogen (Brady and Weil, 2002). The removal of phosphorus from soils by crops however, is low compared to that of nitrogen and potassium, often being only one third or one fourth that of the latter elements (Brady and Weil, 2002). The report by Worku (2017); Dejene (2017) and Worku et al. (2012) revealed that the mean value of AP in soil under conserved lands was relatively higher than in the non-conserved lands, this could probably be due to higher organic matter content in the conserved plots than in the non-conserved ones. Alemayehu (2007) claimed that the low record of available phosphorus content on the non-conserved farmland could be due to the fact that the parent material in which the considered soils were derived could be poor in phosphorus. In contrast Kebede et al.(2011) reported significantly high ($P < 0.05$) AP content in non-terraced croplands adjacent to LSB aged 4 year, stone bund aged 6 year and stone bund aged 8 year, these were perhaps due to the difference in the past land degradation resulting from continuous cultivation, extractive plant harvest and soil erosion.

The study results of Bobe (1997) showed that the available phosphorous content of the soil was found to be higher at the lower positions of a terrace. Similarly, Vancampenhout et al. (2006)

have reported higher AP and the high fertility were in the accumulation zone and a gradual lower fertility towards the erosion zone. Moreover, Amare et al. (2013) revealed that variation in available P between deposition and loss zones can be due to washing out in the upper parts and accumulation at the lower parts. It is apparent that with higher phosphorous concentration in the depositions zone there will be relatively higher biomass production and in turn produces higher soil organic matter which is the store of phosphorous.

2.3.7. Exchangeable bases (K^+, Ca^{2+} and Mg^{2+})

Any process that will encourage high levels of the exchangeable bases such as calcium, magnesium, potassium, and sodium will contribute toward a reduction in acidity and an increase in alkalinity (Brady and Weil, 2002). At low pH, the risks of deficiency of base nutrients (K^+, Ca^{2+} and Mg^{2+}) increases due to their low content; also the solubility of Mo and P compounds is decreased, thus decreasing its availability (Delgado & Gómez, 2016). Consequently, bases that have been replaced from the colloidal complex or dissolved by percolating acids are removed in the drainage waters. This process encourages the development of acidity in an indirect way by removing those metallic cations that might compete with hydrogen and aluminum on the exchange complex (Brady and Weil, 2002).

Worku (2017) revealed that the highest exchangeable K^+ content in the conserved land which was related with its high pH value. Similarly, Worku et al. (2012) reported that exchangeable base cations didn't show significant variations ($P \leq 0.05$) between (fanya juu 5 years and 10 years old) and adjacent control farm plots except with the exchangeable Na^+. Conversely, Dejene (2017) found non-significance difference between 10 years old funyajuu and un-conserved farmland for exchangeable potassium. The concentrations of divalent basic cations were higher in accumulation zone than the loss zone, which could be due to washing away of cations from the loss zone and accumulations in the deposition zone (Amare et al., 2013). Leaching of bases is the major soil nutrient management problem for the soils of humid tropics (Mulugeta and Karl, 2010). The low calcium concentration in acidic soils is usually related to an increased dispersion of colloids if Al is not present at high concentration (Deldago and Gomez, 2016).

The amount of exchangeable potassium was increased in the soil by many factors. Plants have adapted to respond to the soil conditions and presence of microbes through various mechanisms, one of which is the secretion of root exudates (Rovira, 1969). In fact those increasing root exudates, which contain organic acids, would increase exchangeable soluble K^+ in the soil (Shin, 2014). The potassium ions remaining in plant residues after harvest and in manure are quickly returned to the soil by water leaching through the plant materials and manure (Covert, 1999). Leaching of Mg in soils when applied with various water-soluble fertilizers may also vary depending on the fertilizer's chemical composition, granule size, and effect on soil pH and cation balance (Senbayram et al., 2016).

2.3.8. Zinc

In very acid soils there is a relative abundance of the ions of iron, manganese, zinc, and copper. In fact under these conditions the concentrations of one or more of these elements is often sufficiently high to be toxic to common plants (Brady and Weil, 2002). Zn deficiency results in severe yield losses and in acute cases plant death (Salgueiro et al., 2000). Yield of several important food crops (beans, citrus, fruit trees, grapes, maize, onions, pecan nuts, rice, sorghum, sweet corn etc.) as well as the quality of the crop product may be decreased under Zn deficiency conditions (Noulas, 2018). Ethiopian national mean values for plant and soil Zn are high compared to those of most other countries (Sillanpää, 1982). A zinc soil test above 1.5 ppm using the DTPA extraction method is sufficient for most crops (Horneck, 2011).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study area is situated in Southern Nations Nationalities and Peoples Regional State (SNNPRS) at Gamo Zone, Arba Minch Zuria Woreda (AMZW), Ubale Micro Watershed. Geographically, it lies between 6^0 and $6^04'00''$ N latitude and $37^04'00''$and $37^05'00''$ E longitudes. The study area was located 11km from Arba Minch town and 516km away from Addis Ababa, the capital of Ethiopia.

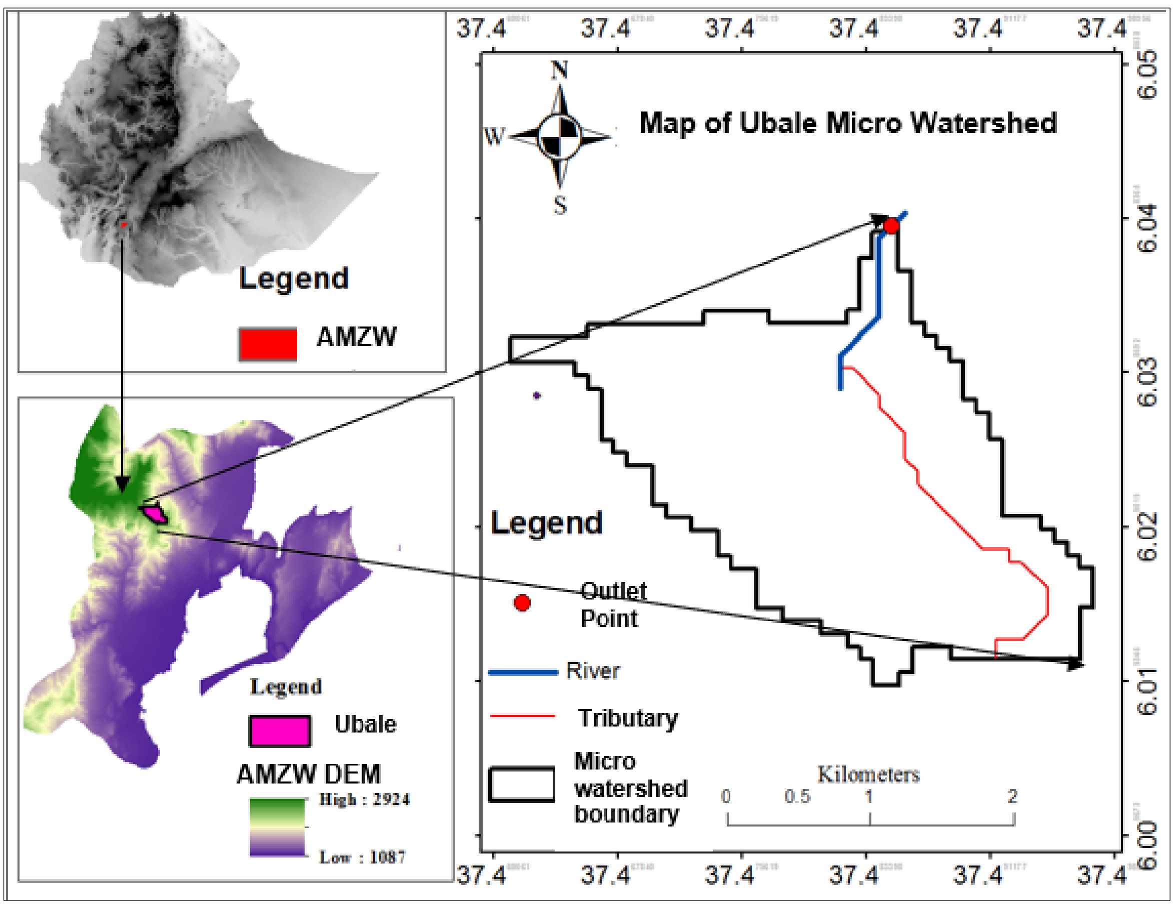

Figure 1: Location map of the study area

3.1.2. Topography and soil

With a total catchment area of 577.15 ha the altitude of Ubale micro watershed ranges between 1668 and 2456 meter above sea level. The study area has different topographic setups as it is seen during field observations. The watershed drains to Kulfo River which is part of the Great Rift Valley River basin. The dominant soil type of the study area was Orthic Acrisols soil group (FAO, 1988). According to Gray et al. (2011) the soils of the study watershed is characterized by clay rich subsoil's with low activity clay and low base saturation, which has features of low agricultural potentials-acid and nutrient poor rapidly degrade, prone to erosion. This type of soil groups is having angelic B horizons: having a base saturation, which is less than 50% (by NH_4OAC) in at least some part of the B horizon within 125 cm of the surface (Huang and Sumner, 2011). The partial view of the topography of the study micro watershed is shown in (Figure 2).

Figure 2: Partial view of the topography of the study site watershed

3.1.3. Climate

The study area is characterized by bimodal rainfall pattern. The small rainy season (Tsedey) occurs from Septembers to October, while the main rainy (Kremt) season occurs from April to May. The total (2007-2016) annual rainfall is 1113.68 mm. The annual mean minimum and mean maximum temperatures for the periods from 2007 to 2016 were 17.12 and 28.72 ^{0}C respectively (Appendix 1). The agro-ecology of the study is moist Weyna Dega agro-climatic zone. The highest rainfall during April and September is the major rainfall events that may cause a run-off for the study areas where there is no SWC activities and in poorly managed farmlands. The graphical presentation of rainfall and temperature of the study area is below in (Figure 3).

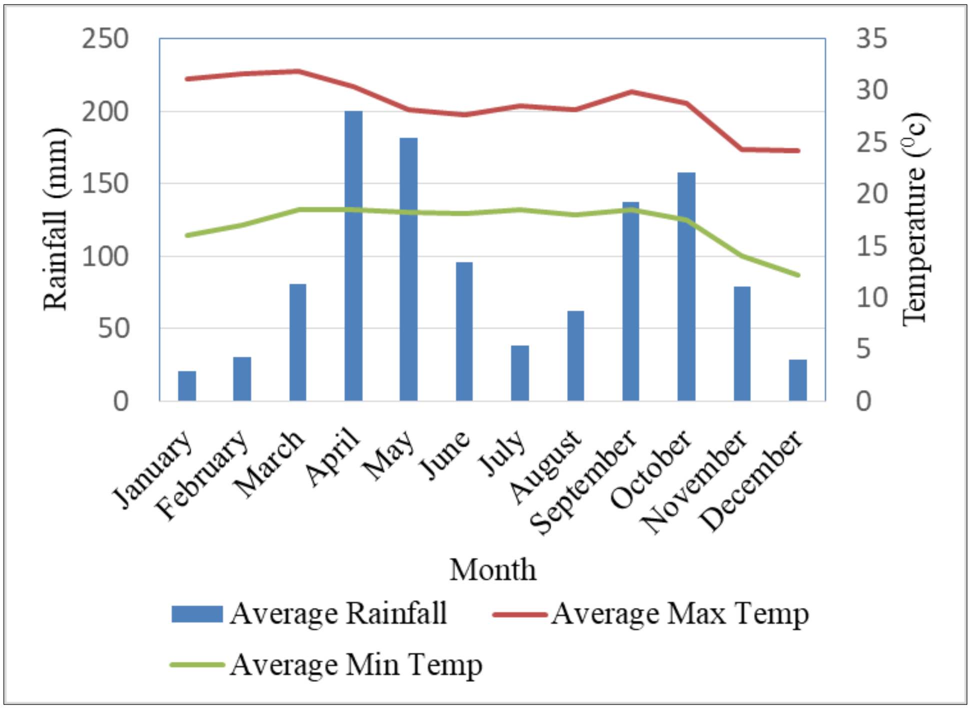

Figure 3: Average rainfall and maximum and minimum temperatures from the year 2007-2016

3.1.4. Agriculture and livestock

The study area inhabited by a population of 1048 in 2019 EC census. The major economic activity of the area is mixed farming. There are varieties of food crops and fruits are grown: Maize is the primary food crop followed by sorghum, teff and barely, respectively. Livestock production, including the fattening of oxen is another important income source. Traditional crop rotation, intercropping and livestock rearing system are the predominant farming system in the study area. The major crops grown include cereals (maize, sorghum, wheat and teff), pulses (haricot bean, chickpea), banana, fruit trees and coffee around homesteads Kebeles (AMZWAO, 2018).

3.1.5. Soil and Water Conservation Activities in the Study Area

Soil and water conservation measures have been widely implemented in Arba Minch Zuria Wereda. Different kinds of SWC measures were implemented with the help of Productive Safety Net programs (PSNP), mass mobilization of the people themselves, Collaborating partners including the Agricultural Office from Arba Minch Zuria Wereda and Mercy Corpus NGOs.Before the intervention through the Productive Safety Net Program (PSN) and World Food Programs (WFP), farmers in the area were exclusively practicing traditional methods (by cutting of the frmland they make a traditional terraces) and apply animal manure). The introduced soil and water conservation measures implemented in the Ubale micro watershed in both farmland and other land uses,which is a part of watersheds in Arba Minch Zuria Wereda. In this watershed the SWC measures adopted were gabion checkdomes, micro and eyebrow basin, stone bund, soil bund, funyajuu terraces, trenche works, hillside terraces and tree plantation. Stone and soil bunds were widely practiced and adopted by the local farmers on the cultivated land (AMZWAO, 2018).

Most of the structures in the area were not integrated with biological measures such as grasses although only some of the physical structures were supported by biological measures. The areas covored by different soil and water conservation activities by the aid of govornment and people themselves were 250 ha land. The SWC measures constructed in the erosion prone areas of this specific moist weyna dega region agro ecolgical zone of Ubale micro watershe in Arba Minch Zuria Wereda was for the purpose of reducing soil erosion to improve the soil fertility.

3.2. Treatments

Reconnaissance survey was carried out to know the overall conditions and the existing SWC practices in the watershed. Convenience sampling method was used to sample the area to identify the sampling plot from the micro watershed with a view to accessibility of the site for soil sample collection and availability of the structures (Dörnyei, 2007). The criteria considered for the selection of these experimental sites were: the same 5 years old age bunds, major soil type being similar; slope uniformity; sites not too far from each other and same management and cultural history.

Experimental sites were selected within the study area as part of the treated or non-treated farms selected for the treatments considered in this study. Since the level stone and soil bunds are constructed on the same slopes, the treatment factors considered for this study were different conservation structures and slope position. The treatments were level stone bund, soil bund and control, while the three slope positions of an inter-terrace area were named the upper, middle and lower positions. Here, slope refers to the original ground slope of the area before the construction the level stone bunds and soil bund.

The experimental site on a treated farm refers to the site located between two consecutive level stone bunds and soil bunds (the inter-terrace area) structure with a given slope. On the non-terraced farm, the experimental site (control) refers to that part of the farm considered with a structural treatment factor. Within each terraced experimental site, three slope positions were identified. The factorial experiment with RCBD was conducted. Because there is blocks or three replicates for each treatment but without the randomization. The treatment structures and slope position was assigned to the main factor. The data obtained from non-terraced sites was used to compare with the results of the terraced areas with respect to the structure treatment, because the slope position treatments apply only to the terraced fields. Thus, a total of 9 plots (3position*3 replication) for the terraced sites, and 3 replicated plots for the control treatments were considered in the study.

In the watershed, the level stone bund were constructed with a height of: 60cm, top width of 30-40 cm at a vertical interval of up to 2 m according to the gradient of the area, the effective height of the stone bund reached up from 75-100 cm, base width 1.2-1.5 m and top width 30-40 cm depending on the soil type and rainfall amount of the area. The level stone bunds were build strong walls along the contour with large rock fragments that had stone riser across the slope. Soil bunds are used to reduce run-off, to conserve soil and water, to reduce soil erosion thereby to increase the amount of water that the soil can hold. The dimensions of the ridges and the spacing between the conservation structures are according to the recommendation of the Ethiopian SWC guidelines at a vertical interval of up to 2 m according to the gradient of the area and the width of the ditch, and the height of the bund may be reaching 60 cm after compaction, base width 1-1.2 m and top width 30-40 cm and also the depth and width of the ditch are 30cm by 30cm and 30cm by 40cm depending on the soil type and rainfall amount of the area(AMZWAO, 2018).

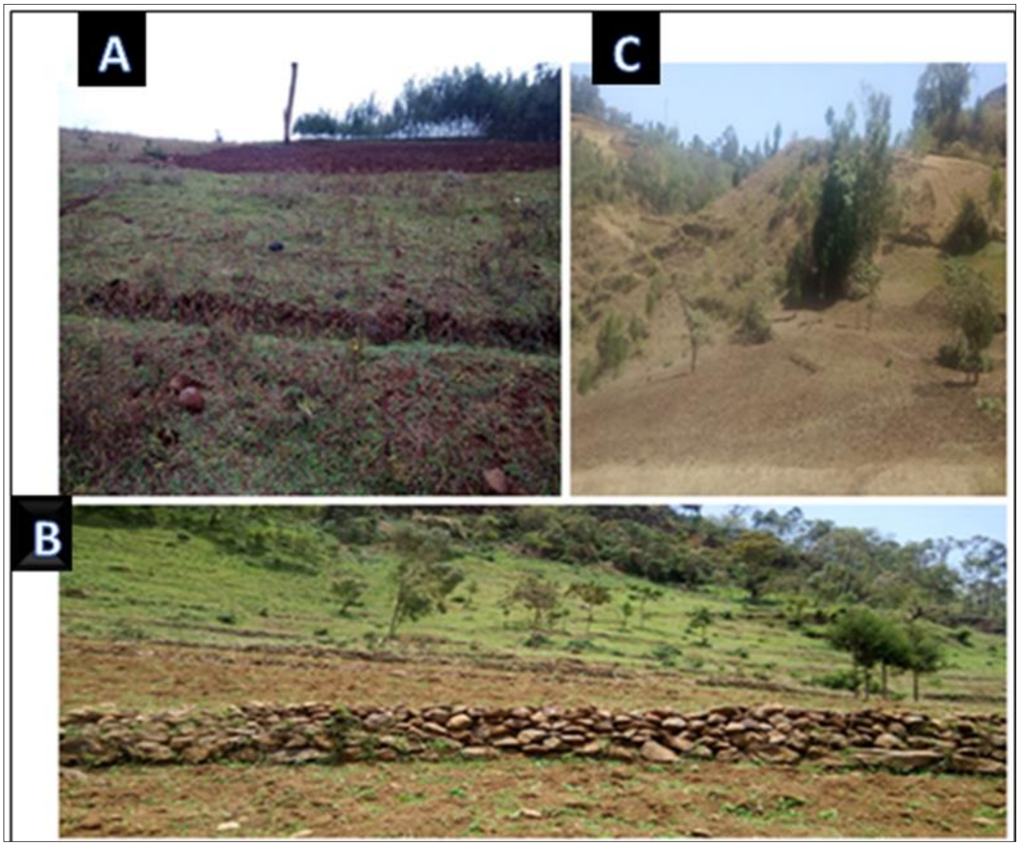

Figure 4: Treated and untreated plots of the study micro watershed: Level soil bund (A) and Level stone bund (B) and Control plot (C)

3.3. Data Collection

From Arba Minch Zuria woreda, Ubale micro watershed with a total area of 577.15 ha was selected based on accessibility to the field; all treatments (level soil bund, level stone bund and the control) within the watershed, all bunds were constructed at the same time. After reconnaissance survey, primary data was collected by measuring of bunds (slope and distance between bunds), laboratory analysis of soil (physical and chemical properties). Secondary data related to previous management history and information on soil and water conservation ages in the watershed were collected from Woreda Agricultural Office, Kebele Development Agents (DA's).

3.4. Soil Sampling and Preparation

Composite soil samples representing the treatments were collected from upper and lower positions and, at equidistance from middle positions at 15 cm soil depth systematically using "W" sampling design sampling method (Margesin and Schinner, 2005) and adjusted at 1m away from the bunds (Lakew et al., 2005). Lower slope position (deposition zone) refers to the location 1m from the lower terrace riser (above the bunds) in the upslope direction, middle slope position is the midpoint between two successive terraces, and upper slope position (loss zone) refers to the location 1m from the lower wall of the upper terrace riser (below the bunds) in the down slope direction. The 1m distance from both the lower and upper terrace wall was to reduce the effect of water accumulation and splash by the overtopping water, respectively.

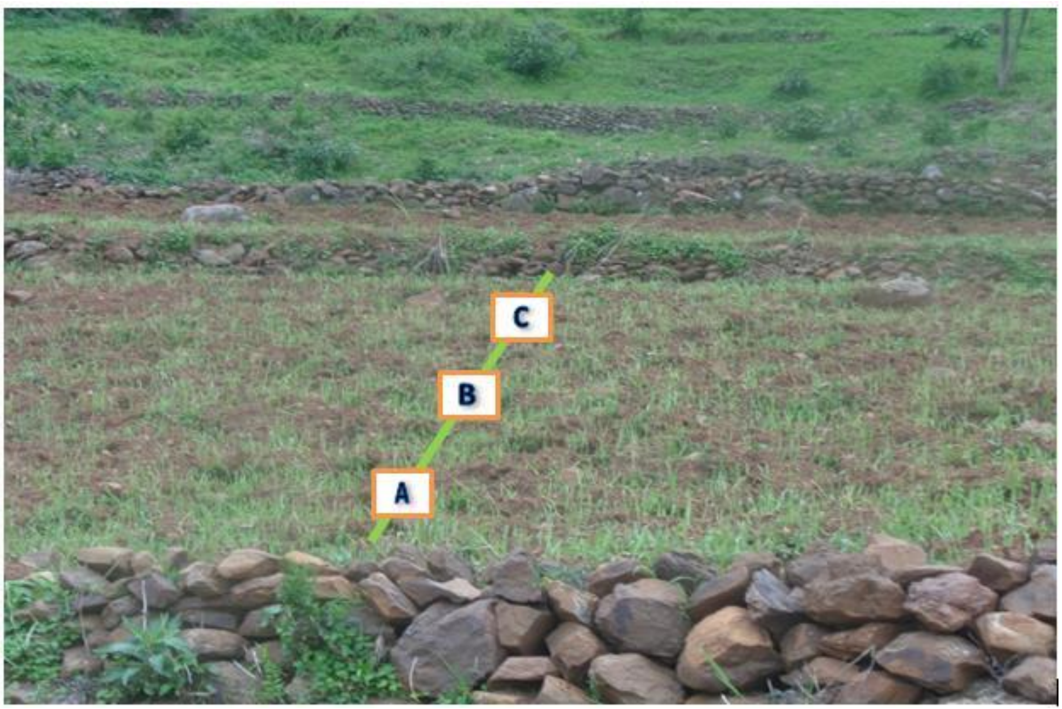

Figure 5: Layouts point of data collection

Where, (C) = upper slope position (B) = middle slope position and (A) = lower slope position

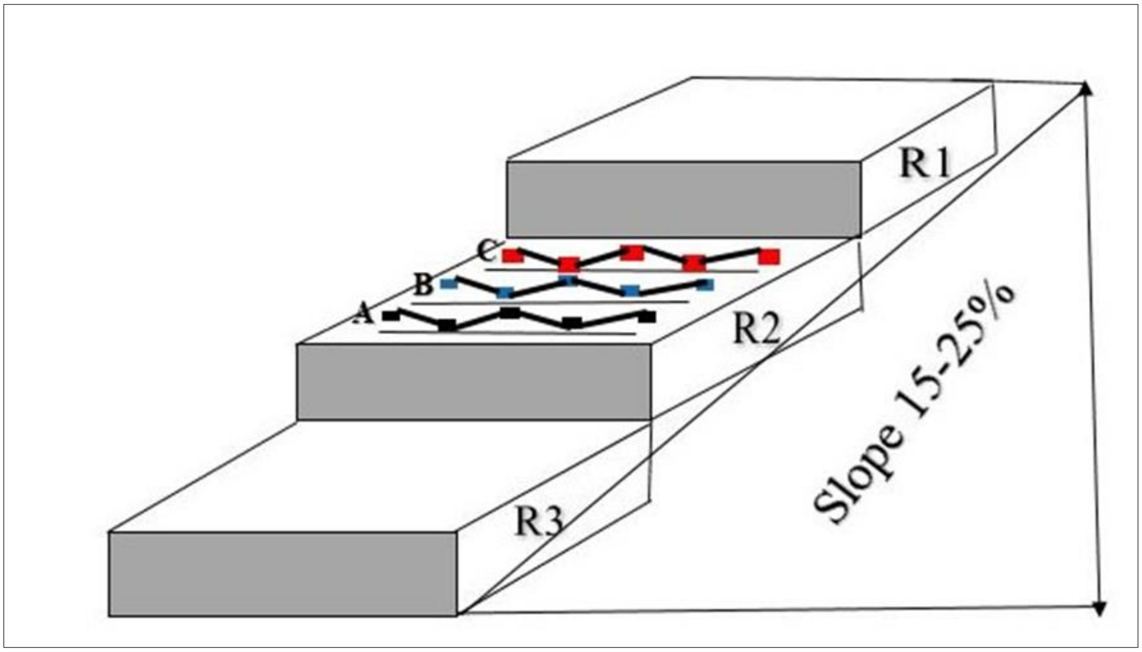

Figure 6:“W” design soil sampling technique

Where, R= Replication (R1, R2 and R3); (C) = upper slope position (B) = middle slope position and (A) = lower slope position

The main physical and chemical properties for analysis were soil texture, bulk density (BD), total porosity (TP), and moisture contents (MC), pH [H_2O], electrical conductivity (EC), soil organic carbon (OC), soil organic matter (OM), total nitrogen (TN), available phosphorus (AP), Zinc (Zn), exchangeable (Ca^{2+}), exchangeable (K^+) and exchangeable (Mg^{2+}). Thus a total of 21 composite soil samples, 18 from terraced plots (level stone and soil bund) and 3 from the control plots were collected for soil physical and chemical analysis using the standard laboratory procedures. For soil bulk density 21 core sample were collected, 18 from terraced plot and 3 from the control plots. The soil samples collected were bagged separately with appropriate plastic bag and transported to the laboratories, air dried at room temperature, crushed and ground to pass through different sieve sizes for laboratory soil analysis. The physical properties were analyzed at Arba Minch University Soil Mechanics Laboratory while, the chemical properties were analyzed at Arba Minch University Chemistry Laboratory.

3.5. Laboratory Analysis for Soil

The texture of soil was determined by hydrometer method using sodium hexa Meta phosphate ($Na_6(PO_3)_6$) as a dispersing agent (Bouyoucos, 1951). 50gm of air dried soil sample was weighed and added to 250ml beaker. Then 125ml of distilled water and 5gm sodium hexa Meta phosphate dispersing agent were mixed and the solution was stirred for 10min and shacked again for 10 minutes in the electronic shaker. Finally the reading was taken from the 1000ml jar by nothing hydrometer and temperature reading.

Bulk density of the soil was determined from undisturbed soil clods collected in core sampler after drying the soil samples in an oven at 105°C for about 24 hours (Baruah and Barthakur, 1997). This method involves sampling a soil using short cylindrical iron cores of about 5cm long and 5cm in diameter at a depth of 0-15cm. A soil sample ring is forced into the soil, causing it to fill entirely with undisturbed soil. The dry bulk density was then calculated from the ratio of the oven dry mass of soil and the bulk volume.

$$\mathbf{BD} = \frac{\mathbf{wd}}{\mathbf{vt}} \qquad (\mathbf{Eq}.\ 1)$$

Where: BD= bulk density (gm/cm^3), Wd= weight of dry soil (gm) and Vt= volume of the bulk soil (cm^3). Volume of the soil is assumed to be equal to the internal volume of cylindrical sampling core, $\pi r^2 h$ where r is the internal radius (cm) of the core and' h 'is height (cm) of sampling core.

Total porosity percentage pore space was computed from the values of bulk density (BD) and particle density (PD) (Brady and Weil, 2002) as:

$$\mathbf{f} = \frac{\mathbf{1-BD}}{\mathbf{PD}} * \mathbf{100} \qquad (\mathbf{Eq}.2)$$

Where, f is total porosity (%), BD= bulk density (g/cm^3), and PD= particle density (g/cm^3). It is a constant number which is 2.65.

Gravimetric method was used to determine the soil moisture content by drying the soil sample in an oven at 105 ^{0}C (Hillel, 1980). The percent soil moisture content on mass basis was determined as:

$$\boldsymbol{\theta_m = \frac{swi - swd}{swd} * 100} \qquad (\textbf{Eq}.3)$$

Where: θ_m = gravimetric water content (%), swi = initial weight of the soil (g) and swd = oven dry weight of the soil (g).

Infiltration rate: Infiltration rates of the soil in the experimental field were determined using double ring infiltrometer (Johnson, 1963). Double ring infiltrometers are generally preferred over single rings in that the error resulting from lateral flow in the soil is reduced. The purpose of the outer tube is to eliminate to some extent the edge effect of the surrounding drier soil and to prevent the water within the inner space from spreading over a larger area after penetrating below the bottom of the ring (Raghunath, 2006). 100 liters of water were used for this infiltration experiment. The water was transported using 20 liter plastic water containers from the stream nearby the farmland to the measurement site. Three infiltrometer tests were carried out on each of the treatments plots (Osuji et al., 2010), three plots (replication) for each treatment (level stone and level soil bund) soil and in the farmland soil without bunds of the same landscape position from 15-25% slope categories during the spring season before rainfall was coming in June 2018 G.C.

Double ring concentric infiltrometers of 30 and 60 cm diameter of inner and outer rings and 25 cm height was driven into the ground to a depth of 5cm with a sledge hammer to avoid lateral flow of water (Figure 8). A constant head of 7 cm of ponded water was maintained in both rings throughout experimental runs. The rate of infiltration was determined by the depth of water that infiltrates into the soil per unit of time. The readings were continued until a steady state of equilibrium 120 minutes was reached. The water is poured in to the inner/outer ring until the depth is approximately 200 mm (Figure 8). The stop watch time was recorded to measure the water level on the measuring rod and water in the ring refilled as water level on the measuring rod drops down. Same test done in the three places and same procedure is continued the drop in water level is the same. Readings were taken frequently 10 minutes at the beginning of the test until the time goes on (Selim, 2011). The tests were run for two hours and once the values were constant, the basic infiltration rate had been reached.

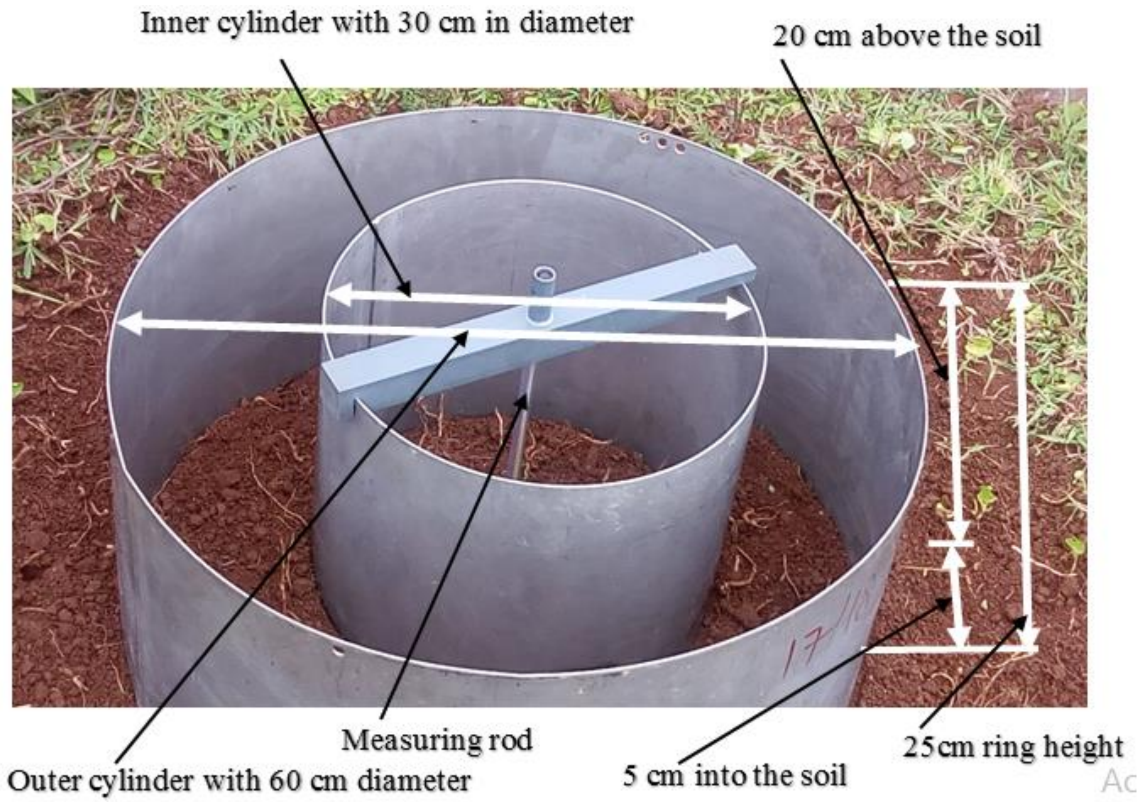

Figure 7: Typical double ring infiltrometer

$$\mathbf{I} = \frac{\mathbf{D}}{\mathbf{T}} \quad \text{(Eq.4)}$$

Where: D= depth of water, I= infiltration rate and T= duration of time

The observed data was fitted with two different infiltration models (L-K and Horton models) to determine the relationship.

Horton Model

$$\text{Cumulative} = i_f t + \frac{ia - if}{k}\left(1 - e^{-kt}\right) \quad \text{(Eq. 5}$$

$$\textbf{Rate} = \boldsymbol{i_f} + (\boldsymbol{ia} - \boldsymbol{if})\boldsymbol{e^{-kt}} \quad \text{(Eq. 6}$$

Where $i0$, is initial infiltration rate at t=0, and ic is final constant infiltration rate after a long time from the start of infiltration. The constant "k" determines the rate at which ic approaches $i0$. Unlike other equations, the Horton equation has a finite infiltration rate, $i0$ at t=0. The equation is somewhat cumbersome as it has three constants, which need be evaluated experimentally.

Kostiakov Model

The Kostiakov equation for cumulative infiltration *(I)* and infiltration rate *(i)* can be expressed as follows

Cumulative $= \boldsymbol{kt^{a}}$ (**Eq.** 7**)**

Rate= $\boldsymbol{akt^{(a-1)}}$ (**Eq.** 8)

Where parameters *k and a* are constants. These parameters do not have a physical meaning and can be obtained by fitting the equation to the experimental data, at t=0, I approaches ∞. However, as t increases further, I tend to become zero. Therefore, Eqs. Explain the horizontal infiltration. However, for vertical infiltration, the Kostiakov (1932) equation is inadequate.

The pH of soil was measured electrometrically by means of pH meter in the suspension of 1:2.5 soils to water ratio following the procedure outlined by Sahlemedihn and Taye (2000). The suspension was stirred well at a regular interval for 30 minutes and also stirred again before immersing the electrode for pH reading.

The electrical conductivity of the soil was determined in a 1:2.5 soil to water suspension ratio using conductivity meter according to the methods outlined by the United State Salinity Laboratory Staff (1954).

The total nitrogen content of the soil was determined using the Kjeldahl method as explained by (Bremner & Mulvaney, 1982). Briefly weighed 1.0 gram of air dried soil was taken and 6ml of distilled water were added into digesting tube then after flask was swirled for few minute and allowed to stand for further 30 minutes. About 1gram of selenium mixture and 10ml of concentrated sulfuric acid were added and digested at 375^0c until the sample turns turquoise up to 1-2hr and cooled for 5 minutes. The sample was then transferred to 800ml distillation flask containing 150ml of distilled water and 40ml of 45% NaOH and connected immediately to the distillation unit and distilled in 30ml of boric acid (H_3BO_3) mixed indicator. In the final steps the sample was titrated with 0.1N HCl (Hydrochloric acid) and the volume of titrant (hydrochloric acid) were record.

The organic carbon content was analyzed by wet digestion method using the Walkley and Black procedure (Nelson & Sommers, 1982). Briefly 1g of air dried soil, sieved in 500 micro meshes was added in 250ml conical flask and 10ml of 1.0N $K_2Cr_2O_7$and 20 ml H_2SO_4 was added in a flask containing soil. The flask was swirl gently to disperse the soil in the solution then after it was allowed to heat on a hotplate at 150^0C for 1 minute. Next the flask was allowed to stand for 30minute and 200ml of distilled water was added. Then 5-6 drop of ferroin indicator and titrate with 0.5N ferrous solutions were added. As the end point is approached, the solution takes on a greenish cast and then changes to dark green. At this point, the ferrous sulphate added drop by drop until the color changes sharply from blue to red (maroon color in reflected light against a white background). Organic matter was obtained from the organic carbon content by a factor of 1.72 (Brady and Weil, 2002).

$$\mathbf{OM}\ (\%) = \mathbf{OC}\ (\%) * \mathbf{1.72} \qquad (\mathbf{Eq}.9)$$

Available phosphorus content of the soil was analyzed using sodium acetate ($NaC_2H_3O_2 \cdot 3H_2O$) extraction using Morgan method according to the procedure outlined by (Jones, 2001). The extraction reagents was prepared from 100 g sodium acetate ($NaC_2H_3O_2 \cdot 3H_2O$) in about 900 mL water in a 1000-mL volumetric flask with 30 mL glacial acetic acid (CH_3COOH) by adjusting the pH to 4.8 and diluted to 1l with deionized water. 5g of air dried 2 mm sieved soil was scooped into a 50 mL extraction vessel. 25 mL extraction reagent was added and the content was shacked for 5 min immediately and the solution was filtered and collected for P concentration determination. 2ml of soil filtrates was taken into 25 ml volumetric flask and 23 ml of the freshly prepared ascorbic acid and ammonium molybdate solution (working solution) was added to the flask containing 2ml soil extract, shacked well and kept for 20 minutes until the formation of blue colored solution. Finally the solution was measured and the absorbance of the solution was recorded at 882 nm using UV-VIS Spectrophotometry (Specord 50, analytikjena, Germany).

The exchangeable bases such as K^+, Ca^{2+} and Mg^{2+} were analyzed by using ammonium acetate method (pH=7) as described by Rowell (1994). A 1g of air dried soil was weighted and 20ml of 1M NH_4OAAC was added to 100ml conical flask. Then the solution was shacked for 20 minutes shaker and the solution was stand for 30 minutes and then the supernatant were filtered into 100 volumetric flasks and the filtrate was diluted with distilled water to 100ml volumetric flask. Finally the solution was analyzed by Atomic Absorption Spectrometry (210 VGP Flame Atomic Absorption Spectrophotometry).

Soil zinc content (Zn) were extracted by DTPA (Diethylene Triamine Pentaacetic Acid) as described by Sahlemedhin and Taye (2000), in which 1gram of a 2 mm sieved soil samples was added with 20 ml aquaregia (mixture of HCl and HNO_3, ratio 3:1) and 10ml of 30% H_2O_2. The H_2O_2 was added in small portions to avoid any possible overflow leading to loss of material from the beaker. The content was digesting for 2hr in beaker covered with watch a glass, and reflex over a hot plate at 90°C. The beaker wall and watch glass was washed with distilled water and the sample was filtered out to separate the insoluble solid from the supernatant liquid. The volume was adjusted to 100 ml with distilled water. Blank solution was handled as detailed for the samples. All samples and blanks were stored in plastic containers. Finally the solution was analyzed by Flame Atomic Absorption Spectrometry (FAAS).

3.6.Data Analysis

The soil properties data generated from the laboratory were subjected to the analysis of variance (ANOVA) following the General Linear Model (GLM) procedure of the statistical analysis system (SAS Institute, 1999). The least significance difference (LSD) test at 5% level of significance was used to separate significantly different treatment means (Gomez and Gomez, 1984). The mean of soil infiltration rate was calculated at Micro-soft office 10 and the result was presented using graphs.

4. RESULTS AND DISCUSSION

4.1. Effect of Level Stone and Soil Bund on Soil Physical Properties

4.1.1. Soil texture

Results of level stone and soil bund effect on soil texture were presented in (Table 1). The textural analysis shows that the percent sand and silt fractions were significantly different with a P value of ≤ 0.05 between soil and water conservation (SWC) measures, while the percent clay fractions was significantly different between SWC measures and interaction effect of the two factors (Appendix 3).

Table 1: Soil texture in relation to type of conservation measures across position within terraces of top soil (0–15 cm) depth

Soil properties	Position on terraces	Level stone bund (LSTB)	Level soil bund (LSB)	Control	Mean
Sand fraction	Upper	44.70±7.66	42.70±5.74		43.90^{a}
	Middle	46.60±2.00	40.30±0.30		44.40^{a}
	Lower	50.40±5.17	43.46±1.96		44.82^{a}
	Mean	47.23^{a}	42.15^{b}	43.67^{ab}	
Silt fraction	Upper	22.00±5.29	16.33±4.04		21.25^{a}
	Middle	23.33±1.15	18.86±1.02		22.87^{a}
	Lower	21.33±6.42	16.66±3.05		22.80^{a}
	Mean	22.20^{b}	17.28^{c}	26.00^{a}	
Clay fractions	Upper	33.30^{b}±2.45	40.96^{a}±1.90		34.65^{a}
	Middle	30.06^{cd}±1.15	40.70^{a}±1.17		33.48^{ab}
	Lower	28.26^{d}±1.25	39.86^{a}±1.36		33.17^{b}
	Mean	30.54^{b}	40.51^{a}	30.26^{b}	

Means within a column and rows followed by the same letter are not significantly different from each other at $P \leq 0.05$

With respect to SWC measures, the level stone bund recorded the highest sand fractions of 47.23% while the minimum sand fractions of 42.16% was recorded on the level soil bund. There was a significant difference ($P \leq 0.05$) observed between level stone bund and level soil bunds, but no significant difference was observed between LSB and control plots (Table 1). The high sand fraction on the level stone bund plots may be due to soil erosion impacts in the past. Sandy soils are less cohesive than clayey soils and thus aggregates with high sand content are more easily detached (Blanco and Lal, 2008).

With respect to SWC measures, the control plots received the higher (26%) silt fraction while the level soil bund recorded the lowest 17.29% silt fraction (Table 1). There was a significant difference ($P \leq 0.05$) observed between level stone bund, level soil bund and control plots for the silt fraction. The control plots received the highest silt fractions compared with level stone bund and level soil bund structures. The highest silt content on the control plot may be due to the erosion and sedimentation processes from upslope areas as a result of the absence of any structures that trap the sediments. Soils high in silt, low in clay and low in organic matter are the most erodible (Wischmeier and Smith, 1994). This finding was in agreement with Mengistu et al. (2015) in that silt content was high in the non-conserved rather than conserved land which is characterized with basaltic trapping series of volcanic eruptions parent material. Silt may lead to compaction and crusting of the soil surface unless it is supplemented by adequate amounts of sand, clay and organic matter (Brady and Weil, 2002).

With respect to SWC measures, the level soil bund was recorded significantly ($P \leq 0.05$) high amount of 40.51% clay fraction, while the level stone bund and control plots were recorded the lowest clay fraction of 30.54% and 30.27% respectively. There was no significant difference ($P \leq 0.05$) observed on the level soil bund from level stone bund and control plots. The higher clay fractions on the level soil bund may be due to the exposure of top soil to soil erosion by water which ultimately exposes the subsoil with high amount of clay into the surface, while the low clay fraction on the level stone bund and control plot could be due to the higher percent sand fractions due to washing of clay or fine material by soil erosion leaves less amount of clay soil on the surface. This result was also agrees with Kebede et al. (2011) who have reported the significant difference for clay fractions in croplands under LSB aged 6 year when compared with adjacent non-terraced croplands.

Considering the interaction effects of conservation measures by position within terraces, significantly the highest and the lowest clay fractions were recorded in all positions of the level soil bund and level stone bund respectively (Table 1). With the exceptions of all positions of the level soil bund and the middle and lower position of the level stone bunds, which were statistically not significant difference, the mean clay fractions of the remaining treatment combinations were significantly different ($P \leq 0.05$) from each other due to the interaction effects.

The significant differences for sand, silt and clay fraction indicate that, it is the inherent soil property which causes the variation in texture rather than due to the structures. Pedogenic processes such as erosion, deposition, elevation and weathering can alter the textures of various soil horizons (Foth, 1990; Ahmed, 2002). In order to have a balanced proportion of soil separates; organic matter amendments should be incorporated in order to improve the texture of soil by improving the soil aggregates and structures. Soil texture affects soil compaction through its effect on aggregation and porosity, absorption of water and other organic compounds by altering surface area, water and nutrient storage through charge properties, transport of solute and gaseous exchange through porosity (Lal & Shukla, 2004).

4.1.2. Bulk density (BD) and total porosity (TP)

A result of level stone and soil bund effect on soil bulk density and total porosity were presented in Table 2. The bulk density and total porosity of the soil was significantly different between SWC measures, however, this was not significantly different between position within terraces and interaction effect of the two factors with a P value of ≤ 0.05 (Appendix 3).

With respect to SWC measures, the level stone bund recorded 1.34gm/cm^3 of the highest soil ***bulk density*** while the level soil bund recorded relatively low soil bulk density value with 1.20gm/cm^3. There was no significant difference observed between level soil bund and control plots. However, this was significantly different on the level stone bund from the level soil bund and control plots (Table 2).

Table 2: Soil physical properties bulk density (BD), total porosity (TP) and moisture content (MC) in relation to type of conservation measures across position within terraces of topsoil (0–15 cm) depth

Soil properties	Position on terraces	Level stone bund (LSTB)	Level soil bund (LSB)	Control	Mean
BD (gm/cm^3)	Upper	1.32±0.15	1.14±0.06		1.25^{ba}
	Middle	1.30±0.11	1.23±0.01		1.22^{b}
	Lower	1.41±0.06	1.23±0.01		1.31^{a}
	Mean	1.34^{a}	1.20^{b}	1.24^{b}	
TP (%)	Upper	50.05±5.71	56.72±2.57		52.57^{ba}
	Middle	50.68±4.46	53.33±0.57		53.66^{a}
	Lower	46.53±2.56	53.58±0.57		52.95^{b}
	Mean	49.09^{b}	54.54^{a}	52.95^{a}	
MC (%)	Upper	28.42^{de}±4.21	43.98^{ba}±10.02		30.53^{b}
	Middle	24.72^{de}±2.12	33.90^{dc}±2.90		37.23^{a}
	Lower	24.40^{fe}±5.81	31.94^{dce}±3.60		31.42^{b}
	Mean	27.53^{b}	36.61^{a}	35.05^{a}	

Means within a column and rows followed by the same letter are not significantly different from each other at $P \leq 0.05$

The highest soil bulk density recorded on the level stone bund than soil bund and control plots could be due to higher sand fractions. This result was in agreement with Abay et al. (2016) in that he reported the higher soil BD values on the six year graded stone bund than control plots. Soils with a high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space (Brady and Weil, 2002).

The mean bulk density of soil in the studied micro watershed for both treated and untreated plots was from 1.14-1.41gm/cm^3 with an average value of 1.27gm/cm^3. This range of soil BD could affect the crop rooting depth in the study area. The ideal soil bulk density for sandy clay loam, clay loam is <1.40gm/cm^3 and for clay soil (<45% clay) is 1.39, however the bulk density of the study area was in the appropriate ranges, that may not affect and restrict root growth (Soil Survey Staff, 2014).

With respect to SWC measures, the highest ***total porosity*** of 54.54% was observed under the level soil bund while the lowest total porosity of 49.09% was observed under the level stone bund plot (Table 2). There was no significant difference observed between LSB and control plot, however this was significantly different on the level stone bund from the level soil bund and control plots ($P \leq 0.05$).

The highest total porosity on the level soil bund could be due to the low soil bulk density value (Table 2). Total porosity and soil bulk density have an indirect proportional to each other, as porosity of soil decreased the bulk density in the soil become increased and vice versa. If soil pores lay close together as in sands or compact sub soils the total porosity is low (Brady and Weil, 2002). Hillel (2003) stated that coarse-textured soils tend to be less porous than fine-textured soils, though the mean size of individual pores is greater in the coarse textured soil, however in clayey soils the porosity is highly variable because the soil alternately swells, shrinks, aggregates, disperses, compacts, and cracks. The porosity of the soil on both the treated and control plot was ranges between in 46.53-56.72% with an average value of 52.19% in the studied micro watershed. Lal (2004) also pointed out that a normal range for soil porosity in relation to plant growth is 0.3-0.7 (30-70%) fraction (Appendix 16). Sandy surface soils show a range of 35-50%, whereas medium to fine-textured soils vary from 40 to 60% even more in cases of high organic matter and marked granulation (Brady and Weil, 2002).

4.1.3. Moisture content (MC)

A result of level stone and soil bund effect on soil moisture content was presented in Table 2. The moisture content of soil in the study area was significantly different between SWC measures position within terraces and interaction effect of the two factors with a P value of $\leq$ 0.05 (Appendix 3).

On average significantly highest ***soil moisture content*** of 36.61% was recorded on the level soil bund and the lowest 27.53% value on the level stone bund. The moisture content of soil was not significantly different between LSB and control plots, however, this was significantly different on the level stone bund from the level soil bund and control plots ($P \leq 0.05$). With respect to position within terraces, the highest (37.23%) soil moisture content was recorded on the middle position of terrace while the lowest soil moisture content of 30.53% was recorded on the upper position of terraces. There was a significant difference observed on the middle position from the upper and lower position at ($P \leq 0.05$).

Considering interaction effect of conservation measures by position within terraces, the highest 43.98% value of soil moisture content was recorded at the upper position of the level soil bund and the lowest (24.40%) interaction mean value of soil MC was recorded on the lower position of the level stone bund (Table 2). With the exceptions of middle and lower positions of the level soil bund and all position of the level stone bunds, which were statistically not significant difference, the mean soil moisture content of the remaining treatment combinations were significantly different ($P \leq 0.05$) from each other due to the interaction effects.

The higher moisture content on the level soil bund may be due to the highest clay fraction (Table 1). Clay fraction has large surface areas that enable it to store ample amount of water. The highest moisture content on the control plot may be due to the highest silt fraction (Table 1). According to Brady and Weil (2002) during expansion and contraction on wetting and drying usually are great and the water-holding capacity of clayey and silt soils generally are high. The low moisture content on the level stone bund may be due to the higher sand fraction as a result of soil erosion impacts in the past. The other reason could be due to the filtration characteristics the level stone bund, which might allow the flow of runoff through the wall. According to Lakew et al. (2005) the stone bund increase the moisture retention capacity of the soil profile and water availability to plants, they are also semi-permeable structures unless sealed with soil in their upper side. Similar with Imke W.F. Erven (2017), no significant difference was observed between level soil bund and control plots. In contrast to this finding. In contrast Belay (2016) have found significantly higher soil moisture (%) on treated plots with stone faced soil bund with 33.5% than the non-treated plots with mean value of 25.6%. The highest interaction mean value of soil moisture content on the upper position of the level soil bund may be due to the lateral flow of water from up slope areas during runoff distribution. The moisture content of soil in the study area was ranges from 24.63-43.98% with an average value of 33.06%.

4.1.4. Infiltration characteristics of the soil

Results of level stone bund and soil bund effect on soil infiltration rate were presented in (Table 3-5 and Figure 8-13). Initially, the water infiltrates rapidly and as more water replaces the air in the pores, the water from the soil surfaces infiltrates more slowly and finally reaches basic infiltration rate. The basic infiltration rate found in this experiment were 13.17 mm/hr^{-1}, 5 mm/hr^{-1} and 9.78mm/hr^{-1} on the level stone bund, level soil bund and control plots respectively (Table 3). This means that a water of 13.17 mm, 5 mm and 9.78 mm on soil surface will take one hour to infiltrate.

Table 3: Comparison of observed infiltration data with infiltration models: stone bund plot

Cum. time	Observed data		Predicted by L-K model With k = 30.22 a = 0.7358 Cumul. $= kt^{a}$ Rate= $akt^{(a-1)}$		Predicted by Horton's model Cumul= $i_f t + \frac{ia-if}{k}(1 - e^{-kt})$ Rate= $i_f + (ia - if)e^{-kt}$	
Min	Cumulative infiltration. depth (mm)	Infiltration rate (mm/hr.)	Cumulative infiltration. depth (mm)	Infiltration rate (mm/hr)	Cumulative infiltration. depth (mm)	Infiltration rate (mm/hr.)
0.16	7.63	45.71	8.09	36.07	25.80	69.59
0.33	13.47	34.93	13.36	29.79	32.66	48.198
0.50	18.97	32.93	18.14	26.69	37.30	34.45
0.66	23.3	25.95	22.26	24.70	40.10	26.28
0.83	26.97	21.96	26.35	23.32	41.82	21.21
1.00	31.47	26.95	30.22	22.23	42.91	18.11
1.16	35.27	22.75	33.70	21.37	43.55	16.23
1.33	38.4	18.76	37.27	20.61	43.94	15.08
1.50	41.23	16.97	40.72	19.97	44.20	14.34
1.66	43.67	14.57	43.88	19.44	44.34	13.89
1.83	45.87	13.17	47.14	18.94	44.44	13.63
2.00	48.07	13.17	50.32	18.51	44.49	13.46
			$R^2 = 0.99$	$R^2 = 0.82$	$R^2 = 0.70$	$R^2 = 0.69$

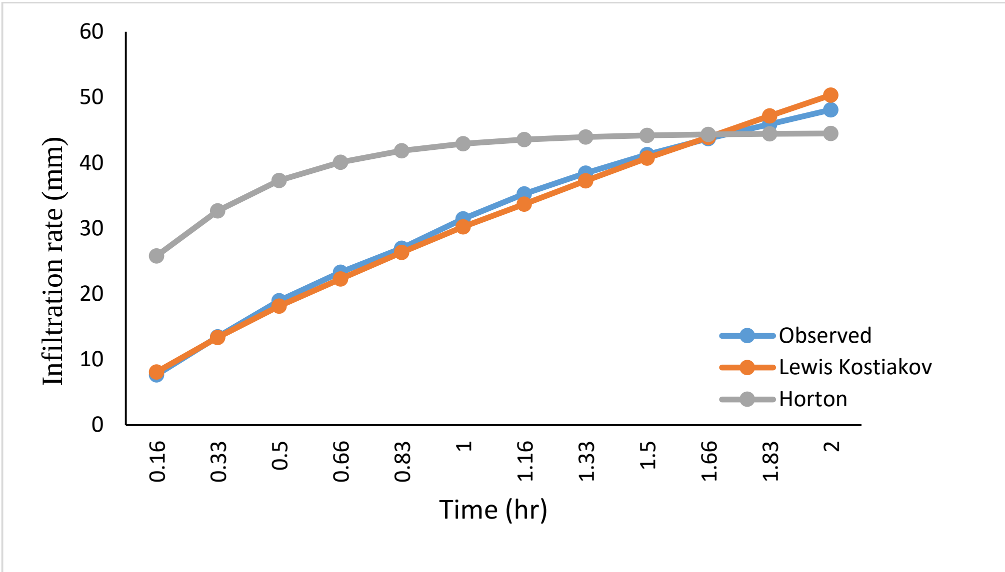

Figure 8: Infiltration depth on the stone bund plot

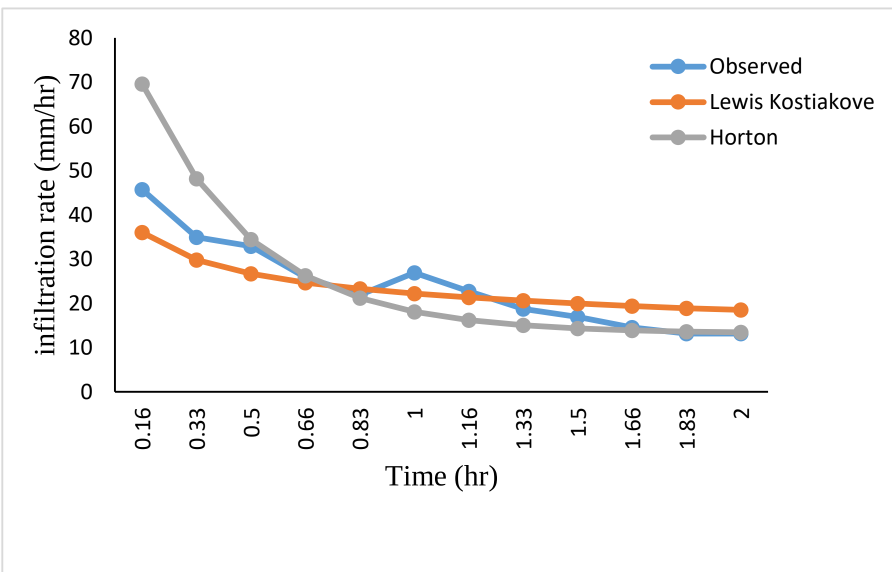

Figure 9: Infiltration rate on the stone bund plot

Table 4: Comparison of observed infiltration data with infiltration models: control plot

Cum. time	Observed data		Predicted by L-K model With k = 26.43 a = 0.666 Cumul. $= kt^{a}$ Rate= $akt^{(a-1)}$		Predicted by Horton's model Cumul= $i_f t + \frac{ia-if}{k}(1 - e^{-kt}$ Rate= $i_f + (ia - if)e^{-kt}$	
min	Cumulative infiltration. depth (mm)	Infiltration rate (mm/hr.)	Cumulative infiltration. depth (mm)	Infiltration rate (mm/hr)	Cumulative infiltration. depth (mm)	Infiltration rate (mm/hr.)
0.16	8.00	47.90	8.02	31.98	18.66	52.89
0.33	12.50	26.95	12.63	25.47	24.45	38.74
0.50	16.37	23.15	14.01	22.17	28.48	28.91
0.66	19.67	19.76	16.85	20.20	31.01	22.61
0.83	24.67	29.94	19.63	18.71	32.79	18.38
1.00	27.93	19.56	26.43	17.59	34.00	15.43
1.16	30.60	15.97	29.17	16.73	34.74	13.62
1.33	32.87	13.57	31.95	15.99	35.27	12.33
1.50	34.83	11.78	34.62	15.36	35.62	11.46
1.66	36.63	10.78	37.04	14.85	35.84	10.92
1.83	38.27	9.78	39.52	14.37	36.00	10.54
2.00	39.90	9.78	41.93	13.95	36.10	10.29
			$R^2 = 0.98$	$R^2 = 0.81$	$R^2 = 0.75$	$R^2 = 0.75$

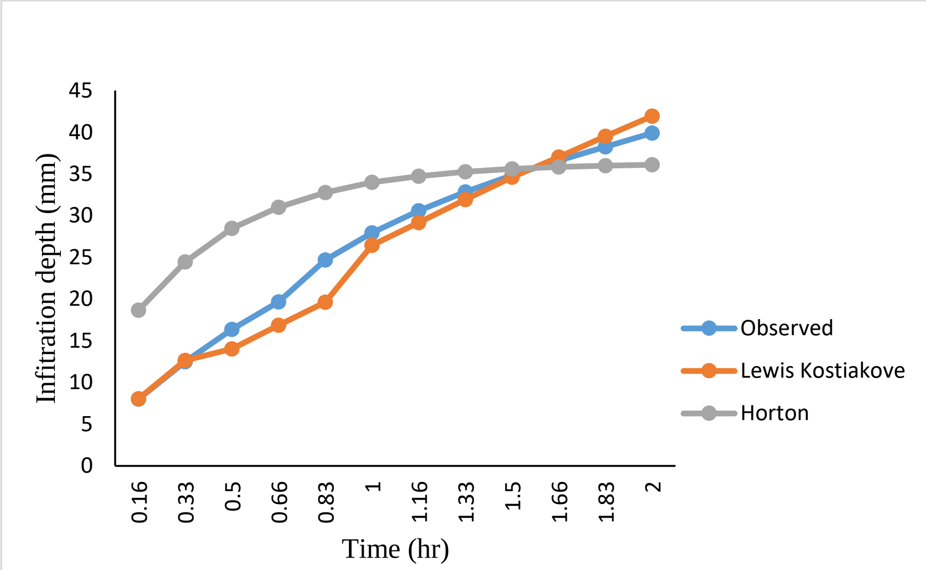

Figure 10: Infiltration depth on the control (un-conserved plot)

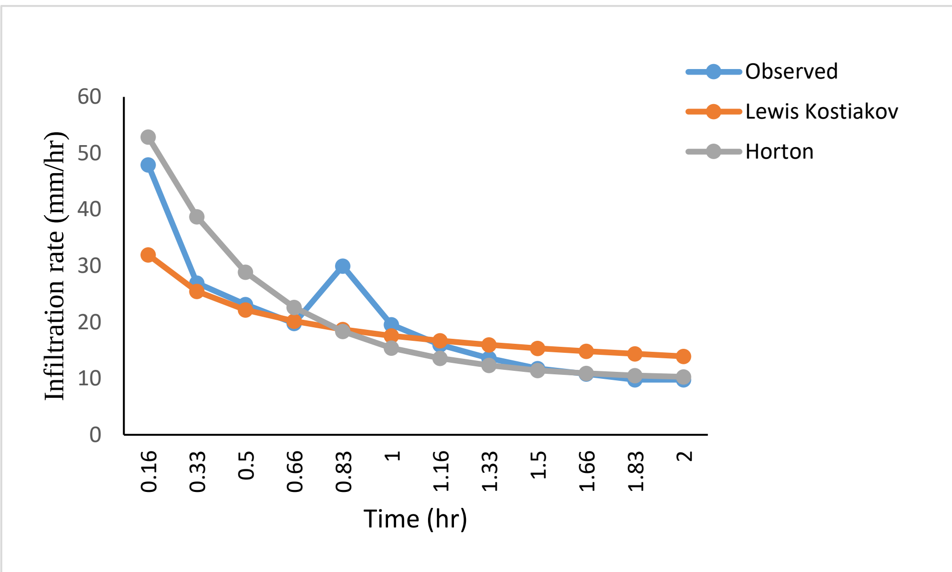

Figure 11: Infiltration rate on the control (un-conserved plot)

Table 5: Comparison of observed infiltration data with infiltration models: soil bund plot

Cum. time	Observed data		Predicted by L-K model With k = 27.368, a = 0.6108, Cumul. $= kt^{a}$, Rate= $akt^{(a-1)}$		Predicted by Horton's model Cumul= $i_f t + \frac{ia-if}{k}(1-e^{-kt})$, Rate= = $i_f + (ia-if)e^{-kt}$	
min	Cumulative infiltration. depth (mm)	Infiltration rate (mm/hr.)	Cumulative infiltration. depth (mm)	Infiltration rate (mm/hr)	Cumulative infiltration. depth (mm)	Infiltration rate (mm/hr.)
0.16	8.00	51.90	9.17	32.96	14.70	54.22
0.33	12.50	31.94	13.90	25.46	21.48	40.94
0.50	16.37	23.95	17.92	21.88	26.75	30.65
0.66	19.67	19.96	21.23	19.58	30.18	23.95
0.83	24.67	28.94	24.42	17.93	32.98	18.48
1.00	27.93	20.96	27.36	16.71	34.94	14.65
1.16	30.60	13.77	29.96	15.79	36.24	12.40
1.33	32.87	11.18	32.57	14.95	37.26	10.11
1.50	34.83	8.38	35.05	14.32	38.02	8.63
1.66	36.30	5.99	37.29	13.78	38.51	7.66
1.83	38.27	4.99	39.58	13.28	38.90	6.91
2.00	39.90	4.99	41.79	12.84	39.17	6.37
			$R^2 = 0.98$	$R^2 = 0.79$	$R^2 = 0.82$	$R^2 = 0.82$

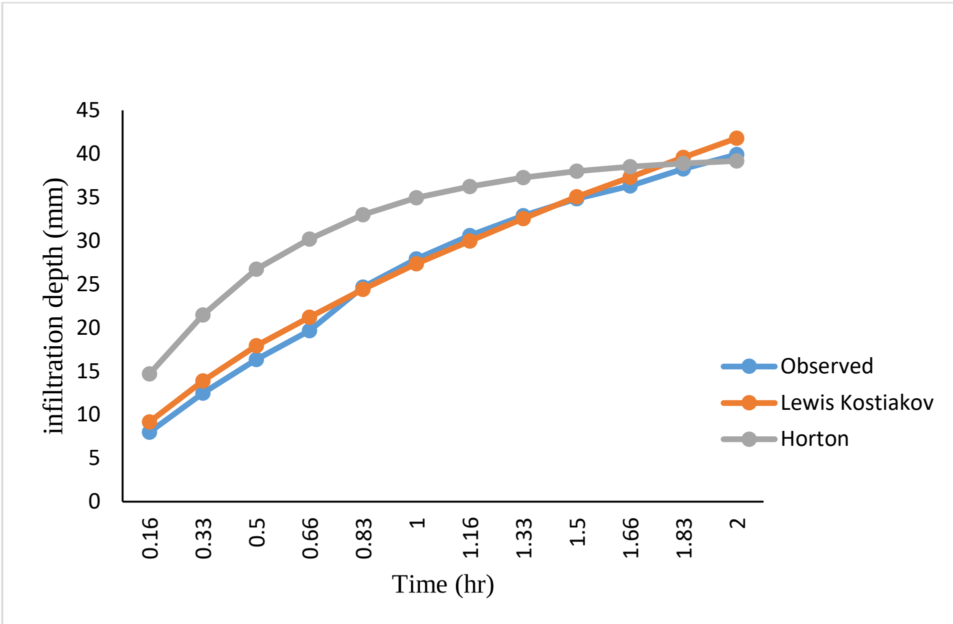

Figure 12: Infiltration depth on the soil bund plot

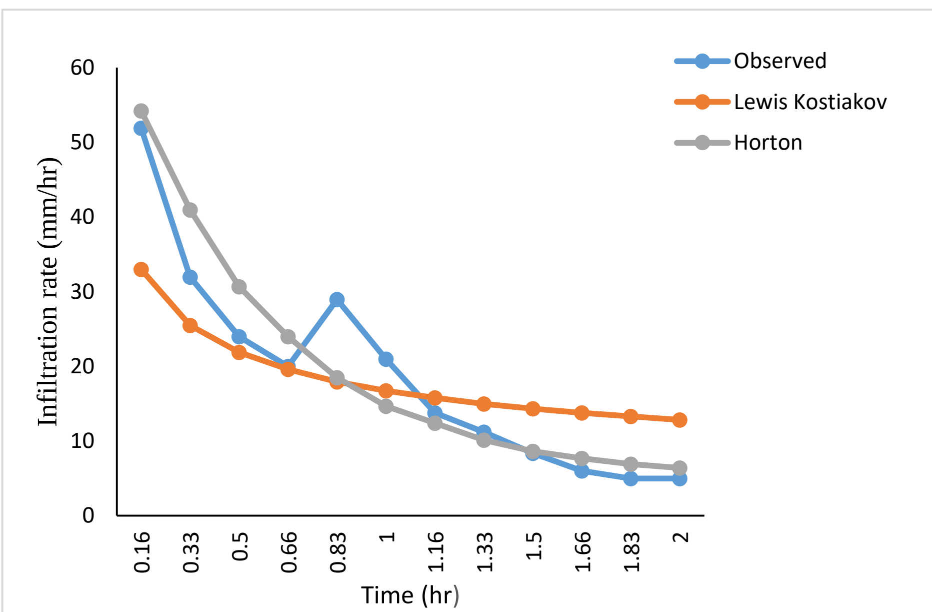

Figure 13: Infiltration rate on the soil bund plot

Statistical indicators showed that there is good relationship between the fields observed infiltration data and simulated data with soil infiltration model (Lewis-kostiakov and Horton's models). Among the two models L-K model gave the better representation of the infiltration rate with observed data with coefficient of determination 0.82 and 0.81 on the level stone bund and control plots respectively. For the level stone bund Hortons gave better representation of infiltration rate with observed data with coefficient of determination 0.82 than stone bund and control (un-conserved plot). At the start of the process, infiltration rates by the Lewis Kostiakov models were greater than the observed, while the infiltration rate by the Hortons were smaller than the observed in all the three plots. As we have seen in (Table 3-5 and Figure 8-13) the final cumulative infiltration depth by Horton model was smaller than the observed data. In this model reduction in infiltration with time was largely controlled by factors operating at the soil surface. The basic infiltration rate by L-K model was greater than the observed data.

From the observed data, the highest basic infiltration rate was found on the level stone bund soil with sandy clay loam fraction (Table 3-5 and Figure 8-13). The medium basic infiltration rate was found under the control plots soil with clay loam textural classes (Table 3-5 and Figure 8-13). The lowest basic infiltration rate was found under the level soil bund soil with clay textural classes (Table 3-5 and Figure 8-13). Infiltration rates measured showed that of the three treatment, LSB suppressed infiltration; the control plot showed medium improvement while LSTB had the highest value. Hence, soils with a larger pore size have a highest infiltration rate in the studied watershed like stone bund with higher sand fractions. Sandy soil is characterized with macro pores which enable the water to pass quickly through the soil layer. Hence, soils with a larger pore size have a highest infiltration rate in. In a sandy soil, in spite of the relatively low total porosity, the movement of air and water is surprisingly rapid because of the dominance of the macro spaces (Brady and Weil, 2002). The other reason could be due to the low moisture content of the soil as a result of past soil erosion impacts in the area.

The medium basic soil infiltration rate on the control plots could be due to the higher average value of clay compared with LSTB and presence of higher silt fraction with intermediate value of sand fractions compared to soil bund (Table 1).The textural class was clay loam. According to Amooh & Bonsu (2015) loamy soil has both sand and clay and so have macro pores and micro pores giving a more balanced supply of both air and water (i.e. in the macro pores and micro pores respectively).

The difference in basic infiltration rate was due to the texture of soil (Appendix 2). The lowest soil IR on the level soil bund could be due to the high clay fraction; these soils have a larger interconnected pore space with swell and shrinking effect while the higher infiltration rate on the level stone bund may be due to higher sand fraction in all positions. This was attributed to the inherent soil properties which are easily influenced and changed over time. This finding was in line with the finding of Lal & Shukla (2004) in that increase in clay content increases surface area, swell-shrink capacity, absorption, water retention, plasticity, adhesion, and total porosity, in-contrast however, increase in clay content decreases water infiltration rate and soil bulk density. As soils become wet, infiltration rate slows to a steady rate based on how fast water can move through the most restrictive layer, such as a compacted layer, or a layer of dense clay (Center, 2017). The presence of a few macro pores, large pores (>2 mm diameter), or cracks as in a drying clay, can considerably influence the flow of surface applied water into and through soil (FAO, 1999). Similar results were reported by different researchers Mulugeta and karl (2010); Yihenewet al. (2009) were reported in that the SOM content and percent clay soil separates seemed to play a role for the variation of infiltration rates, organic matter was positively correlated with the infiltration rate while clay percentage was negatively correlated.

Based on FAO soil infiltration rate group, the basic infiltration rate of the soil in the study area was categorized under lowest infiltration rate (Appendix 13). This could be due to high soil bulk density (Appendix 2). The low infiltration rates could leads to runoff effects in the study area. Soil with low soil organic matter content may enhances soil erosions by affecting the aggregates of soil structure thereby reducing infiltration of water into the soil. This finding was supported by Haghnazari et al. (2015) in that infiltration rates of soil can be restricted by poor management during this condition the water does not readily enter the soil and it moves downslope as runoff or ponds on the surface, where it evaporates and less water is stored in the soil for plant growth, further decrease the infiltration rate. Repeated tillage in the cultivated land and the low soil organic matter could lead to low aggregate stability, both of which consequently increase the detachment of soil particles and transport by generated runoff (Dessalegn et al., 2017).

Therefore, sustaining enhanced water infiltration ability into the soil of terraced and non-terraced cultivated land of the study area is considered as a precautionary way for improving the soil fertility by enhancing soil moisture level and protection against downstream river floods. Water infiltration is actually one of the preservative means of soils, especially against erosion induced by surface runoff and improvement of the soil properties. Gebeyehu et al. (2015) have reported in their finding on the evaluation of the effectiveness of stone bunds and trenches in reducing runoff and soil loss in the semi-arid Ethiopian highlands indicated that all SWC structures are more effective in reducing soil loss than runoff.

4.2. Effect of Level Stone and Soil Bund on Soil Chemical Properties

4.2.1. Soil pH (H_2O)

Table 6, presents about the results of level stone bund and soil bund effect on soil pH. Soil pH did not show any significant differences ($P \leq 0.05$) between SWC measures, position within terraces and interaction effect of the two factors (Appendix 4). Even though the pH of soil was not significantly different, the maximum mean of soil pH 5.55 was found on the control plots compared to 5.35 values on the level soil bund (Table 6). With respect to position the pH of soil decreased from upper to lower positions within terraces (Table 6). The highest was being obtained from the upper terraces position and the lowest from the lower position within terraces.

Table 6: Soil chemical properties Available phosphorous (AP), soil pH (H_2O) and Zinc (Zn) in relation to type of conservation measures across position within terraces of topsoil (0–15 cm) depth.

Soil properties	Position on terraces	Level stone bund (LSTB)	Level soil bund (LSB)	Control	Mean
pH (H_2O)	Upper	5.64±0.62	5.33±0.14		5.47^{a}
	Middle	5.39±0.42	5.33±0.06		5.37^{a}
	Lower	5.39±0.17	5.36±0.02		5.34^{a}
	Mean	5.47^{a}	5.34^{a}	5.57^{a}	
AP (ppm)	Upper	7.15±1.52	7.07±1.68		6.70^{a}
	Middle	7.38±2.30	7.46±1.33		6.89^{a}
	Lower	7.94±1.23	6.09±1.43		6.43^{a}
	Mean	7.49^{a}	6.87^{ab}	5.66^{b}	
Zn (ppm)	Upper	0.52±0.05	0.58±0.16		0.61^{a}
	Middle	0.61±0.06	0.58±0.09		0.59^{a}
	Lower	0.72±0.26	0.55±0.04		0.73^{a}
	Mean	0.62^{ab}	0.57^{b}	0.74^{a}	

Means within a column and rows followed by the same letter are not significantly different from each other at $P \leq 0.05$

The low mean soil pH at the treated plot compared to control plot may be due to the past erosion impacts in the watershed before implementation of the SWC measures and after construction of the structures, due to absence of bund stabilized with biological measures the change was not brought yet. Absence of biological measures like grasses on the bunds may be the causes for low pH because, grasses are able to uptake the nutrients through their roots thereby optimizes the soil pH level. This result confirms with Kebede et al. (2011) who observed low soil pH in LSB aged 4 year, in stone bund aged 6 year and stone bund aged 8 year compared to the respective adjacent non-terraced cropland. These were probably due to loss of relatively more basic cation resulted from erosion before the structures built and did not restore yet after the structures. Similarly, Abay et al. (2016) reported the highest soil pH on the non-conserved farmland than 6 year graded stone bund. The non-significance difference between positions within terrace was in line with the finding of Shimeles (2012), Amare et al. 2013, Bob (1997) and Vancampenhout et al. (2006). The pH of soil was decreased from upper to lower positions (upper >middle > lower), in contrast Bobe (1997) and Amare et al. (2013) have founds an increasing trend down the terraces.

The pH of the soils sampled from the treated and untreated plots and positions within terraces was low and varied from 5.35 to 5.5 with an average value of 5.46. The low soil pH could be due to continuous cultivation coupled with heavy rainfall and steep slope. Supported with this view Yihenew et al. (2015) reported that, continuous cultivation practices, excessive precipitation, steepness of the topography and application of inorganic fertilizer could have attributed as some of the factors which are responsible for the reduction of pH in the soil. Similarly, Shimeles (2012) observed the higher acidity on the 8-30% slopes than on the 3-8% slopes due to topographic influences and leaching of exchangeable bases down the soil profile through runoff. Low productive soils and sites were associated with low pH and corresponding low levels of exchangeable bases and organic matter (Mulugeta and Karl 2010). Soil with these ranges of pH could reduce the nutrients availability to the crops. Soil pH <5.5 is deficient in Ca^{2+} and Mg^{2+} and should be limed, poor root growth due to low CEC and possible Al^{3+} toxicity (Soil Survey Staff, 2014). Combining soil bunds with biological measures enhanced the efficiency of soil bund (Amare et al., 2014).

4.2.2. Available phosphorous (AP) and zinc (Zn)

Results of the effect of LSTB and LSB on soil available phosphorous and zinc were presented in Table 6. AP and Zn has a significant difference with a P value of ≤0.05 between SWC measures, but did not show any significant differences between position within terraces and interaction effect of the two factors (Appendix 4).

With respect to SWC measures, the LSTB was recorded of the highest ***available phosphorous (AP)*** contents of 7.49 ppm followed by the LSB with 6.87ppm. On the other hand the control plots recorded 5.66 ppm of the lowest values (Table 6). No significant difference was observed between level soil bund and control plots.

Even though there was non-significant difference between position within terraces, the middle position of terraces was recorded the highest AP than upper and middle position. This finding was in line with the result of Vancampenhout et al. (2006) who founds the high amount of available phosphorous in the middle positions. In all positions LSTB recorded the high amount of AP than LSB (Table 6). The higher AP content in the deposited zone of the LSTB may be due to deposition of nutrients from upper positions by runoff.

The high amount of available phosphorous in the treated plot could be due to the high amount of soil OM content influenced by the presence of structures (Table 6). This could be due to relatively higher biomass production and in turn produces higher soil organic matter which is the store of P influenced by the presence of structures. The result was in agreement with several researchers Worku (2017); Worku et al. (2012); Dejene (2017) and Mathewos et al. (2016) in that the mean value of AP in soil under conserved land was relatively higher than the non-conserved lands; this could probably be due to higher organic matter content in the conserved plots than in the non-conserved ones. The low value AP content on the control plots may be due to the extractive harvest, during extraction the AP on the plants and soil could be washed by soil erosion. In contrast Kebede et al. (2011) found high AP in non-terraced croplands adjacent to LSB aged 4 year; stone bunds aged 6 year and stone bunds aged 8 year.

Based on Morgan test method the available phosphorous content of soil in the study area was medium (i.e. from 11-20lb/acre or 5.5-7.5ppm) (Appendix 8). The medium range was due to the management practices by the land users and residual effects of crops in the past. The other reason could be due to the relatively high amount of sand percent in the study area, which enhances aeration which is crucial for micro-organisms living in the soil to breakdown organic matter. The normal phosphate absorption by plants would be expected so long as the pH was not too low, the removal of phosphorus from soils by crops, is low compared to that of nitrogen and potassium, often being only one third or one fourth that of the latter elements (Brady and Weil, 2002).

With respect to SWC measures, the control plots was recorded 0.74 ppm of a higher **zinc value** and relatively low value of 0.57 ppm from the level soil bund. However, both treated plots (level stone bund and level soil bund) were recorded low values zinc compared with control plots (Table 6). There was no significant difference observed between LSTB and LSB at $P \leq 0.05$.

The low ***zinc (Zn)*** content on the treated farmland could be due to the crop harvest and sheet and rill erosions that were aggravated by continuous cultivation with very low input of farming system. Generally the zinc content of soil in the studied micro watershed was low which is <0.9 ppm (Appendix 8). Most soil zincs are available in acid soils (Brady and Weil, 2002). The pH was found to be strongly acidic, the availability of zinc in both conserved and control land was low. The low zinc content of soil could affect the growth of plants. Zn deficiency results in severe yield losses and in acute cases plant death (Salgueiro et al., 2000). Noulas (2018) observed yield of several important food crops (beans, citrus, fruit trees, grapes, maize, onions, pecan nuts, rice, sorghum, sweet corn etc. as well as the quality of the crop product may be decreased under Zn deficiency conditions. The micronutrient like soil zinc was all harmful when the available forms are present in the soil in larger amounts than can be tolerated by plants (Brady and Weil, 2002).

4.2.3. Electrical conductivity (EC), soil organic carbon (SOC), soil organic matter (SOM) and total nitrogen (TN)

Results of the effect of LSTB and LSB on soil electrical conductivity, organic carbon, organic matter and total nitrogen were presented in (Table 7). There was significant difference ($P \leq 0.05$) observed between SWC measures, positions within terraces and interaction effect of the two factors (Appendix 4).

With respect to SWC measures, the surface soil of the control plot was recorded 0.093 ds/m of higher soil ***electrical conductivity (EC)*** value than that of low values of 0.068 ds/m on the LSB (Table 7). There was no significant difference observed between LSTB and LSB, but this was significantly different on the control plot from LSTB and LSB ($P \leq 0.05$). With respect to position within terraces, the electrical conductivity of the soil was significantly different on the upper position from the middle and the lower position of both LSTB and LSBs ($P \leq 0.05$) (Table 7).

Considering the interaction effect of conservation measures by position within terraces, the highest 0.1ds/m and the lowest 0.046 ds/m interaction mean value of soil electrical conductivity was observed in the lower and upper position of the level stone bund (Table 7). With the exceptions of all positions of the level soil bund and the middle and lower position of the level stone bunds, which were statistically not significant difference, the mean bulk density of the remaining treatment combinations were significantly different ($P \leq 0.05$) from each other due to the interaction effects.

Table 7: Soil chemical properties such as electrical conductivity (EC), soil organic carbon (SOC), soil organic matter (SOM) and total nitrogen (TN) in relation to type of conservation measures across position within terraces of topsoil (0–15 cm) depth

Soil properties	Position on terraces	Level stone bund (LSTB)	Level soil bund (LSB)	Control	Mean
EC (ds/m) at $25^{0}C$	Upper	$0.046^{c} \pm 0.01$	$0.06^{bc} \pm 0.03$		0.07^{b}
	Middle	$0.09^{a} \pm 0.01$	$0.08^{ba} \pm 0.02$		0.09^{a}
	Lower	$0.1^{a} \pm 0.03$	$0.063^{bc} \pm 0.02$		0.08^{a}
	Mean	0.078^{b}	0.06^{b}	0.09^{a}	
SOC (%)	Upper	$1.20^{a} \pm 0.14$	$1.14^{a} \pm 0.16$		1.03^{b}
	Middle	$1.28^{a} \pm 0.31$	$1.30^{a} \pm 0.08$		1.30^{a}
	Lower	$1.37^{a} \pm 0.06$	$1.23^{a} \pm 0.22$		1.12^{b}
	Mean	1.28^{a}	1.22^{a}	0.94^{b}	
SOM (%)	Upper	$2.07^{ba} \pm 0.24$	$1.95^{b} \pm 0.26$		1.76^{b}
	Middle	$2.21^{ba} \pm 0.53$	$2.23^{ba} \pm 0.15$		2.24^{a}
	Lower	$2.36^{a} \pm 0.11$	$2.12^{ba} \pm 0.36$		1.94^{b}
	Mean	2.21^{a}	2.10^{a}	1.62^{b}	
TN (%)	Upper	$0.17^{ba} \pm 0.02$	$0.17^{b} \pm 0.20$		0.15^{b}
	Middle	$0.18^{ba} \pm 0.03$	$0.18^{ab} \pm 0.01$		0.18^{a}
	Lower	$0.20^{a} \pm 0.02$	$0.18^{ab} \pm 0.02$		0.17^{ab}
	Mean	0.19^{a}	0.17^{a}	0.14^{b}	

Means within a row followed by the same letter are not significantly different from each other at $P \leq 0.05$

The higher electrical conductivity (EC) on the control plot could be due to the higher exchangeable calcium content relative to the treated plot (Table 4). This result was supported with Seifi et al. (2010) find in that the increasing concentration of electrolytes (salts) in soil water will dramatically increase soil electrical conductivity. In contrast to this result of Mulugeta and Karl (2010); Worku et al. (2012) and Worku (2017) reported that EC did not show significant variation (P>0.05) between treated and control farm land. A higher EC were recorded on the conserved land (Mathewos et al., 2016). The low EC value on the upper position of bunds could be due to low SOM contents (Table 7).

The high levels of precipitation can flush soluble salts out of the soil and reduce the soil electrical conductivity. This clearly shows that in the study area, soil electrical conductivity does not have effect on the draining ability of the soil. However, the soil was grouped under the low range of EC or non-saline i.e. it has low nutrient or fertility level. Therefore, treated plots with (level stone and soil bund) structures and untreated plot requires amendment of the soil with organic matter to bring an appropriate salt level for crops. Classification of saline soils and the assessment of the negative effects of salinity on crops are based on the electrical conductivity (EC) of the saturation extract of the soil (Delgado & Gómez, 2016). According to Schoeneberger et al. (2012) the ranges of EC in the studied micro watershed was none saline (Appendix 10). On the basis of a saturation extract, values of 0 to 2 dS/m are safe for all crops; yields of very sensitive crops are affected between 2 to 4 dS/m; many crops are affected 2between 4 and 8 dS/m; while only tolerant crops grow reasonably well above that level (Estefan, et al., 2013).

With respect to SWC measures, the LSTB was recorded 1.28% of the highest ***soil organic carbon (SOC)*** content followed by LSB with 1.22% whiles, the lowest organic carbon content of 0.94% was recorded on the control plots (Table 7). There was no significant difference ($P \leq 0.05$) observed between LSTB and LSB structure (Table 7). With respect to position within terraces, there was a significant difference observed on the middle position from the upper and lower position at ($P \leq 0.05$). The middle position was recorded 1.30% of higher soil organic carbon content than upper and lower positions within terraces. There was no significant difference observed between upper and lower positions within terraces ($P \leq 0.05$).

Considering the interaction effect of conservation measures by position within terraces, the highest 1.37% value of soil organic carbon was recorded at the lower position of the level stone bund followed by 1.30% in the middle position of the level soil bund (Table 7). On the other hand, the lowest 1.14% interaction mean value of SOC was observed in the upper position of the level soil bund. However, the mean soil organic carbon of the treatment combinations were not significantly different at ($P \leq 0.05$) from each other due to the interaction effects.

The low value of soil organic carbon content under the control plots could be due to the absence of soil conservation structures that trap and retaining sediment and water to enhancing the soil organic carbon input. This result agrees with the finding of Worku et al. (2012) in that soil organic carbon content in soils under the control farm was significantly lower than in the cultivated land under 5 and 10 years of aged fanya juu structures. Similarly, Dejene (2017) found higher soil organic carbon content on the stone bund compared to the corresponding non-terraced farmland. Without soil conservation structures, the fate of accumulated nutrients is to be washed away from the farm and transported to other ecosystems; mostly to water bodies which is another cost for the nation (Amare et al., 2013).

The highest soil organic carbon content on the middle position of terraces might be due to the management practices by the land users in the area. In contrast Amare et al. (2013); Shimeles (2012); Bobe (1997); and Vancoumphanhunt et al. (2006) have found higher SOC content in the lower position than in the upper because soil nutrients transported from the upper parts of the terrace are trapped by the conservation structures at the lower sides of the terraces and maintained there. The low amount of soil organic carbon content on the upper position of LSTB and LSB were due to the truncation of sediment by runoff from up slope takes its way to remove the top most soil, because, the gradients between terraces was steep and narrow.

According to Landon (1991) ratings of organic carbon in all treatments was very low (Appendix 7). The low amount of organic carbon in the studied area was due to poor management of soil such as intensive cultivation practices and by using crop residues for fuel consumption. Cultivation and tillage can reduce soil SOC content and lead to soil deterioration (Liu et al., 2006). The inputs like leaving the soil with cover crops and residues decompose and enhancing the soil carbon input. Soil compatibility, friability and soil erodibility were favorably improved by increasing the levels of soil organic carbon (Murphy, 2015). The large effect of management, possible fertility losses in the erosion zone can be compensated by adapted soil management and therefore pose no long term threat on stone bund sustainability (Vancoumphanhunt et al., 2006).

With respect to SWC measures, the LSTB was recorded the highest ***soil organic matter (SOM)*** content of 2.217% followed by LSB with 2.10% while the lowest SOM of 1.63% was found on the control plots. No significant difference was observed between LSTB and LSB ($P \leq 0.05$) (Table 7). With respect to position within terraces, the middle position was significantly different from upper and lower position at ($P \leq 0.05$). Similar to SOC content the higher SOM content was recorded on the middle position of terraces.

Considering interaction effect of conservation measures by position within terraces, the highest 2.36% value of soil organic carbon was recorded at the lower position of the level stone bund followed by 2.23% in the middle position of the level soil bund (Table 7). On the other hand, the lowest 2.07% and 1.95% interaction mean value of SOM was observed in the upper position of the level stone bund and soil bund respectively. With the exceptions of all positions of the level soil bund and level stone bund, which were statistically not significant difference, the mean soil OM of the remaining treatment combination was significantly different ($P \leq 0.05$) from each other due to the interaction effects. The highest SOM contents on the lower position of the LSTB could be due to the deposition of nutrients from upper position. The lowest interaction mean values on the upper position of the LSB could be due to truncation of sediments by runoff.

The high SOM contents on the treated plots could be due to the high amount of soil organic carbon input of the structures (Table 4), which could be attributed to the erosion reduction effects of soil and water conservation measures implemented and biomass accumulation. This result was line with the findings of Abay et al. (2016) in that he found the higher SOM content in plots with 6 year graded stone bunds than non-conserved farm plots. This could probably be attributed to accumulated and retained organic matter due to bund construction. With respect to position, the high amount of SOM contents on the middle position of both LSTB and LSB could be due to the higher SOC contents. The low SOM contents on the upper positions of both level stone bund and soil bund could be due to the truncation of nutrient by runoff from upper position to lower/deposited zone. In contrast Million (2003) has observed relatively higher OM and TN contents at the upper slope position (i.e. below bund sampling plots) of the inter-terrace area.

In the study area the level of SOM content in the soil was very low according to London (1991) rating. This may be due to the steep slope of land in the study area, nutrients might be easily be washed down the slope by soil erosion as a result of lack of bund stabilizing with biological measures. Previously the area which was covered with the structures has severe erosion events. Therefore soil management by using compost along with bund stabilization with grasses should give a pare amount importance to improve the SOM content to enhancing the soil microbial activities on both treated and untreated plots to improve the SOM contents. Loss of organic matter appeared to be a linear function of erosion (Stalling, 1957). The addition of organic materials to the soil must equal the loss due to decomposition for the sustainability of the system to be maintained (Evanylo & McGuinn, 2000). Microbial activity is greatly increased by incorporating fresh organic residues such as green manure or crop residues, which can be readily mineralized by microbes (Deldago and Gomez, 2016).

With respect SWC measures, the LSTB was recorded the highest ***total nitrogen (TN)*** content of 0.19% followed by LSB with 0.18% while, the lowest TN content of 0.15% was recorded on the control plots (Table 7). There was no significant difference observed between LSTB and LSB, the control plots was significantly different from the treated plots at ($P \leq 0.05$). With respect to position within terraces, the middle position was significantly different from upper and lower position at ($P \leq 0.05$). Similar to SOC and SOM content the higher TN content was recorded on the middle position of terraces.

Considering the interaction effect of conservation measures by position within terraces, the highest 0.20% interaction mean value of total nitrogen was observed in the lower position of the level stone bund. On the other hand the lowest interaction mean 0.17% was recorded on the upper position of the level stone bund and soil bund respectively. With the exceptions of all positions of the level soil bund and level stone bund, which were statistically not significant difference, the mean soil OM of the remaining treatment combination was significantly different ($P \leq 0.05$) from each other due to the interaction effects.

The high amount of soil TN on the treated plots could be due to the high amount of soil organic matter content (Table 7). Mineralization of soil organic matter by which nitrogen in soil organisms, plant material and soil organic matter is converted to mineral (nitrate and ammonium ions) and made available to plants is a major process for the provision of N (Murphy, 2015). This result was also in agreement with the findings of Worku et al. (2012) who reported that lower TN from the control land compared with treated land under fanya juu of 5 and 10 years old. This finding was supported with Million (2003) in that the mean total nitrogen contents of the terraced site with the original slope of 15, 25, and 35% were higher by 26, 34, and 14%, respectively compared to the average total nitrogen contents of their corresponding non-terraced slope. In-contrast Alemayehu (2007) founds relatively higher amount of total nitrogen on the non-terraced plots than on the terraced ones, this could be attributed to manuring or other soil management activities practiced by the respective farmers.

The higher total nitrogen contents on the middle position of both LSTB and LSB could be due to the highest SOM contents. In contrast to, Amare et al. (2013), Alemayehu (2007); Bobe (1997); and Vancampenhout et al. (2006) have reported the higher total nitrogen (%) content at the lower positions of a terrace. The lower TN content on the upper positions of LSTB and LSB could be due to the high mobility the total nitrogen, from the upper slope positions by leaching process as a result low TN was observed on the upper position. Inorganic nitrogen is subject to loss from soils by leaching and volatilization (Brady and Weil, 2002). In contrast Million (2003) has observed relatively higher TN contents at the upper slope position (i.e. below bund sampling plots) of the inter-terrace area. This could be due to fertility management practice undertaken by the respective owners of these sites.

The TN content of soil of treated and control plot was in the low ranges due to low level of SOM contents. Similarly, due to the steepness of the topography coupled with lack of maintenance of bunds and poor management practices along with the structures result in the low level of TN in the soil. According to Landon (1991) nitrogen rating, the soil was classified under lower ranges (Appendix 4). Similarly, Mathewos et al. (2016) reported that the low level of TN on the steep slope could be due to the removal of organic materials from the higher or steep slopes as a result of soil erosion. Nitrogen is the most deficient element in the tropics for crop production (Mesfin, 1998; Yihenew et al., 2009).

2.3.9. Exchangeable bases (K^+, Ca^{2+} and Mg^{2+})

Results of level stone bund and soil bund effect on soil exchangeable potassium, calcium, and magnesium were presented in Table 8. There were a significant difference ($P \leq 0.05$) observed between SWC measures, except exchangeable Ca^{2+} other base cations didn't show significant difference ($P \leq 0.05$) between position within terraces and, interaction effect of the two factors (Appendix 5).

With respect to SWC measures, the LSTB and LSB was recorded a higher mean soil ***exchangeable potassium (K^+)*** contents compared to control plots. The higher mean exchangeable K^+ with 0.19 cmol (+)/kg was found on the level stone bund compared to low amount on the control plots (0.15 cmol (+)/kg (Table 8). The control plots received a low amount of exchangeable K^+ content than level stone bund and soil bund structures. There was no significant difference ($P \leq 0.05$) observed between LSTB and LSB for exchangeable K^+ cations (Table 8).

Table 8: Effects of SWC measures and positions within terraces on soil exchangeable calcium (Ca^{2+}), = exchangeable potassium (K^+) and exchangeable magnesium (Mg^{2+}) from topsoil (0–15 cm) depth.

Soil properties	Position on terraces	Level stone bund (LSTB)	Level soil bund (LSB)	Control	Mean
Ca^{2+}(cmol (+)/kg)	Upper	$0.22^{bc}\pm0.01$	$0.24^{b}\pm0.01$		0.23^{b}
	Middle	$0.21^{cd}\pm0.02$	$0.23^{b}\pm0.01$		0.22^{c}
	Lower	$0.22^{bc}\pm0.01$	$0.22^{bc}\pm0.01$		0.24^{a}
	Mean	0.22^{b}	0.23^{a}	0.24^{a}	
K^+(cmol (+)/kg)	Upper	0.18±0.04	0.18±0.04		0.17^{a}
	Middle	0.18±0.05	0.19±0.03		0.16^{a}
	Lower	0.20±0.03	0.15±0.04		0.16^{a}
	Mean	0.19^{a}	0.18^{ab}	0.14^{b}	
Mg^{2+}(cmol (+)/kg)	Upper	0.73±0.02	0.73±0.01		0.73^{a}
	Middle	0.71±0.04	0.74±0.01		0.72^{a}
	Lower	0.72±0.01	0.73±0.01		0.73^{a}
	Mean	0.70^{a}	0.74^{b}	0.73^{ab}	

Means within a row followed by the same letter are not significantly different from each other at $P \leq 0.05$

The higher soil exchangeable potassium contents on the treated plots could be due to nutrient retention of soil organic matter, the soil Microbial activity increases the secretion of substances that could enhance the production of potassium cations. The low amount of soil exchangeable K^+ on the control plot could be due to soil washing by soil erosion during crop harvesting time due to the absence of structures. This finding was supported by Covert (1999) in that the potassium remaining in plant residues after harvest and in manure is quickly returned to the soil by water leaching through the plant materials and manure. Plants have adapted to respond to the soil conditions and presence of microbes through various mechanisms, one of which is the secretion of root exudates (Rovira, 1969). Shin (2014) also suggested that increasing root exudates, which contain organic acids, would increase exchangeable soluble K^+ in the soil. This result was agreed with the finding of Worku (2017) and in-contrast to Worku et al. (2012).

With respect to SWC measures, the control plots recorded the higher ***exchangeable calcium (Ca^{2+})*** content of 0.24 cmol (+)/kg while, the LSTB was recorded relatively of low 0.22 cmol (+)/kg values. There was no significant difference observed between LSB and control (Table 5), however there was significant difference observed on the LSTB from LSB and control plots at ($P \leq 0.05$). With respect to position within terraces, the higher exchangeable Ca^{2+} was recorded on the lower positions while the lower exchangeable Ca^{2+} was obtained from the middle positions within terraces (Table 8). The higher exchangeable calcium on the lower zones could be due to washing away of cations from the loss zone and accumulations in the deposition zone. Which is similar with the finding of Amar et al. (2013).

Considering interaction effect of conservation measures by position within terraces, the highest 0.24 cmol (+)/kg value of soil exchangeable Ca^{2+} was recorded at the upper and middle position of the level soil bund (Table 8). On the other hand, the lowest 0.21cmol (+)/kg interaction mean value of soil exchangeable calcium was observed in the middle position of the level stone bund. With the exceptions of upper and lower positions of the level stone bund and the lower positions of level soil bunds, which were statistically not significant difference, the mean exchangeable calcium of the remaining treatment combination was significantly different ($P \leq 0.05$) from each other due to the interaction effects.

The low amount of exchangeable calcium on the conserved farmland may be due to high amount of OM on the conserved land that releases H^+ ion in the soil solution that could result in reducing the amount of exchangeable calcium by lowering the pH level. This finding was supported with Brady and Weil (2002) in that the leaching encourages acidity consequently; bases that have been replaced from the colloidal complex or dissolved by percolating acids are removed in the drainage waters.

With respect to SWC measures, the higher mean soil ***exchangeable magnesium*** **(Mg^{2+})** content of 0.74 cmol (+)/kg was found on the level soil bund compared to low values on the level stone bund (0.70 cmol (+)/kg (Table 8). No significant difference was observed between LSB and control plots. Even though there was no any significant interaction effect, the middle position of the LSB received 0.74 cmol (+)/kg of higher exchangeable Mg^{2+} than low value on the middle positions of the LSTB.

The low value of sol exchangeable Mg^{2+} cations on the middle position of the LSTB could be due to the high amount of sand fraction (Table 1). This finding was supported by Senbayram et al. (2016) in that the exchangeable Mg^{2+} losses by leaching might occur in sandy soils with high water conductivity. He also suggested that leaching of exchangeable Mg^{2+} in soils when applied with various water-soluble fertilizers may also vary depending on the fertilizer's chemical composition, granule size, and effect on soil pH and cation balance. Both accumulation and loss zones produced non-significant difference among the mean values of exchangeable K^{+} and exchangeable Mg^{2+}, this trend was similar with Amare et al. (2013); Shimels (2012). The low amount of exchangeable Mg^{2+} was found on the upper position of terraces (Table 8). In-contrast to this Amare et al. (2013) found the highest exchangeable Mg^{2+} values on the loss zone.

The range of soil exchangeable (Ca^{2+}, K^{+} and Mg^{2+}) were very low in the studied micro watershed, according to rating by London (1991) it is weak (Appendix 6). This may be due to the steepness of the topography of the area coupled with heavy rainfall could be resulted in the washing of the soil exchangeable cations and result in low soil pH. The amount of exchangeable bases in the increasing order was $Mg^{2+}>Ca^{2+}>K^{+}$, this was different from other studies (Amare et al., 2013). pH of soil is important soil properties that evaluate the presence and absence of other soil properties. The overall average pH of soil in the study area was strongly acidic, as the pH of soil reduced the presence of exchangeable bases become reduced. Deldago and Gomez (2016) suggested in that at low pH the risks of deficiency of base nutrients (K^{+}, Ca^{2+} and Mg^{2+}) increases due to their low content. Shimels (2012) have reported that the exchangeable base suspensions may not have time to precipitate into the soils of terraces located at the upper-slope positions, and could therefore be washed down the slope. Similarly, Mulugeta and Karl (2010) reported that leaching of bases is the major soil nutrient management problem for the soils of humid tropics.

5. SUMMARY AND CONCLUSIONS

Despite various controversies on the merits and performance of farmland bunds, inadequate empirical evidence exists concerning the role of bunds or terraces on soil fertility. In the study area both governmental and non-governmental organizations have worked to introduce conservation technologies, among this level stone bund and soil bund were widely implemented. However, apart from monitoring and evaluation works no substantive studies made and documented on the performance of bunds on soil properties. The purpose of this study was to analyze the impact of farmland with each with 5 year old age level stone bund and soil bund in maintaining soil fertility and improvement of soil infiltration rate by comparing with untreated plots. Composite soil samples were collected from the surface 0-15 cm depths using "W" sampling design with auger. A total of 21 soil samples were collected for laboratory physical and chemical analysis, 18 from treated plots and 3 from untreated plot along 15-25% slope categories. For analysis of soil bulk density, moisture content and total porosity a total of 21 core samples, 18 from the conserved plots and 3 from the control plots was collected. The infiltration rate of the soil was measured using a double ring infiltrometer in the three treatment with three replicates.

The conservation structures tested in Ubale micro watershed of Arba Minch Zuria Wereda influence significantly ($P \leq 0.05$) the soil physical properties such as soil MC (%), EC (ds/m), SOC (%), SOM (%), TN (%) and exchangeable Ca^{2+} cmol (+)/kg by SWC measures, under different position within terraces and interaction effect of the two factors. Percent clay was significantly different between SWC measures and interaction effect of the two factors. Except soil pH, which was not significantly different, the other parameters were significantly different between SWC measures. Soil texture, BD, TP, MC, Ca^{2+} and Mg^{2+} were significantly different between level stone bund and level soil bund. EC (ds/m), SOC (%), SOM (%) and TN (%) were significantly different on the control plots from the LSTB and LSB while, the BD, TP, MC and Ca^{2+} were significantly different on the level stone bund and control plots. Clay and Zn were significantly between level soil bund and control plots. Level soil bund in all positions recorded significantly higher MC than the level stone bund. MC, SOC, SOM and TN were significantly different on the middle position within terraces from the upper and lower position, TN was significantly different between upper and middle position within terraces.

The level stone bund increased BD (gm/cm^3) and basic infiltration rate and, decreased soil MC (%) and TP (%), while the level soil bund have almost similar BD (gm/cm^3), MC (%) and TP (%) with control plots. The highest SOC (%) (%), SOM (%), TN (%) and K^+ (cmol(+)/kg) were recorded on the treated plots than control plots. On average control plot recorded the higher pH, Ca^{2+} (cmol (+)/kg), Zn (ppm) and EC (ds/m) than treated plots. SOC (%), SOM (%) and TN (%) of the soil was not significantly different between upper and lower positions of terraces. The middle position was recorded a higher value than both upper and lower. In the interaction effect of the two factor the highest OC (%), SOM (%) and TN (%) was recorded on the lower position of the LSTBs.

In overall performance, this suggesting that structural conservation measure (stone bund) with lower position was better in soil physicochemical properties in the study area than the level soil bund and control plots. The result of the study provide clear evidence that level stone bund and soil bund had a positive impact on maintaining the soil fertility and sustaining the productivity of the land, however the improvement were better for some properties. The most important soil properties were smaller on the control plot than conserved one. The range of the soil properties was also below the recommended rang. This may be due to the steepness of the topography of the area with narrow spaces between bunds result in low nutrient deposition due to soil erosions. The other reason could be due to the areas before conservation measures adopted was highly degraded as a result of cultivation of the steep slope. After establishment of bunds within 5 years the expected output from constructing buns was low. This clearly show bund constructed at slope from 15-20% ranges like in the study area requires due attention to enhances the soil quality and to protect downstream industries such as farmland, Kulfo River, Chamo lake ecosystem due to soil erosion. Hence the results require urgent efforts to minimize soil erosion.

Hence, level stone bund and soil bund constructions reduced soil erosion and improved the soil fertility level. Construction of these structures is not enough, it should be stabilized. Conservation measures mulching; liming, cover cropping and stabilizing bund with grasses was recommended to improve soil structure thereby soil infiltration capacity. The slope of the land should be considered during implementations of SWC practices in the area. In order to compensate the low nutrients on the upper position within terraces the farmers should apply the compost. An integrated and comprehensive approach should be taken account into all factors personal and social, economic, institutional and bio-physical in the preparation of soil and water conservation plans and the implementation. Thus, further research need to be conducted on the effectiveness of bunds in relation to functions relevant for biomass and environmental quality.

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7. APPENDICES

Appendix 1: Mean monthly air temperatures and rainfall for the years (2007 to 2016)

Month	Rainfall (mm)	Maximum Temperature (^{0}C)	Minimum Temperature (^{0}C)
Jan	20.59	31.14	16.00
Feb	30.88	31.62	17.05
Mar	80.55	31.87	18.51
Apr	200.51	30.36	18.55
May	181.23	28.20	18.30
Jun	95.80	27.72	18.16
Jul	38.21	28.47	18.56
Aug	61.90	28.14	18.00
Sep	137.77	29.85	18.56
Oct	158.19	28.77	17.53
Nov	79.10	24.30	14.07
Dec	28.95	24.15	12.15
Mean		28.72	17.12
Total	1113.68		

Sources: National meteorological agency (Arba Minch Station)

Appendix 2: Mean values for physical properties of soils from the experimental sites

Treatment	Sand (%)	Clay (%)	Silt (%)	Textural Class	BD (gm/cm^3)	TP (%)	MC (%)
Stone bund	47.23	30.54	22.22	Sandy Clay loam	1.34	35.51	27.53
Soil bund	42.15	40.51	17.28	Clay	1.20	54.5	36.61
Control	43.73	30.27	26.00	Clay loam	1.24	49.09	35.05

Appendix 3: Mean square and analysis of variance for bulk density, total porosity, moisture content and texture

Source of variation	Degrees of freedom	Mean Squares					
		BD (gm/cm^3)	TP (%)	MC (%)	Soil Texture		
					Sand (%)	Silt (%)	Clay (%)
Replication	2	0.009ns	6.48ns	39.53ns	0.12ns	1.36 ns	2.12ns
CM	2	0.049*	70.71*	212.18*	60.78*	171.74*	306.54*
PWT	2	0.018ns	25.65ns	118.91*	1.92ns	1.05ns	5.46ns
CM*PWT	4	0.012ns	18.27ns	336.40*	28.31ns	9.87ns	8.96*
Error	10	0.241	0.911	1.14	1.32	1.155	0.44
Total	26						
Grand Mean		1.27	52.19	33.06	44.37	21.83	33.77
CV (%)		5.72	5.23	13.46	8.96	15.86	3.87

*Significant at ($P \leq 0.05$). CM = conservation measures, PWT = positions within terraces, BD = bulk density, TP = total porosity and MC = moisture content, ns= non-significance difference between means

Appendix 4: Mean square and analysis of variance for soil reaction, electrical conductivity, organic carbon, organic matter, total nitrogen, available phosphorous and zinc

Source of variation	Degrees of freedom	Mean Squares						
		pH (H_2O)	EC (ds/m)	OC (%)	OM (%)	TN (%)	AP (ppm)	Zn (ppm)
Replication	2	0.11ns	0.0006ns	0.050ns	0.15ns	0.0009ns	2.04ns	0.0066ns
CM	2	0.10ns	0.0015*	0.298*	0.89*	0.005*	7.85*	0.071*
PWT	2	0.92ns	0.0015*	0.171*	0.51*	0.002*	0.49ns	0.049
CM*PWT	4	0.02ns	0.0007*	0.092*	0.27*	0.0014*	0.94ns	0.032
Error	10	0.083	0.0045	0.046	0.08	0.0058	0.437	0.038
Total	26							
Grand mean		5.45	0.08	1.15	1.98	0.17	6.67	0.64
CV (%)		4.57	16.73	11.86	11.70	10.11	19.63	18.0

*Significant at ($P \leq 0.05$), CM = conservation measures, Rep = replication, PWT = positions within terraces, ns= non-significance difference between means, OC = organic carbon, OM = Organic matter, TN = total nitrogen, AP = available phosphorous

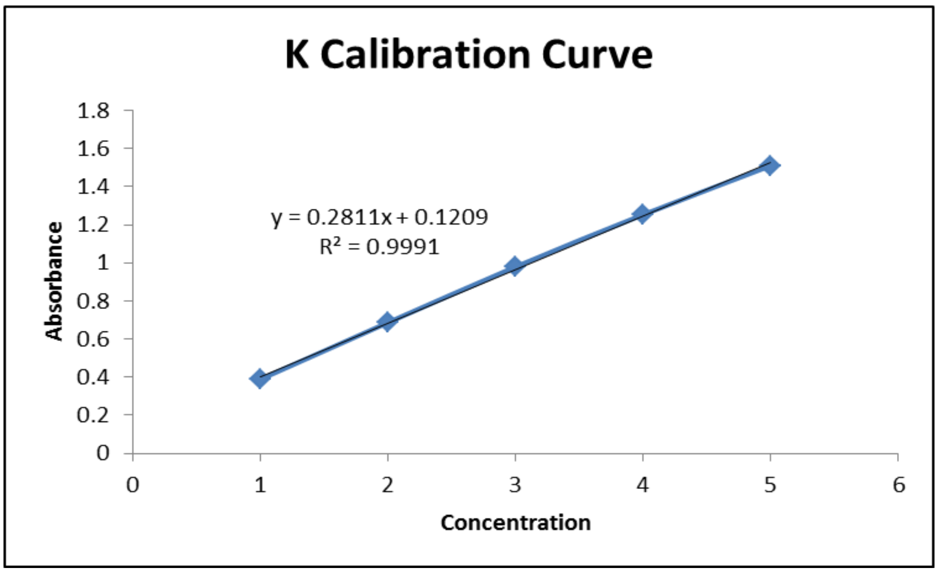
Appendix 5: Mean square and analysis of variance for exchangeable potassium, exchangeable calcium and exchangeable magnesium

Source of Variation	Degrees of freedom	Mean square		
		Exc. Ca^{2+} (cmol (+)/kg)	Exc. K^{+}(cmol(+)/kg)	Exc. Mg^{2+}(cmol (+)/kg)
Replication	2	0.00004ns	0.0012ns	0.00034ns
CM	2	0.00074*	0.0053*	0.002*
PWT	2	0.0013*	0.00034ns	0.00068ns
CM*PWT	4	0.0014*	0.00064ns	0.00044ns
Error	10	0.031	0.0271	0.0048
Total	26			
Grand mean		0.23	0.1678	0.7228
CV (%)		5.10	24.38	2.51

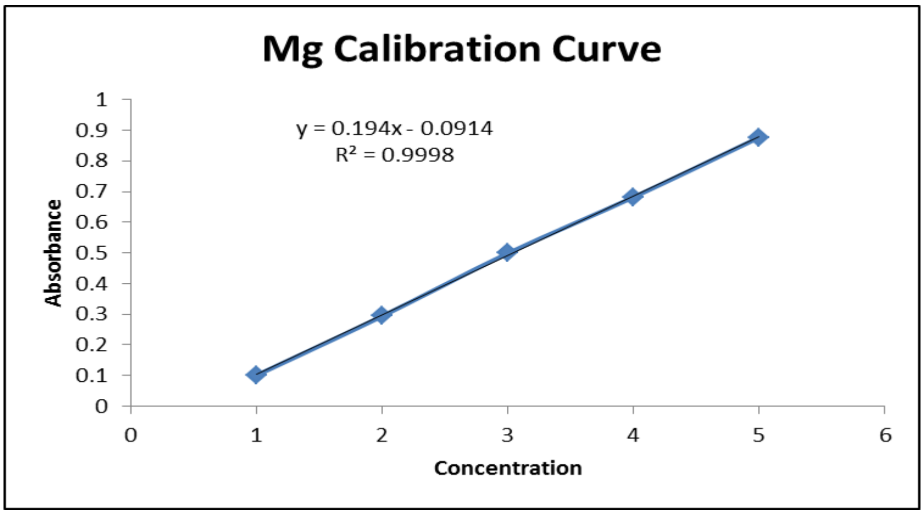
*Significant at ($P \leq 0.05$), CM = conservation measures, PWT = positions within terraces, ns= non-significance difference between means, Exc. Ca^{2+} = exchangeable calcium, Exc. K^{+}= exchangeable potassium and Exc. Mg^{2+}= exchangeable magnesium

Appendix 6: Standard calibration curve of absorbance against concentration for potassium, magnesium, calcium, zinc and phosphorous

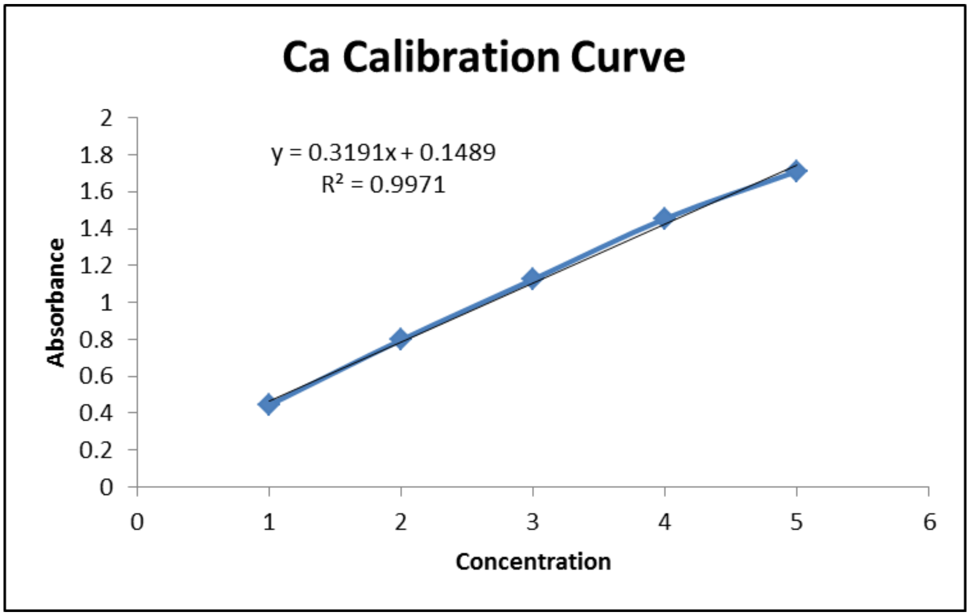
Standard	K absorbance
2ppm	0.389
4ppm	0.687
6ppm	0.995
8ppm	1.254
10ppm	1.511



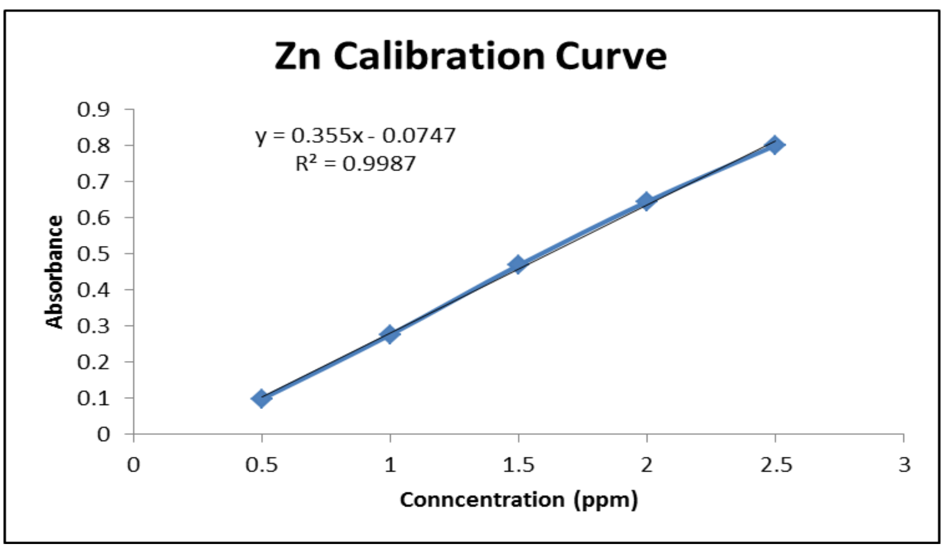
Standard	Mg absorbance
0.5ppm	0.101
1ppm	0.294
1.5ppm	0.499
2ppm	0.682
2.5ppm	0.877



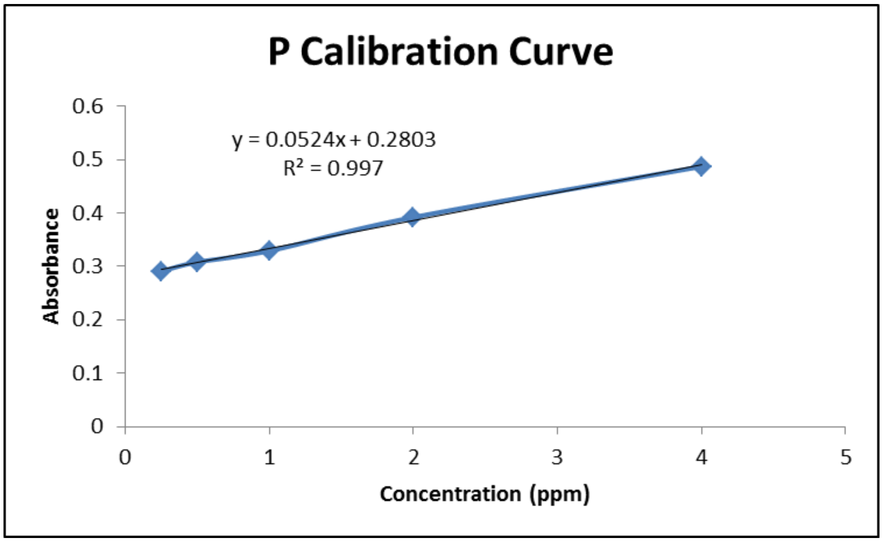
Standard	Calcium absorbance
3ppm	0.444
5ppm	0.797
7ppm	1.125
9ppm	1.454
11ppm	1.711



Standard	Zinc absorbance
0.5	0.098
1	0.276
1.5	0.469
2	0.645
2.5	0.801



P (ppm)	P (absorptions)
0.25	0.291
0.5	0.308
1	0.329
2	0.392
4	0.487



Source: Output of Laboratory data from own survey data (2018)

Appendix 7: Rating of organic matter, total nitrogen and organic carbon

Parameters	Very low	Low	Medium	High	Very high
Organic matter (%)	<2	2-4	10-20	4-10	>20
Total Nitrogen (%)	<0.1	0.1-0.2	0.2-0.5	0.5-1.0	>1. 0
Organic carbon	<2	2-4	4-10	10-20	>20

Sources: (Landon, 1991)

Appendix 8: Range of available phosphorous using Morgan method

No.	Ranges	Categories
1	10 lb P/acre (<3.68 ppm)	Deficient
2	11 to 20 lbP/acre (4.05-7.36 ppm)	Sufficient
3	21 to 30 lb P/acre (7.73-11.04 ppm)	High

1lb/acre= 0.368ppm. Sources: (Jones, 2001)

Appendix 9: Ratings of soil exchangeable bases

Exchangeable bases	Mean Values	`Classification
Calcium (Ca)	>10	High
	4-10	Middle
	<4	weak
Magnesium (Mg)	>4	High
	1.5-3.0	Middle
	1.5-3.0	Weak
Potassium (K)	>0.6	High
	0.2-0.6	Middle
	0.2-0.6	Weak

Sources: (London, 1991)

Appendix 10: Rating of Soil Electrical Conductivity

No	Class	Electrical Conductivity (dS/m)
1	None saline	0-2
2	Very slightly saline	2-4
3	Slightly saline	4-8
4	Moderately saline	8-16
5	Strongly saline	>=16

Sources: (Schoeneberger *et al.*, 2012)

Appendix 11: Rating of soil pH

Classes of soil pH	
Ultra Acid	<3.5
Extremely Acid	3.5-4.4
Very strongly Acid	4.5-5.0
Strongly Acid	5.1-5.5
Moderately Acid	5.6-6.0
Slightly Acid	6.1-6.5
Neutral	6.6-7.3

Sources: (USDA, 1998).

Appendix 12: Index Values for Zn

Category	Zn (mg/kg in soil)
Low	0.0-0.9
Marginal	1.0-1.5
Adequate	>1.5

1mg/kg= 1ppm. Sources: (Jones, 2001)

Appendix 13: Ranges of soil infiltration rate

	A range of values for infiltration rate	
1	Low infiltration rate	<15 mm/hr.
2	Medium infiltration rate	15-50 mm/hr.
3	High infiltration rate	>50 mm/hr.

Sources: http://www.fao.org/docrep/r4082e/r4082e03.htm

Appendix 14: Selected physical properties of the soils in the study area as affected by physical SWC measures

Treatment	Slope Position	Replication	Sand (%)	Clay (%)	Silt (%)	Bulk density (gm/cm^3)	Total porosity (%)	Moisture content (%)
Level Stone bund	Upper	1	42.6	33.4	24	1.39	47.54	29.45
	Middle	1	48.6	29.4	22	1.38	47.92	31.88
	Lower	1	46.6	27.4	26	1.34	49.43	29.85
	Upper	2	53.2	30.8	16	1.15	56.60	32
	Middle	2	44.6	31.4	24	1.17	55.84	29.05
	Lower	2	48.3	27.7	24	1.44	45.66	25.69
	Upper	3	38.3	35.7	26	1.43	46.03	23.77
	Middle	3	46.6	29.4	24	1.37	48.30	27.73
	Lower	3	56.3	29.7	14	1.47	44.52	18.36
Level Soil bund	Upper	1	49.2	38.8	12	1.17	55.84	43.58
	Middle	1	40.3	41.7	18	1.22	53.96	36.88
	Lower	1	41.2	38.8	20	1.24	53.20	34.67
	Upper	2	38.3	41.7	20	1.20	54.71	34.16
	Middle	2	40	41	18.6	1.25	52.83	30.95
	Lower	2	44.6	39.4	16	1.22	53.96	27.86
	Upper	3	40.6	42.4	17	1.07	59.62	54.20
	Middle	3	40.6	39.4	20	1.24	53.20	33.87
	Lower	3	44.6	41.4	14	1.23	53.58	33.33
Control plot		R1	44.3	29.7	26	1.30	50.94	19.23
		R2	46.3	29.7	24	1.14	56.98	48.24
		R3	40.6	31.4	28	1.30	50.94	37.69

Appendix 15: Selected chemical properties of the soils in the study area as affected by physical SWC measures

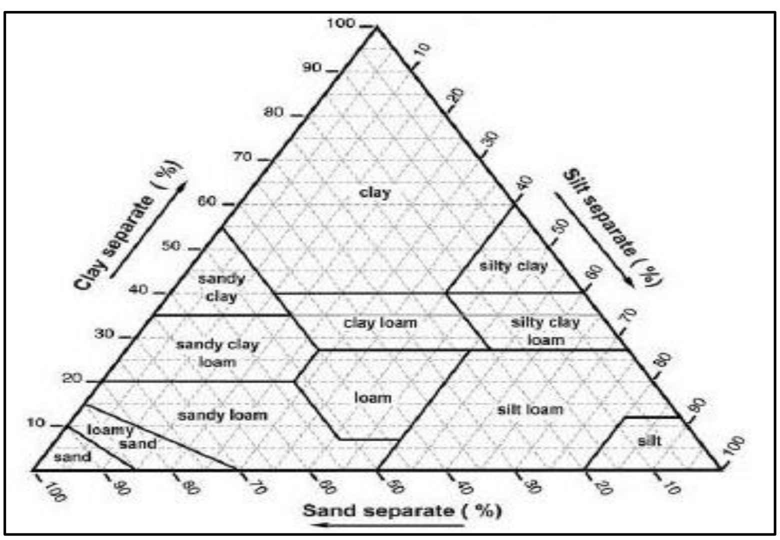
Treatment	Slope Position	Replication	pH (%)	EC (ds/m)	OC (%)	OM (%)	TN (%)	AP (ppm)	K^+ (cmol/(+)/kg)	Ca^{2+} (cmol/(+)/kg)	Mg^{2+} (cmol/(+)/kg)	Zn (ppm)
Level Stone bund	Upper	1	6.35	0.04	1.25	2.15	0.18	5.58	0.14	0.22	0.75	0.58
	Middle	1	5.85	0.1	1.05	1.81	0.16	8.7	0.22	0.23	0.71	0.69
	Lower	1	5.51	0.08	1.36	2.34	0.2	8.98	0.23	0.23	0.71	0.53
	Upper	2	5.31	0.05	1.32	2.27	0.19	8.62	0.22	0.23	0.72	0.51
	Middle	2	5.03	0.08	1.64	2.82	0.23	8.73	0.22	0.19	0.64	0.56
	Lower	2	5.19	0.09	1.44	2.48	0.23	6.58	0.17	0.23	0.71	0.62
	Upper	3	5.26	0.05	1.05	1.81	0.16	7.26	0.19	0.23	0.71	0.48
	Middle	3	5.31	0.09	1.17	2.01	0.17	4.73	0.12	0.22	0.71	0.59
	Lower	3	5.47	0.13	1.32	2.27	0.19	8.28	0.21	0.22	0.72	1.03
Level Soil bund	Upper	1	5.19	0.03	0.97	1.67	0.15	8.11	0.21	0.23	0.74	0.77
	Middle	1	5.29	0.06	1.25	2.15	0.18	5.93	0.15	0.24	0.74	0.69
	Lower	1	5.36	0.05	1.13	1.94	0.17	7.45	0.19	0.22	0.74	0.52
	Upper	2	5.35	0.08	1.17	2.01	0.17	7.98	0.2	0.24	0.74	0.5
	Middle	2	5.4	0.09	1.25	2.15	0.18	8.21	0.21	0.24	0.74	0.54
	Lower	2	5.35	0.06	1.48	2.54	0.21	6.22	0.16	0.22	0.73	0.6
	Upper	3	5.47	0.07	1.29	2.19	0.19	5.13	0.13	0.25	0.73	0.48
	Middle	3	5.31	0.09	1.4	2.41	0.2	8.26	0.21	0.23	0.74	0.52
	Lower	3	5.39	0.08	1.09	1.88	0.16	4.6	0.12	0.24	0.74	0.55
Control plot		1	5.64	0.09	0.74	1.27	0.12	5.88	0.15	0.23	0.73	0.75
		2	5.57	0.1	1.32	2.27	0.19	5.84	0.15	0.21	0.72	0.58
		3	5.45	0.09	0.78	1.34	0.13	5.26	0.13	0.28	0.74	0.91

Appendix 16. Infiltration characteristics of the soil at the study area

Time (min)	Cum time (min)	Infiltration depth (mm)			Cumulative infiltration depth (mm)			Infiltration rate (mm/hr.)		
		LSTB	Control	LSB	LSTB	Control	LSB	LSTB	Control	LSB
0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	10	7.63	8.00	8.67	7.63	8.00	8.67	45.71	47.90	51.90
10	20	5.83	4.50	5.33	13.47	12.50	14.00	34.93	26.95	31.94
10	30	5.50	3.87	4.00	18.97	16.37	18.00	32.93	23.15	23.95
10	40	4.33	3.30	3.33	23.30	19.67	21.33	25.95	19.76	19.96
10	50	3.67	5.00	4.83	26.97	24.67	26.17	21.96	29.94	28.94
10	60	4.50	3.27	3.50	31.47	27.93	29.67	26.95	19.56	20.96
10	70	3.80	2.67	2.30	35.27	30.60	31.97	22.75	15.97	13.77
10	80	3.13	2.27	1.87	38.40	32.87	33.83	18.76	13.57	11.18
10	90	2.83	1.97	1.40	41.23	34.83	35.23	16.97	11.78	8.38
10	100	2.43	1.80	1.00	43.67	36.63	36.23	14.57	10.78	5.99
10	110	2.20	1.63	0.83	45.87	38.27	37.07	13.17	9.78	4.99
10	120	2.20	1.63	0.83	48.07	39.90	37.90	13.17	9.78	4.99

LSTB= level stone bund, LSB= level soil bund

Appendix 17: Textural triangle



Appendix 18: Laboratory soil analysis and field infiltration measurement