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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. sativa*, 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 Proteem 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 & Voltaire, 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  $\text{NH}_4^+$ , 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 (Oloff *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 °C 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**

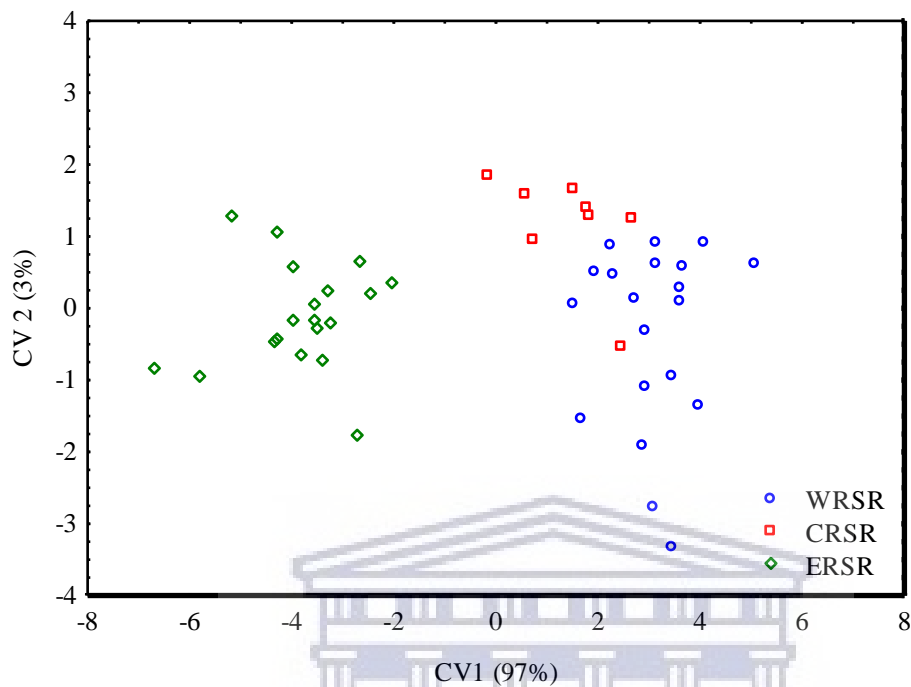
The chemical variables were natural log transformed to meet the parametric analyses requirements, where necessary, and were conducted in Statistica 8 (StatSoft, Inc.). The variables were subjected to multivariate analysis using canonical discriminant analysis (CDA) to assess the geographical areas, farm 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 priori* 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 Plaitjieskraal sites in the ERSR were highest in comparison to the other sites, whereas total P was highest in the De Vlei and Plaitjieskraal sites. Similarly, Plaitjieskraal 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.



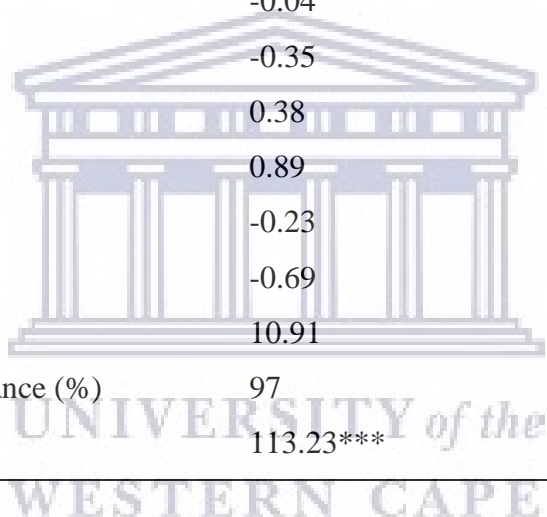
**Figure 3.1:** Scatterplot of canonical scores separating soils from three geographical areas from the Overberg renosterveld vegetation, 2014, based on the mineral concentration, including Total N, Total P, Bray II P, K, Ca, Mg, Na. WRSR, CRSR and ERSR = Western-, Central- and Eastern- Rûens Shale Renosterveld,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

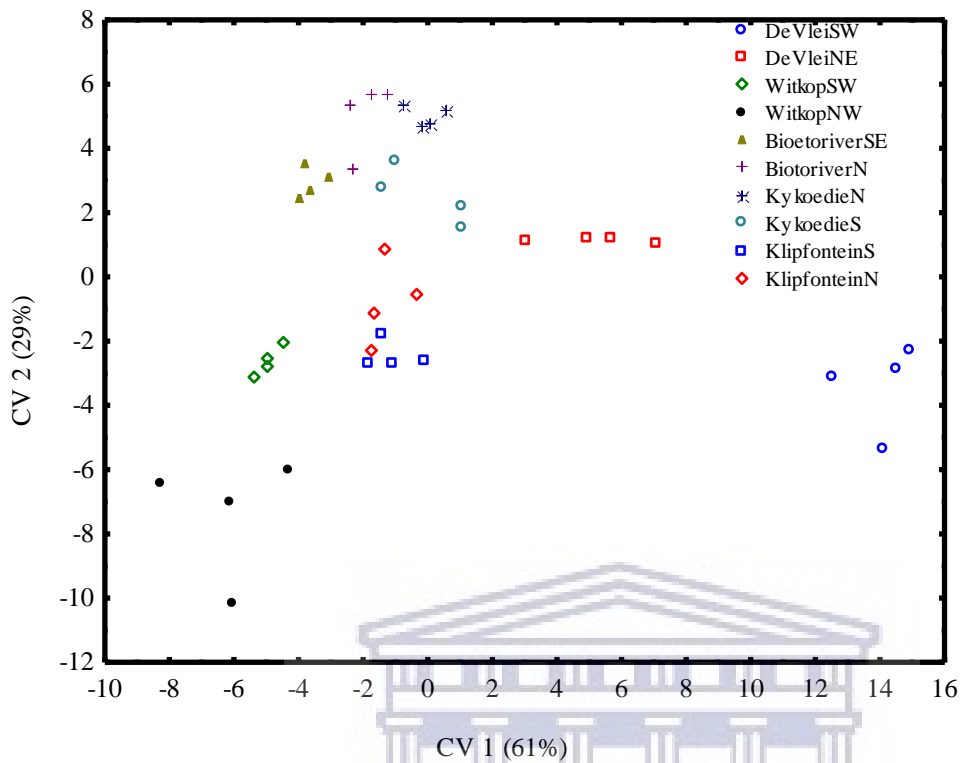


**Table 3.3:** Soil nutrient concentrations from different sites from three geographical areas in the Overberg renosterveld vegetation where forage species were collected. Mean values with different letters indicates significant difference at \*\*\* P<0.001, \*\* P<0.05, NS= Not significant, - = not 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 <sup>-1</sup>					mg g <sup>-1</sup>	
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	Onderschietspad	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
	Plaitjieskraal	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 <sup>NS</sup>	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 canonical 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.

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**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 <sup>NS</sup>
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 \*\*  $P < 0.05$ .

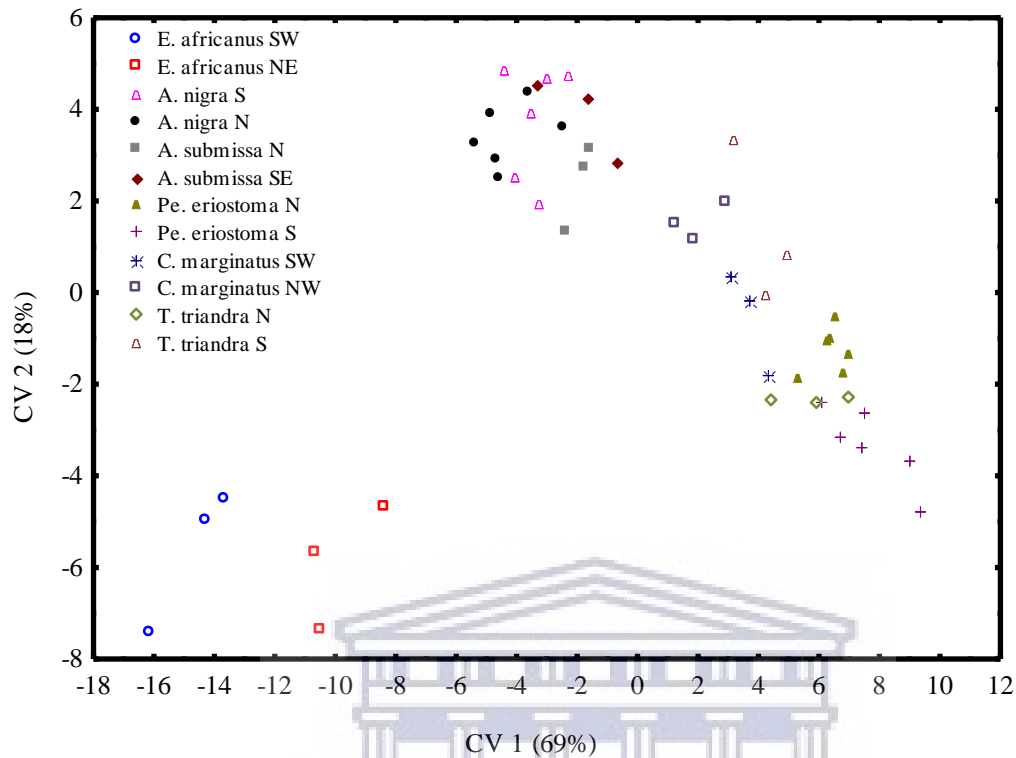
Soil parameter	Standardized coefficient (CV)				
	CV1	CV2	CV3	CV4	CV5
N	0.04	0.28	0.93	0.47	-0.30
Total P	0.62	0.57	0.24	-0.40	-0.66
Bray II P	0.14	-0.90	0.30	-0.10	0.91
K	0.03	0.49	-0.85	0.49	0.55
Mg	0.97	-0.17	-0.27	0.06	0.09
Na	-0.57	0.77	0.15	-0.61	0.21
Eigenvalue	40.78	19.51	4.08	1.67	1.16
Among 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 <sup>-1</sup>						(mg g <sup>-1</sup> )
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 Burt 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.

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

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**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.

		N	P	K	Ca	Mg	Na	Crude protein	NDF	ADF
Site/Species		mg g <sup>-1</sup>						%		
De Vlei	<i>Eriosephalus africanus</i> SW	11.05ef	1.07e	6.28a-c	10.94c	3.60e	10.34	6.91ef	49.6a	44.1
	<i>E. africanus</i> NE	6.96a-e	0.93de	5.25ab	8.10a-c	2.01bc	7.78	4.35a-e	48.6a	39.8
Klipfontein	<i>Aspalathus nigra</i> S	10.66ef	0.67a-e	5.79a-c	9.70a-c	3.48de	1.79	6.66ef	64.1b-e	47.8
	<i>A. nigra</i> N	7.90a-e	0.37a	5.95a-c	10.14bc	2.39c-e	1.22	4.94a-e	63.9b-e	48.4
	<i>Pentamaris eriostoma</i> S	5.76a-c	0.80b-e	5.17abc	8.53a-c	0.57a	0.53	3.60a-c	71.1def	42.6
	<i>P. eriostoma</i> N	4.36ab	0.40ab	6.63a-c	7.79a	0.63a	1.07	2.72ab	74.2ef	43.2
Witkop	<i>Cymbopogon marginatus</i> 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
	<i>C. marginatus</i> 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	<i>Aspalathus submissa</i> SE	13.66f	0.60a-d	10.39d	9.61a-c	1.17a-c	1.33	8.54f	54.7ab	40.6
	<i>A. submissa</i> 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	<i>A. nigra</i> S	10.5def	0.37a	5.28ab	9.65a-c	1.75a-c	0.47	6.54d-f	65.5b-f	48.8
	<i>A. nigra</i> N	9.57c-f	0.50abc	6.13abc	8.51a-c	2.35cd	1.07	5.98c-f	58.8a-c	45.3
	<i>P. eriostoma</i> S	6.69a-e	0.93de	4.98ab	4.67a	0.63a	1.31	4.18a-e	74.1ef	42.0
	<i>P. eriostoma</i> N	3.50a	0.40ab	4.53a	5.79ab	0.59a	0.54	2.19a	76.1f	44.4
	<i>Themeda triandra</i> S	8.23b-e	0.50abc	5.21ab	6.00a-c	1.07ab	0.92	5.14b-e	69.5c-f	41.6
	<i>T. triandra</i> 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 <sup>NS</sup>	8.92***	5.77***	2.16 <sup>NS</sup>

## 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 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 & Wyszowska, 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. Unfortunately 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 identify and characterize 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 *et 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 utilise a mixed grazing system that incorporates a diversity of native, high quality forage species to support their livestock's dietary 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.

Unfortunately, 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	<i>Eriocephalus africanus</i> L.	
		Fabaceae	<i>Aspalathus nigra</i> L. <i>Aspalathus submissa</i> R. Dahlgren	
		Poaceae	<i>Cymbopogon marginatus</i> (Steud.) Stapf ex <i>Themeda triandra</i> Forssk.	
	Klipfontein	Asteraceae	<i>Printzia polifolia</i> (L.) Hutch	
		Fabaceae	<i>Aspalathus angustifolia</i> (Lam.) R. Dahlgren <i>Aspalathus nigra</i> L. <i>Aspalathus submissa</i> R. Dahlgren	
		Poaceae	<i>Cymbopogon marginatus</i> (Steud.) Stapf ex <i>Pentameris eriostoma</i> (Nees) Steud. <i>Themeda triandra</i> Forssk.	
	Bietorivier	Asteraceae	<i>Eriocephalus africanus</i> L.	
		Fabaceae	<i>Printzia polifolia</i> (L.) Hutch <i>Aspalathus nigra</i> L. <i>Aspalathus spinosa</i> L. <i>Aspalathus submissa</i> R. Dahlgren	
		Poaceae	<i>Cymbopogon marginatus</i> (Steud.) Stapf ex <i>Pentameris eriostoma</i> (Nees) Steud. <i>Themeda triandra</i> Forssk.	
	CRSR	Witkop	Asteraceae	<i>Printzia polifolia</i> (L.) Hutch
			Fabaceae	<i>Aspalathus hispida</i> Thunb. <i>Aspalathus spinosa</i> L. <i>Aspalathus submissa</i> R. Dahlgren
			Poaceae	<i>Cymbopogon marginatus</i> (Steud.) Stapf ex <i>Pentameris eriostoma</i> (Nees) Steud. <i>Themeda triandra</i> Forssk.
Onderschietspad		Asteraceae	<i>Eriocephalus africanus</i> L.	
		Fabaceae	<i>Printzia polifolia</i> (L.) Hutch <i>Aspalathus angustifolia</i> (Lam.) R. Dahlgren <i>Aspalathus hispida</i> Thunb. <i>Aspalathus nigra</i> L. <i>Aspalathus spinosa</i> L. <i>Themeda triandra</i> Forssk.	
		Poaceae	<i>Pentameris eriostoma</i> (Nees) Steud. <i>Themeda triandra</i> Forssk.	
Kykoedie		Fabaceae	<i>Aspalathus angustifolia</i> (Lam.) R. Dahlgren <i>Aspalathus hispida</i> Thunb. <i>Aspalathus nigra</i> L. <i>Aspalathus spinosa</i> L.	
		Poaceae	<i>Pentameris eriostoma</i> (Nees) Steud. <i>Themeda triandra</i> Forssk.	

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



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