VARIABILITY OF SELECTED SOIL PHYSICOCHEMICAL PROPERTIES UNDER DIFFERENT HOMEGARDEN AGROFORESTRY SYSTEMS OF WONDO GENET AND DALE DISTRICTS, SIDAMA REGION, ETHIOPIA

MSc THESIS

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BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGROFORESTRY AND SOIL MANAGEMENT

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APPROVAL SHEET- I

This is to certify that the thesis entitled **"Variability of Selected Soil Physicochemical Properties Under Different Homegarden Agroforestry System of Wondo Genet and Dale Districts, Sidama Region, Ethiopia"** was submitted in partial fulfillment of the requirement for the degree of Master of Science with specialization in Agroforestry and Soil Management of the Graduate Program of the Department of Agroforestry, Wondo Genet College of Forestry and Natural Resources, and is a record of original research carried out by Ribka Mekuria (ID number GP AFSMR/07/13), under my supervision. No part of this thesis has been submitted to educational institutions for achieving any academic awards. The assistance and help received during this investigation have been duly acknowledged. Therefore, I recommended to be accepted as fulfilling the thesis requirement.

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APPROVAL SHEET-II

We, the undersigned, members of the board of examiners of the final open defense by Ribka Mekuria have read and evaluated the thesis entitled **“Variability of Selected Soil Physicochemical Properties Under Different Homegarden Agroforestry System of Wondo Genet and Dale Districts, Sidama Region, 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 of Master of Science in Agroforestry and Soil Management at Wondo Genet College of Forestry and Natural Resources.

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SGS Approval	Signature	Date

DECLARATION

I the undersigned, hereby declare that this MSc. thesis entitled **"Variability of Selected Soil Physicochemical Properties Under Different Homegarden Agroforestry System of Wondo Genet and Dale Districts, Sidama Region, Ethiopia"** is my original work and has not been submitted for a degree of award in any other university, and all sources of material used in this thesis have been duly acknowledged.

Ribka Mekuria	__________________________	__________________
Name of Student	Signature	Date

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ACRONYM AND ABBREVIATIONS

a.s.l.	Above sea level
ANOVA	Analysis of Variance
BD	Bulk Density
CSA	Central Statistical Authority of Ethiopia
FAO	Food and Agriculture Organization
K	Potassium
LSD	Least Significant Difference
MC	Moisture Content
OM	Organic Matter
P	Phosphorus
PA	Peasant Association
pH	Potential of Hydrogen
SAS	Statistical Analysis System
SNNPRS	Southern Nations Nationalities and Peoples' Regional State
SOC	Soil Organic Carbon
SOCS	Soil Organic Carbon Stock
TLU	Tropical Livestock Units
TN	Total Nitrogen
TNS	Total Nitrogen Stock

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ABSTRACT

Homegarden agroforestry system is well recognized as an inclusive and ecologically sound system. However, the recently observed change from enset-based homegardens to cash crop khat is expected to cause a decline in soil fertility. Thus, this study was initiated on one hand to assess the effect of the traditional homegarden system change to a khat-based system on soil physicochemical properties at Wondo Genet and on the other hand to understand nutrient conservation potential of stable homegarden system in Dale districts, Sidama Region. Four kebeles were selected of which thirty-six households were considered for soil sampling. Following the identification of the enset, khat, and coffee land uses types, soil samples were taken from each farm household of each land use type at five different points from two different depths (0 – 20 and 20 – 40 cm). A total of 144 soil samples were collected. The selected soil physical properties were soil texture, moisture content, and bulk density whereas selected soil chemical properties were soil pH, soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and nutrient stocks. Two-way analysis of variance (ANOVA) was used to test the significant differences among different land uses on soil physicochemical parameters. The results showed significant ($p<0.01$) differences between the land uses in soil physical and chemical properties. The enset land use had significantly ($p<0.01$) higher pH, moisture content, soil organic carbon, total nitrogen, exchangeable potassium, and nutrient stocks than the khat land use in Wondo Genet. However, at Wondo Genet, available phosphorus was significantly higher under the khat land use than in the enset land use. Similarly, the enset land use had significantly ($p<0.01$) higher pH, moisture content, soil organic carbon, total nitrogen, exchangeable potassium, and nutrient stocks than the coffee land use in Dale. Regarding soil depths, except bulk density, other physical and chemical soil properties were significantly ($p<0.01$) higher at the upper soil depth than at the lower soil depth. Generally, land use systems like enset-based homegarden improve the soil physical and chemical properties. Therefore, future soil management strategies should be focused on mitigating the continuous loss of soil nutrients in khat and coffee land use through the retention of crop residues, application of organic fertilizer, and scaling-up agroforestry practices.

Keywords: *coffee, enset, homegarden, khat, soil physicochemical property*

1. INTRODUCTION

1.1. Background

Agroforestry is a prevalent land-use system in tropical countries, with a rich diversity of production systems, and an efficient, ecologically and socio-economically sustainable system (Kefale, 2020; Mellisse, 2017). It is found in several ecological zones like humid lowlands, mid-altitudes, highlands, and semi-arid to sub-humid areas (Abebe, 2005). The popularity of agroforestry practice is mainly related to the possibility of producing diverse products per unit area through the combined production of crops and trees together with livestock besides its role in climate change adaptation and mitigation (Mbow et al., 2014).

In Ethiopia, agroforestry is commonly practiced despite the variation in distribution and effectiveness from place to place in response to the variation in agroecology, management practice, and resource endowments such as farm size, family labor, and livestock herd size (Jiru, 2019). Homegardens are one of the agroforestry types which constitute various socio-economic and environmental benefits such as providing wood, food, fodder, and cash from a small farm area. Similar to other tropical countries homegarden agroforestry systems are practiced in densely populated areas of Ethiopia where farmland constraints are severe (Mellisse, 2017).

In densely populated areas of southern Ethiopia, homegardens are distinguished by their unique combination of two native perennials, such as coffee (*Coffea arabica* L.) and Enset (*Ensete ventricosum* Welw. Cheesman) (Gebrehiwot, 2013). These homegardens are commonly called Enset-coffee-based homegarden systems which account for 576,000 hectares, or 31% of the region's cultivable land (Abebe, 2005). In these land-use systems, perennial staple food crops, particularly enset and cash crop coffee, are generally grown together with annual crops, multifunctional trees, and livestock husbandry (Abebe et al., 2010). Enset is a herbaceous crop cultivated as a staple food for over 15 million people in southern Ethiopia (Abebe, 2005). In addition to a food source, enset leaves are utilized as cattle feed and as a mulch to decrease soil erosion and runoff (Amedea and Dirob, 2005).

In the homegarden systems, the advantage of mixing crop and livestock activity is connected to the availability of inexpensive fodder for livestock in the form of enset leaves, as well as animal manure, which recycles nutrients to promote enset and coffee production (Mellisse, 2017). Also, livestock plays a critical role in providing protein and nutrient-rich products and trees provide multiple functions such as fuelwood, construction materials, animal feed, and soil fertility maintenance, and serve a variety of other purposes (Abebe, 2005; Brandt et al., 1997; Kumar and Nair, 2004).

Homegardens are more stable than mono-cropping systems, which is one of the reasons for their appeal in densely populated areas of tropical countries such as like in Kerala India, Java, Indonesia, and southern Ethiopia (Torquebiau, 1992). The potential of homegardens in carrying a dense population is largely explained by the opportunity it makes to harvest diverse products and obtain more biomass from key components of the system like enset than annual crops (Tsegaye and Struik, 2001).

The importance of agroforestry practices for carbon sequestration and soil fertility improvements especially when nitrogen-fixing tree-crop species are planted in intercropping systems was reported by various researchers. For example, Gelaw et al. (2014) reported an increase in carbon by 0.19 Mg/ha/year and total nitrogen by 0.022 Mg/ha/year in the topsoil depth (0 – 30 cm depth) in the agroforestry-based crop production system of northern Ethiopia. The main reason for enhanced soil organic carbon was mainly due to the presence of woody perennials which sequester carbon and transport it from the air to below ground to support root growth and on the other hand add organic matter to the soil in the form of litter fall. Similarly, better soil quality parameters for crop production were obtained under the agroforestry-based conservation tillage system than the conventional tillage under the maize system (Ketema and Yimer, 2014).

Agricultural lands in Ethiopia are affected by different mismanagements like deforestation, overgrazing, and inappropriate land use system which leads to soil erosion and poor soil fertility. Therefore, agroforestry practices like homegardens are important to increase soil nutrient supply through nitrogen fixation, improve soil structure, and reduce soil erosion and nutrient losses (Wolle et al., 2021). In southern Ethiopia, homegarden agroforestry systems are regarded as efficient farming system as it allows interactions and synergies between crop, tree, and livestock components (Mellisse, 2017). This is important for influencing the productivity of the agroecosystem through the interaction of trees and crops to enhance soil fertility and crop productivity (Dori et al., 2022).

In Ethiopia in general and particularly in the study area, population growth is very high in which there is pressure on the agricultural system to increase food production to feed the population with limited land area. Contrary to this, the increasing market-oriented mono-cropping system leads to soil fertility depletion that indirectly affects the productivity of the farmlands. However, homegarden agroforestry systems favor different essential conditions for the productivity of diverse species through supplying and conserving essential nutrients and moisture that enhance agricultural productivity. This is the main reason the diverse species under the homegarden agroforestry system have a great advantage over the mono-cropping system to minimize the risk of crop failure and maximize soil fertility through litter fall (Jiru, 2019; Mbow et al., 2014).

Carbon assimilated by the woody perennial plants, which is carried below ground to promote root development and organic matter turnover activities such as fine root dynamics, rhizodeposition, and litter dynamics was attributed to the enhanced SOC in the homegarden and makes this system good for soil health. Different studies revealed that the homegarden agroforestry system has a better impact on soil chemical properties than some agroforestry systems. For example, the study by Dori et al. (2022) showed that the homegarden agroforestry system significantly improved soil organic carbon, organic matter, and cation exchange capacity more than the parkland agroforestry system. Wolle et al. (2021) also studied the effect of homegarden and parkland agroforestry practice on selected soil chemical properties in the Amhara region, Ethiopia. Accordingly, they reported that all studied soil chemical properties except total nitrogen were significantly improved at both agroforestry systems, and soil organic carbon, organic matter, available phosphorus, and exchangeable potassium were highest at homegarden agroforestry. Also, showed that except for soil pH, all soil chemical properties decrease with increased soil depth.

The study by Wolka et al. (2021) also revealed that homegarden agroforestry has higher soil organic carbon concentrations than croplands, especially in the upper soil of 0 – 20 cm depth. That is because for better soil fertility management farmers in Ethiopia apply household waste and manure for homegardens, and inorganic fertilizer for croplands (Wolka et al., 2021). Therefore, homegarden agroforestry practice could be used as an alternative for maintaining soil fertility (Wolle et al., 2021). Likewise, homegarden agroforestry is an important avenue for carbon sequestration in the soil to enhance organic carbon and improve soil moisture availability (Sharma et al., 2022).

Despite the importance of homegarden agroforestry for improving soil fertility, changing to mono-cropping systems leads to homogenization of the landscape. These conversions of the integrated multistory system to the monoculture system are expected to negatively affect the species diversity and the opportunity of harvesting multiple products which led to the loss of agrobiodiversity and soil fertility (Abebe, 2005; Kim et al., 2016). For example, the study by Kim et al. (2016) revealed that the conversion of homegarden agroforestry to the mono-crop field at Wondo Genet decreased soil organic carbon and total nitrogen stocks. This change affects species diversity and herd size (Abebe, 2005; Gebrehiwot, 2013; Mellisse, 2017), food and income source (Gebrehiwot et al., 2016), and soil property (Kim et al., 2016; Mellisse, 2017).

Therefore, field-level investigation about the rate at which different land uses practices affect soil physicochemical properties under homegarden agroforestry is important. Thus, this study was conducted based on the objective to evaluate the variation in selected soil physicochemical properties under different homegarden agroforestry systems at Wondo Genet and Dale districts of the Sidama region.

1.2. Statement of the Problem

Homegarden agroforestry systems have a wider range of composition of species diversity. In the Sidama region, the traditional homegarden agroforestry systems are common despite variation that might be expected from diversity in species composition and productivity from farmer to farmer. However, these traditional homegarden agroforestry systems are changing rapidly due to increasing population pressure on the land, the introduction of new agricultural technologies, new opportunities for agricultural markets, and an increasing need for cash earnings (Abebe, 2005; Gebrehiwot et al., 2016).

Recently, these diverse land-use systems are changed to mono-cropping systems of cash crops such as khat (*Catha edulis* Forsk) in the Sidama region of southern Ethiopia, which may lead to the homogenization of the landscape. Most Enset-based homegardens at Wondo Genet in 1991 were converted to khat-based and enset-cereal-vegetable homegardens in 2013, and the proportion of enset-based farms declined from 44% in 1991 to 7% in 2013 (Mellisse, 2017). However, the share of khat-based products has increased from 10% in 1991 to 55% in 2013. On the other hand, at Dale, the introduction of the khat-based homegarden type was limited to just 3% of the farms (Mellisse, 2017). In the Sidama region, the trend of conversion of homegarden agroforestry to a mono-cropping system has been exhibited (Gebrehiwot et al., 2016). Converting homegardens to mono-crop could result in decreased soil fertility, water availability, species diversity, and food and income source.

The major causes of change in the land use system in the study area include better financial income due to favorable market conditions for khat and the positive experience of farmers in khat production. Moreover, the unavailability of quality seeds and fertilizer for other food crop production, minimum risks of theft, and wildlife damage encouraged farmers to change their farms to mono-cropping khat farms. Due to those major causes, farmers in the study area were forced to change the traditional homegarden to a khat-based system (Abebe, 2005; Gebrehiwot, 2013; Gebrehiwot et al., 2016; Kim et al., 2016; Mellisse, 2017). Similarly, previous research findings revealed the effects of different land use systems on soil properties (Kim et al., 2016; Mellisse, 2017). However, these studies are conducted on limited farms, agroecology, and soil parameters.

The effect of various land uses within homegarden and changing homegarden agroforestry systems on soil physicochemical properties has also received little attention in the study area. In order to compare the variation in soil physicochemical properties between the newly introduced khat field and adjacent enset field within the same farm as well as between the same fields of enset, coffee, and khat a field study is needed. This study was initiated to examine various soil types and heterogeneous farm households by taking into account the hot spot areas of change (Wondo Genet) and stable areas (Dale).

1.3. Objectives

1.3.1. General Objective

- To determine the variation in selected soil physicochemical properties and nutrient stocks under different land use types within homegarden agroforestry systems of the Wondo Genet and Dale districts, Sidama region Ethiopia.

1.3.2. Specific Objective

- To examine the variation in selected soil physicochemical properties under different land use types within homegarden agroforestry systems of the Wondo Genet districts, Sidama region Ethiopia.
- To examine the variation in selected soil physicochemical properties under different land use types within homegarden agroforestry systems of the Dale districts, Sidama region Ethiopia.
- To examine the variation in selected soil nutrient stocks under different land use types within homegarden agroforestry systems of the Wondo Genet and Dale districts, Sidama region Ethiopia.

1.4. Research Questions

- Do different land uses cause variation in selected soil physical properties?
- How selected soil chemical properties vary under different land uses of homegarden agroforestry systems?
- How selected soil nutrient stocks vary under different land use types within homegarden agroforestry systems?

1.5. Significance of the study

In southern Ethiopia, homegarden agroforestry combines the features of two perennial crops enset and coffee. Food from staple food crops, vegetables, enset and tree crops, and coffee as the principal income crop are all advantages of having a homegarden. However, due to increasing population pressure on the land, the introduction of new agricultural technology, new options for agricultural markets, and increased demand for cash earnings, these traditional homegarden agroforestry systems are rapidly altering.

In this study, selected soil physicochemical properties were examined in detail under various land uses in a homegarden agroforestry system. Such information is critical for attempts to improve the system's design and management, as well as to allow resource efficiency and productivity improvements. This study also shows how changing traditional homegarden systems to the commercialization of khat crops could alter soil physicochemical properties. Academics, development agents, and policymakers will use the findings of this study to assure rural communities' food security resilience.

2. LITERATURE REVIEW

2.1. Homegarden Agroforestry

The practice of agroforestry has been sustainable for thousands of years and is an important element of the cultural rural landscape in tropical and temperate regions around the world (Kalaba et al., 2010). Agroforestry practices range from open parkland assemblages to dense imitations of tropical rainforests such as agroforestry homegardens, and from planted mixtures of only a few species to trees planted in hedges or on boundaries with differing levels of human management of the various components (Dawson et al., 2013). There are more than a hundred different agroforestry practices have been identified in tropical and temperate regions (Atangana et al., 2014). The traditional tropical agroforestry homegarden has been practiced in East and West Africa, South and South East Asia, Pacific Islands, and Mesoamerica, where it is a predominant tropical land use practice (Abebe, 2005; Kumar and Nair, 2004).

Commercial production systems towards the end of the intensification gradient are high-input, open systems with low species diversity, and they strive for maximum profitability. In contrast, rainforests are nearly closed systems with little input and a high diversity of organisms. In the middle, there exist agricultural systems with intermediate levels of complexity and species variety, such as agroforestry and intercropping (Abebe, 2005).

Homegardens are complex and diversified agroecosystems, indicating that they are capable of carrying out ecological functions. The presence of diverse species within the homegarden agroforestry makes the system an important genetic conservation site, efficient resource utilization, biological pest control, soil and water conservation, and maintenance of important soil nutrients (Abebe, 2005; Kim et al., 2016). On the forest-mono-cropping continuum, homegardens are a long way from market-oriented commercial production systems. However, this does not necessarily imply that they are less appealing commercially. Due to the inclusion of high-value cash crops, many homegarden in the tropics are economically more feasible than other land-use patterns in the region (Abebe, 2005).

Based on their contribution to the welfare of households, homegardens are classified into two. Small-scale supplementary food production systems surrounding residences in locations where the owners' livelihood is reliant on other land usage or other enterprises are the first. This comprises gardens in rural, semi-urban, and urban areas. The second type of homegarden is the extensive agricultural fields that surround residences and are the primary source of income for farming families. In this situation, the farmers either don't have any other land or it is modest and just serves as a complement to their homegarden. Both types of homegarden are common in cereal-crop-based farming and perennial-crop-based farming system in Ethiopia. Here, staple food crops (enset and maize), as well as other cash and food crops, are grown in the homegarden and these garden farms make the principal means of livelihood for almost all the households in the study area (Abebe, 2005).

2.2. Definitions of Homegardens

Homegarden agroforestry is ‘land-use practices involving deliberate management of multipurpose trees and shrubs in close association with annual and perennial crops and invariably, livestock, within the compounds of individual houses, the entire crop-tree-animal unit being managed by the family labour'(Fernandes and Nair, 1986). Homegarden is often part of a more complex farming system which also includes other cropping systems.

According to Hoogerbrugge and Fresco (1993), the homegarden systems have also been described as a small-scale 'supplementary' food production system using 'marginal land and marginal labor. As a system of permanent land use, the homegarden has well-defined boundaries and is located at or within a reasonable distance from the residence. As a type of cropping system, it comprises soil, crop, weed, pathogen, and insect sub-systems, which transform solar energy, water, nutrients, labour, and other inputs into food, feed, fuel, fiber, and pharmaceuticals (Fresco and Westphal, 1988).

Kumar and Nair (2004) have also described homegardens as a piece of land with a definite boundary surrounding a homestead, being cultivated with a diverse mixture of perennial and annual plant species, arranged in a multilayered vertical structure, often in combination with raising livestock, and managed mainly by household members for subsistence production Homegardens are characterized by place of proximity to home, small in plot size, cultivation of different vegetables, fruits, and other crops; cultivation throughout the year, production mainly for family consumption and sale if in excess; managed by household members namely wife, husband and children and use of low-cost input for cultivation.

2.3. Agroforestry in Ethiopia

In Ethiopia, agroforestry is an ancient sustainable land management practice that farmers in different parts of the country are familiar with it to produce food crops, vegetables, medicinal, ornamental, spices plants, fodder, fruit trees, building materials, and fuel woods (Kefale, 2020; Wolka et al., 2021). The major driving forces for the agroforestry practice in

Ethiopia are due to population pressure, reduction in land size, poverty, and the market situation (Jiru, 2019; Meragiaw, 2017). The common types of agroforestry practice in Ethiopia include homegarden, farmland, woodlot, and coffee farm. These contribute to multiple benefits from a given land as it includes different crops trees and or shrubs that are both used for food and income generation. Homegardens are unique in their architecture, crop mix, and dominant species which are self-sustaining agroecosystems both in biophysical and socioeconomic terms (Kefale, 2020). Studies showed that it enables farmers to secure their food availability, nutritional needs, efficient farming systems, mitigate environmental change, conserve agrobiodiversity and allows interaction and synergies between crops, tree, and livestock, and increase consistency of social-cultural values (Mehari and Abera, 2019; Mellisse, 2017; Sharma et al., 2022).

Mixing trees with annual crops in the agroforestry system leads to diversifying production and increasing the productivity of land and overcoming crop failure due to climate change (Jiru, 2019). Due to this, farmers in Ethiopia are aware of the agroforestry system despite there being variations from area to area. This is more highly recommended and acceptable than mono-cropping as it provides socio-economic benefits beyond food security like income generation through tree products like timber, firewood, construction materials, and fruit within the small land size. Moreover, environmental services like soil conservation and fertility, increased soil moisture, coffee shade, and micro-climate balance are among the major benefits (Jiru, 2019). Moreover, in Ethiopia agroforestry system is one of the basic extension packages and highly practiced in different regions of the country through tree-enset-coffee, tree-enset, woodlot, scattered trees on farmland, pastureland, and boundary planting (Jiru, 2019).

2.4. The Overview of Homegarden Agroforestry System in Ethiopia

The homegarden agroforestry system is one of the major production systems that developed during Ethiopian's early agricultural life and it is the most common practice which is familiar to small holder farmers (Jemal et al., 2018). In the country, there are a variety of traditional agroforestry practices with potential to contribute to the food and nutrition security of the practitioner communities (Abebe, 2005). Among the well-known traditional agroforestry practices, the croplands with scattered trees of *Faidherbia albida* are the oldest form of indigenous agroforestry parklands, mostly practiced in the central and eastern parts of Ethiopia. The Enset-Coffee gardens, *Coffea arabica* planted mixed with *Ensete ventricosum*, dominantly practiced in Gedeo and are well-known to support millions of livelihoods in the most densely populated areas of the country (Asfaw and Agren, 2007).

The traditional enset-coffee system is also well practiced in south-western Ethiopia. In south-western Ethiopia, most of the homegardens are located at altitudes of 1500–2300 meters above sea level where moisture and temperature conditions are favorable for agriculture. These gardens are characterized by a unique combination of two native perennial crops enset and coffee (Abebe, 2005). Enset (*Ensete ventricosum* (Welw.) Cheesman) is an herbaceous multipurpose crop, and a staple food for about 10 million people in the region. Coffee (*Coffea arabica* L.) is mainly used as a cash crop, but also for household consumption. Other components of these multi-species agroecosystems include khat (*Catha edulis* Forsk), a mild stimulant, root and tuber crops, fruits, vegetables, cereals, spices, and other crops. Moreover, livestock is kept in the gardens and different tree species are grown to serve productive as well as ecological functions. These gardens are also known as ‘enset-coffee homegarden (Abebe, 2005).

The enset-coffee homegardens have been stable agricultural systems for centuries supporting very dense populations of up to 500 persons per square kilometer (Kanshie, 2002). The diversity of the systems, and the ability of enset to produce a relatively large amount of food per unit area and time (Tsegaye and Struik, 2001), could be the main factors that contributed to this stability. Abebe (2005) described the enset+coffee homegardens as a practice characterized by displaying a mosaic of patches or farm units which are distinct from one another because of the dominant crop grown on them. For instance, a coffee unit can be recognized where coffee is the dominant crop but grown in association with other crops and trees, or a maize unit that is intercropped with few crops and trees. Near the house, enset is dominant and as one goes further away, other units dominated by coffee, maize, or other crops prevail. Marshy areas are often allotted to pastures, sugarcane, or eucalyptus. The study conducted by Mellisse (2017) reported that Wondo Genet was characterized by the dominance of khat-based homegardens in the Sidama region.

2.5. Structure and Composition of Homegarden

Layers of vegetation (story) resemble the structure of a tropical forest in a tropical homegarden. The top-level canopy of tall trees reduces radiation and the mechanical impact of rainfall creates a relatively constant micro-climate in the lower layers and helps to preserve soil fertility through leaf fall. The lowest layer is made up of staple food and fruit production (such as banana, mango, and papaya), while the third layer is made up of bush-level development (e.g., cassava, maize, peppers, and so on). Climbing species make their way through the lower stories, while in-ground and ground-covering species (roots, tubers, and others) make up the last layer (Fernandes and Nair, 1986).

Ornamental, fruits, food crops, vegetables, medicinal, spices and fodder, construction materials, and fuel woods are some of the crop and tree compositions planted in homegarden. Due to the gardener's educational level, the farmer's indigenous knowledge, the market, and the area of land available, the patterns and compositions of homegarden are disordered. Sociocultural, environmental, and ecological factors determine species composition and types of homegardens (Fernandes and Nair, 1986).

In the highlands of southern Ethiopia, homegarden agroforestry is characterized by a unique combination and dominance of two native perennial crops, enset and coffee commonly practiced. Besides different varieties of staple food crops, vegetables, and tree crops, enset is the major staple food while coffee is the principal cash crop in this area. Unlike most homegarden which are small and supplementary food production units, these homegarden are extended farm fields around houses and they form the principal means of livelihood for farming households (Abebe, 2005).

2.6. Component Interaction in Homegarden

In homegarden agroforestry animals, trees and crops have a symbiotic relationship between them. For example, trees are the most important part of a homegarden since they retain and connect many ecosystem components such as soil, insects, bacteria, and leaf litter. As a result, trees are used as a source of decomposition materials, decomposers or soil fauna, and habitats to improve the soil's production capacity. Trees aid in the regulation of a favorable microclimate for crops and the reduction of evaporation. Farmers can use trees as construction materials for animal shade and make cows feed from the remaining trees. Livestock dung is used to fertilize crops and assist trees in obtaining critical nutrients (Galhena et al., 2013). These factors could attract farmers to adopt homegarden agroforestry around the homestead.

2.7. The Role of Homegarden Agroforestry

The increasing pressure of human and livestock populations is the main cause of natural resource degradation. This is especially critical in climate change conditions where weather is variable including drought and erratic rainfall (Sarvade and Singh, 2014). In Ethiopia, homegarden agroforestry is practiced for improving food security and reducing deforestation (Meragiaw, 2017). Homegarden agroforestry systems could significantly contribute to food security and alleviating poverty. Diverse agroforestry systems can help smallholder farmers increase their food security and diversify their sources of income (Vignola et al., 2015).

It has a huge role in improving the ecosystem quality, conserving soil and water, and improving soil fertility and moisture-holding capacity of the soil as it contributes to nitrogen fixation, nutrient cycling, pumping, and improving organic matter content. This leads to soil amelioration by reversing the trend of declining soil fertility by reducing soil erosion, increasing soil organic matter, and nutrient cycling which contributes to improving crop yield. Besides, it enhances soil moisture availability through mulching, reduction of evaporation and runoff, increasing infiltration, and enhancing the water use efficiency of rain (Sarvade and Singh, 2014; Yirga, 2019). The use of multipurpose trees and an integrated approach enhance the profitability of agroforestry as trees could be a source of income, fodder, edible fruits, non-timber products, and valuable plant nutrients.

2.7.1. Homegarden for biodiversity conservation

Homegarden agroforestry is a type of integrated land use that can improve agrobiodiversity and contribute to landscape biodiversity conservation while also increasing, diversifying, and sustaining rural incomes. The structure and components of the homegarden agroforestry system make the system rich in species diversity. Different species grown in the homegarden give different functional roles for the household also homegarden plays a great role in conserving species through in-situ conservation.

For example, a study conducted at Hawassa city reviled that, 258 useful plant species were observed and identified belonging to 186 genera and 76 families, including (5.43%) vegetable plant species, (8.92%) fruit plant species, (5.81%) spices plant species, (4.65%) root and tubers plant species, (3.1%) cereals, pulses, and oilseeds plant species, (1.16%) stimulant plant species, (4.65%) fragrant plant species, (47.29%) ornamental plant species, (15.12%) firewood plant species, (1.55%) animal feed plant species and (15.89%) medicinal plant species (Reta, 2016).

Similarly, in a study conducted at Bishoftu town of the Oromia region, the homegarden plant composition gave 115 species belonging to 94 genera and 51 families. Among these, 50, 37, 21, and 7 plants were herbs, trees, shrubs, and climbers, respectively. Also, the same report shows that 75 and 25% were cultivated and wild; 95.7 and 4.3% were non-endemic and endemic species (Bekele, 2014). In the Dilla district, Tefera et al. (2016) also found 52 species belonging to 35 genera and 25 plant families (trees 63 %, shrubs 12 %, herbs 19 %, and climbers 9 %). According to the study by Semu (2018) in Kombolcha town, Oromia region the homegarden plant composition gave 78 species belonging to 35 families. This helps homegardens produce a variety of fresh meals with varying quality and amounts of nutrients for a family at a low cost and in a sustainable manner.

The study by Ewuketu et al. (2014) reported they found high plant diversity in the studied homegarden which also acts as a refuge for threatened species in Ethiopia. Their diverse nature makes the system environmentally resilient, allowing them to perform more and better ecological roles. According to Tadesse et al. (2019) study reported that homegarden agroforestry was more diverse and richer in species than parkland agroforestry. Also, the study of Hailu et al., (2021) showed that a wide range of species was found in the homegarden, natural forest, plantation forest, and farm forest, respectively.

In another study conducted at the Gununo watershed, Wolayita zone a total of 32 woody species belonging to 19 families were recorded in the three agroforestry practices. Homegardens had the most indigenous species and the greatest diversity of species, followed by parklands and woodlots (Bajigo et al., 2015). Also, in another study in the Kachabira district, southern Ethiopia A total of 59 plant species, belonging to 56 genera and 36 families were recorded across the homegardens, parklands, and live fences. The highest mean species richness and diversity were recorded in the homegarden agroforestry practice followed by parkland and life fence (Legesse and Negash, 2021). Studies indicated above show that homegarden agroforestry has a great role in biodiversity conservation. Also, homegarden agroforestry has high species diversity than other land use.

2.7.2. Homegarden for food security and income generation

In Ethiopia, homegarden agroforestry is practiced for improving food security and reducing deforestation (Meragiaw, 2017). Homegarden agroforestry systems could significantly contribute to food security and alleviating poverty. Diverse agroforestry systems can help smallholder farmers increase their food security and diversify their sources of income (Vignola et al., 2015). All homegardens contain some sort of food crops and many trees produce fruits or other forms of food, wood, and firewood. This indicates that the most significant function of homegardens is food production and income generation (Fernandes and Nair, 1986).

The community study conducted in Tanzania shows that homegarden agroforestry contributes, 17% towards household food security and 25% towards income generation. Also, food security and income generation over the year form 78% of the motivating factors to adopt homegarden agroforestry (Nzilano, 2013). The study conducted in South Africa reports that food insecurity is related to homegarden ownership and income. Farmers that practice homegarden agroforestry have a high income in this manner poverty is alleviated and assured food security (Bongiwa and Obi, 2015).

According to Zemede (2001), approximately 74% of the crops identified in homegardens were food crops, with the remaining 26% being non-food crops, this was emphasizing the significance of homegardens in supplying food to the household. At Bishoftu town, 36.52 % of homegarden species have been classified as food and nutrition sources. The majority of these food and nutrition plants are year-round fruits and vegetables that are regularly utilized as food and nutrition sources in the household (Bekele, 2014).

Also, another study conducted by Mekonen et al., (2015) reported that from interviewed households, 25 % of plant species were listed as the most important food crops by the local people. Similarly, Musotsi et al., (2009) reported that the presence of different component species, numbers of livestock, and land size of homegarden agroforestry make the system important for household food security and income source. A study at Jima reported that the relative household incomes of homegarden agroforestry were found about 44.5%. Income from homegarden increased the average household income from 2,100 to 3,784 birr. In this area, farmers practice homegarden majorly in response to food security (Kebebew et al., 2011). In the study conducted in Boloso Bombe district southern Ethiopia, the finding also showed that on average homegardens contributed over 34% of household annual income. The findings also showed that the farmers have access to sufficient income throughout the year due to diverse products (Atiso and Fanjana, 2020).

In North-Western Ethiopia income from 2011 to 2013 was higher in homegarden agroforestry than in non-tree-based garden and the diversity of food sources in the system makes homegarden agroforestry more food secured and balanced diet than the non-tree-based garden. The associated component diversity of homegarden agroforestry enhances the livelihood of the local people by providing socio-economic and agro-ecological services than non-tree-based gardens (Linger, 2014). From the above results, it can be observed that homegarden agroforestry has a great role in ensuring food security and income generation. However, according to Gebrehiwot (2013) changing traditional homegarden into mono-cropping has a significant effect on food and income source.

2.7.3. Homegarden agroforestry for soil property

Homegarden agroforestry is an important practice for enhanced soil properties by reducing soil erosion, improving soil fertility through nitrogen fixation, nutrient cycling, pumping, and improving organic matter content (Wolka et al., 2021). In addition to these, it leads to improving the moisture-holding capacity of the soil. Under homegarden agroforestry practices, higher functional composition of different plant species could help for its positive impact on soil chemical properties (Wolle et al., 2021). This interaction between different plant species like trees and crops in the agroforestry system influenced soil physicochemical properties, soil fertility, and crop productivity (Dori et al., 2022; Wolle et al., 2021). This leads to soil amelioration by reversing the trend of declining soil fertility by reducing soil erosion, increasing soil organic matter, and nutrient cycling which contributes to improving crop yield. Moreover, for low level of soil nutrients in the agroforestry system, addition of organic material like house west, animal manure, and compost application is important to increase the concentrations of total nitrogen, organic carbon, organic matter, and CEC (Dori et al., 2022).

Well-managed homegarden agroforestry in Brazil increases soil pH and Phosphorus at a different depth than primary and secondary forests. But no variation was observed at the level of aluminum, organic carbon, calcium, magnesium, and potassium (Salim et al., 2018). The study in India the major essential nutrient exchangeable Phosphorus is higher in homegarden than in the moist-evergreen forest, and semi-evergreen forest during the rainy season (Pandey and Srivastava, 2009). This study also shows that organic C, total N, total P, exchangeable $NH4+$, $NO3-$, exchangeable K, Ca, and Mg were higher under the canopy and between canopy positions of homegarden trees than in the open plot (Pandey and Srivastava, 2009).

Moreover, the improvement in soil characteristics depends on the type of tree species and other agronomic practices. Different studies revealed that topsoil nutrient status under different tree species varies for the same farm field. For example, the study of Gelaw et al. (2014) showed that higher concentrations of total nitrogen, phosphorus, pH, and exchangeable Ca and Mg were observed under *Millettia ferruginea* Hochst and *Cordia africana* Lam than *Eucalyptus camaldulensis* Dehnhardt. Contrary to this, the same report showed that organic C content under *Eucalyptus camaldulensis* Dehnhardt was 11.6% greater than under *Millettia ferruginea* and 23.8% greater than under *Cordia africana*.

On the other hand, homegarden agroforestry has a great advantage over mono-cropping and other land use in improving and sustaining the fertility status of the soil. In the study of Haile et al. (2022), they reported that organic carbon, total nitrogen, and carbon to nitrogen ratio were non-significant but had high mean values in homegarden agroforestry than in cultivated land, natural forest, and plantation forest. However, soil pH is significantly higher in homegarden. Similarly, according to Aklilu Bajigo et al. (2015) study, the top and subsoil organic carbon and organic matter are higher in homegarden than in parkland and woodlot agroforestry practices. Also, in the same area, the EC, pH, and CEC of the topsoil and total nitrogen at subsoil were significantly higher in the homegarden than in the parkland and woodlot (Madalcho and Tefera, 2016).

Moreover, another study on soil property under different land use in the Wolayita zone showed that soil properties were significantly influenced by land use. The homegarden had significantly higher SOC and soil nutrients when compared to the cropland. While the homegarden compared to the woodlot and grazing land uses, had significantly higher values except in SOC, TN, CEC, and exchangeable Ca also low bulk density and high total porosity were found under homegarden than the cropland, woodlot, and grazing land but the particle size fractions were not affected by land use (Lulu et al., 2020).

According to the study of Tesfay (2020), the coffee-fruit-enset-based homegarden agroforestry system had the greatest total C stock (233.3±81.0 t/ha), and the enset-coffee-based homegarden agroforestry system had the lowest total C stock (190.1±29.8 t/ha). Similarly, homegarden agroforestry systems also had significantly higher concentrations of extractable Ca^{2+}, K^{+}, Mg^{2+}, OM, SOC, and TN than adjacent mono-crop farms. Also, the enset-coffee-based agroforestry system showed higher bulk density with an average of (1.12 g/cm^3), and the smallest was found under the coffee-fruit-enset agroforestry system with an average of (0.95 g/cm^3).

Most of the time soil microfauna is related to soil fertility because they act as a decomposer. A study conducted at Wondo Genet on two different agroforestry reported that the two AF systems differed in plant species diversity. In both the dry and wet seasons, more macrofauna was collected from the homegarden agroforestry plot than from the coffee-based agroforestry plot (Asfaw and Zewudie, 2021). Another study conducted in southwest Ethiopia result reveals that soil organic carbon (SOC) concentrations in homegardens were much greater than in croplands. SOC concentrations in homegardens (22.4–26.4 mg/g soil) were twice as high as those in croplands (11.5–12.7 mg/g soil) at 0–20 cm depth. And the bulk density of homegardens soil was significantly smaller than that of croplands (Wolka et al., 2021).

The study by Wolka et al. (2021) showed that homegarden agroforestry received the majority of household waste and manure which leads to greater soil organic carbon as much as twice the croplands in the top 0 – 20 cm depth. Similarly, the same report showed that organic carbon levels in the topsoil are three to five times greater than in croplands. The study of Dori et al. (2022) also revealed that higher soil organic carbon, organic matter, and cation exchange capacity is observed under homegarden agroforestry than in parkland agroforestry. In addition to these, the highest available P (8.65 mg/kg of soil) and K (5.62 c mole/kg of soil) were found under homegarden agroforestry system in the Gedeo area of Southern Ethiopia (Dori et al., 2022).

According to the study by Wolle et al. (2021) higher soil organic carbon, organic matter, available phosphorus, and exchangeable potassium were found in the homegarden agroforestry practice, while the lowest values were recorded in the agriculture field. Moreover, most of the soil chemical properties decreased as the soil depth increased (Wolle et al., 2021). The finding of Kim et al. (2016) revealed that most of the recently converted mono-crop fields had a significantly lower content of soil organic carbon (18.3 – 47.1%) and soil total nitrogen (14.9 – 45%) compared to homegarden. Similarly, converted mono-cropping fields over 10-20 years old showed significantly lower soil organic carbon stocks (18.2–30.2%) and soil total nitrogen stocks (16.7–28.7%) compared to homegarden (Kim et al., 2016).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Geographical location

The study was conducted in two districts (Wondo Genet and Dale) within the Sidama region. Sidama region is located within 5º45'- 6º45' N and 38º5' - 39º41' E, covering a total area of 7,672 km^2 with 3.8 million inhabitants (CSA, 2019). Wondo Genet district is located in Sidama region at 7º06'– 7º07'N, 38º37'–38º42'E. Whereas Dale district is located in the Sidama region at 6°27' - 6° 51' N, 38°00' -38°37'E. Wondo Genet and Dale districts are located about 260 and 320 km south of Addis Ababa, respectively. Sidama region is a representative region for the practice of traditional homegardens. These homegardens are characterized by the production of enset, coffee, and multi-purpose trees, go with root and tuber crops, vegetables, annual cereal crops, and livestock husbandry (Abebe, 2005; Kanshie, 2002).

3.1.2. Climate

The rainfall distribution in both districts is bimodal with a long and short rainy season. The short rainfall period runs from March to April and the long rainfall period cover from June to September. The mean annual precipitation amounts of the Wondo Genet and Dale districts are 800 – 1600 mm and 1041 – 1448 mm, respectively. The mean annual temperatures of Wondo Genet vary between 18^0C and 21^0C. Dale districts have a moist to humid, warm subtropical climate and have a mean annual temperature of 11 to 22°C (Belay, 2016; Ganole, 2010).

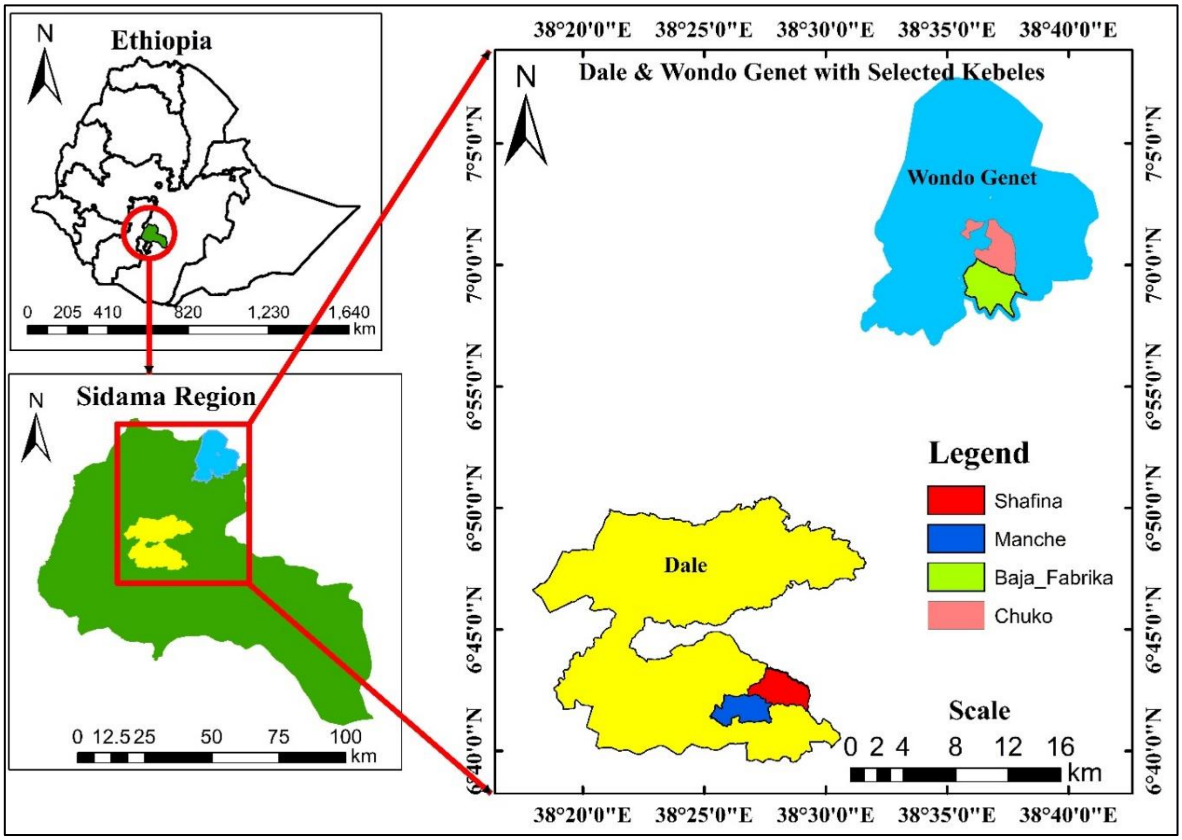

Figure 1. Map of the study area

3.1.3. Population

The two districts are the most densely populated areas in Ethiopia with an average landholding of 0.5 ha. The population density of the Wondo Genet and Dale districts were 958.7 persons/km^2 and 1227.5 persons/km^2, respectively (CSA, 2019).

3.1.4. Soil

The soil under Wondo Genet district is made up of volcanic deposits of ignimbrite, ash, lava, and tuff. The dominant soil type of the district is Mollic Andosols. A Mollic Andosols may easily be identified by its dark color, caused by the accumulation of organic matter(a moderate to a high content of organic matter), its thickness, in most cases a well-developed structure, and an indication of high base saturation (FAO, 2014). In the Dale district, the dominant soil type of the sites is Nitisols. Nitisols may easily be identified by deep and well-drained, reddish brown tropical soils with a clayey nitic horizon that has typically angular blocky, in moist state shiny aggregate faces (FAO, 2014).

3.2. Study Design

Within the Sidama region, two districts (Wondo Genet and Dale) were selected and within each district 2 kebeles, giving 4 kebeles in total were selected. The multistage sampling approach for districts and kebeles was adopted to encompass differences in soil type and land use type. Wondo Genet district represents the hot spot of the homegarden system change to khat while Dale district represents the area where the traditional homegarden system is predominantly practiced.

On average 9 households per kebele, 36 households in total were purposively selected for soil sampling. The households were selected from three wealth category levels (rich, medium, and poor) to take into account the existing heterogeneity in smallholder farmers. The wealth category classification was made by the local administration based mainly on the criteria of land and livestock ownership. According to the district-level Bureau of Agriculture wealth classification, rich households had more than 1.25 hectares of land and more than five livestock (in TLU), while middle-class households had between 0.5 and 1.25 hectares and one to five livestock, while poor households had fewer than 0.5 hectares and zero to one livestock (Mellisse, 2017). Soil samples were collected from different land use types adjacent to each other. For Wondo Genet district soils were collected from adjacent enset and khat fields while in Dale soil samples were collected from adjacent enset and coffee fields.

Enset is commonly grown adjacent to a house in both districts and expected to receive organic matter from cow dung, and kitchen leftovers, with no inorganic fertilizer inputs. Field area covered mainly by khat crops for more than 10–15 years and grown next to an enset field quite far from the house with limited tillage operations but fresh manure and inorganic fertilizer have been applied. The field area covered mainly by coffee crops for more than 20 years and has grown next to an enset field quite far from the house with limited tillage operations but fresh manure and compost have been applied.

3.3. Soil Sampling and Analysis

Soil samples were collected from each cultivated land use (enset, khat, and coffee) of the selected farm households from five points, four from the edge of the longest side and one in the middle of the field. The soil samples were taken from two different depths (0 – 20 and 20 – 40 cm) from each selected land use type using an auger for soil physicochemical analysis.

The collected soil sample of each depth was mixed separately to make a composite soil sample for the particular farm land use. The sample was handled with appropriate sampling bags for each depth and land use separately. The soil samples were weighed in the field to get the fresh weight. A tag was provided for each sample at the field before it was transported to the soil laboratory of Wondo Genet College of Forestry and Natural Resources.

For soil bulk density analysis, soil samples were collected from undisturbed areas using a core sampler of 10 cm height twice for each soil depth of 0 – 20 and 20 – 40 cm at five points where soil samples were taken for other soil parameter analysis. The collected samples were oven-dried at 105 ℃ for 24 hours in the laboratory to determine the dry weight of the soil. Soil texture was analyzed using the hydrometer method for analyzing particle size distribution following the procedure of Bouyoucos (1927) and finally, the textural class was determined based on the percent of sand, silt, and clay in the textural triangle. For moisture content, the collected soil sample was oven-dried at 105 ^oC for 24 hours, and the dry weight was recorded. The moisture content was calculated by subtracting the dry soil weight from the wet soil weight and dividing the difference by the dry soil weight (Estefan et al., 2013).

The soil samples were air-dried and sieved using a 2 mm sieve for analysis of soil parameters like total nitrogen, available phosphorous, available potassium, and soil carbon content. The soil carbon content was determined through Walkley and Black titration method using the wet oxidation method whereby the carbon was oxidized with potassium dichromate in a sulfuric acid solution (Walkley and Black, 1934). Soil total nitrogen was analyzed using the Kjeldahl digestion procedure (Black et al., 1965). Soil pH was determined using a 1:2.5 (soil: H_2O) diluted soil solution and a pH meter. The soil available phosphorous was analyzed by extracting available P using the sodium bicarbonate (pH 8.5) following the procedure of Olsen method and the amount was measured by a spectrophotometer. Exchangeable potassium was determined after leaching the soil with ammonium acetate; and measured using flame photometry (Olsen and Sommers, 1982).

Determination of soil organic carbon stock (t/ha) for each sample depth was determined using the following formula (Pearson et al., 2005)

$$SOCS = \rho_b \times Z \times c \times 100 ------------------------ (1)$$

Where: - SOCS is the soil organic carbon stock (t/ha) of a sample depth, Z is the thickness of a sample depth (cm), ρ_b is the bulk density of a sample depth (g/cm^3), and c is the soil organic carbon content of a sample depth (%).

Similarly, soil total nitrogen stock (TNS) for each sampled depth was calculated using the following formula (Pearson et al., 2005).

$$TNS = \rho_b \times Z \times n \times 100 ---------------------- (2)$$

Where: TNS is the total nitrogen stock of the soil depth (t/ha), Z is the thickness of a sample depth (cm), ρb is the bulk density (g/cm^3) of a sample depth, and n is the soil total nitrogen content of a sample depth (%).

Similarly, phosphorus stock (PS) for each sampled depth was calculated using the following formula (Pearson et al., 2005).

$$PS = \rho_b \times Z \times p \times 100 ---------------------- (3)$$

Where: PS is the phosphorus stock of the soil depth (t/ha), Z is the thickness of a sample depth (cm), ρb is the bulk density (g/cm^3) of a sample depth, and p is the phosphorus content of a sample depth (%).

Similarly, potassium stock (KS) for each sampled depth was calculated using the following formula (Pearson et al., 2005).

$$KS = \rho_b \times Z \times k \times 100 ---------------------(4)$$

Where: KS is the potassium stock of the soil depth (t/ha), Z is the thickness of a sample depth (cm), ρb is the bulk density (g/cm^3) of a sample depth, and p is the potassium content of a sample depth (%).

But, before the determination of nutrient stocks bulk density was determined following a formula (Pearson et al., 2005).

$$\rho b = \frac{ODW}{CV - (RF/PD)} ---------------------(5)$$

Where, ρb = soil bulk density of the < 2mm fraction, (g/cm^3), ODW= oven dry weight of fine fraction (<2mm) in (g), CV= core volume (cm^3), RF = mass of coarse fragments (> 2 mm) in (g), and PD= density of rock fragments (g/cm^3).

And the volume of each soil sample was calculated as follows:

$$CV = h \times \pi r^2 ---------------------(6)$$

Where, CV= volume of the soil in the core sampler (cm^3), h = the height of the core sampler (cm), and r = the radius of the core sampler (cm).

3.4. Data Analysis

The data were subjected to a two-way analysis of variance (ANOVA) the independent factor were land use type and soil depth and the dependent factor was the selected soil parameter. Data of all collected parameters were analyzed using the statistical analysis system (SAS) version 9.4 procedure of a general linear model for the variance analysis. Mean comparisons were carried out to estimate the differences between variables using Fisher's least significant difference (LSD) at a 5% probability level whenever significant variation is observed in the analysis of variance.

4. RESULTS AND DISCUSSION

4.1. Variation in Soil Physicochemical Properties under Different Land Uses

4.1.1. Soil physical properties under different land uses

4.1.1.1. Soil Texture

The study showed a difference in soil texture both under different land use and soil depth. At Wondo Genet represented with Mollic Andosols, higher sand was recorded in the enset land use type followed by the khat at upper depth (0 – 20 cm). While in 20 – 40 cm depth sand was found to be higher in the khat land use type followed by the enset land use type. Likewise, higher content of silt was recorded in the enset land use type followed by the khat in the upper and lower depths (0 – 20 and 20 – 40cm). On the other hand, higher content of clay was recorded in the khat land use type followed by the enset land use in the upper and lower depths (0 – 20 and 20 – 40cm) (Table 1).

Table 1. Soil Textural class for two study sites for two soil depths

District	Soil type	LU	Soil depth							
			0-20			Soil class	20-40			Soil class
			Sand	Silt	Clay		Sand	Silt	Clay	
Wondo Genet	Mollic Andosols	Enset	40.5	38.5	21	Loam	36	37	27	Clay loam
		Khat	38	35	27	Clay loam	41	30	29	Clay loam
Dale	Nitisols	Enset	41	24	35	Clay loam	37	16.5	46.5	Clay
		Coffee	31	30	39	Clay loam	33	25	42	Clay

In Dale, represented by Nitisols a higher content of sand was recorded at the enset land use followed by the coffee land use in the upper and lower depths (0 – 20 and 20 – 40cm). On the other hand, higher content of silt was recorded at the coffee land use followed by the enset land use at upper (0 – 20 cm) and lower depths (20 – 40 cm). Similarly, higher clay was recorded at the coffee land use followed by the enset land at upper depth (0 – 20 cm) while in the lower depth (20 – 40 cm) clay was found to be higher in the enset land use followed by the coffee land use (Table1).

Soil texture is the most stable physical property, the major factor for soil textural variation in a given land is the nature of the parent material which forms the soil (FAO, 2006). In the soil of Wondo Genet under the enset land use type sand, silt, and clay varies from 40.5 to 36, 38.5 to 37, and 21 to 27, respectively. Similarly, in the khat land use type sand, silt, and clay vary from 38 to 41, 35 to 30, and 27 to 29, respectively. Likewise, in the soil of Dale under the enset land use type sand, silt, and clay varies from 41 to 37, 24 to 16.5, and 35 to 46.5, respectively. Similarly, in the Coffee land use type sand, silt and clay vary from 31 to 33, 30 to 25, and 39 to 42, respectively. According to Hazelton and Murphy (2007), they rated all sand, silt, and clay contents of the soil into high (<40%), moderate (25-40%), and low (10-25%), respectively. Thus, the sand, silt, and clay contents of the soils ranged between moderate to high, moderate to low, and moderate to high, respectively in both sites. Clay loam and loam textural classes dominate the nature of the soil at Wondo Genet. Whereas, clay loam and clay soil textural class dominate the nature of the soil at the Dale site. The increase in clay content of the lower soil depth (20 – 40 cm) could be due to the weathering of primary minerals and secondary clay synthesis (Buol et al., 2011).

Table 2. The main effect of land use and soil depth on bulk density and moisture content of the soils at Wondo Genet (Mollic Andosols) and Dale (Nitisols soil types)

Site	Wondo Genet (n=72)			Dale (n=72)	
	BD (gm/cm^3)	MC (%)		BD (gm/cm^3)	MC (%)
Land Use					
Enset	0.90^b	26.29^a	Enset	1.03^b	26.58
Khat	0.96^a	25.57^b	Coffee	1.09^a	26.55
P value	<.0001	<0.001	P value	0.03	0.90
$LSD_{0.05}$	0.02	0.43	$LSD_{0.05}$	0.05	NS
Depth (cm)					
0 – 20	0.89^b	26.45^a	0 – 20	0.95^b	27.52^a
20 – 40	0.97^a	25.41^b	20 – 40	1.17^a	25.61^b
P value	<.0001	<.0001	P value	<.0001	<.0001
$LSD_{0.05}$	0.02	0.43	$LSD_{0.05}$	0.05	0.45

Where: MC – moisture contain; BD– bulk density; LSD – least significant difference; NS – non-significant. Values followed by the same letters in a row are not significantly different at $p < 0.05$.

4.1.1.2. Soil Bulk Density

The study revealed that land use and soil depth at Wondo Genet and Dale had a significant ($p<0.05$) effect on bulk density however didn't significantly affect by the interaction effect at both sites. Higher soil bulk density was observed under the khat (0.96 g/cm^3) and coffee (1.09 g/cm^3) land use than in the enset land use type in Wondo Genet (0.90 g/cm^3) and Dale (1.03 g/cm^3) (Table 2). Similarly, the upper soil depth had significantly lower soil bulk density in both Wondo Genet (0.89 g/cm^3) and Dale (0.95 g/cm^3) than the lower soil depth of 0.97 g/cm^3 and 1.17 g/cm^3 for Wondo Genet and Dale respectively (Table 2).

At both sites, the high concentration of organic matter leads to a low soil bulk density under the enset land use type than in the khat and coffee land use types. furthermore, the concentration of organic matter at the upper soil depth also makes low soil bulk density than at the lower soil depth (20 – 40 cm) (Lemenih, 2004; Wapongnungsang et al., 2020; Yinga et al., 2020). The study indicates the inverse relationship between organic matter and bulk density in the study area. The bulk density increase when the concentration of organic matter decreases. Similarly, increasing trends of bulk density with increasing soil depth were also reported by Manpoong et al. (2020); Moges et al. (2013). This result is also in line with the study of Laekemariam (2020) who report low bulk density at enset land use (1.05 g/cm^3) than other land uses. Similarly, another study conducted by Haile et al. (2022) also reported that higher bulk density in the cereal land use type (1.23 g/cm^3) than in the enset land use type (1.15 g/cm^3). Moreover, this result is also in line with the study of Kebebew et al. (2022) who report lower bulk density at enset and forest land use (1.21 g/cm^3) than eucalyptus land use (1.39 g/cm^3).

This result is in agreement with the study of Negasa et al. (2017) who reported that soil bulk density had a significant variation with land use and soil depth. Lower soil bulk density was observed under agroforestry as compared to cultivated and grazing land use. Also, lower soil bulk density was observed at upper depth than at lower depth. According to Abewa et al. (2013), higher bulk density was found in subsurface soil (20–40 cm) as compared to surface soil (0–20 cm) in the highlands of Ethiopia. Likewise, this study where agree with the study of Fetene and Amera (2018) who reported that soil bulk density is affected by land use but not affected by the interaction effect of land use and soil depth. Moreover, this study is also in line with the study of Dori et al. (2022) who reported that soil bulk density is affected by land use and soil depth. Low bulk density was observed under forest and agroforestry land use than parkland land use also reported lower bulk density was observed at upper depth than at lower depth due to the concentration of organic matter and soil organic carbon. However, in the case of land uses this result did not agree with the study of Moges et al. (2013) ; Tilahun (2007) who reported that soil bulk density did not significantly affect by land use types.

4.1.1.3. Soil Moisture Contain

Moreover, the study also showed that soil moisture content was significantly ($p<0.01$) affected by land use and soil depth at the Wondo Genet. Higher soil moisture content (26.29%) was observed under the enset land use type than in the khat land use type (25.57%). On the other hand, soil moisture content was significantly ($p<0.01$) affected under different soil depths at Wondo Genet and Dale. Significantly higher (27.52 and 26.45%) soil moisture content was observed at the depth of 0 – 20 cm than (25.61 and 25.41%) at the depth of 20 – 40 cm at Dale and Wondo Genet sites (Table 2). However, soil moisture content didn't significantly affect by the interaction effect at both sites.

Land use types did not significantly affect moisture content at Dale site. However, higher moisture content was observed under the enset land use than in the coffee land use. This result is in agreement with the study of Etafa (2022) who reported soil moisture content was not significantly different among the coffee-shaded zones and open areas. On the other hand, land use types at the Wondo Genet site significantly affected soil moisture content it was higher under the enset land use (26.29%) than the khat land use (25.57%). This result is in line with the study of Kebebew et al. (2022) who report available water holding capacity was high under forest and enset land use (142.32 and 140.33%) than khat land use

(128.70%). Similarly, this study is in line with Haile et al. (2022) moisture content was higher under enset land use (31.1%) than eucalyptus land use (26.14%).

This result is in agreement with the study of Chemeda et al. (2017) and Dori et al. (2022) who reported soil moisture content had a significant difference among different land use. This may be due to the presence of shade trees, litter fall, and more application of organic manure at the enset land use than in other land uses in the study sites. Different studies revealed that the presence of shade trees, mulching due to litter fall, and organic matter accumulation under different agroforestry systems improve moisture content and holding capacity of the soil (Ketema and Yimer, 2014; Oguike and Mbagwu, 2009; Wapongnungsang et al., 2021; Wolle et al., 2019).

On the other hand at both Wondo Genet and Dale, soil moisture contents were significantly affected by soil depth. The higher soil moisture content was observed at the upper depth than at the lower depth. This may be due to the presence of shade trees, litter fall, and more application of organic manure in the study sites. This result is in line with the study of Karki et al. (2021); Wapongnungsang et al. (2021) who reported that soil moisture contain significantly higher at the upper depth of homegarden. This result is also in line with the study of Ketema et al. (2015) who reported that soil moisture contain significantly affected by land use and soil depth. The same report revealed that higher soil moisture content was observed under enset-based conservation tillage than cereal conventional tillage land use types and also higher soil moisture content was observed at the upper depth than the lower depth. This was due to the presence of higher soil organic carbon and hence the formation of stable soil aggregate in enset-based conservation tillage.

Similarly, according to Ketema and Yimer (2014) soil moisture content showed significant variations with land use types and soil depths. Higher soil moisture was observed under agroforestry-based conservation tillage than maize-based conventional tillage. Also, higher soil moisture was observed under upper depths of 0 – 10 than 10 – 20 cm. Another study also reported that moisture content has significant variation across land use. Higher soil moisture was observed under forests than in other land use which could be attributed to organic matter's influence on these parameters (Oguike and Mbagwu, 2009). On the other hand, this result did not agree with the study of Chemeda et al. (2017) and Dori et al. (2022) who reported higher soil moisture content in the subsoil than in the topsoil.

4.1.2. Soil chemical properties under different land uses

4.1.2.1. Soil pH

The soil chemical analysis revealed that soil pH was not significantly ($p>0.05$) affected by land use types, soil depth, and interaction effect at the Wondo Genet site. However, a higher soil pH (6.69) was observed under the khat land use than in the enset land use (6.66), and also higher soil pH (6.69) was observed at the upper depth of 0 – 20 cm than (6.65) lower depth 20 – 40 cm (Table 3). On the other hand, soil pH was significantly ($p<0.001$) affected by land use type but did not significantly ($p>0.05$) affected by soil depth at Dale. A higher (6.69) soil pH was observed in the enset land use than in the coffee land use. Even though soil depth had no significant influence on soil pH, a higher (6.38) was found at the upper depth compared to the lower level (6.28) (Table 4). Similarly, at the Dale site, soil pH was significantly ($p<0.01$) affected due to the interaction effect. Higher soil pH was observed in the enset land use type at both upper (6.68) and lower depths (6.70) than the coffee land use type at the depths of 0 – 20 cm (6.08) and 20 – 40 (5.87). The mean soil pH in the enset at both depths was statically similar (Table 6).

Table 3. The main effect of land use and soil depth on selected soil chemical properties at Wondo Genet (Mollic Andosols)

Site	Wondo Genet				
Land use	Soil pH	SOC (g/kg)	TN (g/kg)	Av. P (ppm)	K (cmol(+)/kg)
Enset	6.69	28.12[a]	3.00[a]	19.12[b]	1.58[a]
Khat	6.66	21.50[b]	2.34[b]	31.02[a]	1.43[b]
P value	0.51	<.0001	<.0001	<.0001	0.03
$LSD_{0.05}$	NS	1.08	0.22	1.48	0.14
Depth					
0 – 20 cm	6.69	28.98[a]	2.74[a]	28.26[a]	1.59[a]
20 – 40 cm	6.65	20.64[b]	1.72[b]	21.88[b]	1.41[b]
P value	0.41	<.0001	<.0001	<.0001	0.01
$LSD_{0.05}$	NS	1.08	0.19	1.48	0.14

Where: SOC – soil organic carbon; TN – total nitrogen; Av. P – available phosphorus; K – available potassium; LSD – least significant difference; NS – not significant; Values followed by the same letters in a row are not significantly different at p < 0.05.

The soil pH was not significantly (p > 0.05) affected by both land use and soil depths at Wondo Genet site. This result is in line with the study of Moges et al. (2013) who reported that soil pH did not affect by land use types and soil depth. However, the soil pH was significantly (p < 0.05) affected by land use but not significantly affected by soil depth at the Dale site. This result is also in line with the study of Pham et al. (2018) who reported soil pH did not affect by soil depths. According to the soil pH scale range soil under the enset (6.69) and khat land uses (6.66) at the Wondo Genet site is slightly acidic. Similarly, the soil under the enset land use (6.69) in the Dale site is slightly acidic. However, the soil under coffee land uses moderately acidic (5.97) at the Dale site. Even if the soil pH was not affected by soil depth, the higher soil pH was observed at the upper depth than at the lower depth at both sites.

The higher pH might result from the presence of high concentrations of exchangeable bases such as K^+, Ca^{2+}, and Mg^{2+} due to the continuous application of household wastes including wood ash, cow dung, and crop residues on the enset and khat land uses (Haile et al., 2022; Kiflu and Beyene, 2013). Similarly, the presence of relatively higher organic matter in the top surface soil leads to lower soil pH at upper depth (Moges et al., 2013). This result is in agreement with the study of Kebebew et al. (2022) who reported that the soil pH is affected by different land use with the highest soil pH (5.92) recorded under the khat land-use type whereas the lowest mean (5.01) under forest land. Moreover, this result agrees with the study of Haile et al. (2022) and Kiflu and Beyene (2013) who reported that higher pH was observed under the enset land use compared to other land uses.

4.1.2.2. Soil organic carbon

Soil organic carbon was significantly ($p<0.01$) affected by land use types and soil depth at both Wondo Genet and Dale sites. Higher soil organic carbon was observed under the enset (28.12 g/kg) land use type than the khat (21. 5 g/kg) land use type in Wondo Genet while the coffee land use type had significantly lower (18.64 g/kg) soil organic carbon than enset land use (23.35 g/kg) in Dale. The upper soil depth had significantly higher soil organic carbon than the lower depth in both Wondo Genet and Dale (Tables 3 and 4). Similarly, the interaction of land use and soil depth had significant ($p<0.01$) effects on soil organic carbon at the Dale site but SOC didn’t significantly affect by the interaction effect at Wondo Genet. The higher SOC (31.46 g/kg) was observed under the enset land use at the depth of 0 – 20 cm. However, the lowest SOC was obtained in coffee land use at 20 – 40 cm soil depth, which is statistically at par with enset land use at 20 – 40 cm soil depth (Table 6).

Table 4. The main effect of land use and soil depth on selected soil chemical properties at Dale site (Nitisols soil types)

Site	Dale				
Land use	Soil pH	SOC (g/kg)	TN (g/kg)	Av. P (ppm)	K ($cmol_{(+)}$/kg)
Enset	6.69[a]	23.35[a]	1.95[a]	10.04[a]	3.71[a]
Coffee	5.97[b]	18.64[b]	1.63[b]	4.56[b]	1.33[b]
P value	<.0001	<.0001	<.0001	<.0001	<.0001
$LSD_{0.05}$	0.12	1.60	0.14	0.87	0.28
Depth					
0 – 20 cm	6.38	27.44[a]	2.30[a]	9.78[a]	2.84[a]
20 – 40 cm	6.28	14.55[b]	1.27[b]	4.82[b]	2.20[b]
P value	0.11	<.0001	<.0001	<.0001	0.01
$LSD_{0.05}$	NS	1.60	0.14	0.87	0.28

Where: SOC – soil organic carbon; TN – total nitrogen; Av. P – available phosphorus; K – available potassium; LSD – least significant difference; NS – not significant; Values followed by the same letters in a row are not significantly different at $p < 0.05$.

Moreover, in line with different study reports higher soil organic carbon was observed under the homegarden enset land use in this study. Accordingly, the results of the present study revealed that soil organic carbon has been significantly affected both by land use and soil depth differences. Higher soil organic carbon was observed under the enset land use than khat and coffee in both sites. In addition to this, higher soil organic carbon was observed at the upper depth (0 – 20 cm) than at the lower depth (20 – 40 cm) which indicates that soil organic carbon decrease when depth increase with an inverse relationship. The high concentration of soil organic carbon might be related to the application of a high amount of organic manure, household waste, crop residues, and litter falling in the enset land use (Laekemariam, 2020; Lulu et al., 2020; Negasa et al., 2017).

This result is in line with the study of Haile et al. (2022) who reported that soil organic carbon is affected by land use type and soil depth. The higher soil organic carbon was found under enset land use (2.48%) than in other land uses and also the higher soil organic carbon was found at the top surface (2.46 %) than in the subsurface (Haile et al., 2022). Similarly, this result is in line with the study of Mathewos (2020) who reported that soil organic carbon is affected by land use type and soil depth. The higher soil organic carbon was observed at enset land use (3.07%) than grazing and maize land use at upper depth. This result is also in line with Wolka et al. (2021) who reported that soil organic carbon concentration is higher under enset-based homegarden at depths of 0 – 20 and 20 – 40 cm than cropland. This might be due to the application of organic matter and the presence of permanent vegetable cover in homegarden, which reduces soil erosion and loss of organic topsoil. Moreover, this study agrees with the study of Laekemariam (2020) who reported that soil organic carbon was significantly affected by the variation in land use. Higher soil organic carbon was observed under enset and coffee land uses, which are near to homestead than in other land uses. The same study reported that soil organic carbon and total nitrogen content showed a declining trend from homestead to land uses, which might be due to the application of organic matter and household waste decrease when we go away from home.

In addition, another study done by Kim et al. (2016) reported that soil organic carbon is significantly affected by land use type and soil depth. Higher soil organic carbon was observed under homegarden agroforestry than in the mono-cropping land use and at the upper soil depth. Similarly, other results reported by Lulu et al. (2020) agree with this result which reports that soil organic carbon is affected by the difference in land use. This is maybe due to the variation of input in different land use is vary. However, regarding soil depth, this study does not agree with the result of Lulu et al (2020) who reported that soil organic carbon does not have significant variation across soil depth. According to the study of Negasa et al. (2017), soil organic carbon was also significantly affected by land use and soil depth. Higher soil organic carbon was observed under agroforestry land than in grazing and cropland. The higher soil organic carbon in agroforestry could be attributed to the unique management of agroforestry land use types by the people in the area.

4.1.2.3. Soil total nitrogen

Total nitrogen was significantly ($p<0.01$) affected by land use types and soil depth at both Wondo Genet and Dale sites. Higher total nitrogen under the enset land use type (3.00 g/kg) than the khat land use type (2.34 g/kg) at Wondo Genet while the coffee land uses type had significantly lower (1.63 g/kg) total nitrogen than the enset land use type (1.95 g/kg) in Dale. Moreover, the upper soil depth had significantly higher total nitrogen than the lower depth in both Wondo Genet and Dale (Tables 3 and 4). Similarly, the interaction of land use and soil depth had significant ($p<0.01$) effects on total nitrogen at the Dale site but total nitrogen didn't significantly affect by the interaction effect at Wondo Genet site. The higher TN (2.56 g/kg) was observed under the enset land use at the depth of 0 – 20 cm. However, the lowest TN was obtained in coffee land use at 20 – 40 cm soil depth, which is statistically at par with enset land use at 20 – 40 cm soil depth (Table 6).

The current study result revealed that a higher amount of total nitrogen was observed under the enset land use than in the khat and coffee land uses. Moreover, the concentration of total nitrogen was higher at the upper depth (0 – 20 cm) than at the lower depth (20 – 40 cm) in both sites. The higher concentration of total nitrogen in the enset land use may be due to the presence of a higher amount of organic carbon in the enset land use than in other land uses in the study area. This might also be due to the application of organic manure plus urine, crop residual, and litterfall which are major sources of nitrogen as it is majorly near to homestead at both sites (Bayu, 2016; Laekemariam, 2020).

The current study is in line with the study of Haile et al. (2022) and Kebebew et al. (2022) who reported that higher total nitrogen of 0.21 and 0.23% was observed under the enset land use, respectively. According to Tesfahunegn and Gebru (2020) total nitrogen is significantly affected by land use types in which higher soil total nitrogen was observed under natural forest (0.541%) followed by treated gully (0.257%). Moreover, this result agrees with Chimdi et al. (2012) and Fetene and Amera (2018) who report that total nitrogen varies across land use, and higher total nitrogen was observed under forest land than cultivated land. Similarly, another study by Kiflu and Beyene (2013) reported that soil total nitrogen varies across land use types. This variation across different land use is maybe due to the variation of input in the land uses.

4.1.2.4. Soil available phosphorus

The study revealed that available phosphorus in the soil was significantly ($p<0.01$) affected by land use types and soil depth at both Wondo Genet and Dale sites. Higher available phosphorus (31.02 ppm) was observed under the khat land use and the lower available phosphorus was observed under the enset land use (19.12 ppm) at Wondo Genet (Table 3). However, the higher available phosphorus (10.04 ppm) was observed in the enset land use than in the coffee land use (4.56 ppm) at Dale (Table 4). On the other hand, soil available phosphorus at upper depth (0 – 20 cm) was significantly higher than at lower depth (20 – 40 cm) at Wondo Genet and Dale (Tables 3 and 4). At the Dale site, the interaction effect of land use and soil depth had a significant ($p < 0.01$) effect on the soil available phosphorus. The higher available phosphorus (14.05 ppm) was observed under the enset land use at depth of 0 – 20 than in the enset land use at the depth of 20 – 40 cm, coffee land use at 0 – 20 cm, and coffee land use at 20 – 40 cm. The mean of soil available phosphorus in the enset at 20 – 40cm and coffee at 0 – 20cm depths were statically similar (Table 6).

As the result showed that higher available phosphorus was observed under the khat land use than in the enset land use at Wondo Genet site, this might be due to the application of inorganic fertilizers like phosphorus in the form of DAP and NPS plus organic fertilizer in the khat land use at Wondo Genet site (Kebebew et al., 2022). However, at the Dale site, there was no application of inorganic fertilizer in both land uses (enset and coffee). The higher available phosphorus was observed in the enset land use than in the coffee land use. This might be due to the application of household waste and other organic matter in the enset land use than in the coffee land use (Kiflu and Beyene, 2013). In addition to this, higher available phosphorus was observed at the upper depth (0 – 20 cm) than at the lower depth (20 – 40 cm) at both sites.

This result is in line with the study of Kebebew et al. (2022) who reported that available phosphorus is significantly affected by land use. The higher available phosphorus was observed under cultivated land (9.73 mg/kg) than in other land use. This might be due to the continuous application of P fertilizers in the cultivated lands which leads to a higher available P than in the uncultivated lands. This result is also in line with the study of Haile et al. (2022) who reported that available phosphorus is significantly affected by land use and soil depth. The higher available phosphorus was observed under enset land use (187.52 mg/kg) than other land uses.

This result also agrees with the study of Mathewos (2020) who found that available phosphorus is significantly affected by different land use and soil depth. The higher available phosphorus was obtained under enset land use (7.08 mg/kg) compared with grassland and maize land uses. Likewise, the higher available phosphorus was observed in the surface soil and at the upper slope position. Kiflu and Beyene (2013) also reported that higher available phosphorus is found in the surface soil under the enset land use (36.35 mg/kg) than in other land use systems. Similarly, another study by Fetene and Amera (2018) also reported that available phosphorus was affected by land use types. The higher available phosphorus is found under forest land use than cultivated and grazing land use types which decrease with increasing soil depth. The presence of high amount of organic manure under forest land and enset land use make a difference across land uses.

4.1.2.5. Soil exchangeable potassium

The study revealed that exchangeable potassium in the soil was significantly ($p<0.05$) affected by land use types and soil depth at both Wondo Genet and Dale sites. Higher exchangeable potassium was observed under the enset (1.58 cmol $(^{+})$/kg) land use type. However, the lower exchangeable potassium was observed under the kchat (1.43 cmol $(^{+})$/kg) land use type in Wondo Genet. Similarly, Higher exchangeable potassium was observed under the enset (3.71 cmol $(^{+})$/kg) land use type. However, the lower exchangeable potassium was observed under the coffee (1.33 cmol $(^{+})$/kg) land use type in Dale. On the other hand, soil exchangeable potassium at the upper depth (0 – 20 cm) was significantly higher than the lower depth (20 – 40 cm) at Wondo Genet and Dale (Tables 3 and 4). At the Dale site, the interaction effect of land use and soil depth had a significant ($p< 0.01$) effect on the soil exchangeable potassium. The higher exchangeable potassium (4.17 cmol ($^+$)/kg) was observed under the enset land use at depth of 0 – 20 than in the enset land use at the depth of 20 – 40 cm, coffee land use at 0 – 20 cm, and coffee land use at 20 – 40 cm. The mean of soil exchangeable potassium in the coffee land use at both depths were statically similar (Table 6).

Higher exchangeable potassium was observed under the enset land use than khat and coffee at Wondo Genet and Dale sites. Higher exchangeable potassium was observed at the upper depth (0 – 20 cm) than at the lower depth (20 – 40 cm). The high concentration of exchangeable potassium in the enset land use might be related to the application of a high amount of organic manure, and household waste, especially wood ash (Kiflu and Beyene, 2013). This result is in line with different studies that reported exchangeable potassium is significantly affected by land use (Chimdi et al., 2012; Jemal and Tesfaye, 2020; Mathewos, 2020; Moges et al., 2013). According to the study by Haile et al. (2022) and Kiflu and Beyene (2013), higher exchangeable potassium under the enset land use (3.16 cmol(+/kg) and 1.8 meq/100g soil) than in other land uses. In addition to this, this result agrees with the study of Kebebew et al. (2022) who reported that lower exchangeable potassium was observed under the khat land use (0.71 cmol(+/kg)) compete with other land uses.

4.1.3. Nutrient stock under different land uses

The study showed that, with the exception of potassium stock at Wondo Genet, land use types significantly ($p < 0.05$) influenced soil organic carbon, total nitrogen, phosphorus, and potassium stocks at both sites.

Table 5. The main effect of land use and soil depth on nutrient stocks at both sites

Site	Wondo Genet				Site	Dale			
Land Use	SOCS (t/ha)	TNS (t/ha)	PS (kg/ha)	KS (t/ha)	Land Use	SOCS (t/ha)	TNS (t/ha)	PS (kg/ha)	KS (t/ha)
	Land Use					Land Use			
Enset	114.00[a]	11.37[a]	77.77[b]	2.55	Enset	83.85[a]	6.98[a]	35.59[a]	4.17[a]
Khat	93.52[b]	9.17[b]	134.50[a]	2.48	Coffee	74.22[b]	6.33[b]	17.30[b]	2.85[b]
P value	0.0003	0.002	<.0001	0.773	P value	0.008	0.048	<.0001	0.003
$LSD_{0.05}$	10.43	1.36	11.39	NS	$LSD_{0.05}$	7.00	0.64	4.80	0.82
	Depth (cm)					Depth (cm)			
0 – 20	55.06[a]	5.58[a]	54.62	1.29	0 – 20	48.55[a]	4.07[a]	17.14[a]	1.66
20 – 40	48.70[b]	4.68[b]	51.51	1.22	20 – 40	30.48[b]	2.56[b]	9.31[b]	1.85
P value	<0.001	<0.001	0.13	0.37	P value	<.0001	<.0001	<.0001	0.34
$LSD_{0.05}$	3.76	0.50	NS	NS	$LSD_{0.05}$	2.96	0.27	1.72	NS

Where: SOCS – soil organic carbon stock; TNS – soil total nitrogen stock; PS – phosphorus stock; KS – potassium stock; LSD – least significant difference; NS – not significant. Values followed by the same letters are not significantly different at $p < 0.05$.

Higher soil organic carbon stock was observed under the enset land use type (114.00 t/ha) than the khat (93.52 t/ha) land use type in Wondo Genet while higher soil organic carbon stock was observed under the enset land use type (83.85 t/ha) than the coffee (74.22 t/ha) land use type in Dale (Table 5).

Likewise, the higher nitrogen stock was observed under the enset (11.37 t/ha) land use type than the khat (9.17 t/ha) land use type in Wondo Genet while the higher nitrogen stock was observed under the enset (6.98 t/ha) land use type than the coffee (6.33 t/ha) land use type in Dale (Table 5). On the other hand, the higher phosphorus stock (134.50 kg/ha) was observed under the khat land use type than the enset land use (77.77 kg/ha) in Wondo Genet. Moreover, higher phosphorus (35.59 kg/ha) and potassium stock (4.17 t/ha) were observed under the enset land use type than phosphorus (17.30) and potassium stock (2.85 t/ha) under the coffee land use type in Dale. Despite potassium stock in Wondo Genet was not significantly influenced by land use the higher potassium stock was observed under the enset land use type than the khat land use type (Table 5).

Similarly, soil depth significantly ($p < 0.01$) affected soil organic carbon, total nitrogen, and phosphorus stocks at Wondo Genet and Dale, the study also found that soil depth had no significant ($p > 0.05$) effect on phosphorus stock at Wondo Genet and potassium at either location. The higher soil organic carbon (55.06 t/ha) and total nitrogen (5.58 t/ha) stocks were observed at the upper depth than the lower depth in Wondo Genet. Similarly, the higher soil organic carbon (48.55 t/ha) and total nitrogen (4.07 t/ha) stocks were observed at the upper depth than the lower depth in Dale. Likewise, the higher (17.17 kg/ha) phosphorus stock was observed at the upper depth than the lower depth (9.31 kg/ha) in Dale (Table 5). Even though phosphorus stock was not significantly affected by soil depth at Wondo Genet the higher (54.62 kg/ha) mean of phosphorus stock was observed at the upper depth than at the lower depth (51.51 kg/ha). Similarly, potassium stock was not significantly affected by soil depth at both sites. However, the higher mean of potassium stock was observed in the upper and lower depth at Wondo Genet (1.29 t/ha) and Dale (1.85 t/ha). A smaller mean of potassium stock was observed at lower and upper depths in Wondo Genet (1.22 t/ha) and Dale (1.66 t/ha) (Table 5).

At both the Wondo Genet and Dale sites, the study found that the interaction between soil depth and land use types significantly ($p<0.05$) affected the soil organic carbon stock. At the Wondo Genet site, higher soil organic carbon stocks were found under the enset land use at 0 - 20 (58.08 t/ha) and 20 - 40 cm (55.92 t/ha) soil depths than under the khat land use at 0 - 20 cm (52.04 t/ha) and 20 - 40 cm (41.48 t/ha). The mean of soil organic carbon stock in the enset land use at both depths was statically similar. Also, the mean soil organic carbon stock in the enset land use at 20 – 40 cm depth was statically similar to that of the khat land use at 0 – 20 cm depth (Table 7).

Table 6. Interaction effect of land use and soil depth on soil chemical property on the Dale site

Site	Soil parameters	Depth	Land use		P value	$LSD_{0.05}$
			Enset	Coffee		
Dale	Soil pH	0-20	6.68^{a}	6.08^{b}	0.04	0.17
		20-40	6.70^{a}	5.87^{c}		
	SOC (g/kg)	0-20	31.46^{a}	23.43^{b}	0.0001	2.26
		20-40	15.25^{c}	13.85^{c}		
	TN (g/kg)	0-20	2.56^{a}	2.04^{b}	0.005	0.2
		20-40	1.33^{c}	1.22^{c}		
	Av.p (ppm)	0-20	14.05^{a}	5.50^{b}	<.0001	1.24
		20-40	6.03^{b}	3.60^{c}		
	K^{+} (cmol(+)/kg)	0-20	4.17^{a}	1.50^{c}	0.04	0.4
		20-40	3.24^{b}	1.15^{c}		

Where: SOC – soil organic carbon; TN – total nitrogen; Av. P – available phosphorus; K – available potassium; LSD – least significant difference; NS – not significant. Values followed by the same letters in a row are not significantly different at $p < 0.05$.

Similarly, at the Dale site higher soil organic carbon stock was observed under the enset land use (53.99 t/ha) at 0 – 20 cm depth than the coffee land use (43.10 t/ha) at 0 – 20 cm, 20 – 40 cm (31.11 t/ha) and enset land use (29.85 t/ha) at 20 – 40 cm. The mean of soil organic carbon stock in the enset and coffee land uses at 20 – 40 cm depths was statically similar (Table 7). The study revealed that total nitrogen stock was significantly (p<0.05) affected by the interaction effect at both Wondo Genet and Dale sites. The highest total nitrogen stock was observed under the enset land use (5.78 t/ha) at the depth of 0 – 20 cm in Wondo Genet. However, this was statistically similar to that of enset at the depth of 20 – 40 cm (5.59 t/ha) and khat at the depth of 0 – 20 cm (5.38 t/ha). In contrast, the lowest total nitrogen stock was obtained at the Wondo Genet site under the khat land use at a depth of 20 – 40 cm (3.78 t/ha), which was significantly lower than all others (Table 7).

Table 7. Interaction effect of land use and soil depth on stock at both sites

Site	Soil parameters	Depth (cm)	Land use		P value	$LSD_{0.05}$
			Enset	Khat		
Wondo Genet	SOCS (t/ha)	0-20	58.08[a]	52.04[b]	0.02	5.32
		20-40	55.92[ab]	41.48[c]		
	TNS (t/ha)	0-20	5.78[a]	5.38[a]	0.007	0.71
		20-40	5.59[a]	3.78[b]		
	PS (kg/ha)	0-20	39.24	70.00	0.24	NS
		20-40	38.54	64.49		
	KS (t/ha)	0-20	1.21	1.23	0.46	NS
		20-40	1.34	1.24		
Dale	SOCS (t/ha)	0-20	53.99[a]	43.10[b]	0.0001	4.19
		20-40	29.85[c]	31.11[c]		
	TNS (t/ha)	0-20	4.39[a]	3.75[b]	0.02	0.39
		20-40	2.55[c]	2.57[c]		
	PS (kg/ha)	0-20	24.14[a]	10.14[b]	<.0001	2.44
		20-40	11.45[b]	7.17[c]		
	KS (t/ha)	0-20	2.47[a]	0.86[c]	<.0001	0.56
		20-40	1.71[b]	2.00[ab]		

Where: SOCS – soil organic carbon stock; TNS – soil total nitrogen stock; PS – phosphorus stock; KS – potassium stock; LSD – least significant difference; NS – not significant. Values followed by the same letters are not significantly different at $p < 0.05$.

Moreover, at the Dale site, the highest total nitrogen stock was observed under the enset land use (4.39 t/ha) at 0 – 20 cm depth, which was closely followed by a coffee land use (3.75 t/ha) at 0 – 20 cm depth. On the other hand, the smallest total nitrogen stock (2.55 t/ha) under enset land use was found at a depth of 20 – 40 cm, and it was statistically comparable to that of the coffee land use at the same depth (2.57 t/ha) in the Dale (Table 7).

According to the study, the interaction effect at the Dale site significantly ($p < 0.01$) affected the stock of phosphate and potassium. Under the enset land use, at a depth of 0 – 20 cm, the largest phosphorus (24.14 kg/ha) and potassium stocks (2.47 t/ha) were found. However, the mean of potassium stock in enset land use at the depth of 0 – 20 cm was statistically similar to that of coffee land use (2.00 t/ha) at the depth of 20 – 40 cm. Contrary to this, the lowest phosphorus and potassium stocks were observed under the coffee land use at the depth of 20 – 40 (7.17 kg/ha) and the coffee land use at the depth of 0 – 20 cm (0.86 t/ha) at Dale. However, phosphorus and potassium stock was not significantly ($p>0.05$) affected by the interaction effect at the Wondo Genet site (Table 7).

The high concentration of soil organic carbon, total nitrogen, phosphorus, and potassium stocks might be related to the application of a high amount of organic manure, household waste, crop residues, and litter falling on enset land use than other land uses (Gelaw et al., 2014; Haile et al., 2022; Laekemariam, 2020; Wolka et al., 2021).

The result also indicates that nutrient stocks decrease with depth. The high concentration of phosphorus stock might be related to the application of a high amount of inorganic and organic fertilizer on khat land use than enset land use at Wondo Genet. The result of this study is in line with Haile et al. (2022) who reported that soil organic carbon stock and total nitrogen stock significantly vary across land uses. The higher soil organic carbon (42.45 Mg/ha) and nitrogen stock (2.4 Mg/ha) were observed under the enset land use than other filed. The result also agrees with another study done by Laekemariam (2020) who reported that higher soil organic carbon and nitrogen stocks were higher under coffee (81.4 and 6.3 t/ha) and enset (75.5 and 6.0 t/ha) land uses than in other land uses. Similarly, this result is in line with the study of Tesfay (2020) who reported that soil organic carbon stock was affected by land use difference the higher soil organic carbon stock was observed under coffee-fruit-enset and coffee-enset-based agroforestry than in the adjacent mono-cropping. However, regarding the enset land use, this study does not agree with the same study which reported soil organic carbon stock of the enset-based agroforestry system did not show a significant difference with its adjacent mono-crop plots.

Another study done by Lulu et al. (2020) also reported that higher soil organic carbon stock was observed under homegarden than in cropland. Similarly, different studies revealed that soil organic carbon and nitrogen stocks are affected by land use types and soil depth, and nutrient stocks decrease with increasing soil depth (Gelaw et al., 2014; Girma et al., 2020; José et al., 2021; Kibet et al., 2022; Santana et al., 2019; Toru and Kibret, 2019; Wako and Kitila, 2021). This result also agrees with the study of Mellisse (2017) who reported phosphorus and potassium stocks were affected by different land use. The higher phosphorus and potassium stocks were found under enset land use than other land uses. Moreover, different studies showed that phosphorus and potassium stocks are affected by land use types (Luna et al., 2022; Maranguit et al., 2017; Shah et al., 2022).

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The results of this study showed that land use and soil depth significantly influenced the physical and chemical properties of soils. The sand, silt, and clay contents of the soils ranged between moderate to high, moderate to low, and moderate to high, respectively in both Wondo Genet and Dale sites. Clay loam and loam textural classes dominate the nature of the soil at Wondo Genet while clay loam and clay soil textural classes dominate the nature of the soil at the Dale site.

In Wondo Genet the enset land use type had significantly highest soil moisture content, soil pH, soil organic carbon, total nitrogen, exchangeable potassium, and nutrient stocks than the khat land use type. However, available phosphorus and its stock were highly significant under the khat land use than in the enset land use at Wondo Genet. Likewise, soil bulk density was higher under the khat land use than in the enset land use at Wondo Genet. Moreover, in Dale, the enset land use type had significantly highest soil moisture content, soil pH, soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and nutrient stocks than the coffee land use type. However, soil bulk density was higher under the coffee land use than in the enset land use at Dale. Moreover, all soil physicochemical property except bulk density in this study was higher at the upper depth than at the lower depth at both Wondo Genet and Dale sites.

The interaction effect of land use types and soil depth at Wondo Genet did not significantly affect any soil parameters with the exception of soil organic carbon and total nitrogen stocks.

However, the interaction effect of land use types and soil depth at Dale significantly affected all soil parameters with the exception of soil moisture content and bulk density. In Dale, higher moisture content, soil pH, soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and nutrient stocks were observed under enset land use at upper depth. In contrast, the lower moisture content, soil pH, soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and nutrient stocks were observed under coffee land use at a lower depth.

Similarly, in Wondo Genet soil organic carbon and total nitrogen stocks were higher under enset land use at upper depth. In contrast, the lower soil organic carbon and total nitrogen stocks were higher under khat land use at a lower depth. The result also showed the enset land uses had better potential in improving soil physicochemical properties than the khat and coffee land uses.

5.2. Recommendation

Based on the current study and the results obtained on soil physicochemical properties under different land use systems and soil depth, the following recommendations could be forwarded.

- ❖ Traditional homegarden components (enset) played a larger influence in improving soil fertility than khat-based systems. Therefore, it is better to handle enset-based homegarden agroforestry systems for better soil fertility and health.
- ❖ Khat based mono-cropping system is practiced in some of the study areas government and development organizations should give supportive mechanisms and

cooperate to give awareness on more application of organic fertilizers on the khat land uses and scaling-up agroforestry practices like (intercropping of multifunctional trees, shrubs, herbs, and grasses that may boost internal organic inputs with khat).

- ❖ Government and development organizations should give supportive mechanisms and cooperate to give awareness on more application of organic fertilizers to overcome the decline of nutrients under coffee land use type in Dale. Further study should be conducted in Dale site to understand why coffee land use has lower nutrient content.
- ❖ Further study should be conducted in the study area and other areas to pronounce more on the role of enset-based homegarden agroforestry systems in soil fertility improvement. Moreover, research to identify the reasons and regulatory mechanisms for shifting across a broader range of environments is needed.
- ❖ The current study focused only on selected soil parameters but still, there is a need to see the remaining soil parameters and need to assess annual crops, perennials, and fodder plant productivity in the homegarden system for a better understanding of the ecological and socio-economic role of the system.

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7. APPENDICES

Appendix 1. Effect of different land uses and soil depth interaction on selected soil physicochemical properties at Wondo Genet site.

Site	Soil parameters	Depth	Land use		P value	$LSD_{0.05}$
			Enset	Coffee		
Wondo Genet	Soil pH	0-20	6.70	6.67	0.15	NS
		20-40	6.60	6.69		
	SOC (g/kg)	0-20	32.36	25.61	0.81	NS
		20-40	23.88	17.4		
	TN (g/kg)	0-20	3.21	2.65	0.14	NS
		20-40	2.38	1.56		
	Av.p (ppm)	0-20	21.79	34.72	0.17	NS
		20-40	16.44	27.33		
	K+ (cmol(+)/kg)	0-20	1.67	1.51	0.90	NS
		20-40	1.48	1.34		
	P Stock (kg/ha)	0-20	39.23	70.64	0.24	NS
		20-40	38.53	64.49		
	K Stock (t/ha)	0-20	1.20	1.23	0.46	NS
		20-40	1.34	1.24		
	SMC (%)	0-20	26.78	26.13	0.75	NS
		20-40	25.80	25.01		
	BD (gm/cm^3)	0-20	0.89	1.00	0.10	NS
		20-40	1.17	1.18		

Appendix 2. Analysis of variance of soil physicochemical properties for the types of homegardens and soil depths at the Wondo Genet site.

SOC				TN		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	788.04	<.0001	1	8.51	<.0001
Soil depth(SD)	1	1253.33	<.0001	1	16.53	<.0001
LU*SD	1	0.29	0.8151	1	0.31	0.14
Error	68	362.50		68	9.52	
Corrected total	71	2404.18		71	34.88	
MC				BD		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	9.32	<.0001	1	0.06	0.03
Soil depth(SD)	1	19.81	<.0001	1	0.90	<.0001
LU*SD	1	0.08	0.75	1	0.04	0.10
Error	68	58.88		68	1.01	
Corrected total	71	88.10		71	2.03	
Av.p				K^+		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	2551.83	<.0001	1	0.40	0.03
Soil depth(SD)	1	730.63	<.0001	1	0.58	0.01
LU*SD	1	18.64	0.17	1	0.0013	0.90
Error	68	675.81		68	6.02	
Corrected total	71	3976.94		71	7.01	

Appendix 2. Analysis of variance of soil physicochemical properties for the types of homegardens and soil depths at the Wondo Genet site continued.

pH				SOCS		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	0.01	0.5059	1	1888.78	<.0001
Soil depth(SD)	1	0.02	0.4142	1	727.91	0.001
LU*SD	1	0.07	0.1564	1	316.73	0.02
Error	68	2.32		68	4350.62	
Corrected total	71	2.43		71	7284.06	
TNS				P stock		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	21.91	<.0001	1	14478.61	<.0001
Soil depth(SD)	1	14.37	<0.001	1	173.81	0.13
LU*SD	1	8.94	0.007	1	104.18	0.24
Error	68	78.66		68	5194.81	
Corrected total	71	123.90		71	19951.43	
K Stock						
Soil parameter	DF	Type I SS	P value			
Land use(LU)	1	0.02	0.68			
Soil depth(SD)	1	0.09	0.37			
LU*SD	1	0.06	0.46			
Error	68	8.30				
Corrected total	71	8.48				

Appendix 3. Analysis of variance of soil physicochemical properties for the types of homegardens and soil depths at Dale site.

SOC				TN		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	399.50	<.0001	1	1.78	<.0001
Soil depth(SD)	1	2992.80	<.0001	1	18.91	<.0001
LU*SD	1	198.00	0.0001	1	0.75	0.005
Error	68	788.11		68	6.25	
Corrected total	71	4378.42		71	27.70	
MC				BD		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	0.01	0.90	1	0.05	<.0001
Soil depth(SD)	1	65.60	<.0001	1	0.13	<.0001
LU*SD	1	0.008	0.92	1	0.001	0.31
Error	68	63.57		68	0.09	
Corrected total	71	129.20		71	0.28	
Av.p				K^+		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	540.27	<.0001	1	102.04	<.0001
Soil depth(SD)	1	443.87	<.0001	1	7.38	<.0001
LU*SD	1	168.14	<.0001	1	1.44	0.04
Error	68	236.76		68	25.23	
Corrected total	71	1389.05		71	136.10	

Appendix 3. Analysis of variance of soil physicochemical properties for the types of homegardens and soil depths at the Dale site continued.

pH				SOCS		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	9.26	<.0001	1	417.58	0.001
Soil depth(SD)	1	0.16	0.11	1	5877.30	<.0001
LU*SD	1	0.24	0.04	1	664.49	0.0001
Error	68	4.61		68	2700.96	
Corrected total	71	14.29		71	9660.34	
TNS				P stock		
Soil parameter	DF	Type I SS	P value	DF	Type I SS	P value
Land use(LU)	1	1.71	0.048	1	1504.97	<.0001
Soil depth(SD)	1	40.91	<.0001	1	1103.26	<.0001
LU*SD	1	1.91	0.02	1	425.08	<.0001
Error	68	23.69		68	912.44	
Corrected total	71	68.24		71	3945.76	
K Stock						
Soil parameter	DF	Type I SS	P value			
Land use(LU)	1	7.82	0.001			
Soil depth(SD)	1	0.65	0.34			
LU*SD	1	16.20	<.0001			
Error	68	49.67				
Corrected total	71	74.35				

Appendix 4. Picture during soil sample collection at Dale and Wondo Genet sites

Appendix 5. Picture during soil sample analysis at Wondo Genet College of Forestry and Natural Resources Laboratory

BIOGRAPHY

The author was born on February 23, 1997, in Addis Ababa from her father Mekuria Gobeze, and her mother Melesech Merka. She attended her elementary and secondary education at New Era elementary and secondary school in Addis Ababa, Ethiopia. After completing her high school education, she joined Minilike II preparatory school and then after completing preparatory in 2014 she joined Haramaya University in November 2015 and graduated with a BSc degree in Natural Resource Management in July 2018. Soon after graduation, she Joined at Wondo Genet Agricultural Research Center of Ethiopian Institute of Agricultural Research in October 2018 in the position of Junior Researcher and worked there until she joined the School of Graduate Studies of Hawassa University Wondo Genet College of Forestry and Natural Resources in November 2020 to pursue her MSc Degree study in Agroforestry and Soil Management.