Soil type and grazing management practices: Effect on vegetation composition and distribution in selected Communal Property Associations (CPAs) of Bela-Bela Municipality

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Declaration

I, Malizo Ntalo, declare that this dissertation is my original work and the use of information and other materials obtained from sources other than the author was fully acknowledged. I submit the dissertation with my Supervisors' approval for the degree of Master of Science in Animal Science at the North-West University. I confirm that this dissertation has not been presented to any institution or company other than the North-West University.

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Abstract

The objective of this study was to investigate the effect of grazing management on soil properties, vegetation composition and nutritive value of species found in selected CPAs of Bela-Bela Municipality. The CPAs were as follows: Mawela (Hutton- clay loam: HCL), Bela-Bela (Hutton-clay: HL), Moretele (Hutton-loamy sand: HLS) and Ramorula (Ecca sand-clay loam: ESCL). Three 200 m line transects served as replicates and were laid 50 m apart from each other in each of the three camps per CPA. In each of the three line transects, sub-transects were marked at 50 m intervals (50, 100,150 and 200 m) to create four 10 m x10 m homogenous vegetative units (HVU) making a total of 12 HVUs per camp. For physical and chemical properties, the soil samples (top and sub-soil) were analysed for particle size distribution, acidity, resistance, pH, organic carbon, macro and micro minerals. The abundance, height and nutritive value were determined for both types of grass and woody species. For chemical composition and *in vitro* dry matter degradability of both types of grass and browse leaves were bulked, respectively. All data for soil properties were subjected to a two-way factorial analysis of variance (SAS 2010) while data for species composition were subjected to a one-way analysis of variance (SAS, 2010). The highest ($P < 0.05$) pH (7.1) recorded on the sub-soil was in HLS. The topsoil had the highest ($P <0.05$) nitrate-nitrogen ($N\text{-}NO_3$) concentration (2.4 mg/kg) and ammonium nitrogen ($N\text{-}NH_4$) concentration (4.5 mg/kg) in the HC soil type. Soil organic carbon for both topsoil (0.66 %) and subsoil (0.41%) was significantly low ($P <0.05$) in the HLS soil type and ESCL soil type, respectively. The ESCL and HCL had the highest ($P <0.05$) chlorine (Cl) concentration (42.2 and 66mg/kg, respectively) in the top and sub-soil respectively. Phosphorus (P) and iron (Fe) concentrations were significantly high ($P <0.05$) in ESCL soil type for both topsoil and sub-soil. Sub-soil, manganese (Mn) concentration was found to be higher ($P <0.05$) in ESCL soil type (7.6 mg/kg). Copper (Cu) and zinc (Zn) concentrations were high ($P < 0.05$) in the HC soil type for both the topsoil and sub-soil. The

HLS soil type had the lowest (P <0.05) acidity (0.01) in topsoil while HC had the lowest (P <0.05) acidity (0.02) in sub-soil. The HCL soil type had the highest (P <0.05) soil resistance (2880 Ω) in topsoil, while ESCL had the highest (P <0.05) soil resistance (3640 Ω) in sub-soil. Across all soil types, *Aristida congesta* and *E. rigidor* were the two dominant (P <0.05) grass species. Hutton-clay (HC) soil type had the highest (P < 0.05) biomass (823.3 kg/ha) and also had higher (P <0.05) basal cover (55.8%). The HCL had taller (P <0.05) *Digitaria eriantha* and *Aristida congesta*. For the tuft diameter, *Setaria sphacelata* in the ESCL soil type had the largest (P <0.05) diameter (21.3 cm) when compared to the one found in the HC soil type (4.3cm). *Bothriochloa insculpta* diameter was significantly larger (P <0.05) in ESCL soil type (19.7 cm). The crude protein (CP) content (45.4 g/kg DM) was significantly higher (P <0.05) in ESCL soil type. Bulked grasses in all soil types had similar (P >0.05) neutral detergent fibre (NDF), acid detergent fibre (ADF), digestible energy (DE) and metabolizable energy content. Grasses in the Hutton clay (HC) soil type had the lowest (P <0.05) acid detergent lignin (ADL) content when compared to those from other soil types. The bulked grass species in the HLS soil type had the lowest (P <0.05) ether extract (EE) content (20.8 g/kg DM). The *in vitro* dry matter degradability (DMD) of bulked grasses at 24 (366.1 g/kg), 36 (478.4 g/kg) and 48 (629.8 g/kg) hours was highest (P <0.05) HC soil type. Hutton-loamy sand (HLS) soil type had high (P<0.05) total plant density (TPD) (4300 plants/ha), canopy cover (CC) (55.8%) and total tree equivalent (TTE) (5068.9 plant/ha) compared to other soil types. Bulked browse leaves from all soil types had similar (P >0.05) CP, ash and NDF content. In all soil types, the condensed tannins (CT) concentrations in browse leaves was similar (P >0.05). Browse leaves from the HC soil type had the lowest (P <0.05) soluble phenols concentration (289.8 g TAE/ kg DM). Browse leaves from all soil types had similar (P >0.05) DMD at 36 and 48 h. For most of the soil types, mineral concentration is more in the topsoil than in the sub-soil. This trend explains that the uptake of these minerals by plants took place due to the inconsistencies of grazing management employed in these selected CPA farms. With HC soil type outcompeting others in terms of both basal cover and biomass, which suggests that improved grazing management would improve the productivity of other soil types. The CP content of bulked grasses was low, and which suggests that animals should be supplemented with high protein sources such as the current bulked browse leaves due to their high CP and DMD for optimum livestock productivity. In order to encourage the growth of the herbaceous layer, the principal feed source for ruminants, it is crucial to manage the matured tree population prevalent in some of these CPAs as shown by the highest number of woody species (seedlings and adult trees). The observed high CP and DMD in bulked browse leaves from all soil types shows their potential as a solid, affordable source of protein for livestock.

Keywords: Biomass, Grazing value, Nutritive value, Resource management, , Soil type, Vegetation cover

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Dedication

Mandithathe elithuba ndinikezele ngalomqulu ku tata wam ongasekhoyo uMalibongwe Gilton Mal-B Ntalo, kunye nokhuluza wam ongasekhoyo uNolusapho Queen Ma-J Ntombi kaNtsele Ntalo. Esisibini sithe sadlala eyona ndima enkulu ukuba ndibekwelinqanaba ndikulo.

Yanga imiphefumlo yabo ingaphumla ngoxolo.

Mathol' anyongand' ukudlelana Thole lenkomo nakuwe Jola.

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ADF: Acid Detergent Fibre
ADS: Acid Detergent Solution
Al: Aluminium
AOAC: Association Official Analytical Chemists
AU: Absorbance Units
Bo: Boron
Ca: Calcium
CC: Canopy Cover
Cl: Chlorine
CLARA: Community Land Rights Act
CP: Crude Protein
CPA: Communal Property Association
CRD: Completely Randomized Design
CT: Condensed Tannins
Cu: Copper
DAFF: Department of Agriculture, Forestry and Fisheries
DE: Digestible Energy
DM: Dry Matter
EE: Ether Extract
ESCL: Ecca Sandy-Clay Loam
Fe: Iron
GC: Grazing Capacity
GLM: General Linear Model
HC: Hutton Clay
HCL: Hutton Clay-Loam
HGV: High Grazing Value

HLS: Hutton Loamy-Sand

HVU: Homogenous Vegetation Units

iDMD: *in vitro* ruminal Dry Matter Degradability

K: Potassium

LGV: Low Grazing Value

ME: Metabolizable Energy

Mg: Magnesium

MGV: Medium Grazing Value

Mn: Manganese

N: Nitrogen

Na: Sodium

NDF: Neutral Detergent Fibre

N-NH$_4$: Ammonium-Nitrogen

N-NO$_3$: Nitrate-Nitrogen

NRC: National Research Council

OC: Organic Carbon

P: Phosphorus

PSD: Particle Size Distribution

SAS: Statistical Analysis System

SE: Standard Error

SO$_4$: Sulphate

SOC: Soil Organic Carbon

Sph: Soluble Phenols

TAE: Tannic Acid Equivalents

TPD: Total Plant Density

TTE: Total Tree Equivalent

Zn: Zinc

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background

Rangelands contribute 60% of the earth's land, and 68% of the land area of South Africa (Directorate of Agricultural Information, 1991). They provide food for wildlife and grazing ruminants and are managed according to ecological principles (Mccollum *et al.*, 2017). Efficient rangeland management and monitoring programs entail measurements such as biomass yield, basal cover, species composition and nutritional properties as an indication of rangeland condition (Mirik *et al*., 2005). This is because a rangeland's ability to support animal production depends on biomass production and the nutritive value of herbage (Kwaza, 2013). Animal production is also affected by temporal variation in rangelands which is mainly due to the site-specific differences in average annual rainfall and distribution (Snyman, 2002).

The productivity of rangelands is also determined by both biophysical factors and methods of utilization (Abule *et al*., 2005). Rangelands can be rotationally or continuously grazed depending on ownership patterns. In most instances in privately owned commercial farms in South Africa, rotational grazing is the dominant grazing management system (Dean *et al*., 1995). On the other hand, in communal areas, and sometimes in commonages and communal property associations (CPAs), continuous grazing is predominantly practised (Lebert & Rohde, 2007). Rotational grazing is superior in terms of biomass production, basal cover and animal performance when compared to continuous grazing (Hahn *et al*., 2005; Haveron, 2008).

Semi-arid rangelands in commonages, CPAs and communal areas are characterized by many challenges related to uncontrolled grazing and high stocking rate (Rohde *et al*., 2006). Continuous grazing does not promote the resting of some parts of the rangeland; hence it leads to rangeland degradation which is characterized by poor species composition, low basal cover and biomass (Steinschen *et al*., 1996; Simons, 2005). Degradation usually begins with the creation of smaller bare areas or patches, which in the long term extend or join to form broad bare and depleted vegetation cover (Van den Berg & Kellner, 2005). Furthermore, according to Jacobo *et al*. (2006), continuous year-after-year overgrazing can result in a threshold that making it nearly impossible to maintain a viable livestock herd because of the resultant reduced herbaceous vegetation production and vigour. It ultimately results in reduced animal performance, which is further compounded by a restricted winter dry season feed supply.

The assessment of vegetation conditions provides historical information about the previous methods employed in the utilization and management of vegetation resources (Thackway *et al*., 2006). Furthermore, land-use and management strategies geared toward maintaining rangeland peak productivity may result in a progressive change in vegetation conditions over a long period (Oztas *et al*., 2003). Apart from erratic rainfall, the stocking rate has an additional effect on the rangeland conditions. High stocking rates promote heavy grazing which might create a breeding ground for annual species such as *Aristida species* and *Melinis repens* and browse species such as *Grewia flava* and *Senegalia mellifera* (Fynn & O'Connor, 2000). The function of fodder woody species in supplying the least expensive naturally occurring source of protein, energy, vitamins and minerals is enormous (Mudau *et al*., 2021). A continuous grazing system normally leads to livestock selectivity and there is little control over the timing and intensity of grazing which leads to the disappearance of desirable plants and an increase of invasive species (Abdesalam *et al*., 2017). In South African rangelands, changes in vegetation typically occur unexpectedly in the short term (years) in response to rainfall, and episodically even in long term (decades) in response to rare events, or due to grazing pressure, climate-change changed disturbance regimes, or a combination of these factors (Van den Berg & Kellner, 2005). Poor grazing management impact on vegetation condition has been noticed globally as the most important stress factor which harms grassland productivity leading to land deterioration (Ma *et al*., 2017; Tong *et al*., 2017). A reduction in soil moisture and nutrients alter the physiological and biochemical processes of the plant (Sarker *et al*., 2005), hence the need to investigate how soil and grazing management would impact the vegetation condition of CPAs. Understanding the variation in species (Ravhuhali, 2018), and soil types in rangeland is of colossal importance when a grazing plan is put in place (Ravhuhali & Moyo, 2022), but these CPAs have adopted to some extant the communal (continuous grazing) grazing practices which later detoriorates both physical and chemical properties of soil. Furthermore, overgrazing in rangelands causes soil compaction and reduced water retention (Abril & Bucher, 1999), increase pH levels (Raiesi & Riahi, 2014), decrease nitrogen content (Chartier *et al*., 2011), and reduce soil carbon by the removal of the herbaceous layer from the soil (Semmartin *et al*., 2010).

Communal Property Associations (CPAs) are landholding institutes recognized under the Communal Property Associations Act No. 28 of 1996 (the CPA Act). Bromley (1989) defines common property as a group of authorized and selected users as well as a defined resources that are managed and used by the same group under the control of institutional entities. The group of users tends to collaborate and provide a transparent plan for the utilization and management of resources in order to optimize profit and other benefits (Feder & Feeny, 1991; McKean, 2000). There is a tendency of over-using and free riding of communal property resources because these individuals are widely reported to rely on their perceptions when deciding about livestock productivity and the management of natural resources (Mapinduzi *et al*., 2003). This perception of local farmers influences their common resource management strategy, which in turn influences the sustainability of the same resources (Steins & Edwards, 1999; Reed *et al*., 2009), which may normally lead to over-exploitation.

1.2 Problem Statement

Plant distribution in rangelands is mainly affected by soil type and grazing. These factors eventually affect the biological activity of the rangeland. Vegetation degradation in rangelands managed as a common resource is prevalent in South Africa (Kakembo & Ndou, 2019). A range of factors contribute to this retrogressive process, and they include weak and non-functional local-level institutions (Bennett *et al*., 2010) which leads to mismanagement of the rangeland resources as observed by Bennett *et al*. (2010) in communally shared rangeland resources of Roxeni, Lushington and Allanwater villages in the Eastern Cape. Non-adherence to community rules concerning stocking rates, and grazing management plans harm rangeland conditions (Hoffman & Ashwell, 2001). Municipal commonages are almost similar to CPAs in terms of a group of livestock farmers utilizing common resources. Challenges observed in commonage rangelands include open access to grazing land (Ingle, 2006), lack of necessary set of skills, funding and experience to implement efficient rangeland management in the commonage (Buso, 2003) which results in rangeland degradation (Beinart, 2008). There have been few studies conducted on grazing or rangeland management practices in CPAs, the only research done has been on communal and commercial farms. Furthermore, a comparison of vegetation response and soil properties to different grazing practices on different soil types has not been extensively investigated in CPAs. In addition, information on how grazing management affects soil properties would yield a better understanding of the causes and efficient mitigation strategies that the farmers can apply and adhere to. It is therefore important to evaluate the effect of grazing management practices and soil type on the vegetation composition, and soil properties in selected CPAs of Bela-Bela Municipality. This information would assist the farmers to adjust their grazing management strategies to suit particular soil types for improved species composition and thus enhance livestock productivity.

1.3 Justification

Most grazing ruminant animals in South Africa are raised on natural rangelands. Previous studies (Beyene *et al*., 2014; Abate, 2016) suggested that the traditional knowledge of native people was central to local resource management. The CPA users are known (McCusker, 2002) to manage their livestock based on gaining profit without considering rainfall, soil and vegetation (Abate, 2016). Understanding changes in soil properties in these soil types with different grazing management regimes, and what would be the ultimate impact of this grazing and changes in soil properties on vegetation composition ought to be of colossal importance to farmers. The results on the identification, distribution (composition and diversity) and nutritive value of bulked grasses and browse species would give some insight into the current vegetation and grazing management strategies done in selected CPAs of Bela-Bela Municipality. Such findings would provide knowledge on recommendations for appropriate grazing management and rehabilitation programs needed to restore the veld to its prime state of production.

1.4 Objective

The broad objective of this study was to investigate the effect of grazing management practices on soil properties of different soil types, vegetation composition and nutritive value of species found in selected CPAs of Bela-Bela Municipality, Limpopo province, South Africa.

Specific objectives

I. To evaluate the physical and chemical properties of the soils in selected CPAs of Bela-Bela Municipality.

II. To evaluate grass species composition, distribution and nutritive value as influenced by soil type and grazing management at selected CPAs of Bela-Bela Municipality.

III. To evaluate woody plant density, distribution, and nutritive value as influenced by soil type and grazing management in selected CPAs of South Africa.

1.5 Hypotheses

I. Grazing management and soil type affect both physical and chemical properties of soil in selected CPA s of Bela-Bela Municipality.

II. Grazing management and soil type affect both types of grass and tree species distribution, composition and nutritive value in selected CPAs of Bela-Bela Municipality.

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CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Natural rangelands in South Africa are a significant grazing asset for the nation's domesticated animals, providing food, water and space. The majority of the domesticated ruminant animals in South Africa are raised on natural rangeland. Grazing ruminants especially, cows are held as a form of wealth, particularly in communal areas. Sweet & Khumalo (1994) stated that cows furnish the proprietor with milk, meat, compost, and draft power. Generally, a large portion of South African poor families has their work exclusively subject to domesticated animal raising. Solomon *et al*. (2007) likewise suggest that rangelands indicate a significant economic asset just as a means of subsistence to the people of Southern Africa.

According to Beyene (2003), rangeland degradation is an issue of concern for upcoming animal production and the survival of people who solely depend on animal production. There is no doubt that something must be done to re-establish the sustainability of the environment to guarantee stable animal production. Efforts done to eliminate or slow down negative effects on rangeland ecology may primarily focus on activities like vegetation assessment, rangeland rehabilitation and bush and biological control. Tragically, these may not give long-term solutions considering the weight of human and animal population expansion. In addition, Beyene (2003) also stated that a precise innovative methodology for the future should be tailored to the government approach and practices in rangeland management.

2.2 Importance of livestock to small-scale and communal farmers

Livestock farming is a tradition in rural South African systems. The production of livestock has a colossal significance as a source of income and insurance, especially for poor households in drought-prone areas. Moreover, the findings of a study by Homann & Rooyen (2007), showed little factual information about communal farmers who utilise livestock for gains that are market-related. Livestock market provides new opportunities to increase the production of livestock in the small-scale sector. However, livestock might bring opportunities for farmers, but land depreciation due to mismanaged grazing poses a danger to livestock productivity globally (Randolph *et al*., 2007; Nkonya *et al*., 2015). Furthermore, not only the productivity of livestock is hindered but also soils are compromised by continuous overgrazing. Crovo *et al*. (2021) observed that most soil physical, chemical and biological quality indexes declined drastically as a result of overgrazing, altering the soil conditions to be less conducive for plant production. In communal property associations and commonages, multiple ownership that exists makes it difficult for proper decisions to safely guide the productivity of the rangeland and livestock reared on it. Moreover, livestock contributes to the livelihoods of CPA and commonage farmers, as the world population is expanding the demand for livestock products is growing too. Livestock is well placed to continue to contribute to social change as a strategic tool for poorly resourced farmers (Cousins *et al*., 2018).

2.3 Grazing management

2.3.1 Continuous grazing

Rangelands occupy approximately 40% of the Earth’s terrestrial surface (Reynolds & Frame, 2005). The rangelands have a vast range of functions such as providing an ecosystem, and supplying forage for both domestic and wild herbivores which is the most important function of rangelands (Boval & Dixon, 2012; Joshi *et al*., 2013). Furthermore, Ruppert *et al.* (2012) emphasised the colossal significance of proper grazing management of rangelands, since Snyman & du Preez (2005) showed that mismanagement of animal, particularly overgrazing has been largely noted as the greatest result of the severely poor rangeland conditions and drought in arid and semi-arid areas. The selection of the proper grazing livestock and setting the proper grazing intensity are the most crucial points of grassland conservation and management (Metera *et al.*, 2010). For an effective grazing management plan, Dumont *et al*. (2011) justified how important it was to know and be cognizant of grazing intensity on the respective grassland type when designing a management plan.

Continuous grazing is the kind of management practice where grazing livestock are allowed to graze on a single camp per annum when the vegetation in the camp is matured enough for livestock utilization upon the commencement of the growing season (Huza, 2018). DAFF (2013) also alluded that this grazing system is normally characterized by overgrazing if not well managed. This form of grazing system predominates mainly in communal livestock farming and is the result of absent fences and multiple ownership. However, this practice is not only happening in communal land only. Commecial farmers also practice this grazing system under good management practices, but in communal areas and CPAs is where orvergrazing seen when compared to commercial. Benseler (2003) alluded that in some CPAs and commonages livestock is either communally or a farmer will be allocated a portion of land within the commonage or CPA to graze. Due to lack of uniformity existing within the commonage regarding the grazing strategies, overgrazing is then practised. Furthermore, Beyene (2003) highlighted that the reasons for the increased density of woody plants in any type of rangeland are diverse and complex. In most situations, man has changed the determinants of the savanna system, either directly or indirectly. A generally accepted theory is that the historical range growth and density of many woody species are indeed encouraged by the introduction of domestic livestock and the subsequent overgrazing of herbaceous plants (Smet & Ward, 2005). Long-term heavy grazing unquestionably contributes to the diminishing or extinction of palatable species and the transition of vegetation from perennial to annual grasses, making less feed (biomass) available to livestock and putting pressure on CPA farmers (Magandana, 2016; Nenzhelele, 2017; Tóth *et al*., 2018; Gonzalez & Ghermandi, 2021). Subsequently, Crovo *et al*. (2021) highlighted that overgrazing alters the biochemical pools of carbon (C), nitrogen (N) and phosphorus (P). Furthermore, changes in soil physical indicators also reflect changes in the hydrological behaviour of these soils, potentially reducing the water storage, and availability while increasing runoff.

2.3.2 Rotational grazing

The term rotational grazing is defined by Mosley *et al*. (1997) and Kgosikoma *et al*. (2012) as a practice in which animals are kept on a piece of land for a stipulated amount of time (time of the season) and transferred to a new camp to allow re-growth of grass in the initial camp. Managing the timing and the number of times animals spend on the rangeland has the potential to reduce the direct disturbance that the animals may have on the rangeland and its vegetation, for example trampling and faecal deposition (Swanson & Evans, 2015; Venter, 2019). Furthermore, Brunson & Burritt (2009) alluded that the rotational grazing system can transform and positively improve not only the management but also the profitability of livestock production. As such, Belsky *et al*. (1999), Huntsinger *et al*. (2007) and Jakoby *et al*. (2015) also highlighted that managing how much time animals spend on rangeland can limit the disruption of the ecosystem. The impact of grazing on species community structure and ecosystem functionality is the key issue in rangeland management to maximise livestock production and sustainability of the operations (Jacobo *et al*., 2006).

Management of rangelands through rotational grazing, according to Dostálek & Frantík (2008) has shown a potential for the recovery of grassland biodiversity through scientific research and practice. Contrarily, Briske *et al*. (2011) highlighted that even though rotation grazing has the potential to improve rangelands, there is inadequate data reflecting its benefits on the impact it has on vegetation response. However, Biggs & Huntsinger (2021) highlighted that in rotational grazing, livestock grazing can affect soil organic matter (SOM) by affecting mineral availability, soil microbial activity and land productivity through the modification of associated carbon (C)-nitrogen (N) processes. Teague *et al*. (2013), Conant *et al*. (2017) as well as Biggs & Huntsinger (2021) highlighted the effects of grazing on C:N stoichiometry in plant litter and SOM can increase N mineralization and availability, which is particularly important in rangelands where N is frequently a defining resource for primary production. Additionally, Jacobo *et al*. (2006) also revealed that there are very few deleterious effects of rotational grazing on vegetation response, instead the plant community increased where this type of grazing was practised, thus stocking rate can be increased when compared to continuous grazing with a very noticeable consequence on the vegetation. These noticeable consequence on the vegetation are the change in species compositing (loss of perennial species) and reduced basal cover of the rangeland. Perennial species provide strong soil cover, and when these species are lost due to heavy grazing, the rangeland will be more vulnerable to wind and soil erosion (Oztas *et al*., 2003; Tokozwayo, 2016). A significant rangeland improvement in plant vigour, desirable palatable grass species, biomass, basal cover, grazing capacity and overall ecological condition of the rangeland has been noted by Teague *et al*. (2003), Müller *et al*. (2007) and Teague *et al*. (2008) when rotational grazing is practised.

2.4 Vegetation response

Grazing, as noted in a study by Christensen *et al*. (2004), could significantly affect both the above-ground and below-ground productivity of vegetation. Mori *et al*. (2013) added that grazing can alter the response of vegetation, influencing ecosystem processes and biodiversity. Thus, Fynn & O'Connor (2000) along with Fuhlendorf *et al*. (2001) concluded that grazing is the primary agent of vegetation change on rangelands. Contrary to that, other researchers have emphasized climatic variability as the primary change agent (Miranda *et al*., 2011; Ouled Belgacem & Louhaichi, 2013).

Complementary to the aforementioned, Diaz *et al.* (2001) proved that grazing has a very distinct effect on vegetation response. For example, the functional responses of vegetation are strongly linked to the type of grazing animal and can be affected by the habitat type (productivity and related abiotic factors) (Peco *et al.*, 2012). Additionally, research studies conducted in previous years have reported multiple effects of long-term grazing on rangelands (Wang, 2004; Yu *et al.*, 2004; Li *et al*., 2008). Many rangelands across the world are degraded or are experiencing large-scale desertification due to changes in climate, intensive grazing or agricultural uses (McSherry & Ritchie, 2013). Such changes vary across different regions and have different ecological attributes. Changes in vegetation, species composition, soil quality and biodiversity loss are a few of the indicators of rangeland degradation (Villamil *et al*., 2001).

Sharp ecological thresholds in vegetation response, as studied by Sasaki *et al*. (2008), are most likely to occur along local grazing gradients. This is particularly seen in steep grazing gradients that may be found in close vicinity to water points. Oñatibia & Aguiar (2018) reported that the vegetation response in a grazing area within the proximity of water points has less vegetation cover and the presence of increaser species. This is induced by a high concentration and return rate of livestock that drink water, graze intensively and trample the vegetation. Furthermore, high stocking rate and high grazing intensity reduce plant cover, subsequently, this leads to a decline in plant diversity (Ravhuhali, 2018). Rutherford & Powrie (2013) also highlighted that heavy grazing changes plant composition favouring the occurrence of annual and exotic plants. Moreover, high grazing intensity removes fine fuels, consequently, the growth and recruitment of woody species occur (Archer *et al*., 2017).

In some studies, it has been revealed that the relationship between grazing and vegetation response is more prevalent at small scales than at large spatial scales (Fensham *et al*., 2010; Lezama *et al*., 2014). Moreover, Stohlgren *et al*. (1999) and Adler *et al*. (2001) demonstrated that vegetation response is scale-dependent. Meaning that vegetation response depends on the scale of observation and on the factors that determine animal distribution. The grazing patterns may be stronger or weaker than vegetation patterns or may mirror the spatial structure of vegetation (Searle *et al*., 2009; García *et al*., 2011; Badgery *et al*., 2017). With improper grazing management rangelands shift from perennial to annual species, resulting in increaser species being more abundant. Grass species such as decreasers (*Themeda triandra* and *Digitaria eriantha*) pave the way for Increaser I (*Hyparrhenia hirta*) and II (*Aristida congesta* and *Eragrostis rigidior*) species growth at the expense of heavy grazing (Tokozwayo, 2016).

2.5 Soil

According to MacVicar *et al*. (1977) together with Grey (1979), the Binomial Soil Classification System was used in South Africa. However, during the late seventies to eighties, land surveys expanded further into semi-arid and arid regions of South Africa. It is only then that the shortcomings of the Binomial System were revealed and, in many cases, could not effectively differentiate between the different soils found in these regions based on morphology and genetics (Lambrechts & McVicar, 2004). This prompted a revision of the Binomial System, which resulted in several significant changes. The most important was the discovery of new diagnostic horizons or materials, and thus soil forms as well as the redefining of the existing horizons (Lambrechts & McVicar, 2004; Bockheim & Hartemink, 2013; Turner, 2013). The Hutton soil type is defined as oxidic soils, this is due to the accumulation of iron oxide through weathering of the imparting colour on many soils. Hematite's red colour indicates warmer, drier conditions that are less affected by organic matter. Furthermore, if the conditions are well drained and aerated, these soils are uniformly coloured (Okalebo *et al*., 2002; Mararakanye & Sumner, 2017)**.**

2.5.1 Soil structure

According to various studies (Zhou *et al*., 2010; Monaghan *et al*., 2017; Abdalla *et al*., 2018; Donovan & Monaghan, 2021), the combined effects of livestock grazing on vegetation cover reduction and degradation of soil properties such as macro-porosity, infiltration, pore size bulk density and structural aggregation are pretty much entirely responsible for the soil deficit. The amount of soil deterioration that occurs during grazing depends on many variables, including the stocking rate, hoof effect, time spent grazing and the preceding grazing strategy employed on the land (Greenwood & McKenzie, 2001). The abovementioned can be pronounced as grazing intensity which is directly related to the degree to which soil structure changes. Moreover, different soil structures will respond or react to grazing intensity due to available moisture content, clay and sand content (Drewry *et al*., 2001; Donovan & Monaghan, 2021).

Soil structure can be described as the structural diversification of the various components of soil (Dexter, 1988; Rabot *et al*., 2018). It can also be explained as the important range in particle sizes of soil that can be defined both qualitatively and quantitatively (Phogat *et al*., 2015). Additionally, soil structure has been discovered to influence the accessibility of nutrients in the soil by influencing the rate at which water and air can move through the soil and roots. According to Négyesi *et al*. (2021) an increase in the physical crusting of the soil results in a decrease in the ability of the soil to infiltrate an adequate amount of water correctly, which results in a reduction in the amount of water available to plants. This decline in water availability negatively influences plant productivity, which is likely to cause the loss of plant species or diversity, which further promotes fewer desirable plants to thrive, reducing the overall quality of the rangeland (Mapiye *et al.,* 2008; Bai *et al*., 2010). Good soil structure is a vital quality in the avoidance of soil compaction, poorly structured soil is generally more prone to compaction through external pressures such as livestock moving across the rangeland which affects root growth and function ultimately resulting in poor rangeland productivity (Shah *et al*., 2017).

Furthermore, many processes in soils are controlled by soil structure. It controls water infiltration and retention, as well as gaseous exchanges, humus and nutrient cycling, root development and erosion vulnerability (Rabot *et al*., 2018). The depth of the soil at a given location will determine the species that will survive in that area, soil structure allows the movement of soluble substances to deeper root zone thus favouring salt-tolerant plant species with poor nutritive value (Muazu *et al.*, 2020). Soils that are structured mainly with blocky, prismatic or granular structure are more suitable for rangelands since they promote the movement and dispersion of water in rangeland, contributing to their good health and productivity (Rinehart, 2006). Its significance is due to its effect on a soil type's water-holding capacity, and it is also influenced by soil pores and particles.

The physical parameters of soil porosity and pore size distribution are critical for understanding soil properties since the volume of pores within a specific size range controls the transportation of water and other soluble substances (Liu *et al*., 2016).

Clay-loam soil has a better water-holding capacity than sandy-loam soil because the finer particles stick together and limit water and nutrient movement, whereas sand-loam soil has coarse particles to allow water and nutrients to move quickly (Phogat *et al*., 2015). As a result, different soil types in different regions will produce diverse grass species that are most favoured in that region.

2.5.2 Soil fertility

Soil fertility can be described as a soil's ability to support the growth of plants by utilising all the significant nutrients it contains such as nitrogen, phosphorus, potassium and magnesium, to enhance plant yield. Furthermore, it can be amplified through the addition of organic material by livestock to the soil (Greenwood & McKenzie, 2001; Kekulandara *et al*., 2019).

The interaction between biotic and abiotic elements such as slope, vegetation type, and topographic features, impacting variations in rangeland productivity and species diversity, is caused by temporal and geographic fluctuations in soil properties (ChatzitheodoRidis, 2011). Several factors have been reported to influence the fertility of any soil type, these factors include soil depth, soil moisture content, soil pH, mineral content, organic matter content, the activity of soil microorganisms and contamination (Brockett *et al*., 2012; Cardoso *et al*., 2013). However, the presence of the mentioned nutrients including nitrogen, potassium and phosphorus has been discovered to not necessarily assure the accessibility of the vital nutrients to plants (Kekulandara *et al*., 2019). The ability of plants to establish themselves and grow is also related to the dynamic relationship the soil nutrients have with the moisture, temperature, pH, and presence of toxic or anti-nutritional agents and or salts. The interaction of these factors significantly influences the fertility of soils, whether directly or indirectly (Fageria, 2007; Ameloot *et al*., 2013).

Fertile soil can be identified through the presence of healthy biological activity by animal and plant activity in the soil. Soil that is rich in nutrients has also been observed to contain a rich quantity of organic matter which brings about a darker appearance to the soil, and the ease with which the healthy roots inhabiting the soil are pulled out as the soil crumbles (Bot & Benites, 2005). Infertile soil can be noted by the decreased abundance of soil nutrient availability and cycling as well as a decline in soil biota diversity which results in the soil's inability to supply the suitable conditions required by vegetation and soil biota (Dawoe *et al*., 2012; Menta, 2012).

Studies by Balestrini *et al*. (2015), Sofo *et al*. (2020) as well as Certini *et al*. (2021) highlighted that one of the often-overlooked main influencers of soil fertility is the biota inhabiting the soil. The constant addition of decomposing plant material positively affects the biochemical processes and nutrient cycling in the soil which results in the overall improvement of the soil's health and rangeland health (Bationo, 2004). The addition of this plant material is done by the various organisms/biota inhabiting the soil, they can incorporate plant material by breaking down material such as plant leaves, roots, stems and twigs which also produces acidic or alkaline material from the plants that get incorporated into the soil. This results in a darker appearance of soil which is a good indicator of fertile soil (Schoonover *et al*., 2015). The dependence of rangelands plant growth and biomass yield on the soil properties is a vital component needed to understand the relationship how each factor or component affects the other.

There are various complex properties that soil possesses which are related to its functionality. These properties are linked, function together and positively affect soil quality (Hatfield *et al*., 2017). However, the ability of soil to successfully function and support rangeland vegetation relies on ecological processes such as nutrient cycling, storage of carbon, and arrangement of soil structure (Haygarth *et al*., 2009), which ultimately affects the growth of plants in the rangelands. Moreover, the ability of rangeland to sustain livestock relies on various aforementioned processes, such as ecological processes which are related to the development of soil, cycling of nutrients, the flow of energy and the structure and relationship between plants and livestock communities (Heitschmidt *et al*., 2004). Livestock play a huge role in defining terrestrial ecosystems (Curtin, 2002), but needs to be properly managed. Moreover, results obtained by Li *et al*. (2012) revealed that the exclusion of livestock in overgrazed rangelands had a positive impact on vegetation recovery, increased soil moisture content retention, and increased amount of organic C and total N. Moreover, Dlamini *et al*. (2016) noted that acidic soil pH in overgrazed rangelands influenced the decomposition of plant material hence the reduced soil organic carbon available in such rangelands. Contrary to the abovementioned, Yang & Son (2021) together with Dong *et al*. (2021) stated that soil pH increases with the degree of rangeland degradation, while overgrazing can lead to salinization of these grazing lands due to the deposition of urine and dung.

2.5.3 Soil moisture and temperature

Soil moisture content is a vital constituent of water balance and more importantly, a huge factor in the management of agricultural rangelands (Paige & Keefer, 2008). It is an incorporation and correlation response from the recent climatic conditions, such as precipitation, prior moisture as well as the soil itself and the characteristics the vegetation possesses (Velpuri *et al.*, 2016). Furthermore, Salve & Allen-Diaz (2001) indicated a few factors that influence the quantity of moisture retained in the soil. These factors include the seasonal rainfall, soil texture, vegetation type, elevation of the area and grazing. In a study by Manu *et al*. (2016), it was reported that in overgrazed rangelands nitrogen mineralization declined with decreasing soil moisture due to increasing soil temperatures as the soil is bare. Niu *et al*. (2019) had results that alluded to the fact that the soil cracked open due to overstocking, there was loss of moisture and a rise in soil temperature.

It is important to be aware that inadequate soil water supply results in decreased vegetation performance, thus decreasing yields. As such, soil moisture and nutrient availability should be kept in mind when predicting the nature of any rangeland's productivity (Vose *et al*., 2016). Furthermore, as much as the soil affects the growth of vegetation on rangelands, plants have also been discovered to affect the dynamics between soil moisture and the water cycle (Wang *et al*., 2019). This shows just how significant the co-dependence of the soil and vegetation is and how one factor interacts with the other to affect the productivity of the other.

Soil temperature is the degree of warmth a soil possesses, it varies daily and according to the season which may result due to alterations in radiant energy within the soil (Onwuka *et al*., 2018). The factors discovered to influence soil temperature include soil colour, mulching, solar radiation, the slope of the land surface, vegetative cover, organic matter content and evaporation (Onwuka *et al*., 2018). Soil temperature has a direct effect on the vital processes occurring across the rangeland. These soil processes include the rate at which organic matter is decomposed as well as the mineralization of various organic materials (Davidson & Janssens, 2006). In addition, soil temperature has also been reported to influence the soils' ability to retain, transfer and make soil water accessible to plants (Onwuka *et al*., 2018). The thermal conductivity of soil is affected by the volume fraction of solid, liquid and gaseous substances present in the soil (Lehnert, 2014). It further influences metabolic processes such as the decomposition of organic compounds (Davidson & Janssens, 2006).

2.5.4 Soil pH

Soil pH is the acidity and alkalinity of the soil. Soil pH is a value on a scale from 0 to 14 and is described as acidic, neutral or alkaline (basic) depening on its pH value (McCauley *et al*., 2009). A great number of soil biological, chemical and physical properties, as well as the various processes aimed at the promotion of plant growth and biomass yield, are significantly dependent upon soil pH making it one of the most significant cornerstones affecting plant growth and yield (Neina, 2019). Soil pH is a key indicator because it correlates directly with nutrient availability or solubility and affects microbial activity. Thus, assessment of pH allows for predicting the potential for nutrient availability in a given production system (Arshad & Martin, 2002).

Plant nutrient availability is heavily influenced by soil pH. Macronutrients, except for phosphorus, such as nitrogen, calcium and magnesium are most accessible to plants at a pH of 6.5 to 8 (McCauley *et al*., 2009). Phosphorus is most accessible within a pH range of 6 to 7. The majority of micronutrients such as copper, zinc and iron are more accessible within a range of 5 to 7. Any deviation from the optimal ranges retards and decreases the availability of nutrients, making them less accessible to plants (Prasad *et al*., 2020).

In addition to nutrient availability, soil pH also affects individual plants and the soil biota, the survival and ability of these factors to tolerate soil pH relies on the pH, with a neutral pH having the most preference for optimal vegetation growth (Gentili *et al*., 2018). Soil pH also controls the solubility, mobility, and bioavailability of trace elements, which determine their translocation in plants as well as root growth and functioning which is vital in nutrient uptake by plants (McMichael & Burke, 1998; Neina, 2019). Extreme pH values retard the ability of soil microbes to decompose organic matter which is an important process needed to release vital nutrients to the soil for vegetation growth and good quality feed to livestock (Schröder *et al*., 2016). In overgrazed grasslands, soil pH was negatively affected (Wang *et al*., 2020), which reduced the availability of microbial taxa on soil N mineralization by hindering the enzymatic actions in the soil. However, Lauber *et al*. (2009), Tripathi *et al*. (2012), Raiesi & Riahi (2016) together withEbrahimi *et al*. (2016) indicated that pH that ranges from neutral to alkaline will promote the presence of bacterial community and this can be achieved by the presence of livestock in the rangeland. Livestock, while grazing, drop dung and urinate which ultimately naturalise the pH to the abovementioned range through urine hydrolysis.

2.6 The importance of rangelands assessments

According to Havstad *et al*. (2009), rangelands are land types primarily found in dry and semiarid locations that are managed as a natural ecosystem supporting vegetation of trees, grasses, shrubs and forbs. Furthermore, Ryan *et al*. (2017) stated that the frequency of key grasses, edaphic factors and the availability of woody plant species or vegetation cover form the basis of grassland rangeland condition assessment. Another study by Tainton (1999), revealed two aspects regarding the assessment of plant communities. Firstly, the assessment of plant communities serves as an advantageous way of comparison. Secondly, it provides a way to quantify and observe the spatial and temporal changes that occur within a distinct vegetation type.

Rangeland health plays an integral part and must be monitored as that will enable sustainable rangeland management and continued provision of ecosystem services. Be as it may, in communal areas the whole notion behind using rangeland condition assessment as a tool to assess stocking rate is overlooked as a result of livestock production objectives being prioritized. Hoffman & Todd

(2000) stated that the implementation of rangeland assessment techniques in communal livestock production raises questions that could potentially pose as a gap in literature.

Even though rangeland degradation is not always apparent when not being assessed, farmers may only tell when the land is deteriorating when some grasses disappeared (Snyman, 2003). This can be avoided by frequent assessment of the rangeland to note early indications of vegetation change, carrying capacity change and biomass.

2.7 Resource management in CPAs

The *Communal Property Associations Act* No.28 of 1996 found or introduced CPAs, which are landholding institutions (the CPA Act). Bromley (1989) defined a common property association "as a group of accredited users, a well-defined resource that the accredited members will manage and utilize, and the rules of use for the resource concerned". Communal property associations are a tool for community economic growth. Moreover, they provide an option for income diversification, household income subsidisation and work as a sustainable food source particularly for the poor (Wily, 2000).

People have traditionally relied greatly on the available wild natural resources that surround them (Fabricius *et al*., 2004), hence Africans ended up seeing value in them. The governance system that African people have deployed are designed for the use and management of the available natural resource (Musavengane & Kloppers, 2020). Adaptive management, or 'trial and error', was used to develop practices aimed at improving ecosystem services and maintaining their resilience. Oral testimony has passed down these management strategies from generation to generation and now are accepted as conventional. Natural resource regulation has typically failed to account for the complex interactions between people and nature that are characteristic of most

African cultures (Fabricius *et al*., 2004). The *Communal Land Rights Act* (CLaRA) 16 of 2004 was enacted to resolve the legal problem of ownership by transferring title to communal land (the landless communities), purportedly represented by a land administration committee (Bennett, 2013). Furthermore, after the transfer has been made each CPA has its own rules to adhere to minimize the misuse of natural resources. A study done by Bennett *et al*. (2010) showed that the rotational resting method (urhawulane), whereby one portion of that rangeland is rested for one year, was the most efficient rangeland management strategy in places without fencing. Hence researchers highlighted the importance of sustaining natural resources for livelihoods of communal property association farmers (Naidoo, 2005; Sebola & Mamabolo, 2020). However, most of CPAs around Limpopo province in Bela-Bela were noted (Ravhuhali *et al* 2020) to practice continuous grazing and have taken the route of commonages known of overstocking and overgrazing. In the selected CPAs the primary method of grazing is the communal open grazing, which depends on the free and unrestricted movement of livestock in and out without being constrained by an ideal grazing capacity and stocking rates (Abdelsalam, 2021). Moreover, uncontrolled grazing of livestock will lead to overgrazing and alteration of soil properties. One of the primary variables impacting rangeland vegetation cover, biomass quantity (Bolo *et al*., 2019), forage quality (Teague *et al*., 2011) and soil physical and chemical properties is overgrazing by livestock (Azarnivand *et al*., 2017).

2.8 Chemical composition of herbaceous and woody vegetation

Generally, grass species play an important role in livestock production owing to their persistence, growth and quality under proper management through grazing and clipping (Olanite *et al*., 2014), as they provide some essential nutrients needed by livestock. Moreover, the chemical composition of a variety of grasses has been extensively studied, yet there are numerous factors contributing to grass quality variation. Increased plant maturity, season, soil nutrient content, along with frequency and intensity of grazing, are the prominent factors that affect grass quality (Särkijärvi *et al*., 2012; Demanet *et al*., 2015). The analysis of these grasses' nutritional qualities is of utmost significance. Since there is not much information available for the CPAs chosen for the current study, it is necessary to determine the potential value of the prevalent grasses for grazing.Various studies have stipulated the significant role that browse plants play in providing feed for livestock in semi-arid rangelands of southern Africa (Tefera & Mlambo, 2017; Ravhuhali *et al*., 2021; Ntalo *et al*., 2022). However, the availability of feed containing imbalanced nutrient composition and metabolizable energy is a major problem faced in livestock production (Cheema *et al*., 2011; Chitra, 2018). As a result, research has stressed the significance of determining the chemical composition of leaves and pods in browsing plants for possible protein sources for livestock feed (Melaku *et al*., 2010; Mnisi & Mlambo, 2017). As highlighted by Bakshi & Wadhwa (2012), browse leaves are rich in protein, soluble carbohydrates and minerals thus have great potential to serve as a feed source for livestock. However, the presence of a large concentration of phenolic compounds in browse leaves of species such as *Dichrostachys cinerea* and *Vachellia nilotica* can impair their use. Soliva *et al*. (2005) and Alam *et al*. (2007) also highlighted that the leaves of *V. nilotica* oftentimes contain a very high concentration of condensed tannins and fibre content.

2.9 The nutritional value of plants as influenced by soil type and grazing

Soil type (soil fertility included) might alter the nutritive value of vegetation. Mokgakane *et al*. (2021) highlighted that soil type affected nutritional value of various grass species. Contrarily, Ravhuhali *et al*. (2021) stated that soil type did not have an effect on nutritive value of grasses. Furthermore, the study stressed that most grasses harvested in more fertile clay loam soil did not necessarily have high protein plant content than those harvested in less fertile red brown sand soil.

Grazing is one of the main elements contributing to the degradation of rangelands, which typically affects the vegetation and soil (Zarekia *et al*., 2012). Even though, heavy grazing can be destructive through trampling (Ji *et al*., 2020), grazing livestock wastes (urine and feaces) can be potential sources of phosphorous, nitrogen, sulphur, potassium and magnesium for plants (Tsai & Liu, 2016), which are assumed to be linked with the concentration of these nutrients in plant leaves (Delevatti *et al*., 2019). Browsing has been reported to have a negative effect on chemical composition of tree species by increasing the concentration of secondary compounds such as tannins (plant defence mechanism) (Mlambo *et al*., 2015).

2.10 Dry matter degradability

According to Hawu *et al*. (2022), the degradability of dry matter is important as it typically impacts the digestibility efficiency of livestock; for example, low degradable substrates have a negative impact in livestock performance. Mahyuddin (2008) stated that *in vitro* dry matter digestibility (IVDMD) is broadly regarded as the most accurate and trustworthy approach for predicting feed digestibility in ruminants. *In vitro* dry matter degradability is a better and more cost-efficient method when compared to the sacco method (Msiza, 2021). When compared to other grass species with low dry matter (DM) yield, those with higher and lower leaf proportions typically have differing *in vitro* DM degradability characteristics (Getachew *et al*., 2004). Mahyuddin & Purwantari (2009) stressed that the digestibility of fibre is an important parameter of forage quality because, as forage, fibre varies in ruminal degradability. Additionally, cell wall digestibility also affects animal performance, however, Jung (2012) highlighted that those factors related to cell wall arrangement (maturity, stems and leaf proportion) affect the degradability of forage. Browse species that are a cheap source of protein to livestock, are found to be tanniferous at times (Mnisi & Mlambo, 2017). Futhurmore, Jones *et al*. (2000) as well as Ammar *et al*. (2004) indicated that the addition of polyethylene glycol (PEG) as a tannin binding agent to samples of high tannin browse plants such *Dichrostachys cinerea* and *Ziziphus mucronata* make them more degradable and eventually enhance livestock production.

Grazing intensity is an important factor influencing the change of soil properties in the ecosystem and soil nutrients are affected in grazing areas (Dingaan *et al*., 2016). Consequently, this affects the nutrient concentration of plant species. Defoliation is known to induce chemical defenses in woody plants; however, severe grazing can have the opposite effect, causing either increased N concentrations or decreased phenol and tannin concentrations in individual plant species (Mancilla-Leytón *et al*., 2014). Browsing affects chemical defense of woody species, it can either decrease or increase the chemical defense such as tannins. Even though browsing could increase nitrogen content, tannins (condensed tannins) may lower the protein's bioavailability in browse plants (Mokoboki *et al*. 2019), resulting in decreased degradability of substrates. Soil nutrients have been linked to chemical composition of plant species, which have been linked to degradability of plants. Mudau *et al*. (2022) highlighted that poor soil profiles accumulate high phenolics concentrations. The number of phenolic compounds in the diet determines the degradability or digestibility of plant-based feed for livestock (Mnisi & Mlambo, 2016).

2.11 Summary

Vegetation is an important grazing assets for South Africa's domesticated animals, providing feed with the needed nutrients. In South Africa, natural rangeland is used to grow the bulk of domesticated animals. Livestock are regarded as a repository of wealth, particularly in communal areas. There are several factors that affect the distribution of plant species namely: climatic conditions, soil and grazing. These aforementioned factors do cause a change in vegetation condition. However, in communal property associations, farmers employ different types of management strategies which later have an impact in altering the vegetation condition. This can promote the growth of species that have an ecological niche, which add to the fodder flow for livestock during the dry season. Moreover, each rangeland is indeed a unique blend of species with varying yield and quality, which enables determining its nutritional worth difficult. For the long-term sustainability of natural resources, a thorough insight into the current state of CPA rangelands, vegetation distribution and chemical composition and soil properties is essential.

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CHAPTER 3: PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS IN SELECTED CPAS OF BELA-BELA MUNICIPALITY

Abstract

Communal Property Associations (CPAs) rangeland users need more knowledge on the state of their respective grazing lands and also the interaction of soil properties with the implemented grazing management. The study aimed to investigate the effect of grazing management on the physical and chemical soil properties of four different soil types found in selected CPAs of Bela-Bela municipality. The selected CPAs are Mawela (Hutton- clay loam: HCL), Bela-Bela (Hutton-clay: HC), Moretele (Hutton-loamy sand: HLS) and Ramorula (Ecca sand-clay loam: ESCL). For physical and chemical properties, the soil samples (top and sub-soil) were analysed for particle size distribution, acidity, resistance, pH, organic carbon, macro and micro minerals. All data for soil properties were subjected to a two-way factorial analysis of variance (SAS, 2010). In each CPA, three camps were selected. In each camp, three transects 200m apart at the length of 200m were set. In each transect, soils were drawn at 0,100 and 200m making a total of 9 soil samples per each camp. The highest ($P<0.05$) pH (7.1) recorded on the sub-soil was in HLS. The topsoil had the highest ($P<0.05$) nitrate-nitrogen ($N\text{-}NO_3$) concentration (2.4 mg/kg) and ammonium nitrogen ($N\text{-}NH_4$) concentration (4.5 mg/kg) in the HC soil type. Soil organic carbon for both topsoil (0.66 %) and subsoil (0.41%) was significantly low ($P<0.05$) in the HLS and the ESCL soil types, respectively. The ESCL and HCL soil types had the highest ($P<0.05$) chlorine (Cl) concentration (42.2 and 66 mg/kg, respectively) in the top and sub-soil respectively. Phosphorus (P) and iron (Fe) concentrations were significantly high ($P<0.05$) in ESCL soil type for both topsoil and sub-soil. Sub-soil, manganese (Mn) concentration was found to be higher ($P<0.05$) in ESCL soil type (7.6 mg/kg). Copper (Cu) and zinc (Zn) concentrations were high ($P<0.05$) in HC soil type for both the topsoil and sub-soil. The HLS soil type had the lowest ($P<0.05$) acidity (0.01) in topsoil while HC had the lowest ($P<0.05$) acidity (0.02) in sub-soil. The HCL soil type had the highest ($P<0.05$) soil resistance (least salts)(2880 Ω) in topsoil, while ESCL had the highest ($P<0.05$) soil resistance (3640 Ω) in sub-soil. For most of the soil types, mineral concentration is more in topsoil than in sub-soil, this trend explains that the uptake of these minerals by plants took place due to the inconsistencies of grazing management employed in these selected CPA farms. It is important to implement correct gazing management principles and practices because it assists in the progression of herbaceous layer.

Keywords: Grazing, Vegetation cover, soil type, soil minerals, livestock

3.1 Introduction

The essential function of Communal Property Associations (CPAs) in resource governance is increasingly being recognized (Ghate & Nagendra, 2005; Sebola & Mamabolo, 2020). Moreover, in a communal property association, individuals have authority over resources and therefore common property organizations vary considerably from open access, which lacks resource use rights (Agrawal, 2001). The management of grazing in CPAs is crucial for the maintenance of rangeland production and health. Studies by Herrick & Wander (2018) and Egeru *et al.* (2019) have shown that there is a dynamic relationship that exists between rangeland vegetation and soil properties. The features of any soil type play a role in the widely recognized resilience in semi-arid grazing lands, because they provide a degree of flexibility to the soil, in the notion that they provide pliancy to the soil, thus preventing disturbances in the biological system (Dougill *et al.*, 1998; Walker & Meyers, 2004; Vetter, 2013). Rangeland's health is predominantly dependent on the interaction between the soil and plant communities (Balestrini *et al*., 2015). Continuous grazing by livestock on the rangeland leads to poor physical, chemical and biological soil properties, resulting in a dramatic change in vegetation and nutrient cycling (Lavado, 1996; Bolo *et al*., 2019). When such a challenge is encountered in rangeland, the growth of perennial decreaser grasses will decline, and changes in the herbaceous layer species and woody species establishment will occur (Ash *et al*., 2011). According to studies conducted by Ash *et al*. (2002); Holecheck *et al*. (2003) and Munyai (2012), unfavourable land variations in animal production has resulted to management constraints, particularly the inadequacy of a rapid grazing management approaches.

The variation in soil properties influences the growth and development of both grasses and trees, soil depth influences how deep or shallow the roots of these plants can grow (Stichler, 2002). Furthermore, vegetation change and soils' reaction to grazing pressure can be used as the most reliable indicator of rangeland degradation (Wang & Wesche, 2016; Cao *et al*., 2018). Several studies highlighted the impact that grazing had on soil fertility (Wang & Batkhishig, 2014, Rahmanian *et al*., 2019). Opposite to this study, in comparison between enclosures and non-enclosures, Selemani (2015) found that soil organic matter, nitrate nitrogen, soil organic carbon and exchangeable calcium were lower by 30-60% in enclosures. Schrama *et al*. (2013) also highlighted that other factors such as nutrient addition from cow dung and urine during grazing can also alter the condition of the soil. Moreover, even in physical properties overgrazing increased topsoil's temperature and increased bulk and particle density, which all can be attributed to high stocking rate on the rangeland. The increased densities and loss of moisture from the topsoil would make it less suitable for seed germination, thus a decline in species composition would occur paving the way for invasive species (MacLachlan, 2013). However, in enclosures (in rotational grazing) species composition is enriched and less bare patches that will be prone to erosion and leaching away of important soil nutrients vital for plant growth and development (MacLachlan, 2013).

Land users need more knowledge on the state of their respective grazing lands and the interaction of soil properties with grazing management implemented. Acquiring this in-depth knowledge is importance to these farmers in developing suitable and sustainable grazing management strategies that will promote livestock production. Research is silent on how grazing management in South African CPAs affects soil productivity, thus this study is aimed to explore how grazing management implemented in CPAs of Bela-Bela affects soil productivity. It was hypothesized that soils under these CPAs had been negatively affected by grazing, resulting in both poor physical and chemical properties. Therefore, the objective of the study was to assess the effect of grazing management (continuous grazing) on the available soil minerals in the four different soil types found in the CPAs of Bela-Bela municipality

3.2 Materials and Method

3.2.1 Study site description

This study was conducted in Bela-Bela local municipality at four CPAs namely, Mawela, Bela-Bela, Ramorula and Moretele located at the following altitude and coordinates: 1082m; 25° 6'54.30"S, 28°16'52.96"E; 1118m; 24°57'2.49"S, 28° 7'38.03"E, 1036m; 25°11'36.55"S, 28°14'54.25"E and 1063m; 25° 9'14.78"S, 28°17'34.06"E, respectively. Bela-Bela local municipality is in the southern part of the Limpopo province (Figure 3.1). The veld type is springbokvlakte thornveld, open to dense thorn savannah with a low shrub layer mainly dominated by *Vachellia* and *Senegalia* species, with high calcium carbonate content and gilgai micro-relief. Bela-Bela Municipality receives an average rainfall of 500 to 600 mm per year, and the mean daily temperature varies from 5-35 ºC throughout the year (Mucina & Rutherford, 2006). In all these selected CPAs continuous grazing is employed. In the CPA farms, animals kept there are non-descriptive breeds. The lab analysis of the samples was done at the North-West University experimental farm (Molelwane), Mafikeng (25°47’27” S and 25°37’18” E), North-West province of South Africa, with an altitude of about 1290 m above sea level. All farms were geo-referenced using GPS.

Table 3.1: Profile of all four selected CPA farms in Bela-Bela municipality

	Mawela	Bela-Bela	Moretele	Ramorula
Year obtained	2008	2007	2003	1998
Farm size	1457 ha	600 ha	2000 ha	850 ha
Soil type	Hutton-clay loam	Hutton-clay	Hutton-loamy sand	Ecca-sand clay loam
Vegetation type	The veld type is springbokvlakte thornveld, open to dense thorn savannah with low shrub layer (Mucina and Rutherford, 2006)			
Altitude & coordinates	(1082m) 25° 6'54.30"S 28°16'52.96"E	(1118m) 24°57'2.49"S 28° 7'38.03"E	(1063m) 25° 9'14.78"S 28°17'34.06"E	(1036m) 25°11'36.55"S 28°14'54.25"E
Rainfall & temperature	An average of 500 to 600 mm per year, and the mean daily temperature varies from 5-35ºC throughout the year			

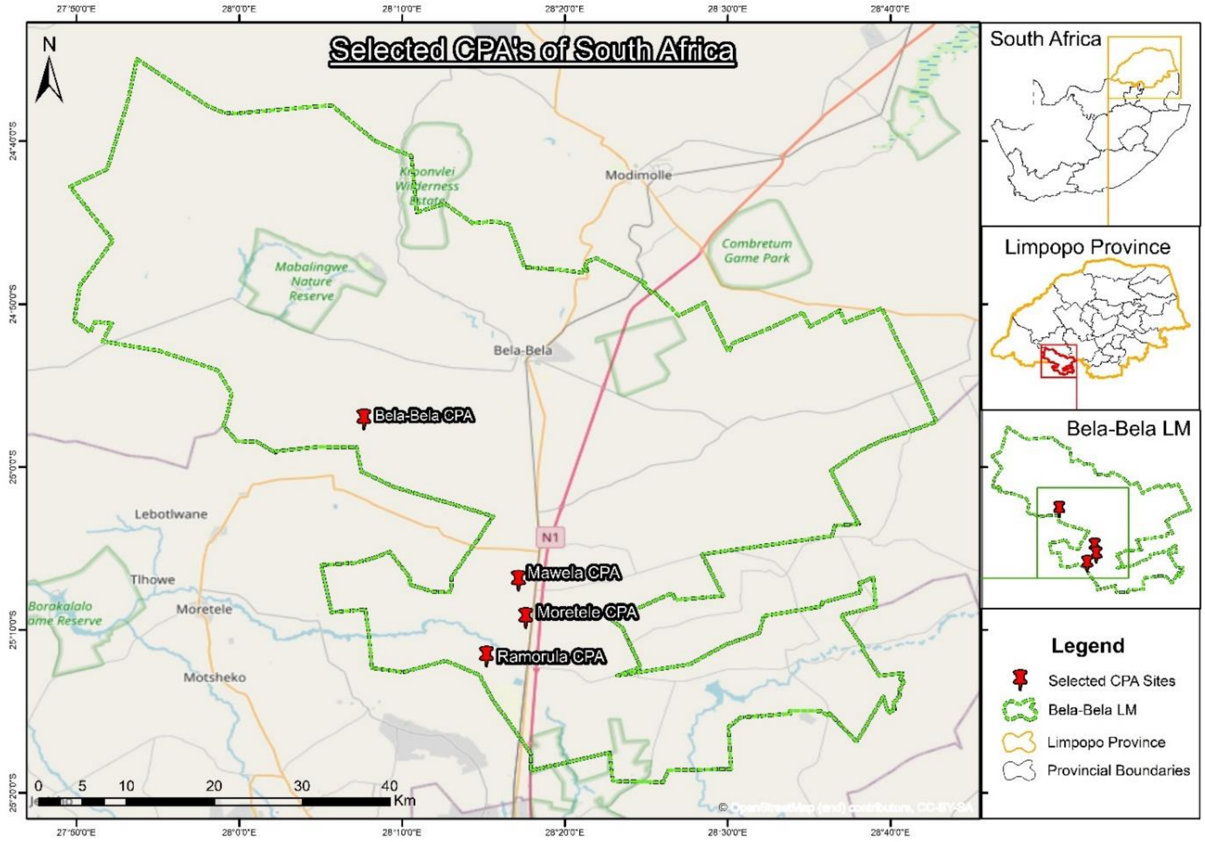

FIGURE 3.1: The location of four selected CPAs

3.2.2 Data collection

3.2.2.1 Soil sampling and analysis

Soil data collection was done in February 2021. Topsoil was sampled at a depth of 0 to 150 mm, whereas subsoil was sampled from 150 to 300 mm at an interval of 100 m (100 – 200 m) from the same transect used for woody species data collection resulting in a total of 18 soil samples per CPA. A 102 mm auger was used when collecting the soil. In each CPA, three camps were selected. In each camp, three 200 m transects which were placed 50 m apart were established. In each transect, soil samples were drawn at 0, 100 and 200 m making a total of 9 soil samples per camp. Sub-samples were bulked per CPA, air-dried, and sieved through a two-millimetre mesh screen pending analysis. Soil pH was analysed as described by McLean (1982), while soil organic carbon (OC) was determined by the wet oxidation methods of Walkley & Black (1934). Soil (Hutton- clay loam: HCL; Hutton-clay: HC; Hutton-loamy sand: HLS and Ecca sand-clay loam: ESCL) samples from all CPA farms were analyzed for both macro and micro minerals following the guidelines provided by the Agri-Laboratory Association of South Africa (AgriLASA, 1998) and N-NO_3, N-NH_4 were determined by the Kjeldahl method. The pH of the soil was determined using a 1:2.5 soil-water relation extraction method. Magnesium (Mg), Calcium (Ca), Zinc (Zn), Copper (Cu), Sodium (Na), Iron (Fe) and Manganese (Mn) were all determined by atomic absorption spectroscopy, while Potassium (K) was determined by emission spectroscopy. An ultraviolet spectrophotometer was used to determine Phosphorus (P) (Olsen & Sommers, 1982). Using an ion chromatograph, the amounts of chloride and sulphate in the soil were determined according to Dick & Tabatabai (1979) and Tabatabai & Dick (1983) methods. Soil texture (particle size) was determined by employing the standard Bouyoucos (hydrometer) method (Day, 1965). The soil was also classified according to structure and texture.

3.2.2.2 Resistance analysis

Soil resistance measures are used in a field method for measuring soil salinity. The electrical resistance of a saturated soil paste is a function of the soil salts concentration and is inversely proportional to the salt concentration. The US Bureau electrode cup was filled with soil, it was then moistened with de-ionised water while being stirred with a spatula until a homogenous mixture was obtained. The mixture was consolidated by tapping the container on the workbench from time to time, then the properties of a saturated paste were measured while adding more water if it was necessary (US Salinity Laboratory, 1954). After an hour, the paste was assessed whether it still retained saturated qualities. The sample was allowed to stand for 4 hours before determining the electrical resistance of the paste in ohms using a resistance bridge corrected for a temperature of 25 °C. It should be noted that the determination reported by the US Salinity Laboratory corrects the resistance (Ω) to a temperature of 15.5 °C.

3.3 Statistical analysis

A two-way factorial analysis of variance (SAS 2010) was used to test the effect of soil type and depth in all measured parameters in the studied CPA farms. The following model was used for statistical analysis:

$$Yij = \mu + Pi + Sj + (Pi\,x\,Sj) + \varepsilon ij$$

Where Yij was the dependent variable (physical and chemical soil properties), μ was the overall mean, P was the soil depth effect, S was the effect of soil type (different CPAs), and ε was the random error associated with observation ij assumed to be randomly distributed. Statistical difference was acknowledged at $P<0.05$.

3.4 Results

3.4.1 Soil pH, nitrate-nitrogen, ammonium-nitrogen and organic carbon

Results on the effect of soil type and depth on soil pH, nitrate-nitrogen ($N\text{-}NO_3$), ammonium-nitrogen ($N\text{-}NH_4$) and organic carbon (OC) concentration in four different soil types of Bela-Bela municipality are presented in Table 3.2. There was a statistically significant difference on effect of soil type, depth and the interaction between the two on the measured parameters. There was no significant ($P>0.05$) difference observed in pH of the topsoil across all different soil types. The highest ($P<0.05$) pH (7.1) recorded on the sub-soil was in HLS. Nitrate nitrogen (2.4 mg/kg) concentration on the topsoil was high ($P<0.05$) in the HC soil type when compared to other soil types. In sub-soil, soil N-NO_3 (2.0 mg/kg) was greater ($P<0.05$) in the HLS soil type compared to other soil types. Soil ammonium-nitrogen (4.5 mg/kg) on the topsoil was high ($P<0.05$) in the HC soil type than other soil types. Furthermore, soil N-NH_4 (3.2 mg/kg) found in sub-soil displayed an increase ($P<0.05$) in the HCL soil type. Soil organic carbon for both topsoil (0.66%) and subsoil (0.41%) was the lowest ($P<0.05$) in both HLS soil type and ESCL soil type respectively. Soil N-NH_4 (4.5 mg/kg) in the HC soil type was more ($P<0.05$) on the topsoil than in the sub-soil. All soil types had more organic matter on topsoil when compared to sub-soil.

TABLE 3.2: Soil pH, nitrate-nitrogen (mg/kg), ammonium-nitrogen (mg/kg) and organic carbon (%) found in four soil types of Bela-Bela municipality (n = 3)

	pH		N-NO_3		N-NH_4		Org. C	
Soil type	Top	Sub	Top	Sub	Top	Sub	Top	Sub
HCL	4.9^{aA}	4.9^{bA}	0.39^{dB}	0.94^{cA}	3.7^{bA}	3.23^{bA}	1.2^{bA}	0.72^{bB}
HC	5.3^{aA}	5.2^{abA}	2.4^{aA}	0.65^{dA}	4.5^{aA}	2.34^{bC}	1.5^{aA}	0.92^{aB}
HLS	6.0^{aA}	7.1^{aA}	1.1^{bA}	1.1^{bA}	3.5^{cA}	2.84^{bB}	0.66^{cA}	0.51^{cB}
ESCL	4.4^{aA}	4.7^{bA}	0.97^{cA}	2.0^{aB}	3.0^{dA}	2.30^{bC}	1.2^{bA}	0.41^{dB}
S.E	0.41		0.018		0.022		0.02	

^{a,b,c,d}= Means with different superscripts within each column arsignificantly different ($P<0.05$). ^{AB} = Means with different superscripts within each soil type are significantly different ($P<0.05$). N-NO_3: Nitrate nitrogen; N-NH_4: Ammonium-nitrogen; Org. C: Organic carbon; HCL: Hutton-clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; SE: Standard error

3.4.2 Soil macro-minerals

There was a significant difference observed in the macro-mineral concentration in different soil types and depth of the CPA soils in Bela-Bela municipality. The results of macro minerals found in four different soil types of CPAs in Bela-Bela municipality are presented in Table 3.3. There was a statistically significant difference on the effect of soil type, depth and the interaction between the two on the measured parameters. Calcium (Ca) concentration was high ($P<0.05$) in the topsoil and sub-soil of the HC soil type (1420 mg/kg) and HLS soil type (1630 mg/kg). Phosphorus (P) concentration was higher ($P<0.05$) in ESCL soil type for both topsoil (12.9 mg/kg) and sub-soil (1.6 mg/kg). The HC soil type had high ($P<0.05$) potassium (K) concentrations for both top and sub-soil. Sodium (Na) concentration was low ($P<0.05$), for both topsoil (5.0 mg/kg) and sub-soil (7.21 mg/kg) in ESCL soil type. Sulphate (SO_4) concentration was high ($P<0.05$) in the HC soil type in the topsoil (82.9 mg/kg) when compared to other soil types. On the sub-soil, the concentration of SO_4^{2-} was high ($P<0.05$) in the HCL soil type. For topsoil and sub-soil magnesium (Mg) concentration was high ($P<0.05$) in the HC soil type. The HLS soil type had the lowest ($P <0.05$) Mg concentration for both topsoil (98 mg/kg) and sub-soil (138 mg/kg).

TABLE 3.3: Macro mineral (mg/kg) found in four different soil types of CPAs in Bela-Bela municipality (n = 3)

	Ca		P		K		Na		SO$_4$		Mg	
Soil type	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub
HLC	679.0^{cA}	618.0^{cB}	2.6^{dA}	0.32^{dB}	221.0^{bA}	144.0^{bA}	5.8^{cB}	7.8^{bA}	35.3^{cB}	85.9^{aA}	288.0^{bA}	288.0^{bA}
HC	1420.0^{aB}	1340.0^{bA}	8.7^{bA}	0.14^{cB}	394.0^{aA}	302.0^{aB}	7.4^{bB}	7.4^{cA}	82.9^{aA}	76.2^{bA}	480.0^{aA}	359.0^{aB}
HLS	845.0^{bB}	1630.0^{aA}	5.1^{cA}	1.1^{bB}	120.0^{cA}	149.0^{bB}	5.0^{dB}	7.2^{cA}	32.2^{cB}	84.5^{aA}	98.0^{dB}	138.0^{dA}
ESCL	333.0^{dB}	353.0^{dA}	12.9^{aA}	1.6^{aB}	125.0^{cB}	109.0^{cB}	8.5^{aB}	14.9^{aA}	72.9^{bB}	41.6^{cA}	129.0^{cB}	156.0^{cA}
S.E	2.3		0.018		1.7		0.074		1.1		2.7	

^{a,b,c,d}= Means in the same column, with different superscripts are significantly different ($P<0.05$). ^{AB} = Means with different superscripts within each soil type are significantly different ($P<0.05$); Ca: Calcium; P: Phosphorus; K: Potassium; Na: Sodium; SO$_4$: Sulphate; Mg: Magnesium; HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; SE: Standard error;

3.4.3 Soil trace/ micro minerals

Results on the effect of soil type and depth on micromineral concentration in four different soil types of the CPAs in Bela-Bela municipality are presented in Table 3.4. There was a statistically significant difference on the soil type, depth and the interaction between the two on measured parameters. Iron (Fe) concentration in both topsoil (11.8 mg/kg) and sub-soil (7.3 mg/kg) in ESCL soil type was higher ($P<0.05$) when compared to other soil types. Manganese (Mn) concentration in the topsoil was high ($P<0.05$) in the HC soil type. The sub-soil had a higher ($P<0.05$) Mn concentration (7.6 mg/kg) in the ESCL soil type. Copper (Cu) concentration was high ($P<0.05$) in HC soil type for both the topsoil (2.6 mg/kg) and sub-soil (3.5 mg/kg). The highest ($P<0.05$) chlorine (Cl) concentration (42.2 mg/kg) was found in ESCL soil type in the topsoil, whereas in the sub-soil the highest ($P<0.05$) Cl concentration (66 mg/kg) was found in HCL soil type. Hutton-clay soil type in both top and sub-soil had high ($P<0.05$) zinc (Zn) concentrations (3.3 and 1.4 mg/kg,) respectively.

TABLE 3.4: Micro minerals (mg/kg) found in four soil types in CPAs of Bela-Bela Municipality (n = 3)

	Fe		Mn		Cu		Cl		Zn	
Soil type	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub
HCL	5.2^{bA}	3.4^{cB}	22.6^{bA}	4.3^{cB}	2.0^{bB}	2.3^{bB}	18.0^{bcB}	66.0^{aA}	1.8^{aA}	0.4^{bB}
HC	5.4^{bA}	3.9^{bB}	40.8^{A}	7.3^{abB}	2.6^{aB}	3.5^{aA}	41.0^{aA}	41.2^{bA}	3.3^{aA}	1.4^{aB}
HLS	2.1^{cA}	1.5^{dB}	14.6^{cA}	6.2^{bB}	0.3^{dB}	0.4^{dD}	16.0^{cB}	41.1^{bA}	0.9^{dA}	0.4^{bB}
ESCL	11.8^{aA}	7.3^{aB}	21.5^{bA}	7.6^{aB}	0.7^{cA}	0.8^{cC}	42.2^{aB}	26.2^{cA}	1.1^{cA}	0.4^{bB}
S.E	0.08		0.23		0.016		0.90		0.097	

^{a,b,c,d}= Means in the same column, with different superscripts are significantly different ($P<0.05$). ^{AB} = Means with different superscripts within each soil type are significantly different ($P<0.05$). Fe: Iron; Mn: Manganese; Cu: Copper; CL: Chlorine; Zn: Zinc; HCL: Hutton-clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; SE: Standard error.

3.4.4 Particle size distribution of different soil types

Results of the particle size distribution of sand, clay and silt found in four different soil types and depth in the CPAs of Bela-Bela municipality are presented in Table 3.5. There were significant differences on the effect of soil type, depth and the interaction between the two on measured parameters. Sand particles (84%) on the topsoil were more ($P<0.05$) distributed in the HLS soil type compared to other soil types. Apart from the HC soil type, the distribution of sand particle size in sub-soil was similar ($P>0.05$) in all other soil types. There was no ($P>0.05$) differences observed for silt particle distribution in both the topsoil and sub-soil across all soil types. There was an increase ($P<0.05$) in clay particle size (24%) distribution in topsoil found in HC soil type compared to other soil types. In sub-soil, the highest ($P<0.05$) distribution of clay particles (30%) was observed in the HC soil than in other soil types. The HLS soil type had the lowest ($P<0.05$) acidity (0.01) in the topsoil, while HC had the lowest ($P<0.05$) acidity (0.02) in sub-soil.

TABLE 3.5: Soil particle size distribution of sand, silt, clay (%), and acidity found in four different soil types (n = 3)

	Sand		Silt		Clay		Acidity	
Soil type	Top	Sub	Top	Sub	Top	Sub	Top	Sub
HCL	72.0^{abA}	68.0^{aA}	6.0^{aA}	8.0^{aA}	22.0^{aA}	24.0^{abA}	0.03^{bA}	0.03^{bA}
HC	68.0^{bA}	60.0^{bA}	8.0^{aA}	10.0^{aA}	24.0^{aA}	30.0^{aA}	0.02^{cB}	0.02^{cA}
HLS	84.0^{aA}	80.0^{aA}	4.0^{aA}	6.0^{aA}	12.0^{bA}	14.0^{aC}	0.01^{dB}	0.04^{bA}
ESCL	76.0^{abA}	76.0^{aA}	4.0^{aA}	4.0^{aA}	20.0^{abA}	20.0^{bcA}	0.14^{aA}	0.09^{aB}
S.E	2.7		1.3		2.0		0.0016	

^{a,b,c,d}= Means in the same column, with different superscripts are significantly different ($P<0.05$). ^{AB} = Means with different superscripts within each soil type are significantly different ($P<0.05$); HCL: Hutton-clay loam; HC: Hutton- clay; HLS: Hutton-loamy sand; ESCL: Ecca sandy-clay loam; SE: Standard error

3.4.5 Resistance of four different soil types

Figure 3.3 depicts the mean resistance of four different soil types and depth in soils of CPAs of Bela-Bela municipality. There was a statistically significant difference on the effect of soil type, depth and the interaction between the two on the measured parameters. Soil resistance (M ±SE: 2880 ± 1.7 **Ω**) measured in topsoil was high ($P<0.05$) in the HCL soil type than in other soil types. The sub-soil had the highest ($P<0.05$) resistance (3640 ± 1.7 **Ω**) in the ESCL soil type.

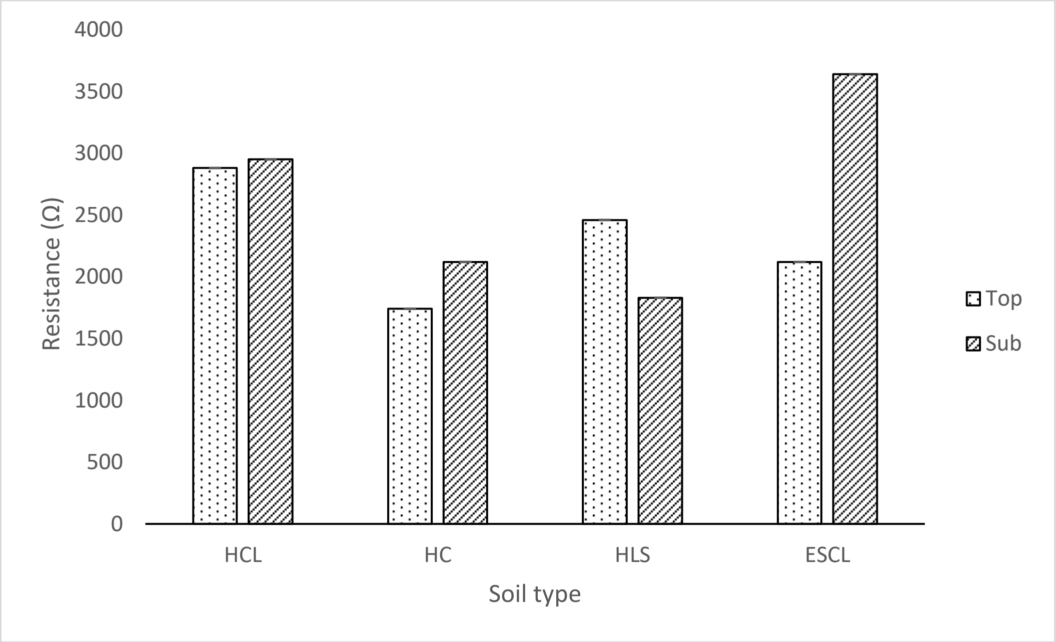

FIGURE 3.2: Mean values for resistance (**Ω**) of four different soil types of Bela-Bela Municipality (n = 3). (HCL: Hutton clay-loam; HC: Hutton-clay; HLS: Hutton sandy-loam; ESCL: Ecca sandy clay-loam)

3.5 Discussion

3.5.1 Soil pH, nitrate-nitrogen, ammonium nitrogen and organic carbon

Grazing alters both the physical and chemical properties of the soil by removing biomass yeild and trampling it (Wang & Wesche, 2016). Moreover, pH under uncontrolled or heavy grazing tends to rise (Steffens *et al*., 2008; Wang & Wesche, 2016). The acidity and alkalinity of a soil solution are measured by its pH, which is altered by both acid and base-forming ions in the soil (McCauley *et al*., 2009). Furthermore, Minasny *et al*. (2016) as well as Neina (2019) highlighted that the pH of the soil does indeed have a huge impact on soil biological processes in the natural environment. As a result, soil pH is referred to as the "chief soil factor", influencing a wide range of biological, chemical, and physical processes that affect plant development and vegetative growth. In the current study, the highest pH (7.1) was recorded in the HLS soil type. According to Lauber *et al*. (2009) along with Tripathi *et al*. (2012), a pH around neutral to alkaline indicates richness in the bacterial community in the soil as they thrive well in alkaline environments. Furthermore, the observed highest pH (7.1) is within the range reported by Tripathi *et al*. (2012) who studied forest and open-land sites. The pH either positively or negatively affects plant growth. Macdonald *et al*. (2014) noted that plant growth is limited in acidic soils. The low productivity of such soil points out the need of finding a better way to alleviate such constraints in plant production under acidic soils. Studies by Raiesi & Riahi (2014) as well as Ebrahimi *et al*. (2016) conducted on natural over-grazed rangelands revealed that the presence of livestock increased soil pH essentially by the hydrolysis of urine urea in the grazing area, hence the current study pH result can also be attributed to the continuous grazing practised in these farms.

Acidic soils also limit plants from accessing very important nutrients such as Mg, N, P, Mn and S for development (Macdonald *et al*. (2014), instead these soils promote the availability of potentially toxic (Aluminium and Boron) nutrients when in excess (Zhao *et al*., 2014). A study by Li *et al*. (2014) and another by Raiesi & Riahi (2014) showed that degraded lands have high pH values, as shown by a shift in pH values from a pre-degradation state (8.7) to a post-degradation state (9.4). Both acidity and alkalinity can promote toxicity, high pH increases osmotic stress and ion toxicity (Shi & Wang, 2005).

Nitrogen is an essential nutrient that is found in the largest proportion of plants and can sometimes hinder plant development and yield. Nitrogen is found quite often in soils as a portion of organic matter (Miller & Sonon, 2014). Abril & Bucher (1999), noted that soil compaction, reduced water retention, increased salinity and the loss of certain soil nutrients, especially nitrogen, are all consequences of overgrazing. Even though the highest nitrate-nitrogen in the present study was recorded in the HC soil type, but still, it fell below 10 mg/kg (Waller & Kookana, 2009), the recommended minimum level for plant growth. In a study by Šimek & Cooper (2002), it was determined that denitrification was quick in soils with a pH greater than 5.8 than in those with a pH range of 3.6 to 4.1. Indeed, the low amount of nitrate-nitrogen than the standard recommendation might be attributed to denitrification occuring in these soils.

Chartier *et al*. (2011) reported that low content of nitrogen, nitrate and ammonium are characteristics of degraded rangelands due to prolonged overgrazing. Furthermore, Bisigato *et al*. (2008) as well as Schiettecatte *et al*. (2008) also alluded to the fact that soil nitrogen is vastly correlated to carbon. Visual observation and farmers' responses during data collection confirm that these farms have been heavily grazed in the past 10 years. Contrary to what was expected and obtained in the current study, Northup *et al*. (2019a) who studied the USDA-ARS grazing lands in

Oklahoma reported that nitrogen increased with continuous and high stocking rates, especially near watering points and some corners of occupied paddocks. Ammonium (NH_4^+) fixation and release can also have a significant impact on the availability of nitrogen (Steffens & Sparks, 1999; Juang *et al*., 2001) because it instigates the available nitrogen (N) for uptake by the plants after defixation has taken place. In the current study, the concentration of ammonium-nitrogen was observed to be less in the topsoil than in the subsoil, these can be attributed to the high demand of N by plants when recovering in response to defoliation, hence ammonium fixation takes place to make N available to plant. As Liu *et al*. (2008) indicated that an increase in the fixation of NH_4^+ does help build up the accessible amount of N in the soil, allowing plants to recover rapidly and halting the loss of nitrogen to the environment.

Livestock has a vital role to play in soil properties through trampling that increase soil bulkiness (Rapti *et al*., 2016). Moreover, Noellemeyer *et al*. (2006) highlighted that heavy grazing, on the other hand, can lead to rangeland degradation that will drastically decrease the herbaceous vegetation and further encourage soil erosion. Soil is indeed the biggest terrestrial carbon and nitrogen storehouse, soil can store three times more carbon and nitrogen than the atmosphere (Stuart Chapin III *et al*., 2009), primarily in the form of decayed plant litter and residues (Lal, 2004; Yusuf *et al*., 2015). Several researchers have highlighted that even grazing does influence the available organic carbon in the soil (Reeder & Schuman 2002; Shrestha & Stahl, 2008; Yusuf *et al*., 2015).

Grazing by livestock does affect soil organic carbon, overgrazing is considered to reduce soil carbon and nitrogen by the removal of the aboveground herbaceous vegetation cover directly from the soil, reducing potential carbon dioxide fixation in photosynthetic plant tissues. Furthermore, carbon dioxide belowground was reduced through the shortfalls of root development and higher root litter turnover (Reeder *et al*., 2004; Semmartin *et al*., 2010).

Soil organic carbon (SOC) (0.41-1.21) in this study is lower than the reported range (1.4-2.1%) as stated by Yusuf *et al*. (2015) along with Abule *et al*. (2005) as well as Belay & Kebede (2010) who all conducted studies in semi-arid rangelands. Wang *et al*. (2018), reported a higher (6.9%) SOC than the present study, and it was noted that the variation amongst SOC was caused by particle size distribution, altitude and rainfall as the main contributors in semi-arid rangelands. Subsequently, Somenahally *et al*. (2020), also reported 1.6% and 25.1% of soil organic carbon (SOC) for both top and subsoil respectively under high grazing pressure. These results are higher than those obtained in the current study. The different woody species encroaching and grazing management employed by these farms could explain the variation in the reported organic carbon. Another key restriction on the decomposition rate is the quality of carbon sources, which are generally determined by their lignin content (Jobbágy and & Jackson, 2000). Woody species have higher lignin content than grasses, and being slowly decomposable can increase the storage of SOC. Woody species might contribute more to the SOC content, but also dead grass biomass (Dinakaran, 2011) does increase SOC. Indeed, the current results agree on the relationship between HC soil type biomass and the SOC content found in the same soil type. Moreover, good basal cover and high biomass yield of the rangeland would promote more storage of SOC (Shiferaw *et al*., 2019).

3.5.2 Macro and micro minerals

The presence of macronutrients, as well as the amount in which they are available, plays a huge role in plant development, plant vigour and yield (Northup *et al*., 2019b). According to Baron *et* *al*. (2001), generally, every grazing management strategy employed has an impact on the nutrient cycle and the net nutrient reservoirs throughout the soil. In the current study, there were significant differences observed amongst macronutrients across all soil types. Chlorine was significantly higher in both top and subsoil in ESCL and HCL respectively. Hook & Burke (2000), as well as Briske *et al*. (2005) along with Northup *et al*. (2019b) stressed that the type of plant community, location within the landscape, and temperature all influence macronutrient abundance and distribution. These characteristics tend to produce varied distributions that cannot be traced back to grazing impacts (Ganskopp & Bohnert, 2009 ; Northup *et al*., 2019a). As noted by Neina (2019) plants can access some nutrients at different pH values, for instance, magnesium and calcium highest values (topsoil and subsoil) were recorded in both HC (pH 5.3) and HCL (pH 4.9) soil types. Moreover, Penn & Camberato (2019) noted that phosphorus (P) solubility normally occurs around the pH of 4.5 to 6.5. However, although the exact P solubility will vary in terms of soil type, geographical location, and climate, the range close to neutral is the most sound, as it is regarded as the best pH range for optimum plant growth. This is comparable to the assertion by McCauley *et al.* (2009), that these macronutrients are most accessible to plants at a pH range of 6 to 8. The good basal cover in the HC soil type might be due to the nutrients being available to the plants accompanied by good grazing management employed in this soil type. However, inconsistencies of soil nutrients in these soil types might be caused by uncontrolled or heavy grazing as practised in these farms. Large quantities of mineralization increase nutrient uptake by stressed plants (Crovo *et al*., 2017; Abdalla *et al*., 2018), and this can play a part in lowering the available macronutrients in the soil. Moreover, Ragimov *et al*. (2020) also stated that high grazing intensity does decline the net productivity of the rangeland, resulting in the decrease of palatable species and soil chemical properties. Contrary to the aforementioned, Rutherford & Powrie (2010) as well as Al-Rowaily *et al*. (2012) found that short-term grazing improved the concentration of some of the soil minerals such as SOC, N, K and P to a depth of 0-30 cm.

The current study recorded the lowest pH values in both the HCL and ESCL soil types, meaning that these soils are acidic. Acidic soils (with pH < 5.5), due to different contributing factors are known to hinder plant growth while the toxicity of aluminium (Al) is the principal limiting factor of plant growth in acidic soils (Kochain *et al*., 2005; Zhao *et al*., 2014). To counteract such a problem in Al-stressed plant production, phosphorus (P) and ammonium can ameliorate Al toxicity and diminish the release of organic acids from plant roots (Sun *et al*., 2008; Chen *et al*., 2010; Zhao *et al*., 2014). This suggests that if both HCL and ESCL soil types were to accumulate more of both Al and P that would aid in increased toxicity and the betterment of the soil's pH, respectively.

Variations in phosphorus (P) concentration obtained from ESCL soil type might be explained by the season (summer) when the soil samples were collected. During, the growing season, when plants are grazed continuously due to mismanagement, they respond by uptaking more minerals from the soil and the results from the current study revealed lower P concentration in the subsoil than that of topsoil. Complementary to the abovementioned, the same was observed with potassium, as it was more on the topsoil than in the subsoil. The vegetation layer especially herbs (Fujita *et al*., 2010) might have taken much of the topsoil P and K which lead to a reduced concentration of these minerals in the topsoil (Van der Salm *et al*., 2012). Moreover, environmental conditions such as runoff and erosion might have contributed to the leaching of these soil minerals (Andersson *et al*., 2013), and these (runoff and erosion) normally take place in overgrazed areas. Sulfur (S) is consistently being cycled amid inorganic and organic forms in soil and the release of SO_4^{2-} from organic S forms is particularly of colossal significance to plants

(Kertesz & Mirleau, 2004; Wilhelm Scherer, 2009). In the current study, sulfate ions were significantly high in both HC and HCL soil types. The high levels of sulfate ions in the two soil types might be attributed to sulfur that is deposited to the ground as urine and dung from livestock. As explained by Whitehead (2000) along with Northup *et al*. (2019a), livestock retains around 25% of the S in the forage they consume, with the rest being eliminated from the body as dung and urine. Sulfur availability to plants can be achieved by making a couple of water points in the paddocks where livestock graze. Sulfur concentration tends to increase close to water points (Whitehead, 2000). The proper accumulation of macrominerals in the soil will surely elevate biomass and vegetation cover when proper grazing management is deployed.

Micronutrients are commonly regarded as important plant nutrients that are taken by plants from the soil in very small quantities and they play a vital role in plant growth, plant metabolism and development (Tavakoli *et al*., 2014). Furthermore, with them being deficient, plants can easily be attacked by pathogens (Monreal *et al*., 2016). Concerning micronutrients, there was a significant variation across soil types for both topsoil and subsoil. According to Shrivastav *et al*. (2020), the majority of micronutrients such as copper (Cu), zinc (Zn), and iron (Fe) are mostly available to plants within the pH range of 5 to 7. Any variation from the ideal range of this pH will slow and reduce nutrient availability, making them less accessible to plants. The current study results were lower when compared to those reported by Márquez-Madrid *et al*. (2017) who conducted a study in grassland sites of Zacatecas, Mexico. This might be attributed to the low pH range of the above-mentioned one and pH varies with location, soil texture and soil structure (Goulding, 2016). Bradl (2004) and Neina (2019) stated that at low pH micronutrients are normally soluble due to high desorption and low adsorption. Under certain assumptions, this can be construed as the reason behind the low content of micronutrients in the soil, plants might have been responding to grazing by livestock.

Manganese (Mn) is one of the trace elements that are required for plant growth. It is an important cofactor for the oxygen-evolving complex of the photosynthetic machinery (Michopoulos *et al*., 2021). Concerning, manganese concentration in the current study, it was recorded to be higher in topsoil than in subsoil in ESCL soil type. The low concentration of Mn in subsoil might be attributed to the uptake by plants (Michopoulos *et al*., 2021), as the low pH enhances the Mn uptake, and the pH range of this soil type is suitable for Mn to be more available to plants. Furthermore, Gandois & Probst (2012) (373 mg/kg) as well as Michopoulos *et al*. (2021) (95.4 - 148 mg/kg) both reported a high concentration of soil Mn when compared to the present study. High grass height in ESCL soil type is influenced by the Mn uptake.

3.5.3 Soil particle size, Acidity and Resistance

According to Su *et al*. (2004) soil is classified in different ways and particle size distribution (PSD) is the most frequently used technique to estimate a lot of soil-related properties. Particle size distribution has a huge impact on how water, ion movements, heat and air movement are retained in the soil. Losses of soil minerals such as organic carbon and other minerals will cause a decline in the water holding capacity, loss of soil structure as well as some biotic qualities which are all coupled by partial dissolution of small particle size fractions due to wind erosion in rangeland soils (Su *et al*., 2004; Bronick & Lal, 2005). Particle size distribution might play a vital role in agricultural land productivity. In addition, Amakor *et al*. (2014) along with Mandal *et al*. (2015) stated that to manage land resources sustainably, accurate and exact salinity measures are essential and need to be accessed, particularly in terms of soil quality and rangeland productivity. Hutton and Ecca soil types contained clay and sandy-loam content in them (Mengistu *et al*., 2019). Moreover, the most dominant PSD across all soil types was sand particles with clay particles coming in second. This suggests that these tiny sand particles can easily be removed by the wind in grazing lands that have large bare areas, slowly causing the rangelands to be degraded with time. However, according to Parwada & Van Tol (2017), clay material provides the necessary bonding between the various soil particles (sand, silt and clay), bringing about the production of more stable aggregates that are less prone to erosion. Species both (grasses and browse) are adapted to different habitats. The high presence of sand particles in the HLS soil type allowed the dominance of grasses and woody species such as *Cynodon dactylon*, *Digitaria eriantha*, *Grewia flava* and *Senegalia mellifera*. While on the other hand clay particles in the HCL soil type permitted the growth of species such as *Cymbopogon pospischilii*, *Aristida congesta*, *Dichrostachys cinerea*, and *Grewia flava* (Van Wyk *et al*., 2012; van Oudtshoorn, 2020).

Land deterioration owing to soil acidity is one element of land degradation that limits rangeland productivity worldwide (Abate *et al*., 2017). In addition, soil acidity is caused by land degradation owing to overgrazing, deforestation and continuous cultivation (Taddese, 2001; Dejene, 2003). The pH is a parameter used to measure soil acidity, in agreement with the current study pH readings in ESCL soil type recorded the most acidic soil. The current study results of acidity are low, and as highlighted by Abate *et al*. (2017), acidic soils are predominant in high-rainfall areas as compared to those with low rainfall. Due to the lack of rainfall in the farms where the current study was conducted, one would not anticipate acidic soils.

The electrical resistance of a saturated soil paste is a function of the soil salt concentration and is inversely proportional to electric resistance (US Salinity Laboratory, 1954), and ideally, the most used method for determining salinity is to test electrical conductivity in saturated paste extracts.

In the current study the soils HCL, HC and ESCL had resistance in the subsoil to be higher than in the topsoil meaning there are less salts in the subsoil than topsoil. Whereas the HLS soil type resistance in the topsoil was higher than in the subsoil, meaning there are less salts in the topsoil than in the subsoil. Continuous grazing does encourage salinization in soils (Chaneton & Lavado, 1996), which also promotes high temperatures and evaporation. In agreement to the current study results, Chaneton & Lavado (1996) as well as Sepehry *et al*. (2012) found that the top soil in continuously grazed camps had high salinity levels when compared to lightly grazed camps. With such soils, continuously grazed rangelands will retain a lot of salts (Van Rensburg *et al*., 2011) if there is not much rainfall to leach them out, thus decreasing the resistivity. The resistance obtained in the study is high, giving insight or suggesting that the soils in the current study have a low concentration of salts. Furthermore, the high levels of soluble salts will surely hinder the growth of salts sensitive plants leading to reduced plant yields in these soil types.

3.6 Conclusion

The objective of the study was to assess how grazing management affected soil properties of four different soil types found in the CPAs of Bela-Bela municipality. Grazing management in these selected CPAs is critical for maintaining rangeland productivity and sustainability as grazing by livestock plays a vital role in the nutrient cycle in the soil. Hutton loamy-sand soil type had an intermediate pH that permits the availability of most macro and micronutrients. This suggests that this soil type would perform well given a good grazing management strategy is used making soil nutrients available to plants thus eventually increasing the basal cover and biomass yield. All soil types had more concentration of soil nutrients on the topsoil than subsoil. Both macro and micronutrients analysed from the soil type, nitrogen (N), chlorine (Cl), iron (Fe) and copper (Cu) were all found to be deficient to support plant growth, as they were below 6.4g/kg. Given the deficiency of nitrogen in the soils, farmers are advised to prioritize more enclosures and keep leguminous trees present in these grazing lands as they will aid in restoring N content. As far as acidity is concerned, all these soil types are not acidic, as this was expected because these soil types (CPA farms) are not situated in high-rainfall areas. From the above results, the emerging key findings are dependent on the type of grazing management employed in these farms, as it accounts for a wide range of things happening in the soil from basal cover to erosion which will lead to poor soil. In short, improved grazing management will positively affect rangeland productivity, health, and sustainability.

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CHAPTER 4: GRASS SPECIES COMPOSITION, DISTRIBUTION AND NUTRITIVE VALUE AS INFLUENCED BY SOIL TYPE AND GRAZING MANAGEMENT AT SELECTED CPAS OF BELA-BELA MUNICIPALITY

Abstract

With little data available globally, an assessment of vegetation distribution in relation to soils and grazing management is important for the efficient development of a proper grazing management system in most areas. The study examined the soil type implication on bulked grass's composition, distribution and nutritive value. Three 200 m line transects serving as replicates and were laid 50 m apart from each other in each of the three camps per CPA. In each of the three line transects per camp, sub-transects were marked at 50 m intervals (50, 100,150 and 200 m) to create four 10 m x10 m homogenous vegetative units making a total of 12 HVUs per camp. Along with each line transect, grasses were identified, their tuft height and diameter measured and were then harvested to be analyzed for chemical composition. All the data was subjected to a one-way analysis of variance (SAS, 2010). A total of twenty-five grass species were identified and collected from the four different selected CPAs of Bela-Bela namely, Mawela (Hutton- clay loam: HCL), Bela-Bela (Hutton-clay: HC), Moretele (Hutton-loamy sand: HLS) and Ramorula (Ecca sand-clay loam: ESCL). Across all soil types, *Aristida congesta* and *Eragrostis rigidor* were the two dominant ($P<0.05$) grass species. Hutton-clay (HC) soil type had the highest ($P<0.05$) herbaceous biomass ye (823.3 kg/ha) and basal cover (55.8%). The HCL soil type had taller ($P<0.05$) *D. eriantha* and *A. congesta*. For the tuft diameter, *Setaria sphacelata* in the ESCL soil type had the thickest ($P<0.05$) tillers (21.3 cm) when compared to the one found in the HC soil type (4.3 cm). *Bothriochloa insculpta* basal tillers were thicker ($P<0.05$) in ESCL soil type (19.7 cm). The crude protein (CP) content (45.4 g/kg DM) was higher ($P<0.05$) in bulked grasses harvested in ESCL soil type. All soil types had bulked grasses similar ($P>0.05$) neutral detergent fibre (NDF), acid detergent fibre (ADF), digestible energy (DE) and metabolizable energy content. The grasses from the HC soil type had the lowest ($P<0.05$) acid detergent lignin (ADL) content when compared to those from other soil types. The HLS soil type bulked grass species had the lowest ($P<0.05$) ether extract (EE) content (20.8 g/kg DM). Hutton clay (HC) soil type had the highest ($P<0.05$) *in vitro* dry matter degradability (DMD) at 24 (366.1 g/kg), 36 (478.4) and 48 (629.8 g/kg) hours for bulked grasses. With one soil type (HC) outcompeting others in both basal cover and biomass yield, which suggests that improved grazing management would uplift the productivity of other soil types. The low CP content in the bulked grasses suggests the need for supplementation with high CP sources to optimize livestock production.

Keywords: Bulked grasses, livestock, grazing value, biomass, vegetation

4.1 Introduction

Grasses are the main feed option for grazing ruminants in arid and semi-arid lands (Ahamefule, 2006). Farmers mostly rely on rangelands to feed their livestock dueto their inability to reliably and consistently provide their livestock with feed as a result of financial contraints (Tavirimirwa *et al*., 2019). When it comes to quantity and quality, grasses can be insufficient to supply the nutritional needs of livestock depending on the seasons, soil fertility and morphological and physiological stages (Rust & Rust, 2013). Ninety-five per cent of food produced worldwide is estimated to rely on the soil (FAOSTAT, 2003; van Zijl, 2019). There is growing evidence that shows that the structure of the plant community affects soil properties (Grayston *et al.,* 2004), and this will have distinct effects on plant development and nutrient absorption (Kotze, 2015). Hufford *et al.* (2014) as well as Inman *et al*. (2020) reported that the relationship between the abundance of different plant species and soil properties may provide means of evaluating species that are appropriate for specific sites in rangeland restoration. This was evident in a study by Mokgakane *et al*. (2021), who found that variations in the number of palatable species, biomass yield, nutrient concentration, and grazing capacity are influenced by soil type. The existing perspective as highlighted in Chapter 3, indicates that soil properties dynamics in grazing lands may well be influenced by changes in plant population and species distribution altered by grazing management practices and erratic precipitation (Jin *et al.*, 2014). Rotational and continuous grazing systems can affect soil nutrient distribution and supply by directly altering soil properties and influencing biological transformations in the rooting zone in rangelands (Fraterrigo *et al.*, 2004). Soil types such as clay soil and clay-loamy have a negative association with a woody cover which can pave the way for herbaceous species to thrive (Sankaran *et al.*, 2008; Ravhuhali *et al*., 2020; Ravhuhali *et al*.. 2021). Indeed, Moyo *et al.* (2010) admitted that high soil nutrients, particularly organic carbon depleted by soil disturbances such as grazing, promote the growth of nutrient-limited grasses such as stoloniferous perennials species that include *Cynodon dactylon* and *Pennisetum clandestinum*.

Grazing management in CPAs varies due to different institutional arrangements and livestock populations as influenced by indigenous knowledge, the objective of the farmers and financial constraints while ignoring the concern about environmental challenges (Brunckhorst & Marshall, 2012; Ravhuhali *et al.*, 2020). Furthermore, soil types in these selected CPAs are different, and vegetation distribution and quality variations that result from these varying drivers are not understood. Evaluating the distribution or status of native vegetation is also important for the efficient development of a grazing management system in these CPAs. Therefore, the objective of this study was to evaluate the effect of soil type on quantity and quality of the herbaceous layer in selected CPAs of Bela-Bela municipality, while hypothesizing that different soils in these selected CPAs influence the composition, distribution and nutritive value of grasses.

4.2 Materials and method

4.2.1 Study site description

The study was conducted in four selected CPAs, Mawela CPA (Hutton- clay loam: HCL), Bela-Bela CPA (Hutton-clay: HL), Moretele CPA (Hutton-loamy sand: HLS) and Ramorula (Ecca sand-clay loam: ESCL) all situated in the Bela-Bela municipality, South Africa as described in section 3.2.1 in Chapter 3.

4.2.2 Data collection

4.2.2.1 Biomass yield and grazing capacity

Three line transects (200 m) which served as replicates, were established in each of the three selected grazing camps per CPA. The three line transects were placed at least 50 m from each other. Along each line transect, points were marked within 50 m from the selected grazing camps to form 12 sampling sub-transects per camp. Within each sub-transect, 10 m × 10 m homogenous vegetation units (HVUs) were marked. In each HVU, one square metre quadrat was randomly placed to sample grass. The basal cover was estimated using the total hits expressed as a percentage and the height, turft diameter, species composition of grasses were measured and harvested (at a stubble height of 5 cm from the ground surface) within each quadrat , bulked and oven-dried at 60 °C until constant weight was reached for biomass determination, grazing capacity and chemical analysis.

The following equation was used for biomass yield determination (van Oudtshoorn, 2015).

Biomass (DM kg/ha): $10000\ (weight\ of\ dried\ grass\ (g))/1000$.

The following equation was used for grazing capacity (van Oudtshoorn, 2015)

Grazing capacity (ha/LSU): $d/(\frac{DM}{r})$

Where d: number of days in a year

DM: dry matter weight in kg (biomass)

r: utilisation factor (2.5% of 450 kg body weight)

4.2.2.2 Species identification and classification

All grasses found were recorded and classified according to the Dyksterhuis (1949), theory of succession, and ecological information for the arid to semi-arid regions of South Africa (Vorster, 1982). The species were divided into (i) highly desirable species: those that occur in the favourable condition rangeland and decrease with overgrazing (decreasers), (ii) desirable species: those which occur in rangeland in good condition and increase with moderate overgrazing (increaser I), and (iii) less desirable species: those which occur in rangeland in good condition and increase with severe/extreme overgrazing (increasers II and III). Furthermore, species were identified and grouped into their life forms (annuals or perennials) and grazing values as described by van Oudtshoorn (2020). Species were categorized into dominant (> 13%) and common (3-13%), rare (1-3%) and present (1% and less) in terms of their abundance. Only dominant and common were considered in a frequency distribution, species height and shoot diameter (cm). Grass collection was done in February 2021.

Sampling sites were geo-referenced using a GPS (Table 3.1). This was done to allow the digitizing of all sample site locations, after being validated, for entry into a spreadsheet or a database. While waiting, the bulked grounded samples were kept in airtight containers and the North-West university experimental farm was used to conduct the laboratory analysis.

4.2.2.3 Chemical analysis of bulked grasses

The DM was determined according to AOAC (2012), in which a one-gram sample of grass was weighed into pre-weighed crucibles and placed in the oven for 24 hours at 100 °C. After 24 hours, the samples were taken out of the oven, placed in a desiccator to cool, and weighed again. Moisture content was calculated as the weight lost, and DM was calculated as the difference between the initial sample weight and the moisture weight. Ash was determined by placing crucibles containing samples used in DM determination in a furnace set at 600 °C for 6 hours, for the detemination of ash content (AOAC, 2012). Total nitrogen (N) was determined by the standard macro Kjeldahl method (AOAC, 2012) and it was converted to crude protein (CP) by multiplying the %N content by a factor of 6.25. Ether extract (EE) was determined using the Soxhlet method (AOAC, 2012). Test solutions were prepared for both neutral detergent fibre (NDF) and acidic detergent fibres (ADF) analysis according to the method of Van Soest *et al*. (1991) using an ANKOM^{2000} fibre analyser (ANKOM Technology, 2005). Acid detergent lignin (ADL) was determined by placing dry ADF bags or samples in a sufficient amount of 72% sulphuric acid. Digestible energy (DE) and metabolizable energy (ME) were calculated using the formula stated by Khalil *et al.* (1986).

4.2.2.4 *In vitro* ruminal dry matter degradability of bulked grasses

The ANKOM Daisy^{II} incubator was used to determine the *in vitro* dry matter ruminal degradability of bulked grass species. The incubator had a thermostatic chamber that was set at 39 °C and four rotating jars. The samples (0.45 - 0.5 g) were weighed into F57 filter bags, heat-sealed, and placed in digestion jars. Two buffer solutions (at a 1:5 ratio) were prepared ahead of time and combined, and 1600 mL of the combined buffer, along with samples, were transferred to each jar.

Rumen fluid (400 mL) was collected in the morning before feeding from the cannulated Bonsmara cow. Rumen fluid was collected using two pre-warmed thermos flasks. Each Daisy jar containing the F57 bags was inoculated with rumen fluid in 1600 mL of ANKOM buffer. To purge the strained rumen fluid, which was kept at 39 °C, carbon dioxide (CO_2) gas was used. Before being closed and placed in the incubation chamber, each jar was purged with CO_2. At 0, 24, 36, and 48 hours after inoculation, ANKOM F57 bags were removed and washed with cold water for 20 minutes. All washed samples were dried for 12 hours at 105 °C. The *in vitro* dry matter degradability was determined using the following formula:

$$\%\text{IVTD (DM basis)} = \frac{100-(W3-(W1*C1))}{W2*DM} * 100$$

Where: W1: bag tare weight, W2: sample weight, W3: final weight after inoculation and C1: correctional factor (final oven-dried weight divided by original blank bag weight).

4.3 Statistical analysis

One-way analysis of variance was used to test the effect of soil type on species composition of dominant grasses, desirability groups, biomass, basal cover, grazing capacity, height, tuft diameter, chemical composition for each CPA and *in vitro* ruminal DM degradability using General Linear Model (GLM) procedures of SAS (2010) within a completely randomized design (CRD). All data were analyzed according to the following linear model: -

$$Yij = \mu + STi + \varepsilon ij$$

Where:

Yij: The response variable (species composition of dominant grasses, desirability groups, biomass, basal cover, grazing capacity, height, tuft distance, chemical composition and *in vitro* ruminal DM degradability),

μ: the overall mean,

STi: the effect of soil type and

εij: the error term associated with observation ij, assumed to be normally and independently distributed.

The probability of difference in the lsmeans statement of SAS was used to separate the means (SAS, 2010). Significant differences were declared at the P<0.05.

4.4 Results

4.4.1 Species composition and distribution

For grass species and composition, the results of life form, ecological status and grazing value are presented in Table 4.1. A total of twenty-five grasses were identified across the study area. of the identified species, twenty were perennial grasses. With regards to the ecological status of identified grass species, 6 were decreasers, 3 were increaser I, 14 were increaser II, and 2 were increaser III. Lastly, in terms of grazing value, 28% was HGV, 40 % MGV and 32% LGV.

TABLE 4 .1: Life forms, ecological status and grazing values of grasses found in all four soil types

Species	Life form	Ecological status	Gazing value
Andropogon chinesis	Perennial	Increaser I	MGV
Aristida adscensionis	Annual	Increaser II	LGV
Aristida congesta	Perennial	Increaser II	LGV
Bothriochloa insculpta	Annual	Increaser II	MGV
Cenchrus ciliaris	Perennial	Decreaser	HGV
Chloris pyncothrix	Annual	Increaser II	LGV
Chloris virgata	Annual	Increaser II	MGV
Cymbopogon pospischilii	Perennial	Increaser III	LGV
Cynodon dactylon	Creeping	Increaser II	HGV
Digitaria argyrograpta	Perennial	Decreaser	HGV
Digitaria eriantha	Perennial	Decreaser	HGV
Eragrostis heteromero	Perennial	Increaser II	MGV
Eragrostis lehemanniana	Perennial	Increaser II	MGV
Eragrostis rigidior	Perennial	Increaser II	MGV
Heteropogon contortus	Perennial	Increaser II	MGV
Hyparrhenia filipendula	Perennial	Increaser I	MGV
Hyparrhenia hirta	Perennial	Increaser I	MGV
Melinis repens	Perennial	Increaser II	LGV
Panicum maximum	Perennial	Decreaser	HGV
Perotis patens	Annual	Increaser II	LGV
Pogonarthria squarrosa	Perennial	Increaser II	LGV
Setaria sphacelata	Perennial	Decreaser	HGV
Sporobolus africanus	Perennial	Increaser III	LGV
Themeda triandra	Perennial	Decreaser	HGV
Urochloa mosambecensis	Perennial	Increaser II	MGV

LGV: Low grazing value; MGV: Medium grazing value; HGV: High grazing value

4.4.2 Species composition of dominant grasses found in four soil types

Results of the frequencies of occurrence of grass species by composition (%) in all four soil types are presented in Table 4.2. When the average frequency of a species in a site surpasses 13%, it is considered dominant, likewise, when the average frequency is between 3 and 13%, it is common. According to these definitions, although statistical differences were not observed, *A. congesta* was the dominant grass in HCL and HLS soil types respectively. *E. rigidior* was the dominant ($P<0.05$) grass in HLS and ESCL soil types, respectively. However, *D. eriantha* was dominant in the ESCL soil type as compared to other soil types, but there was no significant difference observed. *Panicum maximum* was dominant in the HCL soil type but was common in all other soil types. The creeping grass, *Cynodon dactylon,* dominated ($P<0.05$) only in the HLS soil type and *C. ciliaris* is one of the absent species in this soil type.

TABLE 4.2: Composition (%) of dominant and common grass species in all four soil types

	Soil Type				
Species	HCL	HC	HLS	ESCL	S.E
Aristida congesta	38.8^{a}	17.3^{b}	10.0^{bc}	5.4^{c}	5.4
Bothriochloa insculpta	-	0.57^{b}	-	4.3^{a}	0.57
Cenchrus ciliaris	-	5.1	-	-	-
Cymbopogon pospischilii	14.4	-	-	-	-
Cynodon dactylon	0.85^{b}	-	16.7^{a}	-	0.85
Digiteria eriantha	4.7^{b}	0.29^{c}	11.4^{a}	14.6^{a}	0.29
Eragrostis rigidior	6.2^{c}	1.1^{c}	39.1^{a}	25.0^{b}	1.1
Heteropogon contortus	0.31^{c}	15.8^{a}	7.7^{b}	-	0.31
Hyparrhenia hirta	4.2^{b}	31.0^{a}	-	-	4.2
Melinis repens	4.3^{b}	11.8^{a}	-	-	4.3
Panicum maximum	13.3^{a}	4.02^{b}	4.91^{b}	11.4^{a}	4.0
Setaria sphacelata	-	0.57^{b}	-	27.7^{a}	0.57
Urochloa mosembicensis	3.1^{b}	4.0^{b}	9.8^{a}	10.4^{a}	3.1

$^{abc:}$ Means in the same row with different superscripts are significantly different ($P < 0.05$), HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; SE: Standard error

4.4.3 Desirability groups, biomass, basal cover, and grazing capacity of herbaceous layer in four different soil types

Table 4.3 shows the findings of grass species composition in four distinct soil types based on the frequency of desirability groups, biomass yield, basal cover and grazing capacity. The HLS soil type had the highest ($P<0.05$) percentage (14.3%) of moderate grazing value (MGV) species. The

HC and ESCL soil type displayed similar ($P>0.05$) percentages of MGV species. The ESCL soil type had the highest ($P<0.05$) percentage (13.8%) of high grazing value (HGV) species while the HC soil type had the least ($P<0.05$) percentage (1.9%) of HGV species when compared to other soil types. Hutton-clay soil type had the highest ($P<0.05$) biomass yield (823.3 kg/ha) compared to HCL soil type (658.9 kg/ha), ESCL soil type (488.9 kg/ha) and HLS soil type (265.6 kg/ha) soil types which differed significantly. Hutton-clay soil type had the highest ($P <0.05$) basal cover when compared to other soil types. Hutton clay-loam soil type had a poor ($P<0.05$) grazing capacity (GC) (20.6 ha/LSU) when compared to other soil types.

TABLE 4.3: Grass species composition (%) of desirability groups, biomass yield (kgDM/ha), basal cover (%) and grazing capacity (ha/LSU) of common grasses found in four different soil types

	Soil type				
Parameter	HCL	HC	HLS	ESCL	S.E
LGV	10.4^{a}	5.3^{ab}	2.5^{ab}	1.4^{b}	2.8
MGV	2.6^{b}	8.6^{ab}	14.3^{a}	9.9^{ab}	3.3
HGV	3.2^{bc}	1.9^{c}	12.4^{ab}	13.8^{a}	3.2
Biomass	658.9^{ab}	823.3^{a}	265.6^{c}	488.9^{b}	73.6
Basal cover	42.4^{ab}	55.8^{a}	28.4^{b}	37.2^{b}	11.9
GC	7.0^{b}	5.8^{b}	20.6^{a}	8.7^{b}	2.3

^{abc}: Means in the same row with different superscripts are significantly different ($P<0.05$); HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; LGV: low grazing value, MGV: medium grazing value, HGV: high grazing value GC: grazing capacity; SE: Standard error

4.4.4 Grass height of dominant and common grass species found in four different soil types

Table 4.4 shows the results of the height of grass species found across four different soil types. *Digitaria eriantha* was taller ($P<0.05$) in the HCL soil type (162.7 cm) when compared to other soil types. However, it was the shortest ($P<0.05$) grass species in the HC soil type (7 cm) when compared to other soil types. *Eragrostis Rigidior, P. maximum, U. mosambicensis, H. contortus* and *A. congesta* were shorter ($P<0.05$) in the HCL soil type than other soil types. The *Panicum maximum* was taller ($P<0.05$) in the HC soil type. *Setaria sphacelata* and B. insculpta had the tallest ($P<0.05$) height in the ESCL soil type.

TABLE 4.4: Grass height (cm) of dominant and common species found in all four soil types

	Soil type				
Species	HCL	HC	HLS	ESCL	S.E
Aristida congesta	59.3^{a}	43.3^{ab}	13.7^{b}	77.7^{a}	13.3
Bothriochloa insculpta	-	20.0^{b}	-	60.7^{a}	1.7
Cenchrus ciliaris	-	72.8	-	-	-
Cymbopogon pospischilii	97.0	-	-	-	-
Cynodon dactylon	10.0^{a}	-	11.3^{a}	-	2.5
Digitaria eriantha	162.7^{a}	135.3^{a}	79.3^{b}	73.0^{b}	16.0
Eragrostis rigidior	86.3^{a}	60.0^{a}	13.7^{b}	78.3^{a}	8.2
Heteropogon contortus	75.0^{a}	67.3^{a}	22.3^{b}	-	3.1
Hyparrhenia hirta	136.3^{a}	107.0^{b}	-	-	5.3
Melinis repens	86.5^{a}	73.7^{a}	-	-	8.4
Panicum maximum	66.7^{ab}	86.7^{a}	39.8^{b}	84.3^{a}	12.8
Setaria sphacelata	-	22.0^{b}	-	90.3^{a}	4.4
Urochloa mosambicensis	56.0^{a}	69.7^{a}	16.5^{b}	52.3^{a}	8.00

$^{ab:}$ Means in the same row with different superscripts are significantly different ($P<0.05$); HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; SE: Standard error

4.4.5 Grass diameter (tuft) of dominant and common grass species found in four soil types

The grass diameters (turf) of grass species found in four different soil types are presented in Table 4.5. *Setaria sphacelata*, *U. mosambicensis*, *D. eriantha* and *B. insculpta* in ESCL soil type had the largest ($P<0.05$) diameter when compared to the diameter of the other species found in other soil types. *Eragrostis rigidior* in ESCL and HC soils had the thickest ($P<0.05$) tillers (14.7 cm) when compared to other soil types. *Panicum maximum* in HCL (3.3 cm) and HLS (3.3 cm) soil types had the thinnest ($P<0.05$) tillers when compared to other ESCL soil type. *Cynodon dactylon* in the HSL soil type had the thickest ($P<0.05$) tillers when compared to the HCL soil type.

TABLE 4.5: Grass (shoot) diameter (cm) of dominant and common grass species found in four different soil types

	Soil type				
Species	HCL	HC	HLS	ESCL	S.E
Aristida congesta	2.9^{a}	8.0^{a}	4.7^{a}	7.9^{a}	2.3
Bothriochloa insculpta	-	1.6^{b}	-	19.7^{a}	0.23
Cenchrus ciliaris	-	8.7	-	-	-
Cymbopogon pospischilii	5.5	-	-	-	-
Cynodon dactylon	0.57^{b}	-	2.3^{a}	-	0.17
Digitaria eriantha	5.0^{b}	0.83^{b}	3.3^{b}	16.7^{a}	3.1
Eragrostis rigidior	3.5^{b}	10.7^{a}	1.8^{b}	14.7^{a}	1.4
Heteropogon contortus	4.0^{b}	10.7^{a}	3.3^{b}	-	
Hyparrhenia hirta	9.0^{ab}	13.7^{a}	-	-	3.2
Melinis repens	2.4^{b}	5.7^{a}	-	-	2.3
Panicum maximum	3.3^{b}	8.2^{ab}	3.3^{b}	13.5^{a}	1.9
Setaria sphcelata	-	4.3^{b}	-	21.3^{a}	0.61
Urochloa mosambicensis	3.3^{b}	6.7^{b}	1.8^{b}	15.3^{a}	2.4

$^{ab:}$ Means in the same row with different superscripts are significantly different ($P<0.05$); HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; SE: Standard error

4.4.6 Chemical composition of bulked grasses

The chemical composition of bulked grasses harvested in four different soil types of the CPAs in Bela-Bela municipality is presented in Table 4.6. Dry matter (959.5 g kg-1) of bulked grasses was higher ($P < 0.05$) in the HC soil type compared to other soil types. Among the different soil types, no ($P >0.05$) significant difference observed in ash, neutral detergent fibre (NDF), acid detergent fibre (ADF), digestible energy (DE), and metabolizable energy (ME). The ADL content (83.6 g/kg DM) of bulked grasses harvested from the HC soil type was lower ($P< 0.05$) than that soil types. The ether extract (EE) content (30.5 g/kg) and crude protein (CP) content (45.4 g/kg) were higher ($P<0.05$) in bulked grasses from ESCL soil type.

TABLE 4.6: Chemical composition (g/kg DM) (unless stated) of bulked grasses harvested from four different soil types of CPAs in Bela-Bela Municipality

	Soil type				
Component	HCL	HC	HLS	ESCL	SE
DM	954.1^{a}	959.5^{a}	869.5^{b}	941.9^{ab}	27.0
ASH	89.6^{a}	86.4^{a}	82.8^{a}	79.3^{a}	4.6
NDF	715.0^{a}	762.9^{a}	760.4^{a}	760.4^{a}	19.5
ADF	499.0^{a}	493.7^{a}	534.2^{a}	534.2^{a}	28.8
ADL	97.4^{a}	83.6^{b}	98.9^{a}	98.9^{a}	4.4
CP	38.2^{ab}	31.3^{b}	40.3^{ab}	45.4^{a}	3.2
EE	23.4^{bc}	26.0^{b}	20.8^{c}	30.5^{a}	1.2
DE (Mcal/kg)	1.9^{a}	2.0^{a}	1.8^{a}	1.8^{a}	0.12
ME (Mcal/kg)	1.6^{a}	1.6^{a}	1.5^{a}	1.5^{a}	0.10

$^{abc:}$ Means in the same row with different superscripts are significantly different (P<0.05); DM: Dry matter; CP: Crude protein; EE: Ether extract; NDF: Neutral detergent fibre; ADF: Acid detergent fibre; ADL: Acid detergent lignin; DE: Degradable energy; ME: Metabolizable energy; HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; SE= Standard error.

4.4.7 In-vitro ruminal dry matter degradability

There were variations (P<0.05) in the *in vitro* ruminal dry matter degradability (DMD) (Table 4.7) of bulked grasses from different soil types. All the bulked grasses harvested from four different harvesting sites showed similar (P>0.05) values during the DMD 0 hr incubation period. Bulked grasses from Hutton clay (HC) soil type had the highest (P<0.05) *in vitro* dry matter degradability (DMD) at 24 (366.1 g/kg), 36 (478.4 g/kg) and 48 (629.8 g/kg) hours.

TABLE 4.7: The in vitro ruminal dry matter degradability (g/kg DM) of mixed grasses found in four soil types

	Incubation period (Hours)			
Soil type	DMD 0	DMD 24	DMD 36	DMD 48
HCL	99.9^{a}	293.4^{b}	339.1^{b}	577.1^{ab}
HC	110.2^{a}	366.1^{a}	478.4^{a}	629.8^{a}
HLS	97.5^{a}	235.4^{c}	311.3^{b}	549.6^{b}
ESCL	92.9^{a}	158.1^{d}	244.7^{c}	571.5^{ab}
S.E	9.2	18.1	20.7	24.0

$^{abcd:}$ Means in the same column with different superscripts are significantly different (P<0.05), DMD 0, 24, 36, and 48 hr: *in vitro* dry matter degradability at 0, 24, 36 and 48 hr, HCL: Hutton-clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam S.E: Standard error.

4.5 Discussion

4.5.1 Distribution and composition of dominant grasses

Grass species identified in the studied 4 soil types, 80% were perennial grasses. As stated by Zimmermann *et al*. (2010), perennial grasses were found dominant in most semi-arid regions. The remaining 20% were annuals. These grasses have vital functions as they serve as livestock feed throughout the year, covering and holding soils firm from erosion. The remaining twenty per cent was made up of annuals. As reported by Holecheck *et al.* (2001) as well as by Beyene & Mlambo (2012), these are grasses that are rarely considered as grasses of good grazing value, unlike perennial grasses. However, during the winter season, there is a significant growth of some of these annuals when perennials are dormant, they thus offer nourishment to livestock. Grasses are categorized into two groups based on their ecological status and change owing to the relative abundance, which is the increaser and decreaser species. The dominance of increaser I to increaser II species in the different soil types is solely attributed to under-grazing and overgrazing (Vesk & Westoby, 2001; Mansour *et al*., 2012; van Oudtshoorn, 2020). Moreover, increaser I species such as *H. hirta* tend to increase in abundance if the grazing land is under grazed, whereas increaser II species such as *Aristida congesta*, *Urochloa mosambicensis* and *Heteropogon contortus* increase in abundance is attributed to overtilization of the range. Explicitly stating that it is evident that the grazing lands present in these various soil types are improperly managed. Low grazing value grasses, such as *Cymbopogon pospischilii*, *Perotis patens*, *A. adiscensions*, *Pogonarthria squarrosa* and *Chloris pyncothirix*, are commonly found in grazing areas with Avalon soil type (Mokgakane *et al*., 2021) and disturbed soils. Moreover, Abule *et al*. (2007) and van Oudtshoorn (2020) further explained that these grass species serve as a good indicator of poor rangeland.

Mavedzenge *et al*. (2005); Gusha & Mugabe (2013) highlighted that mismanagement in grazing lands causes change in species diversity, and this was attributed with high stocking rate leading to overgrazing. The dominance of *A. congesta* and *E. rigidor* across all soil types is an indication of overgrazing Ravhuhali (2018) and loss of good grazing grasses, respectively (van Oudtshoorn, 2020). However, the dominance of *Digitaria eriantha* in the Ecca sandy-clay loam soil type suggests that with proper management, this soil type has the potential to have better palatable grasses. Highly desirable, grazing grass such as *D. eriantha* in Ecca sandy clay-loam soil was found to be dominant in this soil type, and these findings concur with those of Ravhuhali & Moyo (2022). *Panicum maximum* was found dominanting in the Hutton clay-loam soil. This might be because decreasers do not withstand frequent grazing and often grows better under leguminous trees (Aganga & Tshwenyane, 2004; Ravhuhali, 2018). Furthermore, the dominance of this grass species in the aforementioned soil type might be attributed to the high total plant density making it difficult for livestock to access the forage in between trees. Inevitably the over or underutilization of the rangeland has consequences of it being poor. The dominance of stoloniferous grass species such as the *C. dactylon* in Hutton clay-loam soil might be because cattle due to its height (Beck *et al*., 2020; Mokgakane *et al*., 2021) do not mostly prefer it. This suggests that the introduction of small stock such as sheep would aid in managing this short grass species. Bushveld vegetation is dominated by perennial grasses (*Digitaria eriantha*, *Themeda triandra*, *Eragrostis* spp, *Aristida* spp) and small *Vachellia* tree species (Mucina and & Rutherford, 2006). In the present study, the rare occurrence of *T. triandra* in both Hutton clay-loam soil and Hutton clay soil is a clear indication of mismanagement as this species tends to disappear under heavy grazing.

4.5.2 Desirability groups, biomass, basal cover, and grazing capacity of grass layer in four different soil types

Vegetation cover is of paramount importance to rangeland as it reduces soil erosion, competes well with undesirable plants and is the primary source of feed for livestock (Kioko *et al*., 2012; Dalle *et al*., 2014). Moreover, Mokgakane *et al*. (2021) indicated that a reduction in plant biomass as a result of heavy continuous grazing causes soil loss, which deteriorates the soil's nutrients and eventually results in the decline of soil fertility. The result from the present study suggests that improper rangeland management will hinder the composition of good quality grasses or highly palatable grass species such as *T. triandra*, *D. argyrograpta* and *C. ciliaris*. These results agree with findings by Yonela (2017), where highly rated good palatable grasses showed a great decline in degraded rangelands. High grazing intensity is allied with a decline in highly palatable grasses which are more ecologically beneficial to rangeland (Tessema *et al*., 2012). Amongst all soil types, Hutton clay-loam soil had the most percentage of low-grazing value grass species. The aforementioned could be a result of low soil minerals depicted. Another attributing factor could be the fact that less palatable grass species (Increasers) have a high growth rate when there is a decline of good grazing / palatable grass species (Decreasers). Furthermore, the nutritional value of vegetation may change depending on the type of soil and soil fertility. According to Mokgakane *et al*. (2021), the nutritional value of different grass types varied depending on the type of soil. The high frequency of moderate grasses in the Ecca sandy clay-loam soil type might be because these grasses survive severe grazing and are good indicators of disturbed land with very low biomass yields (van Oudtshoorn, 2020).

Vegetation cover is a crucial feature of any rangeland, particularly when it comes to soil and water conservation (Msiza, 2021). It is particularly essential in the rehabilitation or restoration of degraded lands, where moisture is the primary limiting factor. The highest biomass yield recorded in Hutton- clay soil could be due to the low plant density per hectare in this soil type. These findings are in contrast with those of Magandana (2016), who reported that woody species have a positive impact on biomass yield. Furthermore, Hutton-clay soil was fairly covered well, such results are a true reflection of the good grazing management practised in the soil type. Stocking rates are regulated in order not to compromise the grazing capacity of rangeland and achieve optimum grass production. The highest grazing capacity observed in the present study was in the Hutton-clay soil type. These results agree with what was observed during data collection in this soil type, where the dividing fence in grazing camps was not maintained, livestock grazing in any area was uncontrolled and woody species encroachment was heavy. The current results are in line with those reported by Gusha *et al*. (2017), who observed that woody plant density was inversely related to grazing capacity, hence more studies on how woody species affect grazing capacity are warranted.

4.5.3 Tuft height and diameter of grass species found in four different soil types

In southern Africa, livestock in semi-arid regions have adapted to graze not only grasses but also browse woody species for them to survive, as there is a growing shortage of feed to sustain optimum production (Treydte *et al*., 2013). Individual grass species features determine grass height, but it is also likely that variation might be due to the present grazer species (Hayes & Holl, 2003). Grass heights vary depending on the species. Grass species such as *D. eriantha*, *E. rigidor* and *A. congesta* grew taller in the HCL soil type, which suggests that these species are adapted to this soil type. Furthermore, van Oudtshoorn (2020) highlighted that *D. eriantha* grows well in fertile soils, which suggests the aforementioned soil type has the potential to carry more good grazing grasses provided good rangeland management is employed. The seasonal influence of rainfall on grasses had a role, as grasses were harvested before winter when they do not grow. *Panicum maximum* grew the tallest in HC soil type, in contrast to species such as *U. mosambicensis* and *H. contortus* which are tall as well in height but have low leaf yields. With the presence of high leaf producing good palatable grasses, the biomass would be increased too. The authors have also highlighted the importance of grass species that grow quickly in spreading on the ground such as *C. dactylon*, are of more significance than those that grow vertically with fewer leaf yields and that plant height is an essential component that greatly contributes to biomass yield in grasses (Demlew *et al*., 2019; Msiza *et al*., 2021).

Grass height is not the only important component for soil basal cover, but also the tuft diameter is of great significance. Ecca sandy-clay loam soil type was found to have wider tuft diameters. This could be attributed to the stem development as a result of the canopy's expansion to provide the plant with stronger mechanical support (dos Santos Oliveira *et al*., 2019). Grass species such as *B. insculpta* are well adapted to clay soils (van Oudtshoorn, 2020), hence that might be the reason behind the larger tuft diameter of this species in ESCL soil type. The variation amongst the tuft sizes can be related to a couple of things such as landscape position, soil type and rainfall.

4.5.4 Chemical composition of bulked grasses

The growth stage, soil type and environmental conditions are all elements that have an influence on or determine the nutritional value of grass species. Moreover, when grasses are still in the vegetative stage of growth, they are known to be very palatable making them of high grazing value. In terms of the chemical composition of bulked grasses, the HC and HCL soil types had better overall results when compared to other soil types. The high dry matter content of bulked grasses found in the HC soil type was higher than the average dry matter obtained by Ravhuhali (2018) (934.7 g/kg DM) and slightly lower than the one obtained by Msiza *et al*. (2021) (961.1 g/kg). The type of grasses bulked, the age of the grass species, soil type and adequate soil moisture available (Rajora *et al*., 2017), might have influenced this.Grasses normally have ash content ranging from 3 to 12 % dry matter (Wassie, 2018), and the results from this study fall within the above-mentioned range. Many factors influence the amount and quality of ash concentration in herbaceous biomass, including the species, growing conditions and harvest period (Heinsoo *et al*., 2011). The ash content is important for animal health since ash is directly linked to high mineral levels such as potassium, calcium, phosphorous and a large fraction of silica (Ahmed & Hussain, 2013; Rambau *et al*., 2016; Msiza *et al*., 2021). Results of the present study showed no variation in ash of bulked grasses harvested from different soil types. Except for ESCL and HLS soil types, the ash content obtained in this study was higher than the average ash content reported by Berhane *et al*. (2006) but a study by Katongole *et al*. (2021) obtained a higher ash content than the current study. The low ash content in bulked grasses from the ESCL soil type might be because of the time (maturity stage) that the grasses were harvested. Strullu *et al*. (2011) along with Scordia *et al*. (2016) explain that after the onset of senescence, complete nutrient transfer from the above to belowground section of the plant may explain the low levels of ash content. As per the explanation of Thiex *et al*. (2012) as well as Rambau *et al*. (2016), ash is the mineral matter, which is the inorganic matter concentration in an animal’s diet. In contrast to the current study, Waramit *et al*. (2011) observed that though grasses mature, the amount of ash in them decreases. Moreover, the distinction in ash content obtained in this study from bulked grasses might be due to the different species.

Skamarokhova *et al*. (2020) highlighted that neutral detergent fibre (NDF) is widely regarded as the most appropriate constituent for fibre characterization, as it contains the most significant elements of the plant cell wall, allowing structural and non-structural carbohydrates to be distinguished. The NDF showed no significant difference across all soil types, except for the HCL soil type, it was greater than the 596 g/kg DM as reported by Krizsan *et al*. (2013) and 715.3 g/kg of bulked grasses reported by Kwaza *et al.* (2020) under grazed areas. The present study is in contrast with the results obtained by Matlebyane *et al*. (2009), with a lower NDF average content of 726.7 g/kg DM. The variation in the NDF content of grass species might be attributed to plant age and environmental differences such as soil type. Lima *et al.* (2002) stated that low forage intake by livestock might be caused by grass species containing more than 72 per cent of NDF. Acid detergent fibre (ADF) is a component of the cellulose and lignin-based fibre fraction of feed. Moreover, cellulose and lignin form part of the essential components due to their effect on the ruminants’ capacity to digest and degrade feed (NRC, 2000; Msiza *et al*., 2021). The results from this study were higher than the average value (450.1 g/kg DM) reported by Tavirimirwa *et al*. (2012). Furthermore, Van Soest (1995) together with Tavirimirwa *et al*. (2012) highlighted that ADF concentration greater than 400g/kg DM will negatively affect feed intake, digestibility or degradability in ruminant livestock. In general, as the quality and digestibility of grasses decline owing to prolonged growth, the fibre content of grasses increases (Temel *et al*., 2015) and the high ADF in the current study might be attributed to prolonged growth.

Mature grass species are widely known to have more lignified tissues than grasses in their vegetative stage of growth (Limenih, 2016; Winkler *et al*., 2019; Msiza *et al*., 2021). The present study results on acid detergent lignin (ADL) differed significantly. The low amount of lignin in bulked grasses harvested from HC soil type was lower than noted (318 g/kg DM) by Kwaza *et al*. (2020). However, Ramírez *et al*. (2007) also reported a lower lignin amount in *C. dactylon* hay (73 % DM) which falls below the lignin content obtained in the present study. The fibre and lignin content in grasses influence intake, digestibility and degradability. Indeed, in addition to that, the harvest of the grasses took place while they were still in their reproductive stage, hence the low lignin content can be attributed to the growth stage in this case.

For many past years, metabolizable energy (ME) has been determined by calculation only using the 0.82 factor from digestible energy (DE) (Hales, 2019). For both DE and ME results from the current study, there was no significant difference. The present study results of ME fall within the range reported by Arzani *et al*. (2004) for all growth stages. Arzani *et al*. (2004) also indicated that the ME requirements of grazing ruminants were in harmony with fodder in rangelands in good condition, but not those in bad conditions. Rangeland might be in good condition, but dry matter intake declines when crude protein concentration drops below 70 g/kg (NRC, 1985). The present study results on the crude protein of bulked grasses were the highest in ESCL soil type. Crude protein in grasses is mostly determined by the growth stage and sometimes benefits when they grow near N- fixer browse plants. With crude protein of bulked grasses across all soil types falling below the abovementioned, this means ruminants reared on these farms need supplements to meet their protein requirements. Complementary to the abovementioned, Kubkomawa *et al*. (2015) and

Daba *et al*. (2019) highlighted that a suitable amount of protein in livestock feeds is essential for growth, maintenance, efficiency and fertility. Ether extract (EE) now and then referred to as crude fat, is a part of a complex organic material that is soluble in ether and comprises chiefly of fats and fatty acids. It provides energy for livestock (Mciteka, 2008). Ecco sandy-clay loam soil type recorded the highest EE content of bulked grasses. Arshadullah *et al*. (2009) reported higher EE (4.1% DM) than the current study. Moreover, herbivore fodder intake is reduced, and rumen functionality is disrupted when a feed contains a high level of EE (Palmquist & Griinai, 2006; Muya *et al*., 2020).

4.5.5 In-vitro ruminal dry matter degradability of bulked grasses

According to Mahyuddin (2008), in vitro dry matter degradability is widely acknowledged as the most precise and reliable method for digestibility prediction. Waramit *et al*. (2012) further highlighted that crude protein, crude fibre and *in vitro* dry matter degradability (DMD) are good indicators of how nutritive grasses are, which decline with age. *In vitro* dry matter degradability is done to determine the rate and extent to which degradation of feed is done, which is a significant element in herbivore nutrient absorption (Birgit, 2017). Hutton clay soil type had the highest values at 24 hours (366.1 g/kg), 36 hours (478.4 g/kg) and 48 hours of incubation. From the results above, key findings are that bulked grasses from the HC soil type outcompete all grasses from other soil types because still after 48 hours they (HC grasses) had the highest degradability at 629.8 g/kg DM. This can be explained by the low ADF and lignin (Ravhuhali *et al*., 2021) these bulked grasses had because lignin is widely known to tamper with forage ruminal fermentation. Ecca sandy-clay soil recorded the least degradability at 24 hour incubation whereas it had the highest crude protein and lignin content when compared to other soil types. This means the lignin content inhibited the degradation of the bulked grasses. Indeed, the EE might have played a part in tampering with the degradability at this hour. Muya *et al*. (2020), further explain that forages with high EE content will lead to physically covered particles, off-setting rumen microbes from performing a better job in the fermentation of the ingested forage. Although many forages continue to stay in the digestive system of ruminants for this hour, the 48th-hour incubation period is thought to have validation of *in vitro* dry matter degradability in most forages (Mohammed *et al* 2016, Jack, 2021) further improving animal production.

4.6 Conclusion

Grasses are the most common source of feed for grazing ruminants in arid and semi-arid environments. The current study recorded twenty-five grass species and found that in these selected CPAs, HCL and HC soil types had more species as compared to the other two soil types (HLS and ESCL). Ecca sandy clay-loam soil type was the soil type with the highest number or variety of good grazing grasses, while HC soil type had the highest amount of both basal cover and biomass yield. This is a clear distinction between the outcome of proper management from mismanagement done on other soil types. Surely, if other soil types would follow what is done by HC soil type of good grazing management, improvement would soon be visible by them being covered well. Complementary to the abovementioned high grazing value grasses, ESCL soil type has the potential of performing better than its current state. All the bulked grasses from these different soil types had low crude protein content, which is a clear indication for farmers to consider supplementing of the livestock reared in these farms. *In vitro* degradability, at a prediction benchmark of 48 hours, is more reliable in predicting feed digestibility and the same was observed in the degradability of bulked grasses from HC soil type suggesting that these grasses with the availability of their nutrients to ruminants are suitable for livestock production.

4.7 References

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CHAPTER 5: TREE SPECIES DISTRIBUTION, COMPOSITION AND NUTRITIVE VALUE AS INFLUENCED BY SOIL TYPE AND GRAZING MANAGEMENT IN SELECTED CPAS OF SOUTH AFRICA

Abstract

The study examined woody distribution, canopy cover and nutritive value of bulked browse species in selected CPAs of South Africa. These selected CPAs, Mawela (Hutton- clay loam: HCL), Bela-Bela (Hutton-clay: HL), Moretele (Hutton-loamy sand: HLS) and Ramorula (Ecca sand-clay loam: ESCL) are all situated in Bela-Bela municipality, Limpopo, South Africa. Three 200 m line transects served as replicates and were laid 50 m apart from each other in each of the three camps per CPA. In each of the three line transects per camp, sub-transects were marked at 50 m intervals (50, 100,150 and 200 m) to create four 10 m x10 m homogenous vegetative units making a total of 12 HVUs per camp. Woody plant species density, total tree equivalent, height and canopy cover (CC) were recorded. Harvested leaves were bulked and ground to be analysed for nutritive value. Hutton-loamy sand (HLS) soil type had a high ($P<0.05$) total plant density (TPD) (4 300 plants/ha), CC (55.8 %) and total tree equivalent (TTE) (5 068.9 plant/ha) compared to other soil types. Bulked browse leaves from all soil types had similar ($P>0.05$) CP, ash and NDF content. Hutton clay loam (HCL) had higher ($P<0.05$) soluble phenols (599.9 gTAE/kg) and condensed tannins (CT) concentration (AU_{550}/200mg). The mixed browse leaves from all harvesting sites showed similar ($P>0.05$) *in vitro* ruminal dry matter degradability (DMD) at 36 and 48 hours. Due to the highest number of woody species (seedlings and matured trees), it is important to manage (reduce) the high tree population present in certain CPAs to promote the growth of the herbaceous layer as the ruminant primary feed source. High number of big trees

should be reduced to minimum level since they also play an important role in the development of the herbaceous layer. Their presence, after defoliation, fallen leaves will contribute to the nutritive value of the soil as opposite toshrubs which will be browsed by animal with minimal contribution to the soil. Bulked browse leaves from all soil types had great potential to be a good cheap protein source for livestock as they had high CP and DMD.

Keywords: Woody dominance; browse; ruminant; resource management; height class

5.1 Introduction

The essential function of communal property associations (CPAs) in resource governance is increasingly being recognized in many countries (Ghate, 2005; Sebola & Mamabolo, 2020). In communal property associations, only members have resource use authority and therefore they vary considerably from open access, which does not have resource rights (Agrawal, 2001). The grazing management in CPAs is crucial for the maintenance of rangeland production and health status. Rangeland health status is predominantly dependent on the interaction between the soil, plant communities and grazing (Balestrini *et al*., 2015). Overgrazing caused by poor rangeland management leads to poor soil physical, chemical and biological properties, resulting in a dramatic change in vegetation and nutrient cycling (Lavado, 1996; Bolo *et al*., 2019). According to studies by Dougill *et al.* (1988) and Egeru *et al*. (2019) have shown that there is a dynamic relationship that exists between rangeland vegetation and soil properties. Additionally, other literature displays the significance that soil type possesses in the resilience of semi-arid rangelands. The aforementioned is due to the provision that soil type has on the degree of flexibility in the soil twined with its ability to provide a degree of pliancy; which hampers disturbances in the ecological system (Walker & Meyers, 2004; Herrick & Wander, 2018; Vette, 2019). Vegetation changes include a decline of the decreaser perennial grasses and a change in the herbaceous layer (Ash *et al*., 2011), giving rise to woody seedlings. Moreover, the rise of unwanted land changes in livestock production such as an increasing number of trees poses an added difficulty to management since typically there is no instant response to these land changes when they do occur (Ash *et al*., 2002; Holecheck *et al*., 2003; Munyai *et al*., 2012). Extra management strategies such as burning and mechanical control for firewood purposes can be applied especially to those species that are threatening such as *Vachellia erioloba*.

Plant growth in the savanna habitat varies due to several factors, topographic features (slope and elevation), human and animal activities (logging, burning and grazing) as well as environmental factors, such as rainfall and soil properties, which are the key drivers of large-scale plant-soil interactions at the local level (Magandana, 2016). Findings by Ravhuhali *et al*. (2020) indicated that soil type affected the spread of woody plant species, with red-brown soil type having less nutrient concentration and having more trees compared to far fewer woody plant growing in clay-loamy soil regions with better nutrient concentration. However, unlike the findings of Ravhuhali *et al*. (2020) the results of Pule *et al*. (2018) revealed that woody plant species encroachment was more in soils with more nutrients. This reveals that there are several factors as stated earlier, contributing to woody plant species establishment in an area and these woody plant species can contribute efficiently to livestock production as supplementary feed.

Ruminant nutrition in arid and semi-arid regions of southern Africa is one of the major limiting factors faced by livestock farmers. The lack of regenerative grazing practises in these regions has not only hindered the quantity but also the quality of feed available to livestock (Mlambo *et al*., 2004; Rasal *et al*., 2022). Fodder woody species play a big role in providing the cheapest or natural recurring source of protein, energy, vitamins and minerals (Zampaligré *et al*., 2013; Mudau *et al*., 2022), as these nutritional benefits will complement the herbaceous species (grasses) of low nutritional value especially during the dry season.

Communal property association farmers need to be equipped with better knowledge in understanding the state of their respective grazing lands and the interaction of soil with grazing management implemented, together with their nutrient concentrations. Acquiring this in-depth knowledge is very importance to these farmers in developing suitable and efficient grazing strategies, consequently, that will improve lives. Grazing management as noted by Endale *et al*. (2017) and Zhang *et al*. (2018), influences tree distribution. However, there seems to be a gap in the literature as there is inadequate research pertaining to tree distribution and its nutritive value in South African CPAs. The study aimed at investigating the variations in tree species density, canopy cover, tree equivalent and nutritive value of bulked browse species in selected CPAs of South Africa while hypothesizing that the soils under these CPAs affected tree distribution, composition, and nutritive value.

5.2 Materials and Methods

5.2.1 Study site description

The study was conducted in four selected CPAs, Mawela CPA (Hutton- clay loam: HCL), Bela-Bela CPA (Hutton-clay: HL), Moretele CPA (Hutton-loamy sand: HLS) and Ramorula (Ecca sand-clay loam: ESCL) all situated in Bela-Bela municipality, South Africa as described in section 3.2.1 in chapter 3.

5.2.2 Data collection

5.2.2.1 Woody species

Data collection was carried out between December 2020 and February 2021 in three 200 m line transects per camp, which served as replicates. These transects were laid out in three camps in each of the four CPAs. The line transects were placed at least 50 m apart from each other. Along each transect, points were marked at intervals of 50 m for sampling sub-transects making a total of four intervals (50,100,150 and 200 m). One 10 m x 10 m Homogenous Vegetation Unit (HVU) was marked in each sub-transect, resulting in a total of 12 HVUs per camp and 36 HVUs per CPA. From each CPA, data on density, height, canopy diameter of individual woody plants species composition were collected. The woody plant species identification was done as per the description of van Wyk *et al*. (2012). All rooted live woody plants were recorded and counted in each HVU. Within each sub-transect, woody plants were identified, counted and classified based on height as seedlings (0 - 1 m), young shrubs (1 - 1.5 m), mature shrubs (1.5 - 2m), young trees (2 - 3 m), and mature trees (>3 m) (Ravhuhali *et al*., 2020). Within each HVU, the canopy diameter of every woody plant species was measured along two axes length (L) and width (W) perpendicular to each other. Determination of the canopy cover (CC) percentage was calculated using the equation of Blozan (2006):

$$\text{Canopy cover } (n/2\, L + n/2\, W)/\ 200 \text{ m} \times 100$$

When an overlap was encountered between the canopies of adjacent woody plants, the length of the overlap was subtracted from the length or width of either of the plants. The total tree equivalent was calculated by dividing the total tree length by 1.5.

5.2.2.2 Chemical composition

The same method was used as described in section 4.2.2.3.

5.2.2.3 Soluble phenols

The Folin-Ciocalteau method was employed to estimate soluble phenols (Makkar, 2003) after extracting a sample (200 mg) three times for five minutes at a time with 10 mL of aqueous acetone (7.3 v/v acetone water). After extraction, 0.02 mL of acetone was mixed with 0.25 mL of Folin and Ciocalteau reagent (2N) in a test tube, and 1.25 mL of sodium carbonate (anhydrous) was added to the mixture and vortexed violently. The mixture was allowed to rest for 40 minutes so that it can be able to react. A spectrophotometer (PG Instruments T60 UV- visible) was used to measure the absorbance at a wavelength of 725 (Makkar, 2003). To assess the concentration of soluble phenolics in bulked leaf samples, a standard curve was established using tannic acid. Subsequently, the assay was performed and results for soluble phenols were expressed as tannic acid equivalents (TAE).

5.2.2.4 Condensed Tannins

To determine the soluble condensed tannins, the modified butanol-HCl reagent was used in the acetone (acetone: water (7:3,v/v)) bulked leaves extract sample (Porter *et al*., 1986). The soluble condensed tannin fraction was measured by adding 0.5 mL of the aqueous extract to 3 mL of butanol-HCl (95:5, v/v) in the butanol-HCl test (Porter *et al*., 1986). The test tubes were vortexed violently, and the closed test tubes were heated to 100 °C for an hour using a heating block and then allowed to cool to room temperature. The absorbance of soluble condensed tannins was measured at a wavelength of 550 nm using a spectrophotometer (T60 UV-visible, PG instruments).

The soluble condensed tannins concentration results were reported as AU (absorbance units) per mg sample according to Makkar (2003).

5.2.2.5 In vitro ruminal dry matter degradability of bulked browse leaves

The same method was applied as described in section 4.2.2.4

5.3 Statistical analysis

Effects of soil type on total tree plant densities (TPD), canopy cover (CC), height class distribution, total tree equivalence (TTE), and bulked browse species leaves and chemical composition, as well as *in vitro* ruminal degradability, were evaluated using a one-way analysis of variance (SAS, 2010). The analysis was designed to test the effect of soil type on parameters according to this general linear model:

$$Yij = \mu + Si + \varepsilon ij$$

Where: Yij is the response variable (height, total tree plant density, CC, height class distribution TTE, chemical composition and *in-vitro* degradability),

μ is the overall mean,

Si is the effect of soil type, and

εij was the error term associated with observation ijk, assumed to be normally and independently distributed.

Significant differences were declared at the P<0.05.

5.4. Results

5.4.1 Woody plant species density in four different soil types in Bela-Bela CPAs

Across the four soil types in the Bela-Bela CPAs, a total of 18 browse species were found; Table 5.1 (*D. cinerea, G. flava, S. mellifera, Z. mucronata, C. imberbe, V. nilotica, B. albitrunca, P. africanum, G. flavescens, C. mole, G. senegalensis, V. robusta, V. karoo, V. erioloba, V. tortilis ,T. sericea, S. galpinii* and *S.leptodicyta*) . The results on the effect of soil type on tree density (number of plants/ha) in selected CPAs of Bela-Bela Municipality are presented in Table 5.2. *Dichrostachys* c*inerea* was higher (P<0.05) in the Hutton clay loam (HCL) soils (966.7 plants/ha) when compared to other soil types. *Senegalia mellifera* was higher (P<0.05) in the Hutton-loam sand (HLS) soils when compared to other soil types. The density (177.8 plants/ha) of *V. nilotica* was higher (P<0.05) in the Hutton clay (HC) soil type when compared to the ESCL soil type (33.3 plants/ha). Hutton-loamy sand soil type had more (P<0.05) abundance (133.3 plant/ha) of *G. senegalensis* when compared to ESCL soil type abundance (33.3 plants/ha).

Table 5.1: Scientific, common names, and herbivory of woody plant species found in four selected CPAs of Bela-Bela Municipality

Tree species	Common name	Herbivores/ Utilization
Boscia albitrunca	Shepherd's tree	Cattle
Combretum imberbe	Leadwood	Cattle and goats
Combretum molle	Peppertree	Cattle and goats
Dichrostachys cinerea	Sekelbos/Sicklebus	Goats
Grewia flava	Velvet raisin	Cattle, goats, and game
Grewia flavescens	Sandpaper raisin	Cattle, goats, and game
Gymnosporia senegalensis	Red spikethorn	Cattle and goats
Peltophorum africanum	African wattle	Cattle and goats
Senegalia mellifera	Blackthorn	Cattle, goats, and game
Terminalia sericea	Silver cluster leaf	Cattle and goats
Vachellia erioloba	Camel thorn	Cattle, goats, and game
Vachellia karoo	Sweet thorn	Cattle and goats
Vachellia nilotica	Scented-pod thorn	Goats and game
Vachellia robusta	Robust thorn	Goats and game
Vachellia tortilis	Umbrella thorn	Cattle, goats and game
Ziziphus mucronata	Buffalo-thorn	Cattle and goats

TABLE 5.2: The effect of soil type on tree density (number of plants/ha) in selected CPAs of Bela-Bela Municipality, South Africa

	Soil Type				
Tree species	HCL	HC	HLS	ESCL	SE
Boscia albitrunca	33.3	-	-	-	-
Combretum imberbe	-	88.9	-	-	-
Combretum mole	-	11.1	-	-	-
Dichrostachys cinerea	966.7^{a}	-	500.0^{b}	33.3^{c}	177.2
Grewia flava	700.0^{b}	77.8^{c}	1033.3^{a}	766.7^{b}	77.8
Grewia flavescens	533.3	-	-	-	-
Gymnosporia senegalensis	-	-	133.3^{a}	33.3^{b}	33.3
Peltophorum africanum	33.3	-	-	-	-
Senegalia mellifera	366.7^{b}	44.5^{c}	1666.7^{a}	233.3^{b}	44.5
Terminalia sericea	333.3	-	-	-	-
Vachellia erioloba	-	-	266.7^{a}	33.3^{b}	33.3
Vachellia karoo	-	-	-	533.3	-
Vachellia nilotica	-	177.8^{a}	-	33.3^{b}	33.3
Vachellia robusta	-	-	-	233.3	-
Vachellia tortilis	166.7^{b}	-	400.0^{a}	100.0^{b}	100.0
Ziziphus mucronata	233.3^{ab}	11.1^{c}	766.7^{a}	33.3^{b}	11.1

$^{abc:}$ Means in the same row with different superscripts are significantly different ($P<0.05$), HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; SE: Standard error

5.4.2 Total plant density, canopy cover, total tree equivalents and class height

Results of the effect of soil type on total plant density (TPD), canopy cover (CC), total tree equivalence (TTE) (Table 5.3), and plant height class distribution are shown in Table 5.4. Hutton-loamy sand soil type had the highest ($P<0.05$) TPD (4 300 plant/ha), CC (55.8%), and TTE (5

068.9 TTE/ha) amongst other soil types. Hutton-loamy sand soil type had the highest ($P<0.05$) density of seedlings (2 100 plants/ha) when compared to other soil types. Young shrubs were more ($P<0.05$) abundant in the Hutton clay loam (HCL) soil type (1 207.3 plants/ha) than other soil types. For both young trees (10 plants/ ha) and mature trees (17 plants /ha), the Hutton clay (HC) soil type had the lowest ($P < 0.05$) plant density (10 plants/ha) and (16.7 plants/ha) respectively.

TABLE 5.3: Woody plant density (plants/ha) of four soil types in selected CPAs of Bele-Bela Municipality.

Soil type	TPD	CC	TTE
HCL	3367^{a}	53.7^{a}	4240.0^{a}
HC	67^{c}	7.53^{b}	142.7^{b}
HLS	4300^{a}	55.8^{a}	5068.9^{a}
ESCL	2000^{b}	55.6^{a}	5002.2^{a}
SE	67.0	5.7	142.7

$^{abc:}$ Means in the same column with different superscripts are significantly different ($P<0.05$), HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; TPD: Total plant density; CC: Canopy cover; TTE: Total tree equivalence; SE: Standard error

TABLE 5.4: Total number of trees per height class (number of trees/ha) in four soil types in Bela-Bela CPAs

Soil type	0-1 (Seedlings)	>1-1.5 (YS)	>1.5-2 (MS)	>2-3 (YT)	>3 (MT)
HCL	800.0^{ab}	1207.3^{a}	615.3^{a}	444.7^{b}	300.0^{ab}
HC	20.0^{c}	10.0^{c}	10.0^{c}	10.0^{c}	16.7^{c}
HLS	2100.0^{a}	600.0^{ab}	600.0^{a}	200.0^{b}	800.0^{a}
ESCL	566.7^{b}	433.3^{b}	66.7^{b}	800.0^{a}	133.3^{b}
SE	20.0	10.0	10.0	10.0	16.7

$^{ab:}$ Means in the same column with different superscripts are significantly different ($P < 0.05$). HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; YS: Young shrubs; MS: Matured shrubs; YT: Young trees; MT: Matured trees; SE: Standard error

5.4.3 Chemical composition of bulked browse leaves

Data on the chemical composition of bulked browse leaves harvested from CPAs of four different soil types in Bela-Bela Municipality is presented in Table 5.5. Bulked browse leaves had similar (P>0.05) dry matter (DM), ash, crude (CP), neutral detergent fibre (NDF), and ether extract (EE) in all soil types. Hutton clay loam (HCL) soil type had lower (P<0.05) digestible energy (DE) (2.69 Mcal/kg) and metabolizable energy (ME) (2.2 Mcal/kg) compared to other soil types. Ecca sandy clay loam (ESCL), Hutton clay (HC) and Hutton- loamy sand (HLS) had lower (P<0.05) acid detergent fibre (ADF) while acid detergent lignin (ADL) which did not differ (P>0.05).

TABLE 5.5: Chemical composition (g/kg DM) (unless stated) of bulked browse leaves harvested from CPAs of four different soil types in Bela-Bela Municipality

	Soil types				
Component	HCL	HC	HLS	ESCL	SE
DM	948.4^a	952.3^a	945.0^a	950.2^a	3.1
ASH	77.3^a	80.6^a	71.3^a	71.8^a	3.4
NDF	424.5^a	409.1^a	391.8^a	397.2^a	12.8
ADF	323.6^a	265.1^b	286.5^b	264.9^b	10.0
ADL	207.8^a	145.9^b	165.2^b	150.8^b	8.9
CP	136.6^a	122.3^a	138.6^a	140.6^a	8.2
EE	33.7^a	36.8^a	37.1^a	37.5^a	2.8
DE(Mcal/kg)	2.7^b	2.9^a	2.8^a	2.9^a	0.04
ME(Mcal/kg)	2.2^b	2.4^a	2.3^a	2.4^a	0.03

$^{ab:}$ Means in the same row with different superscripts are significantly different (P < 0.05). HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; DM: Dry matter, CP: crude protein, EE: Ether extract, NDF: neutral detergent fibre, ADF: acid detergent fibre, ADL: acid detergent lignin and DE: Degradable energy, ME: metabolizable energy and SE: Standard error.

5.4.4 Total soluble phenolic and total condensed tannin

The soluble phenols differed (P<0.05) among browse from different soil types with the HCL soil type having higher soluble phenols (599.9 g TAE/kg DM) compared to other soil types. Browse leaves from different soil types did not differ (P>0.05) in condensed tannins (CT) concentration.

TABLE 5.6: Total soluble phenolic (g TAE/kg DM) and total condensed tannin (AU_{550}/200 mg DM) content of bulked browse leaves found in three soil types of Bela-Bela Municipality

Component	HCL	HC	HLS	ESCL	SE
SolublePhenols	599.9^{a}	289.8^{b}	318.0^{b}	466.9^{ab}	71.4
Condensed Tannins	1.1^{a}	0.81^{a}	1.0^{a}	0.98^{a}	0.11

$^{ab:}$ Means in the same row with different superscripts are significantly different ($P<0.05$), HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; SE: Standard error

5.4.5 In vitro ruminal dry matter degradability of mixed browse leaves

The results on *in vitro* ruminal dry matter degradability (g/kg) of mixed browse leaves found in four soil types are presented in Table 5.7. After an incubation period of 24 h, leaves from the HCL soil type had a higher ($P<0.05$) *in vitro* ruminal dry matter degradability (DMD) (330.6 g/kg DM) compared to other soil types. The mixed browse leaves from all harvesting sites showed similar ($P>0.05$) DMD at 36 and 48 hours.

TABLE 5.7: The *in vitro* ruminal dry matter degradability (g/kg) of browse mixed leaves found in four soil types

	Incubation period (hrs)		
Soil type	DMD 24	DMD 36	DMD 48
HCL	330.6^{a}	326.7^{a}	438.5^{a}
HC	257.9^{b}	329.0^{a}	412.7^{a}
HLS	288.3^{b}	330.1^{a}	464.3^{a}
ESCL	286.3^{b}	332.0^{a}	390.0^{a}
SE	12.3	16.0	32.6

^{ab}: Means in the same column with different superscripts are significantly different ($P<0.05$), HCL: Hutton- clay loam; HC: Hutton- clay; HLS: Hutton- loamy sand; ESCL: Ecca sandy-clay loam; DMD 0, 24, 36, and 48 hr: *in vitro* dry matter degradability at 0, 24, 36 and 48 hr; S.E: Standard error.

5.5 Discussion

5.5.1 Woody species distribution, total plant density and canopy cover

Woody plant encroachment, or deterministic development of woody species (Jamison-Daniels *et al.*, 2021), has been extensively reported in southern Africa. Woody plant encroachment in grassland and savannas is a problem that has been there for a while (Ward, 2005; Tjelele *et al.*, 2012). Grasses in general are great competitors for available nutrients (Travese, 2001; Brown *et al.*, 2010), but overgrazing practices promote the establishment of woody plants. However, in this study, the dominance of *D. cinerea*, *Z. mucronata* and *G. flava* in these CPA farms might be attributed to their adaptability to this environment (Pule *et al.*, 2018). A study by Marcora *et al*. (2013) showed that grazing management can reduce the seedling establishment of woody plants in grassland and savannas. This statement was supported by Richter et al. (2001), who stated that species such as *Z. mucronata* and *S. mellifera* that occur in a wide variety of habitats (Van Wyk *et al.*, 2012) negatively affects grazing capacity and livestock productivity. Constant or continuous grazing by livestock reduces grasses' ability to compete for resources with tree seedlings (Grellier *et al.*, 2013). When grass yield becomes low, livestock is left with no choice but to feed on seeds and leaves of woody plants, which later are dispersed as viable woody plant seeds, and through the gut passage and dung fertilization, they may increase seedling emergence, seedling establishment, and recruitment of woody plant species through the process of endozoochory (Tjelele *et al.*, 2012).

Woody plant invasion in grasslands found in semi-arid regions is driven by both universal and local factors. Changes in climate and increased carbon dioxide levels throughout the atmosphere are among the global drivers (Tjelele *et al.*, 2012). Intense grazing pressure, human land use and herbivore seed dispersal are the main factors of woody plant encroachment at the local scale (Mhiripiri & Mlambo, 2021). Based on that observation, this high population of trees begs for bush control programs that are bound to eradicate high volumes of woody species that pose a threat to herbaceous plant growth. Thus, improved herbaceous plant growth will ultimately improve the farms' grazing capacity. This also has a direct link with the biomass for each CPA. For example, areas such as HC have fewer trees and high biomass accumulation, while the areas that contain a high number of trees have less biomass and grazing capacity. Furthermore, a decrease in biomass yield paves the way to the accumulation of pioneer annual plants, less organic reserves, a high number of woody seedling emerging, and ultimately reduced livestock productivity. The current study's findings concur with the results of Wigley *et al*. (2009), that an increase in woody plants will lead to a loss or decrease in the number of perennial grasses (vegetation cover). Hutton-loamy sand soil type has the low grazing capacity amongst other farms where the current study was conducted. Results by Vickers & Palmer (2000) revealed that woody plant density had a positive relationship to canopy cover as also observed in this study where the HC soil type had the lowest woody plant density and canopy cover. This could be because total tree density was low in comparison to other soil types, thus the biomass yield and grazing capacity of this CPA was found to be moderate. The results of Liu *et al*. (2014) showed a significant difference in the canopy cover of trees found in different soil types, which agrees with the present study results.

5.5.2 Height distribution

Sankaran *et al*. (2008) highlighted that woody vegetation cover throughout the Savanna ecosystem varies based on a variety of environmental factors such as soil properties and rainfall, which are regarded as significant determinants at a large scale and, as a result, influences plants' interaction at the micro-level. Except for the HC soil type CPA, there was a high density of seedlings and young shrubs across other soil type CPA farms. This can be attributed to poor grazing management practised in these CPA farms. Even though woody species seedlings can contribute to animal production through browsing, when seedlings are left unattended for a period in the rangeland it is easy for seedling recruitment to occur promoting growth and establishment of woody plants leading to encroachment. Soil type might also have contributed to woody species seedlings development. Moreover, Case & Staver (2017), revealed that encroachment by the woody plants was more accelerated in nutrient-poor soils which tend to be the breeding grounds of woody seedlings once the herbaceous layer has been eliminated, and Blank *et al*. (2007) also noted that overgrazing depletes nutrients such as carbon, nitrates, calcium and magnesium in the soil which negatively affects the biomass on the ground. In such cases, the prospect is that encroachment will occur faster on sandy soil due to the deeper water infiltration properties. Woody plants with deeper roots will eventually outcompete grasses with shallow roots, resulting in less herbage for grazers. The height of 2 to 4m in encroaching woody plants beyond the acceptable height of 1.5m depicts that the woody plant management outpaces seedling recruitment. Thus, resulting in a compromise of the ecological niche. Trees taller than 2 metres are a major concern as they are less prone to fire when used as a woody plant management tool, essentially making encroachment of woody plants difficult to reverse or halt (Higgins *et al*., 2000; Archer & Predick, 2014; Case & Staver, 2017).

5.5.3 Chemical composition of bulked browse leaves

Browse plant leaves are a potential source of nutrients for livestock of poor-resourced farmers (Aganga *et al*., 2005; Ravhuhali *et al*., 2020) Browsed plant leaves arethe major sources of protein for livestock especially during dry season and droughts (Lefroy *et al*., 1992; Ravhuhali *et al*., 2020; Ravhuhali *et al.,* 2021). The chemical composition of bulked browse leaves in this study were similar across soil types in different CPAs, which can be attributed to similar climatic factors such as temperature and rainfall. The average crude protein content obtained by Mudau *et al*. (2021) is in line with the current study results. On the other hand, Ravhuhali *et al*. (2020) discovered that spatial variation has a great influence on the chemical composition of browse plant leaves. Browse leaves from the HCL soil type had lower digestible energy and metabolizable energy ranging from 2.7 to 21 g/kg compared to other soil types, and this is in agreement with the study of Al-Masri (2013) who reported a deep decline in both energies of browsed tree leaves harvested from different locations. In these results, ash content was high ranging from 70 to 80 g/kg which falls within the range of averaged value reported by Mudau *et al*. (2021) as well as Al-Masri (2013) but the current study results were higher than those reported by Petisco *et al*. (2008). The neutral detergent fibre (NDF) content reported by Njidda (2010) was in contrast to the findings of this study, as it was lower than the results of the current study which showed high NDF content ranging between 260 to 424 g/kg. However, in agreement with averaged values of Mokoboki *et al*. (2019) who also reported high NDF content of browse leaves. Lignin is indigestible at high concentrations, and it affects dry matter degradability while improving small particle discharge from the rumen (Sebolai, 2018). Acid detergent lignin (ADL) of bulked browse leaves in the present study was high which was in line with the results obtained by averaged ADL values reported by Njidda & Olatunji (2012). High lignin of browse leaves in the HCL soil type might be influenced by several factors such as soil fertility, age of the leaves (all leaves were matured during harvesting), and plant location (Sebolai, 2018). The current findings contrast with those of Basha (2012) who reported high lignin content in selected browse species of South Africa. The differences in lignin concentration in bulked-browsed leaves might be attributed to the aforementioned factors. The current study's CP content ranges from 122 to 140 g/kg which is within the range reported by Mthi *et al*. (2016). However, Gidado *et al*. (2013) stated that crude protein content of less than 70 g/kg might be deficient for ruminant livestock at a certain production stage, but in this study results of crude protein in bulked browse leaves is sufficient to meet the animals' daily protein requirement for growth (116 g/kg) and lactation (117 g/kg) for goats as standardized by NRC (1985). Moreover, Al-Masri (2013) reported browsing with low CP content, which contrasts with the current study findings. In the case of browse leaves having a high crude protein content, this may be attributed to innate species traits that would enable them to fix atmospheric nitrogen and accumulate nutrients extracted from the soil. Species such as *Z. mucronata* (Hassen *et al*., 2005) and *A. mellifera* (Hagos & Smit, 2005) can fix nitrogen. In this study, ether extract was within the range of the results reported by Njidda (2010) and was much higher than the results obtained by Bakshi & Wadhwa (2004). The high content of EE may be attributed to altitude and genotypic characteristics of the plant as indicated by Mountousis *et al*. (2006).

5.5.4 Total soluble phenolic and total condensed tannin content of bulked browse leaves

The soluble phenols differed significantly among soil types, with the HCL soil type having higher soluble phenols and condensed tannins compared to other soil types. The chemical composition and palatability of plants, as well as plants response to browsing, have all been linked to the unpredictable fluctuation of phenolics in tree plants (Ravhuhali, 2018). A study by Madau *et al*. (2021) and that of Shelton (2004) highlighted that high bioactive compounds such as phenols and condensed tannins present in the most nutritious parts of browse plant species have an egregious effect on southern African livestock production. The distribution of phenols *per se* is determined by factors such as herbivore defoliation of the browse leaves. However, increased tannins and phenolics concentration in animal feed sources inhibit both intake and digestibility. Livestock often browse browsable plants, especially during the dry period when grasses are less nutritive.

When these plants are browsed, they tend to produce or accumulate detrimental compounds that later are evenly distributed across all the edible plant parts as their defense mechanism against herbivores (Mueller-Harvey, 2006). The concentration of both soluble phenols and condensed tannins in browse leaves harvested from different soil types in this current study were low to moderate. Moreover, this might be attributed to being less browsed by the animals, these CPA farms are dominated by cattle.

5.5.5 In vitro ruminal dry matter degradability of bulked browse leaves

The key determinant of feeding value is ruminal degradability (Dambe *et al*., 2015; Mokoboki *et al*., 2019). The *in vitro* ruminal dry matter degradability (DMD) of mixed browse leaves showed a variation after a 24-hour incubation period and the variation was not observed after 36 and 48-hour incubation periods. Though there were no statistical differences observed in all soil types after 48 hours of incubation, browse species found in the HLS soil type were highly degraded. High dry matter degradability values after 48 hours of incubation of browse leaves were considered fairly digestible because degradability values at this time are considered equivalent to digestibility (Moreira *et al*., 2014). The amount of lignin in browse leaves determines how much they will be digested (Mnisi & Mlambo, 2017; Ravhuhali, 2018) and this in line to the current findings which showed high lignin content and low degradability value after 36 and 48-hour incubation in mixed browse leaves harvested from HCL soil type. Furthermore, Moore *et al*. (2001) stressed that lignin acts as a physical barrier to microbes, preventing them from digesting cell wall polysaccharides. The high digestion of bulked leaves from the HCL soil type might have been influenced by the high protein content found in them, due to the presence of N fixer browse species, which are *D. cinerea* and *G. flava*. Mokoboki *et al*. (2019) highlighted that high protein content in browse leaves may be beneficial to rumen microbes that depend on dietary nitrogen. The current study results after 36 hours of incubation (326.7-332.0 g/kg DM) fall within the range reported by Ravhuhali *et al*. (2020). Though not statistically different, the highest degradability of mixed browse leaves harvested from the ESCL soil type might be attributed to the low condensed tannins concentration found in these leaves. Tannins are well known for their ability to tie or bind and form complexes with nutrients like proteins and carbohydrates, making them less degradable within the rumen. Condensed tannins inhibit ruminal degradation due to their microbial effects, leading to lower rumen microbial activity (Makkar, 2003). The current dry matter degradability (DMD) results can be deemed satisfactory in HCL, HC and HLS soil types, as they are within the recommended 40-50 per cent (Modu-Kagu *et al*., 2021).

5.6 Conclusions

In the current study, variation was observed amongst the different soil types, with the HLS soil type having a high number of trees such as *G. flava* and *S mellifera* and seedlings in the grazing camps. This high tree density suggests a need for bush encroachment control that will promote the use of woody species as livestock feed and reduce the threat that woody species might have on herbaceous growth and this will improve the farm`s grazing capacity. When results reveal such a density of woody plants, it is importance to manage and eradicate some of the trees present so as to create a conducive environment for the herbaceous layer (grasses), as it is the primary feed source for all livestock grazing ruminants. Once again, the HLS soil type showed greatest number of seedlings. Regardless of these seedlings being young, it would be easy for them to increase in recruitment of the dominant species leading to bush encroachment, hence the need to be well managed and controlled. Browse bulked leaves from all soil types had high crude protein required to support cattle production. Mechanical and biological control through the use of these woody plant species as livestock feed would aid in reducing seedling recruitment and providing a cheap source of protein to livestock farmers.

5.7 References

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Chapter 6: General discussion, conclusions and recommendation

6.1 General discussion

In the intervening (1998- 2020) years, research is recognizing CPAs' critical role in resource stewardship (Sebola & Mamabolo, 2020). Grazing management in CPAs is critical for maintaining rangeland output and health. There is a dynamic link between rangeland vegetation and soil qualities. The objective of the study was to investigate the effects brought by soil type and grazing management practices on the physical and chemical properties of the soil, grass and tree species composition, distribution and nutritional value. The pH of the soil types in this study ranged from slightly acidic to neutral, as this type of range permits the availability of most macro and micronutrients to plants. As it is widely known that soil pH is the "primary soil factor", it mpacts a variety of biological, chemical and physical processes that affect plant development and growth. The topsoil of the selected CPA farms had a higher concentration of soil nutrients compared to the subsoil of all soil types. Nitrogen (N), chlorine (Cl), iron (Fe) and copper (Cu) were all found to be inadequate to sustain plant growth when minerals were tested in the soil types (Band *et al*., 2022). Complementary to the abovementioned, pH in these soil types would support plant life owing to proper management of resources available. Moreover, Mekuria *et al*. (2007) stated that the use of enclosures does improve the restoration of natural resources such as soil fertility. However, Northup *et al*. (2019a), stressed that the different stocking rates also play a vital role in the distribution of plant-available minerals, thus proper management of stocking rates and the time in a paddock might increase the nitrogen content through livestock deposition and urine. In terms of acidity, none of these soil types is acidic, which can be expected given that these soil types (CPA farms) are not located in locations with considerable rainfall. The type of grazing management used on these farms appears to be a significant feature, as it accounts for a wide range of things happening in the soil, basal cover to erosion.

Grasses are the most common source of feed for grazing ruminants in arid and semi-arid environments. When compared to palatable grasses, most unpalatable grasses are likely to dominate in semi-arid environments where rainfall is uncertain. This puts livestock productivity and the farmers' livelihood at risk. Subsequent to that, highly palatable species such as *Themeda triandra* rarely occurred in all the soil types, such a situation gives a clear picture of how poorly these grazing lands are managed (Inman *et al*., 2020). However, dominating species in the soil types were increaser species, as noted by Londt (2020), Increaser II grasses are those grass species that dominate in poor rangeland or species that increase with overgrazing from mild to severe, these types of grasses dominated most of these soil types. Indeed, the presence of some pioneer species such as *Aristida congesta* and *Melinis repens* is a clear indication of severe disturbances in the soil types (Angassa & Baars, 2000; van Oudtshoorn, 2020). Variations in biomass yield in these selected farms were obtained in the HC and the HLS soil types respectively, which caused variations in species composition and distribution. Even though both HC and HCL soil types carried the most species composition, higher grass heights were found to be more in the ESCL soil type. The ESCL soil type has the potential of performing better than its current state. Since all the bulked grasses from these farms had low crude protein content, farmers should contemplate supplementing livestock raised in these farms (NRC, 2007; Gidado *et al*., 2013), especially during dry seasons or post-growing seasons. Rusdy *et al*. (2019) also highlighted the importance of supplementing ruminant livestock fed or reared in low crude protein grasses as this will increase intake and improve animal production. When predicting feed digestibility, *in vitro* dry matter degradability is known to be reliable. Indeed, having said that, the 48th hour of incubation is regarded as the prediction's high point (Anwer *et al*., 2019). Even though the limiting factor for grasses to be well degraded is the growth stage (Soul, 2017), grasses from the HC soil type degraded well at the 48th hour, indicating that these grasses would be of good use for livestock production because the available nutrients would be accessible to ruminants.

In the current study, variation was observed amongst the different soil types, with the HLS soil type having a high number of young trees and seedlings in the grazing camps. O'Connor *et al*. (2013) highlighted that a high tree population suggests a need for bush control programs that will promote and reduce the threat woody species might be having on herbaceous growth and this will improve the farm`s grazing capacity. Ravhuhali *et al*. (2020) also suggested that using these woody species as animal feed could help reduce the density of plants per hectare. When the findings show a large number of trees, it is critical to manage and eliminate some of them in order to establish a breeding ground for the herbaceous layer, which is the main source of feed for all ruminants. The HLS soil type was the best with the highest number of seedlings. In addition to that Bornkamm (2007) reported that though sandy soil poses a declined nutritional status gradient, it provides a site for faster emergence of the woody seedlings. Even though these seedlings are immature, they can enhance recruitment of the dominant species type, resulting in bush encroachment, necessitating careful management and eradication. All soil types had appropriate crude protein and degradability levels in bulked leaves. Mechanical and biological control through the use of these species as livestock feed would aid in reducing seedling recruitment and provide livestock farmers with a cheap source of protein. In short, better grazing management would undoubtedly benefit rangeland productivity, health and long-term viability. This suggests that this soil type would perform well given a good grazing management strategy is followed making soil nutrients available to plants thus eventually increasing the basal cover and biomass production and lastly reducing trees occupying the grazing land (Abule *et al*., 2010; Cardoso *et al*., 2013).

6.2 Conclusions

This study yielded results that exhibited how grazing management affected soil minerals of different soil types. Thus, it can be deduced that, out of all soil types included in this study, the HLC soil type had outstanding soil mineral characteristics such as intermediate pH which permitted the availability of micro and macronutrients. Commonly, all the soil types in the CPA farms had low acidity and that may be attributed to the low rainfall geographic area in which they were situated. Hutton clay and HCL soil types recorded a vast variety of grass species whereas ESCL soil had the highest good grazing grass types. Noticeably, the HC soil type had the most desirable characteristics with regard to grass species due to its greater basal cover and biomass yield. This clearly indicates that HC soil type is properly managed compared to other soil types. The grazing camps in the HLS soil type had the highest number of trees and seedlings compared to other soil types in other grazing camps and this may pose a threat to the herbaceous layer. The results from this study conclusively indicate that based on the crude protein of bulked browse leaves, they have the potential of being cheap and available protein sources for livestock reared in these farms.

6.3 Recommendation

It is recommended that limited resource farmers to be capacitated, equipped and trained for better utilization of natural resources especially in proper grazing management practices. This study has shown the importance of proper grazing management in CPA farm grazing camps of different soil types and how grazing mismanagement has a an effect on characteristics such as soil nutrients, grass species and browse plant species. For farmers to control the density of trees and seedlings in grazing camps, bush control programmes ought to be implemented thereby promoting herbaceous growth. Furthermore, for grasses to fully recover, a deferment grazing system should be employed in order to rehabilitate the CPAs.

6.4 References

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