THE EFFECT OF GRAZING EXCLUSIONS AND SOIL AND WATER CONSERVATION MEASURES ON GRASS BIOMASS PRODUCTION AND SELECTED SOIL PROPERTIES IN THE CENTRAL HIGHLAND OF ETHIOPIA

MSc. THESIS

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THE EFFECT OF GRAZING EXCLUSIONS AND SOIL AND WATER CONSERVATION MEASURESON GRASS BIOMASS PRODUCTION AND SELECTED SOIL PROPERTIES IN THE CENTRAL HIGHLAND OF ETHIOPIA

A Thesis Submitted to the Department of Natural Resource Management
College of Agriculture and Natural Resource Sciences, School of Graduate Studies, Debre Berhan University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Soil and Water Conservation

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Major Advisor: Daniel Bekele (Ph.D.)
Co-Advisor: Fikrey Tesfay (Ph.D.)

June 2021
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DEBRE BERHAN UNIVERSITY
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This is to certify that the thesis entitled: **The effect of grazing exclusion and soil and water conservation measures on grass biomass production and selected soil properties in the central highland of Ethiopia** submitted in partial fulfillment of the requirements for the degree of Masters of Science with specialization in**Soil and water conservation** of the Graduate Program of the Department of **Natural resource management**, College of Agriculture and Natural Resource Sciences, Debre Berhan University and is a record of original research carried out by **Misiker Aragaw, PGR/037/11,** under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.Therefore, I recommend that it can be accepted as fulfilling the thesis requirements.

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We, the undersigned members of the boarded of the examiners of the final open defense by Misiker Aragaw have read and evaluated her thesis entitled: **The effect of grazing exclusions and soil and water conservation measures on grass biomass production and selected soil properties in the central highland of 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 **Soil and water conservation**.

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As members of the Board of Examiners of the final Masters' open defense, we certify that we have read and evaluated the thesis prepared by **Misiker Aragaw** under the title **“The Effect of Grazing Exclusions and Soil and Water Conservation Measures on Grass Biomass Production and Selected Soil Properties in the Central Highland of Ethiopia”**,and recommend that it be accepted as fulfilling the thesis requirement for the degree of Master of Science in **Natural resources management** with Specialization in **Soil and Water Conservation.**

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I hereby certify all the correction and recommendations suggested by the board of Examiners are incorporated in the final thesis **“The Effect of Grazing Exclusions and Soil and Water Conservation Measures on Grass Biomass Production and Selected Soil Properties in the Central Highland of Ethiopia”**

Daniel Bekele (PhD) __________ 02/10/2013
Name of the Major Advisor Signature Date

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DEDICATION

I would like to dedicate this thesis to my committed and hardworking father Mr. Aragaw Bekele, who has been waiting to see his fruit in me.

STATEMENT OF THE AUTHOR

I, Misiker Aragaw hereby declare that, this thesis is my genuine work, and that all sources of materials used for this thesis have been profoundly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for Master of Science (MSc) at Debre Berhan University and it is deposited at the University library to be made available for users under the rule of the library. I intensely declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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Place: College of Agriculture and Natural Resource Sciences, Debre Berhan University.

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BIOGRAPHICAL SKETCH

The author, Mrs.Misiker Aragaw, was born on April 9, 1998 G.C in Bishoftu town, Oromia National Regional State, Ethiopia. She attended her primary education at Tokkumaa primary school; her secondary education at Bishoftu secondary school and preparatory education at Bishoftu preparatory school. In September 2016 she joined Haramay University for a BSc degree in natural resource management and transferred to Debre Berhan University, due to health conditions, and graduated in 2018. In the same year, she was hired at Debre Berhan University as a graduate assistant and started serving the university with her mandate. In October 2019, she joined the school of graduate studies of Debre Berhan University to attend her MSc degree in Soil and Water Conservation.

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ABBREVATIONS AND ACRONYMS

ANOVA	Analysis of Variance
AGB	Above Ground Biomass
C: N	Carbon to Nitrogen Ratio
CEC	Cation Exchange Capacity
CRD	Complete Randomized Designed
DM	Dry Matter
FAO	Food and Agricultural Organization
FG	Free Grazing
GE	Grazing Exclusion
GLM	General Linear Model
LSD	Least Significance Difference
SAS	Statistical Analysis System
SLM	Sustainable Land Management
SPSS	Statistical Package for Social Science
SWC	Soil and Water Conservation
USD	United States Dollar

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THE EFFECTS OF GRAZING EXCLUSIONS AND SOIL AND WATER CONSERVATION MEASURES ON GRASS BIOMASS PRODUCTION AND SELECTED SOIL PROPERTIES IN THE CENTRAL HIGHLAND OF ETHIOPIA

By

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ABSTRACT

The traditional and uncontrolled grazing system in the communal grazing lands of the central Ethiopian highlands, had resulted in severe soil degradation. This study was intended to determine the effects of grazing exclusion and soil and water conservation(SWC)measures on grass biomass production and selected soil properties and to assess the strategies and perceptions of farmer's towards grazing and its management. Six grazing exclusion (GE) fences and adjacent six free grazing (FG) plots, each 2X 2m, were established at Gedda watershed, of which three of them were in treated lands with SWC measures while the rest three were in areas where there was no SWC treatment. A total of 192 aboveground biomass (AGB) samples were collected at four sampling periods.The soil samples were collected in two of the randomly selected quadrants from both the exclosures and adjacent FG plots within two soil depths, 0-15 and 15- 30 cm.The analysis result revealed that bulk density, sand, silt, Ca^{2+}, Mg^{2+}, Na^{+}, SOM, SOC, TN, available Pand AGB were significantly affected as a result of grazing exclusions while EC, pH, CEC, $K^{+}$and C: N showed no significant difference. SWC greatly impacted different soil parameters, i.e. lower bulk density and sand percentage, higher clay, SOM and SOC, illustrating the effectiveness of employing SWC measures together with other management strategies so as to prevent soil erosion and degradation in grazing lands. Thus grazing exclusion and SWC should be adopted jointly and soil conditions prior to exclusions should be considered for better outcomes.

Keywords: Biomass production; Grazing Exclusions;Landuse; Soil properties; Soil and water conservation

1. INTRODUCTION

Natural resource depletion is a major environmental concern that threatens livelihood and sustainable development. Soil is one of the most vital life-supporting natural resource (Parks, 2013; Lu *et al*., 2015). Nowadays, it is being eroded and losing its productive potential (Ebrahimi *et al*., 2016; Souza *et al*., 2019). Inappropriate utilization of grazing lands is one of the causes of nutrient depletion, land degradation, and subsequent soil erosion.Livestock overgrazing is one of the major factors that evoke grassland, vegetation, and soil degradation(Zhao *et al*., 2018). Continuous and unmanaged grazing negatively impacts plant community composition, diversity, and biomass production thereby potentially limiting the ability of the site to recover following disturbance(Louhaichi *et al*., 2012). Vegetation cover is one of the common parameters used in assessing the relationship between grazing and soil erosion. The different strata of vegetation near ground layers such as grass and other layer are more important in the regulation of soil erosion than the canopy layers (Zhao *et al*., 2019). Reduction in the vegetation cover below a critical level could increase the impact of a raindrop, decrease soil organic matter and soil aggregates, increase soil surface crust, decrease water infiltration rates.Ultimately,it increasesthe intensity and rate of soil erosion (Zhongming *et al.,* 2010).

There are mainly three ways where by grazing causes degradation to the soil. These are loss of vegetative matter from defoliation, deformation of soil structure from animal treading which increases bulk density (Singer & Schoenecker, 2003), and increased nutrient deposition from animal wastes (Bilotta *et al*., 2010). Soil compaction, due to the action of animal trampling, degrades the soil's physical characteristics, and lowers plant coverage, which in turn results in a increasing runoff and soil erosion (Zerihun *et al*., 2018). Long-term overgrazing had limited the productivity of the grazing lands in Ethiopian highlands (Giday *et al*., 2018). Even with major soil and water conservation efforts(Yan *et al*., 2015), these lands continue to erode andlarge proportions of the rainfall are lost due to destructive surface runoff (Tamene *et al*., 2017).The average annual productivity decline in cropland due to soil erosion in the central highlands of Ethiopia is estimated to be 0.21% and the average annual soil loss from arable land in the highlands of Ethiopia was estimated to be about 42 tons per ha per year and nutrient depletion is estimated at 30 kg ha^{-1} of nitrogen and 15– 20 kg ha^{-1} of phosphorus (Kassahun *et al*., 2009).

However, grazing is not at all a damaging process; the grazing intensity, daily grazing hour, and stocking rate are among the major factors behind the beneficial or detrimental effects of grazing and/or browsing. Given appropriate attention and applying sustainable management and utilization approach, grazingcan have a tremendous impact on grasslands through its effect on plant populations and community composition, energy flow(Cislaghi *et al*., 2019), nutrient cycling, landscape-level heterogeneity, and movement of materials(Blair *et al*.,2014).Grazing management is about controlling where animals graze, when they graze and how much they graze. Different grazing management treatments cause diverse changes in plant growth. These changes affect the quantity of the aboveground biomass produced on grazing lands(Kebede *et al*., 2016). There are several methods acquired to prevent grassland degradation. Grazing exclusionby fencing is a worldwide practice (Zhao *et al*., 2018; Liu *et al*., 2020) that uses the natural potential of restoration of degraded grasslands (Souza *et al*., 2019). The effect of grazing exclusions on vegetation character and soil properties and its effectiveness depend on grassland ecotype, climate characteristics, historical grazing practice, and stocking rates (Zhao *et al*., 2018).

In arid and semi-arid areas where there are limited resources (i.e., low residue inputs and available water), the effect of overgrazing is very common. Even in these ecologically fragile areas with harsh environmental conditions grazing exclusion is an effective restoration practice(Allen *et al*., 2011). For instance, a study conducted in Syrian rangelands indicated that sites protected from overgrazing had experienced halted or even reversed land degradation while the diversity and structure of dominant and palatable plant species have shifted toward less desirable species in response to overgrazing (Louhaichi *et al*., 2003). The effect of grazing exclusions is also revealed in soil physicochemical properties. Many kinds of research have demonstrated that grazing exclusion significantly increased vegetation cover and density(Fernandaze *et al*., 2009; Zhao *et al*., 2018)enhanced plant biomass and soil carbon and nitrogen stocks as well as soil respiration. In contrast, some studies (Medina-Roldán *et al*., 2012; Yan *et al*., 2015)have found no significant change both on plant biomass and soil properties.

Grazing landprovides forage for livestock (Chai *et al*., 2019), stores carbon, and supports a wide diversity of plant and animal communities (Louhaichi *et al*., 2012) yet given less attention in researches. These land-use systems have been used extensively to support livestock production.

Due to these grazing lands are now being degraded and exposed to soil erosion while severely losing their potential. In an attempt to meet the increasing food demands of the rapidly growing populations, farmers are cultivating grasslands permanently and grazing lands are diminishing(Kassahun *et al*., 2009). Hence, grazing is pushed to marginal areas that are ecologically fragile(Wuletaw Mekuria *et al*., 2016; Wang *et al*., 2017). For years, most of the land management practicesand previous studies had mainly focused on cultivated lands whilegiving less attention to the manipulation of soil, plant, and animal ecosystem through grazing management (Alemu *et al*., 2017).

In the study area,livestock graze on communal and fallowgrazing lands during the cropping season and on croplands after harvest. During free grazing, the grass vegetative cover is completely grazed, the soils become bare and compacted(Kebede *et al*., 2016). Farmers have to till the grazing landseveral times to loosen up the soil to allowinfiltration of the rains and avoid sheet erosion. Even if this action can help to avoid sheet erosion, the repeated tillage exposes the topsoil to other forms of erosion i.e. (rill and gully)(Mohammed, *et al*., 2020). In addition to this, due to the damage caused by the trampling action of the animals,the free-grazing system harms the physical soil and water conservation (SWC)practices (such as soil bunds, terraces) (Samuel & John, 2002). Several studies(Alemayehu *et al*., 2013; Ma *et al*., 2016; Zhang *et al*., 2018;Cislaghi *et al*., 2019)revealed the adverse effect that unmanaged grazing imposes on vegetation characteristics and soil properties.

In central Ethiopian highlands, most of the communal grazing lands had become severely degraded due to soil erosion (Gebremedhin *et al*., 2001). To boost the productive potential of these lands, further degradation must be prevented through natural recovery and prevention strategies such, as exclosures, reforestation as well as other SWC practices (Mekuria & Aynekulu, 2013;Mekonnen *et al*., 2015). Therefore, investigating the effects of restoration practices is important for developing sustainable management strategies and prevents further degradation.

General objective

To determine the effects of grazing exclusions and soil and water conservation measures on grass biomass and selected soil properties in the central highland of Ethiopia.

Specific objectives

- To evaluate the effect of grazing exclusions and soil and water conservation measures on selected soil properties,
- To determine the change in grass biomass production of a land over time when excluded from grazing pressureand,
- To assess the perceptions and strategies of farmers towards grazing and its management.

2. LITERATURE REVIEW

2.1. Concepts and Definitions of Grazing

Though rangelands and grasslands are used interchangeably, rangeland is a broader term than grasslands. Grasslands, which cover about 40% of the terrestrial land surface (Steffens *et al*., 2008; Ma *et al*., 2016), are ecosystems characterized by a relatively high cover of grasses, as a dominant plant species, in an open, often rolling, landscape with little or no cover of trees and shrubs(Monson, 2014). While rangelands areuncultivated geographical regions dominated by grass and grass-like species with or without scattered woody plants, occupying between 18–23% of world land area excluding Antarctica(Blench & Florian, 2015; Oliveira Filho *et al*., 2019). Rangelands are vast natural landscapes that include tall grass and short grass prairies, grasslands, shrub-lands (bushy lands), woodlands, wetlands,savannas, chaparrals, steppes, and tundra,and deserts(Gautam, 2020).

The relationship between grazers and/ or browsers and grasslands has developed over millions of years (Blair *et al*., 2014), and it is among the important processes in grazing lands affecting species composition and biomass production.The term grazing animals refers to grazing herbivores, both domesticated and wild, that feed mainly or only on forageand do not include insects or other animals that consume vegetation to some degree. Grazing is a form of herbivory in which herbaceous plants (grasses and forbs) are consumed by herbivores while browsing refers to a process in which the leaves and woody twigs are consumed from trees and shrubs (Allen *et al*., 2011). Grazing and browsing occur both aboveground (leaves and stems) and belowground (fine roots and root hairs) by a wide variety of animal herbivores from microscopic invertebrates to the large mammalian mega fauna.

Grazing animals have several direct and indirect impacts that can improve or degrade rangelands depending on the timing and intensity of grazing.Grazers promote heterogeneity in grazing lands by selectively consuming some species while leaving others, through trampling, soil compaction, soil tunneling, and redistribution of nutrients(Geng *et al*., 2020).Overgrazed rangeland is often characterized by an increase in less palatable plants, increased soil erosion, an increase in weedy species that thrive under disturbance, and decreased production of important forage plants(Yisehak *et al*., 2013). However, the adaptability of grazing lands to higher grazing intensities depends on several geographical and agro-ecological factors such as the evolutionary history of the grazing land, the specific site where the grazing land occurs, the growth form of the vegetation, and inherent soil and vegetative characteristics (Taboada *et al.*, 2015).

2.2. Soil Erosion and Land Degradation

Various natural factors (rainfall, vegetation, topography, and soil) combined with human activities result in an important cause of land degradation, productivity decline, and ecological deterioration named soil erosion (Chen *et al.*, 2019). Though the occurrence of erosion, in space and time, is strongly influenced by social, economic, political, and institutional factors (Morgan, 2005), mainly the clearing of land during times of intensive human settlement gave rise to soil erosion (Jackson, 2002).Soil erosion is a worldwide environmental problem (Zhou *et al.*, 2008; Anh *et al.*, 2014;Gezahegn & Arus, 2020)and a major threat to the productivity of land (Res*et al.*, 2002) that degrades soil productivity, water quality, causing sedimentation and increasing the probability of flood (Zhou*et al.*,2008). It is a combined effect of terrain, rainfall, soils, land use land cover, and management practices, that threatens sustainable land use(Li *et al.*, 2019)and mainly occurs in areas that are being converted from forests to agriculture or undergoing rapid development such as urbanization(Thi *et al.*, 2014).It is mostly associated with unsustainable utilization and exploitation of land resources (Alemayehu *et al.*, 2013).

Soil erosion can be a slow process that continues relatively unnoticed or can occur at an alarming rate, causing serious loss of topsoil. Soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinization, and soil acidity problems are other serious soil degradation conditions that can accelerate the soil erosion process(Mohammad & Adam, 2010).On agricultural land, surface runoff and sediment losses occur even more frequently than on undisturbed natural soils, because the continuous tillage results in decreased soil organic matter and increased surface sealing and crusting (Cerdà*et al.*, 2009). It is a two-phase process consisting of the detachment of individual soil particles from the soil mass and their transport by erosive agents such as running water and wind. It simply refers to the destruction of soil, activated by human activity i.e. accelerated erosion, through erosive agents i.e. water or wind (Zachar, 2012). Factors that enhance soil erosion include, but are not limited to, bare soils, sloping terrain, extreme rainfall events, and intensive tillage(Rodrigo-comino *et al.*, 2018). Soil properties such as low organic matter content, poor structure, and weak aggregate stability make soils susceptible to water erosion. Soil erosion by water occurs in different forms i.e. splash erosion, sheet erosion, rill erosion, and gully erosion(Chen *et al*., 2019).

Soil splash detachment is the initial process that occurs when a raindrop strikes the soil surface, scatter and then splash the soil by displacing particles from their original location. A raindrop-soil particle momentum is formed after the hitting of raindrops to the soil surface before discharging their energy in the form of a splash. These raindrops form holes or cavities after hitting the soil like small bombs of different shapes and sizes. Sheet/inter-rill erosion is mainly caused by the shallow flow of water. Immediately after it starts, runoff quickly forms small rills and part of the runoff flowing in between these rills is called sheet or inter-rill erosion (Safdar & Irshad, 2017). Some soil particles in form of a thin sheet are moved away with the runoff and some settle in these small rills. Inter-rill erosiongenerally does not occur in forested areas because forest litter and understory vegetation form a protective surface cover(Nanko*et al*., 2008).

Erosion that occurs in small channels or rills due to rigorous flow is termed rill erosion. The soil is eroded more quickly in small channels by the runoff water. The concentrated runoff which joins in lower slopes is the primary mechanism of formation Vor U-shaped channels named gullies. Gully erosion can either be permanent and ephemeral. The normal tillage practices can easily remove the ephemeral gullies that contain shallow channels. On the other hand, permanent gullies require expensive means of reclamation and control as these are too large to be corrected by regular tillage(Philor, 2011).

Erosion and subsequent land degradation are the most serious environmental problems in Africa and this is also true in Ethiopia(Dagnew *et al*., 2017), where significant amounts of soil are lost every year through runoff (Mhiret *et al*., 2019). Land use land cover change have been accounted for an overall increase of 2.5% in the global average soil erosion between 2001 and 2012(Thi *et al*., 2014). Currently, soil erosion is a fundamental problem in Ethiopia with a detrimental impact on soil quality, land productivity, water pollution, and sedimentation. Productivity impacts of soil erosion are due to a decline in soil fertility and water availability on-site where soil erosion occurs. As a result, vast areas of fertile lands in Ethiopia have become unproductive(Adimassu *et al*.,2019).

Soil erosion in the Ethiopian highlands is a natural phenomenon due to erosive rainfall and steep and undulating topography(Guzman *et al*., 2013), however severe land degradation started in the 1960s when people started clearing forests for agriculture and cultivating marginal lands(Ali & Hagos, 2016). Soil degradation by water erosion is the principal cause ofthe decline in agricultural productivity. The loss of topsoil by water erosion in Ethiopia was estimated at 1.5 billion tons per annum with a mean erosion rate of 42 t ha^{-1} yr^{-1}. The rate of soil erosion in Ethiopia ranges up to 300 t ha^{-1} yr^{-1} and the highlands lose about 1.9 billion metric tons of fertile soil every year(Tadesse *et al*., 2017).

Mekuria & Aynekulu (2011) in their studies reported a soil loss of 35 t ha^{-1} $yr^{-1}$from cultivated steep slopes of the northern highlands of Ethiopia. Soil erosion rates in the cultivated highlands of Ethiopia can reach over 130 t ha^{-1} yr^{-1}(Tamene *et al*., 2017). About 50% of the Ethiopian highlands is estimated to be significantly eroded while 25% is believed to be seriously eroded. The estimated annual soil loss from the highland areas varies widely from 200 t ha^{-1} yr^{-1} to as high as 300 t ha^{-1} yr^{-1}(Fisseha *et al*., 2011). Continued soil erosion seriously threatens peoples'livelihoods, especially in highland parts of the country, which are characterized by rugged topography, dense population, and intensive cultivation.

2.1.1. Effects of soil erosion

The impacts of soil erosion begin with a change in the physical, chemical, and biological characteristics of the soil, causing a gradual drop in its potential productivity (Telles *et al*., 2013). Biological degradation refers to the process that leads to a decline in the humus content of soil through mineralization. The erosion carrying away includes humus carrying away as well, it carries away microorganisms living the soil; it carries away other substances such as heavy metals, synthetic materials, and others(Jurík *et al*., 2019). Physical degradation may occur as a result of sealing, compaction, and reduction in aeration, and reduced permeability. Lack of organic matter and a high percentage of very fine sands and silt in soils are some of the factors contributing to surface sealing (Tefera *et al*., 2002).

Soil erosion could have both on-site and off-site effects. The effects are said to be on-site when the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure, and the decline in organic matter and nutrient result in a reduction of cultivable soil depth and a decline in soil fertility (Morgan, 2005). It includes soil loss, the decline of soil organic matter content and soil structure, leading to decay in soil fertility and water-holding capacity, and ultimately to reduced food security and vegetation cover (Vente *et al.*, 2013) while off-site problems consist of sedimentation, reduction of the capacity of rivers and drainage ditches, enhancement of the risk of flooding, blockage of irrigation canals and shortening the lifetime of reservoirs and other infrastructures (Boardman*et al.*,2003).

Erosion displaces soil organic carbon and the most important nutrients and consequently affects vegetation growth, biodiversity, and overall sustainability of ecosystem services and functions(Gezahegn & Arus, 2020). Soil erosion can also cause severe environmental problems, including soil and water degradation, a decrease in land productivity, and eutrophication and sedimentation of water bodies. Soil erosion can also cause sedimentation of hydropower dams and result in significant economic losses due to frequent power cuts. High erosion and sedimentation can also undermine the overall provision of ecosystem functions and services of landscapes (Cerdà *et al.*, 2009). The loss of soil from land surfaces by erosion is widespread globally and adversely impacts the productivity of all-natural, agricultural, forest, and rangeland ecosystems, seriously decreasing water availability, energy,and biodiversity throughout the world(Zuazo & Pleguezuelo, 2009).

During the 1980s, statistics indicated that about two billion hectares of agricultural land had completely deteriorated since 1000 AD, and currently, the FAO estimates about 75 billion tons of agricultural soil loss, causing an annual cost of USD 400 billion. Currently, more than 12 million ha yr^{-1} of fertile soil were excluded from agricultural production due to soil erosion (Gashaw *et al.*, 2020). More than 75 billion tons of top soil per year are lost due to soil erosion(Mohammed,*et al.*, 2020)from the arable land worldwide. Of all the regions in the world, sub-Saharan Africa suffers most from the impacts of accelerated soil erosion. In Ethiopia, the annual loss due to erosion and soil nutrient reaches 80 million USD which amounts to 3% of the agricultural gross domestic product(Alemayehu *et al.*,2013). For instance, a study by Ciampalini *et al.*,(2012) in Tigray region revealed a soil loss rate of 35- 42 t ha^{-1} yr^{-1}which in monetary value is about 1-2 billion USD yr^{-1}.

2.2.2. Vegetation cover and soil erosion

Control of soil erosion is important for sustaining the long-term productivity of natural resources and for protecting aquatic ecosystems. The amount of water that infiltrates into the soil or leaves as runoff depends on many factors including soil characteristics, vegetation cover, and root system.The loss of ground cover due to deforestation, agriculture, over-grazing, and fires can lead to the formation of a soil crust, which results in increased overland flow and soil erosion. Lack of adequate vegetative cover during heavy rains creates severe soil erosion and the formation of wide gullies in agricultural fields(Du *et al.*, 2013). A commonmethod for decreasingrunoff and soil erosion is through a stable and suitable vegetative cover.

Surface cover by litter or live vegetation is one of the important parameters that control infiltration, surface runoff, and erosion(Nanko*et al.*, 2008). It can significantly affect runoff production and sediment transportation, including slowing velocity, increasing infiltration, and the resistance of overland flow. Vegetation plays an important role in the hydrologic cycle. It controls runoff water, hence, soil erosion, through its canopy, roots, and litter components(Mohammad & Adam, 2010). Vegetation is a vital part of ecosystems and provides a link among the soil, atmosphere, and moisture. It plays an important role in the energy exchange of the land surface, the global biochemical cycle, and the water cycle (Zhang *et al.*, 2019). It is usually composed of different strata or layers such as tree canopies, shrub canopies, grass cover, and litter which influence soil erosion to varying degrees (Zhongming *et al.*, 2010).

Litter generally refers to the fallen dead or dying plant material (leaves, stems, etc.) that cover the transect floor (Gillison, 2006). Forest litter refers to recently fallen and partially decomposed tree leaves, twigs, and small branches, distinct from humus, resting on the upper surface of soils(Li *et al.*, 2020). Litter cover forms a porous barrier that retains a small portion of the incident rainfall. It plays a major role in soil erosion processes by reducing erosivity of raindrops, decreasing sediment discharge, and lowering runoff volume compared to the bare ground (Goebes *et al.*, 2013). On places where floor litter has developed on the near-ground surface, rainfall is intercepted by the litter layer, though the interception capacity varies across tree species and depends entirely on its physiological and morphological characteristics, and subsequently evaporates back into the atmosphere(Ren *et al.*, 2018). It also is an important intermediate link of vegetation and soil, and plays an essential role in biogeochemical cycles and energy exchange in grassland ecosystems, maintaining soil organic matter and soil fertility.

The absence of vegetation cover allows raindrops access to the soil surface(Rodrigo-Comino*et al*.,2018). On bare agricultural soils, erosion by water and/or wind detaches and removes soil particles, reduces soil fertility, and induces land degradation (Cerdà*et al*., 2009). Increasing land cover and reducing the direct impact of raindrops are the fundamental measures that prevent soil erosion. The increase in vegetation coverage could enhance the interception of rainfall, reduce the kinetic energy of raindrops, weaken rainfall erosivity, improve soil aggregate stability and infiltration, and thereby reduce soil loss(Dur & Roc, 2008; Chen *et al*., 2019).

Louhaichi *et al*.,(2012)observed that rangeland degradation usually leads to increased surface water runoff and soil compaction due to decreased plant cover, reduced aggregate stability reduced soil fertility, and decreases in the soil water content in all soil layers. Moreover, (Hao *et al*., 2016)reported that bare plots produced significantly more runoffthan did a variety of vegetative plots. The positive effect of vegetation cover in reducing soil erosion is indicated in researches (Mohammad & Adam, 2010; Zhongming*et al*., 2010; Chen *et al*., 2018). In line with this,Zhou *et al*., (2016) reported that one of the most common methods for rehabilitating degraded land and reducing the risk of soil erosion is to use forest cover. Plants shelter and fix the soil with their roots, reduce the energy of raindrops with their canopy, can act as a physical barrier, altering sediment flow at the soil surface. Moreover, the way the vegetation is spatially distributed along the slopes is an important factor for decreasing the sediment runoff (Dur & Roc, 2008).

2.2.3. The erosion process in grazing lands

Human-induced activities (urbanization, industrialization, overgrazing, etc.) result in severe deterioration of ecosystem functioning, particularly to vegetation dynamics (Li *et al*., 2019) and soil physicochemical properties (Gros *et al*., 2004). Grazing, as one of the main land uses of natural grazing lands, affects the species composition of communities, vegetation characteristics, and plant biomass(Wang *et al*., 2019). Overgrazing by grazing and/or browsing animals is among the most influential anthropogenic factor that degrades the land and accelerates soil erosion (Lu *et al*., 2015; Mhiret *et al*., 2019). Though vegetation cover varies greatly across different places depending on climate, land use, land management practices, the quality of the soil and its properties, freely open communal grazing lands have barely harvestable biomass at any given time of the year (Alemayehu *et al*., 2013).

Overgrazing greatly contributes to the higher extent and intensity of forest cover loss in the central highlands of Ethiopia (Giday *et al*., 2018); where most of the available land is under cultivation or used for grazing.In the past few decades, human-induced livestock grazing has increased accelerated soil erosion (Li *et al*., 2019).Due to overgrazing, the natural vegetation in the NorthernHighlands of Ethiopia has virtually disappeared, leaving degraded communal grazing lands with irregularly spaced trees and shrubs and vast areas of bare lands devoid of vegetation(W Mekuria & Aynekulu, 2011).

The decline in vegetation cover, as a result of overgrazing, results in increased soil bulk density, decreased water infiltration rate, and increased sediment production (Tadesse & Peden, 2001) hence, higher amounts of runoff and soil erosion.Studies(Shrestha & Stahl, 2008;Mofidi *et al*., 2012;Kairis *et al*., 2015)have reported the effect of animal grazing on soil quality indicators (physical, chemical, and microbiological properties), and in most cases continuous overgrazing resulted in more soil erosion. The effects of grazing are, however, variable among ecosystems and depend on factors such as the identity and density of grazers, the grazing regime, and the ecosystem attribute/process considered (Gaitán *et al*., 2018).

Generally, there are three mechanisms by which grazing causes degradation to the soil (Ma *et al*., 2016) i.e. loss of vegetative matter from defoliation, deformation of soil structure from animal treading which increases bulk density (Singer & Schoenecker, 2003), and increased nutrient deposition from animal wastes (Bilotta *et al*., 2010). The trampling impact, determined by the animal's weight, is vertically transferred to the soil through the hoof area. In the meantime, compaction of soil degrades its physical quality, decreases its hydraulic conductivity and soil porosity (Li *et al*., 2019),and lowers plant coverage resulting in a greater magnitude of runoff hence, soil erosion (Zerihun *et al*., 2018). Though grazing can suppress greenhouse gas emission (Hong-fen *et al*., 2019), due to low gas diffusivity during soil compaction, and consequently inhibits grassland soil greenhouse gas fluxes; it highly increases soil erosion and grassland nutrient losses.

A significant change in abiotic and biotic factors following extensive grazing directly or indirectly impacts soil C storage capacity, and the activity and diversity of soil biota (Raiesi & Riahi, 2014), by influencing biomass production, removal and exportation, the incorporation of plant residues into the soil matrix by trampling and hoof action (Parks, 2013), disruption of soil macro-aggregates, and subsequent degradation of soil structure, especially in the top few centimeters and a change in environmental conditions such as soil moisture, temperature, and porosity (Onatibia & Aguiar, 2016).

The main factors influencing erosion on grazed lands are the type of grazing systems, stocking rate, forage type and growth patterns, and soil characteristics (Charles *et al*., 2019).Susceptibility of grasslands to the damaging impact of animal trampling varies with, soil type, soil water content, climatic conditions, and vegetation type. As the vegetation cover declines soil bulk density increases organic matter content and aggregate stability decrease under grazing impact, water infiltration rates decrease, and surface runoff level increases.Over grazed grasslands generate more runoff and erosion as compared to croplands (Dagnew *et al*., 2017). Several studies have reported the impacts of grazing system on specific farm components, such as forage quality and productivity, animal productivity, soil nutrient, and water cycling and soil greenhouse gas emissions and soil carbon sequestration (Mekuria & Aynekulu, 2013; Alemu *et al*., 2017; Lal, 2019; Yu *et al*., 2019).

2.3. Erosion and Sustainable Land Management

Land use refers to the purpose a land serves, for example, recreation, wildlife habitat, agriculture; while land cover refers to the surface cover on the ground for example vegetation, infrastructure, bare soil, and water; the use of land might be different for lands with the same cover type (Bekele, 2019). In short land use indicates how people are using a given land while land cover indicates the physical land type. Numerous studies have reported that the magnitude of soil erosion rates has been accelerating worldwide due to land use and land cover change and inappropriate land useand management practices resulting in widespread land degradation process(Kairis *et al*., 2013). Thus, land management is a key factor impacting soil erosion both on cultivated and grazing lands (Cerdà *et al*., 2009).Land management is the process by which the resources of the land are put into good effect. It encompasses all activities associated with the management of land (both natural and built environment) that are required to achieve sustainable development (Sanz *et al.*, 2017). Land management is said to be sound when operational processes of land policies are implemented comprehensively and sustainably. Land administration comprises an extensive range of systems and processes to manage land tenure, i.e. allocation and security of rights in lands, land value, i.e. assessment of the value of land and properties, land use, i.e. control of land use through adoption of planning policies and land use regulations and land development (Enemark, 2005).

Sustainable land management (SLM) is a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management to meet rising food and fiber demands while sustaining ecosystem services and livelihoods(Borrelli *et al.*, 2012). It is the adoption of land-use systems that enhance the ecological support functions of land with appropriate management practices, and thus enable land users to derive economic and social benefits from the land while maintaining those of future generations (ELD Initiative, 2019). It is crucial to minimize land degradation, rehabilitate degraded areas and ensure optimal use of land resources for the benefit of the present and future generation. It mainly involves preserving and enhancing the productive capabilities of land, sustaining productive forest areas and potentially forest reserves, maintaining the ability of aquifers to serve the needs of farm and other productive activities, and maintaining the integrity of watersheds for water supply and hydro-power generation needs and water conservation zones (Jakhar & Devesh, 2018).

The typical measures of SLM include agronomic measures, vegetative measures, structural measures, and management measures (Recha *et al.*, 2014). Agronomic measures are associated with annual crops and include mixed cropping, inter-cropping, relay cropping, cover cropping, and conservation agriculture, and so on. Vegetative measures involve the use of perennial grasses and/ or shrubs. Some examples include agro-forestry, wind breaks, hedges, grass strips, etc. Structural measures are mostly permanent and often lead to a change in slope profile. For instance, terraces, earth bunds, stone bunds, infiltration ditches, etc. Management measures involve a fundamental change in land use and include area closures, afforestation, irrigation, rotational grazing, crop residue management, etc. The benefits of SLM are attributed to farm level, regional, national, and global benefits. On a farm level, the basic strategies of SLM include, but not limited to, mechanical soil conservation (construction of terraces, bunds, grass strips, etc.), improved tillage regimes, and agricultural intensification i.e. increasing inputs to increase the sustained value of the land’s output (Mike & Timothy, 2005).

Even though beneficial, there are limiting factors for SLM, for example; many SLM practices are an investment or labor-intensive (terracing, stone lines, water-spread- ing weirs, etc.); economic returns are not always achieved immediately, (Kairis *et al*., 2013) agricultural service providers and extension often focus on short-term gains and neglect sustainable soil and resources management, thereby causing a lack of know-how on appropriate SLM measures at farmer level (ELD Initiative, 2019); weak tenure security and limited access to finances, inputs and machinery hamper the application of SLM measures; and social and cultural barriers to innovations (Recha *et al*., 2014).

The ability of soil to resist breakdown by external forces, soil aggregate stability, influence soil physical and/or chemical processes, such as soil nutrient storage, water infiltration, and the ability to resist soil erosion (Barthès & Roose, 2002; Siddique *et al*., 2017).It affects the movement and storage of water in the soil, soil aeration, soil erosion, soil microbial activity, and crop growth (Zeng *et al*., 2018) hence it is useful for sustainable land management, as a key indicator of soil structure and soil erosion and the subsequent degradation(Wang *et al*., 2019). Land management has been suggested as a factor that can have a major impact on erosion prevention in grazing lands (Steffens *et al*., 2008).The land type is an important factor affecting soil aggregates via the binding agents in soils, such as soil organic matter. In general soil structure depends on the presence of stable aggregates composed of primary particles and binding agents, which are the basic units of soil structure (Wang *et al*., 2019). Barthès & Roose, (2002) in their study confirmed that decreased soil aggregate stability is related to increased susceptibility to erosion thus enhancing soil aggregate stability, through different vegetation restoration methods, is an effective way to prevent soil erosion and increase soil quality.

2.3.1. Grazing exclusion

Grazing exclosures may be defined as an area of land, which is enclosed by a fence to prevent grazing by livestock and restore vegetation resources; which are usually established in steep, eroded, and degraded areas that have been used for grazing in the past (Aynekulu *et al*., 2017). It is usually considered as an effective method for restoring the degraded grassland and increasing ecosystem sustainability, for its favorable influence on vegetation, soil physicochemical, and microbiological properties (Chen *et al*., 2018). In Ethiopia, the birth of exclosures dates back to the 1980s and coincided with the introduction of large-scale land rehabilitation and soil and water conservation programs(Giday *et al*., 2018). Though its effectiveness depends on different environmental and socio-economic conditions, establishing exclosures is among the soil and water conservation methods used to prevent soil erosion on grazing lands(Chesterman *et al*., 2019).

Enforcing a short-term grazing exclusion is important and essential for restoring degraded grassland. The exclusion of grazing is considered the starting point for vegetation recovery, allowing the plants to recover leaf area, produce seeds, and accumulate reserves(Antoneli *et al*., 2020). Grazing reduces the aboveground biomass and vegetation cover, but both quickly recover after the implementation of GE(Wang *et al*., 2019). A comparison of the impact of four typical restoration practices, i.e. GE, small watershed conservation, over sowing, and basic ranch, foundthat grazing exclusion was the most effective way to balance the maintenance of species diversity and plant growth(Li *et al*., 2018). The recovery process of overgrazed and degraded grazing lands can be obtained by temporary grazing exclusion and a management strategy that can promote the spontaneous rehabilitation of the vegetation condition without use of any additional input(e.g. fertilization, seed bank enrichment, irrigation).

Different studies revealed that soil physical properties such as bulk density, particle size distribution(Mofidi *et al*., 2012)water holding capacity, total porosity, and infiltration rates (Yuan *et al*., 2012; Haynes *et al*., 2014) had improved due to the effect of grazing exclusions. Bulk density often increases in soils under heavy grazing pressure by animal trampling, poaching, and pugging (Steffens *et al*., 2008;Fernandaze *et al*., 2009). Yet, the chemical property of soil in grazing exclusions and freely grazed areas had not been consistent in different research results.For instance, previous studies on the effects of grazing exclusions on soil organic carbon indicated an increased (Zuo *et al*., 2008; Raiesi & Riahi, 2014), neutral (Shrestha & Stahl, 2008; Medina-Roldán *et al*., 2012), and a decreased results. The variation in these results is due to the inconsistent years of grazing exclusions, soil heterogeneity (Mekuria & Aynekulu, 2011), the total number of samples, degradation level (Steffens *et al*., 2008)type of grazing animals,and different environmental conditions (Raiesi & Riahi, 2014; Lu *et al*., 2015).

2.3.2. Rotational grazing

Rotational grazing is a process whereby livestock are strategically moved to fresh paddocks, or partitioned pasture areas, to allow vegetation in previously grazed pastures to regrow before they are grazed again(Beetz & Lee, 2010). In this system,access to the grazing area is limited in time and space which leads to more uniform grazing(Anja & Isselstein, 2020). Under rotational grazing, only one portion of pasture is grazed at a time while the remainder of the pasture "rests." To accomplish this, pastures are subdivided into smaller areas (referred to as paddocks) and livestock are moved from one paddock to another.

Rotational grazing encourages an even distribution of grazing throughout a paddock, allowing resting periods in between rotations that help maintain the health of forage. This discourages competition from weeds and undesirable plant species that often invade when forage is overgrazed and weakened(Xu *et al*., 2018). It is more efficient and productive because it reduces the presence of overgrazed and under-grazed areas throughout a pasturesince livestock are only permitted to feed in paddocks for a limited period. However, for rotational grazing to be successful, the timing of rotations must be adjusted to the growth stage of the forage(Probo *et al*., 2014).

There are many benefits associated with rotational grazing. These include economic benefits (the only capital cost specific to rotational grazing is fencing), environmental benefits, increased pasture productivity, animal health and welfare, and aesthetics and human health benefits. Besides, other advantages of rotational grazing include; limited soil compaction which encourages root growth and reduces leaching of fertilizers(Adolfo & Jos, 2019), reduced soil erosion due to the presence of continuous ground cover throughout the year, reduced weeds from ample resting periods, longer grazing season because of shorter forage recovery periods when rotating paddocks, improved animal productivity, more efficient use of forage compared to continuous grazing, and improved nutrient distribution (manure) since livestock have fixed schedules(Beetz & Lee, 2010).

2.3.3. Mixed species grazing management system

A single species grazing system consists of one animal species grazing an area, while a mixed species (multispecies) grazing system consists of two or more species concurrently grazing the same area(Parks, 2013). It refers to the practice of utilizing different livestock species to diversify farm income; utilize pastures of different ecological types on the farm; manipulate the plant community to meet the production goals of the farm; and interrupt parasite life cycles (Rinehart & Karreman, 2018). Each animal species have their particular feeding behavior and requirement and, as a consequence, the single and mixed animal species activity will impact the environment differently.The main benefits associated with mixed-species grazing include, but not limited to, increasing the carrying capacity, improving ecological resilience and pasture health, aid in vegetation management, and help in parasite control(Kassahun *et al*., 2008).

Mixed species grazing increases carrying capacity. This is because of the differences in grazing habits andthe amount of dietary overlap between the species. Cattle, sheep, and goats evolved eating different plant types. For instance, in order of their preferences, cattle typically consume grasses, forbs, and shrubs while sheep consume forbs, grasses, and shrubs, and goats seek shrubs, forbs, and grasses. This management practice may be one of the most biologically and economically viable systems available to producers, especially on landscapes that support heterogeneous plant communities(Xiao *et al*., 2020). Because different animal species have different grazing habits and select various forages and combinations of forages, pastures that are grazed with multiple species have more uniform defoliation. This uniformity of grazing contributes greatly to forage quality and resiliency by keeping forage growth constant, i.e. resetting the plants to the same stage of growth with each grazing event and preventing weedy or unpalatable plants from taking over.

Cattle graze by bringing in forage with their tongue and tearing or shearing it off with the teeth on their lower jaw.It is difficult for them to get sufficient bites if forage is shorter, and it requires much more time for them to get longer forage into a form that they can swallow. Horses, on the other hand, have both upper and lower teeth and graze by nipping forage. Sheep use upper lips and lower teeth to graze nearly as close to the ground as do horses(Rinehart & Karreman, 2018).Pastures that have infestations of weeds or brush can be grazed with species appropriate to the plants present, which reduces the ability of any one plant species to dominate the landscape. Grazing managers must understand the growth habits of weeds and desirable plant species and know what animals graze them, to targetgraze such that weeds are reduced and palatable plants are allowed enough rest to recover. This is especially important where invasive plants are involved(Chen & Shi, 2017).

One species may eat what another will reject and, by using the correct livestock, managers can suppress and reduce a weed problem in a cost-effective and ecologically responsible way. For instance, when cattle, being primarily grass eaters, remain in a pasture for long periods, they tend to exhibit grazing selectivity and choose vegetative grasses and young forbs over noxious weeds. Although cattle prefer not to graze around their dung, sheep have been reported to graze around cattle dung, thus increasing the utilization of pasture(Tschopp et al., 2010). Moreover, it has been noted (Kosmas *et al.*, 2015) that grazing systems consisting of sheep and cattle grazing improved livestock productivity and reduced methane emissions relative to sheep-only systems. Combined with an integrated parasite-management plan, grazing multiple species together or in sequence can reduce parasite populations due to the timing of grazing and the characteristics of the parasites that infect each species of livestock. Given that sheep parasites do not usually affect cattle, cattle can be used to break the life cycle of sheep and goat parasites (and vice versa)(Anderson *et al*., 2012).

2.4. Soil and Water Conservation

Although poorly recorded and rarely recognized by experts, indigenous soil conservation techniques have been applied for centuries in Ethiopia. Ethiopia has a history of traditional soil and water conservation practices (SWC) back to the time of the Aksumite kingdom (400 BC to 800 AD) (Haregeweyn *et al*., 2015). The traditional terraces in Konso, Tigray, and Chercher highlands constitute a remarkable example of a living cultural tradition (Hurni *et al*., 2016). Before the 1974 revolution, soil erosion did not get the policy attention it deserved. The famines of 1973 and 1985 provided an impetus for conservation work through a large increase in food aid. Following these severe famines, the government launched an ambitious program of soil and water conservation supported by donor and non-governmental organizations (Ertiro, 2006).

The institutionalized SWC programs have been initiated due to the outcomes of erosion surveys in the late 1960s and1970s (Haregeweyn *et al*., 2015; Sileshi *et al*., 2019). Since the late 1980's, various nationwide and modern soil and water conservation practices have been applied by the ministry of agriculture on the cultivated land in many parts of Ethiopia, especially in the northern parts (Hurni *et al*., 2016), and had shown encouraging results. Nonetheless, the highly increasing population number negatively changed the land-use system (such as cultivation on steep slopes, clearing of vegetation, and overgrazing) in most parts of the country (Alemayehu *et al*., 2013), which then accelerated soil erosion. One of the ways of addressing soil and water degradation and improve crop productivity is the use of SWC measures.

SWC technologies are activities that maintain or enhance the productive capacity of land in areas affected by or prone to soil erosion. It includes the prevention, reduction, and control of soil erosion alongside proper management of the land and water resources (Tesfaye, 2019). Adoption of SWC practices reduces erosion to acceptable levels where soil loss can be offset by natural soil development, improve the physical structure of the soil (Dagnew *et al*., 2015), increase or maintain the level of organic matter, make the best use of available water and maintain the soil fertility level by reducing nutrient loss (Ashoori *et al*., 2016). These efforts intend to reduce soil erosion, restore soil fertility, rehabilitate lands, improve micro- climate, and boost agricultural production and productivity. A variety of practical methods of SWC measures are used and they are broadly grouped into physical (mechanical or technical) and biological (vegetative and agronomic) measures.

Physical SWC structures are permanent features made of Earth, stones, or masonry, designed to protect the soil from uncontrolled runoff and erosion and retain water where needed. Some examples include stone bunds, soil bund, Fanya juu, cutoff drain, waterway, check dam, and terrace. Biological measures prevent erosion by reducing the raindrop impact and increasing infiltration rates. These approaches are categorized into five groups: crop management (the use of cropping systems and mulching), soil management, contour farming, organic matter and fertilizer management, and agroforestry (combining the use of crops and/or animals with trees/shrubs on the same land) (Sinore *et al*., 2018). They have a low cost of adoption compared to the structural SWC measures. Some of the examples include; vegetative barriers, alley cropping, grass strip establishment, spreading manure, crop residues, contour cultivation, and mulching.

Proper design of physical SWC structures (especially drainage control structures such as graded bunds, cutoff drains, and waterways) is important for their effectiveness in protecting the soil from raindrop impact and hydraulic forces of runoff. The design of these structures considers the severity and extent of erosion damage or risks, the factors causing erosion, as well as the suitability of the land to the identified intervention (Tesfaye, 2019). In an attempt to combat soil erosion and degradation, the construction of physical SWC measures receives a lot more attention than biological and agronomic measures. However, the integration of biological practices with physical structures highly contributes to the prevention of soil erosion and the improvement of soil fertility (Li *et al*., 2001). In addition to this, for SWC practices to be effective the evaluation of technical standards, planning of SWC structures by experts, minimizing knowledge and skill gaps, and provision of sufficient materials along with trained manpower must be achieved.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study area,Geda watershed, is administratively located in Gudoberet Kebele,Basona Werena district, north shewa zone of Amhara national regional state of Ethiopia. Geographically, it lies between 9° 76′ to 9° 81′ north and 39° 65′ to 39° 73′ east (Figure 1).The altitude of the study area varies from2828 to 3700 m above sea level. It is located about 162 km to the northeast of Addis Ababa, the capital city of Ethiopia in the main road to Dessei town.

The population size of the study watershed is about 1429 inhabitants. It covers 2425 ha of land of which a high proportion of the land is under cultivation followed by plantation forests, grazing lands, and infrastructures (Mekuria *et al*., 2016). Eucalyptus trees are the most predominant plantation and are found around homesteads, hillsides, and gully buffers.The area is subject to continuous livestock grazing mainly by sheep, donkeys, and cattle. The major farming system in the area is crop-livestock production. The major crops grown include *Hordeum vulgare* (barley), *Triticum aestivum* (wheat), *Vicia faba* (fava bean), *Pisum sativum* (field pea), *Lens culinaris* (lentils), *Linum usitatissimum* (linseed), and vegetables while sheep, cattle, and donkey were the major livestock types reared in the area.

Agro-ecologically,the study site is classified as moderate to cool sub-moist highland. It is 75% *dega*, 22% *weyna dega*, and 3% *kola* (75%) (Anne *et al*., 2014).It receives a bimodal rainfall, *Kiremit* (June to September) being the long-rainy season and *Belg* (February to March) is a short-rainy season, with annual rainfall between 1278 and 2060 mm. However, there is a little occurrence of rains and/or absence during the short-rainy season (*Belg* rain)(Yaekob *et al*., 2020). More than 90% of the topography has medium to steep slopes and is dominated by undulated topography. The geology of the study area is characterized by volcanic rocks with rhyolites, trachyte, tuffs, and basalts (Bayat *et al*., 2019). Vertisols (locally *Tikur afer*), Lithosols (stony & shallow) and Cambisols were the three dominant soil types(Wuletaw & Mekonnen, 2018).

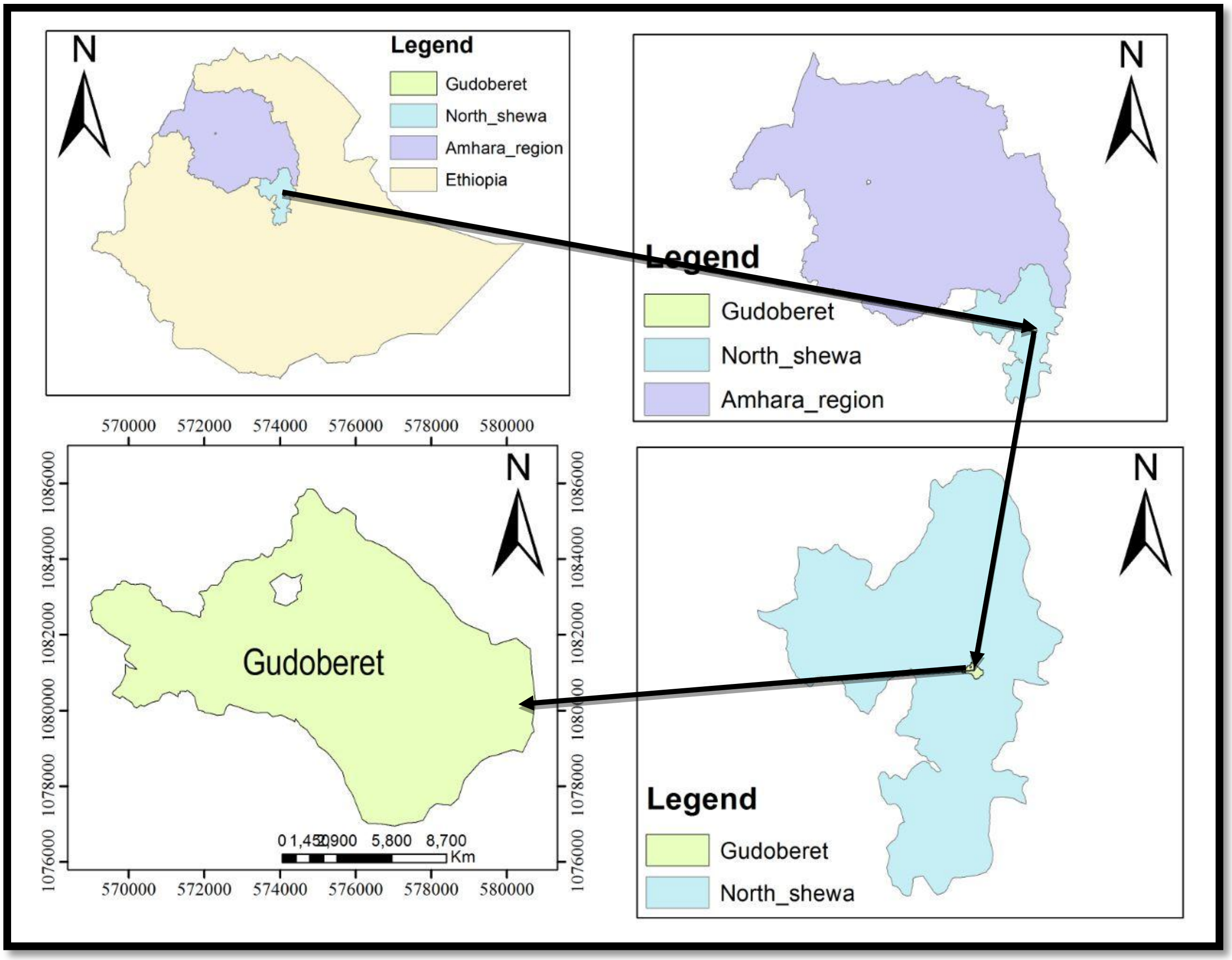

Figure 1.Map of the study area

3.2. Site Selection, Sampling Design, and Data Collection

To gain an overall overview and adequate description of the study area, preliminary field assessments were carried out. The study site was purposively selected because of the high livestock density, mixed crop-livestock production practices, and the trend of free grazing in the area. The crop-livestock production system in the area is characterized by an outward growth of cereal crop fields, which gradually reduced the area of land owed to grazing thereby marginalizing the grazing lands into areas that have no farming potential such as hilly tops, roadsides, and other marginal lands (Kebede *et al*., 2016). In addition to this, there is a trend of free grazing in the area which highly contributed to soil erosion and degradation(Wang *et al*., 2017).The grazing land in this system is perceived as a common resource over which nobody has direct responsibility and whose utilization is open to all members of a community, and thus is typically under enormous threat (Yisehak *et al*., 2013).

A preliminary reconnaissance survey, on August 5, 2019, was undertaken to select the sampling sites for grass biomass and soil sample collection. To evaluate grazing exclusion (GE) effects in the study area, six 2 X 2m grazing exclusion plots (Figure 2) in which three of the plots were in areas where there is no SWC practice (treatment 1) and the rest three in the managed area for soil and water conservation (e.g. soil bunds, soil bunds with biological interventions, percolation pits and water collecting ditches) (treatment 2) were excluded using a poultry netting fence. Most of the communal grazing lands in the study site, serve both as cultivated land (during the cropping season) and grazing land (after harvest). Excluding larger GE plots in these lands was not socially acceptable and economically feasible. Adjacent to each exclusion, six free grazing plots, each 30 cm distant from GE plots, were marked as control. Due to the undulating topography of the study site, the adjacent control plots were 30 cm distant from the GE plots so as to make sure that each pair of sites was as similar as possible in slope, aspect, vegetative and soil conditions. Uncontrolled numbers of free-ranging animals continuously grazed in the open site (FG) while there was no grazing in the GE plots for one year (from September 2, 2019, to September 26, 2020).The experiment was complete randomized design (CRD) with three replications.

Figure 2: Sample picture of the exclusion fence

A metal ring with a diameter of 27.5 cm (Figure 3) was used to collect the aboveground grass biomass, which was taken at four sampling periods i.e. initial sampling date, early growing season, optimum vegetative state, and end of the rainy season. Samples were then washed to remove any soil and oven-dried at 105℃for three hours and its dry matter content was determined. During the whole sampling period, a total of 192 samples (at one sampling period 4 samples from the 12 sites i.e. six fenced and six adjacent free grazing plots) were collected.

Figure 3: A metal ring with a diameter of 27.5 cm

At the time of the last sampling date, soil samples were collected using a soil auger in two of the randomly selected quadrants from both the exclosures and adjacent unenclosed sites within two soil depths (0-15 and 15-30 cm) (Mekuria *et al.*, 2016).A total of 48 soil samples were taken for laboratory analysis. The soil samples were air-dried for two weeks at room temperature (25℃) grinded and passed through different mesh sizes based on the requirements for chemical analysis. Soil laboratory analyses were undertaken at Debre Berhan Agricultural Research Center.

3.3. Soil Analysis

Particle size analysis was done using the Bouyoucos hydrometer method (Bouyoucos, 1962) and soil textural class was determined using the USDA texture triangle. Soil bulk density (g cm^{-3}) was determined by the core sample method (Blacke & Hartge, 1986). Soil pH was measured in an aqueous soil extract in distilled water (1:2.5 soil: water) using a pH meter (glass–calomel combination electrode)as described in Thomas (1996).

Soil organic carbon was determined according to the Walkley and Black method (Nelson & Sommers, 1982).The total soil nitrogen was analyzed using the Kjeldahl method(Bremner & Mulvaney, 1982)and the available Phosphorus was analyzed using the Olsen-P method (Olsen and Dean, 1965). C: N was calculated by dividing the organic carbon by the total soil Nitrogen.

Sodium acetate extract was used to determine the cation exchange capacity (CEC) (Chapman, 1965). Exchangeable calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were determined from the extraction of 1 M ammonium acetate (NH_4OAc) solution buffered at pH 7.0. Exchangeable Ca and Mg were read using atomic absorption spectrometry, while K and Na were read using flame photometry (Albert*et al.*, 1982).

3.4. Household Sampling

Two-stage purposive sampling techniques were employed for the household sampling. In the first stage, the study watershed was selected purposively owing to the high livestock density and production potential for the mixed crop-livestock systems. In the second stage, farmers who own grazing animals and directly take part in grazing land management were selected. The sample size was determined using the following formula (Israel, 1992).

$$\mathrm{n} = \frac{N}{1 + N(e)^2}$$

$$n = \frac{850}{1} + 850(0.1)_2$$

n~ 90

Where, e = confidence level (0.1), N = the total number of farmers who own grazing animals in Gudoberet Kebele (850), and n = sample size.

Both qualitative and quantitative data were collected to acquire the desired information. Field observations, structured and semi-structured questionnaires were used as a data collection tool to gather primary data from intended respondents. The questionnaire survey (See the appendix) was implemented via direct house-to-house visits.

3.5. Data Analysis

Soil properties and the grass biomass yield were subjected to a two-way analysis of variance (ANOVA) following the general linear model (GLM) procedure and means were separated and compared using the Least Significant Difference (LSD) procedure at a 5% level of significance. The relationship between analyzed parameters was performed using Pearson’s correlation analysis. All statistical analyses were performed using SAS 9.0 statistical software. Descriptive statistics was used to analyze the data from household respondents regarding their perception and strategies towards grazing and its management using SPSS 20.

4. RESULTS AND DISCUSSION

4.1. Effect of Grazing Exclusions and SWC measures on Soil Physical Properties

4.1.1. Bulk density

Bulk density was significantly ($p < 0.001$) affected by the effects of grazing exclusions and SWC measures but showed no significant difference as a result of soil depth. It was lower under grazing excluded sites and with SWC treatments, 1.30 g/cm^3 being the lowest value (Table 1).Bulk density generally decreased under the exclusions due to the effect of fences that enhance the ground cover thereby improving the soil organic matter. Besides it could be due to the elimination of soil compaction resulting from animal trampling (Raiesi & Riahi, 2014) as well as higher biomass accumulation (Yan *et al*., 2015). This result is supported by Steffens *et al*., (2008) and Ma *et al*., (2016), who found significantly ($p<0.01$) and ($p< 0.05$), respectively, lower bulk densities under grazing excluded plots compared to free grazing plots. The mean bulk density value of the treated sub-watershed had lower bulk density than the untreated one (Table 1). In the treated sub-watershed the impact of animal trampling is minimized due to the controlled grazing system. Moreover, the higher sand fraction in the untreated sub-watershed could also contribute the lower bulk density under the treated sub-watershed.

However, it was in contradiction with the findings of Feyisa *et al*. (2017) who found insignificant yet higher bulk density (1.1 to 1.5 g/cm^3) in open grazed areas than exclosures. The values of bulk density vary with the type of grazing land i.e. whether it is private or communal. Alemayehu *et al*., (2013) found a lower bulk density in restricted communal and private grazing lands compared to freely open communal grazing lands. This is because, in freely open communal grazing lands, there is a higher stocking rate and thus high grazing intensity which significantly increases the trampling effect by livestock. Therefore, the results of this study indicated that exclusion of grazing lands or the reduction of the pressure from free grazing can significantly improve soil compaction there by reducing bulk density.

4.1.2. Particle size distribution

The results showed a significant difference on the percentage of sand ($p< 0.05$) and silt ($p< 0.001$), respectively, while clay showed no significant difference as a result of grazing exclusions. SWC measures had significantly ($p < 0.001$) affected the sand and silt fractions, yet no significant difference was found across soil depths on sand, silt, and clay fractions (Table 1). The lowest value of sand (26.3%) and higher values of silt (39.3%) were recorded under the grazing excluded sites (Table 1), which could be due to the silt trap capacity of the grown grass under the exclusions. Moreover, grazing exclusion enhances the ground cover thereby preventing exposure of topsoil to the direct raindrop impact, which then results in relatively lower sand particles and higher amounts of smaller particles (clay) on the surface soil. Similar to the findings of this study, Feyisa *et al*., (2017) found no significant variation in the sand, silt, and clay among soil depths, and Chen *et al*., (2012), found lower sand and higher silt percentage under grazing excluded sites.

As a result of the effect of SWC measures, the treated sub-watershed had lower sand (27.67%) and higher silt (38.67%) values. The SWC measures had an undeniable role in preventing top soil removal, reducing runoff and improving soil conditions. On the contrary, the higher sand particles in the untreated sub-watershed could be the result of removal of fine particles through erosion. Moreover, the biological SWC interventions in the treated sub-watershed contributed to the higher silt contents via the action of organic matter deposition.

Table 1: The effect of land-use types and soil depth on selected physical properties

Factors	Attribute of factors	Bulk density (g/cm^3)	Particle size distribution (%)			Textural class
			Sand	Silt	Clay	
Land use type	FG-noSWC	1.39 ^{a}±0.02	43.30^{a}± 4.22	24.00^{b}± 3.80	32.70±2.95	Loam
	FG-SWC	1.32 ^{b}±0.01	29.00^{b}± 2.62	38.00^{a}±1.03	33.00±2.23	Clay
	GE-noSWC	1.39 ^{a}±0.02	39.70^{a}± 3.03	23.30^{b}±3.79	37.00±2.62	Clay loam
	GE-SWC	1.30 ^{b}±0.02	26.30^{b}± 2.16	39.30^{a}±1.03	34.30±0.80	Clay loam
	p-value	0.0004***	0.0046*	0.0002***	0.5724^{ns}	
	SWC	1.31^{b}± 0.01	27.67^{b}± 1.67	38.67^{a} ±1.08	33.67± 1.15	
	No SWC	1.39^{a}± 0.01	41.50^{a}± 2.54	23.67^{b}± 1.97	34.83± 1.99	
	p-value	<.0001***	0.0002***	<.0001***	0.6058^{ns}	
Depth (cm)	0- 15	1.36 ± 0.01	33.30 ±8.54	30.70 ±8.06	36.00 ±4.43	Clay loam
	15- 30	1.34 ± 0.02	35.80 ±11.77	31.70 ±10.85	32.50±6.16	Clay loam
	p-value	0.1559^{ns}	0.450 ^{ns}	0.6912^{ns}	0.1599 ^{ns}	
	LU*D	0.9409^{ns}	0.6209 ^{ns}	0.6243 ^{ns}	0.8845 ^{ns}	

CV %	2.66	22.89	19.43	16.98

Overall means followed by the same letter (s) across columns are not significantly different at *p*>0.05; * = significant at *p*< 0.05; ** = significant at *p*< 0.01; *** = significant at *p*< 0.001 for land use types and soil depth. FG-no SWC = free grazing site in the untreated land; FG- SWC = free grazing site with SWC treatment; GE-no SWC = grazing exclusion fence in the untreated land; GE- SWC = grazing exclusion fence with SWC treatment; CV = coefficient of variation

4.2. Effect of Grazing Exclusions and SWC Measures on Soil Chemical Properties

4.2.1. Soil pH and electrical conductivity

Soil pH showed no significant (p >0.05) variation as a result of the effects of grazing exclusions and soil depths (Table 2). However, it was significantly (p < 0.01) affected by the effects of SWC measures. It was lower under SWC treatments than the untreated sub-watershed, yet the differences were not significant between the grazing exclusion and free grazing sites. This could be due to the buffering capacity of the soil and less leaching of base cations. This is similar to the findings of other studies (Lu *et al*., 2015; Yimer *et al*., 2015). However, the results of this study contradicts studies (Onatibia & Aguiar, 2016) that found higher pH values under SWC treatments. This could be due to the type of plant grown in the area, types of fertilizer applied, past land use practices and loss of base cations before the installation of SWC measures could be the reason for the lower pH values under the treated sub-watershed. SWC measures improve the soil condition and result in an increase on the amount of organic matter. The accumulation of organic matter in the soil results in higher soluble base cations (Ca^{2+} and Mg^{2+}) that reduce the hydrogen ion concentration responsible for acidity, which then increases soil pH making the soil more alkaline. In the present study, the values of soil pH varied between 6.04 in the FG-SWC and 6.39in the FG-noSWC indicating a slightly acidic soil in the study area (Landon, 1991).

Though EC was not statistically significant (p>0.05) between the land use type and soil depth, the EC mean value indicated that the soils under all the land use types are salt-free (Landon, 1991).Due to the solubility and leaching characteristics of soluble salts, areas with a high amount of rainfall tend to have lower values of EC. The low EC values of the present study might be attributed to the high rainfall of the study area that causes leaching of the available nutrients and base cations. Land uses, such as overgrazing, leads to low organic matter, poor infiltration, and high soil compaction increases the EC of soil, due to the accumulation of soluble salts near the surface of the soil. Reda *et al*., (2020), found higher values of EC under old-aged exclosures and free grazing areas.

Table 2: The effect of land-use types and soil depth on pH and EC

Factors	Attribute of factors	pH (1: 2.5)	EC (ds/m)
Land use type	FG-noSWC	6.39±0.05	0.09±0.01
	FG-SWC	6.04±0.08	0.09±0.01
	GE- noSWC	6.36±0.09	0.08± 0.02
	GE-SWC	6.16±0.13	0.10± 0.01
	p-value	0.08^{ns}	0.20^{ns}
	SWC	6.10^{b}± 0.07	0.09 ±0.01
	No SWC	6.37^{a}± 0.05	0.08± 0.004
	p-value	0.0061**	0.1353^{ns}
Depth (cm)	0- 15	6.19±0.07	0.08±0.02
	15- 30	6.28±0.08	0.09±0.02
	p-value	0.36^{ns}	0.17^{ns}
	LU*D	0.99^{ns}	0.52^{ns}
	CV %	3.92	16.66

Overall means followed by the same letter (s) across columns are not significantly different at $p > 0.05$; * = significant at $p < 0.05$; ** = significant at $p < 0.01$; *** = significant at $p < 0.001$ for land-use types and soil depth. FG-no SWC = free grazing site in the untreated land; FG- SWC = free grazing site with SWC treatment; GE-no SWC = grazing exclusion fence in the untreated land; GE- SWC = grazing exclusion fence with SWC treatment; CV = coefficient of variation

4.2.2. SOM, SOC, TN, C: N and Available P

Soil organic matter and soil organic carbon were significantly (p< 0.05) affected by the effects of grazing exclusion, SWC measures (p <0.001)and soil depth. Both tend to increase within soil depth and were higher in treated areas with SWC. Total nitrogen was higher in treated areas with SWC than those with no SWC measures and significantly (p< 0.01) increased as a result of grazing exclusion and SWC measures, but showed no significant difference between soil depths (Table 3). The higher amount of biomass as a result of the effect of both grazing exclusion and

SWC measures results in the decomposition of higher amounts of organic material, which results in relatively higher amounts of total nitrogen in the treated sub-watershed. Moreover the nitrogen fixation through the biological SWC measures (e.g. tree lucerne) contributes to the higher total nitrogen under the treated sub-watershed.

It is well noted that higher grazing intensity decreases both above and below-ground biomass. In addition to its effect on plant biomass, grazing indirectly affects soil properties through the reduction of organic matter input to the soil. Since soil carbon and nitrogen inputs are mainly derived from plant root and litter (Zhao *et al*., 2018), the establishment of exclosures stimulates the sequestration of soil carbon and nitrogen through the act of fences that eliminates the disturbance of livestock grazing and enhances plant biomass. Studies (Steffens *et al*., 2008;Ma *et al*., 2016) revealed a significant increase in SOC and TN as grazing intensity decreases. However inconsistent results were obtained on the effects of grazing exclusions in SOC and TN contents in different grazing lands, which could mainly be due to grazing intensities, an altitudinal difference (Zhao *et al*., 2018), grazing history and the species composition of plant communities (Onatibia & Aguiar, 2016).

Plant cover removal by overgrazing, followed by a decrease in the thickness of the topsoil layer due to erosion, have been considered the main factors for reduced SOM contents and for the loss of basic essential nutrients in the soil as observed for the Ca^{2+} and K^{+} nutrients in overgrazed areas(Schulz *et al*., 2016). Under the conditions of this study, however, the available P, Mg^{2+} and Na^{+} levels remained constant, showing no changes as a function of alterations to the topsoil layer by GE. Moreover, animal trampling has a severe effect on soil compaction (Hamza and Anderson, 2005), and at the same time may stimulate organic matter decomposition, due to the destruction of soil aggregates by mechanical stress. The increase in soil OM and nutrient contents, in the present study, due to grazing exclusion could have been a result of an increase in the amount of plant litter on the one hand and a decrease in soil compaction on the other hand, which together creates a favorable environment for microorganisms.

There was no significant difference ($p > 0.05$) in C: N as a result of grazing exclusion, SWC measures and soil depth (Table 3). This could be due to a similar rate of change of SOC and total nitrogen before and after establishing exclosures. This result is in line with (Raiesi & Riahi, 2014; Li *et al*., 2018) who found no significant difference in soil carbon and nitrogen ratios between freely grazed and excluded plots.

Results showed that available phosphorus was significantly ($p< 0.05$) affected as a result of grazing exclusion and SWC measures ($p < 0.001$) (Table 3) but showed no significant difference between soil depths. Available P was significantly higher (7.69 ppm) in the free grazing areas with no SWC measures and the significantly lowest value (3.83 ppm) was recorded under grazing exclusion plots with SWC treatments. Due to the slightly acidic nature, the soils of the study area are regarded as low (Landon, 1991) in available phosphorus. Since soil P is mainly derived from rock weathering (Chen *et al*., 2013), the grazing exclusion effect that enhances both above and below-ground biomass reduces the weathering of parent materials by erosion resulting in lower available P values under grazing excluded sites. Moreover, the fertilization effects during grazing, through animal dung and urine, contribute to the higher concentration of soil available phosphorus (Liu *et al*., 2020) in free-grazing sites.

Table 3:The effect of land-use types and soil depth on SOM, SOC, TN, C: N and Av. P

Factors	Attribute of factors	(%)				Av. P (ppm)
		SOM	SOC	TN	C: N	
Land use type	FG-noSWC	1.71^{b} ± 0.47	0.99^{b} ± 0.27	0.08^{b} ± 0.02	13.15 ± 2.13	7.69^{a} ±1.10
	FG-SWC	3.17^{a} ± 0.22	1.84^{a} ± 0.13	0.15^{a} ± 0.01	12.38 ±0.39	4.05^{bc} ±0.70
	GE-noSWC	1.91^{b} ± 0.41	1.11^{b} ± 0.23	0.09^{b} ± 0.02	12.00 ±0.74	6.55^{ab} ± 0.81
	GE-SWC	3.07^{a} ± 0.47	1.78^{a} ± 0.27	0.14^{a} ± 0.02	12.16 ± 0.52	3.83^{c} ± 0.56
	p-value	0.0262*	0.0262*	0.0083**	0.9215^{ns}	0.0157*
	SWC	3.13^{a}± 0.25	1.81^{a}± 0.14	0.15^{a}± 0.01	12.27±0.31	3.94^{b}± 0.43
	No SWC	1.81^{b}± 0.29	1.05^{b}± 0.17	0.09^{b}± 0.01	12.57±1.09	7.12^{a}± 0.67
	p-value	0.0008***	0.0008***	0.0002***	0.7894^{ns}	0.0008***
Depth (cm)	0- 15	2.95^{a} ±0.34	1.17^{a}±0.20	0.13±0.01	13.02±0.61	5.53± 0.59
	15- 30	1.99^{b}±0.27	1.16^{b} ±0.20	0.10 ± 0.01	11.83±0.93	5.53±0.86
	p-value	0.0232*	0.0232*	0.3616^{ns}	0.0546^{ns}	0.9921^{ns}
	LU*D	0.9704^{ns}	0.9704^{ns}	0.9701	0.9200^{ns}	0.7480^{ns}
	CV %	38.00	38.00	31.54	25.03	38.85

Overall means followed by the same letter (s) across columns are not significantly different at $p > 0.05$; * = significant at $p < 0.05$; ** = significant at $p < 0.01$; *** = significant at $p < 0.001$ for land use types and soil depth. FG-no SWC = free grazing site in the untreated land; FG- SWC = free grazing site with SWC treatment; GE-no SWC = grazing exclusion fence in the untreated land; GE- SWC = grazing exclusion fence with SWC treatment; CV = coefficient of variation

4.2.3. CEC and exchangeable bases

Results showed that grazing exclusion, SWC measures and soil depth did not significantly ($p > 0.05$) affect the values of CEC (Table 4). The results in CEC values fall within the range 34.7 for FG- SWC to 37.4 for GE- no SWC (cmol $_{(+)}$/kg) and is regarded as high according to the classification by Landon, (1991). The soil colloidal surfaces are electrically charged, which could either be permanent charge or pH-dependent charge. The major sources of pH-dependent charges in soils vary depending on the extent of weathering, parent material from which the soil is formed, soil reaction (pH) and, organic matter content. Soils with higher clay particles and organic matter tend to have higher CEC. This is due to the higher water holding capacity of high CEC soils. However, the insignificant results of CEC might be due to the age of grazing exclosure in the area since CEC accumulation requires a relatively long time. Feyisa *et al*.,(2017) found a significant ($p < 0.05$) difference for CEC values between 30 years and 20 years of exclusions. Additionally (Reda *et al*., 2020)found higher values of CEC in the old-aged exclosures (> 20years).

Ca^{2+}, $Mg^{2+}$and Na^{+} showed a significant ($p < 0.05$) variation as a result of the effect of grazing exclusions while, K^{+} had no significant ($p > 0.05$) difference. There was also a significant ($p < 0.001$) difference as a result of the effect of SWC measures on the values of exchangeable Ca^{2+}, $Mg^{2+}$and Na^{+}. Yet, each showed no significant difference across the two soil depths (Table 4). Unlike the results of this study that found no significant difference in the values of K^{+},Oliveira Filho *et al*. (2019), found a significant increase in Ca^{2+}andK^{+}values.The variation in Ca^{2+} and K^{+} values between the grazing exclusions and free grazing sites were more significant in the topsoil layer (0-10 cm), indicating that for these nutrients, the process of natural restoration of the soil as a result of GE was more efficient than the other nutrients (Mg^{2+} and Na^{+}). This is could be due to the age of exclusions (17 years).

Table 4: The effect of land-use types and soil depth on CEC and Exchangeable bases

Factors	Attribute of factors	(cmol $_{(+)}$/kg)				
		CEC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Land use type	FG-noSWC	36.7±1.46	20.7^{b}±1.41	8.1^{b}±1.75	0.11^{c}±0.02	0.41±0.05
	FG-SWC	34.7±3.21	21.9^{b}±1.69	11.9^{b}±1.81	0.27^{ab}±0.02	0.51± 0.03
	GE- noSWC	37.4± 4.93	29.7^{a}±2.3	8.8^{b}±2.70	0.22^{bc}±0.03	0.41± 0.06
	GE-SWC	33.5±3.82	23.1^{b}±1.47	18.4^{a}±1.62	0.31^{a}±0.01	0.51±0.03
	p-value	0.88^{ns}	0.01^{*}	0.01^{*}	0.01^{*}	0.17^{ns}
	SWC	34.1^{a}± 2.38	22.5 ± 1.08	15.2^{a}± 1.52	0.29^{a}±0.01	0.51^{a}±0.02
	No SWC	37.0^{a}±2.46	25.2 ± 1.88	8.4^{b}± 1.54	0.21^{b}±0.02	0.39^{b}±0.04
	p-value	0.4069^{ns}	0.2136^{ns}	0.0059**	0.0017**	0.0128*
Depth (cm)	0- 15	37.3±2.47	25.3±1.6	11.3±1.69	0.25± 0.02	0.49±0.03
	15- 30	33.8±2.5	22.4± 1.47	12.3± 1.98	0.25± 0.02	0.41± 0.03
	p-value	0.37^{ns}	0.12^{ns}	0.63^{ns}	0.94^{ns}	0.09^{ns}
	LU*D	0.59^{ns}	0.78^{ns}	0.71^{ns}	0.44^{ns}	0.88^{ns}
	CV %	25.42	18.17	44.56	22.32	24.86

Overall means followed by the same letter (s) across columns are not significantly different at $p > 0.05$; * = significant at $p < 0.05$; ** = significant at $p < 0.01$; *** = significant at $p < 0.001$ for land-use types and soil depth. FG-no SWC = free grazing site in the untreated land; FG- SWC = free grazing site with SWC treatment; GE-no SWC = grazing exclusion fence in the untreated land; GE- SWC = grazing exclusion fence with SWC treatment; CV = coefficient of variation

4.3. Correlation of Soil Parameters

Bulk density showed a significant and positive ($p < 0.001$) correlation with sand and a significant and negative correlation with silt ($p < 0.001$), and EC ($p < 0.05$). This result is supported by (Terefe et al., 2020) who found a strong and significantly positive correlation between bulk density and sand. Moreover, bulk density and sand were significantly and positively correlated with available phosphorus and were significantly and negatively correlated with silt, $Mg^{2+,}$ and TN (Table 4).

Sand was significantly and negatively correlated with Na^{+} ($p < 0.001$), K^{+}($p < 0.01$), clay, SOC and SOM ($p < 0.05$). In contrast, silt was significantly and positively correlated with Na^{+}, K^{+}, TN

($p < 0.001$), Mg, SOC ($p < 0.01$), EC, and SOM ($p < 0.05$) and was significantly and negatively correlated with available phosphorus ($p < 0.001$). Similar to the findings of this study, Yan *et al*. (2015), found a significant and positive correlation of silt and a significantly negative correlation of sand with SOC and SOM. This is due to the higher water and nutrient holding capacity of silt compared to sand. The exchangeable bases, except for Ca^{2+} which showed a significantly negative correlation with Mg^{2+} ($p < 0.05$), had a significantly positive correlation to each other and were significantly and negatively correlated with available phosphorus.

Soil pH and available phosphorus were significantly and negatively correlated with TN, SOC, and SOM at $p < 0.001$ and $p<0.01$ respectively. Soil pH, as one of the chemical properties of soil, directly affects microbial activities and plant growth. Excessive pH inhibits plant root growth there by reducing the accumulation of SOC. This might be the reason for the significantly negative correlation between soil pH and SOC. The results of the present study are supported by the findings of (Liu et al., 2020).

On the other hand, K^+ and TN were significantly and positively correlated with SOC and SOM at $p<0.05$ and $p < 0.001$respectively.Soil organic carbon was also significantly and positively correlated with SOM ($p < 0.001$). The source of nitrogen in the soil is SOM, which might be the reason for the positive relationship between TN and SOM. Moreover the increase in SOM increases the TN and vice versa. The positive correlation between K^+ and TN with SOM is similar to the findings of (Khadak, 2016).

Table 5:Pearson correlations for soil properties

	BD	Sand	Silt	Clay	EC	pH	Ca	Na	Mg	K	P	TN	SOC	OM	C:N
BD															
Sand	0.74***														
Silt	-0.76***	-0.84***													
Clay	-0.08	-0.41*	-0.15												
EC	-0.43*	-0.19	0.43*	-0.39											
pH	0.40	0.37	-0.50	0.13	-0.26										
Ca	0.25	0.07	-0.18	0.17	-0.04	-0.25									
Na	-0.41	-0.61***	0.69***	-0.05	0.37	-0.34									
Mg	-0.47*	-0.51 *	0.59**	-0.07	0.23	0.06	-0.50*	0.65***							
K	-0.33	-0.61**	0.70***	-0.07	0.22	-0.28	-0.14	0.63**	0.56**						
P	0.45 *	0.57**	-0.77***	0.26	-0.20	0.38	0.01	-0.43 *	-0.50*	-0.58**					
TN	-0.46 *	-0.51*	0.68***	-0.22	0.34	-0.90***	0.25	0.39	0.20	0.58	-0.69				
SOC	-0.40	-0.44*	0.53**	-0.09	0.25	-0.79***	0.23	0.30	0.11	0.47*	-0.55**	0.95***			
OM	-0.40	-0.44*	0.530*	-0.08	0.25	-0.79***	0.23	0.30	0.11	0.47*	-0.55**	0.95***	0.99***		
C:N	0.043	0.09	-0.30	0.33	-0.01	-0.17	-0.12	-0.11	-0.20	-0.26	0.42	-0.06	0.23	0.23	
CEC	0.17	0.10	-0.28	0.28	-0.33	0.33	-0.05	-0.01	0.03	-0.03	0.43	-0.37	-0.30	-0.3	-0.01

Overall means followed by the same letter (s) across columns are not significantly different at *p* >0.05; * = significant at *p*< 0.05; ** = significant at*p*< 0.01; *** = significant at *p*< 0.001 for land-use types and soil depth.

4.4. Effect of Grazing Exclusions on Grass Biomass

The aboveground biomass showed significant changes ($p < 0.001$) as a result of grazing exclusions and the highest value (377.25 g/m^2) was recorded in grazing excluded and treated areas (Table 6). This result is similar to the findings of (Liu *et al*., 2020; Yongwen *et al*., 2020), who found higher above-ground biomass in the grazing excluded sites than freely grazed plots. Moreover, (Al-rowaily *et al*., 2015), in their study, noted that grasses were the most sensitive growth form to overgrazing as they were absent from freely overgrazed sites.Establishing exclosures had a positive effect on vegetation cover and density as well as on the improvement of vegetation diversity in terms of increasing species richness and diverse functional groupssince vegetation grows better, produces more root exudates, and develops a wider ramified root system under grazing exclusions than freely grazed sites.

Table 6: Effect of land-use types and seasons on aboveground grass biomass yield

Factors	Attribute of factors	AGB yield (g/m^2)
Land use type	FG-no SWC	158.59c ± 23.19
	FG-SWC	219.77bc ± 24.19
	GE-no SWC	280.55b ± 31.00
	GE-SWC	377.25a ± 35.69
	p-value	<.0001***
Seasons	Initial sampling season	246.55^b ± 33.29
	Early growing season	204.12^b ± 32.76
	Optimum vegetative state	258.33^b ± 35.16
	End of rainy season	327.17^a ± 39.29
	p-value	0.0084*
	LU*S	0.0622^{ns}
	CV %	31.71

Overall means followed by the same letter (s) across columns are not significantly different at $p>0.05$; * = significant at $p< 0.05$; ** = significant at $p< 0.01$; *** = significant at $p< 0.001$ for land use types and soil depth. FG-no SWC = free grazing site in the untreated land; FG- SWC = free grazing site with SWC treatment; GE-no SWC = grazing exclusion fence in the untreated land; GE- SWC = grazing exclusion fence with SWC treatment; CV = coefficient of variation; AGB = aboveground biomass

There was significant ($p < 0.05$) variation, though inconsistent, in the seasonal values of the aboveground biomass yield (Table 6). The lowest valuewas recorded during the early growing season (i.e. during November and December) while the last sampling season, the end of the rainy season i.e. during September and October, had the highest dry matter yield of all. After the crop harvesting time (the early growing season in this context) around mid-October, livestock, in the study area, start freely grazing on the croplands which continues until June i.e. the next tillage season. Since the second grass biomass sampling took place in this free grazing season, it greatly contributed to the reduced biomass yield.

Although it is known that grazing exclusion can enhanceaboveground biomass, high seasonal variability is generally considered to be a more important driver of this measure (Milne *et al*., 2002). Medina-Roldán *et al*., (2012), revealed that the effects of grazing exclusion on aboveground biomass werehighly dependent on the season. Furthermore,Li *et al*., (2018), illustrated that the aboveground biomass showed seasonal changes and grazing excluded sites always had higher aboveground biomass than that of free grazing during the whole seasons.

4.5. Strategies and Perceptions of Farmers towards Grazing and its Management

Out of the total respondents, the majority (81.3%) of them were male and the average age was about 38.39 years. Regarding their educational level, about 33.3% were literate, 30.7% can read and write,and the rest (36 %) were illiterate. About 81.4 of the respondents were married, 16% single, and 1.3 were divorced and widowed (Table 7). 81.3% of the respondents owned land that was used for cultivation (0.66 ha), grazing (0.1 ha), and other purposes such as eucalyptus and vegetables (0.05 ha). The primary livelihood activity of the respondents was majorly agriculture i.e. crop and livestock (85.3%), trade (6.7 %), agriculture and trade (4 %), and labor (4 %)(Table 8).

Table 7:Demographic information of respondents

Variable	Descriptive results	Proportion (%)
Total sample size (n) = 90 households		
Sex	Male	81.3
	Female	18.7
Age	Mean = 38.39 years; SE = 1.14	
Educational level	Illiterate	36.0
	Able to read and write	30.7
	Elementary	29.3
	High school and above	4.0
Marital status	Married	81.4
	Single	16.0
	Divorced	1.3
	Widowed	1.3

Table 8: Socio-economic information of respondents

Variable	Descriptive statistics	Proportion (%)
Land ownership	Yes	81.3
	No	18.7
Land used for cultivation (ha)	Mean = 0.66 ha; SE = 0.05	
Land used for grazing (ha)	Mean = 0.10 ha; SE= 0.02	
Land used for other purposes (ha)	Mean = 0.05 ha; SE = 0.02	
Livelihood	Agriculture (crop and livestock)	85.3
	Trade	6.7
	Agriculture and trade	4.0
	Labor	4.0

In the study area, grazing lands were mainly freely open communal (53.3%). Private grazing landholdings accounted for about 34.7% and restricted communal grazing lands about 12%. During the grass biomass collection, it was possible to confirm, with an informal interview, that some part of the grazing lands, in the treated part of the watershed, was not allowed for grazing during selected seasons of the year. Twelve percent of the respondents also confirmed that there is an informal village rule to stop or reduce free grazing which is moderately (55.5%) applicable at some parts and inapplicable (44.4%) at other parts (Table9).

Though most (54.6 %) respondents highly practice free grazing, all year round even without any resting season (38.6%), some practice different grazing land management strategies (45.4%). The mean daily grazing hour was 7.38 hrs. Most of the respondents practice seasonal grazing (25.4 %). The seasons by which the land is relived from grazing are winter (21.3 %), spring (12%), summer (10.7 %), both autumn and winter (14.7%), and autumn (2.7 %) (Figure 4). The respondents also practice rotational grazing (10.7 %) and selective species (9.3 %) grazing as grazing land management strategies (Table 9). The rotational grazing practiced in the area lacks fencing of the land and dividing it into smaller paddocks and regular intervals during which animals will be rotated. Most of the farmers apply this practice to protect their lands (in private grazing lands), to abide by the village rules (in restricted yet communal lands), and to improve grass productivity and save hay for feed shortage seasons. They simply practice this management system as a traditional trend without understanding its benefit on animal production, animal health benefits, and other environmental benefits.

Regarding the factors that affect the practice of grazing land management in the area, 25.3% of the respondents replied land tenure, 24%lack of awareness, 18.7% educational level, 10.7% unavailability of agricultural experts, and 21.3% didn’t know the factors affecting grazing land management (Table 9). Similar to this (Haymanot, 2018) distinguished the factors affecting grazing land management practices as physical (such as topography, landforms, and land tenure), socio-economic conditions (such as educational level, livestock holding size, and farm size), and institutional factors (such as access to extension services and access to persistence information). Furthermore, (Agidew & Singh, 2019) classified the factors influencing land management practices as farmers’ characteristics, technology characteristics, farmers’ resources, and policy and institutional environment.

The respondents were asked whether free grazing imposes a negative impact and 17.3% said it has a negligible impact, 28 % moderate, 36% severe and 18.7 % said it has no adverse impacts. Regarding the effects that free grazing have on soil erosion, 48 % implied it directly contributes to soil erosion, 17.3% saidindirect effect, 16% implied that free grazing and soil erosion are unrelated while the remaining 18.7% don't know the relationship between free grazing and soil erosion. Respondents were asked about their attitude on the phrases "free grazing has an effect on the destruction of SWC structures" and "free grazing affects grass productivity" and 49.3% agreed, 24% disagreed, 12% believed that they are unrelated and 14.7% doesn't know the effect of free grazing on SWC structures. On the second phrase 64% of the respondents agreed, 18.7% disagreed and 17.3% doesn't know whether free grazing affects the productivity of grasses (Table 9).

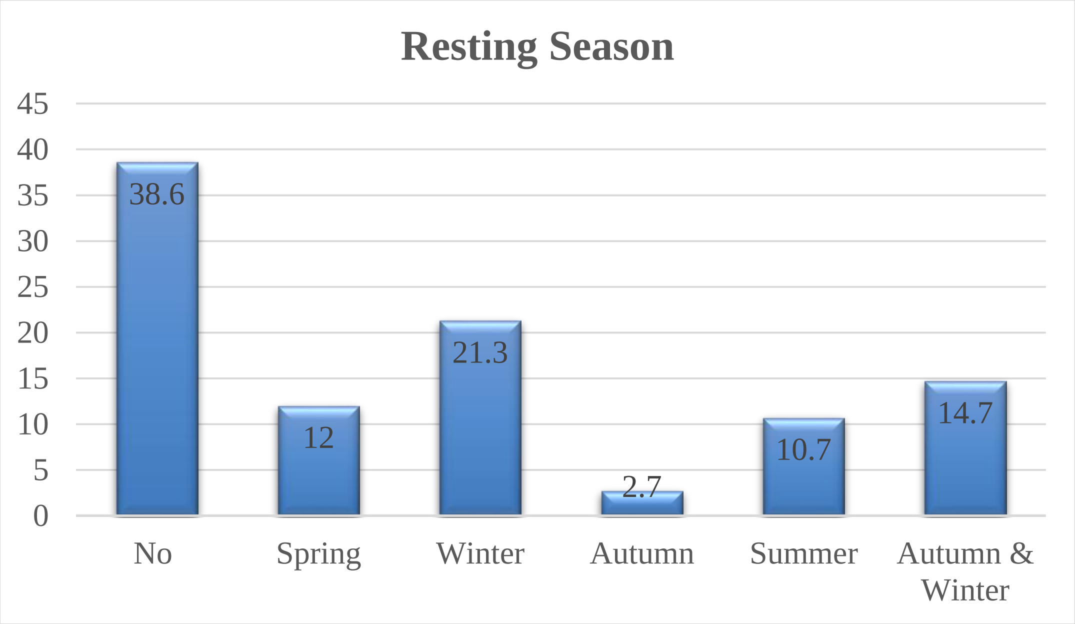

Figure 4: Resting season of lands from grazing

Table 9:Perceptions of farmers towards grazing and its management

Variable	Descriptive statistics	Proportions (%)
Practice of GLM	Free grazing	54.6
	GLM	45.4
Type of GLM	Rotational grazing	10.7
	Seasonal grazing	25.4
	Selective species	9.3
Factors affecting GLM	Lack of awareness	24.0
	Land tenure	25.3
	Educational level	18.7
	Unavailability of agricultural experts	10.7
	I don’t know	21.3
Impact of FG	No	18.7
	Negligible	17.3
	Moderate	28.0
	Severe	36.0
Effect of FG on soil erosion	Direct	48.0
	Indirect	17.3
	I don’t know	18.7
	Unrelated	16.0
FG has effect on SWC structures destruction	I agree	49.3
	I disagree	24.0
	I don’t know	14.7
	Unrelated	12.0
FG affects grass productivity	I agree	64.0
	I disagree	18.7
	I don’t know	17.3

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

The study aimed to study the effects of grazing exclusions and soil and water conservation measures on grass biomass production and selected soil properties using adjacent free grazing sites as a control. Grazing exclusion significantly influenced the selected physical properties, i.e. bulk density, silt ($p < 0.001$), sand ($p < 0.01$), except for clay. There was lower bulk density and sand fraction in the grazing excluded sites than the open grazing sites. Regarding the chemical properties, Ca^{2+}, Mg^{2+}, Na^{+}, available phosphorus and soil organic carbon showed a significant difference ($p < 0.05$) as a result of the effect of grazing exclusions. Moreover, Soil organic matter ($p < 0.05$) and total nitrogen ($p < 0.01$) significantly increased due to the effects of grazing exclusions. Grazing exclusion did not affect the values of EC, pH, $K^{+,}$ and CEC.

Grazing exclusion increases the vegetation height and canopy cover, which can reduce evaporation and improve soil water conditions. The results showed that the aboveground grass biomass significantly ($p < 0.001$) increased due to the effects of grazing exclusion. It also showed significant increase ($p < 0.05$) in the seasonal values of aboveground grass biomass yield. The grazing system in the study area greatly varies by season. At the time when most arable lands were covered by crops, livestock graze on farm strips, and steep hillsides, resulting in soil disturbance and trampling effect on the hillsides, which in turn contributes to soil erosion.

In the central highlands of Ethiopia, most of the grazing lands are freely open communal. In freely open communal grazing lands, each userof the resource enjoys the full benefit but bears only a fractional part of the direct cost. As a result the uncontrolled free grazing system in these lands results in severe degradation. This is also true in the study area that had 53.3% freely open communal grazing lands. In the study area, after crop harvesting period, fallow and cultivated lands are considered grazing lands without any restrictions. Thus livestock freely graze on these lands until the next tillage season. Due to the fact that these lands are communal, lesser sense of ownership and belongingness results in exploitation and reduction in the productive potential of these lands.

Although there are restricted grazing lands (12%) in the other part of the watershed i.e. treated with SWC measures, the village rules to reduce or stop free grazing are rarely applicable (44.4%). Despite the respondents understanding on the adverse effects of free grazing on grass productivity (64%), SWC destructions (49.3%) and the direct relationship between free grazing and soil erosion (48%); land tenure (25.3%), lack of awareness (24%), educational level (18.7%) and unavailability of agricultural experts (10.7%) hinders grazing land management strategies from being effectively implemented.

The free and uncontrolled grazing system in the area results in the depletion of palatable species and invasion by less palatable or unpalatable ones. Moreover, grazing on cropland contributes to soil compaction and the need for frequent tillage to prepare fields for crops, making practices such as reduced tillage less feasible.In addition to its contribution to the degradation of grazing lands, the grazing system has negative effects on the soil and water conservation efforts. It damages the physical conservation structures such as stone terraces and soil bunds and biological conservation practices such as grass strips and tree plantations through the trampling effect of freely roaming animals.

Both grazing elimination and grazing intensification reduces grass biomass production. Since, grazing is not an all damaging process; it should be accompanied with grazing management strategies so as to protect the degradation of both soil and vegetation. It is noted that continuous and moderate grazing promotes grass a grass biomass increase, without major undesired changes in species composition or the grass-shrub ratio, and have remarkable impact through its effect on plant populations and community composition, energy flow, nutrient cycling, landscape-level heterogeneity, and movement of materials.

Effects of grazing exclusion on soil physicochemical properties and grass biomass production, on different studies revealed inconsistent results which could be attributed to grazing intensity, duration of exclosures, vegetation community composition, as well as edaphic and climatic conditions.Whether grazing intensity exceeds the carrying capacity of a site, different climatic and agro-ecological conditions, grazing seasonality and intensity, socio-economic conditions and land tenure policy must all be taken into consideration before planning any grazing land management strategies.

5.2. Recommendations

- Grazing exclusion with soil and water conservation practices greatly improve the vegetation and soil characteristics and must be adopted jointly for effective outcomes.
- The results of the present study found insignificant results in the values of soil chemical properties (EC, pH, K^+, CEC and C: N) which could be due to the age of grazing exclusion. Thus further studies should consider a longer age of exclosures for reliable results.
- The present study didn't consider the soil conditions prior to grazing exclusions.Thus future studies should take this into consideration.
- In the study area, the animal dung in the grazing lands is washed away by runoff during rainfall. Further studies should focus on ways how the collection and recycling of manure can be achieved through precise manure management plan.

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7. APPENDIXES

Table 1: Aboveground biomass collection periods

Sampling seasons	Initial sampling	Early growing season	Optimum vegetative state	End of rainy season
GE- no SWC	September2, 2019	November 25, 2019	July 4, 2020	September 24, 2020
FG- no SWC	September 4, 2019	November 28, 2019	July 5, 2020	September 26, 2020
GE- SWC	September 8, 2019	November 30, 2019	July 7, 2020	September 28, 2020
FG- SWC	September 10, 2019	December 2, 2019	July 9, 2020	September 29, 2020

Table 2: Two-way ANOVA for soil chemical properties

Soil parameters	Source of variation	Df	Sum of squares	Mean square	R- Square	F-value	p-value
Bulk density	Model	7	0.042	0.007	0.65	5.34	0.0029

	Error	16	0.022	0.0013			
Sand	Model	7	1361.17	194.45	0.58	3.10	0.0288
	Error	16	1002.67	62.67			
Silt	Model	7	1428.67	204.09	0.71	5.57	0.0022
	Error	16	586.67	36.67			
Clay	Model	7	165.167	23.59	0.23	0.70	0.6741
	Error	16	541.33	33.83			

Table 3: Two-way ANOVA for soil chemical properties

Soil parameters	Source of variation	Df	Sum of squares	Mean square	R- Square	F-value	p-value
pH	Model	7	0.54	0.077	0.36	1.30	0.3126
	Error	16	0.954	0.059			
EC	Model	7	0.002	0.00029	0.38	1.39	0.2755
	Error	16	0.003	0.000209			
SOM	Model	7	16.11	2.3014	0.54	2.66	0.0501
	Error	16	13.87	0.867			
SOC	Model	7	5.42	0.77	0.54	2.66	0.0501
	Error	16	4.66	0.29			
TN	Model	7	0.03	0.004	0.57	3.06	0.0302
	Error	16	0.021	0.0014			
C: N	Model	7	15.49	2.21	0.09	0.23	0.97226
	Error	16	154.68	9.67			
Av. P	Model	7	70.44	10.06	0.49	2.18	0.0932
	Error	16	73.85	4.615			
CEC	Model	7	289.08	41.29	0.18	0.51	0.8170
	Error	16	1306.66	81.66			

Ca^{2+}	Model	7	363.72	51.959	0.55	2.77	0.0433
	Error	16	300.12	18.75			
Mg^{2+}	Model	7	445.14	63.59	0.50	2.30	0.0798
	Error	16	442.95	27.68			
Na^{+}	Model	7	0.055	0.0079	0.53	2.56	0.0565
	Error	16	0.049	0.0031			
K^{+}	Model	7	0.124	0.018	0.38	1.40	0.2713
	Error	16	0.202	0.013			

Table 4: Rating of soil parameters

Soilparameters	Very low	Low	Moderate	High	Very high	Sources
SOM (%)	0-0.4	0.4-1	1-1.8	1.8-3	> 3	Charman and Roper, (2007)
SOC (%)	< 0.5	0.5-1.5	1.5-3.0	> 3.0	-	Tekalign, (1991)
TN (%)	0-0.1	0.1-0.2	0.2-0.5	0.5-1	> 1	Landon, (1991)
CEC (cmol$_{(+)}$/kg)	0-6	6-12	12-25	25-40	>40	Hazelton and Murphy, (2007)
Soil BD (g/cm^3)	< 1	1-1.3	1.3-1.6	1.6-1.9	> 1.9	

Survey Questionnaire for Households Interview

The sole purpose of this questionnaire is to gather information for the research entitled "Effect of grazing exclusions on grass biomass production and selected soil properties in central highlands of Ethiopia: Implications for soil and water conservation" and the responses that you will provide will be used for academic purposes and will be kept confidential.

Date: ____________

Respondent ID: ____________

Village: ____________

I. Demographic Information

1. Sex
    a. Male
    b. Female
2. Age
    a. 18- 30
    b. 31- 40
    c. 41- 50
    d. > 50
3. Educational level
    a. Illiterate
    b. Able to read and write
    c. Elementary
    d. High school and above
4. Marital status
    a. Widowed
    b. Divorced
    c. Married
    d. Single
5. Family size
    a. Two
    b. Three
    c. Four
    d. Five and above

II. Socio-economic Information

a. Are you a household head?

a. Yes
b. No

1. If No, what is your relation to the household head?

____

2. For how long did you stayed in this Kebele?
   - a. 5 – 10 years
   - b. 10 – 15 years
   - c. 15 – 20 years
   - d. > 20
3. Do you own a land (as a household)?
   - b. Yes
   - c. No
4. If yes, what is the land used for?
   - a. Cultivated land (how much)
   - b. Grazing land (how much)
   - c. Other (specify) ________________
5. What is the primary livelihood activity of your household?
   - a. Agriculture
   - b. Livestock
   - c. Wage labor
   - d. Other (specify) ________________
6. How many animals do you have?
   - a. Cow, Ox
   - b. Horse, Donkey, Mule
   - c. Sheep, Goat

III. Strategies and Perceptions of Farmers Towards grazing and its Management

1. In your area, are grazing lands,
   - a. Freely open communal
   - b. Restricted communal
   - c. Private holding
   - d. Other
2. If you choose "b", who manages the communal grazing lands?
   - a. Local community
   - b. Kebele administration
   - c. District municipality
   - d. Other
3. What is the daily grazing hour, on average?

   ____

4. Is there any resting season by which the land is relived from grazing?
   - a. Yes (specify)
   - b. No
5. Is there any grazing land management strategy practiced in the area? Or is it just freely grazed?
   - a. Grazing land management
   - b. Free grazing
6. What kind of grazing land management strategy do you practice?
   - a. Rotational grazing
   - b. Grazing exclusions

   c. Seasonal grazing
   d. Other

7. What factors affect grazing land management?
   a. Land tenure policy
   b. Educational level
   c. Lack of awareness
   d. Other
8. Do you think free grazing have negative impacts?
   a. Yes
   b. No
9. If yes, how do you explain the impacts?
   a. Severe
   b. Moderate
   c. Negligible
10. Is there any community rule by which you agreed up on to reduce or stop free grazing?
    a. Yes
    b. No
11. If yes, is it applicable?
    a. Highly applicable
    b. Moderately applicable
    c. Inapplicable
12. Free grazing has effect on soil erosion.
    a. Direct
    b. Indirect
    c. Unrelated
    d. I don’t know
13. Free grazing has effect on soil and water structures destruction.
    a. I agree
    b. Unrelated
    c. I disagree
    d. I don’t know
14. Free grazing has effect on productivity of grasses in the grazing area.
    a. I agree
    b. Unrelated
    c. I disagree
    d. I don’t know

Thank you in advance for your cooperation!!!

The ANOVA Procedure

Dependent Variable: EC

```
                              Sum of
Source             DF        Squares        Mean Square     F Value    Pr > F

Model               7     0.00232917        0.00033274        1.63       0.1977

Error              16     0.00326667        0.00020417

Corrected Total    23     0.00559583


          R-Square    Coeff Var     Root MSE     EC Mean

          0.416232    16.25254      0.014289     0.087917


Source             DF       Anova SS    Mean Square    F Value    Pr > F

DEPTH               1     0.00070417     0.00070417       3.45    0.0818
LU type             3     0.00104583     0.00034861       1.71    0.2056
DEPTH*LU type       3     0.00057917     0.00019306       0.95    0.4419
```

Dependent Variable: pH

```
                              Sum of
Source             DF        Squares     Mean Square     F Value    Pr > F

Model               7     0.54205000     0.07743571       1.30    0.3126

Error              16     0.95453333     0.05965833

Corrected Total    23     1.49658333


          R-Square    Coeff Var     Root MSE     pH Mean

          0.362192    3.916887      0.244251     6.235833

Source             DF       Anova SS    Mean Square    F Value    Pr > F

DEPTH               1     0.05226667     0.05226667       0.88    0.3632
LU type             3     0.48468333     0.16156111       2.71    0.0798
DEPTH*LU type       3     0.00510000     0.00170000       0.03    0.9933
```

Dependent Variable:Ca

```
                              Sum of
Source               DF      Squares     Mean Square    F Value   Pr > F

Model                 7   363.7183333    51.9597619       2.77    0.0433

Error                16   300.1150000    18.7571875

Corrected Total      23   663.8333333


          R-Square    Coeff Var     Root MSE     _Ca Mean

          0.547906     18.16550     4.330957     23.84167


Source               DF      Anova SS     Mean Square   F Value   Pr > F

DEPTH                 1    50.4600000     50.4600000      2.69    0.1205
LU type               3   292.7541667     97.5847222      5.20    0.0107
DEPTH*LU type         3    20.5041667      6.8347222      0.36    0.7796
```

Dependent Variable: Na

```
                              Sum of
Source               DF      Squares     Mean Square   F Value   Pr > F

Model                 7    0.05652917    0.00807560      2.55    0.0576

Error                16    0.05073333    0.00317083

Corrected Total      23    0.10726250


          R-Square    Coeff Var     Root MSE     _Na Mean

          0.527017     22.63725     0.056310     0.248750


Source               DF      Anova SS     Mean Square   F Value   Pr > F

DEPTH                 1    0.00003750     0.00003750     0.01    0.9148
LU type               3    0.04714583     0.01571528     4.96    0.0128
DEPTH*LU type         3    0.00934583     0.00311528     0.98    0.4257
```

Dependent Variable: Mg

```
                                   Sum of
Source                  DF        Squares     Mean Square    F Value    Pr > F

Model                    7     445.1400000     63.5914286       2.30    0.0798

Error                   16     442.9483333     27.6842708

Corrected Total         23     888.0883333


              R-Square     Coeff Var      Root MSE      Mg Mean

              0.501234      44.55823      5.261584     11.80833


Source                  DF       Anova SS     Mean Square    F Value    Pr > F

DEPTH                    1      6.5104167       6.5104167       0.24    0.6343
LU type                  3    399.4608333     133.1536111       4.81    0.0142
DEPTH*LU type            3     39.1687500      13.0562500       0.47    0.7063
```

Dependent Variable: K

```
                                   Sum of
Source                  DF        Squares     Mean Square    F Value    Pr > F

Model                    7      0.12679583     0.01811369       1.45    0.2538

Error                   16      0.20000000     0.01250000

Corrected Total         23      0.32679583



              R-Square     Coeff Var      Root MSE       K Mean

              0.387997      24.73071      0.111803     0.452083


Source                  DF       Anova SS     Mean Square    F Value    Pr > F

DEPTH                    1     0.04420417      0.04420417       3.54    0.0784
LU type                  3     0.07414583      0.02471528       1.98    0.1581
DEPTH*LU type            3     0.00844583      0.00281528       0.23    0.8775
```

Dependent Variable: P

```
                               Sum of
Source                DF       Squares     Mean Square    F Value    Pr > F

Model                  7     70.3748000     10.0535429       2.18    0.0935

Error                 16     73.8450000      4.6153125

Corrected Total       23    144.2198000


           R-Square     Coeff Var      Root MSE       P Mean

           0.487969      38.84860      2.148328     5.530000


Source                DF       Anova SS     Mean Square    F Value    Pr > F

DEPTH                  1     0.00041667     0.00041667       0.00    0.9925
LU type                3    64.70123333    21.56707778       4.67    0.0158
DEPTH*LU type          3     5.67315000     1.89105000       0.41    0.7482
```

Dependent Variable: TN

```
                               Sum of
Source                DF       Squares     Mean Square    F Value    Pr > F

Model                  7     0.02791496     0.00398785       3.04    0.0310

Error                 16     0.02098867     0.00131179

Corrected Total            23     0.04890363


           R-Square     Coeff Var      Root MSE      TN Mean

           0.570816      31.32425      0.036219     0.115625


Source                DF       Anova SS     Mean Square    F Value    Pr > F

DEPTH                  1     0.00555104     0.00555104       4.23    0.0564
LU type                3     0.02173779     0.00724593       5.52    0.0085
DEPTH*LU type          3     0.00062612     0.00020871       0.16    0.9223
```

Dependent Variable: SOC

```
                                  Sum of
Source                  DF       Squares     Mean Square    F Value    Pr > F

Model                    7     5.42578333     0.77511190       2.66    0.0499

Error                   16     4.66386667     0.29149167

Corrected Total         23    10.08965000


             R-Square     Coeff Var      Root MSE      SOC Mean

             0.537757      37.68933      0.539900      1.432500


Source                  DF       Anova SS     Mean Square    F Value    Pr > F

DEPTH                    1     1.83706667     1.83706667       6.30    0.0232
LU type                  3     3.52021667     1.17340556       4.03    0.0260
DEPTH*LU type            3     0.06850000     0.02283333       0.08    0.9708
```

Dependent Variable: SOM

```
                                  Sum of
Source                  DF       Squares     Mean Square    F Value    Pr > F

Model                    7    16.12002917     2.30286131       2.66    0.0497

Error                   16    13.84186667     0.86511667

Corrected Total         23    29.96189583


             R-Square     Coeff Var      Root MSE       OM Mean

             0.538018      37.66289      0.930116      2.469583


Source                  DF       Anova SS     Mean Square    F Value    Pr > F

DEPTH                    1     5.44353750     5.44353750       6.29    0.0233
LU type                  3    10.46794583     3.48931528       4.03    0.0259
DEPTH*LU type            3     0.20854583     0.06951528       0.08    0.9697
```

Dependent Variable: C: N

```
                                 Sum of
Source               DF         Squares     Mean Square    F Value    Pr > F

Model                 7      15.5071292       2.2153042       0.23    0.9721

Error                16     154.6739333       9.6671208

Corrected Total      23     170.1810625


          R-Square     Coeff Var      Root MSE     C__N Mean

          0.091121      25.03129      3.109199      12.42125


Source               DF       Anova SS     Mean Square    F Value    Pr > F

DEPTH                 1     8.50850417      8.50850417       0.88    0.3621
LU type               3     4.68104583      1.56034861       0.16    0.9207
DEPTH*LU type           3      2.31757917      0.77252639       0.08    0.9700
```

Dependent Variable: CEC

```
                                 Sum of
Source               DF         Squares     Mean Square    F Value    Pr > F

Model                 7      289.081850       41.297407       0.51    0.8170

Error                16     1306.659200       81.666200

Corrected Total      23     1595.741050


          R-Square     Coeff Var      Root MSE      CEC Mean

          0.181158      25.41499      9.036935      35.55750


Source               DF       Anova SS     Mean Square    F Value    Pr > F

DEPTH                 1     71.3460167      71.3460167       0.87    0.3638
LU type               3     55.9591167      18.6530389       0.23    0.8752
DEPTH*LU type         3    161.7767167      53.9255722       0.66    0.5883
```

Dependent Variable: BD

```
                                  Sum of
Source                DF         Squares     Mean Square    F Value    Pr > F

Model                  7      1.52460000      0.21780000       5.68    0.0020

Error                 16      0.61373333      0.03835833

Corrected Total       23      2.13833333


              R-Square     Coeff Var      Root MSE       BD Mean

              0.712985      7.870844      0.195853      2.488333


Source                DF        Anova SS     Mean Square    F Value    Pr > F

DEPTH                  1      0.21281667      0.21281667       5.55    0.0316
LU type                3      1.27346667      0.42448889      11.07    0.0004
DEPTH*LU type          3      0.03831667      0.01277222       0.33    0.8017
```

Dependent Variable: Sand

```
                                  Sum of
Source                DF         Squares     Mean Square    F Value    Pr > F

Model                  7     1361.166667      194.452381       3.10    0.0288

Error                 16     1002.666667       62.666667

Corrected Total       23     2363.833333


              R-Square     Coeff Var      Root MSE    _Sand Mean

              0.575830      22.89030      7.916228      34.58333


Source                DF        Anova SS     Mean Square    F Value    Pr > F

DEPTH                  1       37.500000       37.500000       0.60    0.4505
LU type                3     1209.833333      403.277778       6.44    0.0046
DEPTH*LU type          3      113.833333       37.944444       0.61    0.6209
```

Dependent Variable: Silt

```
                          Sum of
Source            DF        Squares    Mean Square   F Value   Pr > F

Model              7    1428.666667     204.095238      5.57   0.0022

Error             16     586.666667      36.666667

Corrected Total        23    2015.333333


            R-Square    Coeff Var     Root MSE    Silt Mean

            0.708898     19.42877     6.055301     31.16667


Source            DF       Anova SS    Mean Square   F Value   Pr > F

DEPTH              1       6.000000       6.000000      0.16   0.6912
LU type            3    1356.666667     452.222222     12.33   0.0002
DEPTH*LU type      3      66.000000      22.000000      0.60   0.6243
```

Dependent Variable: _Clay

```
                              Sum of
Source            DF        Squares    Mean Square   F Value   Pr > F

Model              7    165.1666667     23.5952381      0.70   0.6741

Error             16    541.3333333     33.8333333

Corrected Total   23    706.5000000


            R-Square    Coeff Var     Root MSE    _Clay Mean

            0.233782     16.98290     5.816643     34.25000


Source            DF       Anova SS    Mean Square   F Value   Pr > F

DEPTH              1    73.50000000    73.50000000      2.17   0.1599
LU type            3    69.83333333    23.27777778      0.69   0.5724
DEPTH*LU type      3    21.83333333     7.27777778      0.22   0.8845
```