EFFECT OF LAND MANAGEMENT PRACTICES IN THE LOWLANDS ON GRASS PRODUCTIVITY AND SOIL PROPERTIES IN THE RANGELANDS OF LESOTHO

BY

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DECLARATION

I, **Motlatsi Stephen Ramochela**, hereby declare that this work presented in this thesis is my own original research, and has not been previously submitted to any other University or similar Institution for the award of any Degree or Certificate. Also all sources of information have been duly referenced.

Signature: .....Dat**e:** ……

DEDICATION

This thesis is dedicated to God who made everything possible. Also to my wife; Mrs `Mamahlape Ramochela, my parents; Mr Motoai Ramochela and Mrs Mamochela Ramochela (late), and my siblings, for their unwavering support and encouragement throughout my academic studies.

THESIS APPROVAL

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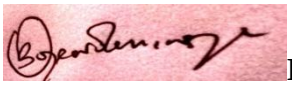
External Examiner:  **Date**: 2-11-2024

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ABSTRACT

The study was conducted at Mahloenyeng rangeland, Matsieng, Maseru, Lesotho, to determine the effect of land management practices on grass productivity and soil properties in the lowland rangeland. The experiment had two treatment sites; rangeland fire and stone gabions, and three control sites which are the north-facing slope, the south-facing slope, and a riparian area, each with three replications. The indices determined were ecological data (vegetation characteristics), nutrient content, soil properties, and grass seed production. Grass cover, diversity, density, and frequency were measured using line transect and the point method. The Nitrogen-Isotope Ratio method was used to evaluate crude protein, the analysis of dietary fibre method was used to determine neutral detergent fibre, and the forage fibre analysis was used to determine acid detergent fibre and acid detergent lignin. The soil pH was determined using 1:2 (w/v) ratio, soil organic matter was determined using the Walkey-black method, and soil phosphorus was determined using Bray and Kurtz 1 (1980) method. Soil nitrogen was determined using the Kjeldahl method and soil potassium was calculated using the slope. The grass seed weight was determined using an electronic scale. This study found that rangeland fire and stone gabions had significant ($p<0.05$) effect on vegetation characteristics in rangeland sites in autumn and winter seasons and with no significant ($p>0.05$) differences amongst grass species. Rangeland fire and stone gabion sites had significant ($p<0.05$) effect on forage nutrient content namely neutral detergent fibre, acid detergent fibre, acid detergent lignin, crude protein, cellulose, hemicellulose, and ash content but not on dry matter ($p>0.05$) in autumn and winter seasons. Rangeland fire and stone gabions significantly ($p<0.05$) affected soil properties namely soil pH, soil organic matter, soil nitrogen, soil phosphorus, and soil potassium, in both seasons and likewise on seed production ($p<0.05$) in autumn and winter. The correlation of vegetation indices in autumn and winter seasons had significant ($p<0.05$) effect. Therefore, the vegetation characteristics of grass cover in rangelands must be understood for the sustainable use of grass cover for long term use of rangelands and the development of long-term range management strategies which can govern grazing length, carrying capacity, and distribution of animals in a rangeland should be investigated.

Key words: Rangeland sites, vegetation characteristics, soil properties, nutrient content, seed production

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The Mountain Kingdom of Lesotho is projected to be 30,355 km^2 in total area, and the rangelands cover about 60% of the country's total area. The country is divided into four agro-ecological zones, which are the Lowlands which have altitude ranges of 1400m to 1800m, the Foothills with altitudes of 1800m to 2000m, the Senqu River Valley with altitudes of 1400m to 1800m and the Mountainous areas occurring at an elevation of 2000m to 3400m (Lesotho Meteorological Services, 1999). The climate of Lesotho is moderate with hot summers and cold winters with maximum and minimum temperatures ranging from 10.9°C to 27°C in summer, and average minimum temperatures ranging from 0.1°C to 17.3°C in winter (Lesotho Meteorological Services, 2013).

Rangelands, comprising natural grasslands, scrublands, woodlands, wetlands, and (semi-) deserts are predominant form of ice-free land protection found worldwide (Alkemade *et al*., 2013; Godde *et al*., 2020; Reid *et al*., 2014). These areas, defined by the dominance of grasses and less than 10% trees or shrubs, contribute significantly to global land use, covering an estimated aerial range of 18 to 80% and play a key role in providing ecological, social, and economic services worldwide (Sala *et al*., 2017). Grass, a vital nutrient source for domesticated ruminants for a greater part of the year plays essential role in these landscapes (Taweel *et al*., 2005). Livestock grazing is one of the means of utilizing rangelands, predominantly in communal and/or pastoral areas, thus emphasizing the pivotal role that rangelands play in Lesotho (Lesilo *et al.*, 2013). Grasslands are a source of goods and ecosystem services and millions of people depend on these grasslands since they are an essential feed source for their livestock thereby contributing to their livelihoods and food safety (Lemaire *et al*., 2011). Furthermore, rangelands provide significant benefits to societies through establishment of essential ecosystem services that include regulation of climate, water, livestock fodder and other indigenous products such as timber and firewood (Godde *et al*., 2020). Also, rangelands provide important ecosystem services such as flood control, carbon sequestration, biodiversity, and wildlife habitats (Hartman *et al*., 2016). The relative importance of ecosystem goods and services in communal rangeland systems is determined by the interests of a range of different stake-holders at the national level, policymakers in the public sector and at the local level and the community levels who are land stewards (Briske *et al*., 2020). Livestock productivity in

Lesotho depend basically on the rangeland forage quality, and quantity available for animal consumption, contributing significantly to the livelihoods of rural communities through provision of meat, milk, draught power and transport (Department of Range Resources Management, 2014). Rangelands globally are known to host rare and endemic plant species vital for various threatened bird species, supporting a healthy population of birds identified as species of conservation concern (BirdLife International, 2020; Grieve and Downs, 2015).

In Southern African region, livestock is a major sector of the agricultural economy, though, more than 60% of the total land area in this region is not suitable for crop production (Dzama, 2016). Therefore, sustainable use of semi-arid rangelands depends on the complex management of animal species, stocking rates, and the vegetation composition, structure, phenology, and quality of rangelands. Whether publicly or privately owned, effective supervision of rangeland watersheds becomes increasingly crucial towards enhancement of the availability of clean water for irrigation, industrial use, and recreational purposes. In Lesotho, livestock production is experiencing some measure of growth and thereby contributing to income generation, employment creation, mitigating food insecurity in addition to providing organic fertilizers and draught power. However, the majority of rangelands in Lesotho are degraded, mostly due to poor farming practices (Schmitz and Rooyani, 1987), which have facilitated plant invasions (both native and alien) (Rahlao *et al.*, 2023). Meanwhile, plant invasions compromise the ability of rangelands to support livestock and wildlife in Lesotho (van Wilgen *et al*., 2020). Due to the broad challenges facing the rangelands in the country, it employs for the management of the rangelands through construction of gabion structures, fire management and the ecological sites which was the main aim of the study. The rehabilitation or restoration of rangelands is essential for maintaining ecosystem function, providing ecosystem services and promoting biodiversity.

1.2 Problem Statement

In Lesotho, rangelands, like all other ecosystems, play a crucial role by providing essential goods and services for environmental functionality. Nevertheless, periods of drought, characterized by a lack of precipitation leading to reduced soil water content, contribute to the mortality of certain grass species in the rangelands. This, in turn, diminishes the diversity and productivity of grasses on the rangelands. Moreover, soil degradation amplifies rainfall variability and transforms prolonged droughts into floods during the rainy seasons. The mounting grazing pressures associated with such practices jeopardize nutritious grass species.

Simultaneously, soil compaction and erosion impede the regeneration of fresh grass on the rangelands. The accelerated changes in climate, exacerbate the existing challenges, contributing to the negative impacts on the rangelands (Zhou *et al*., 2018). Anthropogenic activities, both direct, such as improper land use, and indirect, including climate change with rising temperatures, heat stress, and un-prescribed burning of rangelands, pose heightened risks of wildfires. Ineffectual grazing management, driven by high stocking rates also lead to the increased carrying capacity of the rangelands. Consequently, ongoing vegetation changes due to soil erosion, loss of biodiversity, disrupt grazing patterns, and diminish livestock productivity which fail to provide benefits to both animals and humans. These transformations may have severe repercussions on the livelihoods and food safety of the local communities.

1.3 Justification

The study is expected to highlight practices for effective rangelands management to promote a healthy ecosystem for enhanced productivity of livestock. When managed sustainably, rangeland vegetation can reduce surface flows, improving water infiltration, enhancing soil moisture, and restoring ground water resources, which contribute to reducing the risks of natural hazards such as floods and drought on the rangelands (IUCN, 2015).

1.4 Objectives

1.4.1 General Objective

To evaluate the effect of range management practices (erosion control, fire management and ecological sites) and soil properties on grass productivity in the Lowlands agro-ecological zones of Lesotho.

1.4.2 Specific Objectives

a. To determine ecological data, biomass yield, soil properties, seed production and yield of grass and forage quality of grass species in areas under erosion control with or without mechanically cleared gabions.

b. To determine ecological data, biomass yield, soil properties, seed production and yield of grass and forage quality of grass species in areas with fire management.

c. To determine ecological data, biomass yield, soil properties, seed production and yield of grass and forage quality of grass species in areas with different ecological sites (north area, south area, and riparian area).

1.5 Hypotheses

1.5.1. Null Hypothesis (N_0)

Land management practices do not have effect on herbaceous vegetation structure in the Lowland agro-ecological zones of Lesotho.

1.5.2. Alternate Hypothesis (N_1)

Land management practices do have effect on herbaceous vegetation structure in the Lowland agro-ecological zones of Lesotho.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Description of rangelands or grass

Grasslands are environments dominated by grasses and containing less than 10% trees or shrubs (Boval and Dixon, 2012). Grasslands are classified as natural and improved grasslands. Natural grasslands are dominated by naturally occurring grass species, whereas improved grasslands are generated through sowing and vegetative proliferation of certain grass species (du Toit *et al.,* 2017). Rangelands are typically characterized by low-nutrient grass species which nurture on unproductive and, more commonly, erosion-degraded soils (Facuri *et al.,* 2014; Sokupa *et al.,* 2024). With over one-third of the above and below-ground carbon stocks found in rangeland ecosystems, these ecosystems provide a variety of products and services which are crucial to the global carbon cycle (Zhao *et al.,* 2020; Peri *et al.,* 2021; Jaman *et al.,* 2022). Because it provides several ecosystem services, vegetation is essential to the riparian ecosystem (Tánago *et al.,* 2021; Ye *et al.,* 2024). Additionally, rangelands frequently serve as the boundaries for urban and agricultural growth, as well as the pressure to convert land use, which is stronger in rangelands with dense populations (Schlecht *et al.,* 2020). Furthermore, rangelands are becoming more widely acknowledged for their many contributions to the supply of ecosystem services, such as carbon sequestration (Denboba, 2022) and other beneficial provisions (Samuels *et al.,* 2023). On the rangelands, tree-grass compete for light, soil water, and nutrients which favour woody plants over grasses, in return, these trees reduce grass productivity (Hare *et al.,* 2020) and cause a decline in livestock carrying capacity (Mndela *et al*., 2022). According to Bouwman *et al.* (2005), forage accounts for 35% to 75% of the feed base in livestock production such as beef cattle and 45% to 95% in sheep and goats. As a result, using pasture legumes, other herbaceous dicotyledonous plants, and browsers frequently increases the quantity and, more importantly, nutritional quality of available fodder (Coates and Dixon, 2007). Finally, rangelands act as a habitat which consists of natural or semi-natural vegetation supporting herbivore communities (O'Connor *et al*., 2020).

2.2 Utilization of rangelands or vegetation in Lesotho

2.2.1 For animals

Rangelands are generally used to raise livestock, which produces goods with added value such as wool and mohair. Although dry-land (rain-fed) agriculture is performed in urban areas and

to a very limited extent in rural regions, communal rangeland grazing use natural grasslands for cattle grazing (Mugido and Shackleton, 2017). This forage, which includes both grasses and forbs, is crucial to the animals which serve as the main source of nutrition throughout the dry seasons (George *et al.,* 2001). In addition to producing animal products at a lower cost, grasslands are used to generate premium, specialty, and/or high-quality meals which have a higher market value than comparable goods from intensive livestock enterprises. Due to this circumstance, there is competition between livestock and wildlife that is influenced by two different sets of processes in social-ecological systems and the economy as a whole. These processes have an impact on livestock and wildlife-based small-holder farmers, which generate revenue for farmers (du Toit *et al.,* 2017). However, Seddon *et al.* (2016) contended fluctuations in the environment and an increase in human activity have an impact on grasslands' ability to support grazing animals. Large animal herds are kept by farmers because of the necessity for animal products, and causing the human population to promote the spread of cultivated areas at the expense of grassland (Kavana *et al.,* 2017). Because of this condition, there is less grassland and excessive grazing, which lowers the ability of rangeland to sustain grazing animals. Millions of people around the world depend on the production of livestock for their livelihood. This industry has a major role in generating revenue, creating jobs, and ensuring food security, mostly in Africa. It also supplies organic fertilizer and draught power, which are useful agricultural inputs (Gerber *et al.,* 2010). Ironically, by producing roughly 18% of the world's greenhouse gas emissions, cattle contributes to climate change (FAO, 2012).

2.2.2 For human beings

From large savanna rangelands, livestock production contributes significantly to the livelihoods of rural dwellers in many locations. Samuels *et al.* (2023), provides the foundation for the distribution of environmental advantages to humans. Dry land supports livelihoods by providing vital ecosystem services such as food for livestock and wildlife (Mangani *et al.,* 2022). Apart from saleable animal products like as milk, skin, and hides, grasslands provide a range of social and economic commodities, as well as cultural services, which are key components of the agricultural economy (Thornton and Herrero, 2010). Contributions of grazing livestock systems include a) the provision of household safety and the ability to deal with seasonal fluctuations such as crop failure and other disasters b) the transportation of goods and people, as well as a workforce for numerous agricultural activities c) the contribution to soil fertility and crop harvests while contributing to the recycling of by-products and waste reduction and d) the provision of fuel as manure and biogas. In developing nations, numerous

rural poor people rely heavily on livestock for protection and safety, and this function is often more significant than livestock as a commercial enterprise. Such functions need be addressed when making policy decisions affecting poor people's livelihoods (Boval and Dixon, 2012). Furthermore, one important goal for improving productivity and reducing the negative effects of livestock use of grassland resources is that livestock products are among the scarce commodities extensively produced by smallholder farmers and have a rapidly growing global demand (Delgado *et al.*, 2008; Boval and Dixon 2012). There is thus an opportunity to alleviate poverty.

2.2.3 For medicinal purposes

Africa is equipped with a diverse variety of indigenous plants which play an important role in supporting the livelihoods of various communities (Okole, 2004). Some of these plants are utilized as traditional medicine, cosmetics, flavorants, and ornaments, while a tiny percentage are used in the food and pharmaceutical industries. Meanwhile, vegetation is valued for its medicinal properties, feed for cattle grazing, recreation, and landscaping. Medicinal plants are a major source of curative and preventive medical therapeutic preparations for humans, and are utilized to extract key bioactive components (Mbuni *et al.*, 2020). This is because traditional medicines are less expensive than modern pharmaceuticals and probably, the only natural therapies available and accessible in isolated rural communities in underdeveloped nations (Popović *et al.*, 2016). According to Seleteng-Kose *et al.* (2023), Lesotho has a rich indigenous flora, with 2096 species representing 674 genera and 172 families documented. Grasslands also produce honey (since bees live in these biomes) and are used for game hunting and extracting medicinal plants and fruits. Plant roots are preferred over other plant parts because they are traditionally thought to have a greater medicinal strength and readily available throughout the year (Nankaya *et al.*, 2020), while plant leaves are also widely used because they are easily obtained in large quantities. Furthermore, the majority of traditional healers prefer to employ leaves since they are thought to contain active substances via photosynthetic pigments such as alkaloids and tannins (Fortini *et al.*, 2016). Plants contain essential bioactive elements such as glycosides, acids, saponins, tannins, terpenoids, and alkaloids which have therapeutic properties. Rangelands comprise of high-value curative plants as well as genetic resource reserves, such as local livestock breeds which have been selected to be highly adapted to ecological, socio-cultural, and management requirements. These native breeds are well-adapted to the highly changing environment, capable of walking great distances, resisting

illnesses, and withstanding drought. As a result, rangelands are essential for genetic pools and phenotypic variation.

2.2.4 For soils

Livestock has a significant impact on soil properties through trampling, which increases the bulkiness of the grasses (Rapti *et al.,* 2016). As a result, proper rangeland management is regarded as critical in the maintenance of food sources, sustaining forage productivity, improving soil infiltration, and reducing erosion. In rangelands, bush clearing is crucial for the modification of microclimate increasing soil water and nutrient availability for shade-intolerant bunch grasses (Stephens *et al*., 2016) and increasing forage production (Hare *et al*., 2021). However, the rangeland productivity loss in communal areas may be linked to continuous grazing and uncontrolled rangeland fires (Rutherford and Powrie, 2013). Soil is the major terrestrial carbon and nitrogen storage, capable of storing three times as much as the atmosphere (Stuart *et al.,* 2009), mostly in the form of decomposed plant litter and residues (Yusuf *et al.,* 2015). Soil microbial communities in hilly settings are critical for soil development and important elemental cycles which influence plant establishment, growth, and survival (Ardley and Sprent, 2021; Eid *et al.,* 2021). Changes in soil microbial communities may lead to important changes in carbon and nitrogen cycling in plant-soil systems (Mareque *et al.,* 2018).

2.3 Impact of climate change on rangelands or grass

Lesotho is susceptible to climate change and the most significantly hazardous, drought, high temperatures and heat waves, floods, hail, and frost. Grassland ecosystems play key role in the global climate change (Manlike *et al*., 2020), also grasslands play an irreplaceable role in water conservation biodiversity protection and provision of steady increase in carbon sinks (Kandwal *et al*., 2009). Poverty, land degradation, soil erosion, and hilly geography all contribute to this vulnerability. Droughts are a significant concern. Climate hazards in the Kingdom cause a variety of issues, including farmers planting too late or not at all, crop failures, deteriorating rangelands and pastures, reduced seed germination due to hardened soils and a deficiency of water, livestock emaciation and death, and higher food costs, particularly for staple grains such as maize. Current climate change consequences have an impact on the hydrological cycle by changing precipitation patterns and increasing the frequency of extreme dry periods. Climate influences rainfall patterns because soils break in dry spells and separate easily in periods of

excessive rainfall, resulting in deep gullies in rangelands (Engdawork and Bork, 2016). Rising temperatures and erratic rainfall patterns caused by climate change also contribute greatly to the invasion of woody plants (Gxasheka *et al.,* 2023).

2.4 Livestock Production in Lesotho

Agriculture supports a large component of Lesotho's livelihoods, particularly in rural areas. Lesotho's agricultural activities include crop production, fishery, forestry, and livestock production, with cattle, sheep, and goats being the most widely farmed species (CPF, 2017). Crops cultivated in Lesotho include maize, sorghum, wheat, and beans. Lesotho has an estimated 1.2 million sheep, 845 000 goats, and 650 000 cattle (FAO STAT, 2013). Livestock production makes a significant contribution to the country's GDP (WFP, 2006). The majority of Basotho see cattle production as a source of income. For example, in 2005, it was estimated that over 170,000 people were active in cattle herding, demonstrating that, this sector makes a substantial contribution to rural development (CPF, 2017).Therefore, mountain areas feature huge livestock populations, with sheep and goats being kept in high numbers and most families managing cow herds (Lewis *et al.,* 2011). The sector is critical for supporting rural people's livelihoods by providing food, money from wool, mohair, and animal sales, organic fertilizers, and draught power (Gerber *et al.,* 2010), as well as a source of investment. Traditional events, such as funerals and weddings, also include animal participation.

2.5 Land management practices in the rangeland

2.5.1 Rangeland fire

According to Pheko (2021), rangeland site stability refers to a rangeland's ability to stay unchanged or the potential to return to its prior condition following disturbance, such as fire. Fire and other disruptions of an ecosystem's nature modify the operation of the ecosystem when they are heavily hit, resulting in the emergence of a completely different environment (Pheko, 2021). Rangeland burning practice is mostly employed to remove the woody vegetation to promote new grassland growth from the start of the rains. However, Bond and Zaloumis (2016) stated that late-season rangeland fires are considered to be more extreme than early to mid-season fires, and these makes them harmful to grass species which are sensitive to fire. Because the higher grass biomass covers larger regions than smaller ones, early to mid-season rangeland fires encourage woody encroachment by fire-sensitive and fire-resistant species (Archibald, 2016; Bond and Zaoumis, 2016). Early agro-pastoralists in the grassy habitats of the

Drakensberg engaged in seasonal rangeland burning to facilitate animal grazing (Wright and Mazel, 2007; Finch *et al.,* 2022). Also, by eliminating the old foliage, rangeland burning extends the periods during which plants are in green development and makes new growth vulnerable to herbivores (Vallentine, 2001). Rangeland fire burns are significant tools for changing the landscapes because they eliminate dead foliage and litter material, which may encourage grass regrowth and boost productivity in grasslands (Finch *et al.,* 2022). Fire is common in rangelands due to the dryness and high seasonal temperatures (Onyango *et al.,* 2022). Rangelands are often fire-adapted and fire-dependent, as fire establishment improves rangeland health and productivity. Rangeland fire is a common disturbance on shrub-grass rangelands because it maintains the equilibrium of grasses, forbs, woody shrubs, and trees. Fires typically open up dense vegetation canopies, allowing grass-forb communities to thrive, resulting in ecological renewal with increased grass species variety and a flush of new growth of fire-adapted species, resulting in an increase in biomass. Livestock herders regularly use rangeland fire to remove low-quality vegetation and replace it with more digestible vegetation and desirable grazing species on the rangelands (Rundel *et al.,* 2018). Lesotho's vegetation has endured tremendously as a result of key disturbances such as uncontrolled fire, overgrazing, and encroachment by alien plants, towns, and farming. Thus, fire is used to reduce woody vegetation and stimulate pasture growth on rangelands (Vega-Cofre *et al.,* 2023). However, in ecosystems vulnerable to uncontrolled fire, vegetation species composition and structure change, result in unnecessary soil erosion during wet seasons (Forsyth *et al.,* 2010). Fire affects ecosystem components both above and below the soil surface, but the effects are most noticeable below the soil surface (Pheko, 2021). Long-term droughts in the rangelands have a significant impact on grassland ecosystems because they can spread wildfires and destroy wetland habitats, which are necessary for grass species movement and habitat alterations (Holdo *et al.,* 2011). However, the grassland's poor condition is linked to either successful or ineffective management, such as extensive burning or rangeland overgrazing (43%). Grasses senensce into fine fuels which dry out quickly, generating dense mats that are flammable, and increasing the connectedness of plants, allowing fires to spread (Gianella and Sanchez, 2024). According to Pereira *et al.* (2016), the effects of fire in rangelands include a decrease in plant cover and composition. Fire alters species composition, boosts biodiversity, and promotes seed banks for pyriscent plants. Rangeland fires affect species composition, vegetation structure and dynamics, habitat values, and ecosystem functioning. They can also be helpful or harmful to humans and property (Van Etten, 2010). For example, increasing output and diversity, species

richness, perennial grasses, and plants with excellent palatability are some of the favorable benefits of fire (Mirzaei *et al.*, 2015).

2.5.2 Stone Gabions

According to Pathak *et al.* (2005) and Hartman *et al.* (2016), gabions are prefabricated, wire cages or baskets which are rectangular or cylindrical and filled with small stones, riprap, or cobbles. Advantageously, gabions are packed with tiny rocks to resist stream erosion. The tiny stone gabions are typically bigger than the wire mesh. Thin, mattress-shaped gabions are used for stream-bank protection in addition to strengthening channel beds (Freeman and Fischenich, 2000). To minimize structural collapse, stone gabions must constantly be maintained to prevent cage dislodgement or distortion, as well as to monitor wire breakage. It is anticipated that grass cover planted on gabions enhances on-site water retention over time by lowering runoff velocity and extending the structure's lifespan (Freeman and Fischenich, 2000). Soil erosion exacerbates the severity of land degradation (Kiage, 2013). Lesotho's low agricultural productivity is caused by grassland burning (Kangalawe, 2012), changes in land use and drought, inappropriate land management strategies, and overgrazing. Nevertheless, activation of re-vegetation is considered to be significant in degraded ecosystems. As an illustration, consideration of sowing grass patches or an entire region with herbaceous plants (Kimiti *et al.*, 2017). Over time, woody plants improve soil quality and increase pasture productivity by accelerating the creation of fertility islands and boosting geo-ecological sites (Stavi *et al.*, 2020). Hailu (2017), further stated that low vegetation density on stone gabions containing woody species may be a sign of an improved soil nutrient quality, which can promote conditions favourable for grass growth.

2.5.3 Ecological Sites

According to Blanco *et al.* (2014), ecological sites are unique types of land with particular soil and physical characteristics which set them apart from other types of land in their capacity to produce particular vegetation types and quantities as well as their capacity to react to natural disturbances and management decisions. Climate, soils and landforms, hydrology, vegetation, and natural disturbance regimes all contribute to the definition of an ecological site. According to Brischke *et al.* (2018), each ecological site can be defined, differentiated, and described based on the interactions between environmental elements and how they affect plant

community composition and other environmental processes. Furthermore, ecological site concepts are critical to grasp because they influence the success or failure of management actions (Bestelmeyer and Brown, 2010). This therefore calls for the inventory, monitoring, analysis, and evaluation of rangeland data, which needs competence and knowledge of ecological sites and their interrelationships with others on the landscape (USDA-NRCS ESIS, 2008). Ecological sites split the landscape into manageable parts, serving as a standard reference for land management, research, and monitoring (Karl and Herrick, 2010).

2.5.3.1 South Facing Slopes

According to Gxasheka *et al.* (2023), south-facing slopes receive the least amount of insolation, are chilly, damp, and have gradual fluctuations in seasonal and diurnal microclimate. In the polar hemisphere, south-facing slopes receive more sunlight and become more xeric and warmer, which favours drought-resistant flora but is less conducive to tree growth. South-facing slopes in the northern hemisphere absorb more solar energy than north-facing slopes, making the latter more humid and cooler. However, southern-oriented slopes and steep slopes are susceptible to soil loss processes (Keyserlingk *et al.,* 2021). South-facing slopes receive more direct sunshine than north-facing slopes (Elnaker and Zaleski, 2021). Furthermore, due to the higher rate of solar radiation, the soil moisture content on south-facing slopes is lower than the field capacity, resulting in increased transpiration rates and decreased plant development. South-facing slopes have greater soil temperatures and more active layers than north-facing slopes (Singh, 2018; Elnaker and Zaleski, 2021). Because south-facing slopes receive more sunshine, these conditions are not conducive to vegetation growth, but rather encourage drought-resistant flora (Auslander *et al.,* 2003). Rangeland fires are more prone to occur on the southern side due to the abundance of dry leaves and debris. Ahmed *et al.* (2023) also demonstrated that south-facing slopes have vegetation which is highly resistant to stress and drought, whereas northern slopes have fragile grass species which are more prone to drought. Warmer aspects to the south and west in the northern hemisphere experience increased grazing pressure, particularly in the spring and autumn when warmer weather conditions prevail. Furthermore, south-facing slopes typically experience increased temperatures, greater light intensity, and less moisture availability than north-facing slopes (Small and McCarthy, 2003), resulting in an aspect-related gradient in humidity, soil moisture, and both soil and air temperatures (Badano *et al.*, 2005; Gong *et al.*, 2008). According to Bennie *et al.* (2006), south-

facing slopes preserve more stress-tolerant or drought-resistant species, whereas mesic habitats on northern slopes contain fragile plant species which are sensitive to drought effects.

2.5.3.2 North Facing Slopes

The rangeland's vegetation composition varies by ecological location. In the southern hemisphere, north-facing slopes receive the most solar radiation and are often hot, dry, and susceptible to fast fluctuations in seasonal and diurnal microclimate (Gxasheka *et al.,* 2023). North-facing slopes have less vegetation cover because they are warmer and dryer than the southern hemisphere (Hannah, 2015), reducing evapotranspiration and increasing soil loss. The northern aspect have a consistently greater mean of soil moisture. In addition, the north-facing slopes retain soil moisture, are cold, and humid, accordingly and support moisture-loving plants such as *muhly* grass (Gutiérrez-Jurado *et al*., 2013). The south facing slope are richer in paleotropical xeric biota, whereas the NFS has a higher density of mesic temperate species (Auslander *et al.,* 2003). North-facing slopes in the northern hemisphere receive less direct sunlight than south-facing slopes (Searcy *et al.,* 2003). The common of species in north-facing slopes are palatable, while unpleasant species dominate south-facing sides (Louhaichi *et al.,* 2022). Higher plant cover on either sites is an indication that more primary source of humus formation and accumulation in the north facing slope (Zhou *et al.,* 2023). As a result, north slopes have higher plant productivity than south slopes, especially in semiarid grasslands (Austin *et al.,* 2004; Feng *et al.,* 2016; Liu *et al.,* 2019). Soils on north facing slope have higher vegetation cover and more distinct litter decomposition, resulting in larger humus deposition on the north-facing or shady slope (Yang *et al.,* 2020; Jiang *et al.,* 2022; Zhu *et al.,* 2022). These findings corroborate the idea that species on north-facing slopes are less drought resistant (Louhaichi *et al.,* 2022). Plant cover, density, species variety, and biomass output are all higher on north-facing slopes than south-facing slopes (Louhaichi *et al.,* 2021). In autumn, the northern view has more grass than the southern aspect (Singh, 2018).

2.5.3.3 Riparian Areas

Riparian areas are zones of contact between land and water ecosystems, defined as mesic, productive environments bordering streams, rivers, lakes, and springs (McClain *et al.,* 2005). Riparian vegetation preserves streams and accompanying animals, hence maintaining ecosystem purity (Dietrich *et al.,* 2015. Riparian buffers are linear in nature and serve as an effective link between terrestrial and aquatic ecosystems due to their location in the landscape.

However, the riparian zones have suffered significant degradation in recent years (Qian *et al.,* 2018). Riparian zones have critical roles in numerous physical, chemical, biological, and socioeconomic systems across all biomes (Esler *et al.,* 2008). Frequent disturbances in riparian ecosystems create several chances for changes in the diversity and relative abundance of component species. Microbial composition, plant and animal diversity are frequently boosted in riparian habitats due to natural disturbance regimes, increased resource availability, and inherent variety (Décamps *et al.,* 2004; Pettit and Naiman, 2007). However, not all riparian habitats have greater species diversity than uplands (Stromberg, 2007). Because they are susceptible to perturbations, riparian regions are frequently used to monitor environmental change (natural or manmade). Riparian zones serve as both a corridor for biota mobility and a habitat for biodiversity (Esler *et al.,* 2008). Plant cover improves riparian zone efficiency by filtering nutrients and pesticides, and thus, plays an important role in maintaining the biotic integrity of streams and rivers within the rangeland (i.e. water quality) (Pettit and Naiman, 2007). Furthermore, they support rangeland river banks and regulate light inputs, which helps to moderate river temperature through evapotranspiration and shading (Reinecke *et al.,* 2007). In riparian areas, grasses also limit soil erosion, which impacts the availability and quality of potable water, as well as the health consequences of contaminated water. Mostly importantly, both riparian soils and plants can be utilized as ecological indicators to track the effectiveness of riparian management strategies aimed at restoring and maintaining soil ecosystem services (Hale *et al.,* 2014; Saint-Laurent *et al.,* 2014). Riparian vegetation, in particular, has the potential to support ecological balance, biodiversity, and agricultural production by stabilizing stream banks and increasing water quality. Furthermore, greater trampling hindered plant regeneration during grazing, diminishing species richness and variety.

2.6 Morphological characteristics of grass

The morphological characteristics of grass species have diverse roles in water storage and sediment harvest regulation (Pan and Ma, 2020; Liu *et al.,* 2023). Vegetation structure adjustment in rangelands reduces and prevents soil and water loss by improving soil qualities, especially in areas with limited water resources (Fu *et al.,* 2011). Nonetheless, inadequate plant structure promotes severe soil erosion in rangelands (Pan and Ma, 2020). Soil erosion processes have a major impact on the kind, geographical patterns, and diverse morphological aspects of plants (Li and Pan, 2018). Vegetation spatial patterns have the capability to affect the source-sink erosion distribution, which is required for describing the transport route of runoff and

sediment in catchments or at larger geographical scales (Puigdefábregas, 2005; Zhang *et al.*, 2024).

2.7 Identification of grass species

The exterior traits of plants or grasses are used to identify the species of vegetation available on the rangeland. Liu *et al.* (2023), claim that grass or plant leaves are simpler to obtain than other exterior organs like roots, stems, and blossoms. As a result, using vegetation's leaf features to determine the different species of vegetation is the most straightforward and efficient way.

2.8 Vegetation Characteristics in the Rangelands

2.8.1 Vegetation or grass cover

According to Shiferaw *et al.* (2019), strong basal grass cover and high rangeland biomass can recover the storage of soil organic carbon and matter. The amount of nutrients accessible to the grass, together with good grazing management in the rangeland, accounts for the basal cover in the soil. However, the combination of loss of plant cover and soil erosion reduce the ecosystem's ability to resist and recover during droughts (Keyserlingk *et al.*, 2021). While greater grass cover is beneficial to grazing animals, it also raises the dangers and ecological consequences of increased rangeland fire frequency (Samuels *et al.*, 2023). As a result, plants' ability to compete in natural ecosystems decreases, resulting in lower canopy cover and density of grass species (Wang *et al.*, 2016). Furthermore, overgrazing reduces vegetation cover (Kawamura *et al.*, 2005) by trampling on the soil seedbank, making the ecosystem more susceptible to soil erosion (Keyserlingk *et al.*, 2021). As grazing intensity increases, plant cover declines and bare soil areas increase on rangelands (Kohandel *et al.*, 2011). North-facing slopes have higher coverage and species diversity than south-facing slopes, which could be attributed to higher soil nitrogen content (Yang *et al.*, 2020).

2.8.2 Density of grass

Reintroduction of grass species and thus increased variety in restored landscapes are heavily reliant on the presence of viable seeds in the soil and the ability of established plant species to refill the seed bank (Mganga *et al.*, 2021). According to MacLachlan (2013), higher densities and topsoil moisture loss prevent circumstances favourable for grass seed germination,

resulting in a fall in species composition and the introduction of exotic species onto rangelands. High grazing pressures on rangelands limit the density of edible plants, forcing animals to feed on species of low nutritional value (Jawuoro *et al.,* 2017). Due to increased grazing pressure on the rangeland, most palatable grasses stop to grow, allowing for the expansion of forb dominance. The reduction in vegetation cover and density makes it easier to tiller dormant grass buds (O'Connor *et al.,* 2020). In temperate climates, most grassland species are more abundant on neutral or basic soils than on acidic soils (Amorim and Batalha, 2008). Animal grazing increases richness and density in grazed sites compared to ungrazed sites (Funk *et al.,* 2019; Hu *et al.,* 2019), but highly grazed ecological sites have low species richness and grass seed density (Gonzalez and Ghermandi, 2021; Erfanzadah *et al.,* 2022. High basal cover, tiller, and grass densities indicate that suitable species prevent soil loss by increasing infiltration and decreasing surface flow velocity. Winters are cold and dry, therefore the growth season for vegetation is rather short, reducing plant productivity in rangelands and worsening feed shortages for animals. However, the higher elevation grasslands are unsuited for winter grazing due to the very cold temperatures and frequent snowfalls, as well as the dramatic decline in fodder quality.

2.8.3 Frequency of grass

According to Vogel and Masters (2001), frequency is defined as the presence or absence of a grass species in a sampling unit, represented in percentages. The benefits of grass frequency include the fact that it is rapid and straightforward to measure because the presence or absence of a plant or grass is recorded, which is then combined with density and dispersion properties. The plant composition of rangelands varies depending on grazing pressure. According to Zhang *et al.* (2018), increasing grazing intensity in short grass may diminish grass (palatable) presence while increasing less palatable forbs on rangeland. Overgrazing rangelands can reduce the palatable plant contribution to botanical composition and rangeland conditions and changes in vegetation composition (Yanyan *et al.,* 2017). Rangeland fires can change the composition of available grass species (Pausas and Ribeiro, 2017), potentially influencing plant nutrients at the functional and communal levels. Wu *et al.* (2014), discovered that fire boosted plant diversity but had little effect on dominant grass species. The changes in grass species abundance in the botanical composition over time show distinct tendencies across ecological sites. However, mismanaged communal area rangelands cause changes in species composition, biomass, and basal cover. Furthermore, soil nutrients Critchley *et al.* (2002), soil type

(Ravhuhali, 2018), and animal management techniques all influence plant species composition and distribution. The presence of *Themeda Triandra* species in rangeland clay soils indicates good veld condition since these species have higher grazing value and are considered palatable grasses for ruminants. According to Novellie and Kraaij (2010), *Themeda*, a decreaser species, which can only be increased by improving grazing management practices and conducting frequent rangeland burning. According to Doherty *et al.* (2017) and Pausas and Ribeiro (2017), rangeland fires can alter species composition, potentially affecting plant nutrients and community levels.

2.8.4 Diversity of grass

There are two main elements of species diversity are species richness and evenness, which respond differentially to disturbance intensities and environmental conditions (Svensson *et al.,* 2012). Species richness is the number of perennial grass species sampled within each quadrat. The link between species diversity and aboveground biomass is affected by environmental issues (Liu *et al.* 2014). Regardless of the impact of species richness on aboveground biomass or production, species evenness is critical for the structure, variety, and function of plant communities (Grace *et al.,* 2016; Sanaei *et al.,* 2018). Furthermore, disturbances such as local grazing have an impact on plant coverage and species diversity because they remove aboveground biomass and open up the vegetation canopy (Grace *et al.,* 2016; Larreguy *et al.,* 2017). According to Oba *et al.* (2000), competitive exclusion, and compensatory growth the remaining vegetation improved light availability and higher rates of biomass acquisition. However, intense grazing pressure reduces species richness by eliminating less-grazing-tolerant plants (Soder *et al.,* 2007), and livestock grazing reduce the evenness and chaos of plant community structure on rangeland. According to Moghbeli (2016), sites with varying rangeland management strategies have greater evenness. This is where low to moderate grazing pressure causes the canopy to expand, enabling greater light penetration for minor species to flourish, resulting in increased grass species richness and diversity. Mechanical solutions, such as the construction of bunds and terraces, gully and stream management, river banks, gabions, and mattresses, are employed to conserve ravine sites (Mgbenka *et al.,* 2012). Trampling and defoliation near piospheres explain the much decreased plant species diversity, richness, and evenness in rangelands (Jawuoro *et al.,* 2017). Overgrazing alters botanical composition and species diversity by reducing the vigor and presence of dominating species, allowing colonization by grazing-tolerant plant species.

2.9 Grass Seed Weight

Natural ecosystems rely heavily on the dynamics of their soil seed banks. Animal grazing can harm plant establishment by reducing the soil seed banks (Moghbeli, 2016) and trampling the biological surface of the soil, limiting seed survival (Bertiller and Ares, 2011). Burned rangelands can have different ecosystem traits than unburned regions as a result of range fire. The north slopes have higher soil moisture and nutrient availability compared to south slopes (Liu *et al.,* 2018). As a result, north slopes exhibit better plant productivity than south slopes, particularly in semiarid grasslands (Feng *et al.,* 2016; Liu *et al.,* 2019). Ligavha-Mbelengwa and Bhat (2013), noted that grass seed yield can be increased by annual burning of the grass as rangeland fires indicate increase in growth rate, flowering and seed production of grass species. In these regard, autumns are anticipated to be wetter, whereas winters are likely to be drier, which could lead to more floods and recurrent drought. This decreases the rangeland productivity and lower carrying capacity. Meanwhile, animal grazing can reduce the seed production of perennial species due to the decline of photosynthetic tissue and the elimination of flowers and seeds stalks (Bakoglu *et al.,* 2009). Grazed species have less seed production ability because grazing encourages vegetative reproduction over sexual reproduction (Sternberg *et al.,* 2003). Furthermore, seeds produced by grazed plants have a short lifespan in the soil. Overgrazing may result in reduced seed production of the palatable species. Cool season grasses cannot yield seeds after their reproductive shoots are grazed in the spring because they need vernalisation, which is not achievable during the growing season (Koç, 2001).

2.10 Nutrient Content in Grass

2.10.1 Dry matter in grass

Forages' nutritional value is determined by a combination of genetic and environmental variables. Dry matter refers to the amount of feed ingested by an animal (Connor, 2015). Dry matter is an estimate of how much fodder an animal will ingest when just forage is provided. This could be linked to a higher NDF content, which influences how much feed an animal can consume (Decruyenaere *et al.,* 2009; Louhaichi *et al.,* 2021). Normally, in winter, dry matter in vegetation increases on the north-facing slope. This finding is consistent with Yang *et al.* (2020), who found that north-facing slopes have more dry matter than stone gabions and south-facing slopes during the winter season due to higher soil nutrient content. The reduced DM

content of forage may cause behavioural changes such as smaller bite sizes (Tuna *et al.*, 2009). According to Carlyle *et al.* (2014), and Magandana *et al.* (2020), dominant grasses such as *Eragrostis curvula* at various ecological sites may contribute more dry matter than less dominant grass species, and thus, these grasses determine whether or not the rangeland is productive for animal production. This emphasizes that shorter resting intervals improve grass dry matter in the autumn season, but longer resting periods improve grass dry matter in spring. Dry matter (DM) is a significant contributor to feed efficiency and animal performance which is influenced by forage quality (Hutjens, 2005). The DM concentration in free-grazing rangeland grasses at early bloom ranged between 30.4% and 36.4% while the DM content of mature grasses ranges between 39.9% and 47.5% (Sultan *et al*., 2008). According to the studies, as plants age, dry matter increases (due to higher NDF and ADF levels), whereas cell contents decrease (Sasoli, 2022).

2.10.2 Neutral detergent fibre (NDF)

In rangelands, the NDF is used as a quality assessment indicator for ruminant feeds (Truong and Van Thu, 2022). NDF content of forages is important measurements because it provides an estimate of digestibility. The NDF is made up of hemicellulose, cellulose, lignin, and ash, which is also known as the cell wall or fibre portion of rangeland plants (Chaves *et al.*, 2002). According to Tham and Udén (2013) the primary component of the feed regulating feed intake is NDF. However, feeds containing 58% NDF are not adequate for high-producing animals (Brandao and Faciola, 2019). Forage feedstuffs in ruminant diets have a high degree of NDF digestibility, which indicates the total digestibility of forage feedstuffs (Kara, 2019). In general, legume forages have lower NDF digestibility than grass forages (owing to increased lignification and lignin content) (NRC, 2001). Kara (2019) further mentioned that grasses have a wide range of NDF concentration (46% for pasture, 50-69% for immature-mature hay, and 51-66% for silage) and NDF digestibility. According to Combs (2018), the total tract NDF digestibility, varies from 25% to 70% for lucerne hay, 25% to 80% for maize silage, and 15% to 80% for grass hay. Ruminal digestion of grass and legume forages is influenced by lignin concentration and lignification in plant species (Musco *et al.*, 2016). The high NDF digestibility of forage improves the digestion of dry matter and organic matter in forage feeds (Kara, 2019). Ramírez *et al.* (2002) found that the proportion of NDF in grass was lowest during the autumn and largest during the winter.

2.10.3 Acid detergent fibre (ADF)

The use of acid detergent, which reduces protein contamination (Van Soest, 1994), frequently underestimates the lignin content of forages, primarily grasses, due to the partial solubilization of phenolic compounds (Gomes *et al.,* 2011). The concentrations of ADF (the primary structural cell wall components of cellulose and lignin) and lignin in weathered biomass rose by 24.1-44.6% and 3.4-28%, respectively. According to Al-Jabareen (2009), ADF is made up of cellulose and lignin. Wetter seasons such as autumn with a higher percentage of grasses increases ADF and lignin concentrations. Thus, higher peak biomass in wetter areas correlates with higher ADF concentrations and lower TDN and energy (Larsen *et al.,* 2021).

2.10.4 Acid Detergent Lignin (ADL)

According to Mosisa *et al.* (2021), ADL is the indigestible fraction of the plant cell wall. ADL in grasses play an significant role in the structural integrity of individual cells, tissues and organs (Ramírez *et al.*, 2009). ADL is a major anti-nutritional component in grasses (Chaves *et al.*, 2002). It functions as a glue, binding cell wall components (cellulose, hemicellulose, and pectin) and providing mechanical strength to plants. Photo-degradation preferentially reduces lignin because it readily absorbs energy across a wide range of wavelengths (Austin and Ballaré 2010). The loss of lignin decreases dry forage integrity and result into increased fragmentation by wind and fauna disturbance (Larsen *et al.*, 2021). Grass species have higher lignin concentration due to slow decomposition and increased storage of soil organic carbon, which contributes more to soil organic carbon content however, dead grass biomass increases soil organic carbon (Dinakaran *et al*, 2011). Because it is indigestible and decreases the potentially degradable fibrous fraction, lignin is principally responsible for the limiting of fibrous forage component breakdown (Gomes *et al.*, 2011).

2.10.5 Cellulose and hemicellulose

According to Waliszewska *et al.* (2021), the amount of cellulose in grasses vary significantly and depend on several factors, such as species, grass or plant age, and growth conditions, as well as the part of the grass. Doczekalska *et al.* (2020), in a study on the chemical composition reported the content of cellulose ranging from 40.30% to 45.12%. Plant cell wall components such as cellulose, hemicellulose, and lignin are the primary source of carbohydrates in forage feedstuffs (Kara, 2019). The amount of cellulose, hemicellulose, and lignin varies by kind of forage, and they all have a varying effect on digestibility. Furthermore, hemicellulose is the

most digestible fibre fraction in rangeland grass species (Sasoli, 2022), hence the proportion of hemicellulose content in free-grazing rangeland grasses during the early bloom stage ranges from 21% to 43%. At maturity, hemicellulose concentration ranges between 24% and 43% (Sultan *et al.,* 2008). According to Felton *et al.* (2018), hemicellulose, while more fermentable than cellulose, requires slower retention than non-structural carbohydrates. However, cellulose and hemicellulose are the principal fuels for ruminants, providing for up to 80% of energy (Barboza *et al.,* 2008). The fermentation of hemicellulose and cellulose produces up to 80% of the energy required for livestock (Stolter *et al.,* 2022).

2.10.5 Ash content

Ash content in grasses is composed of potassium, and calcium, to name the few (Insam *et al.,* 2009). According to Dahl and Obernberger (2004), the ash percentage of grass is influenced by plant species such as switch-grass (8.3%), giant reed (6.1%), miscanthus (2.3%), and cardoon (17.4%), as well as wood pellets (0.50%). The ash component of fodder grasses ranges between 5% and 8%. Ash content in grasses from diverse sources is utilized as fertilizer or as an additive in multi-component fertilizers (Codling *et al.,* 2002). The ash concentration in grass fodder fluctuates widely (4-14%) in harsh conditions, although usually ranges between 7-10%. According to Tuna *et al.* (2009), the percentage ash in grasses vary from 6.4 to 10.29. In general, rangeland grass plant species have a higher ash-to-fibre ratio, a lower protein percentage, and a moderate detestability level. Dry matter, crude fibre, neutral detergent fibre, acid detergent fiber, hemicellulose, and acid detergent lignin levels often rise with plant maturity, whereas crude protein, ether extract, and ash levels fall.

2.10.6 Crude protein (CP)

Crude protein is an essential dietary nutrient for animals' maintenance, growth and reproduction (Koidou *et al.,* 2019). The CP content in forage is not only a key measure of fodder quality, but it also reflects climatic circumstances throughout plant growth and development (Roukos *et al.,* 2011). Grasses crude protein content in rangelands can reach 15% during the early vegetative growth stage, but it declines to as low as 3% after drying (George and Rice, 2016). Low protein levels are a limiting factor in herds with parturition following pasture weathering (Larsen *et al.,* 2021). Crude protein concentrations also enhance the interaction of rangeland fire and animal feeding. Crude protein in grasses is lower during the vegetative stage than in the fall and winter seasons (Jensen *et al.,* 2003). However, the limiting

nutritional variables influencing livestock performance and production are crude protein (CP) content (Mahmoud *et al.,* 2017), because protein is required for growth, weight gain, and lactation (Liamadis, 2003). When compared to autumn seasons, the concentration of CP in mature grasses in grasslands drops to 1-2% during the winter (Louhaichi *et al.,* 2021). In rangelands, CP content is a reliable index for nutritional quality (Ramírez *et al.,* 2009).

2.11 Effect of Land Management Practices on Soil Properties

Soil nutrients are critical to the establishment and dispersion of vegetation across elevation gradients (Gxasheka *et al.,* 2023). Soil nutrient levels fluctuate with elevation due to factors such as lower temperatures and more rainfall (Badía *et al.,* 2016; Drollinger *et al.,* 2017). Introduced annual grasses on rangeland change soil nutrient recycling and biological activity (Dickens *et al.,* 2013), which affects the carbon and nitrogen cycle, pH, and bacterial abundance (Caspi *et al.,* 2019; De Stefano *et al.,* 2024). The influence of climate on rainfall patterns is that, soils fracture during dry spells and detach easily after heavy rains, resulting in the formation of deep gullies in rangeland (Engdawork and Bork, 2016). With these, soil microorganisms play a significant role in ecosystem processes by maintaining plant production and soil fertility (Zhang *et al.,* 2022), which causes changes in their habitats (Ren *et al.,* 2019). Therefore, changes in soil physiochemical parameters caused by land use and management have a significant impact on the composition and organization of microbial communities (Hu *et al.,* 2021).

2.11.1 Soil pH

According to Dewangan *et al.* (2023), soil pH is a measure of the acidity or alkalinity of the soil, which influences nutrient availability to plants, microbial activity and soil structure. Soil nutrient availability is subject to pH and clay content variations because they affect grass performance (De Stefano *et al.,* 2024). Also, Rahlao *et al.* (2023) found that increasing soil pH has an impact on edaphic factors with lower pH values which reduce nutritional availability. Animal grazing also has an impact on soil physical and chemical qualities by removing biomass and trampling it (Wang and Wesche, 2016). Soil solutions' acidity and alkalinity are determined by their pH, which influences the acid and base-forming ions in the soil (McCauley *et al.,* 2009). As a result, soil pH is known as the 'primary soil factor' because it influences a variety of biological, chemical, and physical processes which influence plant development and vegetative growth. According to Shi and Wang (2005), acidity and alkalinity promote toxicity

in soils, while high pH enhances osmotic stress and ion toxicity. Moreover, according to Tripathi *et al.* (2012), pH values ranging from neutral to alkaline indicate a strong bacterial community in the soil since these pH ranges are ideal for growth.

2.11.2 Soil organic matter

Soil organic matter is stable and protects aboveground carbon from disturbances such as waterlogging, development, and severe fires (Dass *et al.,* 2018; Provencher *et al.,* 2023). Climate, erosion, soil texture, slope, vegetation, grazing effect, and topographic characteristics all have an impact on soil organic matter levels (Dai *et al.,* 2009). The loss of organic matter in soil can be attributed to numerous factors (Ratsele, 2013). According to Czimczik *et al.* (2005), rising rangeland fire intensities reduce organic matter content in the organic soil because high-intensity fires destroy the entire topsoil. Ecological factors such as soil moisture and temperature influence the rate of caries, which is crucial for the balance of organic matter (Tilaki *et al.,* 2022). Livestock grazing has an impact on soil organic matter in rangeland ecosystems (Wang *et al.,* 2008). Southern African soils, for example, have a low organic matter content. As a result, anthropogenic perturbations in the ecosystem have a negative impact on the organic matter in the topsoil. Soil microbes regulate organic matter, which is susceptible to changes in soil parameters (Li *et al.,* 2019; Hu *et al.,* 2021). Organic matter levels in autumn vary from 2.1-2.34%, in winter from 2.01-2.16%, and in spring from 2.01-2.4% (Konthoujam *et al.,* 2021).

2.11.3 Soil nitrogen (N)

According to Maren *et al.* (2015), soil nitrogen is the most limiting nutrient in majority of rangeland ecosystems. Nitrogen is a vital nutrient that plants require in significant quantities, but it can hamper plant development and output. Nitrogen is typically contained in soils as part of the organic matter component (Miller and Sonon, 2014). Nonetheless, Abril and Bucher (1999) reported that overgrazing can cause soil compaction, decreased water retention, improved salinity, and the disappearance of certain soils. Soil nitrogen availability frequently limits plant productivity in grasslands (Sestedt *et al.,* 1991), as well as crude protein content in grass. Moreover, nitrogen addition into the soil enhances the crude protein for sprouting of young, and green grasses which grow after rangeland burning and photosynthetic rate increases. In rangelands, nitrogen is the most key elemental components of forage crude protein (Fu *et al.,* 2022). As a result of the interplay of rangeland fire and nitrogen addition, young

grass leaves are higher in crude protein than grasses from unburned rangeland locations with no nitrogen addition, where crude protein gradually declines but digestible material increases. The new plant development after rangeland burning reduces the stem ratio while increasing the digestibility of young grass stems and leaves. According to Chartier *et al.* (2011), degraded rangelands have low nitrogen content, nitrate, and ammonium levels due to persistent overgrazing. Soil microorganisms can control soil nutrient availability, plant development, and diversity (Zhang and Fu, 2021). Rangeland fires also increase soil nutrients, such as inorganic soil nitrogen, which affects above-ground vegetation and boosts plant and seed production (Jurand *et al.*, 2013).

2.11.4 Soil phosphorus (P)

Natural rains deposit phosphorus from the atmosphere onto the soil, thereby, increasing soil nutrient levels. Grazed rangelands have higher phosphorus levels of grass during the dry (winter) seasons, although phosphorus concentrations steadily drop from the wet (autumn) to the dry (winter) seasons. The interaction between rangeland fire and grazing increases phosphorus levels in grass, which is related to the age of grass following rangeland burning and grazing (Mbatha and Ward, 2010). After burning the rangeland, the sprouting of young grass leaves becomes more phosphorus-rich than the older leaves in unburned rangelands, hence the phosphorus content gradually decreases with age.

2.11.5 Soil potassium (K)

According to Rogers *et al.* (2008), soil potassium is an important component in plant nutrition. Potassium regulates plant water utilization and ensures plant quality. In addition, livestock faeces and urine can be a source of potassium in rangelands. Exchangeable potassium in soil is stored at negatively charged sites in soil particles and organic matter, where it is easily exchanged with other cations which plants can quickly access. The amount of potassium increases in heavy grazing areas due to increased livestock and manure emission (Moghbeli, 2016).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Site

The study was conducted in Mahloenyeng Rangeland (Matsieng) in the Lowland Agro-ecological zone of Lesotho, which is approximately 50 km Southeast of Maseru, Lesotho. Matsieng is located at an elevation of 1768.45 m above sea level and has a temperate highland tropical climate with dry winters. Mahloenyeng is geographically situated at 29º36"0 south, 27º32"0 east and it is composed of grasses, shrubs, forbs, and some woody plants such as trees. Matsieng typically receives about 83.36 mm of precipitation and has 114 rainy days annually (Lesotho Meteorological Services, 2024). The country, Lesotho is generally located at a high altitude that ranges from 1500 m to 3482 m above sea level (UNDP-GEF, 2011).

Fig 3.1: The selected ecological sites of the study area in Mahloenyeng Rangeland (Pin pointer). Vegetation sampling and Data collection

3.2 Experiment and Management

The Mahloenyeng rangeland was monitored for a total of 182 days using the construction of quadrats 3 m×3 m=9 m² to evaluate the vegetation improvement after the rangeland

management was carried out by the community people. Grass species were selected randomly within a 9 m^2 quadrat set up randomly in each site, the grass species within the quadrat were identified visually and recorded. Once a month, the vegetation was measured by using a measuring tape (30 m) by constructing quadrats for different parameters. The rangeland was divided into three categories depending on the management practiced, namely a) fire management, b) stone gabion structures, and c) ecological sites. The ecological sites were further divided into three ecological strata (north-facing area, south-facing area, and riparian area). The stone gabion structures were built mainly to control soil erosion on the rangeland such as the huge gullies/dongas. On the ecological sites, visual monitoring was done to determine the degree of soil erosion on the slopes. All parameters were measured in two seasons; autumn and winter for all experimental sites.

3.3 Experimental Design

From each ecological site of the rangeland, three different experimental treatments were arranged using a randomized complete block design (RCBD) with three replications**.** Grass and soil samples were randomly selected within the quadrats. The measuring tape was placed at a random straight line for each ecological site to ensure a proportional sampling of crop cover and diversity of grass. The quadrant sampling was done to determine the density, frequency, and species identification on each ecological site (area). For each ecological data, measurement was taken once per month, per season for three months to obtain three replicates. Soil properties indices, biomass data, forage quality parameters, and seed production data were randomly taken once in each of the two seasons of autumn and winter. The rangeland was divided into three blocks depending on the management practices which were a) Rangeland fire management, b) Stone gabion structures, and c) Ecological sites.

3.4 Data Collection

3.4.6 Ecological data of grass in the rangeland

a) Species identification of grass

The grass species characteristics namely leaf shape, growth habit, and vernation were examined for proper identification. The seed head, stem, root system and inflorescences were also examined. The grass species were monitored monthly within the quadrat set up randomly in each experimental site.

b) Grass cover

Grass cover refers to the percentage of ground surface covered with vegetation. It can also be defined as the amount or number of grass covering the soil on each hit on the measuring tape. Percentage cover was done on a meter difference point on a 20 m length. The grass population was visually observed at each point and recorded for each experimental site. Monthly observation was conducted for three months each in the autumn and winter seasons. Grass cover is expressed as a percentage (%) of the area.

c) Frequency of grass

Frequency is the number of times a plant species occurs in a given number of quadrats. Three 1 m^2 quadrats were set randomly to assess the plant species occurrence in all the ecological sites. Replications were taken each month, thus three replications per season. Frequency is usually expressed as a percentage (%). Percentage Frequency was expressed as follows;

$$\textbf{\% Frequency} = \frac{Number\ of\ plots\ in\ which\ species\ occur}{Total\ number\ of\ plots\ examined} \times 100$$

d) Density of grass

Plant density refers to the number of individual plants (grass) per unit of area. Three 1 m^2 quadrats were set at random to assess the total number of grass species within a quadrat per total area of a quadrat. Replications were taken each month which gave three replications per season. The percentage density was expressed as;

$$\textbf{Plant Density} = \frac{Total\ number\ of\ grass\ speices\ in\ a\ quadrat}{Total\ area\ of\ a\ quadrat}$$

e) Diversity (richness and evenness) in grass

Diversity refers to the variety of plant (grass) species which are found in a particular area. Diversity can be measured using two components which are species richness and species evenness. Species richness (S) is a measure of the variety of species or a count of the number of species or number of species present in a particular quadrat whereas species evenness refers to the measure of how relatively abundant each species is or how evenly distributed the species are in a particular quadrat (community). Grass species were counted visually and recorded within a 9 m^2 quadrat set up randomly in each site, and then replications were taken each month with three replications per season.

3.4.7 Biomass yield of grass in the rangeland

Stem fresh mass and stem dry matter, root fresh mass, and root dry matter of grasses were determined according to AOAC (1990). Two grass samples per season were taken to the Animal Science Laboratory at The National University of Lesotho. The weight of the fresh

grass samples was taken with an Electronic Floor Scale (FLS and FLC SERIES) and thereafter was put in the oven set at 105 ℃ for 24 hours to determine moisture content and the dry matter. The moisture content of grass was calculated as follows;

$$\% \text{ MC} = \frac{weight\ of\ sample+dish\ before\ drying-weight\ of\ sample\ and\ dish\ after\ drying}{weight\ of\ sample+dish\ before\ drying} \times 100$$

Dry matter (DM) was calculated as;

% DM = 100-%MC

3.4.8 Soil properties measurements

Soil samples were analyzed at AgriSoil Solutions - MatLab to determine soil pH, soil organic matter, soil phosphorus, soil potassium, and soil nitrogen.

a) Soil pH

The pH or the hydrogen ion in the soil was determined potentiometrically in water and soil-KCl suspension using a 1:2 (w/v) ratio. The value displayed was read directly as pH and recorded. To ensure accuracy, the temperature of the samples and calibration buffers were made identical.

b) Soil organic matter

Organic matter was determined using the Walkey-black method (Poudel, 2020). The organic matter was considered to contain 58% carbon, and therefore multiplying factor 1.72 was used to convert organic carbon to organic matter. The organic matter percentage of the soil was calculated as follows;

% easily oxidizable organic C is

$$\text{C} = \frac{(B-S)\times N\ of\ Fe^{++}}{g\ of\ soil} \times \frac{12}{4000} \times 100$$

Where; B = ml of Fe^{++} solution used to titrate blank,

S = ml of Fe^{++} solution used to titrate the sample,

12/ 4000 = milliequivalent weight of C in g, and

$N_{(Fe^{++}\ solution)}$ = normality of ferrous ammonium sulfate

$$\% \text{ Organic matter} = \frac{\% C}{0.58} \text{ or } \% \text{ C} \times 1.72$$

Where;

0.58= the ratio of organic carbon to humus, Organic C/Humus = 5.8%

1.72= conversion factor

c) Soil phosphorus

Phosphorus was determined using Bray and Kurtz 1 method (Vaughn and Jones, 1980). Phosphorus was extracted from the soil using Bray 1 solution as an extractant. The available phosphorus in the soil was calculated as follows;

Available phosphorus = (a-b) × 7 × M

Where: a = ppm P in the sample extract

b = ppm P in the blank

7 = extraction ratio

M = moisture correction factor which is 1

d) Soil potassium

The concentration of potassium in the sample extract was calculated by slope calculation. For every concentration of the standard solution, 10-100 ppm the concentration is divided by the reading of the apparatus. The mean of the obtained values is the slope (Sparks *et al*., 2022).

e) Soil nitrogen

Nitrogen was determined using the Kjeldahl method (Baethgen and Alley, 1989). The nitrogen in the soil was calculated as;

$$\% \text{ N} = \frac{(s-b) \times m \times 14 \times 50/v}{w} \times \text{M} \times 100$$

Where: s = ml of HCl used for sample titration

b = ml of HCl used for blank titration

m = molarity of the HCl

14 = atomic weight of N

50 = volume of the digestion tube

v = volume of digest used

100 = conversion factor for %

w = mg weight of soil

M = moisture correction factor

3.4.9 Seed production of grass in the rangeland

The grass was selected randomly within the quadrats. Four mature heads per species were selected and harvested. The seeds obtained from each of the four heads were weighed using an electronic scale (Electronic Floor Scale, FLS, and FLC SERIES) to determine the total weight of seeds per species.

3.4.10 Nutrient content of grass in the rangeland

Fibre fraction analysis of grass samples was done using the Standard methods (AFIA, 2014) to determine acid detergent fiber (ADF), acid detergent lignin (ADL), cellulose, hemicellulose, and neutral detergent fiber (NDF). The ash and crude protein in grass samples were also determined using the standard methods.

a) Acid detergent fibre (ADF) in the grass was calculated as;

$$\% \text{ ADF} = \frac{W_3 - W_1}{W_2} \times 100$$

Where: W_1=weight of crucible

W_2= weight of initial sample

W_3=weight of crucible + residue

b) Neutral detergent fibre (NDF) in grass was calculated as;

$$\% \text{ NDF} = \frac{(W_3 - W_1)}{W_2} \times 100$$

Where; W_1 = tare weight of crucible in grams

W_2 = initial sample weight in grams

W_3 = dry weight of crucible and dry fibre in grams

c) Acid detergent lignin (ADL) in grass was calculated as;

$$\% \text{ ADL} = \frac{W_3 - W_1}{W_2} \times 100$$

Where;

W_1 = weight of a crucible after ashing

W_2 = initial weight of a sample

W_3 = weight of a crucible + residue before ashing

d) Cellulose and hemicellulose in grass

The contents of cellulose and hemicellulose were calculated as;

Hemicellulose = NDF - ADF

Cellulose = ADF – ADL

e) Crude protein (CP) in grass was calculated as;

$$\% \text{ N} = \frac{(Vs-Vb)\times N(H_2SO_4)\times 14.007}{Wt\times 1000}\times 100$$

Where;

V_s = Volume in ml of standard H_2SO_4 required to titrate the sample

V_b = Volume in ml of standard H_2SO_4 required to titrate the blank

N (H_2SO_4) = Normality of the acid titrant

14.007 = equivalent weight of Nitrogen

Wt = sample weight in grams

14.007 = mole weight of nitrogen (g)

1000 = conversion factor for grams to mg

% Crude Protein = % N X 6.25

Where; 6.25 stands for all forages and feeds except wheat grains

f) Ash content in grass was calculated as;

$$\% \text{ Ash} = \frac{wt\ of\ crucible + ash - wt\ of\ crucible}{wt\ of\ sample} \times 100$$

3.5 Statistical Analysis

Data collected were entered in Microsoft Excel Spreadsheet. The response variables were analyzed as one-way ANOVA with three treatments as the main effects using the SPSS (2011) version 20 and significantly different means were separated using Least Significance Difference (LSD).

CHAPTER FOUR

4.0 RESULTS

4.1 Identification of Grass Species and Botanical Composition

Different grass species in different ecological sites were identified as shown in Table 4.1. Species found in Mahloenyeng rangeland were identified and recorded according to their scientific and local names, habitat, life cycle, flowering season, grazing value, ecological status, and uses. In terms of grass grazing value, *Themeda driandra* and *Eragrostis curvula* have a very high grazing value in comparison with *Cynodon dactylon, Muhlenbergia capillaris, Sporobolus contractus* and *Paspalum delatatum* which had a high grazing value. However, *Arundinella nepalensis*, *Halcus lanatus* and *Hyperrhnia hirta* have a low grazing value. Grass species were also categorized as increasers or decreasers and according to their uses. Figure 4.1 shows grass cover in the ecological sites (treatments) rangeland fire, stone gabions, south facing, north facing and riparian areas. The stone gabions was dominated with *Cynodon dactylon* and other grass species less dominated the site. Figure 4.2 shows grass density, frequency and diversity in the ecological sites. During winter season, from May throughout July, grass started to dry up with the same species dominating while during autumn season starting from February throughout April, as temperatures dropped and daylight decreased, grass growth started to slow down.

Table 4.1: List of Common Grass Species in the Study Sites and their Ecological Status

Grass species and local names	Life cycle	Habitat	Flowering season	Grazing value	Ecological status	Uses
Arundinella nepalensis, River grass (Molula)	Perennial tufted grass	Cliffs, sandy river banks, riparian belt	Summer to autumn	Low	Increaser	Medicine
Cynodon dactylon, African couch grass (Seihla)	Long-lived perennial grass.	Clay, loam soils	Summer	High	Decreaser	Cut and carry, hay and deferred feed.
Themeda triandra, Red grass (Seboku, Seloka)	Tufted perennial grass	Clay soil	Spring, summer, and autumn	Very high	Decreaser	Thatching
Muhlenbergia capillaris, Hair grass, Pink muhly grass(Joang bo bopinki or Mohale oa boea)	Perennial grass	Clay, loam, and sandy soils, shallow rocky	Summer	High	Increaser	Conservation and landscaping
Halcus lanatus, Common velvet grass, (Mmonyane, Moeane)	Hairy turfted perennial grass	Natural grasslands	Spring	Low	Decreaser	Grazing
Hyperrhnia hirta, Thatching grass (Mohlomo, Manasi)	Tufted perennial grass	Sandy, clay and loam soils	Spring, early summer	Low	Increaser	Weave mats and baskets, crafts
Sporobolus contractus, Spike dropseed (Matolo a Maholo)	Warm season perennial grass	Sandy soils	July to November	High	Increaser	Food source for wildlife species
Paspalum delatatum, Water grass (Bohloa kapa Lepolanka)	Perennial grass	Closed forest areas, wet areas	Spring to summer	High	Decreaser	Grazing
Eragrostis curvula, Weeping lovegrass (Matolo, Moseeka)	Tufted perennial grass	Well drained sandy loam	Summer	High to very high	Decreaser	Pastures or hay

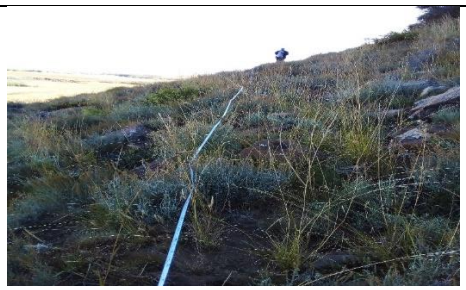
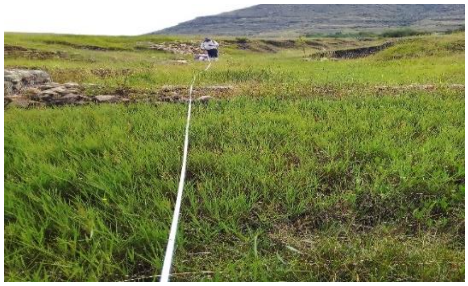
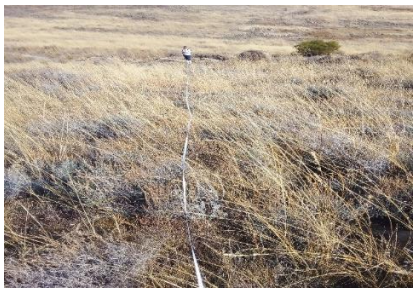
Study Sites	Autumn: February – April, 2023	Winter: May – July, 2023
Rangeland Fire		
Stone Gabions		
South Facing Slope		
North Facing Slope		
Riparian Area		

Figure 4.1: Images showing the Grass cover in Mahloenyeng Rangeland

Study Sites	Autumn: February – April, 2023	Winter: May – July, 2023
Rangeland Fire		
Stone Gabions		
South Facing Slope		
North Facing Slope		
Riparian Area		

Figure 4.2: Images showing the Grass Density, Frequency and Diversity in Mahloenyeng Rangeland

4.2 Effect of Land Management Practices on Vegetation Characteristics at Ecological Sites

The effect of the land management practices in the ecological sites on vegetation characteristics at different seasons is presented in Table 4.2.

4.2.1 Grass cover

Different ecological sites had a significant ($p<0.05$) effect on grass cover in autumn and winter seasons. North facing area had the highest grass cover of 50.56%, and the stone gabions site had the least grass cover of 36.30% during autumn. Fire and south-facing sites had grass cover of 43.15% and 47.22% respectively which were not significantly ($p>0.05$) different, and also statistically similar to north-facing slope which had the highest grass cover. The riparian site had grass cover of 40.74% which was not significantly different ($p>0.05$) from stone gabions and south-facing sites. The north-facing site had significantly ($p<0.05$) highest grass cover of 42.04% while stone gabions had significantly ($p<0.05$) least grass cover of 22.96% in winter. North facing slope (42.04%), south-facing slope (40.56%), and fire (37.22%) sites did not differ significantly ($p>0.05$) in grass cover, while stone gabions (22.96%), and riparian (27.96%) sites did not differ significantly ($p>0.05$). Grass cover during autumn was higher than in winter in all ecological treatments.

4.2.2 Grass diversity

The varied ecological sites had significant ($p<0.05$) effect on grass diversity in both autumn and winter. South-facing site had significantly ($p<0.05$) highest grass diversity of 17.70%, while the stone gabions site had significantly ($p<0.05$) lowest grass diversity of 11.37%. South facing (17.70%) slope site had significant ($p<0.05$) effect on grass diversity, while fire (14.41%), stone gabions (11.37%), north-facing (13.56%), and riparian (12.56%) areas had no significant ($p>0.05$) effect on grass diversity in autumn. During winter season, the south-facing area had significantly ($p<0.05$) highest grass diversity of 13.93%, while stone gabions site had significantly ($p<0.05$) lowest grass diversity of 9.04%. Stone gabions (9.04%), north-facing (11.00%), and riparian (9.30%) areas did not vary significantly ($p>0.05$) from each other, while fire (11.44%) and south-facing (13.93%) sites also did not vary significantly ($p>0.05$) from each other. Grass diversity during autumn was higher than in winter in all ecological treatments.

Table 4.2: Ecological Characteristics of Rangeland Sites

Seasons	Ecological indices	Study Sites					SEM	P value
		F	SG	NF	SF	R		
Autumn	GC (%)	43.15^{abc}	36.30^{c}	50.56^{a}	47.22^{ab}	40.74^{bc}	1.44	0.02
	Di (%)	14.41^{b}	11.37^{c}	13.56^{bc}	17.70^{a}	12.56^{bc}	0.47	0.00
	De (%)	63.81^{abc}	52.78^{c}	76.19^{a}	67.52^{ab}	57.67^{bc}	2.31	0.01
	Fr (%)	59.33^{ab}	45.15^{c}	65.15^{ab}	67.63^{a}	55.52^{bc}	2.01	0.00
Winter	GC (%)	37.22^{ab}	22.96^{c}	42.04^{a}	40.56^{a}	27.96^{bc}	1.97	0.05
	Di (%)	11.44^{ab}	9.04^{b}	11.00^{b}	13.93^{a}	9.30^{b}	0.48	0.01
	De (%)	56.48^{ab}	42.96^{bc}	58.89^{a}	65.11^{a}	36.67^{c}	2.42	0.00
	Fr (%)	56.70^{b}	42.19^{c}	55.56^{b}	76.70^{a}	37.19^{c}	2.23	0.00

^{a,b,c}Means within a row with different superscripts are significantly different ($p<0.05$), SEM=Standard Error of Mean, F=Fire, SG=Stone Gabions, NF=North Facing, SF=South Facing, R=Riparian, GC=Grass cover, Di=Diversity, De=Density, Fr=Frequency

4.2.3 Grass density

Ecological sites had a highly significant ($p<0.05$) effect on grass density in autumn and winter. North facing (76.19%) area had significantly ($p<0.05$) highest grass density, while stone gabions (52.78%) area had significantly ($p<0.05$) lowest grass density in autumn season. Fire (63.81%), south-facing (67.52%), and riparian (57.67%) sites did not differ significantly ($p>0.05$) in grass density. During the winter season, south facing area (65.11%) had significantly ($p<0.05$) highest grass density, while the riparian area (36.67%) had significantly ($p<0.05$) lowest grass density which was not significantly ($p>0.05$) different from stone gabions area (42.96%). North facing (58.89%), south facing sites (65.11%) and fire (56.48) did not differ significantly ($p>0.05$) in grass density. The riparian area (36.67%) significantly ($p<0.05$) reduced grass density similar to the observation at the stone gabions area (42.96%). Grass density during autumn was higher than in winter in all ecological treatments.

4.2.4 Grass frequency

The ecological areas had significant ($p<0.05$) effect on grass frequency in autumn and winter seasons. The result indicated that during autumn, the south-facing (67.63%) slope site had significantly ($p<0.05$) highest grass frequency, while the stone gabions area (45.15%) had significantly ($p<0.05$) lowest grass frequency. Fire (59.33%), and north-facing (65.15%) areas had no significant ($p>0.05$) effect on grass frequency, and similar to the south facing (67.63%), stone gabions (45.15%) and riparian (55.52%) areas which did not differ significantly ($p>0.05$) in frequency, however, stone gabions and south-facing areas significantly ($p<0.05$) differed in grass frequency. In winter, the south-facing (76.70%) slope site had significantly ($p<0.05$) highest grass frequency, while the riparian (37.19%) area had significantly ($p<0.05$) lowest grass frequency. The south facing slope (76.70%) site had significant ($p<0.05$) effect on grass frequency. The north-facing (55.56%) and fire (56.70%) sites showed no significant ($p>0.05$) difference, while riparian (37.19%), and stone gabion (42.19%) areas also had no significant effect on grass frequency. Grass frequency during autumn was higher than in winter in all ecological sites except in the south-facing slopes which was higher than the frequency of grass in autumn.

4.3 Effect of Land Management Practices at Ecological Sites on Soil Properties

The result of different ecological sites on soil properties in autumn and winter is presented in Table 4.3.

4.3.1 Soil pH

Different ecological sites had highly significant ($p<0.05$) effect on soil pH both in both autumn and winter. In autumn, stone gabion had the significantly ($p<0.05$) highest soil pH of 7.66, while the soil pH in fire (6.61), south facing (6.76), north facing (6.75) and riparian (6.39) sites were acidic and did not differ significantly ($p>0.05$). In winter, the ecological sites also had significant ($p<0.05$) effect on the soil pH, and stone gabions (9.19) was highest and south facing least (6.57). The fire (7.47), stone gabions (9.19), and north-facing (8.26) slopes sites had significantly ($p<0.05$) different soil pH, while the south-facing (6.57) and riparian (6.73) areas did not differ significantly ($p>0.05$) in soil pH, which revealed acidity of the soils. Generally, the fire site showed the lowest acidity in the soil pH (6.61) in autumn, while the stone gabions (9.19) showed the highest soil pH in winter.

4.3.2 Soil organic matter

Different ecological treatments had significant ($p<0.05$) effects on soil organic matter in both autumn and winter. In autumn, among all ecological treatments, fire (2.69%) had significantly ($p<0.05$) highest content of organic matter, while stone gabions (1.76%) had significantly ($p<0.05$) lowest content of organic matter. Stone gabions (1.76%), north-facing (1.97%), and riparian (1.77%) had no significant ($p>0.05$) difference on soil organic matter, and the organic matter levels in south facing (2.13%) and north facing (1.97%) sites, were similar. During winter, organic matter content in the south facing (2.93%) site was highest, while it was least in riparian (1.96%), and north-facing (2.70%) slope sites differed significantly ($p<0.05$), while fire (2.05%), stone gabions (2.02%), and riparian (1.96%) sites did not differ significantly ($p>0.05$). The south-facing slope site showed the highest significant ($p<0.05$) organic matter of 2.93%, while the riparian area showed the lowest significant ($p<0.05$) organic matter of 1.96%. For both seasons, fire showed an increased amount of organic matter content during autumn, while all other sites showed a lower amount of organic matter throughout winter.

4.3.3 Soil nitrogen (N)

Varying sites of the rangeland significantly ($p<0.05$) affected nitrogen content in autumn and winter. In autumn, only the fire (65.50%) site had a significant ($p<0.05$) effect on soil nitrogen content, while the soil nitrogen in all other treatments; stone gabions (33.03%), south-facing (30.83%), north-facing (33.67%), and riparian (25.07%) sites did not differ significantly ($p>0.05$). The riparian treatment had the lowest soil nitrogen of 25.07%. In winter, south facing site had soil nitrogen of 64.50%, which was significantly ($p<0.05$) highest while the fire treatment had the lowest significant ($p<0.05$) soil nitrogen of 30.50%. North-facing (33.83%) slope, and stone gabions (33.00%) sites did not differ significantly ($p>0.05$) in soil nitrogen content.

4.3.4 Soil phosphorus (P)

Different ecological sites showed significant ($p<0.05$) effects on soil phosphorus in both autumn and winter. This result showed that the fire site had the significantly ($p<0.05$) highest soil phosphorus of 102.17%, while the stone gabion site had significantly ($p<0.05$) lowest soil phosphorus of 86.50%. Stone gabions (86.50%), south-facing (88.17%), and riparian areas (88.33%) did not have significant ($p>0.05$) effect on soil phosphorus, while fire (102.17%) and north facing slope (98.67%) sites differed significantly ($p<0.05$) in soil phosphorus in autumn season. The winter season gave a significantly ($p<0.05$) highest effect on soil phosphorus for the south facing (103.50%) slope site, and the fire (88.00%) had significantly ($p<0.05$) lowest soil phosphorus. Stone gabions (89.00%), fire (88.00%), and riparian 89.33%) areas showed no significant ($p>0.05$) effect on soil phosphorus, while south facing (103.50%) and north facing (98.50%) slope sites had significant ($p<0.05$) effect on soil phosphorus.

Table 4.3: Effect of Land Management Practices in Ecological Sites on Soil Properties at different Seasons

Seasons	Soil properties	Study Sites					SEM	P value
		F	SG	SF	NF	R		
Autumn	Soil pH	6.61^{b}	7.66^{a}	6.76^{b}	6.75^{b}	6.39^{b}	0.14	0.02
	OM (%)	2.69^{a}	1.76^{c}	2.13^{b}	1.97^{bc}	1.77^{c}	0.10	0.00
	N (%)	65.50^{a}	33.03^{b}	30.83^{b}	33.67^{b}	25.07^{b}	4.28	0.00
	P (%)	102.17^{a}	86.50^{c}	88.17^{c}	98.67^{b}	88.33^{c}	1.74	0.00
	K (%)	164.50^{c}	165.50^{c}	177.50^{b}	178.83^{b}	212.17^{a}	4.65	0.00
Winter	Soil pH	7.47^{c}	9.19^{a}	6.57^{d}	8.26^{b}	6.73^{d}	0.27	0.00
	OM (%)	2.05^{c}	2.02^{c}	2.93^{a}	2.70^{b}	1.96^{c}	0.11	0.00
	N (%)	30.50^{d}	33.00^{c}	64.50^{a}	33.83^{c}	38.33^{b}	3.35	0.00
	P (%)	88.00^{c}	89.00^{c}	103.50^{a}	98.50^{b}	89.33^{c}	1.67	0.00
	K (%)	212.67^{a}	211.67^{a}	165.17^{c}	178.50^{b}	178.17^{b}	5.18	0.00

^{a,b,c,d}Means within a row with different superscripts are significantly different ($p<0.05$), SEM=Standard Error of Mean, F=Fire, SG=Stone Gabions, SF=South Facing, NF=North Facing, R=Riparian, OM=Organic Matter, N=Nitrogen, P=Phosphorus, K=Potassium

4.3.5 Soil potassium (K)

Different ecological sites had significant ($p<0.05$) effect on soil potassium in both autumn and winter seasons. The result indicated that in autumn, the riparian area had significantly ($p<0.05$) highest effect on soil potassium (212.17%), while the soil potassium in south facing (177.50%), and north-facing (178.83%) sites did not differ significantly ($p>0.05$%). Similarly, the soil potassium in fire (164.50%) and stone gabions (165.50%) sites showed no significant ($p>0.05$) difference. The fire site had the lowest soil potassium of 164.50%. During the winter season, the fire site had the highest significant ($p<0.05$) effect on soil potassium (212.67%), though not significantly ($p>0.05$) different from stone gabions (211.67%), while the north facing (178.50%) slope, and riparian (178.17%) sites had no significant ($p>0.05$) effect on soil potassium. The south-facing slope had the lowest significantly ($p<0.05$) soil potassium of 165.17%.

4.4 Effect of Land Management Practices at Ecological Sites on Seed Weight of Grass

The result of the effect of different ecological sites on the seed weight of grass species in autumn and winter seasons is presented in Table 4.4.

4.4.1 Grass seed weight

Different ecological sites had significant ($p<0.05$) effect on seed weight in the autumn and winter seasons. In autumn, the north-facing slope site had significantly ($p<0.05$) highest grass seed weight of 0.63 g, while the south-facing slope site had lowest significant ($p<0.05$) grass seed weight of 0.26 g, which did not differ significantly ($p>0.05$) from 0.36 g in the riparian site. The fire (0.49 g) and stone gabions (0.48 g) treatments did not differ significantly ($p>0.05$) in grass seed weight. During the winter season, the north-facing slope site had highest seed weight of 0.89 g, whereas stone gabion and riparian areas had the lowest significant ($p<0.05$) grass seed weight of 0.25 g each. Also, the grass seed weight in the fire (0.31 g), stone gabions (0.25 g), south facing (0.49 g), and riparian (0.25 g) sites did not differ significantly ($p>0.05$).

Table 4.4: Seed Production at the Ecological Sites in Autumn and Winter

Seasons	Seed Production	Study Sites					SEM	P value
		F	SG	NF	SF	R		
Autumn	Seed weight (g)	0.49^{ab}	0.48^{ab}	0.63^{a}	0.26^{b}	0.36^{b}	0.04	0.03
Winter	Seed weight (g)	0.31^{b}	0.25^{b}	0.89^{a}	0.49^{ab}	0.25^{b}	0.07	0.02

[a,b]Means within a row with different superscripts are significantly different ($p<0.05$), SEM=Standard Error of Mean, F=Fire, SG=Stone Gabions, SF=South Facing, NF=North Facing, and R=Riparian

4.5 Effect of Land Management Practices at Ecological Sites on Grass Nutrient Content

The result of the effect of different ecological sites on forage quality of grasses in autumn and winter is presented in Table 4.5.

4.5.1 Dry matter (DM)

Varying ecological sites had insignificant ($p>0.05$) effect on dry matter in autumn and winter seasons.

4.5.2 Crude protein (CP)

Different ecological sites had significant ($p<0.05$) effect on CP in both autumn and winter. In autumn, stone gabions site had significantly ($p<0.05$) highest CP of 2.21%, while the south facing slope site had significantly ($p<0.05$) lowest CP of 1.31%. Stone gabion CP of 2.21% area, and north facing CP of 1.99% slope site did not differ significantly ($p>0.05$), while fire CP of 1.50% area, south facing CP of 1.31% slope site, and riparian CP of 1.45% area, also had no significant ($p>0.05$) difference in CP. During winter, the CP of north facing (2.27%) slope, and stone gabion (2.27%) areas had significantly ($p<0.05$) highest CP, while the CP of fire (1.60%) was significantly ($p<0.05$) least. Stone gabions, and north facing slope area had no significant ($p>0.05$) effect on CP, and similarly, fire and south facing areas.

4.5.3 Neutral detergent fibre (NDF)

The ecological sites had significant ($p<0.05$) effect on NDF in autumn and winter seasons. In autumn, south facing NDF (80.05%) had significantly ($p<0.05$) highest NDF, while stone gabions site had significantly ($p<0.05$) lowest NDF (70.36%). The NDF of north (79.77%), and south facing (80.05%) slope sites did not differ significantly ($p>0.05$). Also, NDF of fire (76.75%), and riparian (77.59%) sites did not differ significantly ($p>0.05$). In winter, stone gabions site had significantly ($p<0.05$) highest NDF of 79.95%, and NDF for north facing slope site had significantly ($p<0.05$) lowest NDF of 77.09%. South facing slope site had a significantly ($p<0.05$) depressed NDF of 78.57%, which did not differ from the riparian NDF of 79.20% and fire NDF of 78.10%. The north facing NDF (77.09%) was the lowest but was not statistically different ($p<0.05$) from fire NDF of 78.10%.

4.5.4 Acid detergent fibre (ADF)

Varying ecological sites had significant ($p<0.05$) effect on ADF in autumn and winter seasons. In autumn, south facing slope site had significantly ($p<0.05$) highest ADF of 53.94%, while

Table 4.5: Effect of Land Management Practices on Nutrient Content at Rangeland Sites in different Seasons

Seasons	Nutrient Content	Study Sites					SEM	P value
		F	SG	NF	SF	R		
Autumn	Dry Matter (%)	39.30	38.12	40.75	48.76	51.39	2.09^{ns}	0.11
	Crude Protein (%)	1.50^{b}	2.21^{a}	1.99^{a}	1.31^{b}	1.45^{b}	0.12	0.04
	NDF (%)	76.75^{b}	70.36^{c}	79.77^{a}	80.05^{a}	77.59^{b}	1.03	0.00
	ADF (%)	46.72^{b}	42.41^{e}	43.55^{d}	53.94^{a}	44.73^{c}	1.21	0.00
	ADL (%)	7.78^{b}	7.87^{b}	5.46^{c}	8.63^{a}	5.56^{c}	0.41	0.01
	Hemicellulose (%)	30.03^{c}	27.95^{d}	36.22^{a}	26.11^{d}	32.86^{b}	0.98	0.00
	Cellulose (%)	38.94^{b}	34.54^{c}	38.09^{b}	45.31^{a}	39.17^{b}	0.98	0.00
	Ash (%)	3.50^{a}	2.83^{ab}	2.17^{b}	2.17^{b}	3.17^{a}	0.18	0.02
Winter	Dry Matter (%)	40.74	40.58	52.23	43.92	44.33	1.92^{ns}	0.34
	Crude Protein (%)	1.60^{c}	2.27^{a}	2.27^{a}	1.80^{bc}	2.04^{ab}	0.08	0.01
	NDF (%)	78.10^{bc}	79.95^{a}	77.09^{c}	78.57^{b}	79.20^{ab}	0.32	0.02
	ADF (%)	49.19^{b}	43.98^{d}	46.88^{c}	50.22^{a}	43.78^{d}	0.76	0.00
	ADL (%)	8.00^{a}	4.85^{b}	8.04^{a}	7.74^{a}	4.74^{b}	0.49	0.01
	Hemicellulose (%)	28.91^{bc}	35.97^{a}	30.21^{b}	28.35^{c}	35.42^{a}	0.91	0.00
	Cellulose (%)	41.19^{b}	39.13^{c}	38.84^{c}	42.48^{a}	39.04^{c}	0.37	0.00
	Ash (%)	1.00^{bc}	2.17^{a}	0.83^{c}	2.17^{a}	1.83^{ab}	0.18	0.01

^{a,b,c,d,e}Means in the same row with different superscripts are significantly different ($p<0.05$), SEM=Standard Error of Mean, ^{ns}Not significantly different ($p>0.05$), F=Fire, SG=Stone Gabions, SF=South Facing, NF=North Facing, R=Riparian, NDF=Neutral Detergent Fibre, ADF=Acid Detergent Fibre and ADL=Acid Detergent Lignin.

stone gabions site had significantly ($p<0.05$) lowest ADF of 42.41%. The ADF in fire site (46.72%), north facing site (43.55%) and riparian site (44.73%), were in between the south facing and stone gabions values. In winter, south facing site had significantly ($p<0.05$) highest ADF, while riparian area had significantly ($p<0.05$) lowest ADF of 50.22% and 43.78% respectively. South facing (50.22%), fire (49.19%), and north facing (46.88%) areas, had significant ($p<0.05$) difference in ADF, while stone gabions (43.98%), and riparian (43.79%) areas did not differ significantly ($p>0.05$) in ADF.

4.5.5 Acid detergent lignin (ADL)

Different ecological sites had significant ($p<0.05$) effect on ADL during autumn and winter. In autumn, south facing (8.63%) site had significantly ($p<0.05$) highest ADL, while north facing slope site had significantly ($p<0.05$) lowest ADL of 5.46%. Fire ADL (7.78%), and stone gabion ADL (7.87%) sites, did not differ significantly ($p>0.05$) in ADL. Also, north facing ADL (5.46%) slope, and riparian (5.56%) area, did not differ significantly ($p>0.05$). In winter, north facing ADL (8.04%) slope site had significantly ($p<0.05$) highest ADL, and did not differ significantly ($p>0.05$) from fire ADL (8.00%) and south facing ADL (7.74%) sites, while riparian ADL (4.74%) area had significantly ($p<0.05$) lowest. Stone gabions ADL (4.85%) and riparian ADL (4.74%) areas also did not differ significantly ($p>0.05$).

4.5.6 Hemicellulose

Different ecological treatments had significant ($p<0.05$) effect on hemicellulose in autumn and winter seasons. In autumn, north facing and south facing slopes sites had significantly ($p<0.05$) highest and lowest hemicellulose of 36.22% and 26.11%, respectively. North facing hemicellulose (36.22%), riparian hemicellulose (32.86%), and fire hemicellulose (30.03%) treatments differed significantly ($p<0.05$), while stone gabions hemicellulose (27.95%), and south facing hemicellulose (26.12%) areas did not differ significantly ($p>0.05$). In winter, stone gabions hemicellulose area and south facing hemicellulose slope had significantly ($p<0.05$) highest and lowest hemicellulose of 35.97% and 28.35% respectively. Stone gabions hemicellulose (35.97%) and riparian (35.42%) sites did not differ significantly ($p>0.05$). However, both south facing hemicellulose (28.35%), and north facing hemicellulose (30.21%) sites differed significantly ($p<0.05$) in hemicellulose but similar to fire (28.88%) treatment.

4.5.7 Cellulose

Varying ecological sites had significant ($p<0.05$) effect on cellulose in autumn and winter. In autumn, south facing site had significantly ($p<0.05$) highest cellulose of 45.31%, while stone gabion site had significantly ($p<0.05$) lowest cellulose of 34.54%. The south facing cellulose (45.31%) and stone gabions cellulose (34.54%) differed significantly ($p<0.05$), while fire (38.94%), north facing (38.09%), and riparian (39.17%) cellulose sites, did not differ significantly ($p>0.05$). In winter, south facing slope had significantly ($p<0.05$) highest cellulose of 42.48%, while north facing slope had significantly ($p<0.05$) lowest cellulose of 38.84%. South facing cellulose (42.48%) slope, and fire cellulose (41.19%) sites differed significantly ($p<0.05$), while stone gabions cellulose (39.13%), north facing cellulose (38.84%), and riparian cellulose (39.04%) sites did not differ significantly ($p>0.05$).

4.5.8 Ash content

The ecological sites had significant ($p<0.05$) effect on ash content in autumn and winter seasons. In autumn, fire site had significantly ($p<0.05$) highest ash content of 3.50%, while north and south facing ash content slope sites had significantly ($p<0.05$) least ash content of 2.17% each. Fire (3.50%) and riparian (3.17%) cellulose sites did not differ significantly ($p>0.05$) in ash content, and similar to stone gabions ash content (2.83%) site. Both north (2.17%) and south facing ash content (2.17%) ash content did not differ significantly ($p>0.05$) from stone gabions ash content (2.83%) site. In winter, stone gabions and south facing slope sites had significantly ($p<0.05$) highest ash content of 2.17% each, while north facing site had significantly ($p<0.05$) lowest ash content of 0.83%. North facing ash of 0.83% did not differ significantly ($p>0.05$) from fire ash content (1.00%).

4.6 Effect of Grass Species on Vegetation Characteristics at different Seasons

The effect of the available grass species in winter on different vegetation characteristics is presented in Table 4.6. *Sporobolus cotractus, Paspalum delatatum* and *Muhlenbergia capillaries* though identified in autumn, were not available in winter.

4.6.1 Grass cover

Different grass species had insignificant ($p>0.05$) and significant ($p<0.05$) effect on grass cover in autumn and winter, respectively. In winter, *Themeda triandra* species had significantly highest grass cover of 51.33%, while *Halcus lanatus* (25.00%) species had significantly lowest grass cover of 25%. *Themeda triandra* (51.33%) species had significant ($p<0.05$) effect on grass cover, but similar to *Eragrostis curvula* (44.00%), *Cynodon dactylon* (39.00%), and *Hypperhenia hirta* (44.67%) species. *Eragrostis curvula* (44.00%) and *Hypperhenia hirta* species (44.67%) did not differ significantly ($p>0.05$) with *Cynodon dactylon* (39.00%) and *Arudenela nepalensis* (27.67%) species. *Halcus lanatus* (25.00%) species had significant ($p<0.05$) effect on grass cover, but did not differ with significantly ($p>0.05$) with *Arudenela nepalensis* (27.67%) and *Cynodon dactylon* (39.00%) species.

4.6.2 Grass diversity

Different grass species had significant ($p<0.05$) effect on grass diversity in autumn and winter. In autumn, *Themeda triandra* species had significantly ($p<0.05$) highest grass diversity of 18.27%, while *Halcus lanatus* species (11.13%) had significantly ($p<0.05$) least grass diversity of 11.13%. *Themeda triandra* (18.27%) and *Eragrostis curvula* (17.27%) species had no significant ($p<0.05$) effect on grass diversity, but did not differ significantly ($p>0.05$) with *Cynodon dactylon* (15.80%) and *Hypperhenia hirta* (14.60%) species. *Halcus lanatus* (11.13%) species had significant ($p<0.05$) difference in grass diversity, but did not vary significantly ($p>0.05$) from *Arudenela nepalensis* (12.20%) and *Hypperhenia hirta* (14.60%) species. In winter, *Themeda triandra* species had significantly ($p<0.05$) highest grass diversity of 16.20%, while *Halcus lanatus* species had significantly ($p<0.05$) least grass diversity of 7.53%. *Themeda triandra* (16.20%) species had significant ($p<0.05$) effect on grass diversity, but did not differ significantly ($p<0.05$) from *Eragrostis curvula* (14.47%) species. *Cynodon dactylon* (12.40%) and *Hypperhenia hirta* (11.47%) species were significantly ($p>0.05$) the same, and did not differ from *Arudenela nepalensis* (8.80%) species.

Table 4.6: Effect of Grass Species on Vegetation Characteristics at different Seasons

Seasons	Ecological Indices	Grass Species						SEM	P value
		Tt	Ec	Cd	Hh	An	Hl		
Autumn	GC (%)	45.33	48.6	49.67	43.00	46.00	47.00	1.95^{ns}	0.94
	Di (%)	18.27^{a}	17.27^{a}	15.80^{ab}	14.60^{abc}	12.20^{bc}	11.13^{c}	0.63	0.00
	De (%)	70.80	68.53	70.80	61.93	61.87	75.40	3.01^{ns}	0.76
	Fr (%)	68.93	59.33	64.47	62.20	54.80	57.00	2.57^{ns}	0.65
Winter	GC (%)	51.33^{a}	44.00^{ab}	39.00^{abc}	44.67^{ab}	27.67^{bc}	25.00^{c}	2.27	0.03
	Di (%)	16.20^{a}	14.47^{ab}	12.40^{bc}	11.47^{bc}	8.80^{cd}	7.53^{d}	0.65	0.00
	De (%)	73.20	61.87	57.40	68.80	46.20	46.33	3.25^{ns}	0.07
	Fr (%)	71.00	58.53	57.07	62.20	43.73	53.93	2.88^{ns}	0.14

^{a,b,c,d}Means within a row with different superscripts are significantly different ($p<0.05$), ^{ns} Not significantly ($p>0.05$) different, Tt=*Themeda triandra*, Ec=*Eragrostis curvula*, Cd=*Cynodon dactylon*, Hh=*Hyperhenia hirta*, An=*Arundenela nepalensis*, Hl=*Halcus lanatus*, SEM=Standard Error of Mean, GC=Grass cover, Di=Diversity, De=Density, and Fr=Frequency

4.6.3 Grass density

Different grass species had insignificant ($p>0.05$) effects on grass density in both autumn and winter.

4.6.4 Grass frequency

Different grass species had insignificant ($p>0.05$) effects on grass frequency in autumn and winter

4.7 Correlation of Ecological Characteristics between Autumn and Winter

The result of the correlation between ecological indices during autumn and winter is shown in Table 4.7. In autumn, diversity and grass cover had positive, strong and significant ($p<0.05$) correlation of $r=0.58$ and $p=0.00$. Density and grass cover had positive, strong and significant ($p<0.05$) correlation with $r=0.80$ and $p=0.00$. Density and diversity had positive, strong and significant ($p<0.05$) correlation of $r=0.53$ and $p=0.00$. Frequency and grass cover had positive, strong and significant ($p<0.05$) correlation with $r=0.58$ and $p=0.00$. Frequency and diversity had positive, strong and significant ($p<0.05$) correlation of $r=0.45$ and $p=0.00$. Frequency and density had positive, strong and significant ($p<0.05$) correlation with $r=0.63$ and $p=0.00$. In winter, diversity and grass cover had positive, strong and significant ($p<0.05$) correlation of $r=0.83$ and $p=0.00$. Density and grass cover had positive, strong and significant ($p<0.05$) correlation with $r=0.90$ and $p=0.00$. Density and diversity had positive, strong and significant ($p<0.05$) correlation of 0.80 and $p=0.00$. Frequency and grass cover had positive, strong and significant ($p<0.05$) correlation with $r=0.68$ and $p=0.00$. Frequency and diversity had positive, strong and significant ($p<0.05$) correlation of $r=0.67$ and $p=0.00$. Frequency and density had positive, strong and significant ($p<0.05$) correlation with $r=0.69$ and $p=0.00$.

Table 4.7: Correlation of Ecological indices between Autumn and Winter Seasons

Seasons	Ecological Indices	Grass Cover	Diversity	Density	Frequency
Autumn	Grass cover				
	r	1			
	p				
	Diversity				
	r	0.59	1		
	p	0.00			
	Density				
	r	0.80	0.53	1	
	p	0.00	0.00		
	Frequency				
	r	0.58	0.45	0.63	1
	p	0.00	0.00	0.00	
Winter	Grass cover				
	r	1			
	p				
	Diversity				
	r	0.83	1		
	p	0.00			
	Density				
	r	0.90	0.79	1	
	p	0.00	0.00		
	Frequency				
	r	0.68	0.67	0.69	1
	p	0.00	0.00	0.00	

Correlation is significant at the 0.05 level (2-tailed)
r = Pearson's correlation coefficient value
p = Probability value

CHAPTER FIVE

5.0 DISCUSSION

5.1 Identification of Grass Species and Botanical Composition

Nine common grass species namely *Arundinella nepalensis, Cynodon dactylon, Themeda triandra, Muhlenbergia capillaris, Halcus ianatus, Hyperrhnia hirta, Sporobolus contractus, Paspalum delatatum* and *Eragrostis curvula* were identified in the study sites. Some have different botanical characteristics (*Cynodon dactylon, Themeda triandra, and Eragrostis curvula*), grazing value (*Arundinella nepalensis, Muhlenbergia capillaris, and Themeda triandra*) and uses (*Arundinella nepalensis, Paspalum delatatum, and Hyperrhnia hirta*). However, (*Paspalum delatatum, Themeda triandra, Halcus lanatus, and Hyperrhnia hirta*) have comparable botanical characteristics, grazing value (*Hyperrhnia hirta, Sporobolus contractus, and Eragrostis curvula*) and uses (*Paspalum delatatum, Sporobolus contractus, and Themeda triandra*). The availability and quality of different grass species are believed to vary from season to season due to seasonality in rainfall distribution which may affect growth and development of plant species, particularly grasses and other herbaceous species (Alassan *et al.*,2019). Grass species composition varied from site to site in this study, and may be related to the management and utilization aspects of rangelands as observed by Mosisa *et al.* (2021). Botanical composition is one of the means of studying ecological changes in the development of rangelands (Malan and Niekerk, 2005). It has been reported that the ability of grassland to provide forage as an important source of nutrients to support livestock productivity depends on the above-ground net primary productivity and the nutritional value of the available vegetation (Mosisa *et al.*, 2021). The performance of animals grazing rangelands is also influenced by the availability and nutritional quality of the biomass on offer (Vazquez and Smith, 2000). Furthermore, the knowledge of the nutritional variation in grassland forage species is important to sustain satisfactory growth and reproduction of livestock without deterioration of rangelands (Ganskopp and Bohnert, 2001). The grass cover was rated high because it showed no bare grounds even though some areas had more rocks at high elevated areas of the rangeland during autumn and winter. Fire and south facing sites showed more bush with some dominating grass species such as *Themeda triandra* which indicates that it prefers the higher elevated area, and the north facing area showed dominance of *Hyperrhnia hirta, Themeda triandra* and *Eragrostis curvula*, and other grass species dominating less during both seasons. Grass species such as *Sporobolus cotractus* and *Muhlenbergia capillaries* though identified in autumn, were not

available in winter while *Paspalum delatatum* grass was available because it multiplies using its roots.

5.2 Effect of Rangeland Management Practices on Vegetation Characteristics at Ecological Sites in different Seasons

5.2.1 Grass cover

Different range management practices affected grass cover in autumn and winter seasons which could be due to combination of environmental factors which varied across the ecosystems. Rangeland fire and stone gabions did improve vegetation cover but not as high as in the ecological sites of the rangeland which showed higher grass or vegetation cover mainly in the north facing slope with *Hyperhenia hirta* and *Themeda triandra* species dominating. According to Assadian *et al.* (2023), rangeland fires can have positive or negative effects on the ecosystem components. The result in this study concur with Louhaichi *et al.* (2022) who indicated that grass cover was higher in the north-facing slopes than south-facing slopes, rangeland management practices (rangeland fire and stone gabions) and riparian area. The results also agree with Smit *et al*. (2024) who indicated that grassland vegetation is characterized by a relatively high grass cover in the north-facing slope aspect with *Themeda triandra* grass showing dominance in the north-slope, because it adapted well to the soil type and environmental conditions in the north facing slope than other grass species. It could also be because of the prevalence of *Themeda triandra* prevalence across different ecological zones. *Themeda traindra* species have great economic and ecological value, as it is a palatable species (Tsilane, 2018). According to Chau and Chu (2017), increased vegetation cover on the rangeland can lead to improved slope soil quality, and reduction in soil erosion in vulnerable ecological sites such as north-facing sites thus facilitating ecosystem restoration. However, stone gabions site showed little vegetation cover in autumn season. This could be because in rangelands, where the soil was prone to erosion, and the rangeland easily be washed away, these conditions make it difficult for vegetation to establish itself for survival. Again, decreased grass cover could be due to high evaporation rate of soil moisture content (Koç, 2001), and ultimately causing decrease in the canopy cover in rangelands. When it is dry in winter, riparian areas which depend heavily on local water sources may freeze or become reduced and as a result plants may not receive enough moisture content to sustain their growth and consequently caused the limited vegetation cover on the rangelands.

5.2.2 Grass diversity

Varying rangeland management practices affected grass diversity at the ecological sites in both autumn and winter. This could be due to the increased grass diversity in the southern slope because of the presence of herbaceous vegetation. According to Yayneshet *et al.* (2009), the higher diversity, richness, and biomass of grass can be attributable to increased litter accumulation, improved soil organic matter, and other nutrients. The result obtained is in line with Singh (2018) who found that vegetation structure and abundance were greater in the south-facing slopes during winter. Conversely, grass species diversity was higher in south-facing slopes and increased from lower to upper elevation of the rangeland and followed by rangeland fire. Also, the south-facing slope showed higher grass diversity in autumn, which was similar to an earlier report (Auslander *et al.*, 2003). Mostly, plant diversity is higher in the south-facing slope in rangelands. Therefore, a higher abundance of species and presence of grasses in the southern aspect may be related to lower and higher thresholds for air temperature and soil moisture. The grass diversity result in this study did not agree with Louhaichi *et al.* (2022), who found that species diversity and biomass production were higher in the north-facing slope site than in south-facing slopes in autumn and winter.

5.2.3 Grass density

Rangeland management practices affected grass density at the ecological sites in autumn and winter. It could be due to higher grass density in the south-facing slope during winter in response to the abundant and dominant species *Themeda triandra*, which did not only increase grass density, but also increased grass density. The result agrees with Soubry *et al.* (2022) who discovered that cooler slope aspects (south facing slope) are characterized by greater grass density and cover of encroaching woody grass than warmer slope aspects (north facing slope). Furthermore, Louhaichi *et al.* (2022), stated that grass density was higher in the north-facing slopes than south-facing slopes. According to Louhaichi *et al.* (2022), grasses (Poaceae) are more abundant on the south-facing than the north-facing slopes in winter season because south-facing slopes receive more direct sunlight than north-facing slopes and consequently animals graze more in the slope site. Nevertheless, high grazing pressure on the north facing slope can reduce density of palatable grass species, forcing animals to forage on species of low nutrition value (Jawuoro *et al.*, 2017). Also according to Hailu (2017), a low density of vegetation on stone gabions with woody species may indicate an increase of soil nutrient status and thus encourage grass-growing conditions. In autumn and winter seasons, low grass or vegetation density around stone gabions could be because grass seeds are prone to water erosion or runoff and overgrazing which can easily wash away seeds or create an overly dry conditions. Riparian

areas also showed low grass density in winter which maybe because of increased grazing pressure as animal are attracted to the riparian zones due to the available water, and the nutritious vegetation. Hence, the trampling and concentrated animals grazing may lead to the reduction of grass density.

5.2.4 Grass frequency

Different range management practices affected grass frequency at ecological sites in autumn and winter seasons. This could be due to the rangeland receiving adequate rainfall which enabled cool grasses to experience late growth spurt and ultimately leading to the high frequency in the south facing slope. The result agrees with Farzam and Ejtehadi (2017) who showed that annual and perennial grasses were abundant in the southern slope site and increased species occurrence in the rangeland. Grass species' contribution to the botanical composition varied overtime across the rangeland. Rangeland slope has been observed to influence almost all properties of vegetation, such as species composition and distribution, plant performance and photosynthetic efficiency, cover and productivity, species diversity and functional diversity, plant invasion, leaf, distribution of plants, and nutrient dynamics (Yanyan *et al.*, 2017). In the rangeland, after stone gabions were constructed, abundance of deep-rooted native grass increased in the streambed, and species such as *Cynodon dactylon* massively expanded on the rangeland. According to Norman *et al.* (2014), stone gabions improved vegetation changes. In winter season, livestock spend most of the time grazing in bottom lands, riparian areas due to easy access to vegetation and water points so, grass species declined or reduced. In autumn, gabions may influence the distribution of soil nutrients required, therefore areas surrounding stone gabions could have lower organic matter content and nutrients, and as a result may reduce the soil fertility and finally inhibiting growth and development of grass species on the rangeland.

5.3 Effect of Range Management Practices on Soil Properties at the Ecological Sites in different Seasons

5.3.1 Soil pH

Soil pH in autumn and winter seasons differed significantly. From autumn to winter seasons, soil pH generally increased maybe due to the reduction in the rate of microbial and plant growth. Soil pH value was found to be significantly higher in the southern aspect which might be due to wetter conditions on north-facing aspects that facilitate greater leaching which increase the hydrogen (H) ion in the soil. Soil pH has a major influence on the accessibility of

nutrients to plants (Dewangan *et al.,* 2023). Nutrients essential for plant growth and development, such as nitrogen, phosphorus, and potassium, are the most available to plants at a soil pH between 6.0 and 7.0 (Dewangan *et al.,* 2023). When the soil pH is too low or too high, the availability of nutrients decreases, and plants suffer from nutrient deficiencies (Zhang, *et al*., 2016). The report by Ahuchaogu *et al.* (2022), found that even though some grass species or crops can thrive in acid or alkaline media, however, soils with a pH range of 6.0-7.0 (slightly acidic to neutral) are best suited to many plants. The finding of Salim *et al.* (2015), showed that low pH in the south-facing aspect is due to organic matter accumulation in the form of plant or grass litter, compost, and manure which decreased soil pH through the decomposition process that occurred during winter. In general, the autumn season showed superior soil pH that can support grass or plant growth better than winter.

5.3.2 Soil organic matter (OM)

The soil organic matter in both autumn and winter varied significantly across the sites. Organic matter is an important soil quality and can be cited as one of the most effective predictors of soil fertility and structure in rangelands. The amount of organic matter content in soil vary widely because it changes rapidly over time. According to Elakiya *et al.* (2023), following rangeland fire, the amount of organic matter content may increase because of large amount of dead root biomass due to lack of aboveground litter fall in autumn. The cover of the reeds is easily burned by fire, producing high amount of nitrogen and organic carbon in autumn, which leads to increase in the amount of organic matter and nitrogen contents in the soils in the burned rangelands (Al Bayaty *et al.*, 2023). However, increasing amount of soil organic matter content in the north facing aspect in winter can be attributed to more organic carbon and more nitrogen accumulation in the soil because of higher soil water content and less evaporation (Johnson *et al.,* 2011). The southern aspect in the higher elevation in winter tends to accumulate more significant organic matter content but does not show signs of increased chemical weathering in the north facing slopes.

5.3.3 Soil nitrogen (N)

Varying management practices affected soil nitrogen in autumn and winter at the study sites. This could be because nitrogen element is the most limiting factor for grassland productivity because it stimulates tiller development, increases leaf size, and lengthens the period of green leaves colour. This could be due to higher nitrogen mineralisation rate which was higher in the south facing aspect in winter. According to Snyman (2015), nitrogen losses after burning may

limit vegetation growth and development immediately after rangeland fire. From autumn to winter, soil nitrogen declined in the fire site due to loss of vegetation cover, after rangeland fires increased soil erosion due to removal of nutrient-rich top soil layers which contained significant amounts of soil nitrogen on the rangelands in the rangeland fire. Soil nitrogen remain the major limiting resource for plants in ecosystems. The amount of available nitrogen in the soil changes seasonally via plant-microbial interactions, and unpredictable year-to-year fluctuations often occur naturally (Nishitani *et al.*, 2020). Due to temperatures and precipitation, limited rainfall can reduce biological activity which ultimately contributes to nitrogen fixation and organic matter decomposition leading to lower nitrogen availability in riparian soils area in autumn. The current study is in line with Ahuchaogu *et al.* (2022), who found that total nitrogen values for riparian site (autumn) and fire site (winter) were very low and it could be due to leaching of nutrients with high infiltration rate.

5.3.4 Soil phosphorus (P)

Soil phosphorus in autumn and winter seasons differed across study sites. This could be because of plants and leftover burns which were left after fire, turning into ash in the soil, and ultimately increasing P content during autumn. Burning of rangelands is considered to be more beneficial to the accumulation of phosphorus content in the soils (Hanfi *et al.*, 2020). From autumn to winter, rangeland fire showed a decrease in available phosphorus with rise in soil pH from 7 to 9, due to absence of vegetation cover (Ross *et al.*, 2008). According to Singh (2018), available phosphorus was found to be significantly higher in the southern aspect in winter which could be because south facing slopes receive more sunlight which can enhance microbial activity and organic matter decomposition.

5.3.5 Soil potassium (K)

Soil potassium is one of the primary and macronutrient required by plants to complete their life span (Al Bayaty *et al.*, 2023). Different rangeland management practices affected soil potassium during autumn and winter. It could be because of a positive co-relationship between organic matter and available potassium and the increase in organic matter content which tends to increase the accumulation of available potassium in the soil. The highest amount of potassium was observed in the riparian (in autumn) and rangeland fire sites (in winter) which could be due to the presence of livestock throughout the year and higher grazing intensity. Also animal trampling and their excreta could lead to increase in potassium content in the soil as they will be near the water points.

5.4 Effect of Range Management Practices and on Grass Seed Production at Ecological Sites in different Seasons

Different range management practices significantly affected grass seed production in autumn and winter seasons across the study sites. This could be because grass seeds species dropped on the ground surface after maturation, they are small and more durable and as a result become less damaged. In this regard, grass seeds may start to grow in the following year after their dormancy. Mostly, grass seeds are capable of germinating after a rangeland fire, such as annual species with fine seeds and survival seed banks (Assadian *et al.,* 2023). The result in this study is in line with Snyman and Van Wyk, (2005) that rangeland fire and stone gabions increased seedling emergence in comparison with the lower number of grass seed productivity in unburnt ecological sites in autumn and winter. Grass seeds which have a healthy seed coat, embryo, and endosperm can germinate and grow in the growing season. Many grasslands are able to survive recurrent disturbance by re-sprouting. How plants re-sprout after disturbance depends on the number and location of the dormant seeds. These traits varied widely among grass species, depending on the phylogenetic context of the species and disturbance regime in which it evolved (Pausas *et al.*, 2018).

5.5 Effect of Rangeland Management Practices on Vegetation Nutrient Content at Ecological Sites in different Seasons

5.5.1 Dry matter (DM)

Varying range management practices did not affect dry matter of vegetation at the ecological sites in autumn and winter seasons. This could be due to seasonal variations in the nutrient content, which are influenced by multiple factors including soil moisture, plant maturity, and climatic conditions. The results do not agree with Louhaichi *et al*. (2013) where significantly higher dry matter of grass was found on the north-facing slope. The factors which have been reported to affect the nutritive value of herbaceous plants are species variation, soil nutrient status of production location, grazing pressure and rangeland management practices (Mosisa *et al.*, 2021).

5.5.2 Crude protein (CP)

Different range management practices effected crude protein content in autumn and winter seasons. The variation in crude protein content of herbaceous forages among the sites might be due to variation in species composition, soil fertility, and management practices of the

grasslands. Due to less grazing pressure in autumn, animals tend to avoid grazing too close to stone gabions areas due to uneven terrains and then leave more vegetation as a result. The grasses are less grazed and tend to be in their early growth stage and could have higher crude protein content compared to those areas overgrazed by animals. The result is in line with Pule *et al.* (2023) who found that higher crude protein concentrations during the wet season compared with the dry season might be due to a higher photosynthetic rate and moisture content, which increase plant nitrogen uptake

According to Fenetahum *et al.* (2021), crude protein concentration is high during the rainy seasons because grass species' mineralization rate and nitrogen assimilation increase, whereas during the dry season, there is a scarcity of precipitation and thus a slow regrowth rate, and forages are highly mature, resulting in high fibre and low crude protein concentration. The south facing slopes experienced low crude protein content due to the reduced soil moisture stresses and causing grass to grow very slowly and become more fibrous and ultimately decrease crude protein content. However, in winter, water deficit in the growing season enhances the senescence of grass leaves, and as a consequence, crude protein is relocated from plant leaves to the plant roots and forage nutritive value declines (Mainetti *et al.*, 2023). According to (Ramírez *et al.* (2009), crude protein content in grasses decline as the plant increase its maturity, and possibly because of the relative increase in the cell wall and decrease in the cytoplasm. Crude protein losses was greater in winter, which is consistent with this study having appreciably lower crude protein concentration. As the season progressed and grasses matured, crude protein content decreased due to increased proportion of structural carbohydrates against cell contents and the accumulation of nutrients to the flowers and grass seeds.

5.5.3 Neutral detergent fibre (NDF)

The fibre contents of plant sources stand as essential part for knowing their feeding value. This could be due to the higher amount of fibre and the higher proportion of stems in forage or vegetation in the rangeland. The south facing slope showed the highest nutrient detergent fibre content than range management practices in autumn. The result is in line with Ates (2017) who stipulated that south-facing slope showed highest nutrient detergent fibre content which could be due to the fact that grasses in the south facing aspect have more stems and higher stem to leaf ratios, which result in greater concentrations of fibrous tissues compared to other forage types. This result is in agreement with Al-Jabareen (2009) that nutrient detergent fibre

increased with maturity of vegetation. According to Louhaichi *et al.* (2021) grass species nutrient detergent fibre were higher than in other forages. In winter, the stone gabion site recorded the highest nutrient detergent fibre of 79.95% as against 70.36% in autumn. Grasses with high nutrient detergent fibre levels result in modest reductions in voluntary intake (Roukos *et al.*, 2011).

5.5.4 Acid detergent fibre (ADF)

Varying range management practices significantly affected acid detergent fibre in autumn and winter with south facing slope site having the highest acid detergent fibre over other study sites. The result of the study showed that grasses with higher stem-to-leaf ratios had higher concentrations of fibrous tissues than other fodder types in autumn and winter. The results agree with Larsen *et al.* (2021) who found that greater increases in acid detergent fibre concentrations occurred in the south facing slope aspect which was wetter, and had a greater percentage composition of grasses. Also, Louhaichi *et al.* (2021), reported that grass species acid detergent fibre was higher in the south facing slopes than in other forages. Generally, higher fibre concentrations result in low nutritional feed value for animals (Lee, 2018). Therefore, these grass species may offer poor-quality forage. Hussain and Durrani, (2009) had observed increase in nutrient detergent fibre and acid detergent fibre in grass species at different growth stages, which is similar to observation in this study.

5.5.5 Acid detergent lignin (ADL)

Different range management practices affected acid detergent lignin in autumn and winter. This could be because of the warmer and high grazing pressure of the rangeland and the warmer weather conditions. This result agree with the study of Farzam and Ejtehadi (2017) who found that south-facing slopes generally experience higher temperature, greater light intensity, and lower moisture availability than north-facing slopes which have low acid detergent lignin. Furthermore, Larsen *et al.* (2021), greater increases in acid detergent lignin concentrations occurred in the south facing slope, due to greater percentage composition of grasses. The result also agrees with the study of Barshila and Devkota, (2013) who reported high acid detergent lignin in rangeland species in autumn season. Natural pasture yield in the north facing slopes was reported significantly higher than in the south facing slopes due to water availability in the form of ice and snow in winter (Gong *et al.*, 2008). This could be due to lignin content which was proportionally higher in stems than other parts of the plant.

5.5.6 Hemicellulose

Different range management practices affected hemicellulose content in autumn and winter. In the current study, hemicellulose was highest in the north facing slope in autumn while, highest in stone gabions in winter. This could be due to several factors, such as grain hardness, fibre quality, seasonal digestibility and environment. According to Sultan *et al.* (2008), fibre and lignin contents increase over time as grasses mature, and the structural constituent of hemicellulose increased in grasses from early bloom to maturity stage. In winter, stone gabions and riparian areas differed significantly because of variation in the amount of structural carbohydrates which occurred with seasonal changes and growth stages of the plant. According to Van Soest, (1994) most grasses have high hemicellulose content.

5.5.7 Cellulose

Varying management practices affected the vegetation cellulose content in both autumn and winter seasons. The south facing slope aspect had the highest cellulose content and stone gabions the lowest in autumn. This could be due to the varying environmental conditions of the grass species, the plant age and the cellulose chemical composition in grasses. The result of this study reported that due to the regrowth process of vegetation after burning of the rangeland, lower concentrations of cellulose in stone gabions site and north facing slope is caused by the higher productivity in burned rangeland site, combined with more vigorous growth, which is similar to the findings of Johnson *et al*. (2019).

5.5.8 Ash content

The result of the study showed that the management practices had significant effect on ash content. Ash play an important role in promoting balanced growth of animals. Ash content varied between management practices due to changes in soil composition, nutrient availability, and climatic conditions, which had significant effect on plant growth and composition. The result of the study indicate that concentrations of ash was higher in autumn compared with winter. Ash can have profound ecological, hydrological and geomorphological effects. According to Sasoli (2022), a wide range of ash may be due to climate change, draught, humidity and stage of maturity in a specific season. The result of this study agree with Rodríguez-Montesinos *et al.* (2013) who found that the ash content of certain seaweed species varied with seasons depending on geographic and environmental conditions. Similarly, Hussain and Durrani (2009) reported that ash of forage progressively declined with advancing

maturity and that the increase or decrease of ash with advancing age by different grass species may be due to variation in the soil and other habitat features.

5.6 Effect of Grass Species on Vegetation Characteristics in Autumn and Winter

In autumn, grass cover percentages across the species were relatively high with no significant variations noted between grass species. However, the diversity showed significant variances, indicating that grass species may support more biodiversity than others. For example, *Eragrostis curvula (Ec)* and *Themeda triandra (Tt)* had the greatest diversity, whereas *Halcus lanatus (Hl)* and *Arundinella nepalensis (An)* had much lower grass species diversity. This suggests that, the composition of grass species suggests overall biodiversity within grassland ecosystems, which is consistent with findings which showed the competitive advantage of native grasses over others, which can lead to reduced native plant diversity (Davies, 2011; Damasceno *et al.,* 2018). However, winter season showed a significant decrease in grass cover, particularly for *Arundinella nepalensis (An)* and *Halcus lanatus (Hl),* which had the lowest levels. This decrease could be due to seasonal changes in nutrient availability and plant phenology. The significant differences in the diversity in winter showed the impact of seasonal dynamics on the plant community structure. Grass species may be more resilient to winter conditions and supporting greater biodiversity in the rangeland.

5.7 Correlation of Ecological Characteristics between Autumn and Winter

The correlation of ecological characteristics between autumn and winter shows significant relationship among various ecological indices, indicating a consistent pattern of interdependence in these seasons. In autumn, there is a considerable correlation between diversity, density, and grass cover ($r=0.80$ for density and $r=0.58$ for diversity), both of which are significant at $p<0.05$. This shows that as grass cover increases, both the species density and overall biodiversity of the rangeland, indicate a healthy ecological dynamic. The result of the study are consistent with Bi *et al.* (2021), who found that grazing pressure can significantly affect ecological quality, in terms of plant cover and species density in arid environments. In winter, the correlations become considerably stronger, with density and grass cover reaching $r=0.90$, indicating a stronger relationship. This could be attributed to plants and animals' physiological adaptations to winter circumstances, which may promote denser grass cover and higher species diversity. The correlation of $r=0.80$ between density and diversity in winter

suggests that the ecological interactions established in autumn over into winter, reinforcing the importance of grass cover as a habitat component that supports both plant and animal life.

Furthermore, the positive relationships observed in frequency measurements across both seasons (e.g. r=0.68 for frequency and grass cover in winter) shows the importance of grass cover in maintaining ecological diversity. The results of the study are consistent with Kausar *et al.* (2022), who found the impact of seasonal climatic trends on vegetation characteristics, and indicating that favourable conditions in autumn can pave the way for prolonged ecological health into winter. The consistent patterns of correlation between these ecological indices across seasons highlight the significance of preserving healthy grassland ecosystems. The result of the study indicate that interventions aimed at improving grass cover could benefit both species density and diversity in the rangeland, which is crucial for ecosystem resilience, especially in the face of climate change and anthropogenic stresses (Bi *et al.*, 2021; Kausar *et al.*, 2022).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

From this study, it can be concluded that;

a. The rangeland management practices had lower impact on the rangeland, hence the north and south facing slopes had better vegetation characteristics; grass cover, diversity, density, and frequency than the rangeland fire and stone gabion site.
b. Soil organic matter, nitrogen and phosphorus levels were higher in rangeland fire than in the other sites in autumn than in winter, while soil pHs and potassium were higher in the rangeland fire than in the other sites in winter than in autumn.
c. The crude protein, neutral detergent fibre, acid detergent fibre, acid detergent lignin, hemicellulose, cellulose and ash content in the grass vegetation varied significantly ($p<0.05$) across the study sites in autumn and winter seasons, and tended to be higher in winter than in autumn in all the nutrients except acid detergent lignin.
d. Seed weight in autumn was higher in rangeland fire, stone gabions and riparian sites than in winter, while in winter, seed weight was higher in north facing and south facing sites than in autumn.

6.2 Recommendations

a. Vegetation characteristics of grass cover in rangelands must be understood for the sustainable use of grass cover for long term use of rangelands.
b. The development of long-term range management strategies which can govern grazing length, carrying capacity, and distribution of animals in a rangeland should be investigated.

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