Characterizing native palatable legume and non-legume species in the rangelands of the Overberg area

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KEYWORDS

- Overberg renosterveld
- Livestock grazing
- Indigenous Legumes
- Forage quality
- Livestock Nutrition
- Crude protein
- Fibre
- Minerals
- Soil Fertility
- Slope aspect

ABSTRACT

The Overberg renosterveld rangelands of the Cape Floristic Region (CFR) has become well associated with commercial and communal agricultural practices, namely crop and livestock production. This Mediterranean region is characterized as being a semi-arid, winter rainfall area with nutrient-limited soils. Livestock farmers rely largely on introduced legume species such as lucerne (*Medicago sativa*) as high quality forage to sustain their livestock's diets. Generally, these introduced species are reliant on the accessibility of water and nutrients, due to the specific climatic and edaphic conditions of the region. The availability of high quality forage has always been a major concern to farmers when it comes to managing their livestock, since livestock productivity is determined by the quality of the forage consumed. This generates a demand to identify native forage species that are highly nutritive and possess adaptations to the variable environmental conditions of the Overberg. Therefore the objective of this study was to identify and characterize the chemical composition of palatable native legume and non-legume species in the Overberg renosterveld vegetation, by analysing the nutritional variables: crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), and macro mineral concentrations. Plant samples were collected from nine farms in the Overberg region during the spring (2014) and autumn (2015) season to assess the effects of seasonal variation on forage quality. Plant and soil samples were also collected from different slope aspects to assess the effects of soil aspect on forage and soil quality. The main findings were that the Fabaceae species were superior in N, CP and had moderate fibre and mineral contents in comparison to the Asteraceae and Poaceae species. However the Asteraceae species displayed superior concentrations of certain minerals, whereas the Poaceae species contained the lowest mineral and greatest fibre contents. There was a general reduction and elevation in the mineral and fibre contents during the autumn season, respectively. However the forage still contained sufficient nutrients to meet the minimum livestock dietary requirements, except for P which was deficient, which would therefore require supplementation. Additionally, the mineral contents of the soil and plant samples were greater on the south facing slopes in comparison to the north facing slopes, which was likely due to the favourable microclimatic conditions and mineralization process occurring on the south facing slopes. Overall the Fabaceae species, *A. hispida*, *A. angustifolia*, *A. nigra* and *A. submissa* contained superior nutrient levels and should be considered as nutritive forages when managing livestock grazing systems in the Overberg renosterveld.

DECLARATION

I declare that "*Characterizing native palatable legume and non-legume species in the rangelands of the Overberg area*" is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Signed: …………L Gallant……………………. 03/08/2020 ………….........................

Luke Howard Gallant Date

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CHAPTER ONE: INTRODUCTION AND LITERATURE REVIEW

1.1 Mediterranean ecosystems: Cape Floristic Region, Fynbos Biome and Renosterveld

Mediterranean ecosystems are typically associated with semi-arid environments, relatively infertile soils, and species rich vegetation, which are dominated by fire-prone sclerophyllous shrubland species (Underwood *et al*., 2009; Keeley *et al*., 2013). These ecosystems are restricted to five regions in the world, namely the Mediterranean Basin, Californian west coast, central Chile, western and southern Australia and the Cape Floristic Region of South Africa (Dell *et al*., 1986; Rundel, 1998; Keeley *et al*., 2013). The Cape Floristic Region (CFR) is one of the world's 34 biodiversity hotspots, housing an extremely high concentration of endemic species of which 68% are vascular plant species (Goldblatt & Manning, 2002), despite it being the smallest of the world's six floral kingdoms (Myers *et al*., 2000; Reyers *et al*., 2001). Within the CFR are four biomes, the Fynbos Biome, Forest Biome, Succulent Karoo Biome and the Thicket Biome (Cowling & Holmes, 1992; Cowling & Richardson, 1995; Low & Rebelo, 1996). The Fynbos Biome is well defined geographically and is naturally separated into three vegetation types, namely fynbos, strandveld and renosterveld, which occur in the winter and summer rainfall regions (Boucher, 1980; Moll & Bossi, 1984; Mucina & Rutherford, 2006; Rebelo *et al*., 2006).

Renosterveld vegetation types occupy about 29% of the total area of the Fynbos Biome (Radloff, 2008) and is situated within the winter rainfall region, receiving a rainfall range between 250-700 mm per annum (Krug, 2004; Midoko-Iponga, 2004; Stander, 2016). This type vegetation is usually associated with low-lying areas, about 50-500 m above sea level (Krug, 2004), and is positioned in close proximity to other typical fynbos vegetation types. However, what distinguishes renosterveld from typical fynbos vegetation is the lack of Proteaceae, Ericaceae and Restionaceae species. Renosterveld is described as being a shrubland vegetation type, dominated by aromatic shrubs, mostly Asteraceae species, along with grasses and geophytes (Iridaceae, Orchidaceae and Liliaceae species) (Milton, 2007; Curtis, 2013). A characteristic feature of renosterveld rangelands is the occurrence of *Elytropappus rhinocerotis,* which is commonly known as renosterbos. Renosterbos is regarded as a relatively unpalatable shrub species which has the ability to dominate rangelands as a result of intense grazing, replacing the more palatable forage species (Krug, 2004; Midoko-Iponga, 2004; Simons *et al*., 2017). Renosterveld is well known for its extremely high species richness, endemism and rarity of plant species (Cowling, 1990). Consequently, it also possesses high extinction risks, especially due to it being severely fragmented, where an estimated 160 000 ha (>90%) of natural renosterveld vegetation has been transformed through ploughing for agriculture and urbanisation since the 1920s (Cowling *et al*., 1986; Reyers *et al*., 2001; Krug, 2004; Helme & Desmet, 2006; Curtis, 2013).

1.2 Agriculture and pastoralism in the Overberg

Early settlers favoured renosterveld rangelands, as it was considered suitable for agrarian practices due to its fertile soils, flat topography and moderate rainfall as opposed to other fynbos vegetation types. These conditions made it ideal for the production of grapes, olives and wheat (Kemper *et al*., 1999; Krug, 2004). Specifically, in the Overberg, renosterveld rangelands have been transformed for the production of commercial crops, such as canola, wheat, barley, as well as pasture for livestock farming (Cowling *et al.*, 1986; Hoffman, 1997; Kemper *et al*., 1999; Von Hase *et al*., 2003). There are, however, remaining fragments of intact renosterveld that occur in between the agricultural lands which are also utilised as forage reserves for livestock grazing (Kemper, 1997; Krug, 2004; Newton & Knight, 2004; Newton, 2008; Curtis, 2013).

Prior to the introduction of livestock farming to renosterveld rangelands, early settlers reported sighting large herds of wild ungulate species which inhabited and foraged on the renosterveld vegetation. Some of the species included buffalo (*Syncerus caffer*), Cape mountain zebra (*Equus zebra zebra*), bontebok (*Damaliscus pygargus pygargus*), the black rhinoceros (*Diceros bicornis*), and the now extinct bloubok (*Hippotragus leucophaeus*) and quagga (*Equus quagga quagga*) (Boucher, 1980; Krug, 2004). The presence of a mixture of grazers, browsers and generalist feeders in the region during the 1600 to1800's suggests that the vegetation included a grassland-shrubland mosaic in the landscape (Newton & Knight, 2004; Raitt, 2005). About 2000 years ago, indigenous Koekhoen people inhabited the renosterveld rangelands, utilising a mixed herding lifestyle, managing both sheep and cattle (Hoffman, 1997; Allsopp, 1999; Kemper *et al*., 1999). In order to improve rangeland conditions and increase the availability of palatable forage (annuals, geophytes and grasses) to sustain their large herds of livestock, the Koekhoen people would regularly burn the veld and return every 1 to 4 years with their livestock to the rejuvenated grazing sites (Avery, 1981; Tansley, 1982; Hoffman, 1997; Midoko-Iponga, 2004). These fire regimes regenerated the productivity of the rangeland, through the removal of the dominant lower quality shrub vegetation, and allowed the establishment of higher quality forage species (Midoko-Iponga, 2004; Curtis, 2013). Hence, herding and pastoralism became a prominent practice in the Fynbos Biome and especially in renosterveld vegetation by indigenous communities and later with the European settlers (Deacon, 1992; Milton, 2007).

1.3 Livestock diets and legume domestication

Livestock diets are highly dependent on the type and quality of the forage resources, where poor forage quality and nutrient deficiencies have negative effects on livestock production (Ball *et al*., 2001; Dasci & Comakli, 2011; Chiba, 2014). Ruminant feeders possess the ability to digest complex fibrous plant tissues, such as the cell wall, which would reduce the quality of a forage species if present in high concentrations. The digestion is achieved with the aid of microbes and enzymes present in a specialized digestive chamber called the rumen, which serves as a site for the fermentation of the ingested forage. Once the forage is consumed, it remains in the rumen for a significant amount of time, undergoing microbial fermentation under anaerobic conditions, breaking down the principle components of the cell wall, i.e. cellulose and hemicellulose (Givens *et al*., 2000). Ruminant species are especially suited to foraging on rangeland resources as a result of the rumen-hosted microbes that efficiently break down fibre, which can be fairly high in most range species (Dasci & Comakli, 2011).

In order to improve rangeland productivity for livestock grazing, farmers have incorporated the utilisation of legumes into the livestock's diets (Doyle & Luckow, 2003; Ammar *et al*., 2004; Khachatur, 2006; Boufennara *et al*., 2012). Legumes are a group of vascular plants classified under the Fabaceae family, which possesses the ability to fix atmospheric nitrogen (N) through a mutualistic relationship with prokaryotic *Rhizobium* bacteria (Oberholzer *et al*., 1994; Chen *et al*., 2003; Franche *et al*., 2009). The site of nitrogen fixation is isolated in the root nodules of the host legume plant along with the rhizobia, where atmospheric N is reduced to ammonia (NH_4^+), which is then assimilated into the host plant's tissues in exchange for energy which is supplied to the bacteria (Franch *et al*., 2009). Legumes can improve rangeland productivity through the complementary benefits of ecological facilitation, by improving soils with low N concentrations, which would otherwise be unfavourable environments to non-leguminous species such as grasses (Duchene *et al*., 2017). Hence, soils that are vegetated with legumes create nutrient enriched soil niches, due to N fixation and nutrient cycling processes, in comparison to soils that are absent of legumes (Yang *et al*., 2011; Chimphango *et al*., 2015). The implementation of legume species into cropping systems is favoured by farmers, largely due to the species high forage quality status and ability to enrich the soils the species are established in, thereby reducing the reliance on supplements and chemical fertilizers (Callaway, 1995; Sanchez *et al*., 1997; Lascano *et al*., 2000; Brooker *et al*., 2008; Muir *et al*., 2011). There are a few examples of domesticated leguminous forage species which possess superior nutritional values and are well adapted to semi-arid environments, which include tedera, lupin, vetch clover, and lucerne (Howieson *et al*., 2000). For instance, tedera (*Bituminaria bituminosa*) is a Mediterranean perennial legume species that posseses the potential to be a high quality forage resource, due to its extended growing season, thereby increasing its biomass availability, as well as its tolerance to moderate grazing intensities in semi-arid environments (Sternberg *et al*., 2006; Hardy *et al*., 2019). Tedera is traditionally utalised in mixed swards by farmers in the Canary Islands of Spain as a forage legume to sustain goat feeding, and has proven to be a beneficial forage species to fill the 'feed gap' during the dry season of southern Australian grazing systems (Real *et al*., 2011; Real *et al*., 2018). *Lebeckia ambigua* is another example of a perennial legume species that has been domesticated in the wheatbelt region of western Australia, resulting in the inception of the *Lebeckia* cultivar, "Isanti" (Taylor *et al*., 2020). This South African native legume is suitable for farming systems on nutrient deficient and acidic soils. Its is torelant to high grazing pressure and posseses specialised root architecture for nutrient uptake, high fecundity and seed production rates, and a extended growing period (Howieson *et al*., 2013; Edwards *et al*., 2019). In southern Africa, farmers have adopted the utilisation of the introduced species, *Medicago sativa*, commonly known as lucerne, into inter-cropping systems with non-legume crops, such canola and barley (Curtis, 2013). *Medicago sativa* originates from the Mediterranean basin, in Europe and North Africa, and is regarded as a high quality forage species with high concentrations of N and crude protein (Scholtz *et al*., 2009). However, in the Overberg renosterveld, there is a large diversity of understudied native legume and non-legume species, which could hold the potential of being a high quality forage species that could possibly be domesticated and incorporated into livestock diets and grazing management systems.

1.4 Forage resources and forage quality

The term forage can be defined as the edible parts of a plant that can provide feed for grazing animals or can be harvested for feeding (Amiri & Shariff, 2012). Forage quality may be characterized by assessing the palatability, nutrient content, anti-quality factors, digestibility, and intake rates of the forage species (Sprinkle, 2001; Newman *et al*., 2009). Forage quality and availability are two of the most limiting factors in commercial and communal livestock production, especially when the livestock are dependent on natural pastures and crop residues for large periods of the year (Bransby, 1981; Simbaya, 2000; Ball *et al*., 2001; Adesogan *et al*., 2006). Forage quality strongly influences the performance of the livestock which includes weight gain, milk production and reproductive efficiency, and ultimately the profit that the farmer generates (Ball *et al*., 2001; Fulgueira *et al*., 2007).

1.4.1 Crude protein

One of the most limiting nutritional variables that can influence livestock performance and production is the crude protein (CP) content (Paterson *et al*., 1996; Hariadi & Santoso, 2010; Mahmoud *et al*., 2017), since protein is essential for growth, weight gain and lactation (Mattson, 1980; Liamadis, 2003). The CP content is ultimately the N and amino acid components in the forage material (Schroeder, 2004; Muir *et al*., 2007). When ruminant livestock consume forage species, the bacteria in the rumen digest and utilise the CP for growth and energy to digest fibrous forage material (Rayburn, 1991). The bacteria are then digested in the livestock's true stomach where the amino acids are employed for general growth and milk production (Simbaya, 2000). As the microbial activity in the rumen of the host increases due to the supply of materials with high CP, the intake rates of the forage by the livestock are improved. Species composition may influence the nutritional quality of a forage species. For instance, legume species generally contains greater protein contents in comparison to non-leguminous forage species, due to nitrogen fixation processes (Gierus *et al*., 2012). Similarly, the stages of maturity of a plant's life cycle can affect the forage quality, where the protein content generally decreases as plant tissues mature (Fatur & Khadiga, 2007; Muir *et al*., 2007) limiting the amount protein available to the livestock to produce more rumen microbes (Sprinkle, 2001). Therefore, forage consumed during the active growing season of the year, i.e. the spring season, would contain greater CP concentrations compared to the summer or autumn season, as there is more vegetation growth and foliar tissues available for consumption (Stindt & Joubert, 1979). Additionally, nutrient concentrations may vary depending on the portions harvested from the forage species, for example foliar tissues generally contain greater CP and lower fibre concentrations compared those of the stem tissues (Rauzi, 1982).

1.4.2 Neutral detergent fibre and acid detergent fibre

The forage fibre content is another major determinant of forage quality, where the intake and digestibility rates of a forage species can be predicted using this dietary variable. An inexpensive and routine method for determining the forage fibre fraction is namely the analyses of the neutral detergent fibre (NDF) and acid detergent fibre (ADF) (Givens *et al*., 2000). The NDF analysis analyses the insoluble components of a forage species, namely cellulose, hemicellulose, lignin and silica, which collectively is the cell wall fraction of the plant tissues (De Waal 1990, Schroeder, 2004). The NDF content has shown to be inversely proportional to the intake rates of dry matter, therefore when forage NDF contents increases, the livestock consumption of the forage decreases (Schroeder, 2004; Ball *et al*., 2001). The determination of ADF is essential, since it is composed of the highly indigestible fibre fractions and is negatively correlated with the digestibility and energy availability of the forage species (Rayburn, 1991; Ball *et al*., 2001; Schroeder, 2004; Amiri & Shariff, 2012).

The fibre content and the digestibility of the forage generally increases and decreases with plant maturity, respectively. As the plant tissue matures, the quality of the forage declines, due to the increase in the cellulose content, which requires more energy for the microbes to break down the chemical bonds in the rumen (Sprinkle, 2001; Fulgueira *et al*., 2007). Therefore, forage species harvested or consumed at an early growth stage of the life cycle are generally lower in fibre compared to more mature species. Species composition may also factor with regard to fibre content, where legume species generally possess higher intake and digestibility rates, due to reduced fibre concentrations compared to non-legume species (Stobbs, 1975; Simbaya, 2000; Rawnsley *et al*., 2002; Pontes *et al*., 2007). According to comparative studies of the nutritional quality between of legume and grass species, grass species contained greater contents of NDF and ADF in relation to that of legume species (Amiri & Shariff, 2012). The greater fibre contents in the grass species is likely due to the higher proportion of stems, and dry matter contents in the forage (Harrington & Wilson, 1980; Ball *et al*., 2001; Dasci & Comakli, 2011).

1.4.3 Mineral elements

Minerals elements are essential dietary components that are required for a variety of daily metabolic processes and bodily functions (Ahmad *et al*., 2008; Mirzaei, 2012). For instance, certain minerals (i.e. potassium, calcium and magnesium) assist with physiological functions, such as nerve impulse transmissions, osmotic pressure regulation and enzyme activation, as well as the development of biological structures such as bones and tissues (Radwinksa & Zarczynska, 2014). Additionally, certain minerals may influence the uptake and function of other minerals in grazing animals, and may result in nutritional deficiencies that can affect the livestock's metabolism and increase the risk of illness and mortalities (Stindt & Joubert, 1979; Minson, 1990). For example, potassium (K) interferes with the uptake of calcium (Ca) and magnesium (Mg), in grazing animals, and can induce grass tetany, which is a potentially fatal metabolic disorder caused by a Mg deficiency in livestock diets (Wylie *et al*., 1985; Mayland, 1988; Mirzaei, 2012).

Legumes are regarded as superior forage species, due to the greater concentration of CP and mineral concentrations (i.e. nitrogen, calcium, and iron), and digestibility rates and therefore are mixed with lower quality forage to improve livestock diets (Simbaya, 2000; Ammar *et al*., 2004; Amiri & Shariff, 2012; Mahmoud *et al*., 2017). Generally, mixed-diets that are composed of fibrous crop residues and complemented with a legume forage species, have shown an increase in the intake rates of dry matter, therefore increasing the average daily weight gain of the livestock (Holecheck *et al*., 2004; Wang *et al*., 2010; Mischkolz *et al*., 2013). A diversity of native forage species that includes legumes, may improve the availability of high quality forage resources, especially during dry seasons when rangeland forage materials are limited (Lehman, 2001; Schellenberg & Banerjee, 2001).

1.5 Effects of seasonal variation on forage quality

Climatic variables, such as rainfall and temperature can have considerable effects on the nutritional quality and availability of a forage species, where nutritional variability may occur between and within different seasons (De Waal, 1990; Lascano *et al*., 2000). Seasonal variability and the associated climate conditions can have a significant effect on forage and livestock productivity (Fatur & Khadiga, 2007; Ophof *et al*., 2013). For instance, seasonal studies conducted at the Glen Agricultural College in the Free State, recorded a significant decline in the body conditions of lactating South African merino ewes during the drier autumn and winter months, due to reduced forage CP and digestible organic matter contents (Engels & Malan, 1979; De Waal *et al*., 1981). Drought conditions can have variable effects on the internal mobilisation patterns of different nutrients in different plant tissues (Wang *et al*., 2005; Sardans *et al*., 2008). Generally, temperature has a greater influence on forage quality than other environmental variables, where plant tissue maturation and cell wall lignification accelerates with increasing temperatures (Buxton & Fales, 1994; Linn & Martin, 1999). As a plant matures, the lower quality stem components constitute a larger proportion of the total forage material than the foliar components, which are typically of a higher quality and possess greater CP concentrations and higher digestibility rates (Buxton & Fales, 1994; Ball *et al*., 2001; Dasci & Comakli, 2011). Therefore, with maturity, fibrous structures increases and the digestibility and CP content decreases. Additionally, plant maturity can affect foliar mineral concentrations, where younger plant tissues usually contain greater mineral contents, which decline with maturity (McDowell, 1992).

In semi-arid ecosystems like the Overberg, the variability in temperature and of water availability is a major concern to plant productivity, and therefore the identification and selection of native forage species, especially legumes and perennials, that are adapted or tolerant to variable climatic conditions is essential when managing agricultural systems in Mediterranean regions (Simbaya, 2000; Jefferson *et al*., 2004, Boufennara *et al*., 2012). The utilization of native species in livestock diets would extend the livestock's grazing periods by increasing the availability of high quality forage biomass during seasons when forage availability and nutrient contents and are limited, thereby providing farmers with some financial relief with regard to fertilizers, irrigation and dietary supplementation (Simbaya, 2000; Jefferson *et al*., 2004; Hooper *et al*., 2005; Muir *et al*., 2011; Schellenberg *et al*., 2012). An advantage of using native forage species, particularly C_4 grass species, is due to the adaptive mechanisms they possess to withstand drought stress, where C_4 plants are known for their efficient water and nitrogen usage (Brown, 1978; Li, 1993). According to a seasonal study on *Themeda triandra*, a high quality C_4 grass species, had displayed reduced transpiration losses under water stress conditions by closing their stomatal openings (Snyman *et al*., 1997), as well as elevated N concentrations during the drier season.

1.6 Soil quality

1.6.1 Soils of the Overberg renosterveld

The Overberg renosterveld vegetation is usually associated with shallow fertile clay-rich soils with impermeable subsoils (Cowling *et al*., 1986; Mucina & Rutherford, 2006; Midoko-Iponga, 2004). These soils are composed of shale derivatives from the Malmesbury and Bokkeveld Groups, specifically the Ceres Subgroup (Mucina & Rutherford, 2006). Shale bands embedded within renosterveld rangelands usually occur at depths > 60 cm and are significant sources of soil nutrients, including clay and silt particles due to weathering processes (Vermeulen, 2010). Weathering is essentially the transformation of primary minerals to secondary minerals, which contributes to the variability of soil types within and across different regions (Merryweather, 1965). Many of the soil nutrients present in an area are made available through the weathering and deposition of parent rock material in combination with organic material and climate (Lascano *et al*., 2000).

The presence of clay particles in a renosterveld soils can significantly influence the soil's ability to retain water and nutrients. These fine-textured soils contain smaller pores that restrict water from draining freely and possess a higher surface area which provides additional binding area for water and nutrients (Aboudi Mana *et al*., 2017; Kome *et al*., 2019). These particles are also net charged which aids in the attraction of nutrients to them. In contrast, clay particles may also be detrimental to plant growth, due to the formation of soil crusts on the soil surface (Vermeulen, 2010). Soil crusts are thin soil layers that are usually more compact and impenetrable, especially when drier than the sub soil layer (Vermeulen, 2010). Soil crust form due to the high mobility of clay particles, which are readily displaced into open soil pores from the impact of the rainfall, thereby creating an impenetrable surface layer (Mills & Fey, 2004; Simansky, 2014). The presence of soil crusts can influence water infiltration and reduce the porosity of the soil (Vermeulen, 2010; Van der Watt & Valentin, 1992). Crusting formation has been observed to be higher in commercial wheat fields compared to the natural veld, probably due to the prolonged duration of bare ground during the year after harvesting. Even the barren patches in between shrubs in renosterveld rangelands forms an impermeable crusting layer, where water infiltration is poor and surface run off rates are increased (Vermeulen, 2010). The restricted infiltration inhibits the availability of water and nutrients required for seed germination, root development, and the longevity and survival of a plant (Scott & Van Breda, 1937; Canadell *et al*., 1996; Vermeulen, 2010; Mills & Fey, 2004).

1.6.2 Factors that influence soil nutrients

The soil chemical composition is another environmental variable that affects forage quality, where the variability between different soil types within a region can be influenced by several biophysical factors, in combination with the localised climatic conditions (Lascano *et al*., 2000). Climatic events and seasonal variability significantly influences soil deposition and the transportation of soil nutrients, where temperature, rainfall and humidity are some of the primary climatic variables that affect soil mineral and salinity concentrations (Agehara & Warncke, 2005; Guntinas *et al*., 2012). For example, an increase in temperature lowers the soil moisture contents and increases the salt concentrations, as well as the level of water and salt stress on a plant. In contrast, high temperatures in combination with moisture contents can increase soil nutrient availability through the acceleration of soil microbial activity and litter decomposition rates (Sariyildiz, 2015). Soil nutrients may be influenced by various biotic variables, such as fossorial animals that occupy the soil zone, such as earthworms, termites, moles and aardvarks. Burrowing activity contributes to the soil condition through nutrient cycling processes, in addition to improving the aeration and infiltration rates in the soil. For instance, termitaria, commonly known as 'heuweltjies' are common landscape features in renosterveld rangelands, which contribute to the localisation of mineral concentrations in the rangeland (Midgley & Hoffman, 1991; Booi *et al*., 2011). Furthermore, the chemical composition of the soil can also be altered by the presence of plant biomass and vegetation cover (McGratha *et al*., 2000). Plants possess the ability to sequester atmospheric carbon and soil minerals, which are then released in the soil substrate via the decomposition of the plant debris. Soil composition attributes such as the organic matter and soil moisture contents are generally higher under vegetation cover compared to those of bare soils. This is due to there being accelerated rates of decomposition under leaf litter, which increases the availability of nutrients to the plants and productivity of the rangelands (Mills & Fey, 2004).

1.6.3 Effects of soil nutrients on forage growth and quality

There are various soil parameters that may be analysed to characterize the soil chemical composition, namely the soil pH, moisture content and mineral concentrations. Soil minerals are elements that are present and absorbed by plants from the soil substrate, as opposed to non-mineral nutrients which are obtained from the air and water (Mirzaei, 2012; Jones & Olson-Rutz, 2016). Mineral elements are categorised into either macro or micro minerals depending on how much is required from the plant. Macro minerals, which are generally required from plants in larger quantities, include N, P, K, Ca, Mg and Na (Radwinksa & Zarczynska, 2014; Jones & Olson-Rutz, 2016).

Soil minerals are essential for plant productivity and nutritional value, where certain minerals that are absorbed function in the enhancement of plant metabolic processes (Jacobsen *et al*., 1996; Guevara *et al*., 2000; Wang *et al*., 2010). For instance, plants rapidly take up N from the soil in the form of nitrate, which is broken down to ammonium (NH_4^+) and then incorporated into the amino acids for protein synthesis (Estefan *et al*., 2013). In agriculture, there is a high N demand for crop production, where a deficiency of soil N will negatively impact on plant productivity and crop yields (Jacobsen *et al*., 1996; Guevara *et al*., 2000). Nitrogen fertilization is especially beneficial to the yield production of non-legume species, since these species are unable to fix N in the soil unlike their legume counterparts and therefore would have to rely on N already present in the soil (Oelmann *et al*., 2007; Pontes *et al*., 2007; Temperton *et al*., 2007). Furthermore, N fertilization may directly improve forage digestibility by altering the leaf-stem ratio, by lowering the fibrous stem component and increasing the yield of the leaf ratio (Jacobsen *et al*., 1996; Guevara *et al*., 2000; Dasci & Comakli, 2011). Nitrogen fertilization has also been reported to increase NDF digestion and intake rates of forage species, especially herbage and warm-season grasses (Buxton & Fales, 1994). The improvement of forage digestibility in response to increased forage N is due to the demand from the ruminal microbial activity, which requires N for the breakdown the forage. Certain soil minerals have a substantial effect on the endurance and physical condition of certain plant species, in response to environmental stress factors. For example, potassium (K) plays a vital role in mitigating the effects of drought conditions on a plant species, by assisting with the maintenance and stability of the cell membrane as well as with osmotic regulation (Wang *et al*., 2010). Therefore, elevated concentrations of K would favour forage availability for livestock production, especially during the drier period of the year (Ahmad *et al*., 2008). Other minerals play a significant role in the pH condition of soils, such as calcium (Ca), which can be sourced from limestone (CaCO3) deposits in the soil substrate (Ramirez-Orduna *et al*., 2004). The soil pH is an important indicator of soil quality, which influences the availability and solubility of soil nutrients, as well as biological activity (Donahue, 1977; Estefan *et al*., 2013). Available soil Ca can also improve forage digestibility through the compositional changes in the plant cell walls (Lascano *et al*., 2000), as well assists with the uptake and translocation of other mineral elements, such as magnesium. In contrast, the presence of certain minerals may inhibit the absorption of other minerals present in the soil and induce mineral deficiencies. For example, Mg deficiencies may arise in crop plants due to the catatonic competition between K and Mg ions in the soil (Fufa & Dafang, 1998; Guang & Changyan, 2006; Yan & Hou, 2018). Magnesium is an essential component in photosynthesis, where it participates in the formation of chloroplasts and the regulation of excitation energy between chloroplasts (Yan & Hou, 2018). Therefore, Mg deficiencies would inhibit chloroplast formation and produce symptoms of chlorosis in the foliar tissues of the plants. Mineral deficiencies and toxicities can have detrimental effects on a plant's health and survival and may manifest as a variety of symptoms such as wilting, stunted growth and blossom-end rot (Machado & Serralheiro, 2017). In contrast, excessive or toxic concentrations of certain soil minerals, like sodium (Na), can induce salt stress and manifest symptoms of necrosis or scorching of leaf margins, thereby reducing crop productivity and yield specifically in crops with low salt tolerance like broccoli and tomatoes (Lopez-Berenguer *et al*., 2006).

1.7 The effect of slope aspect on soil and forage quality:

The slope aspect or slope orientation is essentially the direction in which the slope is facing towards. The slope aspect can have a substantial effect on the plant productivity, species richness and composition, as well as the nutrient dynamics of the soil and vegetation occurring on the slope (Birkeland, 1984; Chen *et al*., 1997; Gong *et al*., 2008). As a consequence of slope orientation, the environmental conditions may vary significantly across different slope aspects. Some of the environmental variables can include temperature, solar radiation, wind direction and rainfall distribution (Hutchins *et al*., 1976; Tsui *et al*., 2004; Beullens *et al*., 2014), which in turn may manipulate the species composition and distribution by influencing specific plants communities to colonise on different slope aspects (Reid, 1973; Churchill, 1981; Holecheck *et al*., 2004). For example, slopes that receive higher temperatures and evapotranspiration rates are likely to be colonized by plant species that are more tolerant to warmer and drier conditions in order to withstand the aspect-specific conditions (Bennie *et al*., 2006). This was reflected in a study conducted at the research catchment at Cathedral Peak in the Drakensberg, which presented distinct differences in the plant communities occurring on opposing slope aspects, due to variations in the solar radiation received on the different aspects (Granger & Schulze, 1977).

In the Southern Hemisphere, the north facing slopes are generally associated with warmer and drier conditions, and receive more radiation compared to the south facing slopes which are generally wetter and cooler (Cowling, 1983; Newton, 2008). These micro-climatic effects associated with the slope orientation will directly influence the productivity and quality of the forage species on a particular slope aspect. The differences in forage quality on different slope aspects, is largely driven by the amount of precipitation that the slope receives as well as the soil moisture and nutrient contents available to the vegetation (Sternberg & Shoshany, 2001; Badano *et al*., 2005). A process known as the shading effect on specific slope aspects is a major driver that contributes to the moisture and nutrient contents present on cooler and damper slopes, which occurs when the orientation of a slope is shaded from receiving direct sunlight for extended periods of time (Buxton & Fales, 1994). Shading has both direct and indirect effects on the quality of forage, where it alters the chemical composition of forages as well as morphology and yield (Buxton & Fales, 1994). Forage grown under shaded conditions usually contains higher crude protein concentrations and lower fibre contents than unshaded forage (Linn & Martin, 1999; Ball *et al*., 2001). For example, aspects that receive more solar radiation will receive higher temperatures and light intensities, and therefore the respective forage species will experience accelerated rates of tissue maturation and contain elevated fibre concentrations (Probasco & Bjuand, 1980; Dasci & Comakli, 2011). Slope aspects that receive high rates of temperature and water availability, might experiences higher rates of soil mineralization, due to microbial and enzyme activity occurring in the soil substrate (Henderson *et al*., 1966; De Neve *et al*., 2003; Sardans *et al*., 2008). Generally, slope aspects that are associated with wetter conditions have a thicker humic (organic matter) soil layer, introducing higher concentrations of water and nutrient availability to the soil compared to drier slope aspects (Gong *et al*., 2008; Sidaria *et al*., 2008). Organic matter promotes soil structure and function, retention of water and nutrients and even acts as a slow release fertilizer when the organic material decomposes and releases the bound nutrients (i.e. N and P) (Henderson *et al*., 1966; Estefan *et al*., 2013). The availability of soil water is one of the main limiting factors for plant growth (Gong, *et al*., 2008) and therefore the loss of vegetation cover would exacerbate the loss of soil moisture due to increased runoff and evapotranspiration rates, especially on dry and degraded slope aspects (Loch, 2000; Zhou *et al*., 2008). Hence it is important to assess the effects that the slope aspect and the associated climatic conditions have on the soil chemistry and availability of soil nutrients, as well as the chemical composition of forage species (Gupta & Chera, 1996; Rech *et al*., 2001).

1.8 Motivation for study

There is a growing demand to identify high quality native forage species that are adapted to the variable conditions of semi-arid regions and that can be domesticated and incorporated into fodder flow systems to accommodate livestock diets. In semi-arid regions it is predicted that there will be an increase in temperature and variability in rainfall patterns associated with climate change, which will negatively impact agricultural practices and grazing management systems, especially livestock farmers that rely on specific climatic conditions to sustain forage resources. In South Africa, specifically the Overberg renosterveld rangelands, there is large diversity of native forage species that are adapted to semi-arid conditions with variable climatic and edaphic conditions. This provides an opportunity for research to identify and characterize the potential of native forage species in the rangelands as pasture species, particularly since South Africa relies largely on introduced and highly commercialised legume species as livestock fodder. Native forage species are relatively understudied and underutilised and therefore could possess the potential to become a domesticated forage species and incorporated in grazing management systems.

1.9 Study objectives

The aim of the study is to identity and characterize the potential of native legume and non-legume species in the Overberg renosterveld as high quality forage for livestock grazing systems. As well as to assess the effects of seasonal variation, soil type and slope aspect on the quality of native forage species. Therefore, the objectives of the study are to:

(1) Characterize the nutritional quality of native legume and non-legume forage species in the Overberg renosterveld and to assess the effect of seasonal variation on the quality of the native forage species.

(2) Determine the effects of soil type and slope aspect on the nutritive composition of the native forage species.

CHAPTER TWO: CHARACTERIZNG THE CHEMICAL AND FIBRE COMPOSITION OF NATIVE LEGUME AND NON-LEGUME SPECIES IN THE OVERBERG RENOSTERVELD

2.1 Introduction

In the Overberg region, the natural remnants of renosterveld vegetation are regularly utilised by farmers to sustain their livestock's diets during various seasons throughout the year. These natural pastures possess a high floral diversity, mostly dominated by Asteraceae, Poaceae and geophytic species (Krug, 2004; Milton, 2007; Curtis, 2013). Renosterveld rangelands have been utilised for centuries as pastures for livestock grazing, dating back to the native Khoi pastoralists (Hoffman, 1997; Kemper *et al*., 1999). These indigenous communities would regularly burn the veld to improve veld quality through the removal of the dominating unpalatable vegetation, and to allow the establishment of more nutritious forages for their livestock (Hoffman, 1997; Midoko-Iponga, 2004; Curtis, 2013). Currently, in many farming systems, natural pastures are known to provide supplementary feeding to livestock during times of feed scarcity or due to financial constraints to purchase livestock feed (De Waal, 1990). However, natural pastures tend to become less productive if the veld is poorly managed, through overgrazing and irregular burning, resulting in the reduction of more palatable vegetation. Therefore, livestock grazing can have both beneficial and detrimental effects on the quality and quantity of vegetation. Herbivory can encourage the production of younger and more nutritious plant tissues. On the other hand, overgrazing could reduce forage quality, by increasing the concentration of secondary compounds, such as tannins, as a defence response against grazing (Coley & Barone, 1996; Mbatha & Ward, 2010).

Semi-arid regions, such as the Overberg renosterveld rangelands, are highly variable in their biophysical environments, both spatially and temporally (Van Soest, 1994), which in turn influences the species composition and quality of the rangelands. Limited studies are available on the nutritional quality of forage species for livestock grazing, specifically in renosterveld vegetation types. Therefore, research on the native forage species is essential to livestock farmers that utilise these natural pastures to sustain the livestock's nutritional requirements during various seasons of the year (Stindt & Joubert, 1979). Through analysing the quality of native forage species and the factors that influence it, such as seasonal variation, improvements on grazing capacities and livestock production may be achieved

(White & Wight, 1984). Therefore, this chapter deals with characterizing the nutritional quality of native forage species in the Overberg renosterveld rangelands, which are used as forage resources for livestock grazing. The nutritional elements that will be assessed in the native forage species will include, crude protein, neutral and acid detergent fibre, and macro mineral concentrations in grazed plant samples collected during the spring and autumn seasons.

2.2 Study objectives

The aim of this chapter is to characterize the nutritional value of native legume and non-legume species in the Overberg renosterveld rangelands during the spring and autumn seasons. The research questions for this study are:

(1) Are the legume forage species higher in nutritive quality, compared to the non-legume forage species in the Overberg renosterveld rangelands?

(2) How does the nutritive quality (crude protein, neutral detergent acid detergent fibre, and mineral content including N, P, K, Ca, Mg, and Na) differ between the forage species during the spring and autumn seasons in the Overberg renosterveld rangelands?

2.3 Materials and methods

2.3.1 Study area and sample collection

This study was conducted in the Overberg rangelands, situated in the Western Cape of southern Africa, which stretches from Grabouw to Heidelberg (Rebelo *et al*., 2006) (Figure 2.1). The Overberg region has a Mediterranean climate, with mean daily temperatures ranging between 6.1 ºC in July to 26.9 ºC in February, and a mean annual rainfall range of 360 to 700 mm, peaking during the winter months (May-August) (Rebelo *et al*., 2006). Renosterveld is the dominant vegetation type, which can be divided into three main regions, the Western-, Central- and Eastern- Rûens Shale Renosterveld (WRSR, CRSR and ERSR) (Rebelo *et al*., 2006). Sites were selected based on the availability of reasonably sized renosterveld remnants (> 1 ha). Plant samples were collected from three farms from each of the three regions (WRSR, CRSR and ERSR) during the 2014 spring (September-October) and 2015 autumn (March-May) seasons. Plant species were selected based on field observations (evidence of grazing), literature (Van Breda *et al*., unpublished; Van Breda & Barnard, 1991) and interviewing local farmers. This information on palatability and abundance formed the selection criteria for the species to be sampled and revealed that the commonly foraged species belonged to three families, namely Fabaceae, Poaceae and Asteraceae. The edible plant material (about 10 cm from the tip of the shoot into the shrub) was collected using pruning shears, on two separate slopes on each farm, and three replicates were collected per species. The names of the species sampled are presented in (Appendix 1).

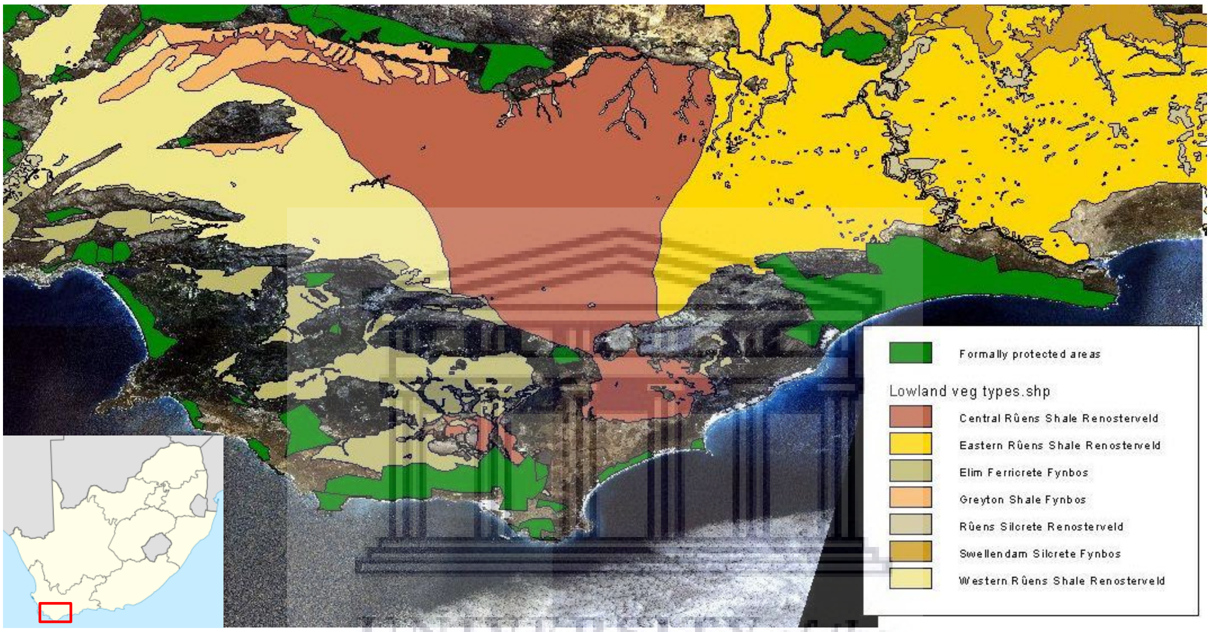

Figure 2.1: Map representing the distribution of the vegetation types across the Overberg region in the Western Cape, South Africa.

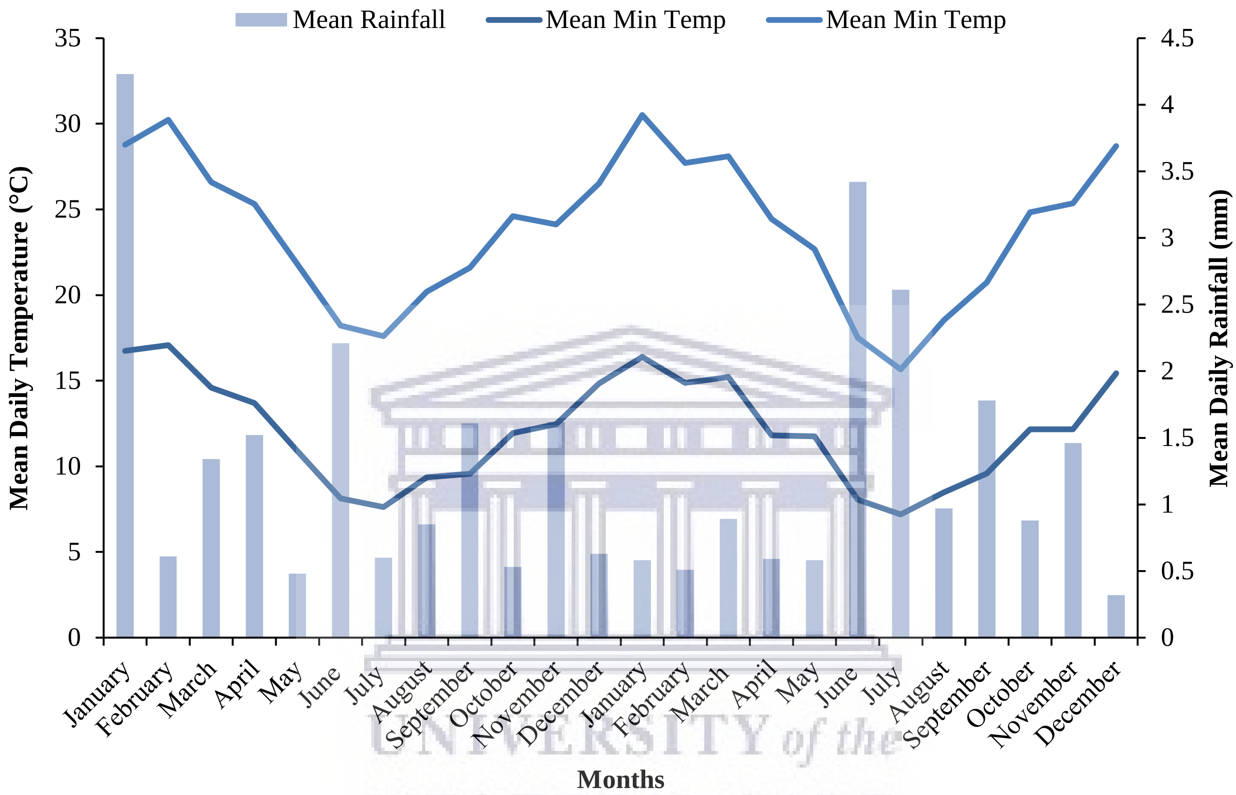

Figure 2.2: Mean daily rainfall, maximum and minimum temperatures collected from the Protem weather station in the Overberg, during 2014 to 2015.

2.3.2 Plant chemical analyses

In preparation for the chemical analyses, the plant samples were dried using an air-forced oven, at 70 ºC for 48-56 hours and were milled using a Wiley Mill grinder, to pass through a 0.5 mm sieve, to maintain homogeneity. The samples were then placed into tightly sealed plastic bags and stored in a cool dry place for chemical analysis.

Mineral elements

Plant samples underwent organic matter decomposition for the elemental determination via acid digestion, using an H_2SO_4 and H_2O_2 (sulphuric-peroxide) solution which was added to 0.4 g of dried sample and placed into a heat block digester (Moore & Chapman, 1986; Kalra, 1998). The aqueous mixture was filtered through Whatman No. 1 filter paper into 100 mL volumetric flasks and diluted to volume. A UnicamPyeSolaar (M-series) atomic absorption spectrophotometer (AAS) (Unicam Unlimited, Cambridge, UK) was used for the determination of the macro mineral concentrations: K, Ca, Mg, and Na, using certified standards for the elements (Merck Millipore (Pty) Ltd.). The P concentration was determined by nitric-hydrochloric acid digestion and the extract was analysed by ICP-OES at Bemlab private laboratory (Somerset West, South Africa).

Crude protein

The plant material was analysed for the N concentration using direct titration with 0.01 N HCl, with a Buchi Nitrogen Distillation Unit (model K-300, Labotec, Büchi Switzerland). The crude protein (CP) content was determined by the product of the N concentrations and 6.25 since most forage species contains about 16% of N in their protein (White, 1983).

Neutral and Acid Detergent Fibre

Neutral detergent fibre (NDF) and acid detergent fibre (ADF) was determined using an ANKOM Fibre Analyser A220, following the ANKOM Technology methods 13 and 12, respectively (ANKOM Technology, https://www.ankom.com/analytical-methods-support/fiber-analyzer-a2000).

2.3.3 Statistical analyses

The plant chemical variables were natural log-transformed to meet the parametric analysis requirements, and the analyses were performed using Statistica 8 (Statsoft, Inc.) programme based on the F values ($p<0.05$). The forage quality variables were subjected to a multivariate canonical discriminant analysis (CDA) to determine whether plant family and species separation based on the foliar chemical and fibre concentrations and to identify the variables that contributed the most in the separation, using the canonical variates' (CV) standard coefficients. The CDA generates CV's, in such a way that the statistical algorithm develops an optimal separation between families and species that are established *a prior* by maximizing between-group variance (Raamsdonk *et al.*, 2001). The original variables that contributed the most in the separation of the groups are identified by the CVs standardized coefficients. A two-way mixed model nested ANOVA was used to evaluate significant differences between forage family and species within the effects of seasonal variation on the univariate nutrient variables, and the means were separated by Tukey's honest significant difference tests at the 5% probability level. For the within-season analysis, species were nested in each family and selected as a random factor, whereas in the inter-season analysis, species were nested in each family and both species and family were nested in a season.

2.4 Results

2.4.1 Spring season

According to the CDA results of the spring season data, there was a clear separation of the three families based on the foliar chemical and fibre composition (Figure 2.3a). This was achieved using a canonical discriminant analysis of foliar chemical and fibre concentrations, which included N, P, K, Ca, Mg and Na, and NDF and ADF, for the 2014 spring samples. The Squared Mahalanobis distances between the plant families confirmed that there was a significant separation ($P<0.05$) based on the chemical characteristics (Table 2.1). According to the standardised coefficients, the chemical variables that contributed the most to the separation were N, NDF, ADF and Na, based on the canonical variate scores of CV1 and CV2, presented in Table 2.2. Similarly, there was a significant separation of the individual forage species based on the chemical characteristics (Figure 2.3b). This significant separation ($P<0.001$) was supported by the Mahalanobis distances between the individual forage species (Table 2.3). Seven of the eight CVs had significant functions ($P<0.001$) with CV1 and CV2 accounting for 60 and 24% of the among group variation, respectively (Table 2.4). The standardised coefficients from the seven CVs indicated that all concentrations of the macronutrients and fibre are essential in the separation of the individual species, with ADF, NDF, N and Na contributing the most to the separation based on the canonical scores for CV1 and CV2.

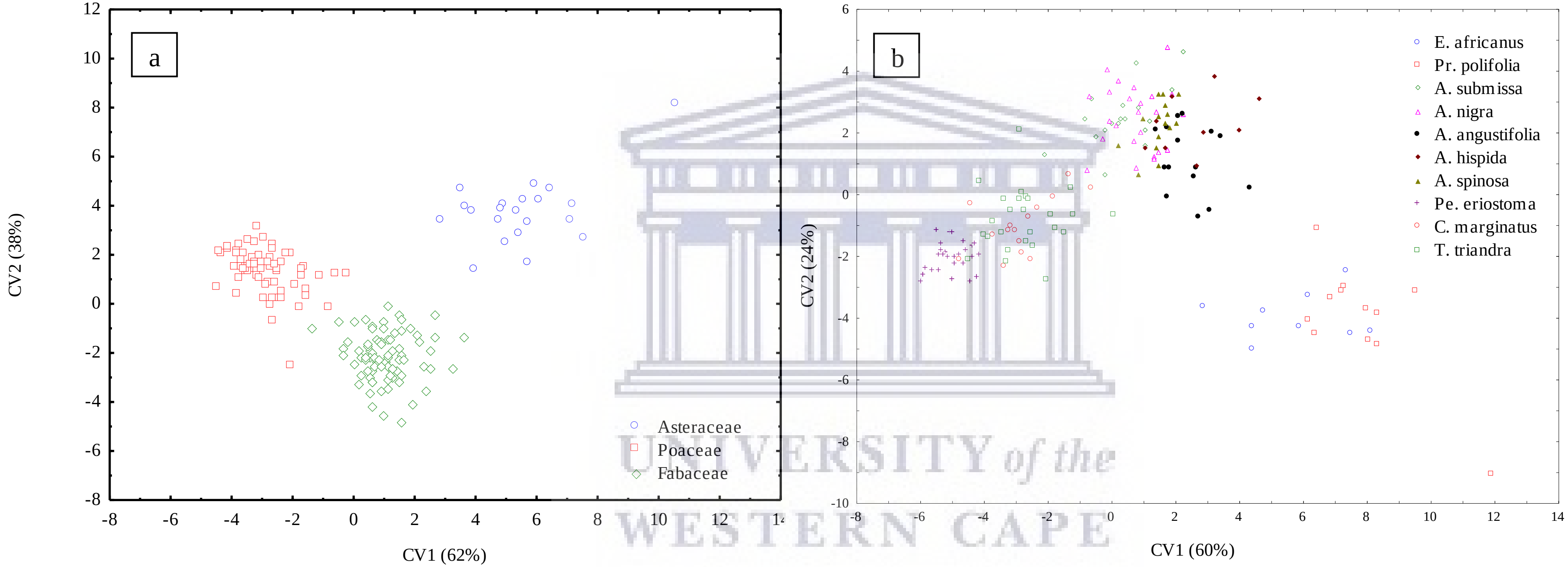

Figure 2.3: Scatterplot of canonicals scores separating a) families and b) species of native forage species from the Overberg renosterveld vegetation during the spring season, 2014, based on the foliar mineral and fibre and concentrations, including N, P, K, Ca, Mg, Na, NDF and ADF.

Table 2.1: Squared Mahalanobis distances between foraged plant families in the Overberg renosterveld vegetation during the spring season, 2014. Distances are given below the diagonals, and above are the F-statistics (df = 8, 161), along with ** indicating significant differences at P<0.05.

	Asteraceae	Poaceae	Fabaceae
Asteraceae		147.4**	110.1**
Poaceae	76.4		120.5**
Fabaceae	55.1	27.0	

Table 2.2: Standardized coefficients of plant nutrition variables along co-variates with significant contribution (P<0.05) to the discriminant function for the separation of foraged families in the Overberg renosterveld vegetation during the spring season, 2014. Eigenvalues indicate how well each canonical variate differentiates the groups. Among group variance indicates the proportion of the total variation accounted for by each canonical variate. Chi-Squared test values at *** P<0.001, and ** P<0.05.

Plant parameter	Standardized coefficient (CV)	
	CV1	CV2
N	0.31	-1.23
P	-0.36	0.40
K	0.09	0.51
Ca	0.03	-0.03
Mg	-0.06	-0.21
Na	0.64	0.72
NDF	-1.13	0.04
ADF	1.12	-0.14
Eigenvalue	7.69	4.68
Among group variance (%)	62	38
Chi-squared Test	641.1**	285.7**

Table 2.3: Squared Mahalanobis distances between native forage species in the Overberg renosterveld vegetation during the spring season, 2014. Distances are given below the diagonals, and above are the F-statistics (df = 8, 154), along with *** indicating significant differences at P<0.001.

	Eriocephalus africanus L.	*Printzia polifolia* (L.) Hutch.	*Aspalathus submissa* R. Dahlgren	*Aspalathus nigra* L.	*Aspalathus angustifolia* (Lam.) R. Dahlgren	*Aspalathus hispida* Thunb.	*Aspalathus spinosa* L.	*Pentameris eriostoma* (Nees) Steud.	*Cymbopogon maginatus* (Steud.) Stapf ex Burtt Davy	*Themeda triandra* Forssk.
E. africanus		11.8***	56.8***	58.0***	32.0***	30.9***	44.9***	98..3***	66.2***	71.0***
Pr. polifolia	19.2		89.1***	90.8***	54.6***	50.8***	73.9***	174.5***	100.8***	123.3***
A. submissa	79.2	103.5		4.1***	20.5***	9.1***	18.8***	68.1***	30.4***	31.8***
A. nigra	74.1	94.9	3.3		12.1***	13.2***	11.2***	83.7***	34.0***	38.2***
A. angustifolia	47.5	68.5	21.0	10.9		17.8***	14.8***	82.4***	42.1***	46.7***
A. hispida	57.5	82.6	12.7	16.9	26.5		16.4***	70.5***	38.7***	37.4***
A. spinosa	66.8	92.7	19.2	10.2	16.5	24.4		80.8***	35.2***	39.4***
Pe. eriostoma	121.8	175.7	52.7	55.1	71.4	87.4	70.1		19.2***	17.4***
C. maginatus	98.5	126.5	31.1	30.8	47.0	57.6	39.3	16.6		3.7***
T. triandra	88.0	124.1	24.6	25.1	40.5	46.4	34.2	10.8	3.2	

Table 2.4: Standardized coefficients of plant nutrition variables along co-variates showing their significant (P<0.05) contributions to the discriminant function for the separation of native forage species in the Overberg renosterveld vegetation during the spring season, 2014. Eigenvalues indicate how well each canonical variate differentiates the groups. Among group variance indicates the proportion of the total variation accounted for by each canonical variate. Chi-Square test values at *** P<0.001, and ** P<0.05.

Plant parameter	Standardized coefficient (CV)						
	CV1	CV2	CV3	CV4	CV5	CV6	CV7
N	0.25	1.05	0.10	0.52	0.30	0.10	-0.10
P	-0.11	-0.33	0.31	0.04	-0.22	0.99	-0.10
K	0.25	-0.32	0.07	-0.72	0.81	-0.15	0.07
Ca	-0.19	0.11	0.47	0.04	-0.03	-0.26	-0.90
Mg	0.21	0.08	-1.08	-0.44	0.27	0.16	0.08
Na	0.39	-0.81	-0.09	0.68	0.16	-0.20	-0.22
NDF	-1.24	-0.27	-0.50	0.52	0.67	0.04	-0.41
ADF	1.35	0.16	0.33	0.13	0.30	0.07	0.63
Eigenvalue	13.83	5.50	1.25	1.13	0.81	0.30	0.10
Among group variance (%)	60	24	6	5	3	1	1
Chi-squared Test	1142.5***	708.3***	407.0***	276.5***	115.0***	59.7***	17.9***

According to the univariate comparison of the plant nutrient variables, there were significant interactions (P<0.001) between species and family (Table 2.5, Figure 2.4). At a family level, Fabaceae showed the greatest concentrations of N and CP, and moderate concentrations of K, Ca, Mg, Na and NDF relative to the other families, which all met the livestock's minimum dietary requirements. In comparison, Asteraceae contained the greatest concentrations of P, K, Ca, Mg and Na, and the lowest concentration of NDF. Subsequently, Poaceae contained the lowest concentrations of all the mineral nutrients, which still met the minimum dietary requirements, except for N and CP. Additionally, Poaceae contained the greatest concentrations of NDF. At a species level, all the Fabaceae species contained superior N and CP concentrations, especially *A. hispida* and *A. angustifolia*, along with moderate concentrations of K, Ca, Mg and Na. *Aspalathus submissa* contained high levels of Ca, while *A. angustifolia* and *A. spinosa* showed greater concentrations of Mg and lower K and ADF concentrations. Furthermore, *A. angustifolia, A. nigra* and *A. submissa* also showed greater levels of NDF and ADF compared to the other Fabaceae species. As for the Asteraceae species, *Pr. polifolia* and *E. africanus*, showed high concentrations in the mineral, P, K, Ca, Mg and Na, moderate concentrations of N, and CP, and the lowest concentrations of NDF. From the Poaceae species, *C. marginatus* possessed greater concentrations of K, Ca and Mg, and moderate CP and NDF and low levels of ADF. While *T. triandra* showed the lowest concentration of Na, and moderate concentrations for the rest of the mineral elements, CP, NDF and ADF. Whereas, *Pe. eriostoma* contained the lowest concentrations in all the mineral elements and CP, apart from Na, as well as the highest concentrations of NDF and ADF.

Table 2.5: Foliar nutrient concentrations of foraged plant families and species in the Overberg renosterveld during the spring season, 2014. Mean values with different letters indicates significant difference at *** P<0.001, and ** P<0.05. Livestock requirements calculated from McDowell (1985) and Dasci *et al*. (2010).

		N	P	K	Ca	Mg	Na
					mg g^{-1}		
	Asteraceae	8.77±0.44b	0.85±0.04b	9.25±0.65b	8.83±0.44b	2.57±0.19c	8.6±0.59c
	Fabaceae	11.11±0.22c	0.58±0.03a	6.27±0.22a	8.62±0.24b	2.03±0.11b	2.02±0.16b
	Poaceae	5.62±0.2a	0.63±0.03a	6.31±0.24a	6.89±0.22a	0.95±0.05a	0.65±0.04a
	F-statistic (df = 2, 161)	191.7***	10.68***	15.8***	12.3***	120.96**	316.79**
Asteraceae	*Eriocephalus africanus*	8.46±0.84cd	0.87±0.09c	6.26±0.39a-c	8.87±0.66bc	2.51±0.34e	8.84±0.73g
	Printzia polifolia	9.01±0.48de	0.83±0.04c	11.49±0.46e	8.81±0.6bc	2.62±0.21f	8.41±0.9g
Fabaceae	*Aspalathus angustifolia*	12.16±0.59f	0.77±0.08bc	6.45±0.46a-c	7.9±0.45a-c	2.94±0.2f	4.07±0.53f
	Aspalathus hispida	12.41±0.57f	0.84±0.04c	6.51±0.46a-c	7.69±0.43a-c	1.12±0.06bc	2.6±0.1ef
	Aspalathus nigra	10.9±0.39ef	0.49±0.03a	6.65±0.39cd	8.53±0.42bc	1.87±0.18de	1.26±0.12d
	Aspalathus spinosa	9.78±0.1d-f	0.43±0.02a	4.33±0.29a	8.83±0.73bc	2.96±0.21f	2.07±0.14e
	Aspalathus submissa	10.98±0.44ef	0.54±0.03ab	7.09±0.52cd	9.62±0.48c	1.18±0.06bc	1.01±0.07cd
Poaceae	*Cymbopogon marginatus*	6.68±0.35bc	0.77±0.05bc	8.51±0.46d	8.08±0.43bc	1.5±0.09cd	0.64±0.07ab
	Pentameris eriostoma	4.51±0.24a	0.51±0.05a	4.94±0.22ab	6.27±0.33a	0.51±0.02a	0.77±0.06bc
	Themeda triandra	6.13±0.3b	0.67±0.05bc	6.45±0.31a-c	6.86±0.34ab	1.07±0.04b	0.53±0.05a
	F-statistic (df = 7, 161)	8.5***	9.89***	16.8***	2.5***	40.23***	16.37***
	Livestock requirements	11.2-30.4	1.6-3.7	5.0-12.0	2.1-11.3	0.4-2.5	0.6-1.0

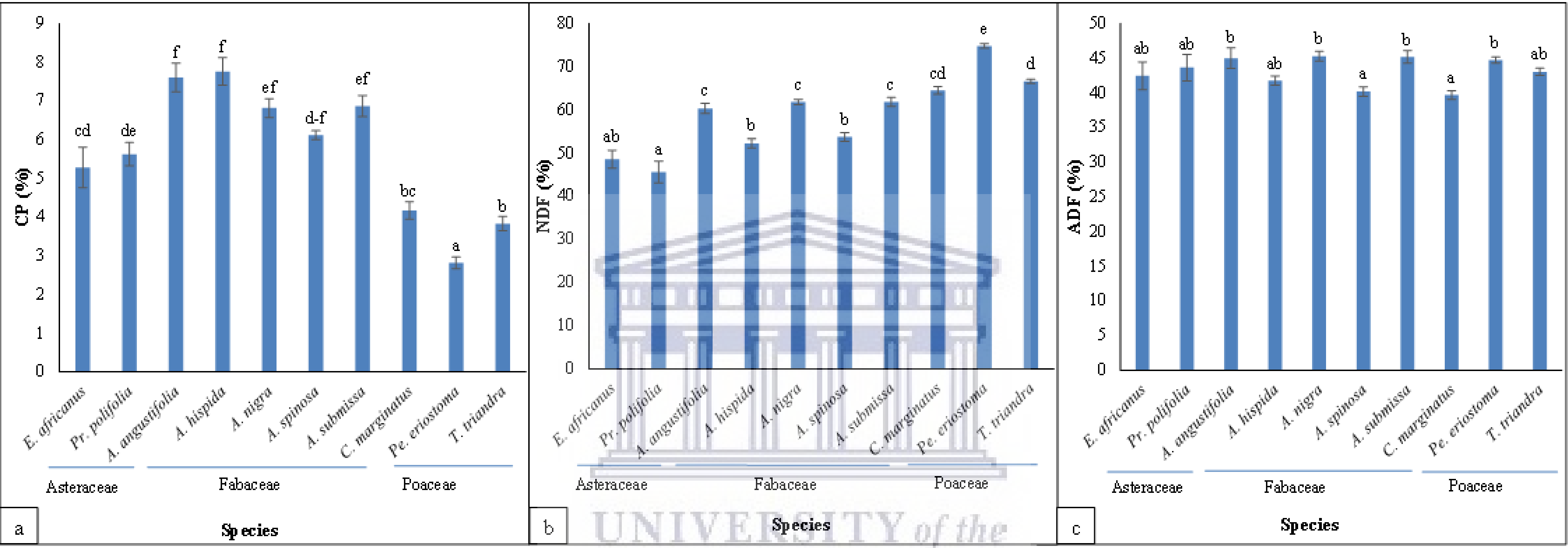

Figure 2.4: Foliar concentrations of a) crude protein (CP), b) neutral detergent fibre (NDF) and c) acid detergent fibre (ADF) contents of foraged species in the Overberg renosterveld vegetation during the spring season, 2014. Mean values with different letters indicate significant difference. Livestock requirements for CP=7,0-19, NDF=60-65, and ADF=<37 (Stindt & Joubert, 1979; Van Soest *et al*., 1991; Dasci *et al*., 2010).

2.4.2 Autumn season

According to the CDA results of the autumn season's data, the pattern of species and family variations were similar to the spring data with a clear separation between the three foraged families based on the foliar chemical and fibre composition (Figure 2.5a). The Squared Mahalanobis distances confirmed that there was a significant separation ($P<0.05$) between the plant families based on the chemical and fibre characteristics (Table 2.6). According to the standardised coefficients presented in Table 2.7, the chemical variables that contributed the most to the separation of the families were N, NDF, Na, ADF and Mg, based on the canonical variate scores of CV1 and CV2. Similarly, there was a significant separation of the individual forage species based on the chemical characteristics (Figure 2.4b). This significant separation ($P<0.001$) was supported by the Mahalanobis distances between the individual forage species presented in Table 2.8. Six of the eight CVs had significant functions ($P<0.05$) with CV1 and CV2 accounting for 54 and 16% of the among group variation, respectively (Table 2.9). The standardised coefficients from the six CVs indicated that all mineral and fibre concentrations are essential in the separation of the individual species, with Na, P, Mg and ADF contributing the most to the separation based on the canonical scores for CV1 and CV2.

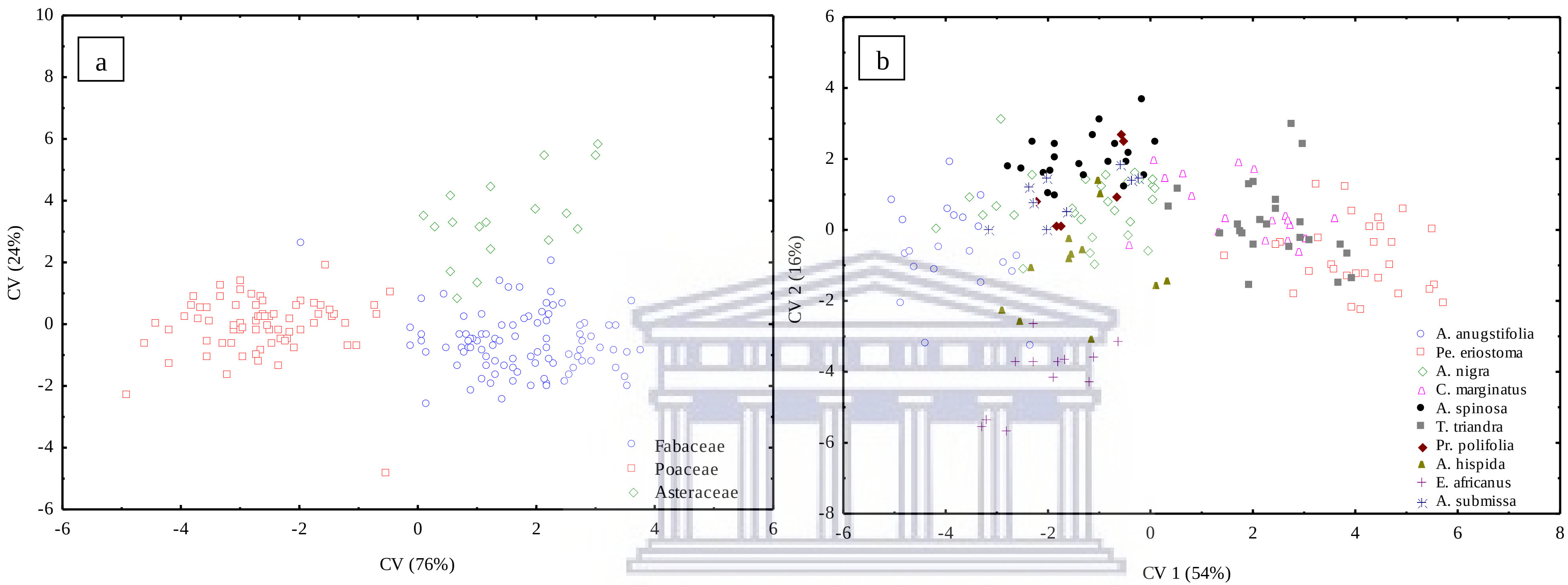

Figure 2.5: Scatterplot of canonicals scores separating a) families and b) species of native forage species from the Overberg renosterveld vegetation during the autumn season, 2015, based on the foliar mineral and fibre and concentrations, including N, P, K, Ca, Mg, Na, NDF and ADF.

Table 2.6: Squared Mahalanobis distances between foraged plant families in the Overberg renosterveld vegetation during the autumn season, 2015. Distances are given below the diagonals, and above are the F-statistics (df = 8, 173), along with *** and ** indicating significant differences at P<0.001 and P<0.05, respectively.

	Fabaceae	Poaceae	Asteraceae
Fabaceae		93.6**	30.1***
Poaceae	19.2		49.4***
Asteraceae	16.6	28.6	

Table 2.7: Standardized coefficients of plant nutrition variables along co-variates with significant contribution (P<0.05) to the discriminant function for the separation of foraged families in the Overberg renosterveld vegetation during the autumn season, 2015. Eigenvalues indicate how well each canonical variate differentiates the groups. Among group variance indicates the proportion of the total variation accounted for by each canonical variate. Chi-Squared test values at *** P<0.001, and ** P<0.05.

Plant parameter	Standardized coefficient (CV)	
	CV1	CV2
N	0.70	-0.58
P	-0.37	0.20
K	-0.13	0.03
Ca	0.22	0.48
Mg	0.50	-0.15
Na	0.26	0.66
NDF	-0.07	-0.68
ADF	-0.14	0.57
Eigenvalue	4.48	1.39
Among group variance (%)	76	24
Chi-squared Test	453.90**	153.54**

Table 2.8: Squared Mahalanobis distances between native forage species in the Overberg renosterveld vegetation during the autumn season, 2015. Distances are given below the diagonals, and above are the F-statistics (df = 8, 166), along with *** indicating significant differences at P<0.001, and NS= Not significant.

	Aspalathus angustifolia	*Pentameris eriostoma*	*Aspalathus nigra*	*Cymbopogon marginatus*	*Aspalathus spinosa*	*Themeda triandra*	*Printzia polifolia*	*Aspalathus hispida*	*Eriocephalus africanus*	*Aspalathus submissa*
A. angustifolia		98.2***	31.8***	47.2***	26.3***	63.2***	24.6***	13.7***	31.4***	15.4***
Pe.eriostoma	66.3		61.7***	21.8***	58.4***	14.3***	32.7***	31.2***	61.6***	34.1***
A. nigra	21.4	34.3		28.0***	14.9***	30.6***	10.6***	6.3***	32.6***	1.4^{NS}
C. marginatus	40.6	16.2	20.7		21.8***	4.7***	15.5***	24.3***	37.4***	16.9***
A. spinosa	20.9	39.4	10.1	18.7		27.7***	7.3***	15.4***	39.2***	11.1***
T.triandra	47.0	8.9	19.1	3.8	20.6		16.1***	22.7***	40.7***	18.6***
Pr. polifolia	44.0	54.5	17.7	28.8	13.0	27.9		14.6***	15.9***	11.5***
A. hispida	15.0	30.4	6.1	28.1	16.9	23.6	30.3		17.9***	5.7***
E. africanus	34.3	59.9	31.8	43.3	42.4	42.4	33.1	24.9		23.5***
A. submissa	20.4	41.0	1.6	23.4	23.7	23.7	26.7	9.2	38.2	

Table 2.9: Standardized coefficients of plant nutrition variables along co-variates showing their significant (P<0.05) contributions to the discriminant function for the separation of native forage species in the Overberg renosterveld vegetation during the autumn season, 2015. Eigenvalues indicate how well each canonical variate differentiates the groups. Among group variance indicates the proportion of the total variation accounted for by each canonical variate. Chi-Square test values at *** P<0.001, and ** P<0.05.

Plant parameter	Standardized coefficient (CV)					
	CV1	CV2	CV3	CV4	CV5	CV6
N	-0.33	0.29	0.56	0.68	0.37	-0.07
P	0.02	-0.58	0.10	-0.33	-0.19	-0.89
K	-0.12	0.24	-0.38	-0.15	-0.85	0.56
Ca	-0.05	-0.01	-0.49	0.54	-0.02	-0.43
Mg	-0.57	0.54	-0.18	-0.71	0.36	0.00
Na	-0.25	-0.78	0.02	-0.02	0.28	0.33
NDF	-0.18	0.20	0.73	-0.41	-0.19	-0.11
ADF	0.43	0.26	-0.78	0.18	0.48	0.00
Eigenvalue	6.84	2.07	1.62	1.33	0.65	0.12
Among group variance (%)	54	16	13	10	6	1
Chi-squared Test	979.6***	623.2***	429.1***	262.2***	116***	29.6***

According to the univariate analysis of the plant nutrient variables, there were significant interactions (P<0.05) between species and family (Table 2.10, Figure 2.6); however, there was a relative amount of variability among the forage species within their family groups. At a family level, Fabaceae continued to display superior concentrations of N and CP and moderate levels of K, Ca, Mg, Na and NDF. Alternatively, Asteraceae presented high concentrations of K, Ca, Mg and Na, moderate levels of N and CP, low concentrations of NDF. In contrast, Poaceae presented the lowest concentrations of all the mineral nutrients and CP, as well as the greatest concentrations of NDF and ADF. At a species level, all the Fabaceae species contained greater N, K and CP concentrations, where *A. submissa* and *A. angustifolia* presented superior levels, compared to the other legume species. Additionally, *A. angustifolia* and *A. spinosa* contained high concentrations of Mg. However, the rest of the mineral nutrients and NDF and ADF concentrations were moderate and variable among the native legume species, with *A. spinosa* containing high NDF and ADF levels. For the Asteraceae species, *E. africanus* recorded superior and inferior concentrations of Na and NDF respectively, while *Pr. Polifolia* contained superior Ca and ADF concentrations, and both Asteraceae species had moderate levels of CP. Whereas, all three Poaceae species showed the lowest mineral and CP concentrations. High fibre concentrations were present in all three grass species, where *Pe. eriostoma* displayed the lowest mineral and highest NDF and ADF contents compared to the other forage species.

Table 2.10: Foliar nutrient concentrations of foraged plant families and species in the Overberg renosterveld during the autumn season, 2015. Mean values with different letters indicate significant difference at *** P<0.001, and ** P<0.05. Livestock requirements calculated from McDowell (1985) and Dasci *et al*. (2010).

		N	P	K	Ca	Mg	Na
					mg g^{-1}		
	Asteraceae	8.14±0.36b	0.79±0.09c	4.61±0.21b	6.41±0.17c	2.37±0.17b	6.2±0.77c
	Fabaceae	11.81±0.27c	0.53±0.03b	4.25±0.16b	3.65±0.14b	2.32±0.12b	1.91±0.13b
	Poaceae	4.81±0.21a	0.4±0.02a	2.39±0.16a	1.69±0.1a	0.7±0.04a	0.87±0.04a
	F-statistic (df = 2, 173)	238.7***	12.68***	59.82***	107.63***	235.39**	98.09**
Asteraceae	*Eriocephalus africanus*	8.47±0.52b	1±0.07d	5.11±0.318bc	4.98±0.45cd	2.04±0.13ab	8.09±0.53f
	Printzia polifolia	7.49±0.12b	0.38±0.08ab	3.63±0.17a-c	9.26±1.33d	3.04±0.31bc	2.42±0.76de
Fabaceae	*Aspalathus angustifolia*	13.09±0.66c	0.83±0.06cd	4.98±0.36bc	2.87±018ab	3.55±0.22c	3.29±0.33e
	Aspalathus hispida	12.08±0.76bc	0.52±0.04bc	2.96±0.27a	3.46±0.57a-c	1.43±0.09a	2.37±0.27e
	Aspalathus nigra	12.04±0.37bc	0.43±0.03b	4.5±0.25bc	4.54±0.22c	1.72±0.18a	1.46±0.18cd
	Aspalathus spinosa	9.34±0.31bc	0.38±0.02ab	3.23±0.23a	2.99±0.18ab	2.79±0.17bc	1.25±0.09b-d
	Aspalathus submissa	13.49±0.53c	0.49±0.04bc	5.86±0.34c	4.25±0.34bc	1.51±0.11a	1.09±0.1a-d
Poaceae	*Cymbopogon marginatus*	4.61±0.28a	0.41±0.04ab	3.64±0.34ab	2±0.18a	1.01±0.09a	0.94±0.1a-c
	Pentameris eriostoma	4.68±0.43a	0.31±0.03a	1.4±0.12a	1.13±0.11a	0.41±0.03a	0.88±0.04ab
	Themeda triandra	5.14±0.22a	0.49±0.03b	2.69±0.24a	2.16±0.14ab	0.81±0.05a	0.82±0.08a
	F-statistic (df = 7, 173)	3.8***	13.57***	20.15**	10.46***	31.34**	19.03**
	Livestock requirements	11.2-30.4	1.6-3.7	5.0-12.0	2.1-11.3	0.4-2.5	0.6-1.0

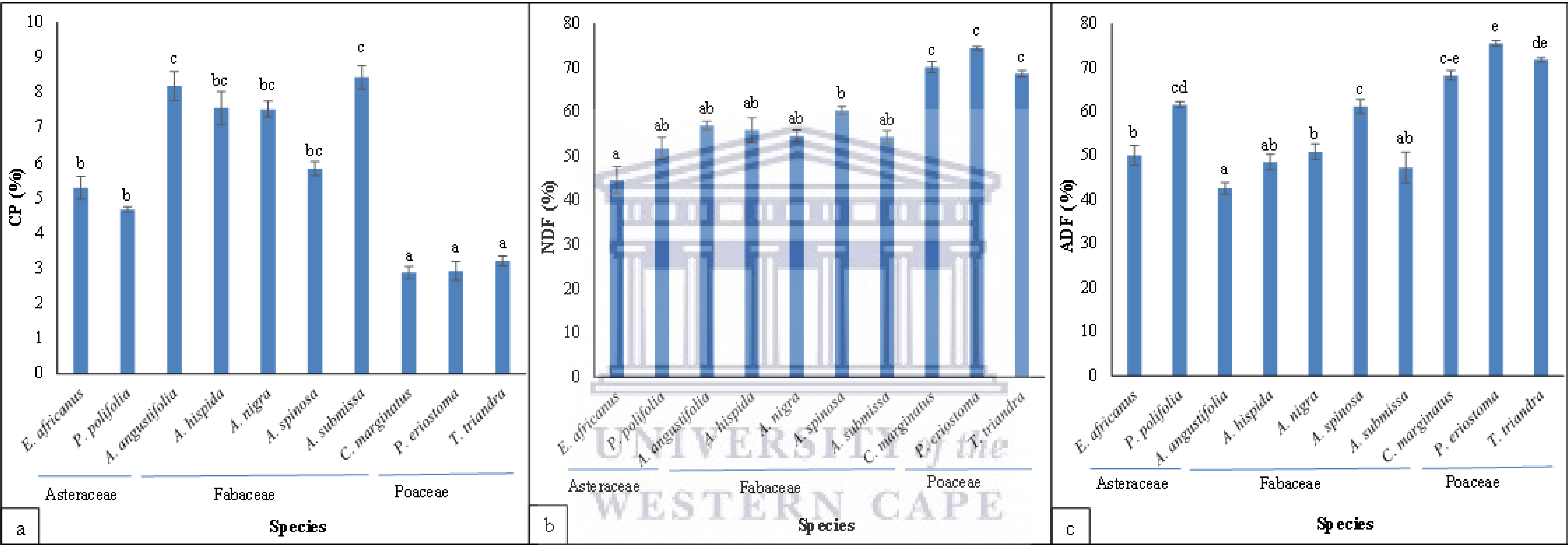

Figure 2.6: Foliar concentrations of a) crude protein (CP), b) neutral detergent fibre (NDF) and c) acid detergent fibre (ADF) contents of foraged species in the Overberg renosterveld vegetation during the autumn season, 2015. Mean values with different letters indicate significant difference. Livestock requirements for CP=7,0-19, NDF=60-65, and ADF=<37 (Stindt & Joubert, 1979; Van Soest *et al*., 1991; Dasci *et al*., 2010).

2.4.3 Seasonal variation

When comparing the nutritional variation in the forage species across the spring and autumn seasons using the univariate analyses (Table 2.11, Figure 2.7), only one Fabaceae species, *A. submissa* showed a significant increase in the N and CP concentrations during the autumn season compared to the spring season. In contrast, the Poaceae species, *C marginatus* showed a reduction in the N and CP concentrations during the autumn season. Similarly, the two grass species *C. marginatus* and *Pe. eriostoma*, along with the Asteraceae species *Pr. polifolia* showed reduced levels of P during autumn. The forage species, *A. hispida* and *A. nigra*, *Pr. polifolia* and all three Poaceae species displayed a decline in the K concentrations during the autumn season compared to the spring season. The foliar Ca concentrations also declined in the Asteraceae species, *E. africanus*, and all of the Fabaceae and Poaceae species during autumn. *Cymbopogon marginatus* was the only species that showed a significant reduction in the Mg concentration, whereas both *Pr. Polifolia* and *T. triandra* showed a decline and incline in Na during autumn, respectively. Neutral detergent fibre contents showed variability among the forage species, specifically the Fabaceae species. Where, *A. spinosa* showed an increase in the NDF concentration, whereas *A. nigra* and *A. submissa* presented a reduced concentration of NDF during autumn. Also, ADF concentrations increased in the Fabaceae species *A. nigra* and *A. spinosa* and all of the Asteraceae and Poaceae species during the autumn season.

Table 2.11: Seasonal variation of the foliar nutrient concentrations of foraged plant families and species from the Overberg renosterveld during the spring (2014) and autumn (2015) seasons. Mean values with different letters indicates significant difference at *** P<0.001, ** P<0.05, and NS= Not significant. Livestock requirements calculated from McDowell (1985) and Dasci *et al*. (2010).

			N	P	K	Ca	Mg	Na
						mg g^{-1}		
Spring			8.61±0.24a	0.63±0.02a	6.65±0.18a	7.95±0.17a	1.66±0.08a	2.28±0.22a
Autumn			8.7±0.29a	0.50±0.02b	3.56±0.13b	3.15±0.15b	1.68±0.09a	1.92±0.15a
		F-statistic	0.4^{NS}	34.50***	196.6**	362.84**	0.68^{NS}	0.16^{NS}
	Asteraceae	*E. africanus*	8.46±0.8d-f	0.87±0.09de	6.26±0.39e-i	8.87±0.66ij	2.5±0.34h-j	8.84±0.73j
		Pr. polifolia	9.01±0.48e-g	0.83±0.04de	11.49±0.46j	8.81±0.6ij	2.62±0.21ij	8.41±0.9j
	Fabaceae	*A. angustifolia*	12.16±0.59h-k	0.77±0.08de	6.45±0.46f-i	7.9±0.45h-j	2.94±0.2ij	4.07±0.53i
		A. hispida	12.41±0.57h-k	0.84±0.04de	6.51±0.46g-i	7.69±0.43h-j	1.12±0.06b-e	2.6±0.1i
Spring		*A. nigra*	10.9±0.39f-j	0.49±0.03bc	6.65±0.39g-i	8.53±0.42ij	1.87±0.18f-h	1.26±0.18d-g
		A. spinosa	9.78±0.18e-i	0.43±0.02bc	4.33±0.29c-f	8.83±0.73ij	2.96±0.21ij	2.07±0.14g-i
		A. submissa	10.98±0.44f-j	0.54±0.03b-d	7.09±0.52hi	9.62±0.48j	1.18±0.06c-e	1.01±0.07b-f
	Poaceae	*C. marginatus*	6.68±0.35cd	0.77±0.05bc	8.51±0.46ij	8.08±0.43ij	1.5±0.09d-h	0.64±0.07ab
		Pe. eriostoma	4.51±0.24a	0.51±0.05bc	4.94±0.22e-g	6.27±0.33f-i	0.51±0.02a	0.77±0.06a-c
		T. triandra	6.13±0.3bc	0.67±0.05c-e	6.24±0.31g-i	6.86±0.34g-j	1.07±0.04b-d	0.53±0.05a

Autumn	Asteraceae	*E. africanus*	8.47±0.52d-f	1±0.07e	5.11±0.18e-h	4.98±0.45e-h	2.04±0.13g-i	8.09±0.53j
		Pr. polifolia	7.49±0.12c-e	0.38±0.08ab	3.63±0.17b-e	9.26±1.33ij	3.04±0.31ij	2.42±0.76f-i
	Fabaceae	*A. angustifolia*	13.65±0.39k	0.83±0.06de	4.98±0.36d-g	2.87±0.18cd	3.55±0.22j	3.29±0.33i
		A. hispida	12.08±0.76g-k	0.52±0.04b-d	2.96±0.27bc	3.46±0.57c-e	1.43±0.09c-g	2.37±0.27hi
		A. nigra	12.04±0.37g-k	0.43±0.03b	4.5±0.25d-f	4.54±0.22e-g	1.72±0.18e-h	1.46±0.18f-h
		A. spinosa	9.34±0.31e-i	0.38±0.02ab	3.23±0.23bc	2.99±0.18cd	2.79±0.18ij	1.25±0.09e-g
		A. submissa	13.49±0.53k	0.49±0.04b-d	5.86±0.34e-i	4.25±0.34d-g	1.51±0.11d-h	1.09±0.1b-g
	Poaceae	*C. marginatus*	4.61±0.28a	0.41±0.04ab	3.64±0.34b-d	2±0.18b	1.01±0.09bc	0.94±0.1b-f
		Pe. eriostoma	4.28±0.21a	0.31±0.03a	1.4±0.12a	1.13±0.11a	0.41±0.03a	0.88±0.04b-e
		T. triandra	5.14±0.22ab	0.49±0.03bc	2.69±0.24b	2.16±0.14bc	0.81±0.05c	0.82±0.08b-d
		F statistic	9.0****	11.82***	22.4**	13.9**	33.3***	17.79***
		Livestock requirements	11.2-30.4	1.6-3.7	5.0-12.0	2.1-11.3	0.4-2.5	0.6-1.0

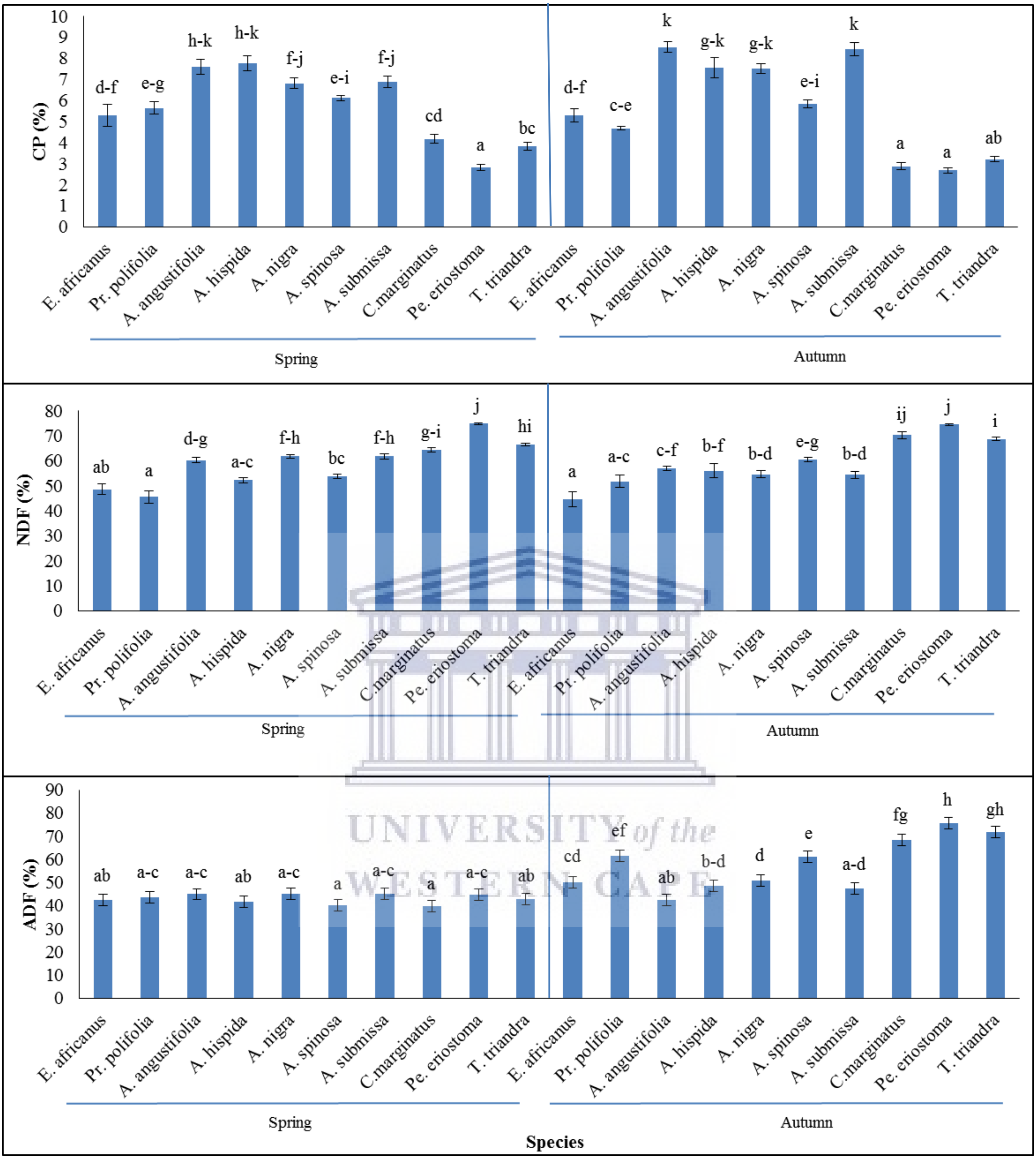

Figure 2.7: Foliar concentrations of a) crude protein (CP), b) neutral detergent fibre (NDF) and c) acid detergent fibre (ADF) contents of foraged species in the Overberg renosterveld vegetation during the spring (2014) and autumn season (2015). Mean values with different letters show significant difference. Livestock requirements for CP=7,0-19, NDF=60-65, and ADF=<37 (Stindt & Joubert, 1979; Van Soest *et al*., 1991; Dasci *et al*., 2010).

2.4.4 Livestock requirements

Despite the reduction of the foliar nutrients during the autumn season, all the Fabaceae, Asteraceae and Poaceae species still contained adequate amounts of N, Ca, Mg, Na and CP necessary to meet the minimum livestock dietary requirements during both seasons, with the exception of the N and CP contents in the Poaceae species. Additionally, the foliar P concentrations were deficient in all three forage families for both seasons of the study. Whereas, K concentrations were sufficient in spring but then reduced below the minimum dietary requirement in autumn, except for *A. submissa, A. angustifolia and E. africanus* which contained adequate K levels. During the spring season, *Pe. eriostoma* was the only species that contained NDF levels above the required amount, whereas during autumn all three Poaceae species were above the required level. Subsequently, all the sampled forage species possessed ADF concentrations that exceeded the dietary requirements during both spring and autumn.

2.5 Discussion

2.5.1 The nutritional quality of native legume and non-legume forage species

In agricultural systems in the Overberg, livestock are free to range in grazing camps, with access to natural renosterveld pastures, where livestock can efficiently select forage resources that generally possess greater nutritional qualities. The diets of free-ranging livestock generally consist of a mixture of different palatable growth forms, consisting of shrubs, grasses and herbaceous species (O'Reagain & Schwartz, 1995; Hendricks *et al*., 2002; Samuels *et al*., 2016). These forage species all contain variable nutrient concentrations which are influenced by several internal and external variables, such as species physiological differences and environmental factors, respectively. Therefore, it is essential to characterize the nutritional quality of these native rangeland species, while considering the effects that seasonal variation have on the chemical composition of the forage species. The integration of native species into livestock diets can provide some relief to farmers during the drier periods of the year, as these species are adapted to the climatic conditions of the region, and would reduce the reliance of external nutrient resources (De Waal, 1990; Lehman, 2001; Schellenberg & Banerjee, 2001; Mischkolz, 2013). Therefore, the utilisation of native forage species, especially legume and perennial species, is advantageous for livestock production, since these species can produce high-quality fodder all year round and can produce large quantities of biomass due to fast growth rates (Simbaya, 2000). However, these forage species may still experience seasonal variability in their nutritional quality.

According to the present study's results obtained from the spring and autumn seasons, there was variability in the nutritional quality between the foraged legume and non-legume families, as well as between the individual species within the same family groups. There are several reasons why variations in the quality of forage species between and within plant families can occur. For example, certain species may possess the ability to assimilate different mineral elements from the soil, using extensive and specialized root systems (Lopez-Bucio, *et al*., 2003). This adaptation might explain the findings related to the native legume species from the study, which all contained superior concentrations of N and CP, in comparison to the non-legume species. The high protein concentration is largely due to the ability of legumes to fix N in the soil, through mutualistic relationships formed with *Rhizobium* bacteria in their roots (Franche *et al*., 2009; Scholtz *et al*., 2009, Schellenberg & Banerjee, 2001). Crude protein is one of the most limiting nutritional variables, where a deficiency can influence livestock voluntary intake rates, rumen microbial activity, and overall performance and production of the livestock (Paterson *et al*., 1996; Hariadi & Santoso, 2010). Therefore, livestock must be provided with sufficient concentrations of protein to meet their dietary requirements (Liamadis, 2003). The CP values presented in the native legume species were about three times less than those in *Medicago sativa*, however the average values for *A. hispida*, *A. angustifolia*, *A. nigra* and *A. submissa* were greater than the minimum level (7%) recommended for effective microbial activity in the rumen (Dasci *et al*., 2010; Hariadi & Santoso, 2010).

The foraged Fabaceae species also contained sufficient mineral concentrations that meet the minimum dietary requirements for livestock production. However, all these forage species were deficient in P, having levels of P lower than the required amount of 1.6 – 3.7 mg g^{-1} (McDowell, 1985). South African rangelands are well known for possessing nutrient-deficient soils, with specifically low P concentrations, which could be the reason for the foliar P deficiency in the native forage species. The soil chemical composition is one of the main environmental variables that can influence forage quality, where the mineral concentrations and pH levels of the soil can affect the availability and concentration of foliar mineral elements present in the foraged species (Snyman, 2003; Ramirez-Orduna *et al*., 2004). *Aspalathus angustifolia* and *A. spinosa* contained significantly higher Mg concentrations compared to the other legume species, however, these forage species also possess spinescence, which is a structural anti-quality trait used as a defence against herbivorous behaviour. Therefore, the presence of spinescence would reduce the intake rates of the forage species and may cause injury if consumed, especially if the species is favoured for higher nutrient concentrations (Emilio *et al*., 2001). Additionally, the Asteraceae species, *E. africanus* and *Pr. polifolia*, also contained adequate mineral concentrations which met the dietary requirements of the livestock, and surprisingly even greater concentrations of P, K, Ca, Mg and Na compared to some of the legume species, which could explain why these species were favoured in the veld by the livestock. In contrast to Fabaceae and Asteraceae, the Poaceae species contained the lowest mineral concentrations and the greatest fibre concentrations (NDF and ADF) out of all the native forage species. Grass species generally have lower mineral concentrations due to the possession of shallow and less developed root systems, therefore limiting the uptake of mineral elements in the soil substrate (Stindt & Joubert, 1979). Nevertheless, the grass species, *C. marginatus* and *T. triandra* contained sufficient concentrations of Ca, while all three of the grass species contained sufficient Mg and Na concentrations for livestock production. This could explain why these grass species were still foraged by the livestock, despite the species containing low levels of certain mineral nutrients.

According to results, the grass species contained more NDF and ADF levels than that of the legumes. The higher fibre contents presented in the grass species could be due to the higher proportion of stems to leaves, in association with the complex structural components, which in turn lowers the digestibility rates of the consumed forage (Amiri & Shariff, 2012). Legume species generally possess lower digestibility rates and higher intake rates compared to other non-legume species, and this is largely due to these species containing lower fibre concentrations (Rawnsley *et al*., 2002; Pontes *et al*., 2007). Therefore, the method of combining higher quality forage species with low quality species, such as legumes and grasses, respectively, could improve the intake rates and overall diets of the livestock. Even though the legume species contained favourable nutrient characteristics, such as high CP and mineral concentrations, it contained variable amounts of fibre between the different legume species and even more than the Asteraceae species. This observation could be due to the variability of the leaf-to-stem ratio of plant material sampled. The stem proportions which are lower in quality, contain higher fibre contents and lower digestibility rates, may have outweighed the more nutritious leaf components of the forage (Buxton & Fales, 1994; Kenneth & Hans-Joachim, 2001). Nevertheless, the results motivate the notion that native legume species can be regarded as a superior forage source, due to the higher CP contents and digestibility rates coupled with moderate fibre contents (Mahmoud *et al*., 2017). Legume species are desirable to livestock farmers as these species provide higher nutrient qualities, in terms of protein content and digestibility rates in comparison to non-legume forage species (Amiri & Shariff, 2012). Overall Fabaceae species are essential when considering the improvement of rangeland quality and productivity (Ammar *et al*., 2004; Boufennara *et al*., 2012).

2.5.2 The effects of seasonal variation on the quality of native legume and non-legume forage species

The nutritional status of a forage species can be influenced by many environmental variables, such as temperature and precipitation, which may vary between and within different seasons of the year. Seasonal changes in temperature and rainfall may significantly influence the phenology and physiology of a plant, like the flowering time and tissue maturation (De Waal, 1990; Lascano *et al*., 2000; Newman *et al*., 2009; Lee, 2017). Consequently, climatic variables may influence the nutrient availability of a forage species in response to different seasons throughout the year.

Minerals

Mineral elements are essential components in livestock diets as certain dietary requirements need to be met for daily life processes and bodily functions. However, variability in the foliar mineral composition of a forage species may occur between and within plant families in response to seasonal climatic events (Rauzi, 1982). According to the seasonal variation results, the legume species, *A. submissa* showed an increase in the N content during the autumn season. This trend corresponds with surveys conducted on *M. sativ*a, which presented an increased plant N content in the legume crop as a result of warming temperatures (Walgenbach *et al*., 1981). The elevated levels of N during warmer seasons (i.e. summer and autumn) could be due to mineralization processes occurring in warmer soils, thus increasing the availability and uptake of N for the forage species (De Neve *et al*., 2003; Dumont *et al*., 2015)., which corresponds with climate data obtained from the Agricultural Research Council (ARC)'s Protem weather station in the Overberg during 2014 and 2015 (Figure 2.2). Also, drought conditions may increase the availability and concentration of foliar N in response to and lowered water availability from precipitation or irrigation. However, there is conflicting literature that presents both increases (Hayes, 1985) and decreases (Murphy *et al*., 2002) in foliar N as a result of reduced water availability. The increase in the nutritional quality of certain legume species such as *M. sativa* and sainfoin has been recorded under drought conditions, possibly be due to drought tolerance mechanisms in addition to the ratio of leaf and stem fractions (Peterson *et al*., 1992; Dumont *et al*., 2015). Certain perennial forage species have developed drought tolerance traits to alleviate the effects of drought, which includes summer dormancy and dehydration tolerance (Farooq *et al*., 2009; Norton & Volaire, 2012). There also was a decline in P in the forage species, *Pr. polifolia*, *C. marginatus* and *Pe. eriostoma* during autumn. This reduction of foliar P levels during the autumn season could be as a result of the lack of water available in the P-deficient soils. Precipitation and soil moisture are known to assist with the uptake of certain mineral elements which in this scenario could have influenced the uptake of P by the forage (Dunham & Nye, 1976; Henderson *et al*., 1966; Ziblim *et al*., 2012). Depressed K levels were observed in the legume species, *A. hispida* and *A. nigra*, all three of the Poaceae species, as well as *Pr. polifolia* during the autumn season. Potassium plays an essential role in a plant's response under drought stress conditions, such as osmotic and stomatal adjustment, water retention and enzyme activation to reduce water loss (Kamanga *et al*., 2018). Thus drought conditions would create an internal requirement and accumulation of K ions in the foliar tissues (Cakmak & Engels, 1999), which contradicts with the reduced K levels during the autumn season of the current study. The reduced concentration of foliar K could be a result of the reduced availability of plant biomass of the forage species as well as reduced soil moisture contents during the drier periods of the year, i.e. summer and autumn (Misra, 2003). There was also a significant decline in the foliar Ca concentrations during autumn in *E. africanus* and all of the Fabaceae and Poaceae species. The reduction of foliar Ca concentrations could be as a result of a water deficit or the occurrence and higher concentrations of opposing minerals present in the soil, such N and Mg, as well as the insolubility of soil Ca ions (Simon, 1978). However, the Asteraceae species, *Pr. polifolia* maintained a high Ca concentration during the autumn and therefore could be regarded as a beneficial food source or supplement for seasonal grazing periods when forage quality declines due to drought conditions. Furthermore, the reduced Mg levels found in *C. marginatus* during autumn could be a result of competing cations such as Ca, Na, H and NH_4^+, thus preventing the uptake of Mg (Warrence *et al*., 2003; Ren-Jie & Sheng, 2017). Whereas, *Pr. polifolia* contained lowered Na concentrations during the autumn season, which could also be as a result of reduced water availability for the transportation of the Na ions to the forage species (Dunham & Nye, 1976; Ziblim *et al*., 2012).

Protein

In this study, when comparing the nutritional quality of the native forage species across a temporal scale, there wasn't much variation in the N and CP contents of the foraged Asteraceae Fabaceae and Poaceae species across the two seasons. However, there was a significant increase and decrease in CP content in *A. submissa and C. marginatus* respectively, during the autumn season. The incline of CP in *A. submissa* is a beneficial finding, especially to farmers, as this would provide a source of protein to livestock when the availability of forage resources is constrained due to drought conditions. However, the legume species' biomass and density in the rangeland needs to be considered when implementing this forage species into livestock diets. The variation in the nutritional quality of forage species across separate seasons is not uncommon in arid and semi-arid regions. For example, studies performed on the rangelands in Sudan recorded seasonal changes in the nutritive value of forage species, where there was a reduction of CP, moisture content and total soluble sugars during the dry period (Fatur & Khadiga, 2007). In contrast, plant nutritive values may also not vary dramatically between different seasons either, where this absence of a seasonal nutritive trend was observed in research conducted on the natural pastures of the Gordonia district in the Northern Cape, South Africa (Faure *et al*., 1983).

Fibre

Concerning the fibre fractions during the autumn season, the Fabaceae species, *A. spinosa* showed an increase in the NDF concentrations, as opposed to *A. nigra* and *A. submissa*, which showed decreased NDF levels. However, ADF levels were significantly higher in *A. nigra* and *A. spinosa* and all three Asteraceae species. Additionally, ADF levels were exceptionally greater in all three Poaceae species, with about 30% more fibre in autumn than during the spring season. Many environmental factors exacerbate the maturing of plant tissues thus increasing the fibre content of the forage species, for example, heat and water stress during drier seasons may increase stem concentrations and decrease leaf concentrations (Buxton & Fales, 1994; Halim *et al*., 1989). From field observations made during the autumn season, there was an obvious reduction of younger, green biomass available to livestock and an increase of matured lignified plant tissues, in comparison to the spring season. The high occurrence of matured plant tissues and loss of leaf cover as a response to increased daily temperatures could account for the amplified fibre concentrations during the autumn season. As a plant matures past the stage where protein and digestibility are highest, more fibrous components are deposited in the plant's tissues (Butterworth & Diaz, 1970; Van Soest, 1982

Mueller & Orloff, 1994). Therefore, with maturity, fibrous structures increases and the digestibility and CP content decreases (Mueller & Orloff, 1994). This effect is more prevalent in warm-season perennial grasses (Harrington & Wilson, 1980), where the leaf-to-stem ratio increases in the indigestible cell wall fraction, typically when plant tissues are older than 35-45 days (Lascano *et al*., 2000; Ziblim *et al*., 2012). This could explain the evident seasonal trend of the increased ADF contents observed in the native grass species. One of the major factors that influences forage quality and intake rates of livestock is the fibre content of the forage resources. The fibre fraction is made up of complex cellular structures, namely cellulose, hemicellulose, lignin and carbohydrates, which are not easily broken down in the digestive system (De Waal, 1990). So, when forage contains high quantities of fibre, along with low protein contents, this may hinder the digestive processes of the livestock (Schroeder, 2004). During seasons with high temperatures, forage tends to decrease in nutritional quality by increasing the rate of maturity and senescence, where the structural components of forage species become more fibrous (Buxton & Fales, 1994). Therefore, the forage becomes relatively resistance to microbial fermentation in the rumen of the livestock, thus lowering the forage digestibility (De Waal, 1990; Simbaya, 2000). When forage contains high fibre contents and low digestibility rates, less energy is available to the livestock for metabolic processes, as more energy is needed for digestion of these fibrous structures (Sprinkle, 2001; Chiba, 2014). Therefore, monitoring and analysing the effects of seasonal changes on native forage species in the Overberg renosterveld rangelands is vital when assessing the availability and nutritional quality of forage species for livestock grazing.

2.6 Conclusion

Based on the crude protein, fibre and mineral contents, the Fabaceae species *A. hispida*, *A. angustifolia*, *A. nigra* and *A. submissa*, and the Asteraceae species could be regarded as superior forage species in the Overberg renosterveld rangelands. These species possessed acceptable concentrations of the assessed chemical parameters, where the legume species recorded the greatest concentrations of CP that were above the minimum requirement for optimum livestock production, along with moderate mineral and fibre contents, for higher digestibility rates. The native Poaceae species contained inferior nutritional qualities, compared to the other foraged species due to high concentrations of fibre, thus lower digestibility rates, along with low mineral and protein concentrations, specifically during the autumn season. Although the nutrient contents of the native Fabaceae and Asteraceae forage species met the minimum livestock dietary requirements, there was relative variability between the autumn and spring seasons as a result of the corresponding environmental and physiological variables. These temporal conditions could affect the intake rates of the forage due to anti-quality variables, such as high fibre and low digestibility, spinescence and secondary metabolite concentrations, which could influence the palatability of the forage. Therefore, recommendations for further research on the species phenology, adaptive and tolerance mechanisms, population density, herbage biomass and seed production, *in vivo* digestibility and specific livestock requirements, needs to be assessed when considering these native species as forage resources for livestock grazing in the Overberg renosterveld rangelands.

CHAPTER THREE: THE EFFECTS OF SOIL AND SLOPE ASPECT ON THE CHEMICAL AND FIBRE COMPOSITION OF THE NATIVE FORAGE SPECIES IN THE OVERBERG RENOSTERVELD

3.1 Introduction

The Cape Floristic Region (CFR) is a temperate biome in South Africa, which has a mosaic distribution of diverse vegetation and soil types. South African soils are derived from deeply weathered granite, limestone, sandstone and shale parent rock (Cowling *et al*., 1986; Mucina & Rutherford, 2006). The CFR is largely dominated by soils derived from the Table Mountain Sandstone Group which are much older, infertile and acidic, in comparison to other soil origins, like granite, limestone and shale, which are finer in texture and more nutrient rich (Mucina & Rutherford, 2006). In the Overberg, the renosterveld rangelands can be divided into three main vegetation types, namely the Western-, Central- and Eastern- Rûens Shale Renosterveld (WRSR, CRSR and ERSR). The soils in the Overberg region are made up of clays and loams that are derived from Bokkeveld Group shales, with dominant Glenrosa and Mispah forms (Rebelo *et al*., 2006). Renosterveld soils are generally shale-derived and possess higher levels of clay properties, which are characteristically known to be more fertile than adjacent fynbos soils (Midoko-Iponga, 2004; Mucina & Rutherford, 2006). The clay properties of the soil, can have a significant effect on the availability of nutrients, where the retention of nutrients are generally greater in soils composed of clay due to lower leaching rates in comparison to sandier soils (Sanchez *et al*., 1997; Aboudi Mana *et al*., 2017; Kome *et al*., 2019). Historically, settlers generally selected locations that possessed conditions which favoured an agrarian lifestyle, like fertile soils, adequate rainfall and moderate temperatures (Sanchez & Buol, 1975). The Overberg renosterveld is a perfect example of these suitable localities, with its nutrient rich soils and moderate rainfall, which has been recognized as a suitable environment for commercial agriculture production. These regional conditions made it possible to produce food crops such as canola, wheat and barley, as well as livestock farming on a large scale (Kemper *et al*., 1999; Krug, 2004). In commercial agriculture, the crop yield is highly dependent on soil fertility for optimal plant growth. Nutrient depleted soils would otherwise compromise food security, by reducing crop and livestock production, which in turn would increase food costs (Smaling, 1993; Mokwunye *et al*., 1996). Unfortunately, as result of agricultural practice, arable lands have gradually become depleted of nutrients due to crop harvest removals, mineral leaching and soil erosion, giving rise to the reliance of mineral supplementation such as fertilizers, manures and crop residues (Sanchez *et al*., 1997).

In the Overberg district, large-scale commercial crop and livestock farming is currently being practiced. The remnants of renosterveld vegetation patches which are interspersed in between the transformed farmlands are utilised as forage pastures for livestock grazing. These natural pastures are regularly used by farmers to support their livestock's diets during various seasons throughout the year. Livestock farming is highly dependent on the quality of the forage that is consumed, which is directly affected by the soil characteristics in which the forage species are established in (Mirzaei, 2012; Jones & Olson-Rutz, 2016). For instance, the mineral content of a forage species is generally dependant on the soil mineral content, in combination with climatic events (Amiri & Shariff, 2012). Weather conditions can influence the soil nutrient availability, where recurring rainfall patterns can leach the soil of mobile mineral elements. The soil moisture content is generally dependent on rainfall patterns and plays an essential role in the absorption of soil minerals by plant's roots (Parks *et al*., 2000; Barbosa *et al*., 2014). For example, certain soluble minerals, such as potassium (K), may be readily leached from the soil especially during seasons with higher rainfall, thus lowering the amount of K available to the forage (Olff *et al*., 2002; Mirzaei, 2012). Therefore, the soil quality of semi-arid regions like the Overberg rangelands are especially prone to the variable effects of rainfall patterns on the storage and uptake of soil nutrients, where plant growth may be limited or promoted due to seasonal variability (Parks *et al*., 2000; Kambatuku, *et al*., 2011). Seasonal changes, like elevated temperatures and evaporation rates may also influence the soil mineral concentrations, by increasing the soil water deficit and in turn increasing the availability of certain soil mineral concentrations (Kramer, 1983). Certain natural processes like fire regimes, which are prominent features in renosterveld and fynbos vegetation types, may elevate the concentrations of certain mineral elements post-fire, such as C, N and P (Cowling *et al*., 1997). These nutrient niches are established as the plant foliar nutrients are cycled back into the soils, thereby contributing to the spatial and temporal variations in the soil chemistry across a rangeland (Chimphango *et al*., 2015). The productivity of agricultural systems is often limited by soil infertility, which is one of the main biophysical constraints limiting crop and forage quality, and thus declining the per capita food production rates (Yates & Kiss, 1992; Smaling, 1993; Mokwunye *et al*. 1996). Hence, it is crucial to characterize the soil composition, in order to further understand the effects of the soil chemistry on the quality of native forage species in the Overberg renosterveld.

Soil properties may be affected by topographical features, such as the slope aspect and gradient, in association with the parent material, vegetation and climate in the region (Chen *et al*., 1997). Variations in topography, climate and edaphic variables, collectively determines the soil moisture availability and mineral concentrations which are significant components used in managing agricultural crop and livestock production (Al-Ahmadi, 2014). Research on the relationship between forage quality and slope aspect is quite limited in agricultural systems, especially in renosterveld environments. In the Overberg, the renosterveld vegetation occurs on moderately undulating landscapes, referred to as the "Rûens" (Mucina & Rutherford, 2006), which possess variable slopes with dominant directions facing the south (S), south-east (SE), south-west (SW), north (N), north-east(NE) and north-west (NW). There is a consensus that in the Southern Hemisphere, the north facing slopes are usually associated with drier and hotter conditions, in comparison to the wetter conditions on south facing slopes (Cowling, 1983; Newton, 2008). These topographical features provide the opportunity to assess the effects that slope aspect has on the soil and forage chemical composition. A clearer understanding of the relationship between soil and slope aspect with the chemical composition of forage species will assist in the selection of high quality forage and the incorporation of these native forage species into grazing management systems and livestock production in the Overberg renosterveld rangelands.

3.2 Study objectives

The aims of this study are to determine the effects that the soil chemical composition and slope aspect have on the nutritional quality of the native forage species in the Overberg renosterveld rangelands for livestock grazing. Therefore, the research questions for this study are:

(1) How does the soil chemical composition (Total N, Total P, Bray II P, K, Ca, Mg, and Na) affect the chemical and fibre composition of the native forage species across and within the three geographical areas in the Overberg renosterveld rangelands during the spring season?

(2) How does the slope aspect (S, SE, SW, N, NE and NW facing) affect the chemical composition of soil substrate and the native forage species across and within the three geographical areas in the Overberg renosterveld rangelands during the spring season?

3.3 Materials and methods

3.3.1 Study area and sample collection

This study was conducted in the Overberg, Western Cape, South Africa, which stretches from Grabouw to Heidelberg. The geology is composed of clays and loam derivatives from the Bokkeveld Group shales and the dominant soils are Glenrosa and Mispah forms (Mucina & Rutherford, 2006) The region's climate has a mean annual precipitation range between 360-700 mm, peaking during the winter months (May-August) (Rebelo *et al*., 2006). The mean daily temperatures are 26.9 °C and 6.1 °C for February and July, respectively (Rebelo *et al*., 2006). The study area is situated in a semi-arid region with undulating landscapes that possesses variable slope aspects, facing the south (S), southeast (SE), southwest (SW), north (N), northeast (NE) and northwest (NW). Plant samples were collected during the spring season (September-November 2014), when most of the forage species were in their vegetative and flowering growth stages. Prior to sampling, the selected forage species were identified by interviewing farmers and in situ observations. Most of the foraged species were selected based on their palatability and abundance in the field. Edible plant material from six replicates of the same species occurring on opposite aspects from five sites was collected using pruning shears for the forage quality analysis (Chapter 2). Additionally, four replicate soil samples were collected, using an auger and a garden trowel, along a diagonal gradient on two separate slope aspects on each farm, at a depth of 10 cm.

3.3.2 Chemical analyses

In preparation for the chemical analysis, the collected plant samples were oven-dried at 70 ºC for 48-56 hours and milled through a 0.5 mm sieve using a Wiley Mill for the chemical analyses conducted by BemLab private laboratory (Somerset West, South Africa). In addition, the soil samples were air-dried for 3 days before it was passed through a 2 mm sieve for chemical analyses also performed by BemLab. The plant and soil samples were subjected to an organic matter decomposition process for the elemental determination using wet ashing or acid digestion. A sulphuric-peroxide digestion mixture was added to 0.4 g of dried sample and placed into a heating block digester (Moore & Chapman, 1986; Kalra, 1998). The aqueous mixture was filtered through Whatman No. 1 filter paper into 100 mL volumetric flasks and diluted to volume. An atomic absorption spectrophotometer (Unicam Unlimited, Cambridge, UK) was used for the determination of the macro mineral elements: K, Ca, Mg, and Na using certified standards for the elements (Merck Millipore (Pty) Ltd.). The total P was determined by nitric-hydrochloric acid digestion and the extract was analysed by ICP-OES and available P was analysed by extracting 2 g of soil in Bray II solution (Bray & Kurtz, 1945). The total N concentrations in the samples were determined using direct titration with 0.01 N HCl, with a Buchi Nitrogen Distillation Unit (model K-300, Labotec, Buchi Switzerland). The crude protein concentrations in the samples were determined by the product of the N concentration and 6.25 (White, 1983). Whereas, the neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined using an ANKOM A220 Fibre Analyzer, following ANKOM Technology methods 13 and 12 respectively.

3.3.3 Statistical analyses

The chemical variables were natural log transformed to meet the parametric analyses requirements, where necessary, and were conducted in Statistica 8 (StatSoft, Inc.). The variables were subjected to multivariate analysis using canonical discriminant analysis (CDA) to assess the geographical areas, farm sites and slope aspect differences based on the chemical composition of the soil and plants sampled. The CDA generates canonical variates (CV) where the statistical algorithm derives an optimal separation between the area and slope aspects that are established *a prior* by maximising between group variance (Raamsdonk *et al*., 2001). The CV's are used to determine the original variables that contributed the most to the separation of the areas and the slope aspects. Additionally, the CDA generated the Squared Mahalanobis distances between the objects to determine whether there were any statistically significant separations. A two-way mixed model nested ANOVA was used to determine the effect of the geographical area and slope aspect on the univariate variables of the plant's and soil's chemical composition, where the random factors, species or soil from each slope aspect, were nested into a fixed factor, the site. The means were separated by Tukey's honest significant difference tests at the 5% probability level.

3.4 Results

3.4.1 Comparison of the soil chemical composition across the three geographical areas

According to the scatterplot from the CDA of the soil chemical composition data (Fig. 3.1), there was a clear separation of the three geographical areas, where the ERSR was more distinguished from the other two areas. The Squared Mahalanobis distances between the geographical areas confirmed that there were significant differences ($P<0.05$ or $P<0.001$) between the areas based on the soil chemical characteristics (Table 3.1). The standardised coefficients showed that all the soil chemical variables contributed to the separation between the geographical areas (Table 3.2), based on the canonical variate scores of CV1 and CV2. Furthermore, the univariate comparison of the soil chemical variables of the sites across the three geographical areas showed that there were significant interactions between the different sites and geographical areas in the Overberg renosterveld (Table 3.3). For instance, regarding the total N concentrations, the Voorstekop and Plaaitjieskraal sites in the ERSR were highest in comparison to the other sites, whereas total P was highest in the De Vlei and Plaaitjieskraal sites. Similarly, Plaaitjieskraal contained the highest K concentrations. Superior Ca concentrations were present in the De Vlei and Witkop sites in the WRSR, whilst Mg concentrations were highest in De Vlei and for Na, the highest concentrations were reflected in the Kykoedie site, which is situated in the CRSR.

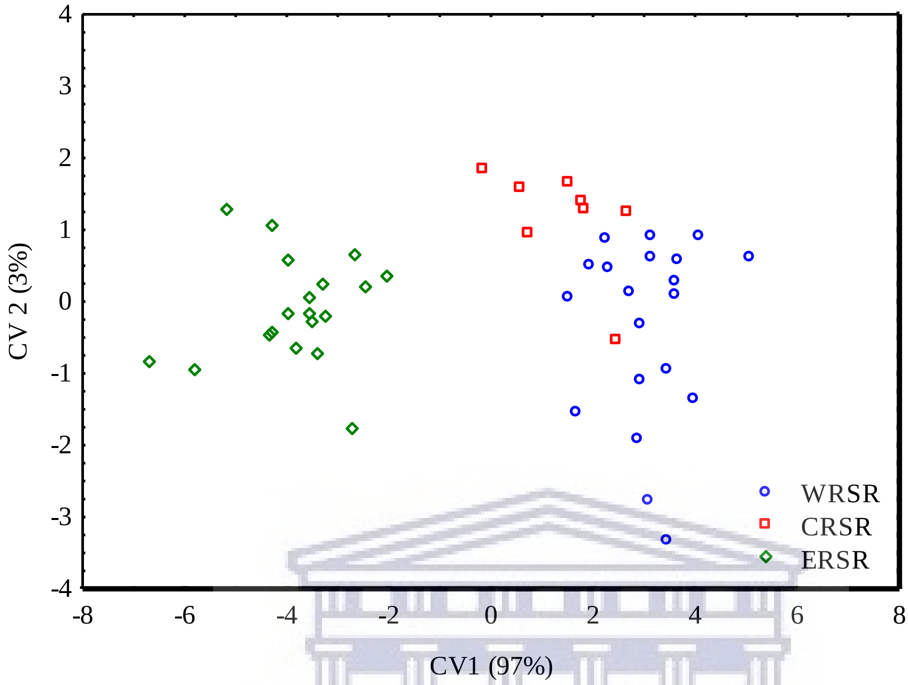

Figure 3.1: Scatterplot of canonicals scores separating soils from three geographical areas from the Overberg renosterveld vegetation, 2014, based on the mineral concentration, including Total N, Total P, Bray II P, K, Ca, Mg, Na. WRSR, CRSR and ERSR = Western-, Central- and Eastern- Rûens Shale Renosterveld, respectively.

Table 3.1: Squared Mahalanobis distances between soils in three geographical areas (WRSR, CRSR, ERSR) in the Overberg renosterveld vegetation, 2014. Distances are given below the diagonals, and above are the F-statistics, along with *** indicating significant differences at P<0.001, and ** at P<0.05.

	WRSR	CRSR	ERSR
WRSR		3.6**	57.4***
CRSR	5.1		20..3***
ERSR	47.7	29.2	

Table 3.2: Standardized coefficients of soil nutrient variables along co-variates with significant contribution ($P<0.05$) to the discriminant function for the separation of the three geographical areas (WRSR, CRSR, ERSR) in the Overberg renosterveld vegetation, 2014. Eigenvalues indicate how well each canonical variate differentiates the groups. Among group variance indicates the proportion of the total variation accounted for by each canonical variate. Chi-Squared test values at *** $P<0.001$.

Soil	Standardized coefficient (CV)	
parameter	CV1	CV2
Total N	-0.79	-0.12
Total P	-0.04	1.32
Bray II P	-0.35	-0.71
K	0.38	0.30
Ca	0.89	0.19
Mg	-0.23	-1.41
Na	-0.69	0.18
Eigenvalue	10.91	0.32
Among group variance (%)	97	3
Chi-squared Test	113.23***	11.36

Table 3.3: Soil nutrient concentrations from different sites from three geographical areas in the Overberg renosterveld vegetation where forage species were collected. Mean values with different letters indicates significant difference at *** P<0.001, ** P<0.05, NS= Not significant, - = not determined, and WRSR, CRSR and ERSR = Western-, Central- and Eastern- Rûens Shale Renosterveld respectively**.**

Area	Farm	Total N	Total P	Bray II P	Ca	Mg	Na	K
					mg Kg^{-1}			mg g^{-1}
WRSR		1508±82a	239±23a	8±1a	7229±582b	585±117b	843±31a	14.16±0.73a
CRSR		1863±60b	272±7a	7±1a	6821±854b	386±44a	1172±51b	17.89±0.6b
ERSR		2655±143c	315±19b	17±2b	2627±299a	474±44ab	1167±36b	14.51±1.1a
	F-statistic (df = 2,64)	5.2***	11.5***	13.6***	39.9***	6.6**	27.5***	26.2***
WRSR	De Vlei	1649±133ab	340±22cd	9±2	9350±462c	1324±120c	817±64a	18±0c
	Witkop	1153±118a	139±15a	8±3	8195±567c	115±13a	845±63ab	11±1a
	Klipfontein	1722±88ab	236±8bc	6±0	4353±919ab	314±24ab	867±34ab	14±0b
CRSR	Onderschietpad	1722±82ab	284±8b-d	9±1	6821±854bc	318±95ab	951±80a-c	15±1b
	Bietorivier	1853±68b	242±12bc	4±0	-	297±55ab	1193±75cd	20±1cd
	Kykoedie	2014±136b	291±8b-d	8±0	-	542±43b	1372±32d	19±1cd
ERSR	Voorstekop	2904±244c	281±27b-d	14±4	2922±484a	396±54ab	1171±79cd	11±1a
	Lofdal	2203±126b	329±26b-d	18±4	2876±489a	458±46b	1169±29cd	15±0b
	Plaaitjieskraal	3064±254c	361±50d	20±4	1541±373a	664±144b	1158±88b-d	22±0d
	F-statistic (df = 6,59)	5.2**	11.2***	0.8^{NS}	8.9***	32.1***	4.1**	35.3***

3.4.2 Comparison of the soil chemical composition across the different slope aspects

Using the soil chemical data scatterplot from the CDA (Figure 3.2) and the Squared Mahalanobis distances between the different slope aspects (Table 3.4), there was a significant separation ($P<0.05$ or $P>0.001$) at all the sites, with the exception of the north and south facing slopes at the Klipfontein site. The standardised coefficients showed that all the soil chemical variables contributed to the separation of the slope aspects, based on the CV scores, presented in Table 3.5. The univariate comparison of the soil chemical variables from the different slope aspects also varied with site and soil chemical nutrients (Table 3.6). For instance, at the sites De Vlei and Witkop, the SW facing slopes contained significantly greater concentrations of total N and total P compared to the NE and NW facing slopes, respectively. Elevated total N concentrations were also present on the south facing slope at Kykoedie compared to the north facing slope. Additionally, De Vlei's SW facing slope contained higher concentrations of Bray II P and Mg than the NE facing slope. Similarly; the Ca concentration was greater on the south facing slope at Klipfontein than the north facing slope. In contrast, the north facing slope recorded greater concentrations of total P and Na at Bietorivier, relative to the SE facing slope. Furthermore, the NE facing slope at De Vlei contained higher Na concentrations compared to the SW facing slope.

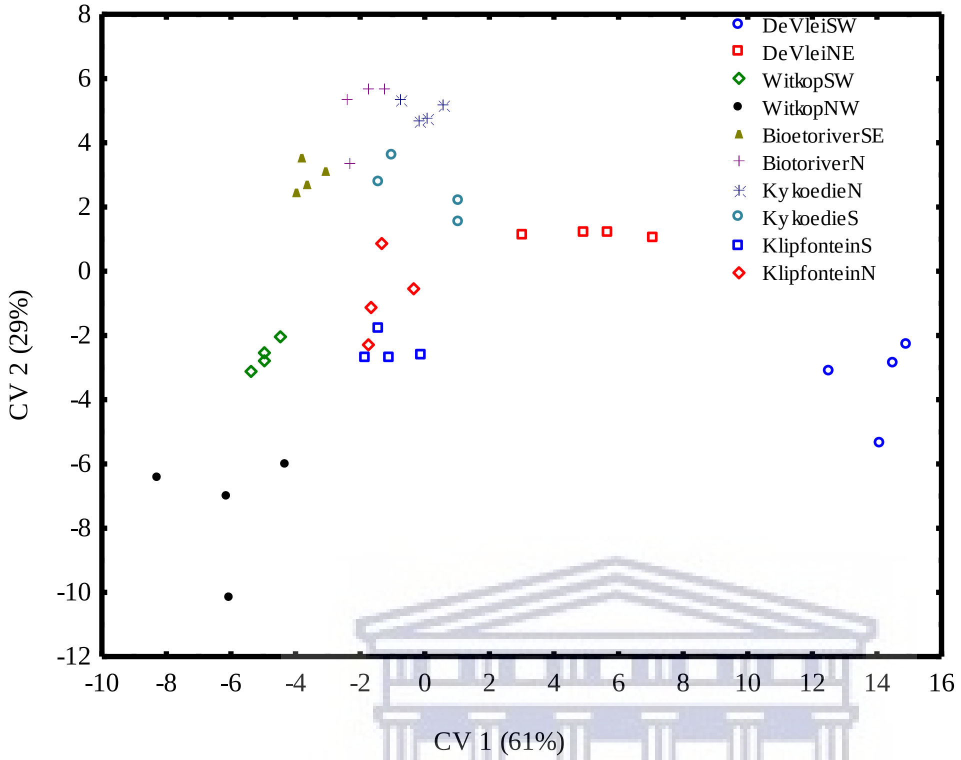

Figure 3.2: Scatterplot of canonicals scores separating soils from different slope aspects at each site in the Overberg renosterveld vegetation, based on the mineral concentration, including Total N, Total P, Bray II P, K, Ca, Mg, Na. SW = southwest facing slope, NE= northeast, NW = northwest, SE = southeast, S = south, N = north.

Table 3.4: Squared Mahalanobis distances from canonical discriminant analysis of soil chemical composition between different slope aspects at each site in the Overberg renosterveld vegetation, in 2014. Distances are given below the diagonals, and above are the F-statistic, along with *** indicating significant differences at P<0.001 and ** P<0.05.

	De Vlei SW	De Vlei NE	Witkop SW	Witkop NW	Bietoriver SE	Bietoriver N	Kykoedie S	Kykoedie N	Klipfontein S	Klipfontein N
De Vlei SW	-	35.2***	100.4***	120.0***	100.4***	91.9***	75.0***	66.9***	64.9***	67.7***
De Vlei NE	126.5	-	38.4***	59.3***	27.3***	22.1***	22.6***	15.5***	22.7***	22.9***
Witkop SW	361.3	138.4	-	8.9***	13.1***	19.1***	24.0***	15.5***	4.6**	5.4***
Witkop NW	432.1	213.5	32.2	-	33.9***	49.5***	56.1***	39.8***	17.8***	23.6***
Bietoriver SE	361.5	98.3	47.1	122.0	-	5.9***	8.8***	10.4***	14.3***	10.2***
Bietoriver N	331.0	79.5	68.6	178.1	21.1	-	4.0**	4.4**	16.9***	11.6***
Kykoedie S	269.9	81.3	86.5	202.1	31.8	14.3	-	4.1**	17.8***	11.0***
Kykoedie N	240.9	55.9	56.0	143.4	37.4	15.7	14.9	-	10.3***	7.4***
Klipfontein S	233.7	81.6	16.5	64.0	51.4	60.7	64.0	37.2	-	1.3^{NS}
Klipfontein N	243.7	82.5	19.5	85.0	36.8	41.9	39.4	26.8	4.8	-

Table 3.5: Standardized coefficients of soil nutrient variables along covariates with significant (P<0.05) contribution to the discriminant function for the separation of slope aspects at each site in the Overberg renosterveld vegetation. Eigenvalues indicates how well each canonical variate differentiates the groups. Among group variance indicates the proportion of the total variation accounted for by each canonical variate. Chi-Square test values at *** P<0.001 and ** P<0.05.

Soil parameter	Standardized coefficient (CV)				
	CV1	CV2	CV3	CV4	CV5
N	0.04	0.28	0.93	0.47	-0.30
Total P	0.62	0.57	0.24	-0.40	-0.66
Bray II P	0.14	-0.90	0.30	-0.10	0.91
K	0.03	0.49	-0.85	0.49	0.55
Mg	0.97	-0.17	-0.27	0.06	0.09
Na	-0.57	0.77	0.15	-0.61	0.21
Eigenvalue	40.78	19.51	4.08	1.67	1.16
Among group variance (%)	60.6	28.9	6.1	2.5	1.7
Chi-Square Test	318***	202***	109***	58***	28**

Table 3.6: Soil nutrient concentrations from different slope aspects at each site in the Overberg renosterveld vegetation, where forage species were collected, 2014. In each column, different letters show significant difference at ***P<0.001, ** P<0.05, - = not determined, SW = south-west facing slope, NE= north-east, NW = north-west, SE = south-east, S = south, N = north.

Site/Slope	Total N	Total P	Bray II P	Mg	Ca	Na	K
				mg kg^{-1}			($mg\ g^{-1}$)
De Vlei	1648.7b	339.8d	8.6c	1324.0d	9350.2b	817.4a	18.0c
Witkop	1152.7a	139.3a	4.8a	115.2a	8195.2b	844.6a	10.6a
Klipfontein	1721.7b	236.0b	6.0ab	314.5b	4352.7a	866.9a	13.9b
Bietorivier	1853.0bc	242.0b	4.3a	297.5ab	-	1192.5b	19.6c
Kykoedie	2013.5c	291.2c	7.8bc	542.5c	-	1372.1c	19.4c
F-Statistic (4,30)	24.1***	90.4***	18.2***	100.8***	40.9***	35.6***	54.6***
De Vlei SW	1984.3de	391.5f	12.4c	1564.7e	9417.5c	667.9a	17.9cd
De Vlei NE	1313.2ab	288.1de	4.7a	1083.3d	9282.9bc	966.9bc	18.2d
Witkop SW	1400.7bc	173.8b	4.6a	134.1a	9228.4bc	950.9a-c	11.7ab
Witkop NW	904.6a	104.8a	4.9ab	96.3a	7162.0bc	738.2ab	94.3a
Klipfontein S	1575.8b-d	236.0cd	6.0ab	286.6a-c	6712.4b	799.7a-c	13.2b
Klipfontein N	1867.6d	236.0cd	6.0ab	342.4a-c	1993.1a	934.1a-c	14.5bc
Bietorivier SE	1926.0de	214.3bc	4.2a	188.6ab	-	1048.4c	20.5d
Bietorivier N	1780.1cd	269.8de	4.4a	406.3a-c	-	1336.6d	18.6d
Kykoedie S	2334.5e	296.7e	7.9b	506.7bc	-	1374.6d	21.3d
Kykoedie N	1692.5b-d	285.7de	7.8b	578.3c	-	1369.6d	17.6cd
F-Statistic (5,30)	13.9***	15.2***	15.3***	6.46***	13.2***	6.7***	4.1**

3.4.3 Comparison of the forage chemical composition across the different slope aspects

Based on the CDA scatterplot of the plant chemical and fibre concentrations of the selected forage species (Figure 3.3), there was a separation of the different slope aspects at the various sites with the exception of *C. marginatus* which could not be separated between the NW and SW slopes. The Squared Mahalanobis distances between the slope aspects combined with the plant chemical data confirmed that there were significant differences ($P<0.05$ or $P>0.001$) for all the forage species, except for *C. marginatus* (Table 3.7). The standardised coefficients showed that all the plant chemical variables except Ca contributed to the separation between the slope aspects based on the canonical variate scores that were significant (Table 3.8). According to the univariate comparison of the chemical and fibre concentrations in the plant species, there were obvious differences between the three pairs of slope aspects, each for different species and nutrients (Table 3.9). At the Kykoedie site, significantly greater concentrations of foliar P in *P. eriostoma* were present on the south facing slope relative to the north facing slope. Similarly, at the Bietorivier site, greater K concentrations in *A. submissa* were present on the SE facing slope compared to the north facing slope, whilst in De Vlei, Mg concentrations in *E. africanus* were greater on the SW facing slope relative to those on the NE facing slope.

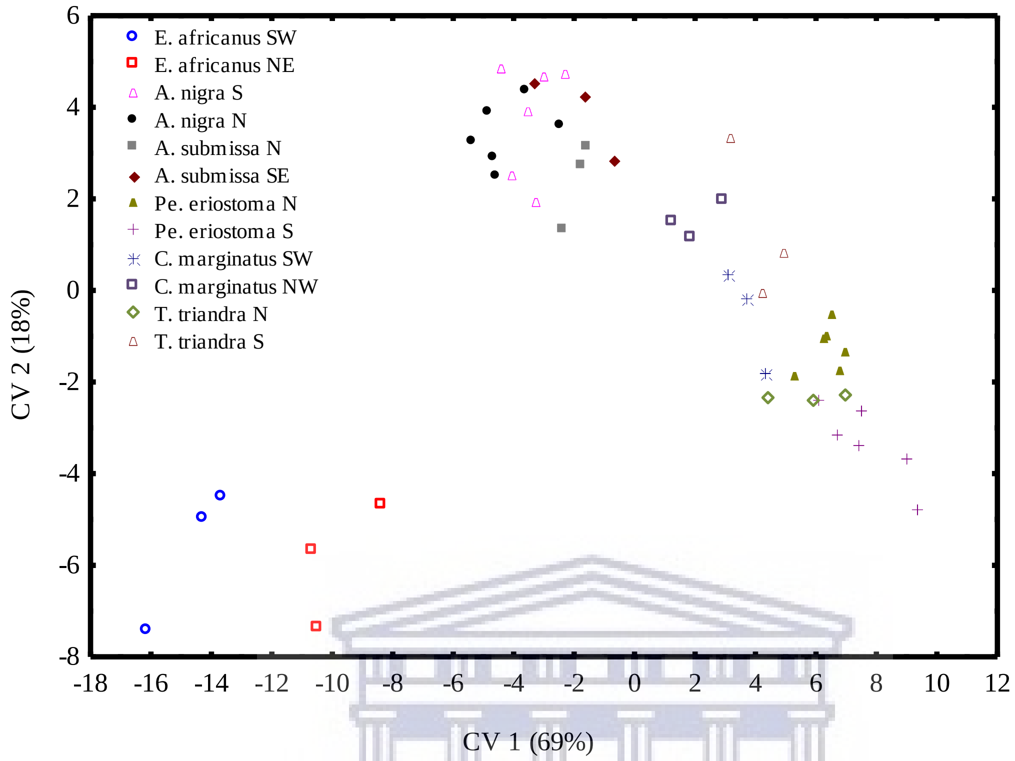

Figure 3.3: Scatterplot of canonical scores based on plant nutrient and fibre concentrations separating species from different slope aspects at each site in the Overberg renosterveld vegetation. The names of the species are: *Eriocephalus africanus* L., *Aspalathus nigra* L., *A. submissa* R. Dahlgren, *Pentameris eriostoma* (Nees) Steud., *Cymbopogon marginatus* (Steud.) Stapf ex Burtt Davy and *Themeda triandra* Forssk. The plant nutrient and fibre concentrations included P, K, Ca, Mg, Na, crude protein, neutral and acid detergent fibre. SW = southwest facing slope, NE = northeast, S = south, N = north, SE = southeast, NW = northwest.

Table 3.7: Squared Mahalanobis distances from canonical discriminant analysis between grazed species from different slope aspects collected in the Overberg renosterveld vegetation, 2014. Distances are given below the diagonals, and above are the F-statistics along with *** indicating significant differences at P < 0.001, **<0.05, and NS = not significant.

	Eriocephalus africanus SW	E. *africanus* NE	*Aspalathus nigra* S	*A. nigra* N	*Aspalathus submissa* N	*A. submissa* SE	*Pentameris eriostoma* SW	*P. eriostoma* NE	*Cymbopogon marginatus* SW	*C. marginatus* NW	*Themeda triandra* N	*T. triandra* S
E. *africanus* SW	-	7.5***	44.4***	40.9***	37.3***	42.9***	95.3***	103.7***	58.1***	52.7***	68.4***	62.1***
E. *africanus* NE	49.4	-	31.7***	25.1***	20.9***	27.8***	60.6***	67.1***	33.7***	30.9***	40.6***	40.1***
A. nigra S	220.7	157.4	-	2.5**	3.7***	9.1***	40.9***	53.3***	18.6***	11.1***	28.6***	14.6***
A. nigra N	203.1	124.6	8.1	-	3.0**	8.1***	43.2***	59.6***	17.8***	9.8***	29.0***	17.3***
A. submissa N	247.0	138.5	18.6	14.7	-	3.4***	19.9***	26.9***	8.8***	5.2***	13.8***	7.5***
A. submissa SE	284.1	184.1	45.4	40.0	22.6	-	27.2***	35.4***	10.9***	7.5***	17.7***	11.6***
P. eriostoma SW	473.1	300.9	135.4	142.9	98.8	134.9	-	8.4***	6.0***	7.9***	6.0***	3.7***
P. eriostoma NE	515.0	333.3	176.6	197.4	133.6	175.7	27.9	-	8.8***	15.8***	3.9***	9.6***
C. marginatus SW	384.5	223.4	92.3	88.5	57.9	72.0	29.6	43.8	-	1.6^{NS}	2.3**	4.8***
C. marginatus NW	349.1	204.8	54.9	48.9	34.5	49.4	39.4	78.4	10.9	-	6.7***	3.7***
T. triandra N	453.0	268.5	142.2	144.2	91.4	117.2	29.9	19.6	15.1	44.2	-	6.5***
T. triandra S	411.4	265.6	72.6	85.7	49.7	76.6	18.2	47.4	32.1	24.2	43.2	-

Table 3.8: Standardized coefficients of plant nutrition variables along covariates showing their significant (P<0.05) contribution to the discriminant function for the separation of native forage species from different slope aspects in the Overberg renosterveld vegetation, 2014. Eigenvalues indicates how well each canonical variate differentiates the groups. Among group variance indicates the proportion of the total variation accounted for by each canonical variate. Chi-Square test values at *** P<0.001.

Plant parameter	Standardized coefficient (CV)					
	CV1	CV2	CV3	CV4	CV5	CV6
P	0.70	-1.11	-0.23	1.15	-0.64	-0.22
K	0.27	-0.09	-0.69	-0.28	0.32	-0.62
Ca	0.12	-0.09	0.35	0.11	-0.04	-0.39
Mg	-0.37	0.56	0.50	-0.48	-0.39	-0.55
Na	-0.74	-0.71	0.31	-0.32	0.64	-0.10
Crude Protein	-0.18	0.82	0.43	0.63	0.79	0.04
NDF	1.98	-0.28	1.11	-0.08	0.83	-0.73
ADF	-1.94	-0.19	-0.39	0.86	-0.63	0.25
Eigenvalue	53.95	14.56	3.80	2.57	1.70	1.12
Among group variance (%)	69.0	21.6	4.9	3.3	2.2	1.4
Chi-Square Test	435***	286***	185***	127***	80***	43***

Table 3.9: Foliar nutrient, percentage crude protein and fibre concentrations of native forage species from different slope aspects in the Overberg renosterveld vegetation, 2014. Means with different letters indicates significant difference at *** P<0.001, ** P<0.05, and NS = Not significant.

Site	Species	N	P	K	Ca	Mg	Na	Crude protein	NDF	ADF
Site/Species		mg g^{-1}						%		
De Vlei	*Eriocephalus africanus* SW	11.05ef	1.07e	6.28a-c	10.94c	3.60e	10.34	6.91ef	49.6a	44.1
	E. africanus NE	6.96a-e	0.93de	5.25ab	8.10a-c	2.01bc	7.78	4.35a-e	48.6a	39.8
Klipfontein	*Aspalathus nigra* S	10.66ef	0.67a-e	5.79a-c	9.70a-c	3.48de	1.79	6.66ef	64.1b-e	47.8
	A. nigra N	7.90a-e	0.37a	5.95a-c	10.14bc	2.39c-e	1.22	4.94a-e	63.9b-e	48.4
	Pentamaris eriostoma S	5.76a-c	0.80b-e	5.17abc	8.53a-c	0.57a	0.53	3.60a-c	71.1def	42.6
	P. eriostoma N	4.36ab	0.40ab	6.63a-c	7.79a	0.63a	1.07	2.72ab	74.2ef	43.2
Witkop	*Cymbopogon marginatus* SW	6.65a-e	0.73a-e	8.56cd	9.32a-c	1.49a-c	0.68	4.16a-e	63.1b-e	40.6
	C. marginatus NW	7.08a-e	0.57a-d	7.76b-d	9.73a-c	1.87bc	0.62	4.43a-e	61.8bcd	40.2
Bietorivier	*Aspalathus submissa* SE	13.66f	0.60a-d	10.39d	9.61a-c	1.17a-c	1.33	8.54f	54.7ab	40.6
	A. submissa N	9.14c-f	0.43a-c	5.80a-c	7.53a-c	0.95ab	0.81	5.71c-f	63.1b-e	46.2
Kykoedie	*A. nigra* S	10.5def	0.37a	5.28ab	9.65a-c	1.75a-c	0.47	6.54d-f	65.5b-f	48.8
	A. nigra N	9.57c-f	0.50abc	6.13abc	8.51a-c	2.35cd	1.07	5.98c-f	58.8a-c	45.3
	P. eriostoma S	6.69a-e	0.93de	4.98ab	4.67a	0.63a	1.31	4.18a-e	74.1ef	42.0
	P. eriostoma N	3.50a	0.40ab	4.53a	5.79ab	0.59a	0.54	2.19a	76.1f	44.4
	Themeda triandra S	8.23b-e	0.50abc	5.21ab	6.00a-c	1.07ab	0.92	5.14b-e	69.5c-f	41.6
	T. triandra N	6.03a-d	0.83cde	7.28a-d	4.67a	0.82ab	0.49	3.77a-d	67.8c-f	42.1
F-statistic (11, 32)		8.92***	6.9***	4.45***	2.98**	16.4***	1.93^{NS}	8.92***	5.77***	2.16^{NS}

3.5 Discussion

3.5.1 The effects of soil chemistry on forage quality

The chemical composition of the soil, along with environmental variables, can have a direct influence on the nutrition of a forage species established within the area, where the concentration of minerals and pH levels can have a significant effect on the availability of the mineral elements that are absorbed by the forage species (McDowell, 1992; Chimphango *et al*., 2015). Therefore, it is vital that adequate concentrations of essential minerals, such as N, P and K, are present in the soil to enhance plant productivity and forage quality (Hanlon *et al*., 1990). For instance, plants growing in N-deficient soils are usually expected to possess reduced foliar N concentrations, and lowered growth and photosynthetic rates. This could account for the forage species, especially non-leguminous species, which occur on the Witkop site in the WRSR, which possessed soils with significantly lower N concentrations. Soil mineralization processes are largely due to microbial activity and chemical reactions occurring in the soil, which are essentially driven by the temperature, moisture content and the state of compaction of the soil (Henderson *et al*., 1966; De Neve *et al*., 2003). This could account for the superior concentrations of soil minerals present in the various regions and sites sampled in the current study. For examples, greater concentrations of total N, total P and K were recorded at the Plaaitjieskraal site, which is situated in the ERSR. This is a region in the Overberg that receives a significant amount of mean annual rainfall (Mucina & Rutherford, 2006) and thus would contain higher soil moisture and mineral contents due to soil mineralization processes (Gong *et al*., 2008).

Certain minerals such as K are advantageous when it comes to plant survival strategies as it plays an essential part in drought tolerance mechanisms (Wang *et al*., 2013). Thus superior concentrations of K present in the soil, like those found at Plaaitieskraal, would favour the endurance of forage species especially during the drier periods of the year. Similarly, the De Vlei site situated in the WRSR contained superior concentrations of total P, Ca and Mg, which could also be due to the region receiving a substantial amount of rainfall in relation to the other sites and geographical areas in the Overberg (Mucina & Rutherford, 2006). Phosphorous, which is generally deficient in the soils of the CFR (Goldblatt & Manning, 2002), is an essential mineral required for plant development, metabolic regulation, energy transfer and legume nitrogen fixation (Schulze *et al*., 2006; Vardien *et al*., 2016). The mobility and absorption of P present in the soil is positively correlated with soil moisture, which is strongly influenced by the rainfall in the region (McGrath *et al*., 2000; He *et al*., 2002). Fluctuations in soil P could also be due to fire regimes in the area, where elevated P concentrations have been linked to high intensity fires in the southern Cape region of South Africa (Ayo & Olojugba, 2014). Therefore, the productivity of a forage species growing in semi-arid regions with variable climatic events (rainfall patterns and fire regimes) will be affected by the geographical location of the established forage species due to the accessibility to certain soluble minerals (Mbatha & Ward, 2010; Olojugba, 2018).

The variability of soil mineral concentrations may be influenced by the occurrence of the vegetation in the area. Vegetation cover is essential when it comes to the sequestration and availability of minerals in the soil through nutrient cycling processes (Du Preez & Snyman, 1993; Burke *et al*., 1997; Whitbread, 2009). For instance, the establishment of native legume species or 'patches' are acknowledged to cycle of nutrients such as N back into rangeland soils and would thereby improve soil quality and increase plant yield. Vegetation cover also reduces the temperature and evapotranspiration rates of the soil by limiting direct solar radiation, particularly during the summer season (Song *et al*., 2013; Lozano-Parra *et al*., 2018). Therefore, the removal of plant biomass through herbivory or fire regimes would lower soil moisture contents, and consequently reduce microbial activity and mineralization rates in the soil (Rhodes & Sharrow, 1990; Stark & Firestone, 1995; Borowik & Wyszkowska, 2016). Furthermore, the presence of herbivores in a rangeland may cycle nutrients back into the soil, specifically N, in the form of urea and proteins through their urine and faeces, respectively (Mbatha & Ward, 2010). Therefore, there are many drivers in a rangeland that would influence the variability in the soil chemistry which as result would impact the quality of the forage species.

3.5.2 The effect of slope aspect on the soil and forage chemical composition

The soil quality in a rangeland may be significantly influenced by the presence of topographic features, such as the slope aspect and gradient. These features may encourage a variation of microclimate events, producing alterations in soil moisture content, temperature rates, organic matter and mineral concentrations, and faunal abundance and diversity (Reid, 1973; Holechek *et al*., 2004; Gong *et al*., 2008). Generally, slope aspects that possess wetter conditions have a thicker humic soil layer, and greater microbial activity and mineralization rates, which result in higher concentrations of water and nutrient availability compared to the soils associated with drier slope aspect conditions (Gong *et al*., 2008).

In the southern hemisphere, north facing slopes are usually associated with drier conditions and experience hotter fires, compared to the wetter conditions on south facing slopes (Cowling, 1983; Newton, 2008). Additionally, north facing slopes receive higher rates of solar radiation, and therefore are subjected to lower rates of weathering, illuviation and mineralization, which could explain the lower concentrations of certain soil minerals (Carter & Ciolkosz, 1991; Gilliam *et al*., 2015). According to the current study, the soils sampled from the south facing slopes contained elevated concentrations of all the measured minerals, with the exception of total P and Na at Bietorivier and total N at Kykoedie, which were greater on the north facing slopes. The variability in the soil chemistry between different slope aspects could be due to wind-driven rain (WDR) effect which is a process that influences the wind patterns and rainfall distribution due to the presence of topographical features in a region, i.e. slopes, cliffs and valleys (Lentz *et al*., 1995; Ragab *et al*., 2003; Sariyildiz *et al*., 2005; Blocken *et al*., 2006). The slope aspect and the associated mineral and pH contents of the soil can have a significant influence on the microbial activity and edaphic stressors associated with the slope and soil substrate. For instance, the Klipfontein site contained greater concentrations of soil Ca on the south facing slope, which would reduce the effects of soil acidity stress on legume and rhizobia symbiosis as well as the assimilation of minerals such as N (Howieson *et al*., 1992). Therefore, fully understanding the effects that the soil condition has on these symbiotic relationships are essential when considering the domestication of forage legume species (Gerding *et al*., 2012).

The trend of elevated nutrient contents on the south facing slopes was also reflected in the foliar parts of some of the forage species sampled from the same slope aspects. Namely, *P. eriostoma* in Kykoedie, *A. submissa* in Bietorivier, and *E. africanus* in De Vlei, which contained elevated concentrations of P, K and Mg on the south facing slopes, respectively (i.e. S, SE, SW). These superior foliar nutrient concentrations may be as a result of elevated soil nutrients concentrations in the respective areas, in association with the assimilation mechanisms of the species and the micro-environmental conditions on the slope aspects (Schut *et al*., 2010; De Waal, 1990). Therefore, the variability in the soil and foliar chemical composition due to the effects of geographical and topographical features (i.e. slope aspect) and the associated microclimates, contributes essential data necessary for the selection and possible domestication of native forage species for grazing management systems in Mediterranean regions.

3.6 Conclusion

According to the results obtained from the study, the soils sampled from the Overberg renosterveld contained a significant amount of variability in the chemical composition, across the different geographical areas and slope aspects. This variability could be as a result of the variable climatic conditions that the semi-arid region is exposed to, where micro-climates created by slope aspect and gradient intensifies these variable trends. In addition, vegetation cover was an environmental factor that could have influenced the soil mineral variations, through nutrient cycling processes, especially with regards to legume species and the addition of N through N-fixation mechanisms. In terms of slope aspect, the south facing slopes in the Overberg reflected greater concentrations of some of the soil and foliar minerals, compared to the north facing slopes, which may be due to the localised climatic conditions coupled with mineralization mechanisms associated with these slope aspects.

Since the environmental conditions of a plant's habitat has a significant effect on the chemical composition and nutritional value of forage species (Ordonez *et al*., 2009; Han *et al*., 2011), this study provides evidence on the effects that these environmental and topographical features might have on fodder flow systems on livestock farms. Therefore, the variability in the nutritional quality and grazing value of native forage species due to topographical features (i.e. slope aspect), will have implications on the selection and domestication of native forage species. Thus slope aspect and the associated microclimates should be considered when managing livestock diets when utilising these natural pastures. However, a wider range of variables are required for a clearer explanation of the spatial variations in soil properties, with reference to slope aspect, especially when considering the effects these variables have on the quality of forage. Unfortunatley due to logistical problems in the analytical procedure, additional soil chemical elements and properties were not included in current study. Therefore, further studies are encouraged to fully understand the interactive relationships between soil properties, topographic features and forage quality to assist with the development of sustainable soil and grazing management practices in the Overberg renosterveld rangelands.

CHAPTER FOUR: GENERAL DISCUSSION AND CONCLUSION

This study was conducted in the Overberg region, an area that is associated with agricultural practices, specifically crop and livestock production (Krug, 2004; Newton & Knight, 2004). Farmers rely largely on introduced species such as *Medicago sativa*, as forage in grazing management systems, which are strongly reliant on water and nutrient availability, to optimize forage quality and yields. Forage quality has always been a major concern to farmers with regard to managing livestock diets, especially since livestock productivity is directly influenced by the quality of the forage that is being consumed (Simbaya, 2000; Ball *et al*., 2001). Livestock farmers in the Overberg also rely on the natural remnants of renosterveld vegetation as forage reserves to support their livestock during various periods of the year (Curtis, 2013). Therefore, in the current study, several targeted native legume and non-legume species were identified and the concentrations of CP, NDF, ADF and mineral contents were assessed to determine whether these species contained adequate levels to meet the livestock's dietary requirements. The utilisation of the native forage species is advantageous since these species generally possess adaptive tolerance mechanisms to variable climate conditions associated with semi-arid regions. There are many environmental variables that can affect the quality of a forage species, namely seasonal variability, soil quality and slope aspect (De Waal, 1990; Lascano *et al*., 2000; Newman *et al*., 2009. Therefore, this study provided an opportunity for research to be conducted on the relationship between these environmental variables and forage quality in the Overberg renosterveld rangelands for livestock production.

The aim of the study was to identity andcharacterize the potential of selected native legume and non-legume species in the Overberg renosterveld as high quality forage species for livestock grazing systems. The objectives of the study were to:

(1) Characterize the nutritional quality of native legume and non-legume forage species in the Overberg renosterveld and to assess the effect of seasonal variation on the quality of the native forage species.

(2) Determine the effects of soil type and slope aspect on the nutritive composition of the native forage species.

The native Fabaceae species contained variable but superior concentrations of N and CP in relation to the native non-legume species. These superior N and CP concentrations correlate with the ability these species possess to assimilate N via biological N fixation mechanisms (Chen *et al*., 2003; Franche *et al*., 2009). It was noted that CP is one of the most important quality characteristics of forages because livestock that consume a diet deficient in CP could reduce voluntary intake rates, and have longer rumen residence time associated with restricted microbial activity resulting in low animal productivity (Paterson *et al*., 1996; Hariadi & Santoso, 2010; Mahmoud *et al*., 2017). As a result, Fabaceae plants are known to play a significant role of improving the quality of pasture in the rangelands due to their high CP contents (Ammar *et al*., 2004; Khachatur, 2006; Boufennara e*t al*., 2012). In the current study, the legume species, especially *A. hispida*, *A. angustifolia*, *A. nigra* and *A. submissa* were regarded as superior quality forage to accommodate livestock dietary requirements, due to the possession of high protein, and moderate fibre contents, digestibility rates and mineral concentrations, in comparison to non-legume species, despite containing CP contents three times lower than those of *M. sativa*.

Furthermore, there was interaction in the chemical composition of the sampled forage species between the families and the species such that there are some Asteraceae and Poaceae species with good quality characteristics comparable to some of the Fabaceae species. The presence of individual species of a high-quality status within each family probably explains why the livestock selectively graze on the rangeland species to meet their mineral requirements during different periods of the year (Stindt & Joubert, 1979). For instance, the native Asteraceae species, *E. africanus* and *Pr. polifolia*, contained greater concentrations of minerals such as of P, K, Mg and Na, and the lowest concentration of NDF relative to the other families. The total fibre fraction of forages measured by NDF and ADF is another important characteristic that indicates the dry matter fraction of the forages (Ghanbari & Sahraei, 2012), and often correlates negatively with digestibility (Ammar *et al*., 2004). This implies that with regard to mineral and fibre contents, the Asteraceae species were better than the Fabaceae species. On the other hand, the *Poaceae* species were of the least quality, containing the lowest concentrations of the mineral elements and greatest concentrations of NDF and ADF. However, *C. marginatus* and *T. triandra* recorded intermediate NDF and CP values that render them acceptable quality forage. Grass species are considered important livestock feed on rangelands in many parts of the world (Aganga & Tshwenyane, 2004; Ayanda, 2013;

Rasool *et al*., 2013), particularly in arid and semi-arid environments. These species are favourable to livestock farmers, because they are well adapted to a variety of ecological conditions. Poaceae species possess a network of deep, dense and fibrous root systems which allow these species to optimise the uptake of water and to withstand extended drought conditions (Aganga & Tshwenyane, 2004; Snyman, 2009). Perennial grass species with specialised root systems are adapted to tolerate water deficits, fire regimes and continuous heavy grazing, especially with cattle production, in comparison to woody shrub and tree species (Van den Berg & Zeng, 2006). The grazing potential of grass species may be enhanced by diversifying livestock diets through the utilisation of legume species. In addition, the establishment of legumes is advantageous to rangeland productivity through the enhancement of soil N concentrations, allowing non-leguminous species to establish in these niches (Nyfeler, *et al*., 2011). A diversity of nutritive forage species or functional groups may enhance the overall productivity of temperate rangelands by increasing the retention of nutrients, as well as the sustainability and multifunctionality of the rangeland (Ayanda, 2013). Therefore, it is encouraged that farmers in the Overberg utalise a mixed grazing system that incorporates a diversity of native, high quality forage species to support their livestock's diertary requirements. Prior to this study, there were limited reports, if any on the chemical composition and nutritive values of native forage species in the renosterveld rangelands in the Overberg with no information on the foraged legume genus, *Aspalathus*, despite the utilisation of these rangelands as foraging reserves by livestock farmers (Radloff *et al*., 2014). Although the importance of legumes in rangelands is well established, only a few south African legumes have been evaluated for forage value and domestication (Trytsman *et al*., 2019). The situation is more extreme in the Fynbos biome where most legumes are not recognized as livestock feed. For instance, for the over 760 Fabaceae species in the biome only 23 species have information published on utilisation, with seven species in cultivation (Edwards *et al*., 2019; Trytsman 2013; Chapter 2). Therefore, there is a rich diversity of native forage legume species in the region that are suitable genetic resources for the selection of possible commercial legume crops, which are adapted to the semi-arid environmental conditions of Mediterranean regions, as well as the climate change predictions of lower rainfall patterns and higher temperatures.

The results on the comparison of soil nutrient elements between slope aspects varied with site and element. For instance, the soil on the SW facing slopes at the Witkop and De Vlei sites showed higher concentrations of Total N and Total P, as well as Bray II P and Mg at the latter, compared to the NW and NE facing slopes, respectively. The concentration of Ca was higher on the south facing slopes compared to the north facing slopes at Klipfontein. On the other hand, the north facing slopes recorded higher concentration of Total P and Na at Bietorivier and Total N at Kykoedie compared to SE and south facing slopes, respectively. The observation of higher concentrations of some nutrient elements on the north facing slopes in the Southern Hemisphere is contradictory to expectation, as they are expected to be hotter and drier compared to the south facing slope aspects (Newton, 2008) and with lower nutrient availability (Temel & Tan, 2011). This contradiction is most likely unsurprising for the Cape region where the prevalence of rainfall is highly influenced by wind direction. The slope aspect has a significant influence on wind direction and speed, as well as rainfall distribution and intensity in a specific region (Lentz *et al*., 1995; Ragab *et al*., 2003). This is known as the wind-driven rain (WDR) effect, which occurs when specific wind-flow patterns develop in relation to topographical features such as slopes, hills, valleys and cliffs. In response to this effect, rainfall that is affected by these wind-flow patterns is redistributed in a specific pattern as well (Blocken *et al*., 2006). Therefore, variations in soil nutrient concentrations would occur in response to the WDR effects in a specific site, resulting in variations in moisture contents, decomposition rates and nutrient availability (Sariyildiz *et al*., 2005). Slope aspects that receive more rainfall and possess higher moisture and humidity contents on the windward side are generally more vegetated in comparison to the hotter and drier conditions on the leeward side of the slope, which is exposed to the rain shadow effect (Beullens *et al*., 2014). In return, vegetation density assists with the conservation of moisture contents, the enhancement of infiltration rates and the reduction of runoff and erosion processes (Loch, 2000; Zhou *et al*., 2008). Therefore, the consideration and utilisation of specific slope aspects for agricultural practices, especially livestock farmers, would be beneficial since these microclimatic conditions would be influential on seed germination and establishment, crop yield and productivity, and forage quality.

Unfortunatley, due to limited time for research associated with the Master's degree programme, only the spring and autumn seasons were monitored for the foliar nutrients in the native forage species in the Overberg renosterveld rangelands. However to ensure a clearer understanding on the potential incorporation and domestication of these native species into grazing management systems, further research should be conducted to assess its success as a reliable forage resource. These studies could include long term nutritional analysis that incorporates all the seasons of the year, specifying the nutritional composition at different stages of maturity and portions of the forage species (i.e. flowers, shoots and stems), herbage biomass and seed production, assimilation and tolerance mechanisms, anti-nutritional qualities (i.e. pyrrolizidine alkaloids and cyanogenic glycosides), as well as preference and *in vivo* studies on the livestock. These fields of research are all necessary components to consider when identifying native forage species that possess the potential to compete nutritionally with the currently used *M. sativa*.

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APPENDICES

Appendix 1: Geographical areas, field sites, family and species sampled from the Mediterranean renosterveld vegetation, Overberg, South Africa

Geographical area	Field site	Family	Species
WRSR	De Vlei	Asteraceae	*Eriocephalus africanus* L.
		Fabaceae	*Aspalathus nigra* L.
			Aspalathus submissa R. Dahlgren
		Poaceae	*Cymbopogon marginatus* (Steud.) Stapf ex
			Themeda triandra Forssk.
	Klipfontein	Asteraceae	*Printzia polifolia* (L.) Hutch
		Fabaceae	*Aspalathus angustifolia* (Lam.) R. Dahlgren
			Aspalathus nigra L.
			Aspalathus submissa R. Dahlgren
		Poaceae	*Cymbopogon marginatus* (Steud.) Stapf ex
			Pentameris eriostoma (Nees) Steud.
			Themeda triandra Forssk.
	Bietorivier	Asteraceae	*Eriocephalus africanus L.*
			Printzia polifolia (L.) Hutch
		Fabaceae	*Aspalathus nigra* L.
			Aspalathus spinosa L.
			Aspalathus submissa R. Dahlgren
		Poaceae	*Cymbopogon marginatus* (Steud.) Stapf ex
			Pentameris eriostoma (Nees) Steud.
			Themeda triandra Forssk.
		Asteraceae	*Printzia polifolia* (L.) Hutch
CRSR	Witkop	Fabaceae	*Aspalathus hispida* Thunb.
			Aspalathus spinosa L.
			Aspalathus submissa R. Dahlgren
		Poaceae	*Cymbopogon marginatus* (Steud.) Stapf ex
			Pentameris eriostoma (Nees) Steud.
			Themeda triandra Forssk.
	Onderschietpad	Asteraceae	*Eriocephalus africanus L.*
			Printzia polifolia (L.) Hutch
		Fabaceae	*Aspalathus angustifolia* (Lam.) R. Dahlgren
			Aspalathus hispida Thunb.
			Aspalathus nigra L.
			Aspalathus spinosa L.
			Themeda triandra Forssk.
		Poaceae	*Pentameris eriostoma* (Nees) Steud.
			Themeda triandra Forssk.
	Kykoedie	Fabaceae	*Aspalathus angustifolia* (Lam.) R. Dahlgren
			Aspalathus hispida Thunb.
			Aspalathus nigra L.
			Aspalathus spinosa L.
		Poaceae	*Pentameris eriostoma* (Nees) Steud.
			Themeda triandra Forssk.

ERSR	Lofdal	Asteraceae	*Eriocephalus africanus L.*
			Printzia polifolia (L.) Hutch
		Fabaceae	*Aspalathus angustifolia* (Lam.) R. Dahlgren
			Aspalathus nigra L.
			Aspalathus spinosa L.
			Aspalathus submissa R. Dahlgren
		Poaceae	*Pentameris eriostoma* (Nees) Steud.
	Voorstekop	Fabaceae	*Aspalathus angustifolia* (Lam.) R. Dahlgren
			Aspalathus nigra L.
		Poaceae	*Cymbopogon marginatus* (Steud.) Stapf ex
			Pentameris eriostoma (Nees) Steud.
			Themeda triandra Forssk.
	Plaaitjieskraal	Fabaceae	*Aspalathus angustifolia* (Lam.) R. Dahlgren
			Aspalathus nigra L.
		Poaceae	*Cymbopogon marginatus* (Steud.) Stapf ex
			Pentameris eriostoma (Nees) Steud.
			Themeda triandra Forssk.

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