# EFFECT OF LAND USE TYPES AND SOIL DEPTH ON SOIL FERTILITY STATUS IN MOCHE, GURAGE ZONE, ETHIOPIA

MSc THESIS

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# EFFECT OF LAND USE TYPES AND SOIL DEPTH ON SOIL FERTILITY STATUS IN MOCHE, GURAGE ZONE, ETHIOPIA

**BY**

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## SCHOOL OF GRADUATE STUDIES
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We, the undersigned, members of the Board of Examiners of the final open defense by Teklil Abadeye Bereka have read and evaluated his/her thesis entitled "Land Use Types and Their Effects on Soil Fertility in Soils of Moche, Cheha District of Gurage Zone, Ethiopia", and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree MSc in Soil Science.

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I would like to dedicate this thesis to my father Abadeye Bereka who was deeply worried about my future life and success but passed when I was elementary student and couldn’t see my present situation and success.

# STATEMENT OF THE AUTHOR

By my signature below I declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged. This thesis has been submitted to Wolkite University in the partial fulfillment of the requirements of MSc degree. This thesis shall be deposited at the University Library to be made available for borrowers under rules of the library. I solemnly declare that this thesis is not submitted to other university anywhere for the award of any academic degree, diploma and certificate.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AAS | Atomic Absorption Spectrophotometer |
| ANOVA | Analysis of variance |
| CASCAPE | Capacity Building for Scaling up of evidence-based Best |
| CEC | Cation Exchange Capacity |
| CUL | Cultivated land |
| CV | Coefficient of variation |
| CWANRDO | Cheha Woreda Agriculture and Natural Resources Development Office |
| CWPCEDO | Cheha Woreda Plan Commission and Economic Development Office |
| EDTA | Ethylene-diamine-tetra acetic acid |
| EIAR | Ethiopian Institute of Agricultural Research |
| ENFL | Enset farm land |
| EUCL | Eucalyptus land |
| FAO | Food and Agricultural Organization |
| FL | Forest land |
| GPS | Geographic Positioning System |
| ISFM | Integrated Soil Fertility Management |
| LSD | List Significant Difference |
| LULCC | Land Use Land Cover Change |
| LUT | Land Use Type |
| M.a.s.l | Meter above sea level |
| MARD | Ministry of Agriculture and Rural Development |
| OM | Organic Matter |
| PBS | Percent base saturation |
| Ppm | Part per million |
| RCBD | Randomize Complete Block Design |
| SAS | Statistical Analysis Soft ware |
| SD | Soil depth |
| SNNPRS | Southern Nation National People Region State |
| USDA | United State Department of Agriculture |

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## ABSTRACT

*The aims of this study was to assess and evaluate the different land use types(LUTs) in relation to their effect on soil fertility status on soils of Moche, Cheha district, Gurage Zone, Southern central Ethiopia. For this study, four different LUTs (cultivated, enset, eucalyptus and natural forest) were selected to assess and evaluate their effect on soil fertility status. A total 24 disturbed soil samples were collected from the selected LUTs and two different SDs (0-20 and 20-40cn) with three replications for laboratory analysis. Two-way analyses of variances were used for statistical analysis. The result of the study indicated that most of the selected soil physicochemical properties were significantly affected by LUTs, SD and their interactions. Bulk density, total porosity, pH, OM, av.P and CEC were significantly affected by LUTs, SD and the interaction of the two factors. The highest sand (43%), silt (46.5%) and clay (30.30) fractions was observed under FL, ENFL and CUL, respectively. With respect to depth higher silt (40.9%) and clay (28.3%) content were found under subsurface soils. Except CUL, textural classes of the LUTs were loamy. The highest (1.37gcm$^{-3}$) value of bulk density was observed under subsurface soils of CUL and lowest (1.06gcm$^{-3}$) value was observed under surface soils of FL and ENFL, respectively. In contrast to bulk density total porosity was highest (60.1%) under surface soils of FL and ENFL and lowest (48.3%) under subsurface soils of CUL. Soil pH was significantly influenced by the interaction of the two factors. The highest (6.54) and lowest (4.82) pH values were obtained under surface soils of ENFL and subsurface soils of EUCL, respectively. Relatively the highest (7.39%) and lowest (3.47%) values of OM content was recorded under surface soils of FL and subsurface soils of EUCL. The highest (22.69mg kg$^{-1}$) and lowest (5.02mgkg$^{-1}$) mean values of av.P were observed under surface soils of ENFL and subsurface soils of EUCL, respectively. The highest (37.96cmol $_{(+)}$ kg$^{-1}$) and lowest (11.90cmol $_{(+)}$ kg$^{-1}$) CEC values were observed under surface soils of FL and subsurface soils of EUCL. The highest value of exchangeable acidity (1.85 cmol $_{(+)}$ kg$^{-1}$) was recorded under soils of EUCL than CUL. As the result indicated soils of FL and ENFLs were relatively more fertile and expansion of EUCL tree to arable land and intensive cultivation might be attributed to the low soil fertility status. Therefore, choosing proper land use and implementing integrated soil fertility managements are indispensable to cope up with soil acidity, depletion in soil fertility and productivity of the study area.*

Keywords: Land use types, soil depth, soil properties

# 1. INTRODUCTION

## 1.1. Background and Justification

Soils can be reflected as a limited non-renewable resource (Certini, 2006; Fageria*et.al.* 2011; Whalen, 2011) and a living dynamic ecosystem (FAO, 2005). Good soil quality now not most effective produces right crop yields however additionally keeps environmental quality and therefore plant, animal, and human fitness (Fageria, 2002). Healthy soil is the foundation of the meal system (FAO, 2006). It produces healthful plants that in turn nourish humans. Soils are also used as a habitat for plant roots and limitless soil organisms.

Soil fertility is the status of a soil with respect to its ability to supply elements essential for plant growth without a toxic concentration of any element (Foth, 1990, Bijay and Yadvinder, 2015) soil nutrient status and the factors controlling the supply of nutrients to plants (Whalen, 2011). The major land degradation problem of the world is soil acidity (Aboytu, 2019). Tropical and sub-tropical regions as well as areas with moderate climatic conditions are mostly affected by soil acidity. Worldwide, 32% of all arable land is acidic (Aboytu, 2019). Similarly, soil acidity is one of the major constraints in the highland area of Ethiopia and which affect crop productivity (Getachew *et al*., 2019).

As explained by Getachew *et al.* (2013) soil fertility depletion is the most pressing development challenge in the Ethiopian agriculture for sustainable crop, livestock and forest production. Land degradation and related soil fertility depletion has been recognized as a major biophysical root cause for the declining per-capita food production in Ethiopia. In the highlands of Ethiopia, due to intensive land use and high population pressure, the land is severely degraded, eroded and the nutrient status of most soils is decreasing. Animal manure and crop residues, instead of being returned to the land, are largely used as fuel and livestock feed respectively (Mulugeta, 2004). It is estimated that about 40% (Taye, 2007; Tolossa and Bashir, 2009; Eshetu, 2011) of the total arable land of Ethiopia is affected by soil acidity. From this land place, approximately 27.7% is fairly acidic (pH in KCl) 4.5 - 5.5) and about 13.2% (Taye, 2007) is strongly (pH in KCl) < 4.5) acidic.

Behailu *et al.* (2014) soil fertility maintenance is a major issue in the country to improve agricultural production in order to feed the growing population. Without retaining soil fertility, one can’t speak about increment of agricultural production in feeding the alarmingly growing population. Consequently, to get optimum, sustained-long lasting and self-sufficient crop production, soil fertility must be maintained (Gebeyaw, 2007).

Land use is described as the preparations, activities and inputs human adopt in a positive land cover type to provide, change or preserve it (Ufot *et al*., 2016). Successful agriculture desires the sustainable use of soil resource, because soil can easily lose its excellent and quantity within a quick period of time because of distinctive reasons including in depth cultivation, leaching and soil erosion (Alemayehu and Sheleme, 2013).

Changes in land use and management practices often affect most soil physical, chemical and biological properties to the extent influenced in agricultural productivity (Heluf and Wakene, 2006) and it have great impacts on soil fertility indicators, particularly at the surface horizon. As Jobira (2018) mentioned the change in LUTs and SDs has a significant impact on soil physicochemical properties and the effect on most parameters was poor on soils of cultivated land (CUL). As an example, soil OM, CEC and available Cu contents of CUL was significantly lower than adjacent FL. According to Stoorvogel and Smaling (1990) and Dereje (2016), on the average 41 kg of N, 6 kg of P and 26 kg of K are lost per ha per year from Ethiopian highlands, displaying that nutrient mining quote is alarmingly very high. Presently, declining soil fertility is taken into consideration to be one of the major elements which might be considerably contributing to decreasing crop production and productivity in Ethiopia.

According to Gebeyaw (2015) comparisons among the crop fields which have been prolongly cultivated on one hand and the forest and grazing lands on the other revealed a highly significant distinction on major soil fertility parameters. For instances, the highest average mean values of exchangeable Ca (10.75 cmol $_{(+)}$kg$^{-1}$), exchangeable Mg (5.02 cmol $_{(+)}$kg$^{-1}$) and CEC (28.17 cmol $_{(+)}$kg$^{-1}$) were observed under the forest land as compared to the lowest values (3.96, 0.81 and 11.83 cmol $_{(+)}$kg$^{-1}$), respectively, in the cultivated land.

Conversion of land use types such as forest land, cultivated land, grassland and grazing land are identified as causes for the changes of soil physical, chemical and biological properties (Ayoubi *et al*., 2011). Soil erosion, soil acidity and decline in soil fertility and productivity are the major problems resulted from land use change without proper management practice in the highland area of Cheha district and Moche kebele in particular. Information on effect of different LUTs and soil depth on fertility status of soil is essential to understand their impact on selected soil physicochemical properties, for the suitable land use choice and sustainable management of soil and land resources to optimize agricultural productivity. So, the main objective of this study was to evaluate the impact of different land use types (LUTs) and SDs on soil fertility status in Moche kebele, Cheha district of Gurage Zone, Ethiopia.

## 1.2. Statement of the Problem

Types of land use practice considerably affect the soil physico-chemical properties (Weldesemayat and Nandita, 2020). According to Yihenew *et al*. (2015), continuous cultivation practices, excessive precipitation, steepness of the topography and application of inorganic fertilizer should have attributed as a number of the elements which are responsible for the reduction of pH in the soil. Ethiopian highland areas are characterized through high rainfall and feature diversified cultivation within fast land use changes (Mohammed *et al.,* 2018). Land use change from natural ecosystem to agricultural land, and the subsequent soil fertility decline is one of the critical environmental challenges within the highlands of Ethiopia (Dereje, 2016). Rapid land use land cover change (LULCC), poor land and soil improvement practices, traditional cropping system, and different agricultural activities are the most important using forces of land degradation and soil fertility declination in Ethiopia (Gougoulias *et al*., 2014).

According to (CASCAPE, 2015 and CWANRMO, 2020) soil acidity, reduction of soil fertility and productivity are among the exiting main problems in Moche kebele, Cheha district. To increase yield and fertility of soil, farmers use inorganic fertilizer (DAP and urea) for annual crops and manure and organic waste for enset farm land for a long period of time. Using inorganic fertilizer for annual crop may contribute to soil acidity problem. Deforestation of natural forest for the purpose of timber production and house and fences construction and expansion of eucalyptus plantation to arable land is increasing year to year in the study area and which resulted in decline soil fertility. The final finding of this study is being helped to identify and compare the soil fertility status under different land use types and soil depth and recommended proper land use and suitable management practices.

Studies that conducted related to the effect of land use types on status of soil fertility are little in the area and more studies are necessary to identify effect LUTs in relation to soil fertility status. For these reasons in this study different LUTs were considered to assess and evaluate their impact on soil fertility by considering selected soil physicochemical properties. The finding of the study would be contribute to fill the knowledge gap about their effect in relation to soil fertility status in soils of the study area that will help for sustainable soil management.

## 1.3. Objectives

### 1.3.1. General objective

- The general objective of this study was to assess and evaluate different land use types in relation to soil fertility status and soil depth in Moche, cheha district.

### 1.3.2. Specific objectives

- To assess the status of selected soil physicochemical properties under different land use types and evaluate their effect on soil fertility status.

## 1.4. Significance of the Study

This research could help to asses and compare different LUTs and their effects on soil fertility status under different soil depth. After their impact and its magnitude being identified, would be knowledge of the soils of the study area so as to recommend proper land use and management practices to improve soil fertility status, to reclaim soil acidity problem and to increase productivity. The information that obtained in this study may support and extend knowledge on the topic, could be used as input for formulating sustainable and appropriate land use policy. The documents may be used as references for other studies and researchers who want to conduct in related task and others. In addition, the study could be strengthen public awareness, on the status of soil acidification in different LUTs, to use and manage their farm land properly and will recommend early reclamation measures in the area.

### 1.5. Scope of the Study

The study was conducted at Moche kebele, Cheha District by selecting four different LUTs (cultivated, cereal based annual crop land, enset farm land, eucalyptus plantation and natural forest land). Due to decline in soil fertility status and productivity of the study area the research was focused on to assess, evaluate and compare each LUT and soil depth in relation to their effect on soil fertility status through considering selected soil physicochemical properties.

# 2. LITERATURE REVIEW

## 2.1.Concepts of Soil Fertility

Soil fertility is a dynamic process comprising physical, chemical and biological properties of the soil (Mohammed *et al*., 2018). A “fertile soil” is determined by the combination of both the physical (texture, structure, profile depth, water-holding capacity, drainage, etc.); and physiochemical properties (pH, level of available essential plant elements, cation/anion exchange capacities) (Jone, 2012). Soil fertility indicates primarily the combined effect of chemical and biological properties, and is probably the most important single soil factor affecting productivity (White, 2006).

There is strong agreement that productivity of arable land depends on both a soil’s fertility potential (soil quality, inherent soil fertility) and present state of soil properties (soil health) to sustain primary production and other ecological services (Whalen, 2011). Karlen *et al*. (1997) defined that soil quality is the capacity of a soil to function in an ecosystem to support plants and animals, resist erosion, and reduce negative impacts on associated air and water resources. Fertile and productive soils are vital components of stable societies because they ensure growth of plants needed for food, fibre, animal feed and forage, medicines, industrial products, energy and for an aesthetically pleasing environment.

### 2.1.1. Soil fertility problem

#### 2.1.1.1.Land degradation

Degradation at global level and across sub-Sahara Africa is a series environmental problem (Shimeles, 2012). Ethiopia is the largest agrarian country in Africa both in terms of area and population (Mohammed *et al*., 2018) and the most affected country by land degradation (Solomon *et al*., 2017). Decline of soil fertility has been one of the most challenging and limiting factors for food security in the country (MoARD, 2010). As a result, many people have suffered from food insecurity and associated health problems due to malnutrition (Gete *et al*., 2010). Due to high variability in climate, relief, soil type, altitude and farming systems, all types of soil degradation take place in Ethiopia (Tolessa and Beshir, 2009). Soil erosion and nutrient depletion that result from land degradation which directly reduces soil fertility are the most challenging problem in Ethiopia (Belay and Eyasu, 2019).

The loss of soil nutrients in Ethiopia is related to cultural practices like cultivation. The removal of vegetative cover (such as straw or stubble) or burning plant residues as practiced under the traditional system of crop production or the annual burning of vegetation on grazing lands are major contributors to the loss of nutrients (Mesfin, 1998), while the use of chemical fertilizer is also minimal. Miss use of land by humans causes for soil fertility and degradations problem.

Depletion of soil fertility has great impact on plant growth and yield. The primary cause of soil fertility decline include loss of organic matter (OM), macro and micronutrient depletion, soil acidity, topsoil erosion and deterioration of physical soil properties. Low soil fertility problem is common problem for SSA countries (Mohammed *et al*., 2018) in which soil fertility is constrained by soil erosion, inherent fertility problem, continuous and long term cultivation and inadequate fertilizer applications. Hence, soil fertility depletion is considered as the fundamental biophysical cause for declining per capita food production in SSA countries in general and Ethiopia in particular (Sanchez *et al*., 1997).

#### 2.1.1.2.Soil acidity

A soil becomes acidic if $Ca^{2+}$, $Mg^{2+}$, $K^{+}$ and $Na^{+}$ ions are leached from the profile faster than they are released by mineral weathering, and $H^{+}$ and $Al^{3+}$ ions become the predominant exchangeable cations and the intensity of the acidity, measured by the soil pH, is the result of an interaction between soil mineral type, climate and vegetation (White, 2006). In the highland of Ethiopia soil acidity and low availability of P are among the major problems limiting crop production (Bereket *et al*., 2018). Soils that have a pH<7 are acid, and those with a pH of >7 are considered alkaline, and those with a pH of 7 are assumed to be neutral (Sparks, 2003; Sposito, 2008; Fageria, 2009; Tolera, 2011; Jone, 2012; Fagera *et al*., 2011). It is one form of chemical degradation of soils. The problems of acid soils is high acidity and low amount of exchangeable cations especially calcium and it is considered to be one of the most important factors that affect the soil chemical fertility. It affects productivity of the soil through its effect on nutrient availability and toxicity by some elements like Al and Fe (Birhanu *et al*., 2014). At pH below 5, Al is soluble in water and becomes the dominant ion in the soil solution (Getachew *et al*., 2019).

Soil acidity and associated low nutrient availability are key constraints to crop production in acidic soils, mainly Nitisols of Ethiopian highlands (Gete *et al*., 2010). Soil acidity mainly at soil pH < 5.5 affects the growth of crops due to high concentration of aluminum (Al) and manganese (Mn), and deficiency of P, nitrogen (N), sulfur (S) and other nutrients (Abreha *et.al*., 2013).

As indicated by Eshetu (2011) and Aboytu (2019), the major causes of soil acidity are land use change, climate or rainfall, parent material, harvest of high yielding crops and complete removal of crop residue from the farm and inappropriate use of inorganic nitrogenous fertilizers. High rainfall leaches soluble nutrients such as Ca and Mg which are specifically replaced by Al from the exchange sites (Brady and Weil, 2016).

The solubility and availability of important nutrients to plants is closely related to the pH of the soil (Marschner, 2011). The availability of plant nutrients is affected by soil pH as indicate in Fig 1.Acid soil limits the availability of crucial nutrients such as P, K, Ca and Mg, and affects the movement of soil organisms plants need to stay healthy (Aboytu, 2019). Soil acidity is one of the key causes of reduced P use efficiency in crop plants (Fageria, 2009). If a pH of a soil is less than 5.5 phosphate can readily be rendered unavailable to plant roots as it is the most immobile of the major plant nutrients (Getachew *et al*, 2019), and yields of crops grown in such soils are very low.

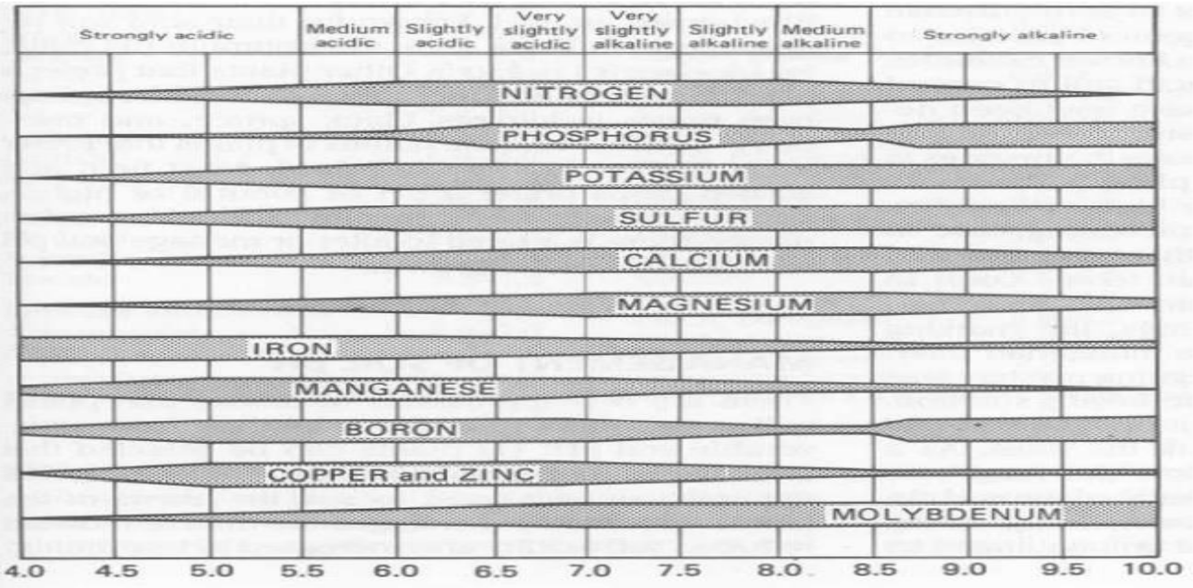

Figure 1. General relationships between soil pH and availability of plant nutrients.

Source: Foth (1990)

### 2.2.Improvement of soil fertility

To cope up the impact of soil fertility problems on plant growth and yield improving fertility status of soil is very crucial. Sustainable soil management practices and the maintenance of soil quality are central issues to agricultural sustainability. For sustainability of agricultural productivity implementing integrated soil fertility management practices are important to give a great attention. Integrated Soil Fertility Management (ISFM) refers to making the best use of inherent soil nutrient stocks, locally available soil amendments (for instance, crop residues, compost, animal manure, green manure), and inorganic fertilizers to increase productivity while maintaining or enhancing the agricultural resource base (Whalen, 2011). Improving soil OM content, keeping the soil surface covered with vegetation, use of conservation or minimum tillage, and preparing soil at an appropriate moisture level can minimize soil compaction and increase porosity (Fageria *et al*., 2011).

### 2.3.Land Use Types

Land use, which is human driven activities on land, is one of the major characteristics of land (Daniel, 2020). It is a complicated term and has different definition from view of different disciplines. Natural scientists define land use in terms of syndromes of anthropogenic activities such as agriculture, forestry and building construction that alter land surface processes including biogeochemistry, hydrology and biodiversity. Social scientists and land managers define land use more broadly to include the social and economic purposes and contexts for and within which lands are managed or unmanaged, such as subsistence versus commercial agriculture, rented vs owned, or private vs communal land (Aspinall and Hill, 2008). FAO (2000) land use is stated as human modification of a natural environment or wilderness into a new environment such as agricultural fields, pasture and settlement, while land cover is the physical cover of the earth surface that can be grass, water, forest, bare ground, crop field and others.

LUTs includes both the manner in which biophysical attributes of the land are manipulated and the intent underlying that manipulation, i.e., the aim for which the land is used (Abad *et al*., 2014). LUTs are also regarded as important components in the agricultural activity that is the decisive factors in the economy of the country (Zeng *et al*., 2009). The effect of LUTs cannot limit on the specific area of the country, it is a primary cause of worldwide environmental changes (Neris *et al*., 2012). Changes in LUTs and soil management can have a marked effect on the soil OM. Several studies that were conducted in the past have indicated that deforestation and cultivation of virgin tropical soils often lead to depletion of nutrients (N, P, and S) (Gebeyaw, 2015). Soil fertility can vary spatially and temporarily from LUT to others LUTs at a local and global level and from field to larger regional scale, in which it can influence by both land use and soil management practices (Mulugeta, 2018).

Land use can influence soil chemical and physical properties due to different anthropogenic activities, namely tillage, livestock trampling, harvesting, planting, application of fertilizer etc. According to Okubay (2018) land use changes have remarkable effects on the dynamics of soil properties. Land-use changes especially cultivation in deforested and in unsuitable lands may rapidly diminish the soil quality, as ecologically sensitive components of the habitats are not able to buffer the adverse effects.

### 2.3.1. Cultivated land

Cultivated lands are the result of anthropogenic transformations of ecosystems for the provisioning of crops. Depending on the particular land use practices and environmental contexts, agriculture can generate both ecosystem services and dis-services (also called negative externalities), with the latter being dominant in most intensive agricultural systems (Plieninger *et al*., 2015). It is the primary medium for food and fiber production for mankind (Fageria *et al.,* 2011). It is characterized by the cultivation of crops such as maize, wheat, barley, potatoes, beans and pea, which are most commonly cultivation land area.

In Ethiopian highlands, land use changes, mainly, from natural vegetation to CUL brought about rapid nutrient depletion. Intensive and continuous cultivation of land without proper management resulted in decline in soil physical, chemical and biological properties which aggravate crop yield reduction and food shortage (Habtamu *et al*., 2014). Distribution and supply of soil nutrients affected by land use practices by directly altering soil properties and by influencing biological transformations in the rooting zone (Mulugeta *et al*., 2005). Cation leaching is accelerated in cultivated soils (White, 2006).

### 2.3.2. Enset farm land

Enset farm land (ENFL) is the land near to home garden allocated for growing of enset crop. *Enset ventricosum* is a monocot perennial crops that belongs to order *Schistaminae*, family *Musaceae* and gene *Enset and Ensete ventricosum* is the only cultivated species in Ethiopia (Chakora and Mekuria, 2015). The enset farming system is believed to be native to Ethiopia and mainly adapted in the highlands of south and southwest parts of the country and it is grown as food crop only in Ethiopia. Here, smallholder farmers cultivate hundreds of landraces across diverse climatic and agro ecological systems. Domesticated enset (*E. ventricosum*) is cultivated at altitudes ranging from 1,500 to 3,100 meters above sea level (m.a.s.l) (Dersha, 2019, Wasse and Abebe, 2013). It is drought tolerant crop and it has several important food security traits. And considered to be a high value crop and thus receives the highest amount of organic fertilizers like manure, household refuse compost etc. (Elias, 2003). This implies that its biomass might contain a large amount of essential plant nutrients and its none-edible part could be a potential source of organic nutrients for soil fertility improvement. Because of its perennial nature, it provides food to households all year round. And also, because of its multipurpose uses and perennial nature, it has been named a 'food security crop' (Wasse and Abebe, 2013). It is an African crop that currently provides the staple food for approx. 20 million Ethiopians (Borell *et al.*, 2019).

In those parts of Ethiopia, particularly in the south and southwest, where Enset is grown as staple food crop, farmers grow it around home garden and use organic farming, i.e. applying a significant amount of organic fertilizer from different sources including; animal manure, organic feed residues, plant residues, household refuse, and traditional forms of compost (Wasse and Abebe, 2013 and Borell *et al.*, 2019). The sustainable soil productivity and fertility of ENFL is maintained due to a wide range of organic input it receives from the above mentioned sources (Wasse and Abebe, 2013).

Enset has a role in soil rehabilitation (Chakora and Mekuria, 2015). Like other parts of southern Ethiopia, Gurage People, grow enset crops near the home garden and as a perennial crop it cover the soil throughout the year. Because of its farming system (organic farming), protecting of soil from evapotranspiration by broad leaves (canopy), water holding and releasing properties to the soil, that increase the fertility of the soil and it has an effect on the soil physicochemical properties.

### 2.3.3. Eucalyptus plantation land

*Eucalyptus spp.* is a group of trees native to Australia and known to have more than 700 diverse genus species (Alemu, 2016 and Liang, 2016). Species of the *genus Eucalyptus* (common name eucalyptus) are widely planted all across Ethiopia including on large areas of land previously allocated to food production (Liang, 2016). It is a flowering plant that belongs to the family Myrtaceae under the plant kingdom. Even though there are a dwarf species, it is believed to be the tallest flowering plant and can grow up to 100 meters (Alemu, 2016). Eucalyptus was first introduced to Ethiopia with the aims of meeting ever-increasing demand for construction poles and firewood in Addis Ababa, the seat of King Menelik II (Yitebitu, 2010 and Amare, 2010) and its surrounding territories (Alemu, 2016).

In many developing country contexts the introduction of exotic eucalyptus has been shown to have ecological impacts ranging from soil nutrient depletion, to lowering water tables, to allelophatic effects (Liang, 2016). Expansion of eucalyptus is increase time to time due to the preference to eucalyptus by small holder farmers is due to a number of advantages gained from the tree. In Ethiopia, 506,000 hectares of land is believed to be covered by Eucalyptus. E. globulus and E. camaldulensis are the main species of Eucalyptus growing in the highlands of Ethiopia. The tree species are preferred more than others due to their fast-growth, coppicing ability, and easy silvicultural management, poorly palatable to animals, the demand for its wood products with reasonable prices, and their adaptations to a wide range of ecological conditions (Birru *et al*., 2013 and Alemu, 2016). Fast growing and short rotation tree plantations such as eucalyptus also use escalated amounts of nutrients from the soil in comparison to slow-growing species (Dessie and Erkossa, 2011 and Heilman and Norby, 1997). Growing of monoculture forests such as eucalyptus plantations may further affect soil chemical characteristics if the organic litter is continuously raked, prohibiting nutrient recycling (Zewdie, 2008).

### 2.3.4. Forest land

Forestland (FL) is land dominated by native or introduced trees with an understory that commonly consists of many kinds of woody plants, forbs, grasses, mosses, and lichens. Some forest communities produce enough understory vegetation to provide forage (USDA, 2018). Also as defined by Lund (2014) FL is land spanning more than 0.5 ha with trees higher than 5 meters and canopy cover of more than 10 percent, or trees able to reach these thresholds in situ, it does not include land that is predominantly under agricultural or urban land use. Humankind has a long history of converting forest to other land uses (FAO, 2016).

Table 1. Description of the land use types in the study area

| Land use types | Description of land use types which selected for this study |
|---|---|
| Cultivated land | Land allocated for annual crop production (e.g. cereals, wheat, and barely without any soil conservation practices ) |
| Enset farm land | Land allocated for growing enset crop (enset ventricosum) near to home garden and managed by applying organic fertilizers (animal manure, house refuse, wood ash and organic waste and covered by enset crop canopy throughout the year). |
| Eucalyptus land | Land on which single eucalyptus trees species (eucalyptus globulus) have been planted and grown for a long period without inter planting and management practices. |
| Forest land | The land covered by natural forest consisted indigenous trees *(Juniperus procera)*, shrubs and herbs. |

## 2.4.Effects of LUTs on Selected Soil Physical Properties

Changes in land use and management practices often modify most soil physical, chemical and biological properties to the extent reflected in agricultural productivity (Heluf and Wakene, 2006). Change in land use associated with deforestation, continuous cultivation, overgrazing, and mineral fertilization can cause significant variations in soil properties and reduction of output (Mulugeta *et al*., 2005).

Long-term cultivation alters soil structure and increases losses of soil organic matter (Lal, 2003). Use of agricultural machinery, irrigation, fertilizers, pesticides, good quality seeds, and intensive cultivation created disequilibria between soil and plant ecosystems, and soil quality started declining. A significant decline in soil quality has occurred worldwide, creating a need to develop criteria to evaluate soil quality and to take corrective actions (Fageria, 2002). As a result of declining soil fertility, together with increasing population pressure, expansion of crop production to marginal lands and forested areas contribute to the destruction of natural ecosystems (Horst and Schenk, 2001).

Physical properties of soil are crucial to the well-functioning of a soil and farm productivity. They influence the movement of water and air through the soil, and the ease with which roots can penetrate the soil. Soil degradation can lead to changes in these properties and decrease crop productivity, even under appropriate soil nutrient status. A decline in the physical quality of a soil can be hard to remediate, and can increase the risk of other soil degradation process such as soil erosion (FAO, 2020).

Human land-use activities impact soil physical characteristics by compaction and decreasing soil organic matter contents. Managing soils on a long-term basis for agricultural production has a significant impact on soil physical characteristics because of the loss of organic matter from soils (Vgote *et al*., 2015 and Fagera *et al*., 2011). Soil texture, bulk density, soil aeration and moisture holding characteristics are soil physical properties strongly influenced by status of land use and productivity of soils (Achalu *et al*., 2012). These properties vary from place to place as a result of natural and anthropogenic activities. LUTs and management influences several physical properties of soil. For instance, many soil physical properties change with intensity of cultivation, the instruments used and the nature of the land under cultivation (Seremesic *et al*., 2011).

### 2.4.1. Particle size

Particle size (texture) is an important soil physical property. It affects total porosity, pore size, and surface area. It is a relatively permanent soil property and is little influenced by tillage or other manipulations unless the modification is drastic. It can be altered by soil loss through erosion or by deposition of new materials from wind or water (Fagera *et al*., 2011). Based on the percentage quantity distribution of sand, silt, and clay soil texture is classified into twelve classes (Jone, 2012). It is the relative proportions of various soils separates, such as sand, silt, and clay in soil. Sand separates have diameters of 0.05–2mm, silt 0.05–0.002mm, and clay less than 0.002mm. Particles greater than 2mm in diameter are known as coarse fragments. Soil texture affects the productivity of crops in several ways. It affects the water-holding capacity of the soil, the aeration, the temperature, the cation exchange capacity (CEC), the nutrient-supplying power, and hence growth and production (Fagera *et al*., 2011).

Land use types have an impact on soil particle size distribution. As indicated by Tewabe (2013) relatively the high clay content (68.56%) was recorded under CUL at upper position of the south facing slope, while the lower clay percentage (43.59%) was recorded under natural FL. It may be due to, continuous cultivation of the soil which leads to movement of particles from one place to another place and results deposition of one particle to a particular place by erosion especially at lower part (Tewabe, 2013; Abera and Kefeyalew, 2017). Also, Gebeyaw (2007; 2015) indicated that the highest average surface sand content (66%) was obtained under the grazing land and the lowest (60%) was recorded in the forest land, whereas, the average clay fraction of the forest, grazing and crop lands were 23, 9 and 14%, respectively. As a result of deforestation and farming practices higher clay fraction was recorded in the cultivated land (Achalu *et al*., 2012).

### 2.4.2. Bulk density (gcm$^{-3}$)

Bulk density is defined as the mass or weight of a unit volume of dry soil. This volume includes both solid and pores. The values for clay, clay loam and silt loam surface soils varies from 1.00 – 1.60 gcm$^{-3}$, for sand and sandy loams from 1.20 – 1.80 gcm$^{-3}$. Fine - texture soils tend to have lower bulk densities and therefore higher porosities in comparison to the coarse textured soils due to loose packing of the clay particles. Bulk density measurement for soils is important since it determines the degree of compactness as a measure for soil structure and is used for calculating pore space of soils (Sarker and Haldar, 2005). And it is an important soil parameter in its own right, influencing water infiltration and plant root health (Vgote *et al*., 2015). As a rule, the higher the bulk density, the more compact the soils, the more poorly defined the structure and the smaller the amount of pore space. Bulk density is really a measure of pore space in the soil. For a given textural class with higher bulk density have the smaller amount of pore space. Changes in soil porosity due to compaction are commonly evaluated in terms of changes in bulk density (Foth, 1990).

Bulk density is highly affected by LUTs and soil management practices. Any factor that influences soil pore space will also affect the bulk density. For instance, intensive cultivation increases bulk density resulting in reduction of total porosity. The results of the study by (Woldeamlak and Stroosnijder, 2003) and Mulugeta, 2004) revealed that the βb of cultivated soils was higher than the bulk density of forest soils. The low organic matter content observed in the cultivated soils might have contributed to its highest bulk density value. In this case, high bulk density coupled with low OM in soils of cultivated land may restrict root penetration and air supply to plant roots due to compacting effect (Berhanu, 2016). Compaction resulting from inappropriate use of agricultural equipment, heavy or frequent traffic or poor soil management can raise the density of the surface horizons to values that may reach 2gcm$^{-3}$ (FAO, 2000).

There is very often a tendency for bulk density values to rise with depth, as effects of cultivation and organic matter content decrease (Landon, 1991). Similarly, Ahmed (2002) reported that soil bulk density under both cultivated and grazing lands increased with increasing soil depth. The study conducted (Berhanu, 2016) in Girar Jarso indicated that, the highest mean value of soil bulk density (1.41gcm$^{-3}$) was recorded in the subsurface layer of the CUL, whereas, the lowest (1.03 gcm$^{-3}$) was observed in the surface layer of the FL. The low OM content observed in the cultivated soils might have contributed to its highest bulk density value.

Particle density is the mass or weight of a unit volume of soil solids. It affects soil porosity, aeration and rate of sedimentation of particles. Information on particle density is needed for estimates of porosity, air-filled voids, settling rates of particles in fluids, and transport of particles by wind or water. Particle density varies widely, but the types of particles most prevalent in most soils have density values in the range of 2.6–2.7g/cm$^3$, with an average of about 2.65g/cm$^3$ (Foth, 1990 and Landon, 1991).Therefore, any practice that affects one also affects the other. According to (Foth, 1990; Hillen, 2004 and Certini, 2006) the bulk density is the mass per unit volume of oven dry soil, calculated as follows:

$$\rho b = \frac{\text{mass of oven dry soil}}{\text{volume}}$$

Where

ρb = bulk density

### 2.4.3. Total porosity (%)

Porosity is a general term used to designate all voids in the soil. There are several systems to designate porosity on the basis of their origin or location within the soil body (Lal and Shukla, 2004). Pore space is the total space of soil not occupied by soil particles, whereas density is the mass per unit volume including pore space. Porosity is an index of the relative pore space in a soil. Its value generally ranges from 30–60% (Hillen, 2004). And according to Certini (2006) porosity is the fraction of the soil volume occupied by pores and is a convenient measure of total pore volume. The particle density for mineral soils is assumed to be 2.65gcm$^{-3}$ (White, 2006). If the bulk density and the particle density are known, the porosity of a soil can be calculated from the formula:

$f\ (\%) = [(1- \rho b/\rho_{\rho})]\ *100$

Where

$f$ = total porosity

$\rho b$ = bulk density

$\beta s_{=}$ particle density

Soil porosity, and particularly macro porosity (or large pores), influences the movement of air and water in the soil. Plants require aerated soils for the efficient uptake and utilization of nutrients. The number, activity and biodiversity of micro-organisms and earthworms are also greatest in well aerated soils and they are able to decompose and cycle organic matter and nutrients more efficiently. Roots are unable to penetrate and grow through firm, tight, compacted soils, severely restricting the ability of the plant to utilize the available water and nutrients in the soil. A high penetration resistance not only limits plant uptake of water and nutrients, it also reduces fertilizer efficiency considerably and increases the susceptibility of the plant to root diseases (FAO, 2020).

### 2.5.Effects of LUTs on Selected Soil Chemical Properties

As stated by Gebeyaw (2007) soil chemical properties are the most important among the factors that determine the nutrient supplying power of the soil to the plants and microbes. The chemical reactions that occur in the soil affect processes leading to soil development and soil fertility build up. Minerals inherited from the soil parent materials overtime release chemical elements that undergo various changes and transformations within the soil. Soil chemical properties such as nutrient deficiencies and toxicities, pH, the cation exchange capacity, oxidation–reduction, and salinity are important soil properties affecting the growth and the production of crops. These soil properties can be modified through management practices for higher crop production (Fageria *et al.*, 2011).

Land use changes have remarkable effects on the dynamics of soil properties (Okubay, 2018). Similarly, as indicated by Habtamu (2018) LUTs have strong effects on the soil fertility status of an area where cultivated field showed nutrient depletion. FL should have been given special attention as it is the base for keeping soil more fertile by serving as the store house of nutrients. The loss of soil nutrients in Ethiopia is related to cultural practices like cultivation. The removal of vegetative cover or burning plant residues as practiced under the traditional system of crop production (Gebeyaw, 2015). The overall results of the study conducted by (Haile *et al*., 2014) indicated that the chemical properties (available P and pH) significantly changed in response to land use and management. According to Bationo *et al*. (1993) the average estimated soil fertility depletion rate of cultivated land in 37 African countries including Ethiopia on 30 years has been 660 kg N $ha^{-1}$, 75kg P $ha^{-1}$ and 450 kg K $ha^{-1}$.

The results of the study that was carried out by (Teshome *et al*., 2013), showed that soil OM, CEC, PBS and available micronutrients (Fe, Mn, Zn and Cu) contents of the cultivated land was significantly ($p < 0.001$) lower than the adjacent forest land and exchangeable cations (Mg, K and Na), PBS and available micronutrients (Fe, Mn, Zn and Cu) contents of the grazing land was significantly ($p < 0.001$) lower than the adjacent forest land.

The results obtained in the study carried out by (Mensah, 2016) entitled effects of eucalyptus plantation on soil physico-chemical properties in Thiririka sub-catchment, Kiambu country, Kenya, indicated that Eucalyptus spp. plantation significantly affects physical and chemical properties of soil. The results showed that cultivation of Eucalyptus spp. significantly lowered the soil pH (4.8), leading to a significant decline in soil total nitrogen (0.09 %) and soil total organic carbon (0.83 %) concentrations. Decomposition of the litter of Eucalyptus spp. also caused increase in concentration of soil exchangeable acidity (0.32 $cmol_{(+)}Kg^{-1}$), soil exchangeable sodium (0.52 $cmol_{(+)}Kg^{-1}$), Fe concentration (95.28 mg $kg^{-1}$), immobilization of soil available phosphorus (concentration of P was 23.2 mg $kg^{-1}$ ), rendering it unavailable for plant use.

### 2.5.1. Soil reaction (pH)

Soil reaction (pH) is defined as the negative log of the hydrogen ion ($H^+$) concentration on a scale from 0 to 14, with 7.0 being the neutral point, and less than 7.0 defined as “acidic” and greater than 7.0 as “alkaline” (Tolera, 2011; Jone, 2012 and FAO, 2020). It indicates the activity of $H^+$ ions in the soil solution, which measures the degree of acidity or alkalinity of a soil. A soil with a pH of 5.0 is 10 times more acidic than one with a pH of 6.0 and 100 times more acidic than one with pH 7.0 (Fageria *et al*., 2011). It is an important measurement in deciding how acid a soil is, and can be expressed as $pH = -\log(H^+)$ (Sparks, 2003).

Soil pH is a factor that defines the “fertility” status of a soil, whose level determines the availability of most essential plant nutrient elements as well as influencing plant growth (Jone, 2012). It is a very import soil chemical property due to its ability to affect the availability of nutrients for plant uptake and toxicity, microbial activity, and root growth. Different soil nutrients are available for uptake by plants at different soil pH levels. Some soil nutrients are available at acidic pH while others are available at alkaline pH levels. The Soil pH level that allows for a wider nutrient availability to crops is in the 5.5 to 7.5 range (Gebeyaw, 2015 and FAO, 2020). In general, organic matter, whether natural or added, decomposes more rapidly in neutral soils than in acid soils. In some strongly acid soils, Al toxicity as well as $H^+$ ion toxicity may limit microbial breakdown of organic matter. As indicated by Foth (1990) maximum nitrogen availability is between pH 6 and 8, because this is the most favorable range for the soil microbes that mineralize the nitrogen in organic matter and those organisms that fix nitrogen symbiotically.

The results reported in the finding of (Binyam, 2015) showed that soil pH significantly varied among land uses. Soil pH under enset farm land was significantly higher as compared to woodlots and cereal farms. On the contrary due to complete removal of crop biomass soil pH is low under cereal lands. Continuous total biomass removal may cause for low pH (Saikh *et al*., 1998b). The long-term application of chemical fertilizer under cereal land may attributed for low level of pH mainly urea which may rise the carbonate level of the soil (Haile *et al*., 2014).

### 2.5.2. Soil organic matter (%)

Soil organic matter (OM) in its broadest sense, encompasses all of the organic materials found in soils irrespective of its origin or state of decomposition (Murphy, 2014). Soil OM is the sum total of all natural and thermally altered biologically derived organic material found in the soil or on soil surfaces irrespective of its source, whether it is living or dead, or stage of decomposition, but excluding the above-ground portions of living plants (Jone, 2012).

The OM of the soil arises from the debris of green plants, animal residues and excreta deposited on the surface and mixed to a variable extent with the mineral component. The dead organic matter is colonized by a variety of soil organisms, most importantly micro-organisms, which derive energy for growth from the oxidative decomposition of complex organic molecules (the substrate). The combination of living and dead OM, irrespective of its source or stage of decomposition (but excluding the living parts of plants above ground), is called soil OM. The nutrient cycling from soil OM is a major source of nutrients for plants (Murphy, 2014) and it contains a wide range of macro and micro nutrients that released in to the soil and improve the physical and chemical properties of the soil and ultimately increase crop yield on a sustainable basis (Adiaha, 2017). During decomposition, essential elements are converted from organic combination to simple inorganic forms, a process called mineralization. For example, organically combined N, P and S appear as $NH_4^+$, $H_2PO_4^-$ and $SO_4^{2-}$, ions, and about half the C is released as $CO_2$. Mineralization, especially the release of $CO_2$, is vital for the growth of succeeding generations of green plants (White, 2006).

Almost all life in the soil is dependent on OM for nutrients and energy. The soils are very light and have low bulk density, high CEC and a high nitrogen, phosphorus, and sulfur content (Foth, 1990). FAO (2005) stated plants obtain nutrients from two natural sources: OM and minerals. OM includes any plant or animal material that returns to the soil and goes through the decomposition process. In addition to providing nutrients and habitat to organisms living in the soil, OM also binds soil particles into aggregates and improves the water holding capacity of soil. Most soils contain 2–10 percent organic matter. However, even in small amounts, OM is very important and it is affected by land use and management practices.

The changes in LUTs affect level of soil OM. In most tropical environments, the conversion of forest vegetation to agricultural land results in a decline of the soil OM content to a newer, lower equilibrium (Woldeamelak and Stroosnijder, 2003). Most cultivated soils of Ethiopia are poor in OM contents due to low amount of organic materials applied to the soil and complete removal of the biomass from the field (Yihenew, 2002), and due to severe deforestation, steep relief condition, intensive cultivation and excessive erosion hazards (Eylachew, 2001). Types of land use systems (forestland, grassland, fallow and cultivated) significantly affect the content of soil organic carbon and total N and both are lower in cultivated land (Yiferu and Taye, 2011).

The importance of organic carbon (OC) estimation lies in the fact that it gives an indication of the OM content of the soil which is an important index of soil fertility. According to USDA (2018) measured OC is multiplied by the Van Bemmelen factor of 1.724 to obtain OM content. And the OC content of soil, is reported directly as percentage of C or calculated as OM by multiplication with a factor of 1.724 assuming that soil OM contains on an average 58 percent carbon, so that 100/58 = 1.724 ( Sarker and Haldar, 2005; Murphy, 2014). As most of the vegetative residues are applied to the surface or the topsoil, the OM content in this layer tends to be higher and to decrease with depth (FAO, 2000).

### 2.5.3. Available phosphorus

Phosphorus (P) is one of the three macronutrients and the 1$^{st}$ or 2$^{nd}$ most commonly limiting nutrient for plant growth. Available P is the amount of P in soils that can be extracted or mined by plant roots and utilized by plant for its growth and development. It is an essential element for plant growth and development, as it plays key roles in plant metabolism, structure and energy transformation (Wallen, 2011). P released to the soil solution from the mineralization of OM might be taken up by the microbial population, taken up by growing plants, transferred to the soil inorganic pool, or less likely lost by leaching and runoff (Barker and Pilbeam, 2007).

P deficiency is a global constraint for crop production. The main causes of P deficiency are low total and available P content in highly weathered acidic soils; immobilization of fertilizer-applied P; loss by soil erosion, by surface runoff, and in drainage water; and uptake in large amount by modern crop cultivars (Fageria, 2009). The main sources of plant available P are the weathering of soil minerals, the decomposition and mineralization of soil OM and commercial fertilizers. Most of the soils in Ethiopia particularly Nitisols and other acid soils are known to have low P contents, not only due to the inherently low available P content, but also due to the high P fixation capacity of the soils (Shiferaw, 2004). Cropping systems also have major effects on changes in P fractions in soils (Whalen, 2011). As cropping systems change from less intensive systems (i.e. crop-summer fallow) to more intensive cropping sequences (i.e. continuous wheat and wheat-wheat-fallow), soil P availability and transformation become less predictable due to larger Pi and Po components from greater residue and litter which are maintained on soil surface.

### 2.5.4. Exchangeable basic cations

#### Exchangeable Ca and Mg

Soils under continuous cultivation, application of acid forming inorganic fertilizers, high exchangeable and extractable Al and low pH are characterized by low contents of Ca and Mg mineral nutrients resulting in Ca and Mg deficiency due to excessive leaching (Gebeyaw, 2007). The results of research conducted on Ethiopian soils indicated that exchangeable Ca and Mg cations dominate the exchange sites of most soils and contributed higher to the total percent base saturation particularly in Vertisols (Mesfin, 1998; and Eylachew, 2001). Different crops have different optimum ranges of nutrient requirements. The response to calcium fertilizer is expected from most crops when the exchangeable Ca is less than 0.2 cmol $_{(+)}$ kg$^{-1}$ of soils, while 0.5 cmol $_{(+)}$ kg$^{-1}$ soil is reported to be the deficiency threshold level for Mg in the tropics (Landon, 1991).

According to Gebeyaw (2015) comparisons between the crop fields that have been prolongly cultivated on one hand and the forest and grazing lands on the other revealed a highly significant difference on major soil fertility parameters. For instance, the highest average mean values of exchangeable Ca (10.75 cmol $_{(+)}$ kg$^{-1}$), exchangeable Mg (5.02 cmol $_{(+)}$ kg$^{-1}$) and CEC (28.17 cmol $_{(+)}$ kg$^{-1}$) were observed under the forest land as compared to the lowest values (3.96, 0.81 and 11.83 cmol $_{(+)}$ kg$^{-1}$), respectively, in the cultivated land.

Where atomic absorption spectrophotometry is possible the ammonium acetate extract can be directly analyzed for Ca and Mg. The spectrophotometric standards are prepared in the ammonium acetate solution and both the standard and extracts are read against ammonium acetate as blank. If AAS is not possible the calcium and magnesium are analyzed by complexometric titrations using ethylene diamine tetra acetic acid (EDTA) (Sarker and Haldar, 2005).

**Exchangeable K and Na**

Soil parent materials contain potassium (K) mainly in feldspars and micas. As these minerals weather, and the K ions released become either exchangeable or exist as adsorbed or as soluble in the solution (Foth and Ellis, 1997). Potassium is the third most important essential element next to N and P that limit plant productivity. Its behavior in the soil is influenced primarily by soil cation exchange properties and mineral weathering rather than by microbiological processes. Unlike N and P, K causes no off-site environmental problems when it leaves the soil system. It is not toxic and does not cause eutrophication in aquatic systems (Brady and Weil, 2002).

Exchangeable sodium (Na) alters soil physical and chemical properties mainly by inducing swelling and dispersion of clay and organic particles resulting in restricting water permeability and air movement and crust formation and nutritional disorders (decrease solubility and availability of Ca and Mg ions). Moreover, it also adversely affects the population, composition and activity of beneficial soil microorganisms directly through its toxicity effects and indirectly by adversely affecting soil physical and as well as chemical properties. In general, high exchangeable Na in soils causes soil sodicity which affects soil fertility and productivity (Gebeyaw, 2007).

### 2.5.5. Cation exchange capacity (cmol (+) kg$^{-1}$)

Cation Exchange capacity (CEC) is the sum of the + charges of all of the adsorbed cations (Foth, 1990). The sum of the exchangeable cations retained by soil is CEC and it is expressed in milliequivalents 100 g$^{-1}$ or in cmol of cations kg$^{-1}$ of soil (Fageria *et al.*, 2011). As mentioned by FAO (2000) the soil CEC is a measure of the quantity of negative charges present on the mineral and organic surfaces of the soil and represents the quantity of cations that can be held on these surfaces. A high soil CEC allows the soil to retain a large amount of nutrients and at the same time, keep them available for the plants. Soils with a low CEC can only hold a small quantity of nutrients on the exchange sites. The nutrients applied to the soil that exceed this amount can easily be leached out by excess rain or irrigation water. This implies that these low CEC soils need different management as regards fertilizer application, small doses of nutrients needing to be applied frequently. The cation exchange capacity of soils is highly variable. The principal factors which determine CEC are the amount and the type of clay present, the organic matter content, and the soil pH (Fageria *et al*., 2011).

As reported by Eyayu and Mamo (2018) deforestation and continuous cropping mainly contributed to depletion of CEC. On the other hand the lowest mean CEC value (43.06 cmol $_{(+)}$ kg$^{-1}$) was reported by (Berhanu, 2016) in the soils of the cultivated land in Girar Jarso District of North Shoa Zone, Oromia National Regional State, Ethiopia. The processes that affect texture (such as clay) and OM due to land use changes also affect CEC of soils. Woldeamlak and Stroosnijder (2003) reported that CEC value was highest in soils under FL and lowest under CUL.

### 2.5.6. Percent base saturation (%)

According to McGrath and Penn (2014) percent base saturation (PBS) is estimated as the amount of exchangeable basic cations divided by the soil CEC and multiplied by 100%. Soils with low PBS are considered infertile, whereas those with high saturation are fertile. Soils with low-base saturation are dominated by $H^+$ and $Al^{3+}$, contributing to acidity and $Al^{3+}$ toxicity in plants. Indeed, it is the increased solution concentrations of $Al^{3+}$ and $Mn^{4+}$ that are often most detrimental to plant growth under acidic pH conditions. Also Jone (2012) indicated base saturation is an important soil chemical property in acid soils, affecting both nutrient uptake and plant growth, it assesses the fertility status of a soil based on what portion of the cation exchange capacity (CEC) is occupied by each of the major cations ($K^+$, $Ca^{2+}$, and $Mg^{2+}$). It can be calculated with the help of the following formula:

$$\text{Base saturation} = \sum\left(\frac{\text{Exchangeable Ca,Mg,K,Na}}{\text{CEC}}\right) * 100$$

### 2.5.7. Exchangeable acidity (cmol (+) kg$^{-1}$)

Exchangeable hydrogen ($H^+$) together with exchangeable aluminum ($Al^{3+}$) is known as soil exchangeable acidity. Soil acidity occurs when acidic $H^+$ ion occurs in the soil solution to a greater extent and when an acid soluble $Al^{3+}$ reacts with water (hydrolysis) and results in the release of $H^+$ and hydroxyl Al ions into the soil solution (Rowell, 1994 and Brady and Weil, 2002). The concentration of the $H^+$ in soils to cause acidity is pronounced at pH values below 4 while excess concentration of $Al^{3+}$ is observed at pH below 5.5 (Nair and Chamuah, 1993). In strongly acidic conditions of humid regions where rainfall is sufficient to leach exchangeable basic cations, exchangeable $Al^{3+}$ occupies more than approximately 60% of the effective cation exchange capacity, resulting in a toxic level of aluminum in the soil solution (Buol *et al*., 1989). Generally, the presence of more than 1 parts per million of $Al^{3+}$ in the soil solution can significantly bring toxicity to plants. Hence, the management of exchangeable Al is a primary concern in acid soils. A soil can become acidic as a result of natural processes, the effects of temperature and rainfall (soil profile leaching), and enhanced by the effects of cropping and crop removal, and by use of acid-forming fertilizers (Jone, 2012).

Currently soil acidity is being a serious problem in the highlands of Ethiopia and due to intensive land use and high population pressure, the land is severely degraded, eroded and the nutrients status of most soil is decreasing. Between 70 and 75% of the agricultural soils of the high land platues area of Ethiopia are phosphorous deficient (Duffera and Robarge, 1999). Crop production or harvesting of crops has its effect on soil acidity development because crops absorb the lime-like elements, as cations, for their nutrition. When these crops are harvested and the yield is removed from the field, then some of the basic material responsible for counteracting the acidity developed by other processes is lost, and the net effect is increased soil acidity. Increasing crop yields will cause high amounts of basic material to be removed. Grain contains less basic materials than leaves or stems. Soil acidification in agricultural production system is the direct consequence of human input and output. These processes however are greatly affected by the physical and chemical properties of soils, climate and farming practices (Sumner and Noble, 2003). Continuous cultivation and inorganic fertilizers applications, results in decline of the soil pH and cause loss in basic cations especially under intensive cropping on inherently poor soils.

# 3. MATERIALS AND METHOD

## 3.1.Description of the Study Area

### 3.1.1. Location

The study was conducted in Moche Kebele, Cheha district, Gurage Zone, Southern Nations, Nationalities and Peoples Regional State (SNNPRS). The district is located between 8° 00' 18.9" to 8° 15' 28.53" N latitude and 37° 35' 46.48" to 38° 03' 59.59" E longitude (Figure 2) with an estimated area of 57315 ha and the elevation ranges between 900-2812 meter above sea level (m.a.s.l) (EIAR, 2011; SNNPRS, 1996; Mohammed, 2016; Bereket *et al*., 2018; CWANRMO, 2020). Cheha district is one of the Gurage zone districts bordered by Abeshge district at the North, Geta and Enemor district at the south, Ezha and Gumer district at the East and both Yem especial district and Oromiya region at the west (CASCAPE, 2015; Belachew and Fekede, 2019). Emdibir is the administrative center of Cheha district, which is located 460 km far from Hawassa, 180 km from Addis Ababa and 30 km from Wolkite, capital of Gurage zone (Bekalu and Digafe, 1996; CASCAPE, 2015; Belachew and Fekede, 2019).

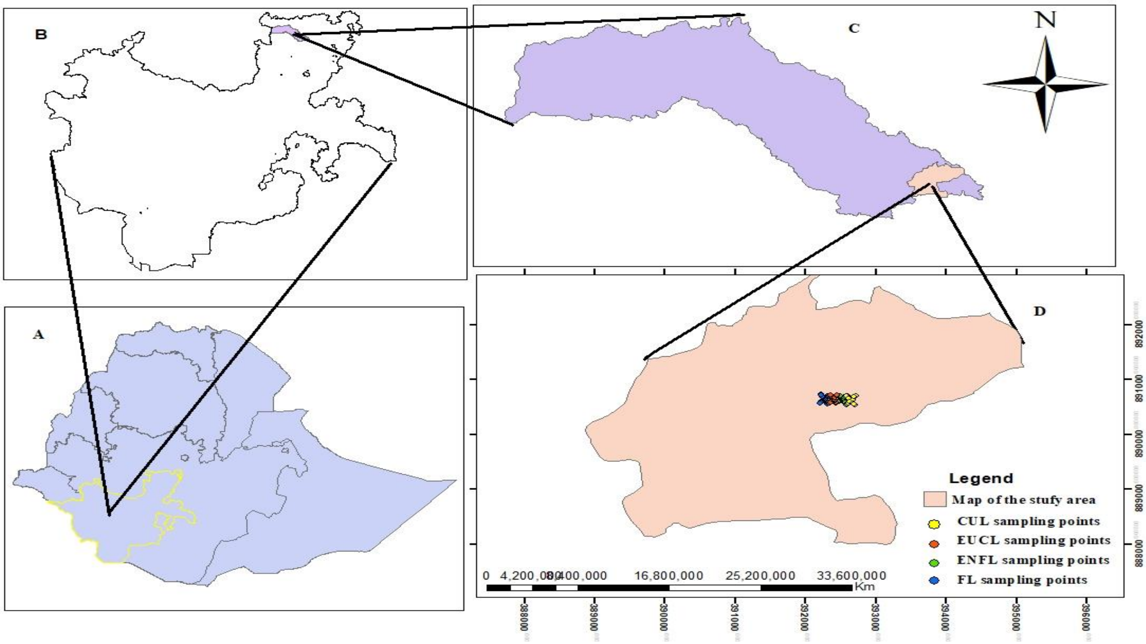

Figure 2. Map of the study area. A shows map of Ethiopia, B shows map of SNNPRS, C shows map of cheha district and D shows map of Moche kebele.

Source: - WGS 1984

### 3.1.2. Topography

According to Cheha woreda plan commission and economy development office (CWPCEDO, 2020), topography of the district was characterized as flat, gentle slope, steep slope, very steep slope and hill (i.e., 60% was level and 40% was steepy or mountainous). Moche kebele was located in the upper Slope of the topsequence (CASCAPE, 2015).

### 3.1.3. Climate

The rainfall and temperature conditions depend on elevation like other parts of Ethiopia. Based on the evidence of Ministry of Agriculture (MoA) (1998), the agro ecology of Cheha district was classified into three traditional agro-ecological zones. These agro-ecological zones include Dega or highlands (2300–3200 m.a.s.l), Weyna Dega or midlands (1500–2300 m.a.s.l), and Kola or lowlands (500–1500 m.a.s.l) (EIAR, 2011; Bereket *et al*., 2018 and Mohammod, 2016). According to CWANRDO (2020) the agro-ecology of the district was 20% Dega, 78% Wayna Dega and 2% is Kola.

The area receives bimodal rainy season (*Belege* and *Mehere*). Belege includes the month from March to May and the main rainy season (Mehere), which accounts for around 70-90% of the total annual rainfall occurs from June to October. Two main distinct seasons, dry and wet seasons are recognized in the area. The 10 years mean annual rainfall of the district was about 1265.7 mm (Fig 3). The mean annual maximum and minimum temperatures were 24.55 and 10.42 °C, respectively (NMA, 2021).

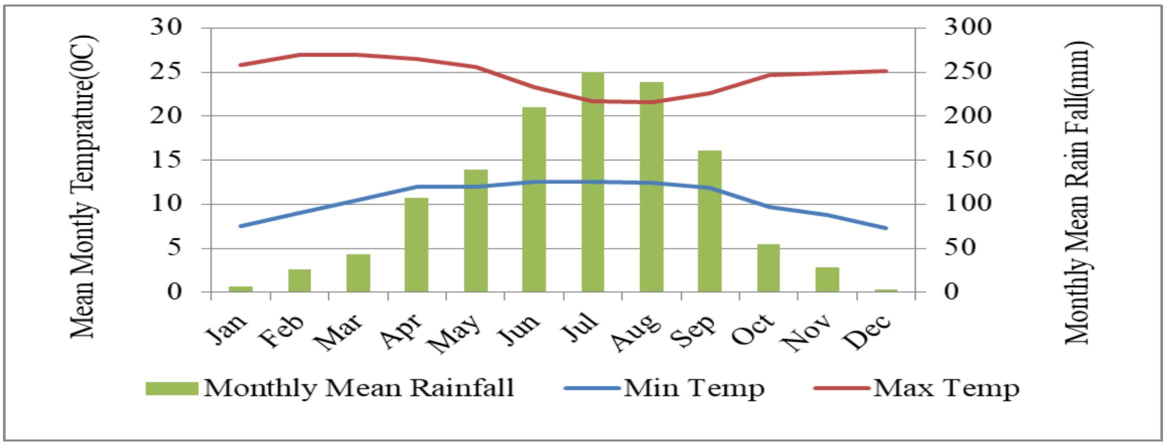

Figure 3. Mean monthly rain fall, maximum and minimum temperatures of the study area. Source: - SNNPRS National Metrology Agency (NMA) (2021) for a period of (2011-2020).

### 3.1.4. Geology and soil

And according to CASCAPE (2015) soils in Cheha district are dominated by Chromic Luvisols, well drained, very deep (>2 m), red color, well structured, sandy clay loam to clay soils with a general increase in clay contents from topsoil to subsoil. These soils dominate the whole high land kebeles of Moche and Yeferzeye and upper areas of the district are Luvisols and the Toe Slope position areas are found to be Vertisol. The color of the soils in the area ranged from red to reddish brown (high elevation areas) through light brown (midland areas) to dark (lowland areas) (Mohammed *et al*., 2016).

### 3.1.5. Farming system and land use types

According to Mohammed *et al*. (2016), production system in the district was dominated by traditional subsistence mixed crop livestock farming. According to CWANRMO (2020), there are two farming season which are "*Belege"* and "*Mehere"*. The major crops grown in the area in the two farming seasons include maize (*Zea mays L.*), wheat (*Triticum aestivum L.),* barley (*Hordem vulgare L.*)*,* and teff [*Eragrotistef (Zucc.) Trotter*], sorghum (*Sorghum bicolor L.*)*,* chickpea (*Cicerarietinum L.*)*,* onion (*Allium cepa*); root and tubers including enset (*Ensete ventricosum*)*,* and potato (*Solanum tuberosum*); fruits (banana, citrus, papaya, mango and avocado); stimulants, such as coffee (*Coffee arabica*)*,* and khat (*Catha edulis*) (Bekalu and Digafe, 1996). According to CWANRMO (2020), the current LUTs of the district was indicated in the table 2 and current land use of Moche kebele was 661 ha is covered by perennial crops, 333 ha covered by annual crops, 330 ha coverd by forest (natural and manmade forest, Eucalyptus plantation), 73 ha grazing land and 256 ha covered by other LUTs.

Table 2. Land use pattern of Cheha district

| No | Land uses | Coverage(ha) | Percent |
|---|---|---|---|
| 1 | Annual crops | 17657.5 | 30.8 |
| 2 | Perennial crops | 27325 | 47.7 |
| 3 | Grazing land | 613.5 | 1.0 |
| 4 | Natural and man-made forest land | 9284 | 16.2 |
| 5 | Degraded land | 60 | 0.1 |
| 6 | Potentially uncultivated land | 1180 | 2.1 |
| 7 | Others | 1195 | 2.1 |
|  | Total | 57315 | 100 |

Sources: - CWANRMO (2020) unpublished annual report.

### 3.1.6. Population

A simple but powerful measure of population distribution is known as density. The highest populations in Ethiopia are in the Enset Belt which covers Gurage, Hdiya, Kambata and Wolaita zones of SNNPRS (Aynalem, 2017). Cheha district has currently 38 rural kebeles and 57,315ha (CWANRMO, 2020). Based on the 2007 census conducted by CSA the total population number of the district were 115,951 of whom 56,851 are men and 59,100 women. According to CWPCEDO (2020), currently the total population number of the district was expected to reach 176,206 of whom 86,879 (49.3%) are men and 89,327 (50.7%) are female and population density of the district was 307 person per km$^2$ (Aynalem, 2017). This indicated that the area is densely populated there was expansion of agricultural land in order to feed the ever increasing population.

## 3.2.Methods

### 3.2.1. Site selection and sampling techniques

Before soil sample collection, field observation and preliminary survey of the study area were conducted by transact walking and visual observation to decide sampling site. Soil samples have been collected from four different adjacent land use kinds. Namely cultivated land (annual crop or cereal based land use type), Enset farm land (*Enset ventricusom)*, Eucalyptus plantation (*Eucalyptus globulus*) and natural forest dominated by *Juniperus* *procera or Habesha Tid* were selected for this study, almost with in similar sites and slope. Regarding to the history and management of the chosen land use types, necessary information collected from farmers and key informants. All the LUTs selected for this study have the age of more than five decays. Variations of topographic positions are used for blocking the land use types by using RCBD method. Soil samples were collected at two different depths (0 - 20cm and 20 - 40cm) from each LUT and from three topographic positions (lower, middle and upper). By using diagonal soil sample taking method, randomly 15-20 sub samples (spots) were taken from every LUT and two respective soil depths within three topographic positions to prepare one representative composite soil pattern. A total of 24 disturbed composite soil samples (four LUTs*three replications*two depths) have been collected from the selected LUTs for laboratory analysis of soil chemical properties and 24 undisturbed soil samples were collected for determination of bulk density with the aid of core sampler of a 100 $cm^3$ volume in the respective two different soil depth. During collection of soil samples; dead plants, manures, spots near trees and the like were excluded.

Disturbed soil samples were used for investigation of soil physical and chemical analysis and undisturbed soil samples were used to determine soil bulk density. Global positioning system (GPS) and clinometers were used to read the geographical locations and slope gradient of the sampling sites of the selected LUTs, respectively. The soil auger which was marked at 20 cm labeled was used to take disturbed soil sample and cylindrical core sampler was used to take undisturbed soil samples to determine bulk density and total porosity of the study area.

Finally, the composite soil samples were taken to Wolkite soil testing laboratory for analysis. The composite soil samples were air dried, grounded and passed through a “0.5 mm” sieve for analysis of OC and 2 mm sieve for other selected soil physicochemical analysis (soil particle distribution, exchangeable acidity, pH, exchangeable bases ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$), CEC and available P).

### 3.2.2. Soil analysis

The soil physicochemical analyses have been carried out at Wolkite Soil Test and Fertility Improvement Laboratory Centers Using Standard laboratory techniques. Soil texture, bulk density and total porosity were soil physical properties that have been analyzed. Soil texture was determined by the hydrometer approach (Bouyoucos, 1951 and Black, 1965). Soil bulk density was determined from undisturbed soil samples collected in core samplers of known volume and dried in an oven at 105$^{o}$c for 24 hours and subsequently calculated as the mass of the oven dry soil per unit volume of the soil which includes the pore spaces (Black, 1965). And total porosity was estimated from bulk density and particle density (by assuming an average particle density of mineral soil is 2.65 g cm$^{-3}$). Then total porosity of soil was calculated as:

$f = [(1 - \rho b / \beta s) * 100]$.

Where

$f$ = porosity

$\rho b$ = bulk density

$\beta s$= particle density

The pH of the soil was measured potentiometrically using glass rod pH meter in the supernatant suspension of a 1: 2.5 soil to water ratio (Rhoades, 1982). Soil organic carbon was determined following the wet oxidation method with potassium dichromate ($K_2Cr_2O_7$) in a sulfuric acid medium as described by (Walkley and Black, 1934). Percent organic matter (OM) was obtained from multiplying the value of percent organic carbon (OC) by the conversion factor of 1.724 (following the assumptions that OM is composed of 58% carbon i.e. 100/58 = 1.724) as: %OM = %OC x 1.724. Available phosphorous content was determined by 0.5M sodium bicarbonate ($NaHCO_3$) extraction solution (adjusted at pH 8.5) method of Olsen (Olsen *et al.*, 1954). The P different extracts were measured by spectrophotometer.

Exchangeable basic cations ($Ca^{2+,}$ $Mg^{2+,}$ $K^+$ and $Na^+$) were extracted with 1M ammonium acetate at pH 7 (Van Reeuwijk 2002) and exchangeable Ca $^{2+}$ and $Mg^{2+}$ were determined from this extract using EDTA method, while $Na^+$ and $K^+$ were determined from the same extract by flame photometer (Chapman, 1965). Cation exchange capacity of the soil was determined from ammonium acetate saturated samples that was subsequently replaced by Na from a percolated NaCl solution after removal of excess ammonium by repeated washing with ethanol alcohol (Chapman, 1965). Exchangeable acidity was determined by saturating the soil sample with 1 M KCl solution and titrating with 0.02 M NaOH as described by (Rowell, 1994).

### 3.2.3. Statistical analysis

A two-way analysis of variance (ANOVA) was performed to assess the significance of differences in soil parameters between LUTs, soil depths and their interaction effects using SAS software 9.2 versions. Treatment means were compared using least significant differences (LSD) by Fisher's test at 0.05. Pearson's Correlation matrix analyses were also conducted among soil parameters.

# 4. RESULTS AND DISCUSSION

## 4.1.Effect of Land Use Types on Selected Soil Physical Properties

### 4.1.1. Soil particle size distribution

The sand fraction was highly significantly ($p < 0.001$) affected by LUTs and ($p < 0.01$) soil depth (SD). It was not significantly affected by the interaction of LUTs with soil depth ($p > 0.05$). Silt fraction was highly significantly ($p < 0.01$) affected by LUTs and it was not affected by SD and the interaction of LUTs with SD ($p > 0.05$). And clay fraction was not significantly ($p > 0.05$) affected by LUT, SD and the interaction of the two factors (Appendix 1). The sand fraction had statistically significantly ($p < 0.05$) different along SDs, while the silt and clay fractions had not statistically different due to SDs (Table 3). The result was agreed with (Berhanu, 2016) who showed that the sand fraction was significantly ($p \leq 0.05$) different along soil depths, while the silt and clay fractions were not statistically different due to soil depths.

The highest average sand content (43%) was observed under the FL. The result of this study was in line with (Mengstu *et al.*, 2017) who described the highest sand content under FL than CUL; similarly, Habtamu (2018) reported the maximum mean sand content on the surface layer of FL followed by the surface layer of grazing land. The average silt content was highest in ENFL (46.5%) and lowest (31.5%) FL (Table 3). The highest clay fraction (30.30%) was recorded on CUL compare to the adjacent three LUTs (Table 3). The result is in agreement with the finding of (Achalu *et al.*, 2012 and Berhanu, 2016) who reported highest clay content under CUL as compared to forest and grazing land. The highest clay percent observed in the soils of the CUL might be due to the degree of weathering and tillage activities. In all the LUTs, except sand, the contents of clay and silt fractions increased with depth (Table 3). This could be due to downward movement of clay particles. Except CUL and subsurface soils the result shows that the textural classes of the study area were loam (Table 3). A textural class of CUL and subsurface layer were clay loam. Even though soil texture was the inherent soil physical properties, LUTs might have contribute indirectly for the change in soil texture as a result of removal through pedologic process such as erosion, deposition and weathering (Brandy and Weil, 2002).

Considering the two SDs, higher (36.4%) and lower (30.8) mean sand fraction was observed within the surface (0-20cm) and subsurface (20-40cm) soils (Table 3). In contrast, higher silt (40.9%) and clay (28.3%) and lower silt (39.3%) and clay (24.3%), fractions were found in the subsurface and surface soils, respectively (Table 3). Similarly, (Shiferaw, 2004; Mengstu *et al.*, 2017 and Abera and Kefeyalew, 2017) mentioned an increase in clay content with depth under CUL due to long period of cultivation, Mulugeta *et al*. (2019) found higher sand content at the surface (0-20 cm) soil layer, whereas the higher silt and clay have been recorded in the subsurface (20-40 cm) of soil layer. The reason might be due to the preferential removal of clay particles and its downward movement into the subsurface soil layer through the method of clay migration.

Table 3. Main effect of LUTs and SDs on soil particle distribution of the soil of Moche

| Land use types (LUTs) | Selected soil physical properties | | | |
|---|---|---|---|---|
| | Soil particle distributions (%) | | | Textural class |
| | Sand | Silt | Clay | |
| CUL | 26.50$^{b}$ | 43.20$^{ab}$ | 30.30$^{a}$ | CL |
| ENFL | 26.20$^{b}$ | 46.50$^{a}$ | 27.30$^{a}$ | L |
| EUCL | 38.7$^{a}$ | 39.30$^{b}$ | 22.00$^{a}$ | L |
| FL | 43.00$^{a}$ | 31.50$^{c}$ | 25.50$^{a}$ | L |
| LSD$_{(0.05)}$ | 5.01 | 5.91 | 7.87 | |
| | | Soil depth (SD) | | |
| 0-20cm | 36.40$^{a}$ | 39.30$^{a}$ | 24.30$^{a}$ | CL |
| 20-40cm | 30.80$^{b}$ | 40.90$^{a}$ | 28.30$^{a}$ | L |
| LSD $_{(0.05)}$ | 3.54 | 4.18 | 5.56 | |
| CV (%) | 12.06 | 11.90 | 24.19 | |
| SE(±) | 1.80 | 1.43 | 1.30 | |

Main effect means within a column followed by the same letter(s) are not significantly different from each other at $p < 0.05$. LSD=list significant difference; CV = coefficient of variation; SE = standard error, LUT = land use type; SD = soil depth, CL = clay loam and L = loam.

### 4.1.2. Bulk density ($gcm^{-3}$)

The bulk density of soils of the study area showed highly significant variations due to land uses ($p < 0.001$), soil depths ($p < 0.001$) and interaction effects of land uses by soil depth ($p < 0.01$) (Table 4 and Appendix 1). The highest mean ($1.37gcm^{-3}$) value of bulk density was observed under the subsurface soils of CUL and the lowest mean ($1.06gcm^{-3}$) value was recorded under the surface soils of FL and ENFL (Table 4 and Appendix 1). Yihenew and Getachew (2013) found similar result of present study that showed the highest bulk density was found in the CUL at both Abechikeli Mariam and Aferfida Georgis, Achefer district, northwestern Ethiopia. Also, in line with other authors (Mulugeta *et al.*, 2019; Daneil , 2020 and Weldesemayat and Nandita, 2020) who found highest bulk density on CUL than the adjacent land uses (forest, grass and grazing land and Eucalyptus woodlot); Gebeyaw (2007) obtained lowest value of bulk density recorded under soils of forest land.

As many research results indicated, the change of bulk density in the CUL might be attributed to the commonly intense tillage activities practiced by the farmers. Intense tillage practices often temporarily loosen the tilled soil layer while compacting of the layer beneath and depletion of OM which then increase bulk density. In addition, the continuous exposure of the soil surface to the direct impact of rain drops under fields with long period of continuous cultivation might have also contributed to the increment of bulk density as raindrop impacts cause soil compaction through disintegration of the soil structure (Landon 1991; Brady and Weil 2002 and Nieder and Benbi, 2008) continuous cultivation tends to raise the bulk density, i.e., to compact the soil and thus reduce infiltration, aeration or root growth and to raise the energy needed for cultivation.

Under all LUTs, bulk density of soil was increased with SDs (Table 4). This is in line with the findings of (Abera and Kefeyalew, 2017 and Singh *et al.*, 2018) who reported an increase of bulk density of soil with increasing of soil depth. The reason for highest bulk density for subsurface soil might be the result less OM content and the reason for lowest bulk density on surface soils of FL and ENFL could be highest OM content (Table 4 and 5). This is agreed with Landon (1991) there is very often a tendency for bulk density values to rise with depth, as effects of cultivation and organic matter content decrease. Bulk density was negatively and significantly correlated with OM ($r = -0.51^{*}$) and $f$ ($r = -0.99^{***}$) (Table 9).

The bulk density values of soils of the studied area were found to be within range the suggested for loam soils, which ranges from 1.0– 1.4 gcm$^{-3}$ (White, 2006). In addition the classification of bulk density indicated by Hazelton and Murphy (2007) >1.9gcm$^{-3}$ very high, 1.6-1.9gcm$^{-3}$ high, 1.3-1.6gcm$^{-3}$ medium, 1-1.3gcm$^{-3}$ low and <1gcm$^{-3}$ were ranged as very low respectively. Based on this rating except subsurface soils of cultivated land which qualify medium range the bulk density of soils of the rest adjacent LUTs were rated as low range.

Table 4. Interaction effects of LUT by SD on bulk density and total porosity of the soil of Moche

| Land use type (LUT) | Bulk density (gcm$^{-3}$) | | Total porosity (%) | |
|---|---|---|---|---|
| | Soil depth | | Soil depth | |
| | 0-20cm | 20-40cm | 0-20cm | 20-40cm |
| Cultivated | $1.14b^{c}$ | $1.37^{a}$ | $56.70^{bc}$ | $48.30^{d}$ |
| Enset | $1.06^{d}$ | $1.14^{c}$ | $60.10^{a}$ | $56.86^{b}$ |
| Eucalyptus | $1.10^{cd}$ | $1.23^{b}$ | $58.37^{ab}$ | $53.70^{c}$ |
| Forest | $1.06^{d}$ | $1.09^{cd}$ | $60.10^{a}$ | $59.0^{ab}$ |
| LSD$_{(0.05)}$ | 0.08 | | 3.05 | |
| CV (%) | 4.03 | | 3.08 | |
| SE(±) | 0.02 | | 0.84 | |

Interaction effect within a column specific soil parameter followed by the same letter(s) are not significantly different from each other at $p < 0.05$; LSD = least significant difference; CV = coefficient of variations SE = standard error.

### 4.1.3. Total porosity (%)

Statistically total porosity ($f$) was affected ($p<0.01$) by interaction of LUTs and SDs (Table 4 and Appendix 1). The highest mean value (60.1%) of total porosity was recorded on the surface soils of FL and ENFL and the lowest mean value (48.3%) was recorded under subsoil of CUL on soil of the study area. The result of present study was in line with the finding of (Weldesemayat and Nandita, 2020) who reported that highest and lowest total porosity under natural forest and agricultural (cultivated) lands compared to other adjacent lands (bamboo forest and degraded forest) at Barkachha, Mirzapur district, Varanasi, India.

In contrast to bulk density, total porosity was decreased with SD under all LUTs (Table 4). Percentage of total porosity varies from the surface soils (60.10%) to the subsurface soils (48.3%). This might be as a result of lowest OM content of the EUCL, the CUL and the subsurface soil and the increase in bulk density with SD, respectively. Finding reported by Wakene (2001) also indicated lower total porosity in the CUL and subsoil depths was a result of low OM in the Dystric Nitosols of Bako area. The reason for the highest mean value under FL and ENFL might be relatively higher OM content, household refuse for ENFL and microbial activities. When soil porosity was become high it indicates that the soil has a better aggregation and better conditions for crop production and to provide good aeration for microorganisms. The result of total porosity shows relatively FL and ENFL were well aerated and suitable for plant root penetration and microorganisms under soils of the studied area. This was in agreement with the finding of (Mulugeta *et al*., 2019) who described the high total porosity of the soil means that the less problem of water logging and surface runoff. Generally, this study clearly indicated that total porosity of soil of the study area has been affected by the land use types and soil depths.

Unlike soil bulk density, total porosity was significantly and positively associated with the OM content ($r = 0.51^{*}$) and negatively associated with the sand ($r = -0.49^{*}$) fraction and highly strongly associated with total porosity with bulk density ($r = -0.99^{***}$) of the soils in the study area (Table 9).

## 4.2.Effect of Land Use Types on Selected Soil Chemical Properties

### 4.2.1. Soil reaction (pH-$H_2O$)

The soils pH-$H_2O$ (1:2.5 soil to water ratio) value was found to be highly significantly affected by LUTs ($p < 0.001$), SD ($p < 0.001$) and the interaction of LUTs by SD ($p < 0.05$) (Table 5 and Appendix 1). With regard to the interaction effects of LUTs and SD the highest (6.54) and lowest (4.82) mean pH-$H_2O$ values were observed under the surface soils and the subsurface soil of ENFL and EUCL, respectively (Table 5). The higher value of pH under surface soils of ENFL could be due to application of manure, house refuses and wood ash that result in higher value of exchangeable bases. This was in agreement with the finding of (Alemayehu and Sheleme, 2013) who reported the pH value under enset was found to be the highest followed by maize at both sampling depths in Sodo Zuria Woreda of Wolaita zone Southern Ethiopia. Binyam (2015) showed that soil pH significantly varied among land uses. Similar to current study, the findings of Yihenew and Getachew (2013) showed the lowest pH values under the Eucalyptus plantation at Abechikeli Mariam and Aferfida Georgis sites, Achefer district, northwestern Ethiopia and they justified the cause as evidence soils under Eucalyptus plantations were more acidic, owing to more uptakes of basic cations by the trees and poor return rate to the soil.

According to Foth (1990) and USDA (1999) the rating class of soil pH level < 4.5 is rated as extremely acidic, 4.5-5.0 very strongly acidic, 5.1-5.5 strongly acid, 5.6-6.0 moderately acidic, 6.1-6.5 slightly acidic and 6.6-7.3 is rated as neutral. Based on this classification, the pH range of soils of the studied area was rated as very strong to slightly acidic and surface soils of ENFL was slightly acidic, FL moderately acidic while CUL and EUCL were strongly and very strongly acidic, respectively. This is in line with study conducted by (Birru *et al.*, 2013; Alemayehu and Sheleme, 2013 and Mensah, 2016) who found to be lowest value and strong acidic pH under soils of EUCL. The reason for lower soil pH might be due to the depletion of basic cations during crop harvest and loss of basic cation due to soil erosion.

Based on the above rating class except EUCL the pH of surface soils of other LUTs were moderate to slightly acidic and subsurface soil was strongly acidic. But the surface and subsurface soils of EUCL was strong and very strongly acidic. In general, under all LUTs pH values decreased with increasing SD (Table 5). The reason could be due to low OM content, the decrease of basic cations (Ca, Mg and K ions) with soil depth which lowers soil pH from top to down the soil layers (Table 5 and 7). As indicated by (Table 9) soil pH was strongly and positively correlated with OM (r = 0.66** and av.P (r = 0.71***), negatively correlated with ExA (r = -0.58*) and basic cations and CEC were significantly positively correlation with a soil Ca (r = 0.54*), Mg (r = 0.59*) and CEC (r = 0.47*).

Soil pH also exerts a very strong effect on the solubility and availability of many nutrient elements. It influences nutrient uptake and root growth, it controls the presence or activity of many soil microorganisms. Most nutrient elements are available in the pH range of 5.5–6.5 and below pH 5.5, the availability of the essential elements P and Mg decline, while the concentration of Al, Mn, and for some soils Cu, begin to advance into the toxic range. The interaction between elements, such as P and Al, result in the formation of complexes that reduce P availability (Vgote, 2015; Jones, 2012 and Motsara and Roy, 2008). So, the soil pH of ENFL and FL of the study area could not influence on the availability of plant nutrients but the soil pH of the CUL in the study area might cause for the unavailability of essential plant nutrients and fixation of P with Al and growth and development of grains and vegetable might be affected. In addition, when an $Al^{3+}$ ion is displaced from an exchange site into the soil solution, it hydrolyzes, splitting water and releasing a hydrogen ion to solution (Vgote, 2015). When soil pH is lower than optimal (5.5 and below) reduces the solubility of nutrients needed for growth. Conditions also usually lead to Al and Mn toxicity plus deficiency in N, P, K, Mg, Ca and various micronutrients (Gete *et al*., 2010 and Abreha *et al*., 2013). This has multiple implications for plant growth and other soil fertility issues: can lead to lack of or reduced response to Ammonium Phosphate and Urea fertilizers, stunted root and plant growth due to nutrient deficiency (yields frequently reduced by 50 percent and can be reduced to 0), increased incidence of disease, and toxicity (e.g. for Mn: black spots and streaks on leaves) (Gete *et al*., 2010). Similarly, soil pH of EUCL and CULs of the studied area were below the optimum range and has great impact on crop growth.

Table 5. Interaction effects of LUT by SD on pH, OM and av.P of soil of the study area.

| Land use types (LUTs) | pH | | OM | | av.P | |
|---|---|---|---|---|---|---|
| | SD (cm) | | SD(cm) | | SD(cm) | |
| | 0-20 | 20-40 | 0-20 | 20-40 | 0-20 | 20-40 |
| CUL | $5.54^{b}$ | $5.13^{bc}$ | $4.78^{b}$ | $3.91^{cd}$ | $9.27^{de}$ | $7.4^{e}$ |
| ENFL | $6.54^{a}$ | $5.15^{bc}$ | $7.08^{a}$ | $3.95^{cd}$ | $22.69^{a}$ | $16.97^{b}$ |
| EUCL | $5.28^{bc}$ | $4.82^{c}$ | $4.39^{bc}$ | $3.47^{d}$ | $7.57^{e}$ | $5.02^{f}$ |
| FL | $5.64^{b}$ | $5.45^{b}$ | $7.39^{a}$ | $3.70^{d}$ | $12^{c}$ | $10.6^{cd}$ |
| $LSD_{(0.05)}$ | 0.54 | | 0.63 | | 2.19 | |
| CV (%) | 5.71 | | 8.05 | | 10.92 | |
| SE(±) | 0.18 | | 0.21 | | 1.16 | |

Interaction effect within a column followed by the same letter(s) are not significantly different from each other at $p < 0.05$; LSD = least significant difference; CV = coefficient of variation; SE = standard error; pH = power of hydrogen, OM = organic matter and av.P = available phosphorus and LUT = land use type, CUL = cultivated land, ENFL = enset farm land, EUCL = eucalyptus land, FL = forest land and SD = soil depth.

### 4.2.2. Organic matter (%)

Organic matter content was significantly ($p < 0.05$) affected by the interaction of LUT by SD. Considering the interaction effect of LUT by SD, the highest (7.39%) value of OM content was recorded under surface (0-20cm) soil of FL followed by ENFL (7.08%) and the lowest (3.47%) values of OM contents were recorded at the subsurface (20-40cm) layer of EUCL, respectively (Table 5 and Appendix 1). This might be due to the fact that in FL and ENFL, falling of plant materials could increase soil OM. This result was in line with the finding of (Lechisa *et al*., 2014; Yihenew *et al*., 2015; Eyayu and Mamo, 2018; Mulugeta, 2018 and Dereje, 2016) who reports highest OM content on the surface soil layer of FL. As indicated by Singh *et al*. (2018) the reason for soil enrichment in soil OM content under tree based systems might be because of several factors such as addition of litter, annual recycling of fine root biomass and root exudates. And the reason for lowest mean value of OM under EUCL was might be less decomposition rate of the eucalyptus leaves (Daniel, 2020). According to the rating of OM indicated by (FAO, 2006) and Ethiosis team (2014), very low (< 2%), low (2-3%), optimum (3-7%) and high (7-8%). Based on these rating, except the surface soils of ENFL and FL the range of OM qualifies optimum range but surface soils of ENFL and FL qualifies high range.

Under soils of all LUTs OM content was decreased with increasing with SD (Table 5). This was in agreement with the finding of (Alemayehu and Sheleme, 2013; Behailu *et al*., 2014; Eyayu and Mamo, 2018; Singh *et al*., 2018 and Mulugeta, 2018) the reason for the higher mean value of OM content on the surface soils might be higher plant leaf, litter, root biomass and microbial activities that involve in decomposition process than subsurface layer. As listed by (Table 9) soil OM was strongly and positively correlated with pH ($r=0.66^{**}$), CEC ($r=0.62^{**}$) and available phosphorous ($r = 0.53^{*}$), total porosity ($r=0.51^{*}$) and negatively correlated with bulk density ($r = -0.51^{*}$).

### 4.2.3. Available phosphorous (mg $kg^{-1}$)

In the soil of the present study area the available phosphorus (av.P) was significantly ($p < 0.05$) affected by the interaction of LUT with SD (Tables 5 and Appendix 1). The highest (22.69 mg $kg^{-1}$ and the lowest (5.02mg $kg^{-1}$) of av.P contents were recorded at the surface soil (0-20 cm) layer of the ENFL and the subsoil layer of EUCLs, respectively (Table 5). The lowest value of av.P content under EUCL and CULs might be due to low soil pH value and highest value of exchangeable acidity and aluminum under EUCL and which may result in fixation problem (Table 5 and 8). This was in agreement with (Alemayehu and Sheleme, 2013) who reported highest value of av.P under enset farms followed by maize and grassland soils. The reason for significant differences and higher available P content under ENFL with the rest LUTs might be due to the consequence of long-term manure and house refuse applications and the associated increase in microbial activity (Alemayehu and Sheleme, 2013) and due to high soil pH value under soils of enset farm land.

As indicated in Table 5 the status of av.P was decreased down with increasing depth under soils of all LUTs. This was agreed with the finding of Eyayu and Mamo (2018), which showed the av.P decreased by 3.75% with increasing SD. Similarly, the result of current study showed the status of av.P was decreased with SD by 11.67%, 20.2%, 25.21% and 33.68% under soils of FL, CUL, ENFL and EUCL, respectively. Lower soil pH value in the subsurface soils, soil acidity, depletion of nutrients by crop and decline in soil OM with depth might be the reason for the reduction of the av.P status in subsurface than surface layer of the studied area. Similar to the current study, Yihenew and Getachew (2013) assured that the values of av.P in all land use systems decreased with increasing SD.

According Hazelton and Murphy (2007 and 2016), soil available P rated as <5 mg $kg^{-1}$ very low, 5 –9 mg $kg^{-1}$ low, 10-17mg $kg^{-1}$ medium, high 18-25 mg $kg^{-1}$ high and >25 mg $kg^{-1}$ very high. Based on the above rating range the soils of CUL and EUCL were qualified low, FL and subsurface soils of ENFL were qualifies medium and surface soils of ENFL was qualified high status, respectively. The content of av.P was positively correlated with pH (r = 0.71***), K (r = 0.82***), Ca (r = 0.65**), CEC (r = 0.59*), OM (r = 0.53*) and negatively correlated with ExA (r = -0.82***) and EAl (r = -0.84***) (Table 9).

The main reason for low content of available P in soils of the studied area might be related to soil acidity. This was in line with finding of many authors as mentioned below. It might be acidic reaction in which free oxides of Fe and Al tend to fix P on the exchange sites Bereket *et al*. (2018). According to McGrath and Penn (2014) inorganic P in acidic soils not taken by plants can be fixed or sorbed by iron (Fe) and Al oxides, clay minerals or precipitate as Fe and Al minerals. According to Adnan *et al*. (2003) phosphorus is deficient in most acid soils because soluble inorganic P is fixed by Al and Fe. This reaction contributes to less availability of P for crops. The main reasons of low available P under most of Ethiopian soils are the impacts of fixation, abundant loss by crop harvest and erosion (Asmare *et al*. 2015 and Wolde *et al*. 2015). Growing agricultural crops implies that nutrients (N, P, K, etc.) are removed from the soil through the agricultural produce (food, fibre, wood) and crop residues. Nutrient removal may result in a decline of the soil fertility if replenishment with inorganic or organic nutrient inputs is inadequate (Hartermink, 2007). The result of this study demonstrated that av. P was influenced by LUTs and unavailability of P except in the surface soils of ENFL.

### 4.2.4. Cation exchange capacity (cmol (+) kg$^{-1}$)

The cation exchange capacity (CEC) of the soils in the study area was significantly ($p < 0.01$) affected by the interaction of LUT and SD (Tables 6 and Appendix 1). The highest CEC value (37.96 cmol $_{(+)}$ kg$^{-1}$) was recorded at the surface layer of the FL, whereas the lowest (11.90 cmol $_{(+)}$ kg$^{-1}$) was observed at subsurface layer of the EUCL (Table 6). This is in line with the finding of Gebeyaw (2007) who indicated that the highest value of CEC on surface soils of FL. It is a general truth that both clay and colloidal OM have the ability to absorb and hold positively charged ions. Thus, soils containing high clay and OM contents have high CEC. The reason for the highest value of CEC on the surface (0-20cm) of FL might be due to presence of higher OM content (Table 5), the pH range which exists and low erosion on the surface of forest and prevent the basic cations form erosion.

The study that conducted by Mulugeta (2018) due to the presence of high OM under FL highest CEC value was recorded on soils of FL rather than the adjacent other LUTs (cultivated, grazing and grass lands) and also the findings of (Teshome *et al*., 2013) indicated that the CEC of soil was higher in FL compared to that of the adjacent grazing and CULs. Additionally, Lechisa *et al.* (2014) reported the highest CEC was observed in

FL followed by grazing land. Meseret *et al.* (2015) also reported the rate of CEC in the soils of natural forest was described as very high compared to the other LUTs. Eyayu and Mamo (2018) indicated the highest values of CEC were detected under the forest. Similar to the results of many authors, considering the interaction effects of LUT by SD, the result of current study showed the values of CEC was affected by LUT and SDs (Table 6).

The highest value of CEC was recorded on the surface than subsoil except CUL (Table 6). This indicates the value of CEC was dropped down by 28% with soil depth. The finding of this experiment agreed with (Behailu *et al*., 2014; Abera and Kefeyalew, 2017 and Eyayu and Mamo, 2018) who reported the values of CEC decreased consistently from the surface to the subsurface horizons. The decrease in CEC with depth could be due to the strong association between OM and CEC as it is also evident from the fact that the higher CEC among the SDs studied were obtained on the surface of FL soil, which also contained the higher OM (Table 5, 6 and 9). Under CUL the value of CEC was increased with SD. This might be due to migration of basic cations and incorporation of OM during tillage practices. As indicated by Landon (1991) the top soil having the CEC of <5 (cmol$_{(+)}$kg$^{-1}$) classified as very low, 5-15 ( cmol$_{(+)}$kg$^{-1}$) low, 15-25 (cmol$_{(+)}$kg$^{-1}$) medium, 25-40 (cmol$_{(+)}$kg$^{-1}$) high and >40 ( cmol$_{(+)}$kg$^{-1}$) very high. Based on these rating the status of CEC of the study area was qualifies from low to high. The surface and subsurface soils of FL and surface soils of ENFL were qualifying for high, the surface soils of EUCL and the subsurface soils of ENFL and CUL were medium and the surface and subsurface soils of CUL and EUCL were qualifying low range, respectively (Table 6).

The reason for the low CEC on EUCL might be the high uptake nutrient demand and depletion of positive cations by eucalyptus trees. The CEC of the soil was significantly and positively correlated with OM (r = 0.62**), pH (r = 0.47*), Mg (r = 0.59*), K (r = 0.49*) and negatively and strongly correlated with ExA (r = -0.63**) and ExAl (r = -0.73***) (Table 9). The negative correlation of CEC with ExA and EAl indicates that soils with high ExA and ExAl have lower CEC. Comparing to the four adjacent LUTs both eucalyptus and cultivated lands were recorded relatively higher value of exchangeable acidity, aluminum and lower value of CEC. Thus, the lower CEC value might be the influence of the reduction in status of OM content, higher value of exchangeable acidity and Al.

A high CEC is regarded as favorable as it contributes to the capacity of soils to retain plant nutrient cations. Based on the above result of CEC growing of eucalyptus trees on the lands that could be used for crop growing, may compute with basic cations, influence status of soil fertility, and it has negative impact on crop productivity. In addition, deforestation and changing of land from forest to crop land without proper management aggravates soil fertility reduction. Therefore, the result of this study shows that the CEC of the FL and ENFL were significantly higher than other adjacent LUTs and relatively more fertile than soils of CUL and EUCL.

Table 6.Interaction effects of LUT by SD on exchangeable Ca and CEC on the soil of Moche.

| Land use type (LUT) | Ca ($cmol_{(+)}kg^{-1}$) | | CEC ($cmol_{(+)}kg^{-1}$) | |
|---|---|---|---|---|
| | Soil depth (cm) | | Soil depth (cm) | |
| | 0-20 | 20-40 | 0-20 | 20-40 |
| CUL | $5.23^{d}$ | $8.30^{ab}$ | $13.83^{c}$ | $17.55^{c}$ |
| ENFL | $10.3^{a}$ | $8.10^{abc}$ | $27.89^{b}$ | $24.17^{b}$ |
| EUCL | $5.53^{dc}$ | $4.26^{d}$ | $16.63^{c}$ | $11.90^{c}$ |
| FL | $12.2^{a}$ | $9.17^{b}$ | $37.96^{a}$ | $27.17^{b}$ |
| LSD $_{(0.05)}$ | 2.72 | | 5.22 | |
| CV (%) | 22.21 | | 15.16 | |
| SE(±) | 0.49 | | 1.47 | |

Interaction effect within a column followed by the same letter(s) are not significantly different from each other at $p < 0.05$; LSD = least significant difference; CV = coefficient of variation; SE = standard error; Ca = calcium and CEC = cation exchange capacity, LUT = land use type, CUL = cultivated land, ENFL = enset farm land EUCL = eucalyptus land and FL = forest land.

### 4.2.5. Basic exchangeable cations ($Ca^{2+,}$ $Mg^{2+,}$ $K^+$ and $Na^+$)

Abdi *et al.* (2018) and Eyayu and Mamo (2018) reported that exchangeable $Ca^{2+}$ followed by $Mg^{2+}$ is the predominant cation in the exchange sites of both the surface and sub-surface soil layers. In line with this based on the average mean values of exchangeable bases (Ca, Mg K, and Na), calcium and magnesium were the dominant cations under all LUTs in the exchange complex of soils at the study area (Table 6 and 7). About 66.6%, 16.6%, 11.4% and 5.4% of the exchange sites of soil of the study area was occupied and abundant by exchangeable base of Ca, Mg, K and Na, respectively. These shows that exchangeable Ca and Mg together accounted about more than 83% exchangeable bases at the exchange site while the monovalent positive ions (K and Na) occupied about 16% of the total exchangeable basic cations in the exchange site of the study area. The descending order of basic cations distribution in the exchange site soil of the studied area was $Ca^{2+} > Mg^{2+} > K^+$ and $Na^+$ (Table 6 and 7). Similar order of distribution of these cations was reported by several studies (Teshome *et al.,* 2013; Asmare *et al.,* 2015*;* Okubay *et al.,* 2015 and Bereket *et al.,* 2018*).*

#### Exchangeable calcium ($ExCa^{2+}$)

Calcium was the predominant positive cations held on soil clays and OM particles because it held more tightly than other $Mg^{2+,}$ $K^+$ and other exchangeable cations (Kelling and Schulte, 2004). Exchangeable Ca was significantly ($p < 0.01$) affected by the interaction effect of LUT and SD (Table 6 and Appendix 1). The highest (12.2 cmol $_{(+)}$ $kg^{-1}$) exchangeable Ca was observed at the surface (0-20 cm) layer of the FL, and the lowest (4.26 cmol $_{(+)}$ $kg^{-1}$) was recorded at the subsoil layer of the EUCL, respectively. In line with Okubay (2018) who found to be the very low exchangeable Ca was observed under soils of EUCL and CUL. As indicated above the highest value of Ca was recorded under surface soils of FL and the value of Ca was decreased with depth except CUL (Table 6). The increasing of the value of Ca with depth under CUL might be due to relatively an increase of clay content with depth and also indicate that there was incorporation of OM from upper to subsurface during tillage practices, higher down ward migration of $Ca^{2+}$ in the crop field than in the other LUTs by erosion as a result of continuous disturbances of soils during cultivation. This was in agreement with the finding of (Gebeyaw, 2007) who reported similar finding about Ca under FL and subsoil, Abera and Kefeyalew (2017) who found to be lower and higher exchangeable Ca in the surface and subsurface layers of cultivated field, and the reason for the lower exchangeable Ca at the surface layer of the cultivated field could be due to removal in crop harvest, high leaching as a result of continuous cultivation and OM decomposition.

As per the rating of FAO (2006) and Hazelton (2007) >20 $\text{cmol}_{(+)}\text{kg}^{-1}$) very high, 10-20 $\text{cmol}_{(+)}\text{kg}^{-1}$) high, 5-10 ($\text{cmol}_{(+)}\text{kg}^{-1}$) medium, 2-5 ($\text{cmol}_{(+)}\text{kg}^{-1}$) low and <2 ($\text{cmol}_{(+)}\text{kg}^{-1}$) very low. Based on these classifications of Ca the result of current study indicated the status of exchangeable Ca under soils of the studied area qualified low to high ranges. Surface soils of FL and ENFL were qualified high and the subsurface soils of EUCL was qualified low status of exchangeable Ca. Exchangeable Ca was significantly and positively correlate with OM (r = 0.53*), av.P (r = 0.65**), pH (r = 0.54*) and CEC (r = 0.65**) and negatively correlated with exchangeable acidity (r = -0.72***) and exchangeable aluminum (r = -0.57*) (Table 9).

### Exchangeable magnesium ($\text{ExMg}^{2+}$)

Exchangeable magnesium content has a statically difference ($p < 0.01$) by SD. On the other hand it was not significantly ($p > 0.05$) affected by LUT and the interaction of LUT by SD (Table 7 and Appendix 1). Even though it was not significantly affected by LUT, the mean exchangeable Mg value was highest (2.63 $\text{cmol}_{(+)}\ \text{kg}^{-1}$) under the ENFL followed by FL (2.52 $\text{cmol}_{(+)}\ \text{kg}^{-1}$) and lowest (1.88 $\text{cmol}_{(+)}\ \text{kg}^{-1}$) on the CUL (Table 7). This was related to the finding of (Alemayehu and Sheleme, 2013) who found to be higher values of exchangeable Mg under enset fields. Considering to SD the contents of exchangeable Mg decreased with SD and it was statistically significant difference. Higher mean (2.56 $\text{cmol}_{(+)}\ \text{kg}^{-1}$) value of exchangeable Mg was observed on the surface soils than the subsurface layer (1.98 $\text{cmol}_{(+)}\ \text{kg}^{-1}$) (Table 7 and Appendix 1). The reason for the decrease in the value of Mg with SD might be the reduction of OM content with SD.

Table 7.The main effects of LUTs and SDs on exchangeable basic cations and PBS on the soils of Moche.

| Land use types (LUTs) | Exchangeable basic cations (cmol$_{(+)}$kg$^{-1}$) | | | PBS (%) |
|---|---|---|---|---|
| | Mg | K | Na | |
| CUL | 1.88$^{a}$ | 0.91$^{b}$ | 0.52$^{c}$ | 59$^{a}$ |
| ENFL | 2.63$^{a}$ | 3.36$^{a}$ | 0.85$^{ab}$ | 63$^{a}$ |
| EUCL | 2.05$^{a}$ | 0.95$^{b}$ | 0.69$^{bc}$ | 57.6$^{a}$ |
| FL | 2.52$^{a}$ | 1.00$^{b}$ | 0.88$^{a}$ | 68.6$^{a}$ |
| LSD$_{(0.05)}$ | 0.75 | 0.58 | 0.18 | 11.21 |
| | | SD | | |
| 0-20cm | 2.56$^{a}$ | 1.74$^{a}$ | 0.64$^{b}$ | 57.1$^{a}$ |
| 20-40cm | 1.98$^{b}$ | 1.37$^{a}$ | 0.83$^{a}$ | 56.9$^{a}$ |
| LSD$_{(0.05)}$ | 0.53 | 0.41 | 0.12 | 7.82 |
| CV (%) | 26.82 | 30.30 | 19.89 | 14.67 |
| SE(±) | 0.16 | 0.24 | 0.05 | 2.8 |

Main effect means within a column followed by the same letter(s) are not significantly different from each other at p<0.05. LSD=list significant difference; CV = coefficient of variation; SE = standard error, Mg= magnesium; K= potassium; Na= sodium; PBS = percent base saturation.

**Exchangeable potassium (ExK$^{+}$)**

Exchangeable K content was significantly ($p < 0.001$) affected by only by LUTs (Tables 7 and Appendix 1). This agreed with the finding of Mulugeta (2018) who showed that exchangeable K was significantly ($p < 0.001$) affected by LUTs. But it was not significantly affected by SD and the interaction of LUTs with SD. The highest (3.36 cmol $_{(+)}$ kg$^{-1}$) value was obtained in the ENFL and lowest (0.91cmol $_{(+)}$ kg$^{-1}$) in the CUL. In line with Alemayehu and Sheleme (2013) indicated concentration of exchangeable K followed trend of being enset field > grass land >maize farms. The highest K content in the ENFL was may be related with the application of animal manure, wood ash and high pH value of ENFL rather than other adjacent LUTs of the studied area. Similar to the result of present study, Wasse and Abebe (2013) indicated significantly higher content of K was obtained in the leaf samples of *Ensete ventricusom* than *E. brucei* and *E. abyssinica* and it could be due to the fact that, enset receives high amount of fertilizers in the form of organic material, Behailu *et al*.(2014) indicated higher K content under ENFL than grazing and CULs and the reason for the higher exchangeable K in the ENFL could be due to application of ashes, Okubay (2018) stated the highest exchangeable K recorded on the home garden while the lowest was obtained on the cultivated field. Agreed with this result (Mesfin, 1996) also reported that high K was recorded under high pH tropical soils and Fairhurst (2012) indicated K is released rapidly from animal manures and crop residues. The lowest status of exchangeable Ca, Mg and K contents in the cultivated and the eucalyptus lands might be due to its continuous losses through harvested and high uptake demand of cations from the cultivated land and eucalyptus trees, respectively.

The finding of this result in lined with the finding of (Okubay, 2015), the lower value of exchangeable K in cultivated soil may be related to intensive cultivation and removal of base cations during crop harvest that enhanced its depletion. Other authors Saikh *et al* (1998) and Heluf and Wakene (2006) who stated intensive cultivation affected the distribution of K in the soil and enhanced its depletion. As per the rating indicated by Hazelton and Murphy (2007) the level of exchangeable K was rated as 0-0.2 very low, 0.2-0.3 low, 0.3-0.7 moderate, 0.7-2 high and >2 $cmol_{(+)}kg^{-1}$ very high. Based on these rating very high (3.36cmol $_{(+)}$ $kg^{-1}$ value of exchangeable K was recorded under soils of ENFL (Table 7). Exchangeable K was positively and significantly correlated with av.P (r = 0.83***), pH (r = 0.49*), Ca (r =0.53*), CEC (r = 0.41*), and negatively and significantly correlated with ExA (r = -0.65**), ExAl (r = -0.74***), sand (r = -0.41*) (Table 9). The increase in competition of $Al^{3+}$ and $H^+$ ion is one of the main reasons for the decrease in $K^+$ availability in acid soils (McGranth and Penn, 2014). This strengthens by the significant and negative association of ExA and significant and positive association of soil pH with $K^+$.

**Exchangeable sodium ($ExNa^+$)**

The status of exchangeable Na was significantly affected ($p < 0.01$) by LUT and SD (Tables 7 and Appendix 1). But exchangeable Na content was not significantly ($p > 0.05$) affected by interaction of LUT with soil depth. Considering the main effects of LUT, exchangeable Na content was highest (0.88 cmol $_{(+)}$ kg$^{-1}$) under the FL and lowest (0.52 cmol $_{(+)}$ kg$^{-1}$) in the CUL (Table 7). This result was in agreement with Habtamu *et al*. (2014) who obtained highest and lowest exchangeable Na under surface soils of FL and CULs, respectively. With regard to SD the higher status of Na was observed on subsoil (0.83 cmol $_{(+)}$ kg$^{-1}$) than surface (0.64cmol $_{(+)}$ kg$^{-1}$) soil layer (Table 7). This was in line with the finding of (Eyayu and Mamo, 2018) who found to be the higher exchangeable Na at the 20-40 cm depth. As indicated by FAO (2006), the rating of sodium was <0.1cmol $_{(+)}$ kg$^{-1}$) very low, 0.1-0.3 low, 0.3-0.5 medium, 0.5-1 high and >1 very high. Accordingly the status of Na on soils of the study area was categorized as high.

Generally, under CUL except Ca the value of the rest three basic cations were recorded the lowest mean value. This indicated change in LUT, low recycling of crop residue in the soil, very low application of chemical fertilizers; continuous cropping and soil erosion may have a great contribution to depletion of basic cations and CEC on the CUL. In addition, high uptake of basic cations and low return of OM, allelophatic effect by eucalyptus trees and lower soil pH and higher value of soil acidity cause for low fertility status under soil of EUCL compared to the other adjacent LUTs.

### 4.2.6. Percent base saturation (%)

PBS was not significantly ($p < 0.05$) affected by LUTs, SDs and the interaction of LUTs and SDs (Appendix 1) and related to the finding indicated by Eyayu and Mamo (2018). Considering the main effects of land use, the highest value was obtained under FL (68.6%) followed by ENFL (63%) and the lowest (57.6%) values were recorded under the EUCLs, respectively (Table 7). The highest PBS indicates that the fertility status (Alemayehu and Sheleme, 2013) similarly highest value of PBS under FL and ENFLs showed that more fertile as compared to that of the rest two LUTs. On the other hand, among the two SDs, higher value (57.1%) was observed in the surface layer than the subsoil layer. The rating of PBS as classified by Landon (1991) and Hazelton and Murphy (2007) >80 % very high, 60-80 % high, 20-60 % medium and 0-20 % low. Based on these rating FL and ENFL were qualifying the high status and CUL and EUCL were under medium status. This indicates that the soil under FL and ENFLs were relatively more fertile than others LUTs because soil with a high PBS contain greater amount of the essential plant nutrients ($K^+$, $Ca^{2+}$ and $Mg^{2+}$). The reason for higher PBS were recorded under the soils of FL and ENFLs could be associated with higher OM content and high protection of soil by plants canopy from impact of erosion under both LUTs and addition of house refuse and manure to soils of ENFL that enhance accumulation of exchangeable basic cations.

The lower value of PBS under soils of EUCL and CULs were might be depletion of basic cations and higher soil acidity. In agreement with the study conducted by (Bereket *et al*., 2018) the possible reason for the low PBS value of soils might be the loss of soluble basic cations through leaching and erosion and similarly other Ethiopian soils also revealed low values of PBS in acidic soils possibly due to intensive cultivation, enhanced loss of basic cations through leaching and erosion (Getachew and Heluf 2007 and Mohammed *et al*., 2016). The status of PBS on soils of CUL is medium and it may be limit crop production and need to apply additional nutrients to increase yield.

### 4.2.7. Exchangeable acidity (cmol (+) kg$^{-1}$)

The analysis of ANOVA showed that exchangeable acidity (ExA) was significantly affected by LUTs ($p < 0.001$) and SDs ($p < 0.01$). But it was not significantly ($p > 0.05$ affected by interaction of LUTs and SDs (Table 8 and Appedix 1). In line with the finding of the study by (Mengstu *et al*., 2017) the exchangeable acidity was not significantly ($p> 0.05$) affected by LUT and SD interaction. Considering the main effect of LUTs the mean exchangeable acidity values under CUL and EUCL 1.33 cmol$_{(+)}$kg$^{-1}$) and 1.85 (cmol$_{(+)}$kg$^{-1}$) respectively and there was a statistical significant differences between each other (Table 8). And based on SD highest value (1.29 cmol $_{(+)}$ kg$^{-1}$) of exchangeable acidity was recorded under the subsoil layer than the surfaces (1.04 cmol $_{(+)}$ kg$^{-1}$). The highest mean value of ExA was observed under soils of EUCL (1.85 cmol $_{(+)}$ kg$^{-1}$and CUL (1.33 cmol $_{(+)}$ kg$^{-1}$. Similar results was reported by (Mensah, 2016) the higher exchangeable acidity ($p < 0.05$) found in the eucalyptus plantation soil is attributed to the low soil pH. As suggested by Okubay (2018), reason for highest status of exchangeable acidity under EUCL indicates the acidifying effect of the eucalyptus tree. However, it has no significant impact on the tree itself as one can see good growth of the trees. The existence of a high level of soil acidity on the eucalyptus plantation is being attributed to the uptake of more basic cations into the trees biomass and low return through its leaf drop and the high status of acidity on cultivated fields indicate the marked influence of continuous cultivation and removal of basic cations by crop uptake and low soil pH value.

The lower the pH of the soil, the higher will be the concentrations of ExAl and ExA (Bereket *et al*., 2018). The reason for highest value of exchangeable acidity on soils of EUCL and CUL may be due to low soil pH and allelophatic impacts of eucalyptus trees and intensive cultivation and application of inorganic fertilizer on soils of CUL. As indicated by (Table 5) the decrease in soil pH under EUCL and CUL may be related to higher availability of Al in the soil solution.

Table 8. The main effect of LUTs and SDs on ExA, ExAl and ExH on soils of Moche

| Land use types | Exchangeable acidity (cmol $_{(+)}$ kg$^{-1}$) | | |
|---|---|---|---|
| (LUTs) | ExA | ExAl | ExH |
| CUL | 1.33$^{b}$ | 0.69$^{b}$ | 0.63$^{ab}$ |
| EUCL | 1.85$^{a}$ | 0.90$^{a}$ | 1.0$^{a}$ |
| LSD$_{(0.05)}$ | 0.33 | 0.16 | 0.43 |
| | | Soil depth (cm) | |
| 0-20 | 1.04$^{b}$ | 0.48$^{a}$ | 0.59$^{a}$ |
| 20-40 | 1.29$^{a}$ | 0.57$^{a}$ | 0.72$^{a}$ |
| LSD$_{(0.05)}$ | 0.24 | 0.12 | 0.31 |
| CV (%) | 23.2 | 26.4 | 30.4 |
| SE (±) | 0.13 | 0.07 | 0.09 |

Main effect means within a column followed by the same letter are not significantly different from each other at $p < 0.05$. LSD = list significant difference; CV = coefficient of variation; SE = standard error, ExA = Exchangeable acidity, ExAl = exchangeable aluminum and ExH = exchangeable hydrogen.

#### 4.2.7.1.Exchangeable Aluminum (cmol (+) kg$^{-1}$)

The analysis of ANOVA showed that exchangeable aluminum (ExAl) was highly ($p < 0.001$) affected by LUTs. But it was not significantly ($p > 0.05$ affected by SD and interaction of LUTs by SD (Table 8 and Appedix 1). Considering the main effect of LUTs the mean ExAl values under CUL and EUCL 0.69 cmol $_{(+)}$ kg$^{-1}$) and 0.90 (cmol $_{(+)}$ kg$^{-1}$), respectively. And there was a statistical significant difference between each other (Table 8). And based on SD higher value (0.57 cmol $_{(+)}$ kg$^{-1}$) of ExAl was recorded under the subsoil layer than the surfaces (0.48 cmol $_{(+)}$ kg$^{-1}$). Similar results reported by (Mensah, 2016) the higher exchangeable acidity ($p < 0.05$) found in the eucalyptus plantation soil is attributed to the low soil pH. When the soil pH is too low, aluminum cations that are toxic to many plant roots can inhibit plant growth and some nutrients become unavailable to plants (Hazelton and Murphy, 2016).

#### 4.2.7.2.Exchangeable hydrogen (cmol $_{(+)}$ kg$^{-1}$)

The analysis of ANOVA showed ExH was statically ($p<0.05$) affected by LUTs and but not affected by SDs and the interactions of the two factors (Table 8 and Appendix 1). Considering to the main effect of LUT the higher (1.0 cmol $_{(+)}$ kg$^{-1}$) mean value was obtained under soils of EUCL (Table 8). With regard to soil depth the lower (0.59) content of exchangeable hydrogen was recorded on the surface than subsurface (0.72 cmol $_{(+)}$ kg$^{-1}$) soils.

Table 9. Pearson’s correlation matrix of selected soil physicochemical properties.

| | OM | Av.P | pH | CEC | Ca | Mg | K | Na | PBS | ExA | ExAl | Clay | Silt | Sand | ρb | *f* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OM | 1 | | | | | | | | | | | | | | | |
| Av.P | 0.53$^{*}$ | 1 | | | | | | | | | | | | | | |
| pH | 0.66$^{**}$ | 0.71$^{***}$ | 1 | | | | | | | | | | | | | |
| CEC | 0.62$^{**}$ | 0.59$^{*}$ | 0.47$^{*}$ | 1 | | | | | | | | | | | | |
| Ca | 0.53$^{*}$ | 0.61$^{**}$ | 0.54$^{*}$ | 0.65$^{**}$ | 1 | | | | | | | | | | | |
| Mg | 0.35 | 0.37 | 0.59$^{*}$ | 0.41$^{*}$ | 0.08 | 1 | | | | | | | | | | |
| K | 0.31 | 0.83$^{***}$ | 0.49$^{*}$ | 0.41$^{*}$ | 0.53$^{*}$ | 0.32 | 1 | | | | | | | | | |
| Na | -0.06 | 0.27 | -0.10 | 0.33 | 0.22 | -0.27 | 0.21 | 1 | | | | | | | | |
| PBS | -0.21 | 0.06 | 0.08 | -0.61$^{**}$ | 0.13 | -0.14 | 0.24 | -0.30 | . 1 | | | | | | | |
| EA | -0.58$^{*}$ | -0.82$^{***}$ | -0.58$^{*}$ | -0.63$^{**}$ | -0.73$^{***}$ | -0.15 | -0.65$^{**}$ | -0.44$^{*}$ | -0.02 | 1 | | | | | | |
| EAl | -0.46$^{*}$ | -0.84$^{***}$ | -0.58$^{*}$ | -0.69$^{**}$ | -0.57$^{*}$ | -0.34 | -0.74$^{***}$ | -0.3 | 0.21 | 0.8$^{***}$ | 1 | | | | | |
| Clay | -0.15 | 0.04 | -0.19 | 0.03 | 0.05 | 0.03 | 0.15 | 0.18 | 0.12 | -0.28 | -0.12 | 1 | | | | |
| Silt | -0.13 | 0.29 | 0.12 | -0.22 | 0.32 | -0.11 | 0.38 | -0.23 | 0.63$^{**}$ | -0.07 | -0.16 | -0.13 | 1 | | | |
| Sand | 0.22 | -26 | 0.04 | 0.20 | -0.29 | -0.11 | -0.41$^{*}$ | -0.05 | -0.58$^{*}$ | 0.26 | 0.22 | -0.61$^{**}$ | -0.70$^{***}$ | 1 | | |
| ρb | -0.51$^{*}$ | -0.49$^{*}$ | -0.55$^{*}$ | -0.47$^{*}$ | -0.04 | -0.42$^{*}$ | -0.37 | -0.24 | 0.42$^{*}$ | 0.41$^{*}$ | 0.55$^{*}$ | 0.28 | 0.36 | -0.49$^{*}$ | 1 | |
| *f* | 0.51$^{*}$ | 0.46$^{*}$ | 0.54$^{*}$ | 0.47$^{*}$ | 0.04 | 0.42$^{*}$ | 0.37 | 0.24 | -0.42$^{*}$ | -0.41$^{*}$ | -0.55$^{*}$ | -0.28 | -0.36 | 0.49$^{*}$ | -0.99$^{***}$ | 1 |

CEC=Cation exchange capacity, Ca = calcium, Mg= magnesium, K = Potassium, Na = Sodium, PBS= Percent base saturation, ExA = Exchangeable acidity, ρb = Bulk density, *f*= Total porosity, OM = Organic matter, Av.P = available phosphorus, *, **, *** = significant at 0.05, 0.01 and 0.001 probability level, respectively.

# 5. SUMMARY AND CONCLUSION

## 5.1.Summary

The main objective of the study was to assess and evaluate the effects of different LUTs and SDs on soil fertility status in Moche, Gurage zone, Ethiopia. The result of this study helps to identify soil fertility status of different LUTs and SDs, used to recommend proper LUTs to improve soil fertility and suitable management practices and might be used as baseline information for researchers and others.

Soil samples were collected from four different adjacent LUTs. Cultivated land (annual crop land), Enset (*Enset ventricusom)* farm land, Eucalyptus plantation (*Eucalyptus globulus*) and natural forest dominated by *Juniperus procera or Habesha Tid* were selected for the study, almost with in similar sites and slope. The soil samples were taken from the selected LUTs following natural topographic variations as replications (lower, middle and upper positions) by using RCBD method. Soil samples were collected from four LUTs at two different depths (0 - 20cm and 20 - 40cm) and three replications. A total of 24 disturbed soil samples were collected from four LUTs at two different soil depths (0-20 and 20-40) and three replications. Disturbed composite soil samples were used for investigation of soil chemical analysis and undisturbed soil samples were used to determine soil bulk density. The soil physicochemical analyses were carried out at Wolkite Soil Test and Fertility Improvement Laboratory Centers using standard laboratory procedures.

As the finding of the study indicated that the sand fraction was significantly ($p < 0.001$) affected by LUTs and SD ($p < 0.01$) but not affected by their interactions. The silt fraction was significantly ($p < 0.01$) influenced by LUTs and but not significantly ($p > 0.05$) affected by SDs and the interaction of LUTs with SDs, while clay fraction was not significantly ($p > 0.05$) affected by LUTs, SD and the interaction of LUTs with SDs. Soil bulk density was significantly ($p < 0.01$) affected by interactions of LUTs and SDs. As a result of intensive cultivation and compaction of soil aggregates the highest value ($1.37gcm^{-3}$) of bulk density was recorded under subsurface soils of CUL. And the lowest value ($1.06gcm^{-3}$) of bulk density was observed under surface soils of FL and ENFL. This might be due to higher OM content, decomposition and microbial activities than other adjacent LUTs. The total porosity was significantly ($p < 0.01$) affected by the interaction of the two factors. The highest

(60.1%) mean value of total porosity was observed under surface soils of FL and ENFL and lowest (48.3%) mean value was observed under subsurface soils of CUL, respectively. The total porosity was inversely and strongly associated with soil bulk density.

The soils pH ($H_2O$) value was very highly significantly ($p < 0.001$) affected by LUTs, SD and interaction effect of LUTs and SDs ($p < 0.01$). The highest (6.54) and lowest (4.82) pH mean value was observed under surface and subsurface soils of ENFL and EUCL. The result of ANOVA showed OM was significantly ($p < 0.05$) affected by the interaction of LUTs by SD. The highest (7.39%) mean value of OM content was recorded under surface soils of FL followed by ENFL (7.08%) and lowest (3.47%) value was observed subsurface layers of EUCL. This might be due to the fact that in FL and ENFL, falling of plant materials and decomposition could increase OM. In the soil of the study area the available phosphorus (P) was influenced ($p < 0.05$) by the interaction of LUTs by SDs. The highest (22.69 mg $kg^{-1}$ and the lowest (5.02mg $kg^{-1}$) of available P contents were recorded at the surface soil (0-20 cm) layer of the ENFL and the subsoil layer of EUCL, respectively. The lowest value of available P content under EUCL might be due to low soil pH value and highest value of exchangeable acidity and aluminum under EUCL and CUL which may result in fixation problem.

The status of the cation exchange capacity (CEC) of the soils in the study area was significantly ($p < 0.01$) affected by the interaction of LUTs by SDs. The highest (37.96 cmol $_{(+)}$ $kg^{-1}$) and lowest (11.90cmol $_{(+)}$ $kg^{-1}$) value of CEC were obtained under surface soils of FL and subsurface soils of EUCL. Except CUL the value of CEC under subsurface soil layer dropped down by 28.4% compared to surface soils and under soils of CUL increased by 21.5%. PBS was not significantly ($p < 0.05$) affected by LUTs, SDs and the interaction of LUT by SD. Exchangeable Ca was significantly ($p < 0.01$) affected by LUT and the interaction of LUT and SD but not affected by SD ($p > 0.05$). The content of Mg was highly significantly ($p < 0.01$) affected only by SD. Exchangeable Na was statistically ($p < 0.01$) affected by LUTs and SDs but not affected by their interactions.

The analysis of ANOVA showed that exchangeable acidity (ExA) was very highly ($p < 0.001$) and highly ($p < 0.01$) affected by LUTs and SDs. But it was not significantly ($p > 0.05$ affected by interaction of LUTs and SDs. Relatively higher mean value of ExA was recorded under soils of EUCL followed by CUL.

## 5.2.Conclusion

The soil analysis result indicated that different LUTs and SDs have an impact on selected soil physicochemical properties and fertility status of soils. As the result of the study demonstrated the values of most soil fertility status indicators were lowest under soils of EUCL and CUL. Thus, growing of eucalyptus trees and repeated cultivation significantly affected the fertility status of soils of the study area and relatively FL and ENFL were more fertile. On the other hand variations in status of selected soil physical and chemical properties between LUTs and SDs were indicated the decline in soil fertility and productivity of studied area. This might be resulted from improper land use, intensive cultivation, using of acid forming fertilizers, changing of FL to crop land, expansion of eucalyptus trees to arable land and absence of ISFM practices.

The result of the study showed that the lowest mean value of the selected soil chemical properties such as, OM, av.P, pH, CEC, Ca and PBS and highest mean value of ExA were observed under soils of EUCL followed by CUL.  Conversely, almost all selected soil chemical properties were highest value under soils of FL followed by ENFL. Soil pH, av.P and exchangeable K were highest in ENFL. Regarding to soil SDs the higher mean values of OM, av.P, CEC, Ca, Mg, K, PBS, sand content and soil pH were found to be on the surfaces soils (0-20cm) but the mean values of CEC and Ca were increased with depth only under CUL. Contrary, the mean value of silt and clay content, bulk density, Na and ExA increased with depth from 0-20 cm to 20-40cm. As the result of the study shows the selected soil physicochemical properties that have attributed to soil fertility, soils of the FL and ENFL were relatively qualifies higher fertility status where as CUL and EUCL were qualifies low fertility status.

Generally, the mean values of basic exchangeable cations were lowest under soils of CUL except Ca. This demonstrate change in LUT, low recycling of crop residue in the soil, very low application of chemical fertilizers; continuous cropping and soil erosion might have a great contribution to reduction of basic cations and CEC on the CUL. Furthermore, high uptake of basic cations into tree biomass and low return of OM, lower soil pH and higher value of soil acidity cause for low fertility status under soil of EUCL compared to the other adjacent LUTS.

## 5.3.Recommendation

The following recommendations were forwarded on the basis of the findings of the study.

- There should be great attention to improve fertility status of soil and to manage soil acidity on cultivated lands by the concerned bodies and the farmers. Due to strong soil acidity problem there might be fixation of problem P with Al and unavailability of essential plant nutrients under soils of CUL. In order to solve this problem soil management practice should focused on the solution of managing soil acidity problem by applying lime.
- Integrated soil fertility management practices are best solution for sustainable use of soil to improve soil quality and productivity. So, encouraging farmers in order to use ISFMP is very important. The concerned and governmental organizations need to formulate land use policy that enforced to land users to follow appropriate land uses and sustainable management to cope up the impacts of inappropriate land use types.
- Also, attentions should be given to strength awareness of the society and local norms to protect and conserve the natural forest in a sustainable way and deforestations and using organic fertilizers, manure and house refuse for enset farm land was advisable to improve fertility status of the soil.

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# 7. APPENDIXS

Appendix Table 1.Mean square estimates for a Two-way analysis of variance of selected soil physical and chemical properties of soils under four land use types and two soil depths in soils of Moche.

| Soil properties | Mean square of sources of variations | | | | | |
|---|---|---|---|---|---|---|
| | Replication (2) | Land use type (3) | Soil depth (1) | LUT*SD (3) | EMS (14) | CV(%) |
| Clay | $10.79^{ns}$ | $72.93^{ns}$ | $100.04^{ns}$ | $6.71^{ns}$ | 40.45 | 24.19 |
| Silt | $15.87^{ns}$ | $249.81^{**}$ | $15.04^{ns}$ | $3.59^{ns}$ | 22.82 | 11.90 |
| Sand | $15.04^{ns}$ | 439.38*** | 192.66** | $3.00^{ns}$ | 16.42 | 12.06 |
| Bulk density | $0.003^{ns}$ | 0.04*** | 0.08*** | 0.009** | 0.002 | 4.03 |
| Total porosity | 4.95 | 58.74*** | 113.53*** | 14.15** | 3.04 | 3.08 |
| Organic matter | 1.09** | 1.40*** | 14.29*** | 0.92** | 0.13 | 8.06 |
| Av. Phosphorus | 10.44** | 213.08*** | 49.94*** | 5.71* | 1.56 | 10.92 |
| pH ($H_2O$) | $0.04^{ns}$ | 0.69*** | 2.26*** | 0.43** | 0.09 | 5.71 |
| Calcium | $6.76^{ns}$ | 18.51** | $2.22^{ns}$ | 9.24** | 2.42 | 22.21 |
| Magnesium | 2.45** | $0.78^{ns}$ | 1.98** | $0.23^{ns}$ | 0.37 | 26.82 |
| Potassium | $0.26^{ns}$ | 8.72*** | $0.80^{ns}$ | $0.20^{ns}$ | 0.22 | 30.30 |
| Sodium | 0.15** | 0.17** | 0.23** | $0.02^{ns}$ | 0.02 | 19.89 |
| CEC | $6.30^{ns}$ | 299.03*** | 55.51** | 37.35** | 8.88 | 15.16 |
| PBS | $29.15^{ns}$ | 988.24*** | $3.84^{ns}$ | $40.63^{ns}$ | 81.89 | 14.67 |
| Exchangeable acidity | 0.76** | 2.01*** | 0.38* | $0.005^{ns}$ | 0.07 | 23.2 |
| Exchangeable aluminum | 0.76** | 0.73*** | $0.04^{ns}$ | $0.01^{ns}$ | 0.019 | 26.4 |
| Exchangeable hydrogen | $0.63^{*}$ | $0.41^{*}$ | $0.09^{ns}$ | $0.02^{ns}$ | 0.12 | 30.4 |

Appendix Table 2. Rating of soil OM and available phosphorus in the soil.

| OM (%) | Rating | P (mg/kg) | Rating |
|---|---|---|---|
| <2 | V/ Low | <5 | V/ Low |
| 2-3 | Low | 5-9 | Low |
| 3-7 | Medium | 10-17 | Medium |
| 7-8 | High | 18-25 | High |
|  |  | >25 | V/high |

Source:- (FAO, 2006), Ethiosis (2014) and Hazelton and Murphy (2007 and 2016).

Appendix Table.3Rating of exchangeable bases (Ca, Mg, K, Na), CEC and PBS in the soil.

| Rating | CEC cmol/kg | Ca cmol/kg | Mg cmol/kg | K cmol/kg | Na cmol/kg | PBS % |
|---|---|---|---|---|---|---|
| Very low | <5 | <2 | <0.3 | <0.2 | <0.1 | 0-20 |
| Low | 5-15 | 2-5 | 0.3-1 | 0.2-0.3 | 0.1-0.3 | 20-40 |
| Medium | 15-25 | 5-10 | 1-3 | 0.3-0.6 | 0.3-0.7 | 40-60 |
| High | 25-40 | 10-20 | 3-8 | 0.6-1.2 | 0.7-2 | 60-80 |
| Very high | >40 | >20 | >8 | >1.2 | >2 | >80 |

Sources:- Tekalegn (1991), London (1991), FAO (2006), Hazelton and Murphy (2007)

Appendix Table 4.Rating of general scale of bulk density and total porosity

| ρb(g/cm3) | Rating | $f$(%) | Rating |
|---|---|---|---|
| <1.0 | V/low | <5 | V/low |
| 1.0-1.3 | Low | 5-10 | Low |
| 1.3-1.6 | Medium | 10-15 | Medium |
| 1.6-1.9 | High | 15-40 | High |
| >1.9 | V/High | >40 | V/High |

Sources:- FAO (2006) and Hazelton and Murphy (2007).

Appendix Table 5. Rating of soil pH

| Soil pH ($H_2O$) | Rating |
|---|---|
| <4.5 | Extreme acidic |
| 4.5-5.0 | Very strong acidic |
| 5.1-5.5 | Strong acid |
| 5.6-6.0 | Moderately acidic |
| 6.1-6.5 | Slightly acidic |
| 6.6-7.3 | Neutral |
| 7.4-8.0 | Moderately alkaline |
| 8.1-9.0 | Strongly alkaline |
| >9.0 | Very strongly alkaline |

Sources:- Foth (1990) and USDA (1999),

# BIOGRAPHICAL SKETCH OF THE AUTHOR

The author was born in Cheha Woreda, Gurage Zone SNNP regional state, on September 28, 1984. He attended his Primary and Secondary School at Gura Awyate Primary and Secondary School and Emdeber Senior Secondary School in Cheha Woreda, Gurage Zone, from 1990-2001.

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