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EVALUATION OF PHYSICOCHEMICAL PROPERTIES OF SOIL IN DIFFERENT LAND USE TYPES IN SELECTED SITES OF GAMBELA REGION, SOUTHWEST ETHIOPIA

M.Sc. THESIS

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JUNE, 2019

JIMMA, ETHIOPIA

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A FINAL THESIS SUBMITTED TO JIMMA UNIVERSITY SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN CHEMISTRY

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APPROVAL SHEET

THESIS ON: EVALUATION OF PHYSICOCHEMICAL PROPERTIES OF SOIL IN DIFFERENT LAND USE TYPES IN SELECTED SITES OF GAMBELA REGION, SOUTHWEST ETHIOPIA.

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LIST OF ACRONYMS AND ABBREVIATIONS

Av. P	Available Phosphorus
BD	Bulk Density
C: N	Carbon to Nitrogen ratio
CEC	Cation Exchangeable Capacity
CL	Cultivated Land
CV	Coefficient of Variance
DTPA	DiethyleneTriaminePentaAceticAcid
EA	Exchangeable Acidity
FAO	Food and Agriculture Organization
FL	Forest Land
GL	Grazing Land
LSD	Least Significant Different
LUT	Land Use Type
OC	Organic Carbon
SAS	Statistical Analysis System
SOM	Soil Organic Matter
TN	Total Nitrogen

ABSTRACT

Change in land use type is particularly from natural forests to cultivated lands, are the major causes of physicochemical properties which lead low agricultural productivity. The aim of the study was to evaluate the selected physicochemical properties of soil in different land use types in selected sites of Gambela region, southwest Ethiopia, under four land use types (natural forest, grazing, cultivated and fallow land) at two different depths (0 – 20 and 20 - 40 cm) in three replicates and totally 24 composite soil samples were collected. The data were analyzed by using appropriate methods. (Particle size distribution was determined by the hydrometer method, soil pH was measured using a digital pH meter, Na and K was determined using flame photometer and Ca, Mg and micronutrients were determined using Atomic absorption spectroscopy. The data were analyzed by using SAS software. The results of particle size distribution analysis in the study area revealed that the three land use types had clay texture but cultivated land use type had clay loam texture. The mean pH (H_2O) values observed in the study area were within the ranges of slightly acidic (6.24 – 6.37), whereas, pH (KCl) values ranged moderately acidic (5.25 – 5.48) the reason is because of high rainfall, conversion of forest land to other land use types and intensive cultivation. The relatively highest mean value of clay content, TP, pH-H_2O, OC, TN, C: N, Av. P, PBS, exchangeable bases (K, Na, Ca and Mg) and the micronutrients (Mn, Fe, Cu, and Zn) was recorded under forest land compared to the other land use types due to the presence of high accumulation of organic matter and higher biological activity in the forest land. It is possible to conclude that burning plant residues practice during field preparation, removal of crop residues for animal feed and conversion of forest lands to cultivated and grazing lands had negative effects on the soil physicochemical properties of the study area. Therefore, it is recommended that soil pH is slightly acidic which significantly affect land use types in the study area. Therefore, the concerned bodies or farmers should focus to improve or maintain soil acidity particularly cultivated land by addition of lime, reducing the activities that can affect physicochemical properties.

Key words: physicochemical, soil depths, land use types

1. INTRODUCTION

Soil is a complex mixture of minerals, water, air, organic matter, and countless organisms that are the decaying remains of once-living things. It forms at the surface of land and it is called "skin of the earth" [1]. Soil is formed by the continuous weathering of the underlying parental rocks. Therefore, the type of soil is a function of the nature of the underlying rocks. Soil formation has been reported to be combination of various interrelated factors of parental materials, climate, organisms, topography and time [2].

The removal of vegetative cover 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, while the use of chemical fertilizer is also minimal [3]. In addition, traditional farming methods, overgrazing and continuous cultivation practice, together with environmental factors magnify the degradation of soil physicochemical properties [4] that results in the reduction of pH in the soil system finally brings soil acidity [5].

Cultural practices such as cutting and burning of tropical forests quicken loss of nutrients by leaching and erosion [6, 7]. Also cultural practices have intense effect on the physical properties of soil, such as bulk density, porosity and water retention [8]. Lal R. (1997), [9] reported that continuous cropping and cultivation of many of the world's soil which had previously been under forest or grass land, are the major cause of substantial decline in soil organic matter. Soil organic matter content is considered important indicator of soil productivity in agricultural soil. It binds mineral particles into stable aggregates [10]. Soil structural stability and soil organic carbon content usually decrease with cultivation [11]. Cultivation reduces soil carbon content and changes the distribution and stability of soil aggregates [12].

Evaluating land use changes in soil properties is essential for addressing the issue of agro ecosystem transformation and sustainable land productivity. The selection of suitable indicators with well established ecological functions and high sensitivity to disturbances is of paramount importance. In this regard, soil organic carbon (SOC) is important for the overall carbon reservoir of the biosphere and plays a highest role in the global biogeochemistry cycle of major nutrients and it has been used extensively by authors to monitor land use change types [13,14]. Though they are sensitive to land use changes, soil organic carbon and nitrogen have been proposed by some worker as indicators for evaluating the effect of land use management [15]. Thus, it is a key source of soil nutrients for plant growth and soil structural stability, as well as carbon stock levels [14]. However, its dynamics and composition are influenced by land use changes, agricultural and management practices [16, 17].

Thus, the soil of such areas finally become almost dead (lost their fertility), showing little microbial activities and less favorable for plant growth. Since erosion removes the finer soil particles, OM and their colloids fractions, and such materials furnish most of the microbiological activities and the Base Exchange capacity of the soil providing sufficient storage for plant food, the removal of such essential particles and their colloids decrease the fertility of the soil [18].

As a consequence of, continuous cultivation and uncontrolled overgrazing of land without proper management resulted in decline in soil physicochemical properties which brings crop yield reduction in the study area. Therefore, the main objective of this investigation is to evaluate soil physicochemical properties in different land use types based on soil depths in the study area.

1.1. Statement of the Problem

Change in land use type, high rain fall, temperature, erosion as well as intensive cultivation affect soil physicochemical properties which can increase soil acidity [19]. However, selected soil physicochemical properties of the study area have not been studied before by any other researcher. To get optimum and sustained self-sufficient crop production, physicochemical properties of soil has to be evaluated and maintain through time. Thus, this research was initiated to evaluate soil physicochemical properties in different land use types based on soil depths in the study area to answer for the following questions:

1. Which soil physicochemical properties are more affected by land use type and soil depth?
2. Which land use types need more treatment of physicochemical properties?

1.2. Objectives of the Study

1.2.1. General objective

The general objective of this study was to evaluate selected physicochemical properties of soil under different land use types and soil depths.

1.2.2. Specific objectives

1. To analyze the selected physicochemical properties of soil under different land use types.
2. To compare the selected physicochemical properties of soil among four land use types and soil depths.
3. To identify the land use type that needs more treatment for productivity.

1.3. Significance of the Study

The result of this study can use to identify the land use type that is more affected in physicochemical properties among the four land use types; also it may help the community who live in the study area to use necessary treatments for the affected soil physicochemical properties. Therefore, it can serve as an input for the policy makers and concerned bodies who are working in natural resource conservation as well as to know potential of physicochemical properties of soil in the study area. It can also help as a reference material for further studies.

2. LITERATURE REVIEW

2.1. Land Use

Land use types are operating over an immeasurably greater proportion of the globe's land area. Different time spans have been observed for the occurrence of these changes after sedentary agriculture was started. Some changes were very short and of an exploitative nature, while others were long and stable [20].

In developing countries, including Ethiopia, the amount, rate and intensity of land use changes are very high. Human impacts upon the land are still very great and increasing [21]. Extensive deforestation and conversion of natural forests into agricultural fields is the most widespread change in land use system in Ethiopian ecosystems. In the past 100 years only, the total area of land covered by forest in Ethiopia has declined from about 40% to an estimated 2.4% in 1990 [22]. The rate of deforestation is estimated to be between 150,000 and 200,000 ha per annum [23] the scale of clearance has been very large. Destruction continued constantly especially in south and the south western parts of the country where most of the remains sub humid tropical forests are found [24].

Findings revealed a general decline in forest land with subsequent expansion of cultivated land. Gete Zeleke and Hurni (2001), [25] reported a 99% decline in forest cover and a 95% subsequent expansion in cultivated land between 1957 and 1995, in north-western Ethiopia.

2.2. Soil Physical Properties

Soil is consisting of minerals, soil organic matter (SOM), water, and air. The composition and proportion of these components greatly influence soil physical properties, including texture, structure, and porosity, the fraction of pore space in a soil. In turn, these properties affect air and water movement in the soil, and thus the soil’s ability to function. Many soil physical properties change with changes in land use system (example cultivated land to forest land) and its subsequent management such as intensity of cultivation, the instrument used and the nature of the land under cultivation expose the soil less permeable and more susceptible to runoff and erosion losses [26].

2.2.1. Soil texture

The soil solid phase as a whole can be characterized in terms of the relative proportions of its particle size groups called soil separates. The relative size of the soil particles is expressed by the term texture, which, qualitatively, refers to the fineness or coarseness of the soil. Quantitatively, it refers to the relative proportions of the different particle size fractions, specifically referred to as sand, silt and clay (with organic and cementing materials removed) [27, 28]. Soil texture affects a number of physical and chemical properties of soil including penetration and retention of water, soil aeration, absorption of nutrients, microbial activities, tillage and irrigation practices [26, 29]. Sandy soil has low water and nutrient holding capacity, low organic matter content, little or no swelling and shrinkage and high leaching of nutrients and pollutants [30]. On the other hand, clayey soil has high nutrient and water holding capacity, poor aeration, very slow drainage unless cracked, high to medium organic matter and relatively high swelling and shrinkage properties compared to the sandy soil [30, 31]. It is also an indicator of some other related soil features such as type of parent material, homogeneity and heterogeneity within the profile, migration of clay and intensity of weathering of soil material or age of soil [32, 33].

Over a very long period, geologic and pedogenic processes such as erosion, deposition and weathering can change the textures of various soil horizons [34]. Although soil texture is considered as a permanent property, [35] indicated that management systems may contribute indirectly to changes in particle size distribution particularly in the surface horizons as a result of clay removal through sheet and rill erosion, and mixing up of soil of the surface and subsurface horizons during mechanical tillage activities. Research results on soil of the Jello micro-catchments in West Hararghe areas of Oromia Region showed that textural class varied with positions of soil in the landscape [36]. According to the same authors, textural class ranged from silty clay loam in the upper slopes to clayey in the lower slope positions; thus suggesting that the amount of clay increases down the slope. According to Belay (1997), [37] the Vertisols in the lower slopes of Watiya catchment in Welo area were much heavier than those on the upper parts and this was mainly attributed to the relatively fine texture of the fresh alluvium reaching the lower slope positions and its more intensive weathering due to higher moisture supply at the site.

2.2.2. Bulk density

Bulk density is a measure of the weight of the soil per unit volume, usually given on an oven dry basis [31]. Bulk density values are important in quantitative studies, such as in calculating the volumetric water content, total porosity, mass of soil per unit area per unit depth and to indicate whether a given soil is too compact for root penetration or not. Variation in bulk density is attributable to the variation in the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil. Consequently, bulk density of soil is influenced by soil texture, structure, OM content and soil management practices. The bulk density of granulated clay surface soil was commonly in the range of 1.0 to 1.3 g cm^{-3}, while, that of coarse-textured surface soil in the range of 1.3 to 1.8 g cm^{-3} [28].The greater development of structure in the fine-textured surface soil and relatively higher OM content accounts for their lower bulk density as compared to the more sandy soil with less structural differentiation [26]. Low bulk density values (generally below 1.3 g cm^{-3}) indicate a porous soil condition [38]. Increase in OM lowers bulk density while compaction increases bulk density. In swelling soil, bulk density decreases with increase in moisture content and vice versa. Bulk density is generally higher in lower profile layers [27]. The density of OM is very low as compared to the mineral soil and hence higher organic matter content results in lower density. Moreover, higher compaction due to the weight of the overlying layers also increases the bulk density of the subsurface layers [39].

2.2.3. Porosity

Porosity, defined as the ratio of total volume of pore spaces to the total volume of soil, is an index of the relative pore space in the soil. For soil with the same particle density, the lower the bulk density, the higher is the percent pore space (total porosity). Total porosity of soil usually lies between 30% (in compacted subsoil) to 70% (in well-aggregated, high-OM surface soil) [36] and may be used as a very general indication of the degree of compaction in a soil in the same way as bulk density is used. As is the case with bulk density, management exerts a decisive influence on the pore space of soil [36]. Coarse-textured soil tends to be less porous than fine-textured soil, though the mean size of individual pores is greater in the former than in the latter [28]. Sand with a total pore space of less than about 40% are liable to restrict root growth due to excessive strength whilst in clay soil limiting total porosities are higher, and less than 50% can be taken as the corresponding value [40]. The decrease in OM and increase in clay that occur with 10 depths in many profiles are associated with a shift from macro pores to micro pores [36]. In contrast to macro pores, micro pores are usually filled with water in the field soil. Even if not water filled, they are too small to permit much air movement. Fine textured soil, especially those without a stable granular structure may have a dominance of micro pores, thus allowing relatively slow gas and water movement, despite the relatively large volume of total pore spaces [27,41] reported that the high total porosity was the reflection of high organic matter content along the toposequence of Woreta agricultural research farm. Similarly, Wakene N. (2001), [35] reported that the low total porosity was the reflection of the low organic matter content and the high bulk density that was imposed by the use of heavy farm machinery for tillage activity and intense grazing of the fallow land of Bako area.

2.3. Soil Chemical Properties

Soil has characteristic chemical properties that are the results of weathering of their mineral components, decomposition of organic materials, and the activity of plants and animals. The more important chemical characteristics, which influence soil fertility and hence plant growth and yield, are soil reaction (pH), cation exchange capacity (CEC), available nutrients, OM content and exchangeable bases [37].

2.3.1. Soil reaction (pH)

Soil reaction (pH) is a measure of the concentration of H^+ ions in the soil solution or in other words a measure of acidity or alkalinity of a soil. It is the simplest and the most important chemical parameter of soil. It has vital role in determining several chemical reactions and in influencing plant growth by affecting the activity of soil microorganisms and altering the solubility and availability of most of the essential plant nutrients particularly micronutrients such as Fe, Zn, Cu and Mn [27, 35]. Soil reaction affects toxicity, microbial activity, and root growth. Descriptive terms commonly associated with certain ranges in pH are moderately acidic (pH 5.6-6.0) and slightly acid (pH 6.1-6.5)[23]. Soil reaction is influenced by different anthropogenic and natural activities including leaching of exchangeable bases, acid rains, decomposition of organic materials, application of commercial fertilizers and other farming practices [34, 42].

Soil acidification is due to either natural or anthropogenic. The major acidification processes are due to the export of basic cations in agricultural products and through leaching. Soil pH increased with depth of soil profile and relatively high pH was observed at subsoil horizons [43]. Continuous cultivation practices, excessive precipitation, steepness of the topography as well as application of inorganic fertilizers could be ascribed as some of the factors which are responsible for the reduction of pH in the soil profiles at the middle and upper elevation zones [43, 44].

2.3.2. Organic carbon

Organic matter (OM) arises from the remains of green plants, animal residues and excreta that are deposited on the surface and mixed to a variable extent with the mineral component [28]. Soil OM is defined as any living or dead plant and animal materials in the soil. Also it comprises a wide range of organic species such as humic substances, carbohydrates, proteins, and plant residues [19]. Humus is the substance left after soil organisms have modified original organic materials to a rather stable group of decay products as is the colloidal remains of SOM [33]. Havlin etal., (2002), [42] has indicated that the distribution of OM in trees and ground cover is 38%, 9% in the forest floor and 53% in the soil including the roots plus the OM associated with soil particles. Soil OM originates from plant and animal residues, which are generally present in various stages of decomposition that is from fresh additions to well-decayed humus.

In all forms of agricultural systems, whether traditional or modern, soil OM plays an essential role in sustaining crop production and preventing land degradation [45]. Because of its positive influence on several soil processes, crop productivity and environmental quality, soil OM is often considered the single most important indicator of soil quality and sustainable land management [45, 46, and 47]. Based on OM content, soil are characterized as mineral or organic. Mineral soil form most of cultivated land and may contain from a mere trace to 20 to 30% OM, but organic soil contain 80% or more OM [48].

Soil OM controls many soil physical and chemical properties. It increases the water holding capacity, structure of soil and source of several essential plant nutrients, especially N, S and P [48]. Organic matter content and aggregate stability are subject to seasonal variation. The positive effect of OM on structural stability is more pronounced on sandy than on more finely textured soil [30]. According to Asefa etal. (2003), [49] crop management practices, such as stubble management play an important role in maintaining an optimal soil environment. According to the same author, the retention of straw on the soil surface can be important for nutrient recycling as increased concentration of most important plant nutrients was observed in the upper layer of the soil. Furthermore, the presence of straw on or near the soil surface can reduce run-off, loss of water and soil erosion, and can increase soil moisture levels. This increased soil moisture level can enhance the activity of microorganisms involved in decomposing residues and changing unavailable forms of nutrients to available forms.

Generally, higher soil OM contents were observed at the surface layers than sub-soil horizons in soil profiles opened at different sites [35, 37, 43, 50, and 51] stated that major differences were observed in the OM contents of Eutric Vertisols mantling the upper and lower toeslopes. The OM contents of the surface soil on the lower toeslopes were 4.2 to 5.0% while those on the upper toe slopes were less than 2.5%. Burke etal. (1988), [52] examined the extent to which soil OC varied at a landscape scale at two sites differing in soil texture and reported that increased OC content (clay and silt content) in down slope position relative to the summits.

2.3.3. Total nitrogen

Nitrogen (N) is the forth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements in the tropics for crop production and critical shortage of this nutrient brings significant grain/biomass yield reduction [53]. Most Ethiopian black or dark grey soil is N-depleted and more than 50% of the cultivable lands are N-responsive soil [54]. Variation in contents of total N is closely related to contents of OM, which is its major source, and thus, the source of its variability [36]. In general, in the surface soil layers, OM and total N increased with increasing elevations while in the subsoil horizons, the contents of these parameters do not reveal consistent relationship with elevation in the soil of the western slopes of mount Chilalo [43]. Total N content of soil ranges from less than 0.02% in sub-soil of humid and sub-humid mineral soil to more than 2.5% in peat soil. Highly weathered soil of the humid and sub-humid tropics have too low total N due to leaching, and saline and sodic soil of arid and semi-arid regions are also poor (less than 0.01%) in their N content which is attributed to the generally very low biomass production and fast oxidation of OM in such climatic zones [42].

Preez, C.C. and M.E. (1995), [55] reported that cultivation causes a significant decrease in the total N fertility in different agro-ecosystems and the rates of losses were rapid during the first few years of cultivation. The high losses of N are due to leaching of soil nitrates as well as loss of OM content because of intensive cultivation [56]. The amounts of total N in the upper topsoil's were higher under zero tillage as compared to soil under continuous mono cropping [57]. According to Havlin etal., (2002), [42] there is a strong positive relationship between total N and OM content. The total N contents are lower in intensively cultivated highly weathered soil of the humid and sub-humid tropics, due to leaching, in saline and sodic soil of semiarid and arid regions, due to low OM content. The total N content is tied to the humus contents of the soil and decreases consistently with soil depth.

Research results in Zimbabwean Vertisol*s* showed that uncultivated soil contained 0.09% total N and this level appeared to be maintained in the fields cultivated for 10 years. For soil cultivated for 30 to 39 years, there was a substantial decrease in total N to about 0.05%. Whereas soil OM levels are usually expected to decrease exponentially with cultivation, eventually reaching a steady state reflecting soil type, climate and land use and/or management practices Syers etal. (2001), [58].

Gregorich, E.G. and D. W. Anderson (1985), [59] measured the concentrations of available N and P at six different slope positions: crest, upper, mid, lower-mid, lower and depression from an eroded hilly area in the brown soil zone of Saskatchewan, Canada. Available N as NO_3^- in the surface horizon varied from 8 to 27 g g^{-1} from the crest to the lower or depression areas. Fiez etal. (1994), [60] reported increased soil OM content and available NO^{3-} from the upper to the lower slope positions.

2.3.4. Carbon to nitrogen ratio

Carbon (C) to nitrogen (N) ratio (C: N) is an indicator of net N mineralization and accumulation in soil. Organic matter rich in N provides a large source of energy to soil microorganisms. Consequently, it brings population expansion of microorganism and higher consumption of mineralized N. Dense populations of microorganisms inhabit the upper soil surface and have an access to the soil N sources. If the C: N is high, there will be no net mineralization and accumulation of N [42]. They further noted that as decomposition proceeds, carbon is released as CO_2 and the C: N ratio of the substrate falls. Conversion of carbon in crop residue and other organic materials applied to the soil into humus requires nutrients [61].

Plant residues with C: N ratios of 20:1 or narrower have sufficient N to supply the decomposing microorganisms and to release N for plant use. Residues with C: N ratios of 20:1 to 30:1 supply sufficient N for decomposition but not enough to result in much release of N for plant use the first few weeks after incorporation. Residues with C: N ratios wider than 30:1 decompose slowly because they lack sufficient N for the microorganisms to use for increasing their number, which causes microbes to use N already available in the soil [33].

They have further stated that the wider the C: N ratio of organic materials applied, the more is the need for applying N as a fertilizer to convert biomass into humus. Microbial respiration (soil respiration) is oxygen uptake or CO_2 evolution by bacteria, fungi, algae and protozoans, and includes the gas exchange of aerobic and anaerobic metabolism [62].

According to the same authors, soil respiration results from the degradation of OM (for example mineralization of harvest residues). This soil biological activity consists of numerous individual activities; the formation of CO_2 being the last step of carbon mineralization. Conditions that favor growth of microorganisms will favor fast decomposition rates: continuous warm temperature, wetness, clay types, suitable soil pH (slightly acidic), and adequate nutrients but absence of other decomposition inhibitors such as toxic levels of elements (aluminum, manganese, boron, chloride) and soluble salts [35]. Walker, B.D. and C. Wang (1994), [63] reported the C: N ratio in Canada, ranging from about 10:1 on hilltops to 11:1 on back slopes and foot slopes, augment the carbon picture. The lower C: N ratios on the hilltops illustrate the role of plant residue. Return of crop residue to the soil has likely been the least on hilltops due to lower yields over the long term. In addition, fresh plant residue and light fraction organic matter have likely been more susceptible to erosion from hilltops.

2.3.5. Available phosphorus

Phosphorus (P) is known as the master key to agriculture because lack of available phosphorus in the soil limits the growth of both cultivated and forest plants [19]. Following nitrogen, phosphorus has more wide spread influence on both natural and agricultural ecosystems than any other essential elements. Phosphorus is rarely found in pure elemental form phosphorus in nature. It is chemically very reactive; thus, it is almost always found combined with other elements, especially oxygen, as $H_2PO_4^-$ or HPO_4^{2-}. These orthophosphate forms react quickly with Al, Ca, Fe, Mn, and other elements to form insoluble compounds that are only slowly available to plants. Phosphorus must be managed very carefully to maximize its availability to plants. Most phosphorus compounds formed in the soil are insoluble and are not readily available to plants. Relatively small quantities of the orthophosphate forms can be taken up by plant roots.

The soluble orthophosphates (HPO_4^{2-} and $H_2PO_4^-$) have negative charges so are not held directly by the negative charges on soil colloids. Phosphorus is retained in the soil primarily because it forms relatively insoluble Fe and Al compounds in acidic soil while, Ca in alkaline soil. This chemical process, which reduces phosphorus availability to plants, is known as phosphorus fixation [64].

Phosphorus consists of 0.15 to 1.00% of the dry weight of most plants. Plants deficient in phosphorus are purple in color and small, and appear to be stunted compared to those supplied with optimum phosphorus fertilizer [65]. Phosphorus is a component of certain enzymes and protein, adenosine triphosphate (ATP), ribonucleic acids (RNA), deoxyribonucleic acids (DNA), and phytin. Furthermore, it is important for the formation of seeds and fruits, proper root growth, and survival and growth of seedlings [66].

Tekalign Mamo and I. Haque (1991), [67] reported that topsoil phosphorus is usually greater than that of the subsoil due to sorption of the added phosphorus and greater biological activities and accumulation of organic materials in the former. The lower concentration of available phosphorus in the subsoil is due to fixation by clay and Ca, which were found to increase with profile depth.

The main sources of plant available phosphorus are the weathering of soil minerals, the decomposition and mineralization of soil OM and commercial fertilizers. Most of the soil in Ethiopia particularly Nitisols and other acidic soil are known to have low phosphorus contents, due to the inherently low available phosphorus content, as well as high phosphorus fixation capacity of the soil [68, 69]. Oxisols, Ultisols, Vertisols and Alfisols are generally low in available phosphorus while andosols are generally high in phosphorus content [70]. Nuga etal. (2008), [71] reported that the distribution of available phosphorus in the toposequence from the upper slope to the valley bottom increase. Generally, the available phosphorus levels in the study area are range from very low to moderate. This phenomenon may be due to the phosphorus fixing capacity and their subsequent slow-release by soil containing relatively high level of iron and aluminum oxides.

2.3.6. Cation exchange capacity

Cation exchange capacity (CEC) is the ability of the soil solid phase to attract or store and exchange cationic nutrients with the soil solution to render them available for plants [72]. Cation exchange capacity is an important parameter of soil because it gives an indication of the type of the dominant clay mineral present in the soil and its capacity to retain nutrients against leaching. The CEC of soil is strongly affected by the nature and amount of mineral and organic colloids present in the soil. Soil with large amounts of clay and OM has higher CEC than sandy soil low in OM. In the surface horizons of mineral soil, where the contents of OM and clay in the soil are significantly high, OM and clay fractions frequently contribute similar values to the CEC while in the sub soil, more CEC is contributed by clay fractions than by OM due to the decline of the latter with profile depth [26].

Belay T. (1997), [37] Mentioned that the CEC of soil on the crest and back slope on the degraded hill slopes of watiya catchment, Wolo, Ethiopia were much higher (129 to 196 $cmol_{(+)}\,kg^{-1}$ clay) when compared to those on the foot slope and toe slope (65 to 87 $cmol_{(+)}\,kg^{-1}$ clay). The CEC in the latter reflects the predominance of smectite clay while the higher values in the degraded soil on the crest and back slope showed the presence of significant amount of vermiculite.

2.3.7. Exchangeable acidity

Exchangeable hydrogen (H) and exchangeable aluminum (Al) are 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 [34]. As soil become strongly acidic, they may develop sufficient Al in the root zone and the amount of exchangeable basic cations decrease, solubility and availability of some toxic plant nutrient increase and the activities of many soil microorganisms are reduced, resulting in accumulation of SOM reduced, mineralization and lower availability of some macronutrients like N, S and P and limitation of growth of most crop plants [73].

Foth, H.D. and B.G. Ellis (1997), [19] stated that during soil acidification, protonation increases the mobilization of Al and Al forms serve as a sink for the accumulation of H^+. The concentration of the H^+ in soil to cause acidity is pronounced at pH values below 4 while excess concentration of Al^{3+} is observed at pH below 5.5 [74]. In strongly acidic conditions of humid regions where rainfall is sufficient to leach exchangeable basic cations, exchangeable Al occupies more than approximately 60% of the effective cation exchange capacity, resulting in a toxic level of aluminum in the soil solution [75]. 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 soil.

2.3.8. Exchangeable bases (K, Na, Mg and Ca)

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 [19]. 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 [34].

Wakene NC, Heluf G (2003), [76] reported that the variation in the distribution of K depends on the mineral present, particles size distribution, degree of weathering, soil management practices, climatic conditions, degree of soil development, the intensity of cultivation and the parent material from which the soil is formed. The greater the proportion of clay mineral high in K, the greater will be the potential K availability in soil [77]. Soil K is mostly a mineral form and the daily K needs of plants are little affected by organic associated K, except for exchangeable K adsorbed on SOM. Mesfin Abebe (1996), [78] described low presence of exchangeable K under acidic soil while [79] observed low K under intensive cultivation. Normally, losses of K by leaching appear to be more serious on soil with low activity clays than soil with high- activity clays, and K from fertilizer application move deeply [19].

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 calcium (Ca) and magnesium (Mg) ions) [80,81]. 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 soil causes soil sodicity which affects soil fertility and productivity.

Soil in areas of moisture scarcity (such as in arid and semi arid regions) have less potential to be affected by leaching of cations than do soil of humid and humid regions [82]. Soil 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 [83]. Exchangeable Mg commonly saturates only 5 to 20% of the effective CEC, as compared to the 60 to 90% typical for Ca in neutral to somewhat acid soil [35]. Research works conducted on Ethiopian soil indicated that exchangeable Ca and Mg cations dominate the exchange sites of most soil and contributed higher to the total percent base saturation particularly in Vertisols [69,70]. 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 of soil, while 0.5 cmol$_{(+)}$/kg soil is reported to be the deficiency threshold level for Mg in the tropics [40].

2.3.9. Percent base saturation

The percent base saturation (PBS) is as much a measure of the actual percentage of cation exchange sites occupied by exchangeable bases. It is influenced by the pH of the CEC determination. The denominator includes oxide-mineral complexes between the initial soil pH and the reference pH (7.0 or 8.2) [84]. According to the same authors, since neither the content of exchangeable Al nor exchangeable H is appreciable above pH 5.5, the effective CEC of the soil above this pH should be essentially 100% base saturated. However, soil in the pH range of 5.5 to 7.0 or 8.2 generally still has measured base saturations well below 100%. Such base saturation values are particularly low for minerals that have a high proportion of pH dependent charge, such as kaolinite clays.

The soil of the new farmland indicates higher values of base saturation as compared to the soil of old farms [85]. In tropical regions under rainforest, the base saturation in humus-rich top-soil is usually in the order of 50 to 80%, while below the humus-rich layer, it drops very sharply to the levels of less than 20% [30]. Getachew F. and Heluf G. (2007), [86] reported that the PBS values throughout the two soil profiles and composite surface soil samples near these profiles described at the Ayehu Research Substation in northwestern Ethiopia were less than 50% that could be due to the intensive cultivation and continuous use of the inorganic fertilizer in the study site that enhanced loss of basic cations through leaching, erosion and crop harvest.

2.3.10. Micronutrients (Fe, Mn, Zn and Cu)

Micronutrients are just as important in plants as the major nutrients except that they simply occur in plants and soil in much smaller concentrations. However, the information available about the status and limitation of micronutrients particularly in soil of sub-Saharan Africa is not adequate and is currently difficult for users to access [87]. Kraus Kopf (1972), [88] stated that the main source of micronutrient elements in most soil is the parent material, from which the soil is formed. Iron, Zn, Mn and Cu are somewhat more abundant in basalt. The solubility and availability of micronutrients is largely influenced by clay content, pH, OM, CEC, P level in the soil and tillage practices [89]. Brady *et al*., (2002), [34] indicated that the solubility, availability and plant uptake of micronutrient cations (Cu, Fe, Mn and Zn) are more under acidic conditions (pH of 5.0 to 6.5). Intensive cropping, in which large amount of plant nutrients are removed in the harvest accelerates the depletion of micronutrient reserves in the soil and increases the likelihood of micronutrient deficiencies [34]. Erosion of topsoil carries away considerable soil OM, in which much of the potentially available micronutrients are held.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted at Gubeti *kebele* in Mengeshi District, Majang Zone, Gambella Regional state, Southwest Ethiopia. It is about 649 km away from the capital, Addis Ababa, and 51 km away from Mengeshi, to the east. Geographically Mengeshi has an elevation ranging 700-2200 meters above sea level [90].

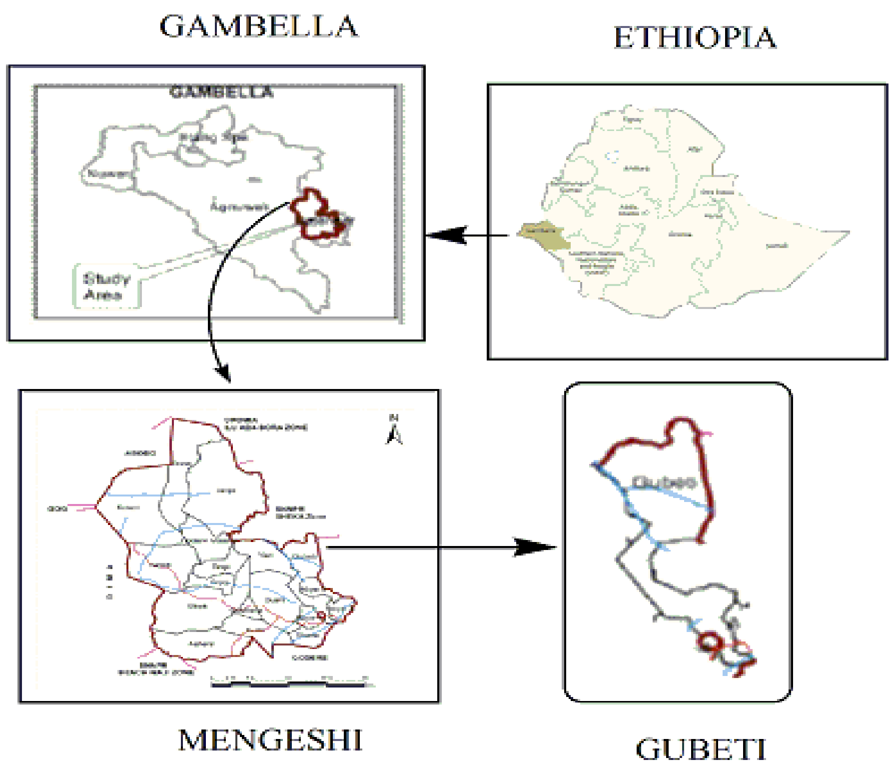

Fig. 1. Location map of the study area

3.1.2. Climate

The climate of the study area is hot and humid type with annual rainfall of 1200-2000 mm. The region is marked on most rainfall maps of Ethiopia as being the wettest part of the country, the area receives its rainfall seasons (Kiremt) from March to October and its dry season (Bega) is between December and February. The maximum rainfall in the months of June, July and August and the mean annual maximum and minimum temperatures are 32^0C and 17^0C, respectively [90].

3.1.3. Soil type and vegetation

The area is suitable for various fruits, vegetables and spices production. There is a growing trend of producing vegetables like cabbage, onions, and potatoes for local consumption. Fruits like Avocado, Mango and banana are also produced. The major food crops in the area are maize and sorghum, although different root crops are also produced in areas dominated by the native inhabitants. The area also is a good potential for eco-tourism, with its diverse natural and cultural landscape, tropical forest adventure, and lake like Bure (also called Bishan Waka) lake, a potential tourist attraction [91]. As information obtained from the District office; the type of soil is clay type soil and has moderately acidic character.

3.2. Apparatus and Chemicals

Table 1. The apparatus, instruments and chemicals used during the study.

Apparatus		**Chemicals**	
Kjeldahl distillation	Burette	H_2O_2	$(NH4)_6 - Mo_7O_{24}.4H_2O$
Stopwatch	Auger	$(NaPO_3)_6$	$KSbOC_4O_6.½H_2O$
Balance an watch	Sieve	H_2SO_4	$FeSO_4.7H_2O$
core sampler	Urine cup	NaOH	$C_6H_8O_6$ (ascorbic acid)
automatic shaker	Beakers	KCl	(Fe, Zn, Cu, Mn) standards
polyethylene bottle	Thermometer	HCl	Na_2SO_4, $CuSO_4.5H_2O$
Erlenmeyer flask	volumetric flasks	$K_2Cr_2O_7$	$CaCl_2.2H_2O$
Hydrometer	Oven	NH_4F	$LaCl_3.H_20$
Graduated cylinders	Kjeldahl flasks	H_3BO_3	DTPA
Mortar and pestle	Stirrer	NaF	NaCl
Filter paper	Glass funnels	NH_4 AC	$N(CH_2CH_2OH)_3$ (TEA) (triethanolamine)
		KH_2PO_4	
Instruments			
pH meter	Flame photometer	AAS	UV-Vis spectrophotometer

3.3. Soil Sampling sites and Preparation

Four major land use types namely natural forest, grazing, fallow and cultivated land were used for this study. Ten sub soil samples were collected from 0 - 20 and 20 - 40 cm soil depth from each representative land use type and composite soil sample was made with three replications and then the soil samples were air dried, ground and passed through a 2 mm sieve to determine soil physicochemical properties. Additionally three replicates of undisturbed soil samples of known volume was collected with a sharp-edged steel cylinder forced manually into the soil for bulk density determination at four sites from each land use types and soil depths. Dead plants, furrow, old manures, wet spots, areas near trees, roads and compost depths was excluded during collection of samples. This minimizes differences, which may occur because of the dilution of SOM due to mixing through cultivation and other factors. To make one composite soil sample the sub-samples were mixed well and about 1 kg of the mixed sub-samples were properly labeled. Completely randomized design (CRD) was used to analyze the composite soil samples. Finally twenty four total composite soil samples was prepared and packed in a plastic bowl, and transported to soil testing centre for further analysis.

3.4. Soil laboratory analysis

The flame photometer and AAS analysis was carried out in Wolkite soil laboratory and Arbaminch. But, the other selected soil physicochemical properties was analyzed at Jimma University College of Agriculture and Veterinary Medicine soil laboratory and Teppi soil laboratory center. Standard laboratory procedures were followed in the analysis of the selected physicochemical properties considered in the study.

3.4.1. Analysis of soil physical properties

The soil physical properties was determined in the laboratory include particle size distribution, bulk density (BD) and total porosity. Determination of particle size distribution was carried out by the hydrometer (Bouyoucos) method as described by [92], after destroying OM using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexametaphosphate ($NaPO_3$). The soil was assigned to a textural class based on the USDA soil textural triangle [75], While, bulk density was determined from undisturbed soil samples by the core method after drying a defined volume of soil in an oven at 105 °C to constant weight [29]. It was calculated as the ratio of mass of oven dried soil to the volume of the sampling core. Finally, total porosity was estimated from the values of BD and average value of PD [34], as described as:

$$\text{Total porosity (\%)} = \left(1 - \frac{BD}{PD}\right) \times 100$$

Where,

BD = bulk density in (gcm^{-3}) and

PD = particle density (gcm^{-3})

3.4.2. Analysis of soil chemical properties

Soil pH was measured potentiometrically in H_2O and 1M KCl solution at the ratio of 1:2.5 for both soil: H_2O and soil: KCl solutions using a digital pH meter [40]. OC contents were determined by the wet combustion or dichromate oxidation methods [93]. Total N was analyzed using the Kjeldahl digestion, distillation and titration method as described by [94], by oxidizing the OM in concentrated sulfuric acid solution (0.1N H_2SO_4). Available P was determined using the Bray II method by shaking the soil samples with an extracting solution of 0.03 M ammonium fluoride in 0.01 M hydrochloric acid as described by [95]. Exchangeable basic cations (Ca, Mg, K and Na) was determined by saturating the soil samples with 1N NH_4OAc solution at pH 7.0 and followed by centrifugation. Then the elemental Ca and Mg was determined by using atomic absorption spectrophotometer (AAS), while exchangeable Na and K was measured by flame photometer from the same extract[96]. For the determination of CEC, the soil samples was leached with 1N ammonium acetate solution and washed with ethanol (97%) to remove excess salt followed by leaching with sodium chloride to displace the adsorbed (NH_4^+). Then the quantity of ammonia was measured by distillation and taken as CEC of the soil [95]. Percent base saturation was calculated by dividing the sum of the base forming cations (Ca, Mg, Na, and K) by the CEC of the soil and multiplying by 100 [97]. Exchangeable acidity was determined by saturating the soil samples with 1 M KCl solution and titrated with 0.02 M NaOH as described by [73]. Exchangeable Micronutrient cations (Fe, Cu, Zn and Mn) were extracted by DTPA extraction method [98], and all these micronutrients were measured by atomic absorption spectrophotometer.

3.5. Statistical Analysis

The data was analyzed using statistical analysis system software (SAS 9.1.3) by using the general linear model (GLM) procedure [99] which was used for performing the significance of differences in soil parameters. A post the separation of means was done by least significant difference (LSD) test after main effects is found significant at $P < 0.05$. Correlation analysis was carried out to determine associations between selected soil physicochemical parameter.

4. RESULTS AND DISCUSSION

4.1. Soil physical properties

4.1.1. Soil texture

The particle-size distribution showed that the soil of the study area were clay and clay loam in texture (Table 2). According to Buol *et al*. (2003), [100] high clay content is an indication of complete alteration of weatherable minerals into secondary clays and oxides. The possible reason for the dominance of clay could be due to the intensive weathering stage of the soil by the high temperature, rainfall and acidic soil properties. The fraction sand were significantly different ($P \leq 0.05$) by land use type, soil depth and the interaction of land use type with soil depth, while, the clay fraction was significantly different ($P \leq 0.05$) by soil depth but silt was not affected (Table 2). Considering the interaction effects of land use type and soil depth, the lowest (33%) clay contents were recorded at the surface layer of cultivated lands than the other land use types (Appendix Table 1). The reason for low clay in surface layers of cultivated lands might be due to selective removal of clay from the surface by erosion. Relatively higher sand content was recorded in cultivated land soil followed by that of forest, grazing and fallow lands in the surface, whereas silt was found to be higher in fallow and cultivated lands soil followed by grazing and forest lands. Sand was negatively correlated with clay correlation coefficients $r = -0.91^{**}$ (Appendix Table 6).

4.1.2. Bulk density

Bulk density value was significantly affected ($P \leq 0.05$) by land use type and soil depth but not by their interaction effects (Table 2). The highest (1.31 g/cm^3) mean value of bulk density was recorded on the cultivated land and the lowest (1.16 g/cm^3) mean value under the forest land in the main effect (Table 2). However, bulk density increased slightly from surface to subsurface layer under all the land use types (Appendix Table 1). Basically, increase in SOM lowers bulk density while compaction increases bulk density, therefore, the highest bulk density in the cultivated land is attributed to the soil compaction and organic matter degradation as a result of continuous and intensive cultivation. This result is in agreement with the research findings reported by [76] who reported that the highest BD in the cultivated land is due to the soil compaction and organic matter degradation. Even though, the average bulk density values of the soil under different land use types in the study area are found in the acceptable range for plant growth as suggest by [93] that was for good plant growth bulk density should be less than 1.4 gcm^{-3} for clay soil. Soil bulk density was negatively correlated with TP, pH, OC, TN and Av. P at correlation coefficients r = -1.0^{**}, -0.63^{**}, -0.56^{**}, -0.55^{**} and -0.80^{**} (Appendix Table 6).

Table 2. Main effects of land use type and soil depth on soil selected physical properties of the study area

LUT	Sand (%)	Silt (%)	Clay (%)	STC	BD (g/cm^3)	TP %
CL	34.17[a]	27.00[a]	38.83[b]	Clay loam	1.31[a]	50.69[c]
GL	31.67[b]	26.00[a]	42.33[ab]	Clay	1.18[c]	55.60[a]
FL	32.50[b]	22.00[b]	45.50[a]	Clay	1.16[c]	56.29[a]
FaL	28.33[c]	27.00[a]	44.67[a]	clay	1.26[b]	52.64[b]
LSD(0.05)	1.41	3.32	3.34		0.03	1.21
SEM (±)	1.29	0.65	1.52		0.16	0.90
CV (%)	3.65	10.65	7.90		2.14	1.85
Soil depth						
0-20 cm	36.83[a]	26[a]	37.17[b]	Clay loam	1.19[b]	54.93[a]
20-40 cm	26.5[b]	25[a]	48.5[a]	Clay	1.25[a]	52.67[b]
LSD(0.05)	1.0	NS	2.93		0.02	0.86
SEM(±)	1.29	0.65	1.52		0.02	0.59
CV (%)	3.65	10.65	7.90		2.14	1.85

Main effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference, SEM = standard error of the mean, CV = Coefficient of variation, STC= soil textural classification, BD = bulk density, TP= total porosity, LUT=land use type, CL=Cultivated land GL= Grazing Land, FL= Forest Land FaL= Fallow Land

4.1.3. Total Porosity

Total porosity value was significantly affected ($P \leq 0.05$) by land use type and soil depth but not by their interaction effects (Table 2). Relatively High values of total porosities (58.87%) were found at surface soil under the forest land, whereas the lowest values (50.06%) were obtained at the subsurface soil under cultivated land (Appendix Table 1). These results showed that land use systems significantly affect soil porosity because intensive cultivation without appropriate soil management results in organic matter degradation and soil compaction. Porosity decreased with soil depth which could be attributed to accumulation of organic matter in surface soil under forest land The results obtained from this study are in agreement with the findings reported by other researchers [101,102].Total porosity was inversely related the bulk density of the soil in the study area (Appendix Table 1 and Table 2). For instance, cultivated land soil is highly subjected to compaction and subsequently decreased porosity than soil of forest, fallow and grazing lands. Previous findings indicate that the total porosity value of soil range as low as 25% in compacted sub soil to more than 60% in well aggregated and high OM surface soil [93]. Thus, in line with these authors limits, the total porosity values of the soil in the study area are in acceptable ranges and do not seem to have poisonous effects on plant growth.

Total porosity should negatively correlated with bulk density ($r = -1.0^{**}$), On the other hand, it was positive correlated with OC ($r = 0.56^{**}$) (Appendix Table 6).

4.2. Chemical properties

4.2.1. Soil reaction (pH)

Soil pH values measured in a solution of soil to KCl ratio are less than a suspension of soil to water ratio. The pH (KCl) value of the soil content was significantly affected ($P < 0.05$) by land use type and soil depth (Table 3). While pH (H_2O) value of the soil content was not significantly ($P \geq 0.05$) affected by soil depth and their interaction effects but affected by land use types (Appendix Table 2). The highest pH (6.61) in the subsurface (20-40 cm) and the lowest (5.8) in the surface (0-20 cm) of soil pH (H_2O) values were recorded under the forest and cultivated lands, respectively. The lower value of pH under the cultivated land may be due to the depletion of basic cations in crop harvest and due to its highest microbial oxidation that produces organic acids, which provide H ions to the soil solution lowers its soil pH value [95]. Soil pH increased constantly with depth in all land use systems. Application of inorganic fertilizers and continuous cultivation practices and erosion could be some of factors which are responsible for the variation in pH in the soil [44]. In general, the pH (H_2O) values observed in the study area were within the ranges of slightly acidic (6.24 – 6.37), and pH (KCl) values ranged moderately acidic (5.25 – 5.48) soil reactions as indicated by [9] (Table 3).

The pH (H_2O) of the soil positively correlated with TP, K, Na, Ca, with $r = 0.63^{**}$, 0.85^{**}, 0.68^{**}, 0.57^{**} respectively, and negatively correlated with exchangeable acidity $r = -0.53^{**}$ (Appendix Table 6).

4.2.2. Organic carbon

Significant differences ($p \leq 0.05$) in OC content of soil were observed among the different land use types and soil depth. The OC contents at both depths were higher at the forest land than the other land use types (fallow, cultivated and grass lands) (Appendix Table 2). The reason may be due to intensive cultivation of the land, burning plant residues practice during field preparation and total removal of crop residues for animal feed and source of energy [8]. The conversion of forest ecosystem to other forms of land cover may decrease the stock of OC due to changes in soil moisture and temperature regimes, and succession of plant species with differences in quantity and quality of biomass returned to the soil [103]. Considering the two soil depths, the higher mean value of OC (2.48%) and the lower (2.26%) were observed within the surface (0-20 cm) layer and the sub surface layer (20- 40 cm) of soil respectively (Table 3). The relatively higher OC in soil at upper depth in all land use systems could be due to relatively better return of biomass for decomposition at the surface. As per the rating of nutrients, Chimdi *et al.* (2012), [95] the soil OC can be categorized as high in the soil of forest and moderate in soil of fallow, grazing and cultivated lands. Studies by Chimdi *et al.* (2012), [95] indicated the decrease of soil OC content due to shifting of natural forest to grass, fallow and to cultivated lands.

Soil organic carbon was associated positively with TP, TN, C: N, av. P and CEC with correlation coefficient r= 0.56^{**}, 0.85^{**}, 0.72^{**}, 0.81^{**} and 0.58^{**} respectively, whereas, negatively correlated with bulk density with correlation coefficient r=-0.56^{**} (Appendix Table 6).

4.2.3. Total nitrogen

Total N content of soil was significantly ($P \leq 0.05$) different by land use type but not affected by soil depth and the interaction of land use type and soil depth (Table 3). Across the land use types, distribution of total N followed same patterns to soil OC distribution. It was highest in forest land (0.19) and lowest in the cultivated land (0.14) (Table 3). As compared to soil of forest land, TN content in grazing, fallow and cultivated lands, depleted by 26.67%, 26.67%, and 35.71% respectively (Table 3), were observed due *to* deforestation and subsequent cultivation but as suggested by [94], the total N in all land use types rated as medium. The mean total N content decreased considerably from surface (0.16%) (0-20cm) to subsurface (0.15%) (20-40 cm) soil layers (Appendix Table 2). The relatively high TN content in the surface layers indicates that the soil of the study area has potentially high N content to support proper growth and development of crops, while Conversion of natural forest to different land use types causes a decline of SOM and total N in the top soil layer.

The relatively high total N content in soil of the forest land could be associated with the high organic carbon, available P and CEC contents of this soil. This is confirmed by the positive and highly significant correlation r = 0.85^{**}, 0.72^{**} and 0.6^{**} respectively, obtained between these parameters (Appendix Table 6).

4.2.4. Carbon to Nitrogen ratio

Numerically, distribution of C: N followed similar patterns to OC and TN distributions except slight variation within the land use types. The carbon to nitrogen (C/N) ratio of the soil at the study area was not significantly ($P \geq 0.05$) affected by land use type, soil depth and their interaction (Table 3). The C: N ratio was higher under forest land as compared to the cultivated, grazing and fallow lands. The reason obviously could be the higher contents of soil OM in case of forest land (Appendix Table 2). Based on this, the observed C: N ratio status in the studied, the forest land can be considered as suitable for plant growth but, the other land use type's needs treatment. This is in line with [103], who reported the C: N ratio of 15:1 to 30:1 is assumed as a favorable condition because nitrogen needs are supplied with minimum oxidation of SOM. C: N ratio was positively correlated with organic carbon and available phosphorus at correlation coefficient, r=72^{**} and 0.54^{**} respectively (Appendix Table 6).

4.2.5. Exchangeable acid

The exchangeable acidity was not significantly affected ($P > 0.05$) by land use type, soil depth and their interaction (Table 3). The relatively highest (0.16 $cmol_{(+)}$/kg) and the lowest (0.12 cmol $_{(+)}$/kg) exchangeable acidity were recorded under the cultivated land and the forest land respectively. On average, however, relatively higher exchangeable acidity (0.15) was recorded in soil of the surface (0 – 20 cm) where relatively lower (0.13) was recorded in soil of the subsurface (Table 3). These results show intensive cultivation and release of organic acids during decomposition of organic matter to the relatively higher exchangeable acidity content under the cultivated land than the other land use types. Exchangeable acidity was negatively correlated with clay, pH, CEC and exchangeable bases, while sand and silt both positively correlated by with r= 0.55^{**} (Appendix Table 6).

Table 3. Main effects of land use type and soil depth on (pH (H_2O), pH (KCl), EA, OC, TN, C: N, Av. P) of soil in the study area

LUT	pH (H_2O)	pH (KCl)	OC (%)	TN (%)	C:N	EA (Cmol(+)/Kg	Av. P (mg/Kg)
CL	5.89^{c}	4.68^{c}	2.00^{d}	0.14^{b}	13.90^{b}	0.16^{a}	6.11^{d}
GL	6.50^{a}	5.63^{a}	2.10^{c}	0.15^{b}	13.91^{b}	0.15^{b}	9.00^{b}
FL	6.54^{a}	5.72^{a}	3.10^{a}	0.19^{a}	16.31^{a}	0.12^{c}	11.04^{a}
FaL	6.28^{b}	5.42^{b}	2.29^{b}	0.15^{b}	14.97^{b}	$0.13b^{c}$	7.03^{c}
LSD(0.05)	0.14	0.12	0.11	0.17	1.21	0.02	0.37
SEM (±)	0.06	0.10	0.10	0.00	0.30	0.00	0.40
CV (%)	1.85	1.86	3.71	9.26	6.55	9.11	3.67
Soil depth (cm)							
0-20	6.24^{b}	5.25^{b}	2.48^{a}	0.17^{a}	14.93^{a}	0.15^{a}	8.56^{a}
20-40	6.37^{a}	5.48^{a}	2.26^{b}	0.15^{b}	14.57^{b}	0.13^{b}	8.03^{b}
LSD(0.05)	0.10	0.09	0.08	0.01	0.86	0.01	0.26
SEM (±)	0.06	0.10	0.10	0.00	0.29	0.00	0.40
CV (%)	1.85	1.86	3.71	9.26	6.55	9.11	3.67

Main effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference, SEM = standard error of the mean, CV = Coefficient of variation, OC = organic carbon, TN = total nitrogen, C:N = carbon to nitrogen ratio, EA= exchangeable acid, AvP= available phosphorus, LUT= land use type, CL= Cultivated land GL= Grazing Land, FL= Forest Land FaL= Fallow Land.

4.2.6. Available phosphorus

The available phosphorus was not significantly different ($P \geq 0.05$) by land use type but affected by soil depth and the interaction of land use type with soil depth (Table 3). Available phosphorus (P) in all land use systems decreased with increasing soil depth. This is in agreement with the findings of Sime D. (2014), [93] who reported that top soil phosphorus is usually greater than subsoil due to sorption of the added phosphorus, greater biological activities and the accumulation of organic matter on the surface soil. According to Landon (1991), [40] the level of available phosphorus on the soil of forest land (11.04 mg/kg) can be illustrated as a high, whereas the other three land use types cultivated, fallow and grazing were described as medium. Among the land use systems, the natural forest land contained relatively higher concentration of available phosphorus as a result of high organic matter which released phosphorus during its mineralization. The other reason for the medium P contents of soil of the study area could be continuous uptake by crops, crop residue removal and erosion. On the other hand, available phosphorus was positively associated with pH, OC, TN and CEC, at r = , 0.75**, 0.81**, 72** and 0.70**respectively, while negatively correlated with bulk density at r= and -0.80** respectively (Appendix Table 6).

4.2.7. Cation exchange capacity

The CEC values of the soil in the study area were significantly different (P≤ 0.05) by land use type and soil depth, while not affected by interaction of land use type and soil depth (Table 4). The CEC value of the study area was 17.18, 14.33, 13.77 and 12.72 cmolkg^{-1}, for the land use types of forest, grazing, fallow and cultivated lands respectively, was registered in decreasing order (Table 4). Based on CEC ratings developed by Mebit K. (2006), [41] the CEC content of soil was rated a low in cultivated, grazing and fallow lands while, medium in the forest land (Table 4). The relatively moderate and low CEC values recorded, respectively, in forest and the three adjacent land use types may attributed to the fact that soil in forest land accumulate high percent OC and has greater capacity to hold cations thereby resulted greater potential fertility in the soil. Therefore, soil CEC is expected to increase through improvement of the soil OM content. However, deforestation, overgrazing and changing of land from forest to crop land without proper management aggravates soil fertility reduction, like in the cultivated land. The low CEC in cultivated land was in line with the low organic carbon contents of the soil under this land use type (Appendix Tables 2 and 3). Soil containing high clay and organic matter contents have high cation exchange capacity. The soil CEC values in cultivated land use types decreased mainly due to the reduction in organic matter content [98].CEC values increased from the (13.68) surface to the (15.32) subsurface in the study area (Table 4). The variation in CEC could be differences in clay contents, as clay increment would result in increased CEC. Cation exchange capacity was positively correlated with clay, OC, K, Na, Ca and Mg With correlation coefficient r = 0.63**, 0.58**, 0.78**, 0.68**, 0.86** and 0.87** respectively, whereas, negatively correlated with EA with r = -0.53** respectively (Appendix Table 6).

4.2.8. Exchangeable bases (K, Na, Ca and Mg)

The content of exchangeable bases was significantly affected (P < 0.05) by land use type but, it was not significantly (P >0.05) by soil depth and the interaction of land use type with soil depth (Table 4). Based on the data obtained, relatively highest mean (0.52,0.38,6.83 and 2.82

cmol(+)/Kg) was recorded in the forest land, where as the lowest (0.26, 0.25, 3.93 and 1.72 cmol (+)/Kg) obtained in the cultivated land, for the exchangeable K, Na, Ca and Mg respectively (appendix Table 3). As result, the mean relative result of basic cations in the exchange complex was in the order of Ca > Mg > K > Na. This is in agreement with that of [93]. In this study, deforestation and continuous cropping mainly contributed to depletion of basic cations on the cultivated land as compared to the adjacent forest land. In accordance the ratings of [41] the soil are categorized under low to medium for Ca, medium to Na, K and Mg.

Exchangeable bases was positively correlated with pH, OC, TN, Av. P and CEC While, it was negatively associated with exchangeable acid (Appendix Table 6).

Table 4. Main effects of land use type and soil depth on (CEC, K, Na, Ca, Mg and PBS) of soil in the study area.

LUT	CEC (Cmol(+)/Kg	K (Cmol(+)/Kg	Na (Cmol(+)/Kg	Ca (Cmol(+)/Kg	Mg (Cmol(+)/Kg	PBS (%)
CL	12.72[c]	0.26[d]	0.25[c]	3.93[c]	1.72[c]	48.57[b]
GL	14.33[b]	0.44[b]	0.34[b]	4.22[bc]	2.23[b]	50.68[b]
FL	17.18[a]	0.52[a]	0.38[a]	6.83[a]	2.82[a]	61.54[a]
FaL	13.77[b]	0.35[c]	0.28[c]	4.48[b]	1.78[c]	50.94[b]
LSD(0.05)	0.70	0.04	0.04	0.44	0.168	4.73
SEM (±)	0.42	0.02	0.01	0.26	0.10	1.70
CV (%)	3.94	8.40	9.64	7.36	6.41	7.31
Soil depth						
0-20 cm	13.68[b]	0.38[a]	0.30[a]	4.57[b]	1.98[b]	57[a]
20-40 cm	15.32[a]	0.40[a]	0.32[a]	5.16[a]	2.3[a]	48.89[b]
LSD	0.49	NS	NS	0.31	0.12	3.35
SEM (±)	0.42	0.02	0.01	0.26	0.1	1.7
CV (%)	3.94	8.40	9.64	7.36	6.41	7.31

Main effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference, SEM = standard error of the mean, CV = Coefficient of variation, CEC= cathion exchange capacity, PBS = percent base saturation, LUT=land use type, CL=Cultivated land GL=Grazing Land, FL=Forest Land FaL=Fallow Land.

4.2.9. Percent base saturation

The percent base saturation (PBS) of the soil at the study area was not significantly ($P \geq 0.05$) affected by land use type, soil depth and their interaction (Table 4).The percent base saturation, which depends on sum of exchangeable bases and CEC. Sime D. (2014), [93] among the two soil depths, relatively higher (57%) PBS was observed in the surface layer than the subsurface layer (48.89%), (Table 4). This is attributed mainly low CEC values recorded under the surface layer. According to [41], PBS is high when its values are > 60, medium when 20-60, and low when < 20%. According to this, PBS of the study area was moderate. Percent base saturation was associated positively with TP, OC and av. P with correlation coefficient $r= 0.65^{**}$, 0.71^{**} and 0.59^{**}respectively. Whereas negatively correlated with bulk density at $r=-0.65^{**}$ (Appendix Table 6).

4.2.10. Available Micronutrients

The contents of extractable micronutrients (Zn Fe,Mn and Cu) were significantly ($P \leq 0.05$) affected by land use type, and soil depth, but not significantly ($P \geq 0.05$) affected by their interaction (Table 5). Considering the main effects of land use type, the highest contents of Mn (14.05), Fe (4.33 mg/kg), Cu (4.41 mg/kg) and Zn (0.89 mg/kg) were recorded under the forest land while the lowest (13.38 3.69, 3.73 and 0.56 mg/kg) contents of Mn, Fe, Cu and Zn were observed under the cultivated land, respectively (Table 5). The results of the study area also indicated that the contents of all these micronutrients were higher at the surface (0-20 cm) layer than in the subsoil (20-40 cm) (Appendix Table 5). From surface (0- 20 cm) to the lower subsurface (40-60 cm) soil layer, available Mn, Fe, Cu and Zn were decreased by 4.39, 8.75, 9.74 and 11.27%, respectively. This shows that the solubility and availability of micronutrient was increased with the increase of OM content (Appendix Table 2 and 5), [98]. The concentration of available micronutrients in studied land use types were found to be Fe > Mn > Cu > Zn in all land use types and soil depth (Appendix Table 5 and Table 5). As per the critical rating recommended by [95], the contents of DTPA extractable Mn, Fe, Cu and Zn was found to be medium in all land use types and soil depths in the study area. Available micronutrients was positively correlated with TP, OC, Av. P and PBS, however, it was negatively correlated with bulk density (Appendix Table 6).

Table 5. Main effects of land use type and soil depth on micronutrients (Mn, Fe, Cu and Zn) of soil in the study area

LUT	Mn (mg Kg^{-1})	Fe (mg Kg^{-1})	Cu (mg Kg^{-1})	Zn (mg Kg^{-1})
CL	13.38^{b}	3.69^{c}	3.73^{b}	0.56^{d}
GL	$13.8a^{b}$	4.00^{b}	3.98^{ab}	0.82^{b}
FL	14.05^{a}	4.33^{a}	4.41^{a}	0.89^{a}
FaL	13.68^{ab}	3.73^{c}	4.24^{a}	0.74^{c}
LSD (0.05)	0.44	0.16	0.45	0.06
SEM (±)	0.11	0.07	0.09	0.03
CV (%)	2.62	3.33	8.91	6.59
Soil depth				
0-20 cm	14.02^{a}	4.10^{a}	4.28^{a}	0.79^{a}
20-40 cm	13.43^{b}	3.77^{b}	3.9^{b}	0.71^{b}
LSD (0.05)	0.31	0.11	0.32	0.04
SEM (±)	0.11	0.07	0.09	0.03
CV (%)	2.62	3.33	8.91	6.59

Main effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference, SEM = standard error of the mean, CV = Coefficient of variation, LUT=land use type, CL=Cultivated land GL = Grazing Land, FL=Forest Land   FaL=Fallow Land.

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The results of this study showed that there are significant differences ($p \leq 0.05$) among the four land use types for all soil properties except silt, C/N, exchangeable acidity, PBS, and micronutrient Mn, Cu were not significantly ($P \geq 0.05$) different. Variations in soil physicochemical properties were observed under soil of selected land use types and soil depth in the study area. For instance, soil clay, TP, pH-H_2O, OC, TN, available P, CEC, PBS and available Mn contents of forest land was significantly higher than the adjacent cultivated land by 14.66, 9.95, 9.94, 35.48, 26.32, 44.66, 25.96, 21.08 and 4.77% respectively. This variation in soil physicochemical properties could be related to high rainfall, burning plant residues practice during field preparation, removal of crop residues for animal feed and conversion of forest land to the other land use types.

5.2. RECOMMENDATION

From the results of the study conversion of forest lands to cultivate and grass lands had negative effects on the soil physicochemical properties under subsistence farming systems of the study area.

It is, therefore, recommended that:-

1. Fertilizers having higher content of phosphorus must be applied to the cultivated land in order to increase the concentration of available phosphorus.
2. Appropriate and integrated land management options for different land use systems are required to sustain agricultural productivity while protecting the environment.
3. The government and non-government rural development strategies should emphasize: to conserve the soil physicochemical properties of the soil of the study area by creating awareness for farmers to reduce the intensive cultivation and to use locally available sources of organic fertilizers like compost and animal dung.
4. Lime should be added to the cultivated land to increase the concentration of exchangeable bases as a result soil acidity can be lowered.

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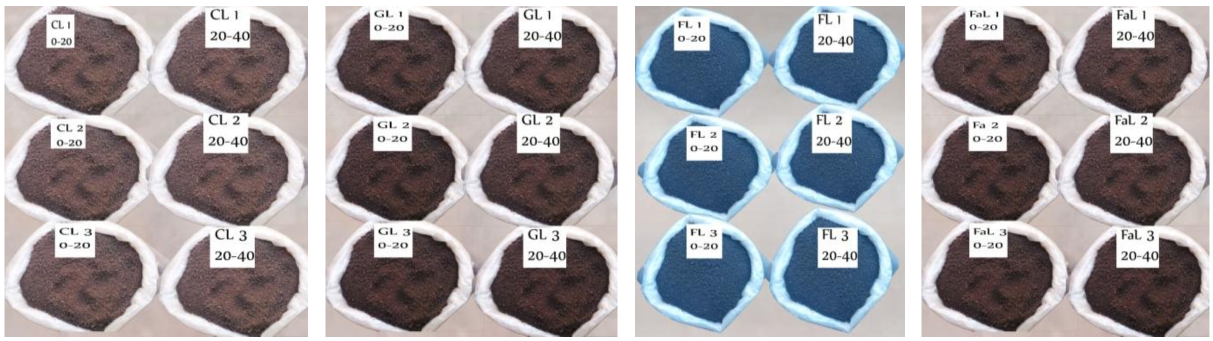
7. APPENDICES

7.1. LIST OF FIGURE IN THE APPENDIX



A. From Forest land   B. From Grazing land   C. From Forest land   D. From Fallow land

Appendix Figure 1. Soil samples collected from the study area

7.2. LIST OF TABLES IN THE APPENDIX

Appendix Table 1. Interaction effect of land use type and soil depth on soil selected physical properties of the study area

LUT	Sand %		Silt%		Clay%		BD g/cm3		TP%		Soil texture Classification	
	Soil depth(cm)		Soil depth(cm)		Soil depth(cm)		Soil depth(cm)		Soil depth(cm)			
	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
CL	39.00[a]	29.33[a]	28.00[a]	26.00[a]	33.00[c]	44.67[a]	1.29[a]	1.32[a]	51.32[c]	50.06[c]	Clay loam	clay
GL	40.33[a]	23.00[b]	26.00[a]	26.00[a]	33.67[bc]	51.00[a]	1.18[b]	1.18[c]	55.60[b]	55.60[a]	Clay loam	clay
FL	34.00[b]	31.00[a]	22.00[b]	22.00[a]	44.00[a]	47.00[a]	1.09[c]	1.23[b]	58.87[a]	53.71[b]	Clay	loam
FaL	34.00[b]	22.67[b]	28.00[a]	26.00[a]	38.00[b]	51.33[a]	1.22[b]	1.29[ab]	53.96[b]	51.32[c]	Clay loam	Silt loam
LSD (0.05)	2.17	2.03	3.99	6.03	4.55	7.63	0.06	0.04	2.14	1.52		
SEM (±)	2.62	2.62	4.42	7.06	4.43	9.35	0.06	1.59	2.07	1.64		
CV (%)	3.13	4.07	8.16	12.81	6.50	8.35	2.52	1.59	2.14	1.43		

Interaction effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference, SEM = standard error of the mean, CV = Coefficient of variation, BD = bulk density; STC= soil textural classification, TP= total porosity, LUT=land use type, CL=Cultivated land, GL= Grazing Land, FL= Forest Land FaL= Fallow Land

Appendix Table 2. Interaction effects land use type and soil depth on (pH (H_2O), pH (KCl), OC, TN, C: N) of soil in the study area

LUT	pH (H_2O)		pH (KCl)		OC%		TN%		C:N	
	Soil depth(cm)		Soil depth(cm)		Soil depth(cm)		Soil depth(cm)		Soil depth(cm)	
	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
CL	5.80^{b}	5.98^{c}	4.27^{c}	5.10^{c}	2.05^{c}	1.93^{c}	0.15^{b}	0.14^{b}	14.00^{b}	13.82^{b}
GL	6.45^{a}	6.56^{a}	5.57^{b}	5.70^{a}	2.30^{b}	1.90^{c}	0.15^{b}	0.15^{b}	15.00^{ab}	12.81^{b}
FL	6.48^{a}	6.61^{a}	5.80^{a}	5.63^{a}	3.12^{a}	3.08^{a}	0.20^{a}	0.18^{a}	15.64^{a}	16.80^{ab}
FaL	6.23^{a}	6.33^{b}	5.37^{b}	5.47^{b}	2.46^{b}	2.12^{b}	0.16^{b}	0.14^{b}	15.09^{ab}	14.85^{b}
LSD (0.05)	0.29	0.10	0.23	0.13	0.17	0.16	0.02	0.03	1.30	1.15
SEM (±)	0.274	0.12	0.27	0.15	0.20	0.14	0.02	0.04	1.52	2.79
CV (%)	2.50	0.85	2.33	1.26	3.54	3.90	6.03	10.08	4.64	7.85

Interaction effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference, SEM = standard error of the mean, CV = Coefficient of variation, OC = organic carbon, TN = total nitrogen, C:N = carbon to nitrogen ratio, LUT= land use type, CL= Cultivated land GL= Grazing Land, FL= Forest Land FaL= Fallow Land.

Appendix Table 3. Interaction effects land use type and soil depth on some chemical properties (EA, Av. P, CEC) of soil in the study area.

LUT	EA (Cmol $_{(+)}$)/Kg		Av. P (mg/Kg)		CEC (Cmol$_{(+)}$)/Kg	
	Soil depth(cm)		Soil depth(cm)		Soil depth(cm)	
	0-20	20-40	0-20	20-40	0-20	20-40
CL	0.19^{a}	0.14^{a}	6.21^{d}	6.00^{d}	12.84^{b}	12.60^{c}
GL	0.15^{b}	0.14^{a}	9.42^{b}	8.55^{b}	12.57^{b}	16.10^{b}
FL	0.13^{c}	0.12^{a}	11.34^{a}	10.75^{a}	16.70^{a}	17.67^{a}
FaL	0.15^{bc}	0.12^{a}	7.25^{c}	6.81^{c}	12.60^{b}	14.93^{b}
LSD(0.05)	0.02	NS	0.37	0.72	0.77	1.31
SEM (±)	0.02	0.03	0.42	0.82	0.91	1.38
CV (%)	5.92	12.24	2.30	4.76	3.01	4.54

Interaction effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference, SEM = standard error of the mean, CV = Coefficient of variation, EA = exchangeable acidity, AvP = available phosphorus, CEC= cathion exchange capacity, LUT=land use type, CL=Cultivated land GL=Grazing Land, FL=Forest Land FaL=Fallow Land.

Appendix Table 4. Interaction effects of land use type and soil depth on (K, Na, Mg, Ca, and PBS) of soil in the study area

LUT	K (cmol/Kg)		Na (cmol/Kg)		Ca (cmol/Kg)		Mg (cmol/Kg)		PBS%	
	Soil depth(cm)		Soil depth(cm)		Soil depth(cm)		Soil depth(cm)		Soil depth(cm)	
	0-20	20-40	0-20	20-40	0-20	0-20	20-40	0-20	20-40	0-20
CL	0.25[c]	0.27[d]	0.24[c]	0.26[b]	4.07[b]	0.25[c]	0.27[d]	0.24[c]	0.26[b]	4.07[b]
GL	0.41[b]	0.46[b]	0.33[b]	0.35[a]	3.87[b]	0.41[b]	0.46[b]	0.33[b]	0.35[a]	3.87[b]
FL	0.50[a]	0.53[a]	0.39[a]	0.37[a]	6.43[a]	0.50[a]	0.53[a]	0.39[a]	0.37[a]	6.43[a]
FaL	0.35[b]	0.35[c]	0.26[c]	0.29[b]	3.90[b]	0.35[b]	0.35[c]	0.26[c]	0.29[b]	3.90[b]
LSD (0.05)	0.07	0.06	0.06	0.05	0.63	0.07	0.06	0.06	0.05	0.63
SEM (±)	0.08	0.06	0.07	0.17	0.47	0.08	0.06	0.07	0.17	0.47
CV (%)	9.31	7.49	10.24	9.05	7.34	9.31	7.49	10.24	9.05	7.34

Interaction effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference, SEM = standard error of the mean, CV = Coefficient of variation, PBS = percent base saturation, LUT=land use type, CL=Cultivated land GL=Grazing Land, FL=Forest Land FaL=Fallow Land.

Appendix Table 5. Interaction effects of land use type and soil depth on micronutrients (Mn, Fe, Cu and Zn) of soil in the study area

LUT	Mn (mg/kg)		Fe (mg/kg)		Cu (mg/kg)		Zn(mg/kg)	
	Soil depth(cm)		Soil depth(cm)		Soil depth(cm)		Soil depth(cm)	
	0-20	20-40	0-20	20-40	0-20	0-20	20-40	0-20
CL	13.69[b]	13.07[a]	3.96[b]	3.42[c]	3.97[b]	3.49[a]	0.62[c]	0.49[c]
GL	13.91[b]	13.69[a]	4.14[ab]	3.86[b]	3.98[b]	3.98[a]	0.88[a]	0.75[b]
FL	14.70[a]	13.39[a]	4.38[a]	4.28[a]	4.71[a]	4.11[a]	0.92[a]	0.86[a]
FaL	13.79[b]	13.58[a]	3.92[b]	3.53[c]	4.44[ab]	4.04[a]	0.75[b]	0.73[b]
LSD (0.05)	0.56	NS	0.27	0.22	0.58	NS	2.30	0.05
SEM (±)	0.66	0.93	0.30	0.25	0.67	0.79	0.12	0.06
CV (%)	2.13	3.06	3.50	3.12	7.20	10.58	8.18	3.74

Interaction effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference, SEM = standard error of the mean, CV = Coefficient of variation, LUT=land use type, CL=Cultivated land GL=Grazing Land, FL=Forest Land FaL=Fallow Land

Appendix Table 6. Pearson's correlation matrix for various soil physicochemical parameters

	sand	silt	clay	Bd	TP	pHH	pHK	EA	OC	TN	CN	AvP	CEC	K	Na	Ca	Mg	PBS	Mn	Fe	Cu	Zn
sand	1	0.12	-0.91**	-0.19	0.19	-0.29	-0.36	0.55**	0.25	0.10	0.33	0.14	-0.44*	-0.14	-0.11	-0.17	-0.23	0.43*	0.28	0.51*	0.12	0.19
silt	0.12	1	-0.53**	0.44*	-0.44*	-0.40	-0.42*	0.55**	-0.59**	-0.62**	-0.27	-0.61**	-0.60**	-0.47*	-0.55**	-0.63**	-0.61**	-0.28	-0.29	-0.30	-0.33	-0.43*
clay	-0.91**	-0.53**	1	-0.03	0.03	0.42*	0.49*	-0.70**	0.04	0.18	-0.16	0.14	0.63**	0.32	0.33	0.41*	0.46*	-0.25	-0.11	-0.31	0.04	0.02
Bd	-0.19	0.44*	-0.03	1	-1.0**	-0.63**	-0.65**	0.16	-0.56**	-0.55**	-0.30	-0.80**	-0.44*	-0.7**	-0.69**	-0.4	-0.55**	-0.65**	-0.72**	-0.71**	-0.6**	-0.81**
TP	0.19	-0.44*	0.03	-1.00**	1	0.63**	0.65**	-0.16	0.56**	0.55**	0.30	0.80**	0.44*	0.70**	0.69**	0.4	0.55**	0.65**	0.72**	0.71**	0.60**	0.81**
pHH	-0.29	-0.4	0.42*	-0.63**	0.63**	1	0.86**	-0.53**	0.47*	0.41*	0.34	0.75**	0.65**	0.85**	0.68**	0.57**	0.73**	0.28	0.20	0.48*	0.25	0.72**
pHK	-0.36	-0.42*	0.49*	-0.65**	0.65**	0.86**	1	-0.69**	0.45*	0.42*	0.29	0.7**	0.56**	0.78**	0.73**	0.48*	0.66**	0.36	0.31	0.30	0.28	0.65**
EA	0.55**	0.55**	-0.70**	0.16	-0.16	-0.53**	-0.69**	1	-0.4	-0.44*	-0.16	-0.35	-0.53**	-0.49*	-0.44*	-0.53**	-0.54**	-0.12	0.05	0.08	-0.16	-0.31
OC	0.25	-0.59**	0.04	-0.56**	0.56**	0.47*	0.45*	-0.40	1	0.85**	0.72**	0.81**	0.58**	0.68**	0.60**	0.78**	0.64**	0.71**	0.45*	0.73**	0.53**	0.69**
TN	0.10	-0.62**	0.18	-0.55**	0.55**	0.41*	0.42*	-0.44*	0.85**	1	0.26	0.72**	0.60**	0.66**	0.61**	0.68**	0.63**	0.59**	0.36	0.57**	0.59**	0.58**
CN	0.33	-0.27	-0.16	-0.30	0.30	0.34	0.29	-0.16	0.72**	0.26	1	0.54**	0.26	0.39	0.30	0.54**	0.33	0.52**	0.36	0.60**	0.20	0.54**
AvP	0.14	-0.61**	0.14	-0.80**	0.80**	0.75**	0.70**	-0.35	0.81**	0.72**	0.54**	1	0.70**	0.9**	0.84**	0.72**	0.83**	0.59**	0.52**	0.80**	0.44*	0.84**
CEC	-0.44*	-0.60**	0.63**	-0.44*	0.44*	0.65**	0.56**	-0.53**	0.58**	0.60**	0.26	0.70**	1	0.78**	0.68**	0.86**	0.87**	0.18	0.19	0.42*	0.34	0.52**
K	-0.14	-0.47*	0.32	-0.70**	0.70**	0.85**	0.78**	-0.49*	0.68**	0.66**	0.39	0.90**	0.78**	1	0.84**	0.72**	0.86**	0.46*	0.39	0.69**	0.38	0.8**
Na	-0.11	-0.55**	0.33	-0.69**	0.69**	0.68**	0.73**	-0.44*	0.60**	0.61**	0.30	0.84**	0.68**	0.84**	1	0.68**	0.82**	0.47*	0.41*	0.57**	0.22	0.68**
Ca	-0.17	-0.63**	0.41*	-0.40	0.40	0.56**	0.48*	-0.53**	0.78**	0.68**	0.54**	0.72**	0.86**	0.72**	0.68**	1	0.85**	0.43*	0.18	0.56**	0.36	0.56**
Mg	-0.23	-0.61**	0.46*	-0.55**	0.55**	0.73**	0.66**	-0.54**	0.64**	0.63**	0.33	0.83**	0.87**	0.86**	0.82**	0.85**	1	0.39	0.20	0.56**	0.28	0.62**
PBS	0.43*	-0.28	-0.25	-0.65**	0.65**	0.28	0.36	-0.12	0.71**	0.59**	0.52**	0.59**	0.18	0.46*	0.47*	0.43*	0.39	1	0.41*	0.7**	0.48*	0.48*
Mn	0.28	-0.29	-0.11	-0.72**	0.72**	0.20	0.31	0.05	0.45*	0.36	0.36	0.52**	0.19	0.39	0.41*	0.18	0.20	0.41*	1	0.52**	0.63**	0.62**
Fe	0.51*	-0.30	-0.31	-0.71**	0.71**	0.48*	0.30	0.08	0.73**	0.57**	0.60**	0.80**	0.42*	0.69**	0.57**	0.56**	0.56**	0.70**	0.52**	1	0.48*	0.78**
Cu	0.12	-0.33	0.04	-0.60**	0.6**	0.25	0.28	-0.16	0.53**	0.59**	0.20	0.44*	0.34	0.38	0.22	0.36	0.28	0.48*	0.63**	0.48*	1	0.59**
Zn	0.19	-0.43*	0.02	-0.81**	0.81**	0.72**	0.65**	-0.31	0.69**	0.58**	0.54**	0.84**	0.52**	0.80**	0.68**	0.55**	0.62**	0.48*	0.62**	0.78**	0.58**	1

**significant at P=0.01 level, * significant at P =0.05 level, BD = bulk density, TP=total porosity OC = organic carbon; Total N = total nitrogen; C:N = carbon to nitrogen ratio; EA = exchangeable acidity, AvP = available Phosphorous, CEC = cation exchange capacity, PBS = percent base saturation.