Qualitative intake and certain rumen parameters of beef cattle in north western parts of Namibia

by

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DECLARATION

I, Ashley England declare that the dissertation, which I hereby submit for the degree MSc (Agric) Animal Science: Animal Nutrition at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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SUMMARY

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Beef production is known to be the most important livestock related activity in Namibia (Just over 2 million cattle in Namibia in 2009) with the majority of weaners being exported to the South African feedlot industry. Extensive beef production requires a sound knowledge of management practices, genetics and nutrition. The nutritional requirements of cattle remain one of the most important factors for maximizing return and profitability of the farming enterprise.

The purpose of this study was to quantify the nutritive value of two veld types in the north western part of Namibia. The thorn bush savanna was assigned as treatment K whilst the mopane savanna was assigned as treatment M.

For the oesophageally collected samples there were differences between the two years (2007 and 2008) for all the parameters as well as differences between the two veld types (treatments) and periods. Crude protein (CP) had a large seasonal variation in both treatments, with treatment K having higher CP concentrations for the majority of the trial period compared to treatment M. Phosphorous (P) also tended to show seasonal variation with higher concentrations during the wet season. The CP requirements for a 400kg cow were not met during the time when the cow is expected to be pregnant, however during lactation and early gestation the CP requirements of a 400kg cow are met from the intake of forage alone. The P requirements of a 400kg cow were met during the majority of the year

except during the last trimester of gestation where the forage alone is not able to supply the P requirements of a 400kg cow.

Treatment K had higher concentrations of calcium (Ca), zinc (Zn) and copper(Cu) compared to treatment M, whilst Treatment M had a higher concentration of manganese (Mn) during the majority of the trial period. The Mn concentration of the forage was shown to be adequate during most parts of the year and was able to supply the Mn requirements of a 400kg cow during gestation and lactation for both treatments. However, Cu, Zn and Mg were deficient especially during the winter months and intake from forage alone was not able to supply the Cu, Zn and Mg requirements for a 400kg cow during both gestation and lactation.

The Ca concentration of both treatments was high, and caution should be taken to ensure that the high intake levels of Ca through feed and water do not cause mineral imbalances. The *in vitro* digestible organic matter (IVDOM) concentrations increased from the winter to the summer months. The neutral detergent fibre (NDF) and acid detergent lignin (ADL) concentrations varied between treatments as well as throughout the trial period.

The rumen cannulated animals showed differences between years, treatments and periods for total volatile fatty acid (VFA) concentration and rumen NH_3-N. The rumen ammonia-N concentrations increased during the periods of higher rainfall whilst the total VFA concentration showed no distinct seasonal pattern.

The faecal CP results indicated that protein supplementation is necessary especially during periods of lower rainfall. whilst the faecal P results fell within the normal range. The relationship between faecal CP and diet CP concentration was not so strong and faecal CP concentration should be used with caution to predict the CP concentration of the forage. The relationship between faecal P and diet P concentration was also not strong when both treatments and years were combined which confirms that such relationships need to be tested under specific conditions.

LIST OF ABBREVIATIONS

ADL - Acid detergent lignin

BW - Body weight

Ca - Calcium

Ca:P - Calcium to phosphorus ratio

CP - Crude protein (N x 6.25)

DM - Dry matter

DMI - Dry matter intake

DOMD - Digestible organic matter dry matter

IVDOM - *In Vitro* digestible organic matter

LW - Live weight

ME - Metabolisable energy

N - Nitrogen

NDF - Neutral detergent fibre

OF - Oesophageally fistulated cattle

OM - Organic matter

P - Phosphorus

P_B - Plant available phosphorus in soil

r - Correlation

R^2 - Coefficient of determination

SBW - Shrunk body weight (overnight fast or 96% of full body weight)

SEM - Standard error of least square means

VFA - Volatile fatty acid concentration

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CHAPTER 1 INTRODUCTION

The ultimate aim of the Namibian farmer is to increase meat production per hectare of farmland in a profitable and sustainable manner. The nutritive value of the natural forage and its ability to provide the necessary requirements needed for animal production need to be studied under realistic and practical grazing conditions (Engels, 1983; De Waal, 1990, DelCurto *et al*., 2000).

The variability in animal performance that has been observed under the specific climatic conditions of Namibia highlights the importance of research in order to enhance the understanding of beef cattle's nutritional requirements as well as their qualitative intake from the natural forage.

The aim of this study was to obtain measurable parameters from oesophageal and ruminally cannulated cattle and relate it to the nutrient intake and nutritional status of the animals during different periods of the year. The trial took place over two years (2007 and 2008) in the thorn bush and mopane savanna of western Namibia. From the results a conclusion can be made as to whether or not the nutritional requirements of free-range foraging ruminants can be met from the forage alone or if supplementation is necessary.

The first objective in this trial was to evaluate the forage in terms of its quality to determine the baseline nutrition of the animals. This was done using oesophageally fistulated cattle. The results were then compared to the nutrient requirements of beef cattle using the NRC (2000), NRC (2007) and the NRC (2016).

The second objective was to obtain animal related status indicators by measuring metabolites in the rumen and nutrient concentrations in the faeces. This was done using ruminally cannulated cattle. The results would explain how intake from forage alone without supplementation affects status indicators and if it would be of diagnostic value.

CHAPTER 2 REVIEW OF LITERATURE

2.1. Background

Namibia has a mean annual rainfall of approximately 270mm and is rated to have the driest climate in sub-Saharan Africa with only 5% of the country receiving more than 500 mm of rain (Sweet, 1998). The only perennial rivers flow along parts of the Northern and Southern borders, and the country is almost entirely dependent on ephemeral rivers and groundwater (Sweet 1998). In the major part of the country there is a single wet season in summer and the bulk of the rain falls between the months of November and March. Evapotranspiration exceeds annual precipitation making drought conditions a common phenomenon throughout most of the country (Sweet 1998).

Rainfall decreases from north to south and east to west. Dry matter growing periods range from 120 days in the north-east to no growing period in the desert areas. Except for the north-east and central northern areas, the agricultural potential of Namibia is restricted to livestock farming (Sweet & Burke, 2002).

Around 97% of the country's soils have a clay content of less than 5% meaning the soils have a very low water holding capacity (Sweet, 1998). Considering soils and rainfall, only around 1% of the land surface is considered to have a medium to high potential for irrigated crop production, the bulk of this occurs within the communal areas in the north-east of the country (Sweet & Burke, 2002). There are three broad categories of land tenure in Namibia. Approximately 44% of the country is commercial farmland with freehold tenure, 41% is allocated to communal areas, and the remaining 15% is state land including conservation areas (Sweet 1998).

Agriculture accounted for 6% of GDP in 2009 and 14% of exports and supports, either directly or indirectly, 70% of the population (IFAD, 2011). In 2009 there were approximately 2.3 million head of cattle in Namibia (Ministry of Agriculture, Water and Forestry, 2011). These numbers tend to fluctuate considerably in response to high and low rainfall years.

Beef production is the most important livestock related activity, followed by small stock production, and most of the output from the livestock sector is exported. The combined livestock sector contributes 75% of total agricultural output making it an important source of income for the country (Directorate of Planning, 2011).

Table 1 Namibia statistics for cattle numbers, beef, veal and live animal exports for the period 2000-2009 (FAO database, 2011)

Item	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Cattle numbers (million)	2.5	2.5	2.3	2.3	2.3	2.2	2.3	2.3	2.3	2.3

The communal sector holds approximately 68% of the total cattle population in Namibia (Directorate of Planning, 2011). Land tenure issues in communal areas, where there are generally open access rights to grazing areas and the farmers are subsistence orientated, considerably hamper the introduction and adoption of improved management practices making successful livestock production more difficult. The commercial farming sector is well developed, capital intensive and export orientated. Commercial livestock production accounts for 69% of national agricultural output and comes from 52% of the grazing land (Directorate of Planning, 2011).

Cattle are predominant in the northern parts of the country where the rangelands generally have a higher carrying capacity. Beef cattle ranching is the largest contributor to commercial farming income, and the major breeds are Brahman, Afrikaner and Simmentaler (Sweet, 1998). Grazing livestock are raised under extensive conditions, relying on the natural grazing and are occasionally supplemented with protein and mineral licks.

Areas receiving medium to high rainfall have become severely bush infested due to burning practices being largely excluded and cutting for fuel or building being minimal. This has been to the detriment of the grazing potential for cattle (Sweet, 1998).

The principal vegetation types of Namibia are shown in Figure 1 (Geiss, 1971). These fifteen vegetation types can then be grouped into three main vegetation regions. Savannas occupy 64% of the land, desert vegetation 16% and dry woodlands 20% of the country (Sweet & Burke, 2002).

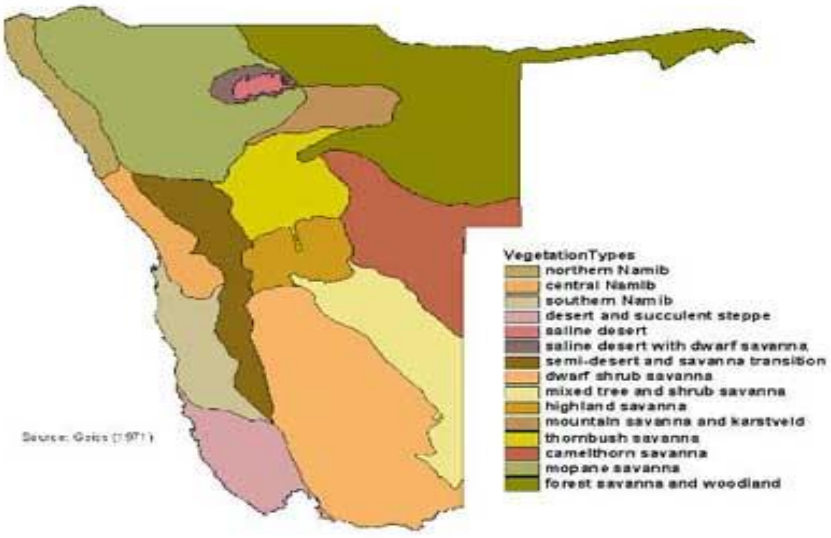

Figure 1 Vegetation *types of Namibia* (Geiss 1971)

The north-western parts of the country is dominated by mopane savanna consisting of the vegetation type Mopane (*Colophospermum mopane)* which is well suited to cattle farming. In the lower rainfall western areas, the grasses are mainly annuals such as Blue Bushman Grass (*Stipagrostis hirtigluma),* Kalahari Grass *(Schmidtia kalahariensis)* and *Entoplocamia aristulata*. In the higher rainfall eastern parts there are perennial grasses including Bushman Grass (*Stipagrostis uniplumis),* Sand Quick Grass *(Schmidtia pappophoroides),* Crab Grass *(Digitaria spp.)* and Blue Buffalo Grass (*Cenchrus ciliaris)* (Sweet & Burke, 2002).

The natural resource in terms of constraints, grazing potential and what animals prefer remains of primary concern. Constraints of the vegetation reflect mineral deficiencies and imbalances, low protein in the dry season (especially in the sourveld areas) and restrictions posed by the environment on the biochemistry and morphology (McDowell *et al*., 1984). These limitations have been exaggerated by overgrazing in sensitive areas. Overgrazing results because of too many animals (often because of socio-economic reasons) and poor management practices. In many cases overgrazing has resulted in lower grazing capacities because less desirable plants have replaced more palatable and nutritious species, veld becomes degraded, soils eroded, and bush encroachment occured (Meissner, 1997).

Constraints to pasture and fodder production and improvement include: (Sweet and Burke, 2002).

1. Low rainfall and poor soils throughout most of the country are the main constraints to the productivity of natural pastures and to the establishment of exotic pasture species.

2. Concern about exotic vegetation becoming problematic limits the introduction and testing of hardy species considered suited to the environmental and utilisation rigours of the communal areas.

3. The availability and price of seeds for pasture/fodder improvement are major constraints to communal area farmers.

4. Considerable portions of the savanna vegetation types in the freehold farms are severely bush infested, but the costs of thinning/clearing generally outweigh the benefits in terms of increased carrying capacity.

5. The open access to rangeland grazing, at least within communities in the communal areas necessitates broad collective agreement and cooperation in any pasture improvement venture.

6. Conventionally, communal area farmers do not retain exclusive use of their unfenced croplands after harvest for their own livestock, so limiting the opportunities and incentives for under sowing or alley cropping (Sweet and Burke, 2002).

2.2 FEED INTAKE OF RUMINANTS ON FORAGE DIETS

2.2.1 Introduction

Intake is the single most important variable determining animal performance (Romney & Gill, 2000). It is important to understand what determines and limits intake of forage to optimize utilization of the resource. Intake has a direct effect on grazing capacity and therefore on stocking rate and veld management. Accurate estimates are vital for performance predictions and for the application of equations.

The factors controlling intake are intricate and are often difficult to understand. Feed samples taken from oesophageally fistulated (OF) ruminants have resulted in the identification of preferred plant species and the demonstration of major differences in quality between animal selected and hand-clipped samples (De Waal., 1980). Animals tend to feed on a wide variety of feed components making it unlikely that the composition of the nutrients supplied would exactly meet the ratio of nutrients required by the animal. Therefore, a adequacy of one nutrient is likely to result in a deficiency or excess of another.

2.2.2 Forage intake dependent on forage quantity

Data summarized by Rayburn (1986) was reviewed by authors of the NRC (1987) and they concluded that with grazing cattle, quantity of forage available can affect feed intake. The results indicated that grazed forage intake was maximized when forage availability was approximately 2250 kg dry matter (DM)/ha or forage allowance of 40g organic matter/kg BW. It also showed a rapid decrease in intake to 60% of maximum when forage allowance was 20g organic matter/kg BW.

Rothauge (2006) studied the different plant types in the diets of cattle in Namibia by using the bite-count-technique and found a significant increase in browsing at the expense of grazing as the season progressed from wet season to the dry hot season. This brings us to believe that cattle were forced to make increasing use of browsed forage during the dry season when grasses were dormant and of lower quantity and quality than browse material.

2.2.3 Forage intake dependent on forage quality

Chemical factors influencing pasture intake include its digestibility and factors related to the nutrients that are regarded as essential for the rumen microbes and the host animal (Minson, 1990). Constituents that primarily limit intake of forages are those associated with the cell

wall. These include neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL). These fractions contain structural carbohydrates such as cellulose, hemicellulose and pectins which are broken down by microbes in the rumen. The distribution of the different molecules within the plant and the linkages between the molecules are important factors affecting the ease with which the microbes can break down the cells and thus reduce the space occupied in the gastrointestinal tract.

2.2.4 Plant physical characteristics affecting intake

Plant physical factors that affect intake are plant and sward structure (Romney & Gill, 2000). These factors directly influence initial gut volume and the rate at which that volume is decreased by digestion and onward passage. In addition, physical characteristics such as tissue origin, shape, buoyancy and specific gravity affect the rate at which particles are broken down for passage along the digestive tract.

Retention time and gut capacity will also have an effect on the amount of herbage which the animal can actually consume within a 24-hour period. Characteristics of the grazed sward such as plant density and height can influence intake through the swards effect on ease of prehension and thus bite size, which has shown to be a major factor influencing daily herbage intake (Hodgson *et al*., 1991). Positive relationships between bite size and sward height have been observed as well as the leaf to stem ratio being a major factor affecting the intake of cattle (Chacon & Stobbs, 1976).

2.2.5 Effect of Nitrogen deficiency on intake

A dietary protein deficiency can decrease feed intake especially if the forage is low in nitrogen and high in fibre. This is because a source of nitrogen is required by the rumen microbes for the fermentation of fibre. Nitrogen deficiency is wide-spread, and provision of supplemental nitrogen often increases dry matter intake (DMI) substantially (Galyean and Goetsch, 1993). The NRC (1987) also indicates that forage intake responses to protein are most typical when the forage's crude protein content is less than 6 to 8 percent.

Moore *et al*., (1999) showed a uniform relationship between digestible organic matter intake and crude protein content. In Figure 2 it can be seen that as soon as crude protein drops below 80g/kg there is a strong linear decrease in the organic matter intake. Under these conditions ruminal microbes may be nitrogen limited relative to energy and the supplementation of nitrogen will lead to increased organic matter intake (Moore *et al*., 1999).

Coleman (2005) postulated that the greatest and most uniform relationship of routine forage analysis to intake occurred when the crude protein concentration was below 8%, as demonstrated in Figure 2, which was an adaption from the data of Moore *et al.* (1999).

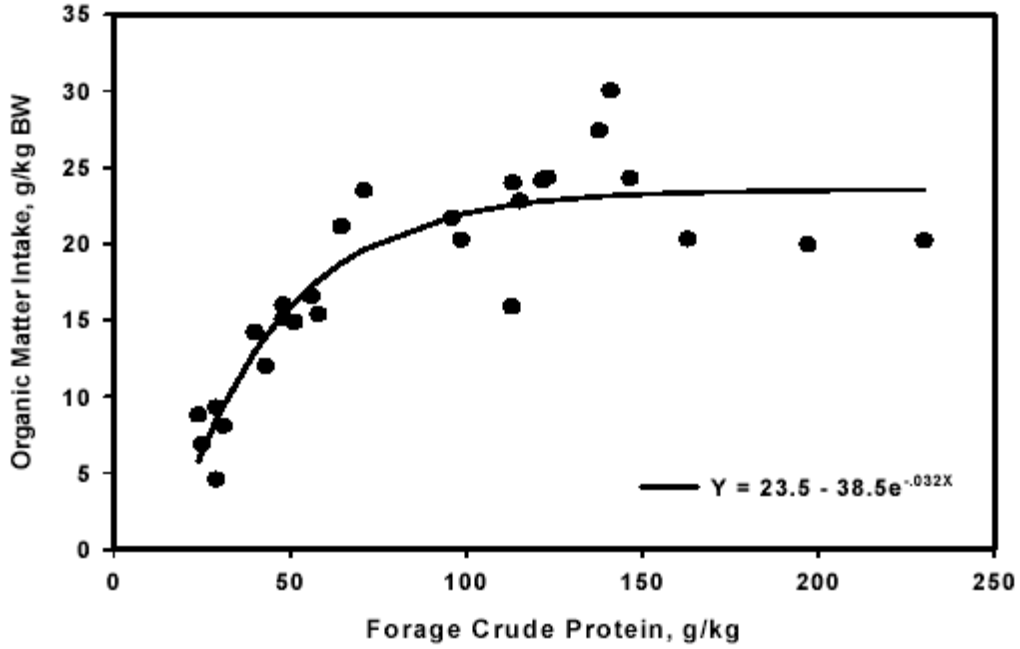

Figure 2 Response of intake to increasing concentrations of crude protein in forages fed alone (Coleman, 2005)

2.2.6 Effect of Phosphorus deficiency on intake

Studies have shown that a primary phosphorous (P) deficiency can cause a decline in voluntary feed intake (Ternouth, 2001; Roodt, 2012). This decline in feed intake is poorly understood but it is most likely due to the fact that P is required by the rumen microbes (Ternouth, 2001) for growth and cellular metabolism (NRC, 2000). The NRC 2001 recommends a P intake level of 0.3-0.4% DM.

Bone is an important storage area from which P is sequestered in times of P deficiency which can lead to bone demineralization as measured by a rib biopsy. Phosphorous plays a role in energy metabolism, pH and osmolality maintenance as well as many enzymatic and metabolic reactions.

Results indicate that the decrease in feed intake from a P deficiency is due to a disturbance of intracellular metabolism. Evidence for such a disturbance, potentially in protein metabolism, was suggested by the significantly higher plasma urea nitrogen concentrations found with P deficient and nitrogen (N) adequate diets which could potentially

be indicative of a disturbance of protein metabolism pathways in the rumen (Bortolussi *et al.,* 1996).

2.2.7 Animal factors affecting intake

Animal factors can also affect grazing intake such as animal size which is related to metabolic body weight (MBW) = $BW^{0.75}$. An animal with a high MBW will have higher energy requirements and is more likely to be a concentrate selector (Van Soest, 1994). Physiological status of animals can have an effect on intake, where pregnant or lactating animals will have higher energy requirements and will need to either eat more or select a diet of higher quality. Intake rate and time spent grazing also has an effect on intake as animals are able within certain limits to alter grazing behaviour when herbage is sparse and are able to increase intake rate. Other factors controlling grazing intake include the animal's capacity to utilize energy which is related to the animal's genetic capacity to utilize energy.

2.2.8 Negative associative effects

Ruminants decrease intake of feeds containing alkaloids, condensed tannins and glucosinolates (Provenza, 1998). The aversion to a particular feed increases with severity of the illness and decreases with increasing delay between feed ingestion and illness caused by that feed. From this the conclusion can be made that animals are able to recognize feeds based on previous experience (Forbes & Provenza, 2000) and the effect it has on the internal environment. Ruminant animals are thus able to learn to associate the post ingestive consequences of eating a feed with the sensory properties of that feed and they use these conditioned preferences and aversions to direct their selection between feeds (Forbes & Provenza, 2000).

2.2.9 Effect of forage type on animal intake and performance

The seasonal change in the quality of forage during a given year as well as the type of forage has a marked effect on animal performance (Groenewald, 1986). The highest quality pastures and intake in tropical climates is usually in spring with lower quality and lower intakes during autumn and winter (Hardy *et al.,* 1997*).*

Cool season grasses (CSG) are more digestible than warm season grasses (WSG) because proportions and arrangements of tissues differ because of differences in photosynthetic pathways and optimal growing temperatures (Akin 1989). Warm season grasses reach flowering earlier than CSG, resulting in a greater proportion of stem (Morris,

1983). Mesophyll and phloem of both grasses are degraded rapidly, but digestion of WSG is slower due to a greater concentration of phenolic compounds (Akin, 1989) and the tightly packed, radial tissue arrangement (Hanna *et al*., 1973). Due to the differences in types and arrangement of tissues, the proportion of ruminal bacteria associated with WSG is greater.

Lag time of ruminal cell wall digestion is longer and digestion rate is slower for WSG because time for hydration and adherence is longer for WSG (Mertens & Loften, 1980). Greater phenolic acid concentrations in WSG may restrict attachment in some areas. Increasing soluble carbohydrate content increases protozoal numbers, therefore, protozoal numbers should be greater with CSG. Ruminal fungi contribute more to the digestion of WSG due to the inverse relationship between fungi and forage quality (Akin, 1986).

With high feed intakes a greater proportion of fibre digestion will take place in the rumen of WSG than CSG. This is likely because of the greater cell wall proportion, lower microbial protein synthesis, lower voluntary intake and slower digesta passage rate for warm season grasses (Sun *et al*., 1992).

The low non cell wall content, relatively low nitrogen content and overall high resistance of cell wall components to microbial digestion all contribute to low duodenal flow of microbial and feed protein with WSG (Doyle, 1987). Intestinal amino acid deficiencies may restrict animal performance and feed intake (Kempton & Leng, 1979). Low fermentability of WSG limits volatile fatty acid production. The fall in voluntary intake with increasing maturity is less for WSG because changes with maturity in physical and chemical characteristics of WSG are less (Jones & Wilson, 1987).

Feed intake is the principal limitation to performance by ruminants consuming WSG. Fermentation of WSG yields little propionate resulting in low efficiency and the low amino acid supply with WSG can limit protein synthesis (Hart & Leibholz, 1985).

2.2.10 Feed intake prediction

Equations should be used as a guideline to predict intake and are not an absolute prediction of intake. When forage makes up a substantial proportion of an animal's diet, special considerations need to be taken into account when determining its nutrient requirements. Because of this Pittroff & Kothmann (2001) found evidence that the two most widely used systems for calculating nutrient requirements for cattle namely the NRC and ARC seemed to not be adequate for application in grazing situations.

An empirical intake prediction equation for different animal species and forage types was developed by Meissner & Paulsmeier (1995). The intake of non-lactating ruminant species could be predicted with the same relationship from the ratio between *in vitro* digestibility of organic matter (IVDOM) and NDF as given in Equation 1.

Equation 1: OM intake g/kg/$BW^{0.9}$/day = 70-$97^{-0.975\ (IVDOM/NDF)}$

The NRC (2000) concluded that further research is needed to develop more accurate means of predicting intake by beef cattle fed all forage diets. Equation 2 was developed by the NRC (2000) as a best-fit equation on a dataset by Mathison *et al.* (1986) on 139 observations of *ad libitum* DMI by beef cattle consuming forages in 3 classes (65 grasses, 39 legumes, 35 grass/legume mixtures). The shrunk body weight (SBW) was used, which is the animal weight after an overnight fast with no feed or water, and is typically 96% of full body weight (NRC, 2000).

Equation 2: NRC DMI (kg)/$SBW^{0.75}$ = 0.002774 x CP% (forage) – 0.000864 x ADF% (forage) + 0.09826

This equation is best suited for determining intake of Namibian forage due to the fact that both crude protein (CP) and ADF concentrations could easily be determined by oesophageally fistulated cattle The extruse samples would however need to be freeze-dried (Engels *et al.*, 1981) to ensure that oven drying did not affect the ADF concentrations.

The most conventional method for predicting intake is by means of total faecal collection using faecal collection bags (Cordova, 1978). The researcher only needs the total amount of faeces voided and the digestibility of the forage to make intake calculations of the animal (Coleman, 2005). The process however is cumbersome with large amounts of faeces collected each day. The bags are troublesome to fit and the loss of some faeces is also a possibility (Adegosan *et al*., 2000).

The use of indigestible markers dosed to animals at known quantities is probably one of the most widely used techniques to determine intake by grazing animals (Coleman, 2005). The concept of the marker technique is that the indigestible markers are fed to animals until an equilibrium is reached. The amount of marker fed to the animal per unit of time is equal to the amount of marker excreted per unit of time (Coleman, 2005).

Animal intake can be determined by studying the grazing behaviour of the animal. Intake is the product of three parameters: grazing time, bite rate and bite size (Rook *et al*., 2004). The grazing time and bite rate can be measured by visual observation (Rook *et al*., 2004).

2.3. Intake predictions of cattle in Namibia

Van Schalkwyk (1978) published intake guidelines derived by the chromic oxide marker method for growing cattle together with forage quality parameters determined by OF.

In Table 2, the average intakes for two different cattle breeds (Afrikaner and Simmental) at three different physiological stages with four replications each were used under free grazing management (24 animals per breed). No differences ($P<0.05$) in intake were found between breeds of the same physiological state although differences were found between different physiological states ($P<0.05$). All cattle had *ad libitum* access to a phosphorus and salt nutrient supplement.

Table 2 Rainfall and forage CP (DM) concentrations collected by oesophageally fistulated cattle in comparison to average daily dry matter intake (g/kg liveweight) of Afrikaner and Simmental growing heifers (15 months to 27 months of age) determined by chromic oxide marker method (Van Schalkwyk, 1978)

Period	Rainfall (mm)	CP % (DM)	Afrikaner (g/kg LW)	Simmental (g/kg LW)	Average (g/kg LW)
Apr, May, Jun 1977	33	9,2	33,6	31,5	32,6
Jul, Aug, Sep 1977	0	4,7	25,8	26,2	26
Oct, Nov, Dec 1977	84	6,4	28,4	28,2	28,3
Jan, Feb, Mar 1978	405	12,7	30,9	32,4	31,6

Every month, OF samples were collected over three consecutive days from three animals from each breed. The average dry matter intake ranged between 26.0 and 32.6g/kg live weight.

In Table 3 the DM intake of heifers in gestation on to early lactation were from 21.4 to 46.9g/kg liveweight. The intakes of cows during late lactation to the dry period were from 29.0g/kg up to 43.1g/kg.

Table 3 Average daily DMI in g/kg liveweight on combined data from Afrikaner and Simmental cows determined by the chromic oxide marker method, under free grazing management, without a phosphorus deficiency (Van Schalkwyk, 1978)

Age over period	27 to 39 months		39 to 51 months	
Period	Pregnant	Early Lactation	Late Lactation	Dry cow
Apr, May, Jun 1977	25,2	-	36,9	-
Jul, Aug, Sep 1977	21,4	-	29,4	-
Oct, Nov, Dec 1977	24,6	-	-	29
Jan, Feb, Mar 1978	-	46,9	43,1	-

2.3.1 Intake prediction based on seasonal forage quality in Namibia

The NRC (2000) suggested that intake prediction equations would have to be developed for the specific beef cattle production situation it was intended to be used in. Equation 2 was adapted into two new intake prediction equations (Equation 3 and 4) that could be used more accurately to estimate intake from forage quality parameters collected by OF during the wet and dry seasons in Namibia (NRC, 2000).

Equation 3: Wet season DMI (kg) / $SBW^{0.795}$ = 0.002774 x CP(OM%) – 0.000864 x ADF(DM%) + 0.09826

A SBW scalar set at 0.795 has the best fit during a wet season with extrusa CP concentrations above 8%.

Equation 4: Dry season DMI (kg) / $SBW^{0.815}$ = 0.002774 x CP(OM%) – 0.000864 x ADF(DM%) + 0.09826

A SBW scalar set at 0.815 has the best fit during a dry season with extrusa CP concentrations of less than 8%.

In Table 4 the average intake for Afrikaner cattle determined by the chromic oxide marker method over a one year period was 8.95kg (Van Schalkwyk, 1978). The average intake calculated in Equation 2 (NRC, 2000) from forage quality parameters determined by Afrikaner OF (Van Schalkwyk, 1978) was 6.60kg, presenting a 26.5% under estimation.

The average intake calculated by Equation 3 for the wet season, from April to June and January to February, and Equation 4 for the dry season, from July to November,

resulted in an average intake of 8.96kg which was a 0.5% over prediction on the actual intake.

Table 4 Intake of growing Afrikaner cattle determined by chromic oxide marker method (Van Schalkwyk, 1978) in comparison to results obtained by using parameters from forage collections by oesophageally fistulated cattle (Van Schalkwyk, 1978) in Equation 2 (Mathison *et al*., 1986) and decreased bias from Equation 3 and Equation 4

	CP (OM)[1]	ADF (DM)[2]	SBW[3]	Intake[4]	NRC[5]	Bias	Equation 3 & 4	Bias
April	12,12	33,92	289	**10,1**	7,2	-28,90%	9,3[6]	-8,20%
May	9,94	34,8	286	**8,6**	6,7	-22,80%	8,6[6]	-0,40%
June	9,59	32,95	289	**10,2**	6,8	-34,10%	8,7[6]	-14,90%
July	4,84	43,94	286	**7**	5,1	-26,30%	7,4[7]	6,50%
August	5,94	43,03	289	**8,8**	5,4	-38,10%	7,9[7]	-10,50%
September	4,21	47,6	285	**6,5**	4,8	-26,50%	6,9[7]	6,20%
October	6,78	41,54	295	**8,4**	5,8	-31,30%	8,4[7]	-0,60%
November	7,81	40,99	294	**8,9**	6	-32,90%	8,7[7]	-2,90%
December	6,68	39,64	295	**7,7**	5,9	-23,70%	8,5[7]	10,50%
January	18,48	39,63	310	**9,9**	8,5	-13,80%	11[6]	11,60%
February	13,33	32,69	348	**10,7**	8,6	-19,60%	11,2[6]	4,70%
March	11,89	32,74	355	**10,6**	8,4	-20,40%	11[6]	3,70%
Average				**8,95**	**6,6**	**-26,50%**	**8,96**	**0,50%**

1 CP corrected for ash, to an organic matter basis, in samples obtained by 3 oesophageally fistulated cattle with pooled collections over 3 days.

2 ADF not corrected for ash, on a dry matter basis, on samples obtained by 3 Afrikaner oesophageally fistulated cattle with pooled collections over 3 days, samples were freeze dried.

3 Shrunk body weight of chromic oxide marker method group determined after a 12 hour fast.

4 Intake determined by chromic oxide marker method on 8 Afrikaner cattle

5 Intake determined by Equation 2 developed by NRC (2000) from data generated by Mathison *et al.* (1986).

6 Intake calculated by Equation 3 for wet season forage that contains >8% CP.

7 Intake calculated by Equation 4 for dry season forage that contains <8% CP.

In Table 5 the average intake for growing Simmental cattle determined by the chromic oxide marker method over a one-year period was 11.50kg (Van Schalkwyk, 1978). The average intake calculated in Equation 2 (NRC, 2000) from forage quality parameters determined by Simmental OF (Van Schalkwyk, 1978) was 8.24kg, presenting a 28.0% under prediction of intake.

Table 5 Intake of growing Simmental cattle determined by chromic oxide marker method (Van Schalkwyk, 1978) in comparison to results obtained by using parameters from forage collections by oesophageally fistulated cattle (Van Schalkwyk, 1978) in Equation 2 (Mathison *et al*., 1986) and decreased bias from Equation 3 and Equation 4

Month	CP (OM)[1]	ADF (DM)[2]	SBW[3]	Intake[4]	NRC[5]	Bias	Equation 3 & 4	Bias
April	12,83	30,71	375	**15**	9,1	-39,10%	11,9[6]	-20,50%
May	9,57	34,52	374	**8,9**	8,1	-9,60%	10,5[6]	18,00%
June	10,36	30,8	375	**11,5**	8,6	-25,50%	11,2[6]	-2,70%
July	6,5	41,98	360	**8,3**	6,6	-20,60%	9,7[7]	16,40%
August	6,34	43,89	375	**11,3**	6,6	-41,30%	9,8[7]	-13,80%
September	4,55	46,17	368	**9,3**	6	-35,90%	8,8[7]	-5,90%
October	6,41	42,38	383	**10,5**	6,9	-34,60%	10,1[7]	-3,70%
November	8,41	41,25	388	**11,3**	7,5	-33,70%	11,1[7]	-2,30%
December	7,51	40,34	388	**10,8**	7,4	-31,60%	10,8[7]	0,70%
January	19,3	39,8	396	**13,8**	10,4	-24,50%	13,6[6]	-1,20%
February	15,78	31,51	423	**14,6**	10,7	-26,50%	14,1[6]	-3,50%
March	15,15	32,46	452	**12,6**	11	-12,60%	14,5[6]	15,10%
Average				**11,5**	**8,24**	**-28,00%**	**11,34**	**-0,30%**

1 CP corrected for ash, to an organic matter basis, in samples obtained by 3 oesophageally fistulated cattle with pooled collections over 3 days.

2 ADF not corrected for ash, on a dry matter basis, on samples obtained by 3 Afrikaner oesophageally fistulated cattle with pooled collections over 3 days, samples were freeze dried.

3 Shrunk body weight of chromic oxide marker method group determined after a 12 hour fast.

4 Intake determined by chromic oxide marker method on 8 Afrikaner cattle

5 Intake determined by Equation 2 developed by NRC (2000) from data generated by Mathison *et al.* (1986).

6 Intake calculated by Equation 3 for wet season forage that contains >8% CP.

7 Intake calculated by Equation 4 for dry season forage that contains <8% CP.

The average intake calculated by Equation 3 for the wet season, from

April to June and January to February, and Equation 4 for the dry season, from July to November, resulted in an average intake of 11.34kg which was a 0.3% under prediction of the actual intake.

2.4 MINERAL STATUS OF GRAZING RUMINANTS

2.4.1 Introduction

Mineral elements potentially lacking under grazing conditions for ruminants are Ca, P, sodium (Na), cobalt (Co), copper (Cu), iodine (I), selenium (Se) and zinc (Zn) (McDowell, 1996). Mineral requirements for cattle will depend on the animal's level of productivity, genotype, age, sex and physiological state (Masters & White, 1996). It is based on the assumption that all other minerals and interfering components are present at specific required levels, any deviation would change the requirement for the specific mineral (Van Ryssen, 2000).

Factors affecting mineral concentrations in plants include (Van Ryssen, 2006). :

• Plant species differ in its potential to take up minerals from soils;

• Plant maturity and plant parts;

• Soil type - minerals present in soil;

• Soil acidity – affect mineral availability to plants;

• Levels of other elements that interact with the absorption of a specific element;

• Fertilizers, dung and urine;

• Contamination - acid rain, sulphur in water, dust and pollution, etc.

2.4.2. Osteochondrosis

In 1982, a new syndrome (osteochondrosis) manifested in, amongst others, areas in South Africa where aphosphorosis was rife. Osteochondrosis was also identified in the south-western parts of Namibia as well as southern Botswana (Botha *et al*., 2016).

Osteochondrosis is a common joint disorder which affects many species. A number of possible aetiologies and predisposing factors have been proposed to be involved in the cause of osteochondrosis, these include over-nutrition, rapid growth, genetics (Hittmeier *et al.* 2006), ischaemia, excess dietary calcium, hormonal influences and trauma (Trostel *et* al., 2002). Osteochondrosis in cattle is found in all types of husbandry systems, including feedlots (Heinola et al. 2006), pure-bred beef (Dutra *et* al. 1999), dairy (Trostle et al. 1997) and animals grazing rangelands (Hill et al. 1998).

Cattle affected with this disorder develop effusions in the weight-bearing joints, in particular the femoro-tibial (stifle) joint, associated with inflammation and pain, causing

lameness of varying degrees (Botha *et al*., 2016). As a result, animals are unable to walk long distances for grazing, have decreased feed intake, have decreased milk production and a loss in body condition, and bulls have decreased mating ability (Persson *et al*., 2007). Animals are often eventually slaughtered as a result of severe lameness and loss of condition.

From a geological point of view, the north-western parts of South Africa, the south-western parts of Namibia, as well as southern Botswana where osteochondrosis was reported are characterised by the presence of superficial dolomitic (carbonate) rock formations (Botha *et al*., 2016). The area also has a history of well-documented syndromes in cattle that are due to mineral deficiencies or imbalance. The best known of these is osteomalacia resulting from aphosphorosis, described by Theiler (1912), which also results in lameness and became known as 'stiff-sickness'.

Davies & Munro (1999) described an outbreak of osteochondrosis in bull beef cattle following failure to provide dietary mineral and vitamin supplementation. Analysis of the metacarpal bone from two bulls revealed adequate magnesium, phosphorus and bone ash, but a slightly low calcium concentration. The vitamin A concentration was also low. Dietary analysis suggested inadequate calcium, sodium and copper intake and mild deficiency of vitamins A, D and E. A balanced mineral and vitamin supplement was added to the diet when it became clear that the supplement had been omitted. A gradual clinical improvement was seen in the majority of the animals. This outbreak provides evidence that in some cases a mineral and vitamin imbalance is a likely contributing factor to the development of osteochondrosis in growing cattle.

Calcium deficiency, with a distorted calcium-to-phosphate ratio, was associated with an outbreak of osteoarthritis in fattening bulls that was probably osteochondrosis. Osteoarthritis lesions occurred in more than 80% of the animals with a calcium-deficient diet (Heinola *et al*., 2006).

Extensive on-farm trials have confirmed that supplementation with balanced minerals, bioavailable phosphorus and vitamins has a significant impact on preventing and curing the condition in the field. Commercial mineral supplements have been formulated for use in affected areas (Botha *et al*., 2016).

2.4.3. Mineral analysis of feed

One could analyse the mineral content of the feed to ensure that the animal is receiving adequate quantities of essential nutrients, however there are certain factors limiting interpretations that can be made from feed analyses (Van Ryssen, 2015):

- Tables of requirements for most elements are uncertain and give incomplete information;
- Animals eat selectively, it is therefore difficult to establish the composition of the consumed feed. Using the oesophageal fistula technique may help increase the accuracy of the estimate of mineral content of feed consumed by the animal;
- The amount of feed and thus the amount of mineral taken in are often unknown;
- Water may contain substantial amounts of elements, which is quite often unknown. Total amount taken in through the water intake is usually also unknown and difficult to determine;
- Minerals ingested through soil can be substantial;
- The bio-availability of elements can vary depending on factors such as the chemical form the mineral is present in;
- There may be antagonistic or synergistic interactions between elements in their metabolism in the body;
- The bio-availability of some elements is controlled homeostatically.

2.4.4. Importance of phosphorus in the grazing animal

Research has shown that a phosphorus (P) deficiency was the most prevalent mineral deficiency throughout the world in grazing livestock (NRC, 2000). Deficiency symptoms include a depressed appetite, suboptimal growth and feed efficiency, depressed fertility and pica which may lead to botulism (Karn, 2001). In serious cases of deficiency the animal will display swollen and stiff joints as well as brittle bones (Karn, 2001).

Assessing the P status of the animal will help with subsequent preventative strategies or treatments. Blood/plasma Pi concentration can be used as a status indicator as well as rib bone analyses (per volume bone) (Van Ryssen, 2003).

2.4.5. Calcium

Calcium (Ca) is absorbed primarily from the duodenum and jejunum by both active and passive diffusion (McDowell, 2003). Diets high in fat can decrease Ca absorption through the

formation of soaps (Oltjen, 1975). Calcium requirements are influenced by age, weight and stage of production (NRC, 2016).

Signs of Ca deficiency include rickets, retarded growth and development and osteomalacia characterized by weak, brittle bones that can break when stressed (NRC, 2016).

2.4.6. Magnesium

Dietary requirements for magnesium (Mg) vary depending on age, physiological state, and bioavailability from the diet. As a percentage of DM, recommended Mg requirements are 0.10% for growing and finishing cattle, 0.12% for gestating cows and 0.20% for lactating cows (NRC, 2016).

True absorption values for Mg in mature ruminants fed hay and grass range from 10 to 37% of the Mg content of the material (ARC, 1980). Other factors affecting Mg content of forages will be discussed in more detail later on.

Low levels of forage Mg may lead to a condition known as hypomagnesemia or grass tetany and can be identified by subnormal serum magnesium (Suttle, 2010). Initial signs of grass tetany are nervousness, decreased feed intake and muscular twitching around the face and ears (NRC 2016). Grass tetany can occur in older cows grazing lush spring pastures where the problem is due more to insufficient quantity rather than the forage being low in Mg. Fertilizing pastures with N and K is associated with increased incidence of grass tetany as these minerals act as antagonists to magnesium absorption (Martens & Schweigel, 2000).

The Mg concentration in forages depends mainly on the plant species and the seasonal and climatic conditions during plant growth, with soil origin being of little importance (Jumba *et al*., 1995). Grasses in temperate and tropical pastures contain on average 1.8 and 3.6 g/kg dry matter, respectively, and legumes 2.6 and 2.8g/kg DM, respectively (results for 930 forage samples). In temperate grasses 65% of samples contain <2g/kg DM (Minson, 1990).

Magnesium concentrations are low in spring when potassium concentrations are high, legume contribution is small and risk of grass tetany is at its highest (Suttle, 2010). High dietary concentrations of nitrogen, organic acids, long-chain fatty acids, calcium and phosphorus can also decrease Mg absorption or utilization (Chester-Jones *et al*., 1989).

2.4.7. Zinc

The recommended requirement of zinc (Zn) in beef cattle diets is 30mg of Zn/kg dietary DM (NRC, 2016). Zinc absorption is homeostatically controlled, and cattle adjust the percentage of dietary Zn absorbed based on their need for growth or lactation (Miller, 1975).

A Zn deficiency is characterized by a loss in appetite, growth depression, abnormalities of the skin and reproductive failure. Zinc plays a role in appetite control, antioxidant defence, gene expression and fat absorption (Suttle, 2010).

A high proportion of all pasture Zn values recorded worldwide lie between 25 and 50 mg/kg DM (range 7 to >100 mg/kg DM) (Minson, 1990). The main influences are soil Zn status and sward maturity (Minson, 1990).

2.4.8. Copper

Requirements for copper (Cu) range from 4 to more than 15mg/kg dietary DM, depending on the concentration of dietary Mo and S. The recommended concentration of Cu in beef cattle diets is 10 mg Cu/kg diet provided the diet does not exceed 0.25% S and 2mg Mo/kg (NRC, 2016).

Copper is known to play a role in cellular respiration, ion transport and protection from antioxidants. Known symptoms of copper deficiency include ataxia, abnormal wool and hair, depigmentation, anaemia, bone disorders, connective tissue disorders, susceptibility to infection and infertility (NRC, 2016).

Molybdenum has an antagonistic action on Cu metabolism which is exacerbated when S is high (NRC, 2016). There is evidence that molybdate and sulphide interact to form thiomolybdates in the rumen. Copper then reacts with the thiomolybdates in the rumen to form insoluble complexes that are poorly absorbed. Sulphur decreases Cu absorption via the formation of copper sulphide in the gut (Suttle, 1991).

The Cu content of pastures and forages varies with the species, strain and maturity of the plant, with certain soil conditions (not pH) and with the fertilizers used (McFarlane *et al*., 1990). Temperate grasses tend to contain less Cu than legumes grown in the same conditions (4.7 versus 7.8 mg/kg DM, respectively), but under tropical conditions the position is reversed (7.8 versus 3.9 mg/kg DM, respectively) (Minson, 1990).

2.4.9. Manganese

The manganese (Mn) requirements for growing and finishing cattle is 20mg of Mn/kg diet whilst the Mn requirements for reproduction are greater at 40mg of Mn/kg diet (NRC, 2016).

The functions of Mn are linked to metalloenzymes such as pyruvate carboxylase and superoxide dismutase which are activated by this element (Suttle, 2010). Manganese deficiency can result in low reproductive performance characterized by irregular oestrus, low conception rate, abortion, still births and low birth weights (NRC, 2016).

Pastures vary markedly in Mn about a high mean value of 86 mg/kg DM, and only 3% of the grass samples reported on by Minson (1990) had <20 mg/kg DM. Differences due to species and state of maturity are generally small (Minson, 1990), but may be masked by high values arising from soil contamination. Soils usually contain 300–1100 mg/kg DM (Suttle *et al*., 2003), much more than the pasture the soil supports. Increases in soil pH markedly decrease manganese uptake by plants.

High dietary Ca and P might also interfere with Mn availability (Spears, 2003).

2.5 OESOPHAGEAL FISTULA TECHNIQUE

2.5.1 Introduction

Increasing feed costs and the need for more efficient food production have drawn attention on the need for more effective evaluation of forage in terms of its nutritive value for ruminants.

The major limitation in accurately estimating chemical composition of feed is obtaining samples that truly represent the diet as selective grazing often results in a diet being different from the pasture on offer (Soder *et al*., 2009).

Two basic approaches are available for obtaining representative samples of the diet selected by range ruminants. The first approach involves the manual collection of forage by following and observing what the animals grazed and then attempting to mimic their selection manually (Decruyenaere *et al*., 2009). The method is rapid, inexpensive and simple, however the hand-plucking method is subject to a mostly unknown bias, as hand-plucked samples are unlikely to represent what the animal has actually taken in due to the simulation technique being imperfect. The method appeared successful if an elaborated stratified sampling approach was used (Wallis de Vries, 1995).

The second approach uses surgically altered (rumen or oesophageal fistula) animals (Coleman, 2001). Rumen evacuation through a ruminal cannula provides satisfactory results and direct comparisons with oesophageal fistulated cattle (OF) results could be made (Olson, 1991). The disadvantages of the rumen cannula above the OF is the time and labour needed to clean and then evacuate the rumen, and additionally the rumen evacuation subjected animals to abnormal physiological conditions (Holechek *et al*., 1982).

2.5.2 Forage quality determination

The most accurate representation of the diet selected by free-ranging ruminants was given by samples collected from OF (Holechek *et al*., 1982). Problems associated with OF sampling were surgery, salivary contamination, rumen content contamination, incomplete collections and obtaining a representative sample (Holechek *et al*., 1982). Another disadvantage was the cost in labour and time needed to properly care for the animals (Coates & Penning, 2000).

2.5.3 Saliva contamination

Mckay *et al.* (1969) studied the effect of saliva on extrusa and found the impact to be minimal. Hart (1983) observed that except for ash, any differences in composition between

forage and extrusa organic constituents were small and probably within the limits of experimental error. To minimise contamination of saliva on the extrusa sample it was lightly squeezed to remove excess saliva. Hart *et al.* (1983) found that rinsing samples with distilled water, compared to squeezing to remove saliva, resulted in significant negative effects on results and discouraged the practice. Rinsed samples were consistently lower in crude protein and IVDOM and usually higher in the different fibre fractions. Although urea was recirculated in saliva, the nitrogen concentration of extrusa provided a reliable estimate of the nitrogen concentration of herbage consumed (Langlands, 1966). There were no differences observed in the protein content of forage selected by OF that received different nutrient supplements containing protein (Bredon *et al.*, 1970).

Similarly the sulphur, copper, molybdenum, calcium, magnesium and zinc concentrations in extrusa could be used to predict dietary concentrations from homogenous forage samples (Pinchak *et al*., 1990).

Although it has been shown that salivary contamination of fistula samples may elevate P content (Pinchak *et al*., 1990), the oesophageal fistula technique still represents the most readily accepted method of sampling forage P for chemical analysis (Karn, 1995).

2.5.4 Sample numbers

Three animals used over three consecutive days for collection gave optimal sample numbers, although three animals over two consecutive days would theoretically be sufficient if all samples were usable (Bredon & Short, 1971). Six or fewer animals were sufficient to sample all dietary chemical constituents within 10% of the mean with 95% confidence (Van Dyne & Heady, 1965). Van Schalkwyk (1978) subsequently found in Namibia that three animals would be sufficient to sample natural pastures for the determination of CP, IVDOM and ADL.

2.5.5 Drying

Rapid and efficient drying of forage material without changing its chemical composition or causing excessive dry matter loss was a fundamental concern (Karn, 1991). When accurate fibre content in extrusa were to be determined, it should be done by freeze-drying but where N (Engels *et al*., 1981) and ash content (Karn, 1991) were to be determined the drying by microwave (Karn, 1991) or conventional oven was acceptable. Karn (1991) suggested that extrusa (350g) could be microwave-oven dried (650W Output) for 30min with a beaker containing 300ml water followed by drying in a forced air oven at 50°C. Concentrations of ADF, acid detergent insoluble nitrogen (ADIN) and NDF tended to be

higher in samples dried in either a microwave or conventional forced air oven compared with freeze dried samples (Karn, 1986). No significant differences were observed for sample size, extended drying time or sample freezing before drying on the chemical composition of samples dried in conventional forced-air oven (Karn, 1986).

Differences between drying methods were probably a result of nonenzymatic browning of extrusa during oven- and air-drying processes compared to freeze-drying (Burritt *et al*., 1988). The nonenzymatic browning is a chemical reaction involving the condensation of sugar residues and amino acids followed by polymerisation to form a brown complex containing 11% nitrogen with physical properties similar to lignin. Unsaturated oils and phenolic compounds, such as tannins, may copolymerize in the reaction. Extrusa samples are typically saturated with saliva, which resulted in increased moisture and pH. This increases the nonenzymatic browning reaction in the extrusa samples and results in the formation of artefact lignin (Burritt *et al*., 1988).

Burritt *et al*. (1988) found freeze-drying was the only method that never artificially elevated fibre fractions (NDF and lignin) due to the formation of artefact lignin during the drying process of an oven at 40°C or being air-dried. Burritt *et al*. (1988) found hemicellulose increased with drying temperature. The digestibility of extrusa was more depressed with forages containing phenolic compounds where the oven- or air-drying may have decreased the solubility of these tannin complexes *in vitro* due to proteins complexing with tannin as well as carbohydrates. Burritt *et al*. (1988) found that extrusa containing immature forages was the most susceptible to oven or air-drying due to higher concentrations of protein and carbohydrates. Oven and air-drying had elevated lignin and decreased IVDOM of bush containing phenolic compounds throughout the growing season.

2.5.6 Reporting of results

McKay *et al.* (1969) found no additional advantage in calculating the CP concentration on an organic matter basis when cattle were fed cut grass and that salivary ash contamination of the samples was minimal. Decreased organic matter content of masticate samples (Olson, 1991) as a result of soil and salivary mineral contamination was corrected for by reporting results on an organic matter basis as defined by Equation 5 (Wallace et al., 1972).

Equation 5 Organic Matter % = Dry matter % – Ash %

2.6 NUTRITIONAL STATUS INDICATOR: FAECAL INDICATORS

2.6.1 Phosphorous

Faecal endogenous P (predominantly from saliva but also intestinal cells and digestive secretions) was the main pathway of phosphorus excretion and averaged 85% of total faecal P. Bravo *et al.* (2003) indicated that an increase in total fibre content of the diet tended to increase saliva secretion and therefore increased the faecal endogenous P flow. The remaining 15% was unabsorbed dietary P and that relatively high urinary P excretion was observed under specific nutritional conditions (Bravo *et al.*, 2003).

Read *et al.* (1986) indicated that faecal P concentrations were likely more indicative of an animal's diet P concentration than an indicator of P status. Read *et al.* (1986) and Groenewald (1986) found that faecal P concentrations were insensitive for distinguishing between supplemented and unsupplemented cattle due to a decrease in feed intake caused by the P deficiency resulting in a lower faecal output. The collections of total faecal output to quantitatively determine P output would be the only reliable measure to relate to P intake by the free-ranging ruminant. Grant *et al*. (1996) showed that faecal phosphorus concentrations in cattle showed a very distinct seasonal pattern.

Grant (1989) recommended that faecal P below 2.2g/kg showed a dietary deficiency in P and that supplementation of P was recommended. The upper critical value for faecal P was 3.5g/kg, should the values have been higher than this the supplementation of this nutrient should be decreased. The intermediate range for P at 2.2 to 3.5g/kg was shown to be normal.

2.6.2 Crude Protein

Grant (1989) found that the N concentrations in faeces could be a practical tool to indicate the N status of the diet consumed, however this method can be unreliable due to the contamination of microbial protein in the faeces. Faecal CP concentrations of below 65g/kg showed a deficiency and that the supplementation of CP was recommended. The upper critical value for CP was 100g/kg and should the values have been higher than this the supplementation of this nutrient should be decreased.

2.7. NUTRITIONAL STATUS INDICATOR: RUMINAL FLUID

2.7.1 Ammonia-N

Ruminal ammonia-N concentrations can be used as a qualitative reference to understand the adequacy of the rumen environment for microbial activity on fibrous carbohydrates (Hoover, 1986). Rumen ammonia-N concentration represents the balance between the formation of ammonia-N in the rumen, utilization by rumen bacteria, metabolism in the rumen wall, absorption into the portal vein and passage into the omasum (Van Soest, 1994).

Satter & Roffler (1977) reported that the concentration of ammonia (NH3-N/100ml) in the rumen of cattle where insufficient nitrogenous substrates for rumen microbial growth occurred was between 2mg/100ml rumen fluid (1.17mmol/l) and 5mg/100ml rumen fluid (2.94mmol/l). Leng (1990) suggested that rumen liquor concentrations were optimal at 6-10mg/100ml rumen fluid (3.52-5.87mmol/l). Detmann *et al*. (2009) showed that optimal NDF degradation rate was achieved at a rumen ammonia-N level of 8mg/100ml.

2.7.2 Volatile Fatty Acids

Volatile fatty acids (VFA) account for 60-70% of metabolisable energy in ruminants (Van Soest, 1994), and are therefore of great importance in beef production. Changes in microbial metabolism can affect how much energy is partitioned between the VFA, methane and heat of fermentation. Total VFA concentration depends on type of diet, level of intake, frequency of feeding and feed additives (Araba *et al*., 2002). The molar proportions of the acids in the rumen liquor broadly indicated the relative rates of production of VFA's. The composition of the mixture of VFA's produced did not only reflect the composition of the substrate fermented but also the metabolic activity of the rumen microbes. Higher total VFA concentrations in the rumen generally reflect increased ruminal microbial fermentation (Loëst *et al.*, 2001).

Diets composed of only forages gave rise to typical VFA mixtures (on a molar basis) of 65-74 % acetic acid, 15-20% propionic acid and 8-16% butyric acid (Thomas & Rook, 1981). Thomas & Rook (1981) characterised the digestion of mature fibrous forages as resulting in high proportions of acetic acid (>68%) and less mature forages tended to give lower acetic acid (64 - 68%). The addition of concentrates to the diet would increase the proportion of propionic or butyric acid or both at the expense of acetic acid (Klevesahl *et al.*, 2003).

Rumen butyric acid concentration had the strongest relationship with dry matter

intake while rumen pH had a negative relationship to total VFA concentration in rumen fluid (Seymour *et al.*, 2005). Rumen acetic acid had nearly no relationship to dry matter intake while a stronger relationship started to show for propionic acid (Seymour *et al.*, 2005).

CHAPTER 3 MATERIALS AND METHODS

3.1. Experimental unit

3.1.1. Location

The trial was carried out on two farms in the western parts of Namibia in the so called "Hardeveld areas". The one farm was located in the Kalkfeld area (Thornbush savanna), coordinates 20.8909° S, 16.1904° E. The other farm was located in the Kamanjab area (Mopanie savanna), coordinates 19.6272° S, 14.8425° E.

3.1.2 Climate

The Mopane treatment's average rainfall over the two year period was 558 mm per annum, the average rainfall in this region is 317 mm per annum (Ministry of Agriculture, Water and Forestry, 2011). The Kalkfeld treatment's average rainfall over the two year period was 530 mm per annum the average rainfall in this region is 346 mm per annum (Ministry of Agriculture, Water and Forestry, 2011). The rainfall for the two treatments over the two year trial period is depicted in Figures 3 and 4.

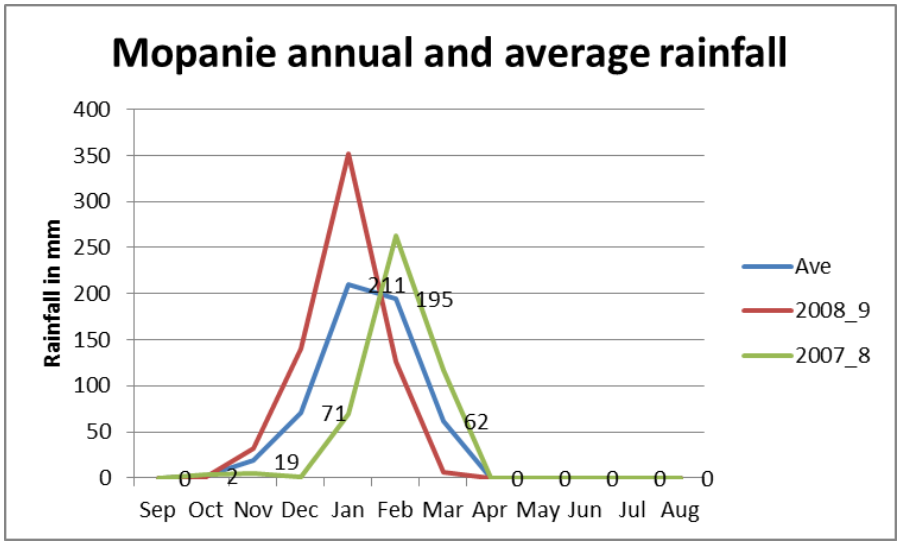

Figure 3 Mopane annual and average rainfall

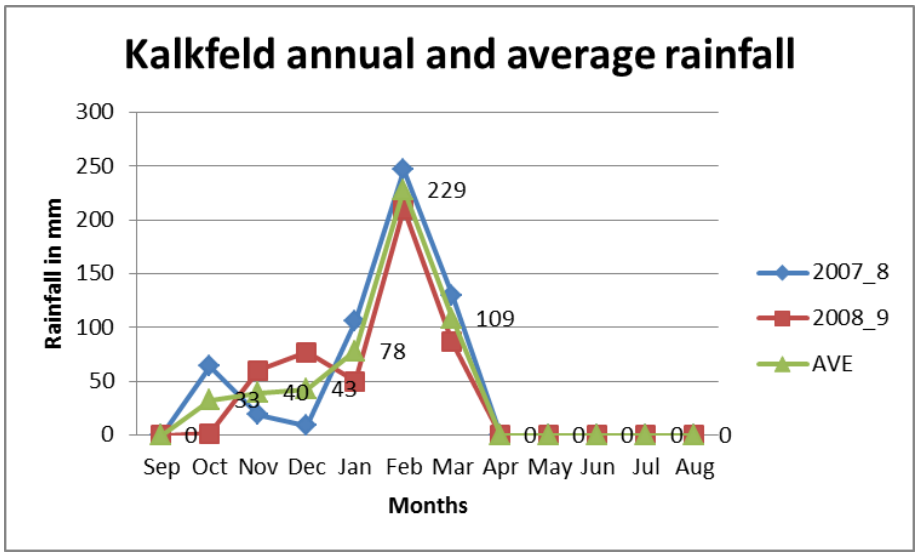

Figure 4 Kalkfeld annual and average rainfall

The maximal rainfall was recorded during the month of January. The peak of the rainy season occurred over January, February and March which are defined as the core rainfall months (Olszweski, 1996).

3.1.3 Vegetation

According to Giess (1971), the Kalkfeld Treatment was situated in the Thornbush-savanna and the Mopane Treatment which was situated close to Kamanjab was located in the Mopane-savannah. Figure 4 clearly indicates the different vegetation types in Namibia.

According to the Geiss (1971), *Colophospermum mopane* is the characteristic species of the mopane-savanna vegetation type and it either occurs as a shrub or tree depending on local conditions.

The vegetation varies in different parts of the Thornbush Savanna, but the characteristic feature is grassland with trees and bigger shrubs in dense or open clumps of varying size. Over large parts of this region *Acacia* spp. are dominant and in some places bush encroachment by *Acacia melifera* takes place (Geiss, 1971).

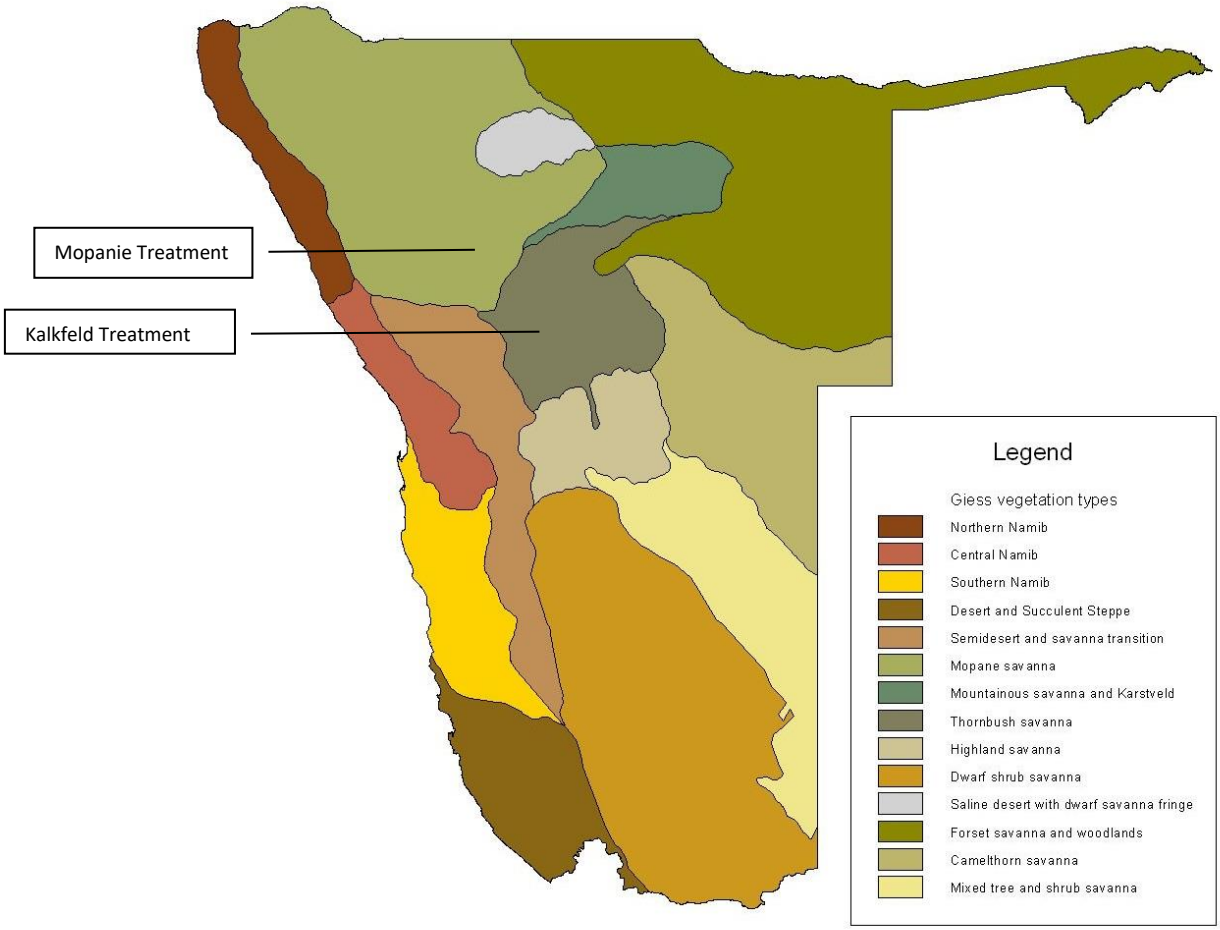

Figure 5 Map of different vegetation types in Namibia

3.1.4 Soil and water properties

Soil samples were taken from each farm where the cattle were kept. Samples included above ground samples (surface) as well as samples deeper than 40cm (deep). These samples were then submitted for soil analysis at Nvirotek Labs in Ifafi, Hartbeespoort (Table 6).

Table 6 Soil analysis

	pH (KCl)	PBray1	K	Na	Ca	Mg	Clay	Silt	Sand
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	%	%
Surface Samples K	5.44	8	116	13	681	119	49	26	25
Deep Samples K	5.92	1	76	12	978	162	51	21	28
Surface Samples M	5.13	13	207	7	706	97	45	15	40
Deep Samples M	5.96	12	267	8	1240	137	33	5	62

The availability of P to the plant from the soil is measured by P_B (Bray 1 or bicarbonate extractable method) in soils that have a pH ≤7.4. The available P is reduced at low pH and high iron and aluminium concentrations (McCosker & Winks, 1994). McCosker & Winks (1994) defined the soil P_B concentrations according to the possible animal P status as acutely deficient at <4mg/kg, deficient at 4-6mg/kg and marginal at 7-8mg/kg. From the results in this trial the soil that was taken below the surface in treatment K indicates an animal's P status as acutely deficient whilst the sample taken from the surface points to a marginal P deficiency. The soil samples taken from treatment M had higher P_B concentrations meaning there is a lower chance of a P deficiency.

The water was collected from the borehole on both farms were analysed and the results are shown in Table7.

Table 7 Water analysis (mg/l)

	Treatment K	Treatment M
pH (Value at 25°C)	7,6	8,3
Total Dissolved Solids (Calculated)	695	597
Total Hardness as CaCO3	434	231
Chloride as Cl	204	115
Sulphate as SO4	57	48
Fluoride as F	2,4	1,2
Nitrate as N	3,1	2,5
Sodium as Na	100	132
Calcium as Ca	103	30
Magnesium as Mg	43	38
Copper as Cu	<0,010	<0,010
Iron as Fe	<0,025	<0,025
Mercury as Hg	<0,001	<0,001
Zinc as Zn	<0,025	<0,025
% Balancing	98,9	94

The water quality guidelines for livestock watering (Casey & Meyer, 1996) were used as a comparison to determine if the water used by the cattle in this trial was safe for consumption.

All of the results from Table 7 fell in the range of having no adverse effects to animal health. However, the guidelines did not take into account (Casey & Meyer, 1996):

- the climatic effect on the animal (macro - and microclimates);
- the feed environment;
- the production system;
- the animal's physiology;
- the animal's production stage;
- the effect of time exposure to the potentially hazardous constituents;
- the effect of a concentrated intake over a short period;
- the physiological effect of exposure to potentially hazardous constituents;
- the economic implications of such exposure for different production systems and production conditions;
- the probable carry-over effect of potentially toxic substances to the user of the animal product after a limited exposure (growth to market weight);
- the synergistic and antagonistic interactions between water quality

- constituents, and water quality constituents and the environment;
- the actual ingestion of a water quality constituent.

3.1.5 Stocking rate

The Namibian carrying capacity was defined by Kruger (1998) as the area of land required to maintain an animal unit in order to achieve maximum profit in the short term, while maintaining the condition of the vegetation and soil in such a way as to be able to fulfil the needs and aspirations of the future land users. The biomass stocking rate was developed in Namibia (Meissner, 1993), as adopted by Venter (1982) and the Directorate of Agricultural Administration (1986), for determining the carrying capacity of the total available farming area.

The decision on the biomass stocking rate for the current trial was guided by the research of Kruger (1998) and Rothauge (2006) under similar climatic conditions. Biomass was determined using the average live mass of cattle, overnight fasted for at least 12 hours over the whole experimental period. An average biomass stocking rate of 25kg live cattle mass per hectare was targeted over the experimental period.

Significant numbers of wild antelope freely roam the area. They consist of Springbok (average weight of 60 kg, predominantly browsers), Red Hartebeest (*Alcelaphus buselaphus*, average weight 130kg, predominantly grazers) and Gemsbok (*Oryx gazelle*, average weight 220kg). The Gemsbok are independent of water sources if they were not available, essentially grazers and dry-region roughage eaters but were also prolific users of the underground storage organs of plants e.g. subterranean roots, rhizomes and bulbs, and ability to select succulent plant parts).

3.1.6 Method

Cattle were kept in two camps, one on each farm, with a total area of 150 ha each and were continuously grazed by each treatment group consisting of six Bos indicus (Brahman) x Bos taurus (Charolais & Hereford) crossbred animals.

The treatment animals were injected together with the rest of the farm animals with the yearly treatment for Botulism, Anthrax and “Sponssiekte” (blackquarter) in a combined dosage called Supavax.

The cattle were removed from feed and water for 24 hours in order to get their shrunk body weight (SBW). The six heaviest cattle (267 ± 6 kg; mean ± SD) from the starting group of 119 animals were selected for the oesophageal fistula technique.

Six crossbred cattle (360 ± 18 kg; mean ± SD) from an adjacent farm were ruminally cannulated during the same time when the oesophageal fistulations took place. A flexible rumen cannula with an inner flange like outer flange, 10 cm centre diameter (Bar Diamond Cannula, Bar Diamond Inc., Parma, Idaho; Order number #2C), with a washer (Bar Diamond Cannula, Bar Diamond Inc., Parma, Idaho; Order number #2-3W) was used.

Every four weeks samples were taken from the three oesophageally- and three rumen cannulated cattle on each farm. Samples consisted of an excreta sample from the rectum, rumen samples and oesophageal samples.

3.2. OESOPHAGEALLY FISTULATED CATTLE (OF)

3.2.1 Method

The cattle were given copper nose rings and were hand tamed before they were oesophageally fistulated as described by Van Dyne & Torell (1964). The oesophageally fistulated cattle were kept in the kraal for four weeks for observation and were fed pellets and grass. The cattle then received a neck loop as described by Kartchner & Adams (1983). The neck loop substantially reduced the time required for the fitting and removal of collection bags because it negated the use of a girth strap.

The spatulas for the fistula plugs were made from parts of PVC pipe and a 6mm stainless steel rod which were fastened with bonding cement and copper wire so that the steel rod had longitudinal movement (Van Dyne & Torell, 1964). The bonding cement needed regular replacement due to wear and tear. Twice a week, the plugs were removed, and the holes cleaned. The plugs, that were holding the spatula in place, were made from a hard and stable wood (*Prosopis glandulosa*, alien invasive tree species to Namibia) which was tapered down on a lathe and a 6mm hole drilled through the centre. Various sizes of plugs were made to accommodate increasing fistula size with age. The plug was kept in place by putting a 25mm washer over the 6mm rod on to the plug and then a 6mm nut was tightened up until the spatula was secured in place. A wing nut was then tightened onto the nut by locking it into each other so that it would not loosen (Roodt, 2012).

The collection bags used were made to the specifications of Bredon & Short (1971) and constructed form canvas tent material. The bottom the screen was made of shade cloth with an 80% weaving density. At both sides 20 mm wide aluminium strips were stitched in to keep the bag from collapsing during collections. Two fastener strips with buckles were stitched in to secure the bag around the animal's neck (Roodt, 2012).

The temporary tubular oesophageal cannula devised by Olsen & Malechek (1987) to prevent fistula contraction while the plug was out, was further refined by constructing the cannula from an ultra-light Teflon material on a lathe. The tubular oesophageal cannulas did not give satisfactory results with the animals used in this experiment and were later not used. It took extra time to apply and remove the cannulas which added to the animal's discomfort. The cannulas were easily dislodged from the fistula during the collections. The dislodging could have been the result of the friction between the collection bag and cannula, the movement of the animal during the collection or the peristaltic movement of the oesophagus. The size of the fistula and the placement of the fistula in the oesophagus could

also have been predisposing factors for the dislodging of the cannulas. The problem of the fistula constricting during collections was easily overcome by only attaching the plug onto the spatula with enough pressure to keep it in place. The peristaltic movements of the oesophagus during the next 24 hours moved the plug into place where it was then secured the next day without much discomfort to the animal.

3.2.2 Sampling periods

Every four weeks samples were taken from the three oeophageally fistulated cattle on each of the 2 farms.

3.2.3 Sampling procedure

During the morning of collection, the collection bags were fitted to the animal's necks, through the neck loop, after removal of the plug and spatula. The sample bags were fitted with filtered strips for saliva drainage. The treatment animals were then herded for 40 – 60 minutes in their allocated camps, until the sample bags were full enough. The animals were allowed to go to their preferred grazing areas in the camps. After the sample collection the bag was removed, the spatulas were reinserted, and the plugs secured in place.

3.2.4 Sample preparation

Extrusa samples were removed from the collection bags and filtered through a single layer of cheesecloth where the excess saliva was discarded. The whole strained extrusa sample was then placed in a plastic bag and frozen until the sample could be dried as suggested by Burrit *et al.* (1988). When enough sample was available, the frozen samples were dried in an oven at 45 ˚C for 5 days and ground to pass through a 1mm sieve screen before further chemical analysis took place at Nutrilab of the University of Pretoria.

3.3 RUMINALLY CANNULATED CATTLE

3.3.1 Sampling procedure

Every four weeks samples were taken from the three rumen cannulated cattle on each of the two farms.

On the previous day, 12 h to 13 h before sample collections, animals were removed from the water and lick intakes were restricted. On the morning of the collection, excreta samples were taken from the rectum and frozen for drying at a later stage when enough samples were available to make it economically viable. The plugs from the rumen cannulas were removed and samples taken from the rumen by way of a syringe attached to a 4-mm wide and 550mm long plastic catheter to withdraw fluid samples. The syringe with a catheter extension was then inserted into a 10 × 500 mm PVC pipe that had 1 mm holes drilled into the front 50 mm part with the end closed off by a wooden stopper to act as a sieve for keeping most of the fibrous material in the rumen fluid entering the catheter and ultimately blocking the syringe. Three 40 ml rumen digesta samples were drawn with one each in the anterior, middle and posterior areas of the rumen. Each of the three samples consisted of fluid collected in the ventral and caudal fluid phase areas by moving the collection apparatus up and down during the collection. The three sub-samples were pooled in a stainless-steel cup. The sample was then strained through a double layer of cheesecloth and the fluid collected and the rumen digesta solids were discarded. Duplicate 18ml rumen fluid samples were pipetted into 35ml urine plastic sample collection jars. One sample was preserved with 2 ml of a 50% H_2SO_4 solution for the determination of rumen ammonia-nitrogen (NH_3-N) (De Bruin, 1995). The other sample was preserved with 2 ml of a 10% (m/v) NaOH solution for the determination of rumen volatile fatty acids (Beauchemin *et al*., 2003). The screw tops of the sample jars were then sealed by a layer of fine wax film to seal the contents and the samples were then frozen and stored until further analysis.

3.4 DETERMINATION OF RESULTS

3.4.1 Lab procedures

Samples were ignited at 550˚C for 6 h to determine organic matter (OM) content. Total N was determined by Kjeldahl analysis (AOAC, 2002). Concentrations of ammonia in rumen fluid (Broderick & Kang, 1980) were determined by distillation and titration procedures. The acid preserved rumen fluid collections were thawed at room temperature, centrifuged at 10,000 revolutions per minute for 10 minutes and the supernatant was analysed for milligrams of ammonia N (NH3-N) per 100ml.

The alkali preserved rumen fluid collections were thawed and 1.1ml 50% (v/v) ortho-phosporic acid was added to 10ml preserved rumen fluid, centrifuged at 4500 revolutions per minute for 20 minutes, internal standard (Pivalic acid) added, filtered and the VFA concentrations in mmol/100ml (acetic acid, propionic acid, butyric acid, valeric acid) were determined by gas chromatography with a flame ionisation detector (Webb, 1994).

The dry matter (DM) and ash levels were determined according to the AOAC (2002) methods. Crude protein (CP) was calculated as 6.25 times the nitrogen (N) content estimated by the Leco method (AOAC, 2002). The neutral detergent fibre (NDF) was determined using the method of Robertson & Van Soest (1981) and acid detergent lignin (ADL) was determined according to Goering and Van Soest (1970).

After wet digestion with a nitric-perchloric acid mixture the calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu) and Zinc (Zn) concentrations were measured using atomic absorption spectrophotometry. The photometric method using molybdovanadate was used to measure phosphorus (P) concentrations (AOAC, 2002).

The *in vitro* digestible organic matter (IVDOM) was determined using the method of Tilley & Terry (1963), as modified by Engels & Van der Merwe (1967).

All samples were analysed in duplicate and the standard error of mean verified before the sample mean was used as a data point. Triplicate samples were analysed for IVOMD. With all analysis runs, standards were included into the group, to verify that the equipment was functioning correctly.

3.4.2. Statistical analyses

The data was analysed statistically with the Proc Mixed model, (Statistical Analysis System 2015) fir the average effects. Means and standard error were calculated and

significance of difference ($P<0.05$) between means was determined by Bonferroni test (Samuels, 1989).

The linear model used is described by the following equation:

$$Y_{ijkl} = \mu + T_i + J_k + M_l + S_j + TJ_{il} + TM_{il} + JM_{kl} + TMJ_{ikl} + e_{ijkl}$$

Where Y_{ijkl} = variable studied during the period

μ = overall mean of the population

T_i = effect of the i^{th} treatment

J_k = effect of the k^{th} year

M_l = effect of the l^{th} period

S_j = effect of the j^{th} animal

TJ_{ik} = effect of the ik^{th} interaction between treatment and year

TM_{il} = effect of the il^{th} interaction between treatment and period

JM_{kl} = effect of the kl^{th} interaction between year and period

TMJ_{ikl} = effect of the ikl^{th} interaction between treatment, year and period

e_{ijkl} = error associated with each Y

3.4.3. Hypothesis

H_0 : There is no difference between treatment K and treatment M for certain qualitative parameters collected by oesophageal fistula and rumen cannula samples between different periods and years.

H_1 : There is a difference between treatment K and treatment M for certain qualitative parameters collected by oesophageal fistula and rumen cannula samples between different periods and years.

H_0 : Faecal crude protein and faecal phosphorus cannot be used to predict diet crude protein and phosphorous respectively in treatment K and treatment M for different years.

H_1 : Faecal crude protein and faecal phosphorus can be used to predict diet crude protein and phosphorous respectively in treatment K and treatment M for different years.

3.5 GROUPING OF DATA

Data from the trial was grouped into 12 periods, 6 in each year.

Season (Year 1)	**Period**	**Season (Year 2)**	**Period**
Sep-Oct	1	Sep-Oct	7
Nov-Dec	2	Nov-Dec	8
Jan-Feb	3	Jan-Feb	9
Mar-Apr	4	Mar-Apr	10
May-Jun	5	May-Jun	11
Jul-Aug	6	Jul-Aug	12

For each nutrient a comparison was done between the nutrient concentration supplied by the forage in each treatment and the NRC requirement for a 400kg beef cow with an average milk production of 6.8kg/day at a dry matter intake level of 2.7% (during lactation) and 2.0% (during pregnancy) of body weight per day. The comparison was done over the six periods where period one was taken to be the last trimester of gestation, period two is when the cows are expected to calve and lactation is said to begin, period three is during lactation, period four and five is during early gestation and period six is the middle trimester of gestation.

CHAPTER 4 RESULTS AND DISCUSSION

4.1. OESOPHAGEAL FISTULA EXTRUSA

Six oesophageally fistulated cattle (OF) were used to collect forage that had been selected by a group of cattle every 4 weeks. The six OF were maintained and managed with the herd of cattle and deemed appropriate to collect samples, as discussed earlier. The forage quality was determined by analysing the extrusa.

The results from the OF samples were obtained on a dry matter basis (DM). These values were then corrected for ash to an organic matter basis (OM) due to the saliva containing small amounts of minerals as well as soil which may have been ingested by the animals especially if they were grazing close to the soil surface.

Comparisons were done between years on the same farm (year effect), between farms of the same year (treatment effect) and between period averages on each farm (period effect).

4.1.1 ASH

The forage grazed by the cattle and analysed from samples collected from OF had ash concentrations ranging from 7.97% to 15.91% in treatment K and 7.37% to 18.45% in treatment M. The highest ash values coincided with periods two and three (Nov-Feb), during these months rainfall was higher. Lower ash values were found during periods four, five and six (March-August), where low to no rainfall was recorded. This trend can be seen in Figure 6.

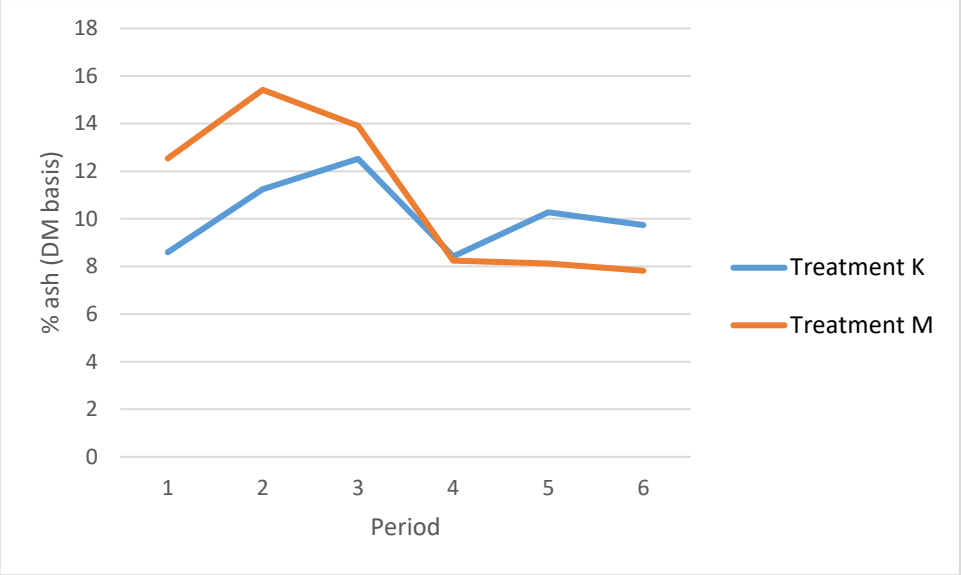

Figure 6 The average ash percentage of two treatments over two years in north western part of Namibia as quantified in grazing cattle fitted with oesophageal fistulae.

The ash results obtained for the osophageally fistulated cattle are presented below. In Table 8, the two years within each treatment were compared to each other. There was more variation between the two years for treatment M than for treatment K.

Table 8 The influence of different years within treatments on ash percentage selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 1.653)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**9.22**	**7.97**	*8.60*	**17.05** [a]	**8.01** [b]	*12.53*
NOV-DEC	2	**10.87**	**11.61**	*11.24*	**18.45** [a]	**12.38** [b]	*15.42*
JAN-FEB	3	**15.91** [a]	**9.13** [b]	*12.52*	**17.38** [a]	**10.44** [b]	*13.91*
MRT-APR	4	**8.25**	**8.58**	*8.42*	**8.65**	**7.84**	*8.24*
MAY-JUN	5	**9.17**	**11.39**	*10.28*	**7.66**	**8.59**	*8.12*
JUL-AUG	6	**9.03**	**10.45**	*9.74*	**8.28**	**7.37**	*7.82*
AVE		*10.41*	*9.86*		*12.91*	*9.10*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

For treatment K, differences were seen between the two years during the third period with a higher value recorded during year one (15.91%) (P<0.05).

For treatment M, differences were found between the two years in periods one, two and three (P<0.05). During period one, a higher ash value was recorded during year one (17.05%) as well as higher values being recorded during year one for periods two and three (18.45% and 17.38% respectively).

In Table 9, the same year was compared between the two treatments. There was little difference between treatments in year one and no difference between treatments in year two.

Table 9 The influence of the same year between treatments on ash percentage selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 1.653)

SEASON	PERIOD	Y1 (K)	Y1(M)	*AVE*	Y2(K)	Y2(M)	*AVE*
SEP-OCT	**1**	**9.22[a]**	**17.05 [b]**	*17.75*	**7.97**	**8.01**	*7.99*
NOV-DEC	**2**	**10.87[a]**	**18.45[b]**	*14.66*	**11.61**	**12.38**	*11.995*
JAN-FEB	**3**	**15.91**	**17.38**	*16.645*	**9.13**	**10.44**	*9.785*
MRT-APR	**4**	**8.25**	**8.65**	*8.45*	**8.58**	**7.84**	*8.21*
MAY-JUN	**5**	**9.17**	**7.66**	*8.415*	**11.39**	**8.59**	*9.99*
JUL-AUG	**6**	**9.03**	**8.28**	*8.655*	**10.45**	**7.37**	*8.91*
AVE		*10.41*	*9.86*		*9.86*	*9.1*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

In year one, there were differences in the first and second period with higher ash values recorded for treatment M (17.05% during period one and 18.45% during period two) (P<0.05).

In Table 10, the averages for each period were compared within each treatment.

Table 10 The influence of different period averages within a treatment on ash percentage selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 1.169)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**9.22**	**7.97**	*8.60*[a]	**17.05**	**8.01**	*12.53*[a]
NOV-DEC	2	**10.87**	**11.61**	*11.24*[ab]	**18.45**	**12.38**	*15.42*[a]
JAN-FEB	3	**15.91**	**9.13**	*12.52*[b]	**17.38**	**10.44**	*13.91*[a]
MRT-APR	4	**8.25**	**8.58**	*8.42*[a]	**8.65**	**7.84**	*8.24*[b]
MAY-JUN	5	**9.17**	**11.39**	*10.28*[ab]	**7.66**	**8.59**	*8.12*[b]
JUL-AUG	6	**9.03**	**10.45**	*9.74*[ab]	**8.28**	**7.37**	*7.82*[b]
AVE		*10.41*	*9.86*		*12.91*	*9.10*	

[ab]Column means with different superscripts differ significantly (P ≤ 0.05)

For treatment K, period 3 differs significantly from period 1, period 4 differs from period 3 and vice versa (P<0.05).

For treatment M, period 4, 5 and 6 differ from period 1, 2 and 3 (P<0.05).

These differences are due to the fact that higher ash values were recorded during months of higher rainfall (periods two and three).

4.1.2 CRUDE PROTEIN

The crude protein (CP) concentrations of forage obtained from OF cattle were directly dependent on rainfall distribution (De Waal, 1990). The months with the highest rainfall (January to April) coincide with the flowering stage of most grasses which is followed by the translocation of nutrients to the roots of the plants, resulting in lower nutritional quality of the top of the plants during the dry season (August to November) (Louw, 1979).

In the study done by Van Schalkwyk (1978) in Namibia the mean CP concentration for the year was 8.2% rising from a mean of 6.2% in the dry season to a mean of 10.3% in the wet season.

Protein was identified as the major limiting nutrient for grazing animals during the dry season when there was no phosphorus deficiency.

The CP (OM) values of the forage in this trial (Table 14) ranged from 3.16% to 12.03% for treatment K and from 2.81% to 9.75% for treatment M. The highest values were recorded

in the third period (January-February) (average of 9.71% and 9.05% for treatments K and M respectively). This coincides with the months of higher rainfall. The CP values decreased from the highest concentrations during the wet season to the lowest averages (average 3.45% and 2.92% for treatment K and M respectively) which were found during the sixth period. During this time there was no rain and low soil moisture levels would have restricted active plant growth. This trend can be seen in Figure 7.

Cronje (1990), reported that the highest crude protein levels always followed on periods of high rainfall in the preceding months. Van Schalkwyk (1975) also found that there was an increase in CP concentration up the point of maximal rainfall in January after which it decreased to its lowest concentration in late winter (July-October).

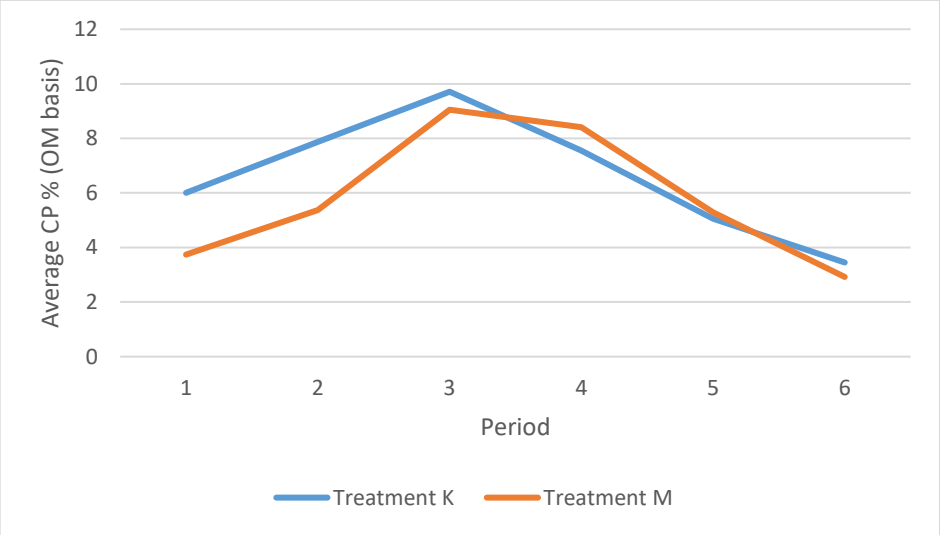

Figure 7 The average crude protein (organic matter) percentage of two treatments over two years in the north western part of Namibia as quantified in grazing cattle fitted with oesophageal fistulae

Roodt (2012) drew up a graph that depicted an equation for the linear regression between rainfall per month and CP on an organic matter basis (R^2 = 0.85), which lead to the conclusion that there is a strong correlation between CP concentration of forage and rainfall. From the linear regression it was concluded that with a monthly rainfall of at least 20mm the veld selected by OF cattle would reach a minimum of 6.8% CP (OM) concentration that would result in improved feed intake provided the amount of forage was not limiting (NRC, 1987).

In Table 11, the two years within treatments were compared to each other. There were more differences between CP values within treatment M compared to treatment K.

Table 11 The influence of different years within treatments on crude protein (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.608)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**6,84** (0.46)	**5,18** (1.97)	*6,01* (1.57)	**3,41** (0.66)	**4,07** (0.42)	*3,74* (0.61)
NOV-DEC	2	**7,46** (0.62)	**8,28** (1.94)	*7,87* (1.36)	**2,82[a]** (0.69)	**7,93[b]** (0.80)	*5,37* (2.88)
JAN-FEB	3	**12,03[a]** (1.53)	**7,40[b]** (2.87)	*9,71* (3.26)	**8,64** (0.68)	**9,46** (1.24)	*9,05* (1.00)
MRT-APR	4	**7,62** (0.41)	**7,48** (1.08)	*7,55* (0.74)	**9,75[a]** (0.22)	**7,07[b]** (0.08)	*8,41* (1.47)
MAY-JUN	5	**4,88** (0.39)	**5,23** (1.09)	*5,05* (0.76)	**3,79[a]** (0.22)	**6,79[b]** (0.64)	*5,29* (1.70)
JUL-AUG	6	**3,74** (0.72)	**3,16** (0.52)	*3,45* (0.64)	**2,81** (0.22)	**3,03** (0.23)	*2,92* (0.23)
AVE (+/-SD)		*7,09* (2.77)	*6,12* (2.33)		*5,20* (2.97)	*6,39* (2.34)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

There were differences between the two years in period three for treatment K, with a higher CP value (12.03%) recorded during year one (P<0.05).

For treatment M, differences were seen between the two years in periods two, four and five (P<0.05). In period two, the higher CP value (7.93%) can be attributed to the higher rainfall in year two. In period four, the higher CP value (9.75%) in year one is due to the higher rainfall during this time which resulted in the growth of green young grass. In period five the forage had a higher CP value during year two (6.79%).

A comparison was done between treatments within the same year in Table 12.

Table 12 The influence of the same year between treatments on crude protein (OM) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.608)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**6,84[a]**	**3,41[b]**	*5.13*	**5,18**	**4,07**	*4.63*
NOV-DEC	2	**7,46[a]**	**2,82[b]**	*5.14*	**8,28**	**7,93**	*8.11*
JAN-FEB	3	**12,03[a]**	**8,64[b]**	*10.34*	**7,40[a]**	**9,46[b]**	*8.43*
MRT-APR	4	**7,62[a]**	**9,75[b]**	*8.69*	**7,48**	**7,07**	*7.28*
MAY-JUN	5	**4,88**	**3,79**	*4.34*	**5,23**	**6,79**	*6.01*
JUL-AUG	6	**3,74**	**2,81**	*3.28*	**3,16**	**3,03**	*3.1*
AVE		*7,09*	*5,20*		*6,12*	*6,39*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

There were differences between the two treatments in periods one, two, three and four within year one (P<0.05). In period one, two and three the higher CP values (6.84%, 7.46%, and 12.03% respectively) for treatment K is due to the higher rainfall recorded during this time. During period four, a higher CP value (9.75%) was recorded for treatment M.

During the second year, significant differences between the two treatments were found during period 3 (P<0.05). Treatment M had a higher CP value (9.46%) during this period which is due to the higher rainfall recorded during this time.

The period averages within each treatment were compared in Table 13.

Table 13 The influence of different period averages within treatments on crude protein (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.430)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**6,84**	**5,18**	*6,01*[a]	**3,41**	**4,07**	*3,74*[a]
NOV-DEC	2	**7,46**	**8,28**	*7,87*[b]	**2,82**	**7,93**	*5,37*[b]
JAN-FEB	3	**12,03**	**7,40**	*9,71*[c]	**8,64**	**9,46**	*9,05*[c]
MRT-APR	4	**7,62**	**7,48**	*7,55*[b]	**9,75**	**7,07**	*8,41*[c]
MAY-JUN	5	**4,88**	**5,23**	*5,05*[a]	**3,79**	**6,79**	*5,29*[b]
JUL-AUG	6	**3,74**	**3,16**	*3,45*[d]	**2,81**	**3,03**	*2,92*[da]
AVE		*7,09*	*6,12*		*5,20*	*6,39*	

[abcd]Column means with different superscripts differ significantly (P ≤ 0.05)

There was great variation between periods for both treatments (P<0.05). During the high rainfall in the summer months (periods two and three), the CP percentage of the forage increased and remained high during period four due to the bloom of annual plants after the good rains in the preceding months. The CP content of the forage then decreased during periods one, five and six when there was little to no rain.

De Waal (1990), recorded the CP content of veld samples selected by oesophageally fistulated cattle in the Northern Cape in South Africa. The results he received were in the range of between 6-11% DM. The CP concentrations of the veld in the current trial fell below this range during the dry season but then increased to within this range during the periods of higher rainfall.

In Figure 8, the CP supplied by the forage from the two treatments is compared to the CP requirements of a 400kg cow.

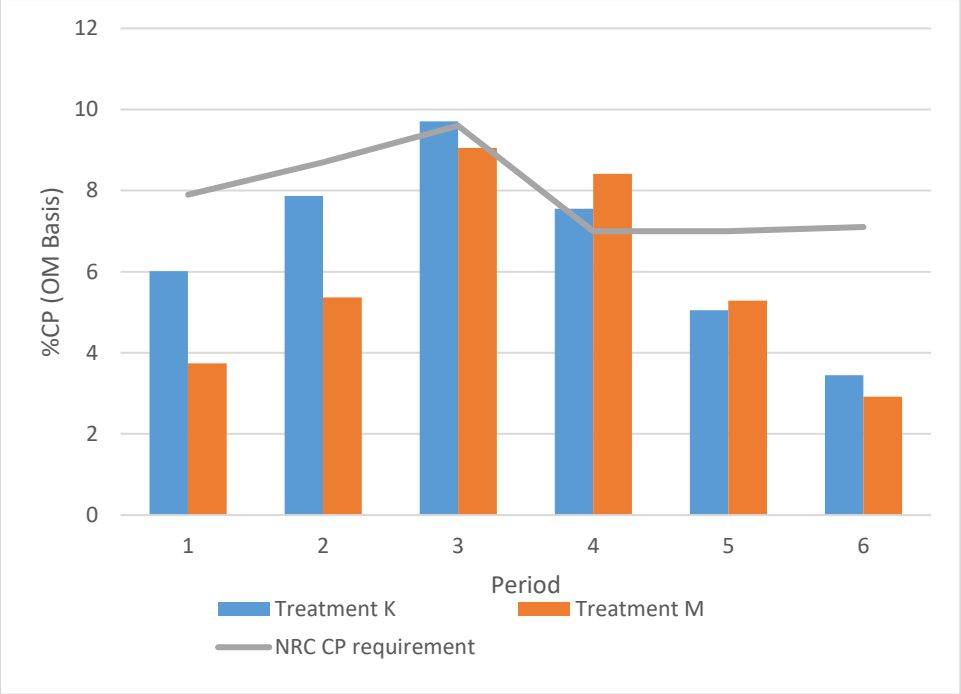

Figure 8 Average crude protein percentage corrected for organic matter for treatment K and M over a two year period compared to the NRC protein concentration requirement for a 400kg cow with an average milk production of 6.8kg/day at a dry matter intake level of 2.7% (during lactation) and 2.0% (during pregnancy) of body weight per day (NRC, 2000)

It is clear that for a large portion of the year the CP supplied by the forage is lower than the requirements for a 400kg producing cow. It is expected that DMI levels will be lower during the times when the cows are pregnant (NRC, 2000). During periods one, two, five and six the protein requirements are not met from the forage alone. During period four which falls during early gestation, the forage is able to meet the protein requirements for both treatments.

During period three the cows are expected to be lactating, their intake therefore will increase back to a normal level of 2.7% of body weight (NRC, 2000). During this time their protein requirements will also increase to 9.6%. This requirement is met from the forage in treatment K however the protein content of the forage in treatment M falls just short of what is required by the animal.

4.1.3 PHOSPHORUS

The phosphorus (P) (OM) values ranged from 0.14% to 0.28% for treatment K and from 0.11% to 0.29% for treatment M collected.

The P concentrations of veld selected by OF cattle are shown in Table 14. The values tended to increase during the season of higher rainfall, with the highest values recorded during the third period (Jan-Feb) in both treatments (average 0.25% for treatment K and 0.26% for treatment M). The P values of the extrusa collected from oesophageally fistulated cattle decreased again during the dry season and were at their lowest during period five (May-June) for treatment K (Average 0.16%) and during period one (September-October) for treatment M (Average 0.14%). This trend can be seen in Figure 9.

According to McIvor (1979), Phosphorous concentration of forage increases after periods of increased rainfall. The decline in P concentration of forage towards the end of the growing season reflects the decline in growth rates, maturation and senescence after plant material after flowering (McIvor, 1979).

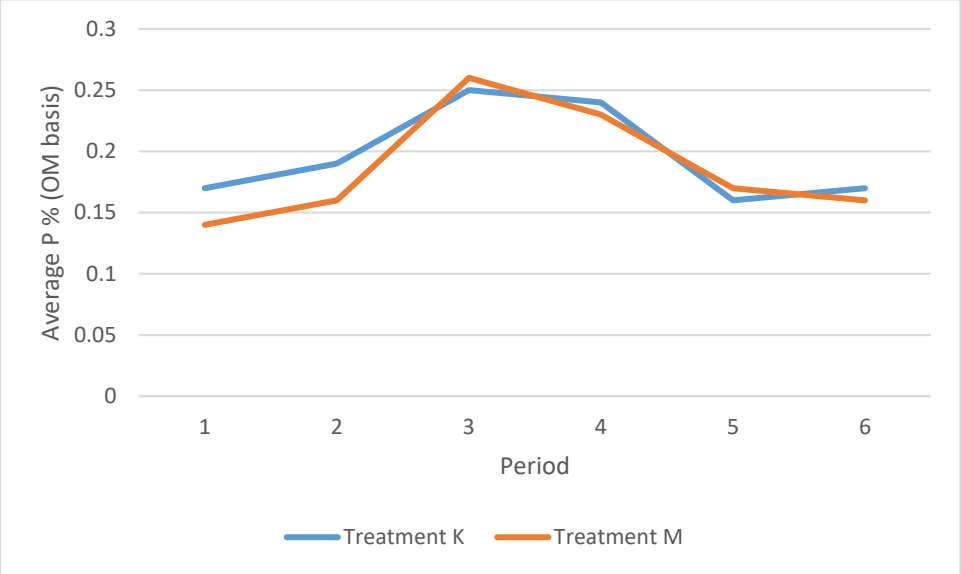

Figure 9 The average phosphorus percentage on an organic matter basis of two treatments over two years in the north western part of Namibia as quantified in grazing cattle fitted with oesophageal fistulae

Roodt (2012) presented a figure depicting an equation for the linear regression between P (OM) and CP (OM) which was calculated to be R^2 = 0.95. This makes the correlation between P and CP selected by OF cattle to be stronger than the correlation between P in veld selected by OF cattle and monthly rainfall (R^2 = 0.78).

Groenewald (1986) found a similar strong relationship between CP and P from hand-cut natural grazing samples (r = 0.77) in the Natal province of South Africa.

The two years within each treatment were compared in Table 14. There was greater variation between the two years in treatment K compared to treatment M.

Table 14 The influence of different years within treatments on phosphorus (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.017)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**0,14[a]** (0.01)	**0,21[b]** (0.04)	*0,17* (0.05)	**0,10[a]** (0.07)	**0,18[b]** (0.01)	*0,14* (0.06)
NOV-DEC	2	**0,17** (0.06)	**0,20** (0.02)	*0,19* (0.04)	**0,11[a]** (0.02)	**0,20[b]** (0.01)	*0,16* (0.05)
JAN-FEB	3	**0,28[a]** (0.03)	**0,21[b]** (0.06)	*0,25* (0.06)	**0,23[a]** (0.00)	**0,29[b]** (0.02)	*0,26* (0.03)
MRT-APR	4	**0,26** (0.02)	**0,22** (0.03)	*0,24* (0.03)	**0,25** (0.02)	**0,21** (0.02)	*0,23* (0.03)
MAY-JUN	5	**0,14** (0.00)	**0,18** (0.02)	*0,16* (0.03)	**0,12[a]** (0.01)	**0,22[b]** (0.01)	*0,17* (0.06)
JUL-AUG	6	**0,15** (0.01)	**0,18** (0.03)	*0,17* (0.02)	**0,14** (0.03)	**0,18** (0.01)	*0,16* (0.03)
AVE (+/-SD)		*0,19* (0.06)	*0,20* (0.03)		*0,16* (0.07)	*0,21* (0.04)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

For treatment K, significant differences between the two years were seen in periods one and three (P<0.05). In period one, a higher P value (0.21%) was recorded in year two. In period three, a higher P value (0.28%) was recorded in year one. This high value was obtained due to an increase in green growth from the high rainfall levels as can be seen in Figure 3.

For treatment M, significant differences were seen between the two years in periods one, two, three and five (P<0.05). During these periods, higher P values (0.18% for period one, 0.20% for period two, 0.29% for period three and 0.22% for period five) were recorded in the second year. During year two, there was a higher average rainfall compared to year one which was accompanied by an increase in green plant growth and thus higher P content of the forage.

In Table 15, the same year was compared between treatments. There was little variation within each year.

Table 15 The influence of the same year between treatments on phosphorus (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.017)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y1(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**0,14**	**0,10**	*0.12*	**0,10**	**0,21**	*0.16*
NOV-DEC	2	**0,17[a]**	**0,11[a]**	*0.14*	**0,11[a]**	**0,20**	*0,16*
JAN-FEB	3	**0,28**	**0,23**	*0.26*	**0,23**	**0,21[a]**	*0.22*
MRT-APR	4	**0,26**	**0,25**	*0.26*	**0,25**	**0,22**	*0.24*
MAY-JUN	5	**0,14**	**0,12**	*0.13*	**0,12**	**0,18**	*0.15*
JUL-AUG	6	**0,15**	**0,14**	*0.15*	**0,14**	**0,18**	*0.16*
AVE		*0,19*	*0,16*		*0,16*	*0,20*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

In year one, differences were seen in period two with a higher P value (0.17%) recorded for treatment K (P<0.05). This is matched with a higher corresponding CP and rainfall value.

In year two, significant differences were seen in period three, with a higher P value (0.29%) recorded for Treatment M (P<0.05). This correlates with a higher corresponding CP and rainfall value.

In Table 16, the period averages were compared within each treatment.

Table 16 The influence of different period averages on phosphorus (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.012)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**0,14**	**0,21**	*0,17[a]*	**0,10**	**0,18**	*0,14[a]*
NOV-DEC	2	**0,17**	**0,20**	*0,19[a]*	**0,11**	**0,20**	*0,16[a]*
JAN-FEB	3	**0,28**	**0,21**	*0,25[b]*	**0,23**	**0,29**	*0,26[b]*
MRT-APR	4	**0,26**	**0,22**	*0,24[b]*	**0,25**	**0,21**	*0,23[c]*
MAY-JUN	5	**0,14**	**0,18**	*0,16[a]*	**0,12**	**0,22**	*0,17[a]*
JUL-AUG	6	**0,15**	**0,18**	*0,17[a]*	**0,14**	**0,18**	*0,16[a]*
AVE		*0,19*	*0,20*		*0,16*	*0,21*	

[abc]Column means with different superscripts differ significantly (P ≤ 0.05)

The differences in P values between periods are due to the fact that in this trial the phosphorus values tend to increase during the periods of higher rainfall (periods three and four). Whilst during times of lower rainfall (periods one, two, five and six) the P values tend to fall due to low growth activity by vegetation meaning supplementation may be necessary. Roodt (2012) recorded P values of between 0.76 – 3.07g/kg OM in the tree and shrub savannah of Namibia of which similar results were recorded in this trial.

Els (2000) found the average P concentrations of Grassveld in Namibia was 0.195%. This is similar to the overall average in this trial.

The P concentration of forage selected by cattle was a useful diagnostic tool in determining the P status of cattle (Karn, 2001). The collection of samples by the OF technique gave the best indication on the quality of the diet that was selected by cattle, although salivary contamination had an effect on the results due to a contribution of P from the saliva (Van Dyne & Torell, 1964). The effect of salivary contamination was regarded as minimal (Marshall *et al.*, 1967) when the surplus saliva drained from a screen-bottomed collection bag and the remainder was squeezed from the sample after collection (Mckay *et al.*, 1969) and would at worst tend to overestimate the P concentration (Karn, 1995).

Figure 10 depicts the average phosphorus concentration for treatment K and M compared to the NRC (2000) requirements for a 400kg cow with a dry matter intake of 2.7% during lactation and 2.0% during pregnancy of body weight per day (NRC, 2000).

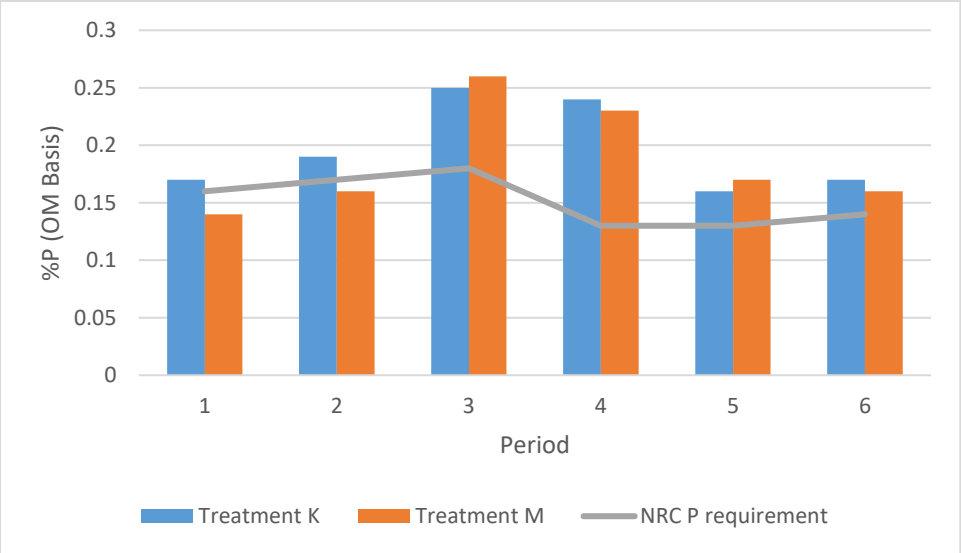

Figure 10 Average phosphorus percentage corrected for organic matter for treatments K and M over a two year trial period compared to the NRC phosphorus concentration requirement for a 400kg cow with an average milk yield of 6.8kg/day at dry matter intake level of 2.7% (during lactation) and 2.0% (during pregnancy) of body weight per day (NRC, 2000)

The majority of the P values for both treatments fell above the requirements for a 400kg cow. During early to mid-gestation, which falls during periods four, five and six, intake is reduced to 2% of body weight per day during which time requirements are met (NRC, 2000). However, during the last trimester of pregnancy which falls within periods one and two, the P content of the forage for treatment M is not able to supply the requirements of a pregnant cow.

During period three the majority of cows are lactating and P requirements increase during this time to 0.18% (NRC,2000). This increase in the P requirement is met for both treatments if intake is estimated at 2.7% of body weight per day.

4.1.4 CALCIUM

The calcium (Ca) concentrations of veld selected by OF cattle are shown in Table 21. The Ca (OM) concentrations ranged from 0.63% to 2.01% in treatment K and from 0.39% to 0.88% in treatment M. The highest Ca (OM) concentrations fell during period two for treatment K (average 1.77%) and treatment M (average 0.66%) when rainfall was higher and then declined towards the dry season. The lowest Ca (OM) concentration occurred during period four for treatment K (average 0.66%) and during period five for treatment M (average 0.47%). This trend can be seen in Figure 11.

Lukhele & Van Ryssen (2003) found no consistent seasonal pattern in the Ca concentrations in the foliage of subtropical tree species, but warned that all species that were investigated had exceptionally high concentrations of Ca and lower P concentrations.

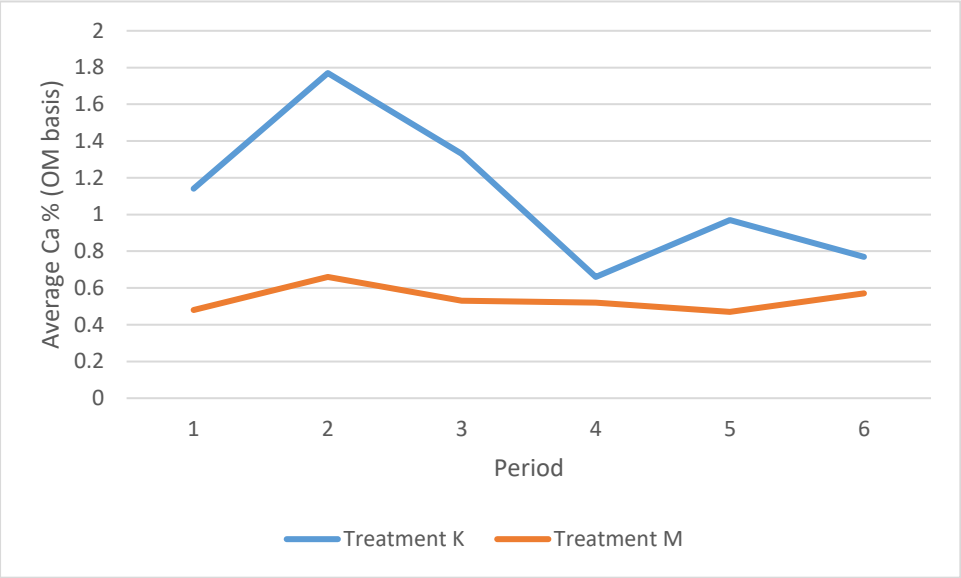

Figure 11 The average calcium percentage on an organic matter basis of two treatments over two years in the north western part of Namibia as quantified in grazing cattle fitted with oesophageal fistulae

In Table 17, the two years within each treatment were compared to each other. The results showed very little variation between years.

Table 17 The influence of different years within treatments on calcium (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.185)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**1,66[a]** (0.15)	**0,63[b]** (0.06)	*1,14* (0.57)	**0,39** (0.11)	**0,57** (0.10)	*0,48* (0.14)
NOV-DEC	2	**1,54** (0.80)	**2,01** (0.83)	*1,77* (0.78)	**0,88** (0.86)	**0,45** (0.03)	*0,66* (0.59)
JAN-FEB	3	**1,71[a]** (0.17)	**0,95[b]** (0.29)	*1,33* (0.47)	**0,58** (0.03)	**0,48** (0.03)	*0,53* (0.06)
MRT-APR	4	**0,68** (0.06)	**0,63** (0.19)	*0,66* (0.13)	**0,65** (0.07)	**0,39** (0.02)	*0,52* (0.15)
MAY-JUN	5	**1,22** (0.33)	**0,73** (0.11)	*0,97* (0.35)	**0,41** (0.03)	**0,53** (0.01)	*0,47* (0.07)
JUL-AUG	6	**0,83** (0.02)	**0,70** (0.17)	*0,77* (0.13)	**0,65** (0.16)	**0,49** (0.01)	*0,57* (0.13)
AVE (+/-SD)		*1,27* (0.51)	*0,94* (0.59)		*0,59* (0.35)	*0,49* (0.07)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

For treatment K, differences between the two years were found in periods one and three (P<0.05). In both periods, a higher Ca value (1.66% during period one and 1.71% during period three) was recorded in year one. This is due to the higher rainfall that occurred during the first year compared to the second year which resulted in active plant growth and thus a higher Ca value.

For treatment M there were no differences between the two years (P>0.05).

In Table 18, the same year was compared between the two treatments. There was greater variation within year one compared to year two.

Table 18 The influence of the same year between treatments on calcium (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.185)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**1,66[a]**	**0,39[b]**	*1.03*	**0,63**	**0,57**	*0.6*
NOV-DEC	2	**1,54[a]**	**0,88[b]**	*1.21*	**2,01[a]**	**0,45[b]**	*1.23*
JAN-FEB	3	**1,71[a]**	**0,58[b]**	*1.15*	**0,95**	**0,48**	*0.72*
MRT-APR	4	**0,68**	**0,65**	*0.67*	**0,63**	**0,39**	*0.51*
MAY-JUN	5	**1,22[a]**	**0,41[b]**	*0.82*	**0,73**	**0,53**	*0.63*
JUL-AUG	6	**0,83**	**0,65**	*0.74*	**0,70**	**0,49**	*0.6*
AVE		*1,27*	*0,59*		*0,94*	*0,49*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

In year one, differences between the two treatments were seen in periods one, two, three and five (P<0.05). In periods one, two and three higher Ca values (1.66%, 1.54% and 1.71% respectively) were recorded for treatment K. This is due to the fact that higher rainfall occurred in year one of treatment K compared to the same year in treatment M which resulted in higher active plant growth. For period five, a higher Ca value (1.22%) was recorded for treatment K which could be as a result of a higher overall rainfall that occurred during the first year in treatment K compared to treatment M giving rise to a higher Ca value due to increased plant growth.

During year two, differences were found between treatments in period two (P<0.05). A higher Ca value (2.01%) was recorded for treatment K.

Olson *et al*. (2002) observed seasonal changes in forage quality which are likely being driven by rainfall patterns that consequently affect plant growth.

In Table 19, the period averages of Ca within each treatment were compared.

Table 19 The influence of different period averages within a treatment on calcium (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.131)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**1,66**	**0,63**	*1,14[a]*	**0,39**	**0,57**	*0,48[a]*
NOV-DEC	2	**1,54**	**2,01**	*1,77[b]*	**0,88**	**0,45**	*0,66[a]*
JAN-FEB	3	**1,71**	**0,95**	*1,33[a]*	**0,58**	**0,48**	*0,53[a]*
MRT-APR	4	**0,68**	**0,63**	*0,66[c]*	**0,65**	**0,39**	*0,52[a]*
MAY-JUN	5	**1,22**	**0,73**	*0,97[ac]*	**0,41**	**0,53**	*0,47[a]*
JUL-AUG	6	**0,83**	**0,70**	*0,77[c]*	**0,65**	**0,49**	*0,57[a]*
AVE		*1,27*	*0,94*		*0,59*	*0,49*	

[abc]Column means with different superscripts differ significantly (P ≤ 0.05)

For treatment K, period two was different from the other periods (P<0.05).

For treatment M, no differences were found between periods (P>0.05).

The reason for significant differences between periods is due to the higher Ca value in veld selected by OF cattle during the periods of higher rainfall, this includes periods two and three (November – February). During periods one, four, five and six (March – October) low to no rainfall was recorded which resulted in lower Ca values in veld selected by OF cattle. Suttle (2010) stated that plant maturity and seasonal changes has an influence on the calcium content of forage.

Roodt (2012) recorded Ca concentrations of between 0.194 –0.688% in the tree and shrub savannah of Namibia. The majority of the Ca concentrations of the forage in treatment K were higher than this range, whereas the values recorded for treatment m fell within this range.

Figure 12 shows that the forage Ca concentrations in both treatments were high enough to sustain a 400kg cow with an average milk yield of 6.8kg/day and a dry matter intake of 2.7% during lactation and 2.0% during pregnancy of body weight per day (NRC, 2000).

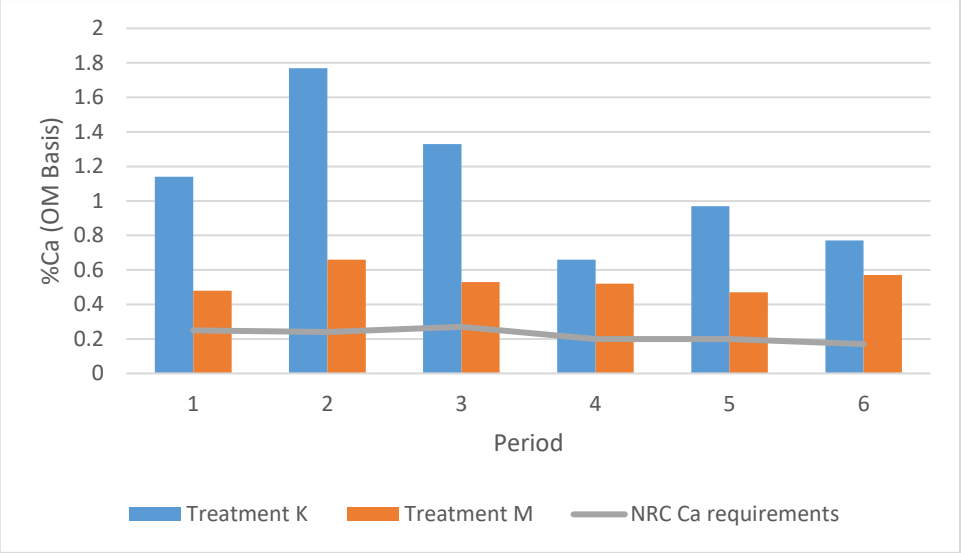

Figure 12 Average calcium percentage on an organic matter basis for treatment K and M over the two year trial period compared to the NRC calcium concentration requirement for a 400kg cow with an average milk production of 6.8kg/day at a dry matter intake level of 2.7% (during lactation) and 2.0% (during pregnancy) of body weight per day (NRC, 2000)

High Ca levels in the drinking water further increased the total daily intake of calcium by the cattle. High Ca concentrations may lead to a decrease in magnesium and zinc absorption, which can lower growth and production rates (McDowell, 2003).

4.1.5. Calcium to phosphorus ratio

The Ca:P is shown in table 20. The ratio ranged from 2.60:1 to 12.19:1 for treatment K and from 1.66:1 to 7.13:1 for treatment M. The NRC (2000) stated that a Ca to P ratio of 1:1 to 7:1 would be adequate for growth of between 0.1kg/day to 1kg/day for cattle provided that the P and Ca intakes were adequate in meeting the minimum dietary requirements for each element. A wide Ca:P could exacerbate a P deficiency (Ternouth, 2001).

The highest ratio fell during period two for treatment K (Average 9.59:1) and treatment M (Average 4.68:1). Whilst the lowest ratio was found during period four for treatment K (Average 2.74:1) and during period three for treatment M (Average 2.06:1).

The change in the Ca to P ratio over the course of the two year trial period is depicted in Figure 13.

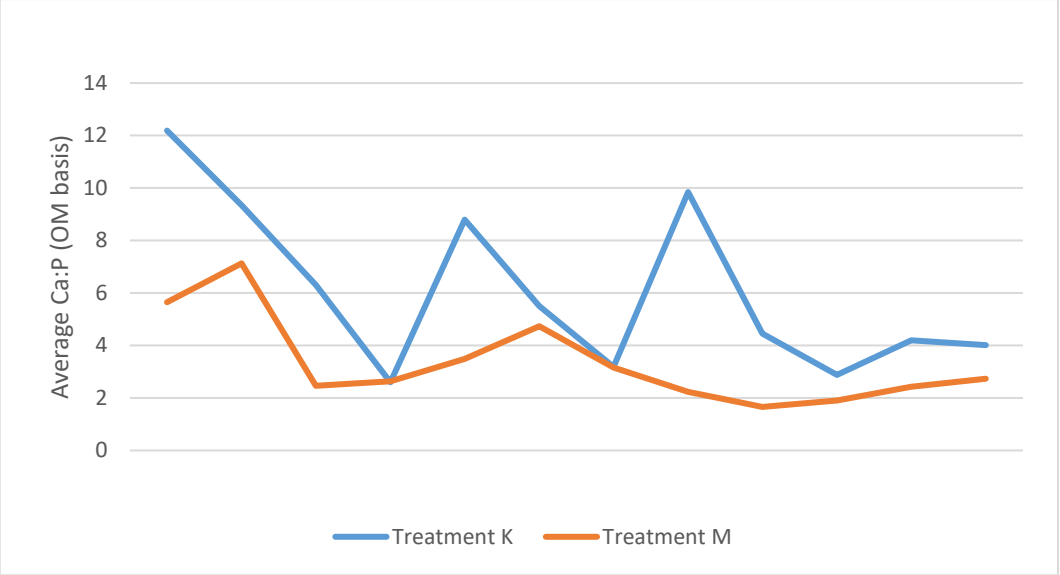

Figure 13 The average calcium to phosphorus ratio on an organic matter basis of two treatments over two years in the north western part of Namibia as quantified in grazing cattle fitted with oesophageal fistulae

The Ca:P (OM) for both treatments was higher during periods one, two, five and six (May – December) where there was little to no rainfall and decreased during the periods of higher rainfall (periods three and four) which fell during the months January – April.

The results are in agreement with Mphinyane (2001) who did a trial in Botswana. Mphinyane (2001) stated that browse has a higher calcium content than grass thus with an increase in the inclusion of browse in the diet so too will the Ca to phosphorus ratio increase. The seasonal plant class distribution in cattle diets showed that the cattle diets consisted of 80% grass and 16% browse at the end of January during spring and the early wet season. The grass contributed less to the diet as the season progressed with April having 20% browse, July 28% browse and the highest inclusion of browse reached 38% with only 60% grass in the month of October and the end of the dry season (Mphinyane, 2001).

4.1.6. MAGNESIUM

Forage magnesium (Mg) concentration obtained from OF cattle ranged from 0.09% to 0.26% for treatment K and from 0.09% to 0.16% for treatment M. There was no clear seasonal trend although Suttle (2010) found that Mg concentrations in forage tends to be low in spring due to a higher potassium concentration which acts as an antagonist to Mg absorption. The opposite is true during the autumn months when Mg concentrations tend to increase due to a decline in forage potassium concentrations (Suttle, 2010).

The highest Mg concentrations were recorded during period two for treatment K (average 0.25%) and during periods three and six for treatment M (average 0.14%). The

lowest Mg forage concentrations occurred during period four for treatment K (average 0.09%) and during period five for treatment M (average 0.10%).

The Mg forage concentrations in the current trial can be seen in Table 20 where the two years within each treatment were compared. There was greater variation between the two years in treatment K compared to treatment M.

Table 20 The influence of different years within treatments on magnesium (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.017)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**0,18[a]** (0.01)	**0,11[b]** (0.01)	*0,15* (0.04)	**0,12** (0.04)	**0,13** (0.03)	*0,12* (0.03)
NOV-DEC	2	**0,26** (0.04)	**0,25** (0.09)	*0,25* (0.06)	**0,11** (0.04)	**0,13** (0.01)	*0,12* (0.03)
JAN-FEB	3	**0,22[a]** (0.02)	**0,13[b]** (0.02)	*0,18* (0.05)	**0,16** (0.01)	**0,13** (0.01)	*0,14* (0.02)
MRT-APR	4	**0,09** (0.01)	**0,10** (0.03)	*0,09* (0.02)	**0,14** (0.03)	**0,10** (0.01)	*0,12* (0.03)
MAY-JUN	5	**0,22[a]** (0.05)	**0,12[b]** (0.01)	*0,17 (0.06)*	**0,09** (0.02)	**0,11** (0.01)	*0,10* (0.02)
JUL-AUG	6	**0,14** (0.02)	**0,12** (0.03)	*0,13* (0.02)	**0,13** (0.01)	**0,14** (0.03)	*0,14* (0.02)
AVE (+/-SD)		*0,18* (0.06)	*0,14* (0.06)		*0,12* (0.03)	*0,12* (0.02)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

. For treatment K, differences were seen between the two years during periods one, three and five (P<0.05). With higher Mg values (0.18% during period one, 0.22% during periods three and five) occurring in year one.

For treatment M, no differences occurred between the two years (P>0.05).

In Table 21, the same year between treatments was compared. There was greater variation within year one compared to year two.

Table 21 The influence of the same year between treatments on the magnesium (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.017)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**0,18[a]**	**0,12[b]**	*0,15*	**0,11**	**0,13**	*0,12*
NOV-DEC	2	**0,26[a]**	**0,11[b]**	*0.19*	**0,25[a]**	**0,13[b]**	*0.19*
JAN-FEB	3	**0,22[a]**	**0,16[b]**	*0.19*	**0,13**	**0,13**	*0.13*
MRT-APR	4	**0,09[a]**	**0,14[b]**	*0.12*	**0,10**	**0,10**	*0.1*
MAY-JUN	5	**0,22[a]**	**0,09[b]**	*0.16*	**0,12**	**0,11**	*0.12*
JUL-AUG	6	**0,14**	**0,13**	*0.14*	**0,12**	**0,14**	*0.13*
AVE		*0,18*	*0,12*		*0,14*	*0,12*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

For year one, differences between treatments were seen during periods one, two, three, four and five (P<0.05). Higher Mg values occurred for treatment K during periods one, two, three and five (0.18%, 0.26%, 0.22% and 0.22% respectively). A higher Mg value was recorded for treatment M during period four (0.14%).

During the second year, a difference between treatments occurred during period two with a higher Mg value (0.25%) seen for treatment K (P<0.05).

In Table 22, the average values in each period within each treatment were compared to one another. There was greater variation between the different periods for treatment K compared to treatment M.

Table 22 The influence of different period averages within a treatment on the magnesium (organic matter) percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.012)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**0,18**	**0,11**	*0,15*[a]	**0,12**	**0,13**	*0,12*[ab]
NOV-DEC	2	**0,26**	**0,25**	*0,25*[b]	**0,11**	**0,13**	*0,12*[ab]
JAN-FEB	3	**0,22**	**0,13**	*0,18*[a]	**0,16**	**0,13**	*0,14*[a]
MRT-APR	4	**0,09**	**0,10**	*0,09*[c]	**0,14**	**0,10**	*0,12*[ab]
MAY-JUN	5	**0,22**	**0,12**	*0,17*[a]	**0,09**	**0,11**	*0,10*[b]
JUL-AUG	6	**0,14**	**0,12**	*0,13*[c]	**0,13**	**0,14**	*0,14*[a]
AVE		*0,18*	*0,14*		*0,12*	*0,12*	

[abc] Column means with different superscripts differ significantly (P ≤ 0.05)

These differences between periods may be due to the fact that as forage matures the Mg concentrations decrease as the forage becomes more lignified and mineral content is diluted (Suttle, 2010). It was also found that Mg concentrations in forage tends to be low in spring due to a higher potassium concentration which acts as an antagonist to Mg absorption. The opposite is true during the autumn months when Mg concentrations tend to increase due to a drop in forage potassium concentrations (Suttle, 2010).

Grasses in temperate and tropical pastures contain on average 0.18-0.36% Mg DM (Minson, 1990). The majority of the Mg values for this trial fell below this range.

Figure 14 shows the Mg requirement for a 400kg cow during gestation and lactation (NRC, 2016).

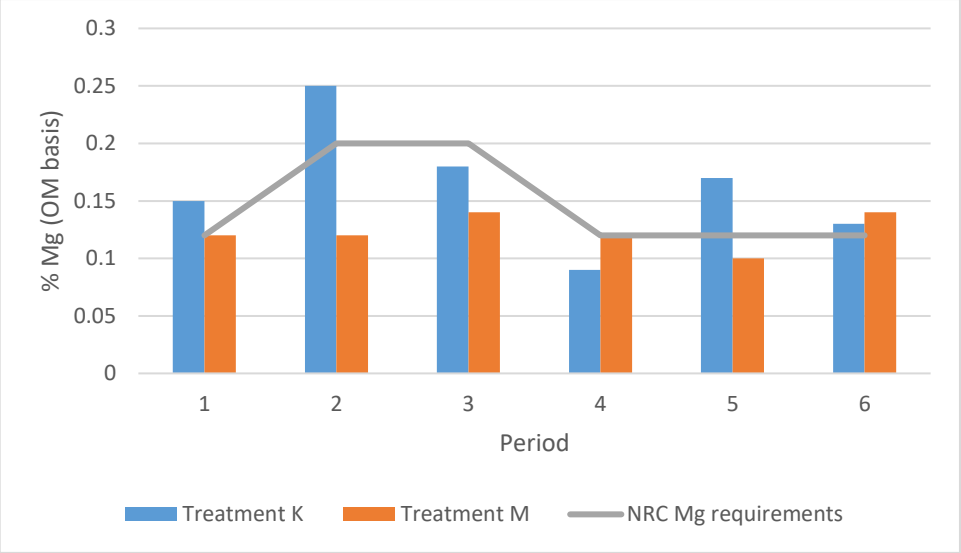

Figure 14 Average magnesium percentage on an organic matter basis for treatment K and M over the two year trial period compared to the NRC magnesium concentration requirement for a 400kg cow with an average milk yield of 6.8kg/day at a dry matter intake level of 2.7% of body weight per day (NRC, 2016)

The Mg requirements increases during lactation to 0.20% (periods two and three) during which time the requirements are not met from the forage alone except during period two for treatment K. During gestation the Mg requirements decrease to 0.12% and are not met except during periods one and five of treatment K and during period six for both treatments.

Nitrogen and potassium act as antagonists to Mg absorption (Martens & Schweigel, 2000) as well as high concentrations of Ca and P having a negative effect on Mg absorption or utilization (Chester-Jones *et al*., 1989).

4.1.7. Zinc

Forage zinc (Zn) concentrations, determined from samples collected by OF animals, ranged from 15.68mg/kg to 27.32mg/kg for treatment K and from 13.35mg/kg to 30.90mg/kg for treatment M.

The zinc (Zn) concentrations in the forage are presented in Table 23. There is a trend for Zn concentrations from OF cattle to increase during the periods of higher rainfall (periods two and three) and then decline towards the periods of low to no rainfall (periods four, five and six). This trend is depicted in Figure 15.

The highest Zn concentrations were recorded during period two for both treatment K (average 26.20mg/kg) and for treatment M (average 26.72 mg/kg). The lowest Zn concentrations occurred during period four for both treatment K (average 18.32 mg/kg) and treatment M (average 17.49mg/kg).

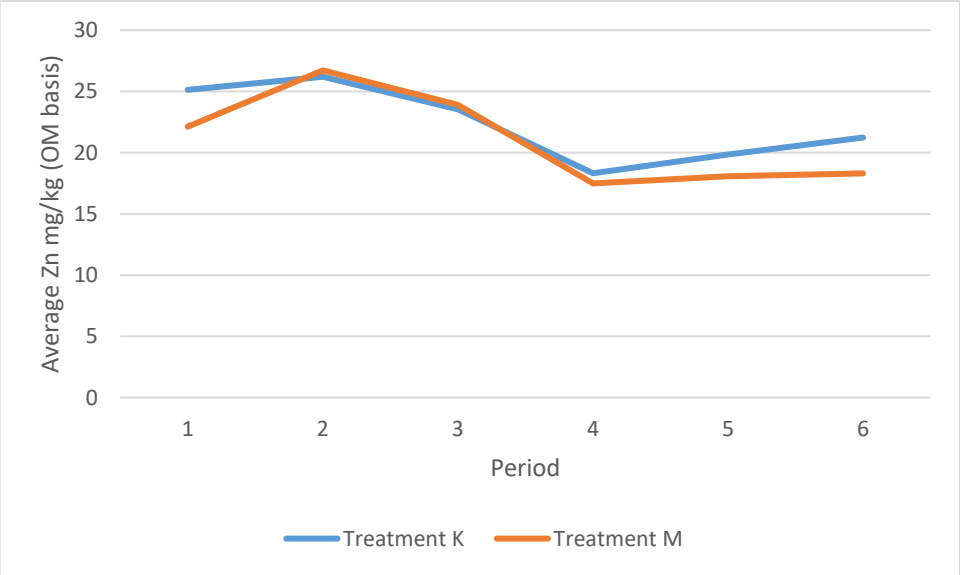

Figure 15 The average zinc concentration (mg/kg) on an organic matter basis of two treatments, over a two year period in north western Namibia as quantified in grazing cattle fitted with oesophageal fistulae

In Table 23, the two years within each treatment were compared. The Zn concentrations showed a fair amount of variation between the two years.

Table 23 The influence of different years within treatments on zinc concentration (mg/kg) corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north Western Namibia (+/-SE: 1.329)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**27,08[a]** (2.11)	**23,18[b]** (1.98)	*25,13* (2.81)	**30,90[a]** (3.00)	**13,35[b]** (1.30)	*22,12* (9.83)
NOV-DEC	2	**27,32** (1.55)	**25,08** (2.33)	*26,20* (2.16)	**29,92[a]** (0.83)	**23,51[b]** (1.02)	*26,72* (3.61)
JAN-FEB	3	**26,65[a]** (0.53)	**20,46[b]** (4.12)	*23,55* (4.29)	**24,52** (1.38)	**23,29** (0.69)	*23,90* (1.19)
MRT-APR	4	**20,95[a]** (2.12)	**15,68[b]** (2.39)	*18,32* (3.53)	**20,09[a]** (0.91)	**14,89[b]** (1.62)	*17,49* (3.08)
MAY-JUN	5	**19,35** (3.72)	**20,33** (2.78)	*19,84* (2.99)	**18,23** (5.28)	**17,91** (0.87)	*18,07* (3.39)
JUL-AUG	6	**19,55** (3.09)	**22,92** (1.83)	*21,23* (2.93)	**15,14[a]** (1.19)	**21,51[b]** (0.87)	*18,32* (3.61)
AVE (+/-SD)		*23,49* (4.20)	*21,27* (3.81)		*23,13* (6.42)	*19,08* (4.20)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

Differences between the two years for treatment K were seen during periods one, three and four with higher Zn values (27.08mg/kg, 26.65mg/kg and 20.95mg/kg respectively) recorded during the first year (P<0.05).

For treatment M, differences between the two years were seen during periods one, two, four and six with higher Zn values occurring in year one of periods one, two and four (30.90mg/kg, 29.92mg/kg and 20.09mg/kg respectively) (P<0.05). A higher Zn value was recorded during year two of period six (21.51mg/kg DM).

In Table 24, the same year between treatments was compared. There seemed to be little variation between Zn concentrations during both years.

Table 24 The influence of the same year between treatments on zinc concentration (mg/kg) corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 1.329)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**27,08[a]**	**30,90[b]**	*29*	**23,18[a]**	**13,35[b]**	*18.27*
NOV-DEC	2	**27,32**	**29,92**	*28.62*	**25,08**	**23,51**	*24.3*
JAN-FEB	3	**26,65**	**24,52**	*25.59*	**20,46**	**23,29**	*21.88*
MRT-APR	4	**20,95**	**20,09**	*20.52*	**15,68**	**14,89**	*15.29*
MAY-JUN	5	**19,35**	**18,23**	*18.79*	**20,33**	**17,91**	*19.12*
JUL-AUG	6	**19,55[a]**	**15,14[b]**	*17.35*	**22,92**	**21,51**	*22.22*
AVE		*23,49*	*23,13*		*21,27*	*19,08*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

Differences between treatments during the first year were seen during period one and six with a higher Zn value (30.90mg/kg) being recorded for treatment M during period one and a higher Zn value being recorded for treatment K during period six (19.55mg/kg) (P<0.05).

During the second year, differences between treatments were seen during period one with a higher Zn (23.18mg/kg DM) value recorded for treatment K P<0.05).

In Table 25, the period averages of Zn within each treatment were compared.

Table 25 The influence of different period averages within treatments on zinc concentration (mg/kg) corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.940)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**27,08**	**23,18**	*25,13*[a]	**30,90**	**13,35**	*22,12*[a]
NOV-DEC	2	**27,32**	**25,08**	*26,20*[a]	**29,92**	**23,51**	*26,72*[b]
JAN-FEB	3	**26,65**	**20,46**	*23,55*[ac]	**24,52**	**23,29**	*23,90*[a]
MRT-APR	4	**20,95**	**15,68**	*18,32*[b]	**20,09**	**14,89**	*17,49*[c]
MAY-JUN	5	**19,35**	**20,33**	*19,84*[bc]	**18,23**	**17,91**	*18,07*[c]
JUL-AUG	6	**19,55**	**22,92**	*21,23*[c]	**15,14**	**21,51**	*18,32*[c]
AVE		*23,49*	*21,27*		*23,13*	*19,08*	

[abc]Column means with different superscripts differ significantly (P ≤ 0.05)

As forage matures there are increases in the proportion of stem to leaf with stems having a lower mineral content (Minson, 1990). This would explain the seasonal variation in forage Zn concentrations in this trial P<0.05). The variation between periods can also be explained by the fact that minerals are lost with the shedding of seed, leaving the remaining stem lower in mineral concentration (Suttle, 1999).

The Zn requirements for lactating and pregnant cows is 30mg Zn/kg dietary DM (NRC, 2016). Only a single requirement value for Zn is given by the NRC (2016); different values are not given for different production phases. The forage zinc concentration results for both treatments indicate that forage alone is not able to supply the Zn requirements of a 400kg with an average milk yield of 6.8kg/day and a dry matter intake of level of 2.7% of body weight per day (NRC 2016). This is depicted in Figure 16.

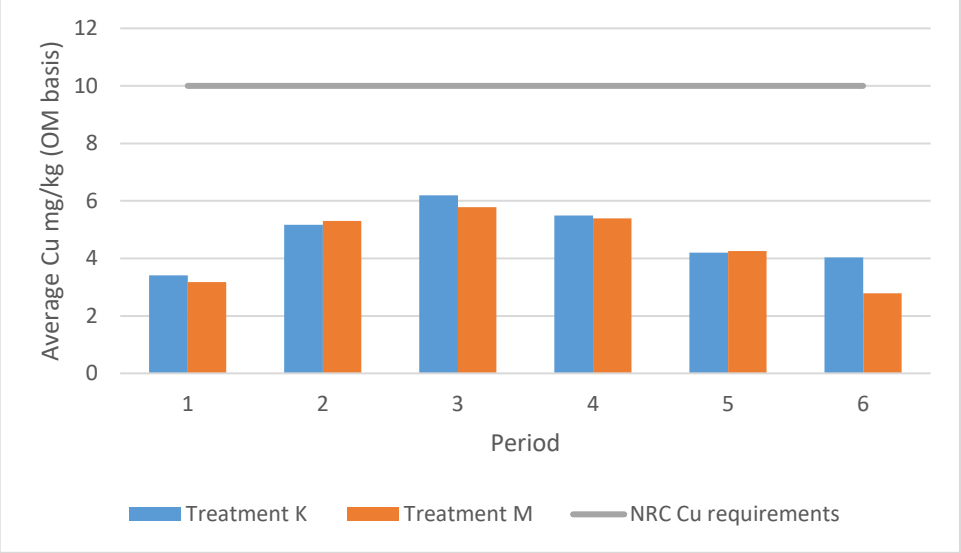

Figure 16 Average zinc concentration (mg/kg) corrected for organic matter for treatment K and M over the two year trial period compared to the NRC zinc concentration requirement for a 400kg cow with an average milk production of 6.8kg/day at a dry matter intake level of 2.7% of body weight per day (NRC, 2016)

4.1.8. COPPER

The forage copper (Cu) concentration as determined from samples collected by OF cattle ranged from 2.74mg/kg to 6.86mg/kg for treatment K and from 2.25mg/kg to 7.09mg/kg for treatment M.

The trend observed was an increase in Cu concentration towards periods of higher rainfall (periods two, three and four) followed by a decrease in copper concentration as rainfall decreased during periods one, five and six. This trend is depicted in Figure 17.

The highest Cu forage concentrations were recorded during period three for both treatment K (average 6.19mg/kg DM) and treatment M (average 5.78mg/kg DM). The lowest Cu concentrations occurred during period one for treatment K (average 3.41mg/kg DM) and during period six for treatment M (average 2.78mg/kg DM).

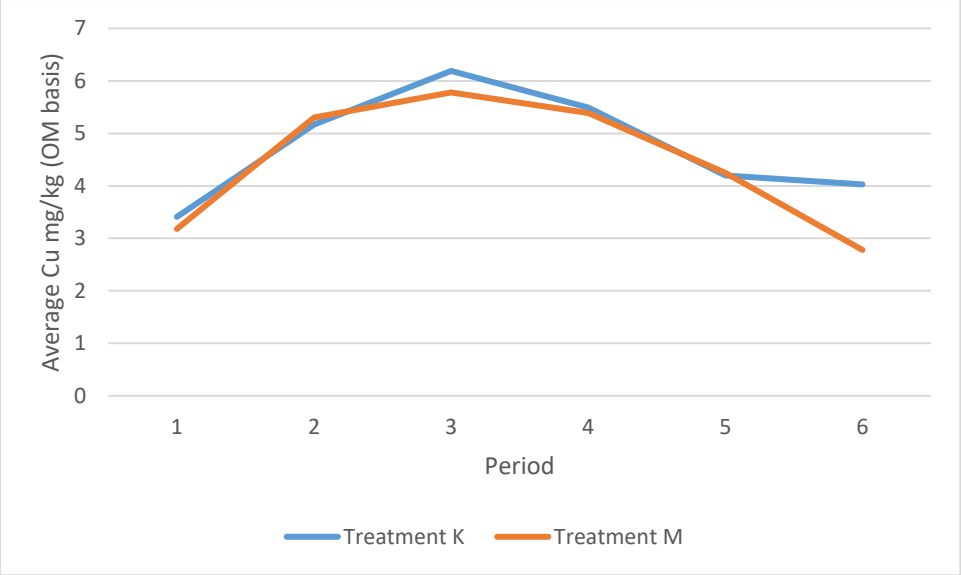

Figure 17 The average copper concentration (mg/kg) on an organic matter basis of two treatments, over a two year period in north western Namibia as quantified in grazing cattle fitted with oesophageal fistulae

In Table 26, the Cu values for both treatments are shown and the two years within each treatment were compared with each other. There was greater variation between the two years for treatment K compared to treatment M.

Table 26 The influence of different years within treatments on copper concentration (mg/kg) corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.427)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**2,74[a]** (0.24)	**4,08[b]** (0.38)	*3,41* (0.79)	**2,25[a]** (0.69)	**4,11[b]** (0.39)	*3,18* (1.13)
NOV-DEC	2	**3,86[a]** (0.55)	**6,47[b]** (0.48)	*5,17* (1.51)	**3,50[a]** (0.71)	**7,09[b]** (0.68)	*5,30* (2.06)
JAN-FEB	3	**6,86[a]** (1.66)	**5,52[b]** (0.63)	*6,19* (1.34)	**5,68** (1.04)	**5,88** (0.11)	*5,78* (0.67)
MRT-APR	4	**5,72** (0.52)	**5,25** (0.83)	*5,49* (0.67)	**5,99** (0.89)	**4,80** (0.53)	*5,39* (0.92)
MAY-JUN	5	**4,05** (0.70)	**4,35** (0.42)	*4,20* (0.54)	**4,29** (0.27)	**4,21** (0.40)	*4,25* (0.31)
JUL-AUG	6	**3,78** (0.51)	**4,28** (1.80)	*4,03* (1.21)	**2,74** (0.27)	**2,83** (0.22)	*2,78* (0.23)
AVE (+/-SD)		*4,50* (1.57)	*5,00* (1.15)		*4,08* (1.56)	*4,82* (1.45)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

For treatment K, differences between years were seen during periods one, two and three with a higher Cu concentration being recorded during year two of periods one and two (4.08mg/kg and 6.47mg/kg respectively) (P<0.05). A higher Cu concentration was recorded during year one of period three (6.86mg/kg).

For treatment M, differences were seen between years during periods one and two with a higher Cu concentration being recorded during the second year (4.11mg/kg during period one and 7.09mg/kg for period two) P<0.05).

In Table 27, the same year within each treatment was compared. There was very little variation within this comparison.

Table 27 The influence of the same year between treatments on copper concentration (mg/kg) on an organic matter basis in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.427)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**2,74**	**2,25**	*2.5*	**4,08**	**4,11**	*4.1*
NOV-DEC	2	**3,86**	**3,50**	*3.68*	**6,47**	**7,09**	*6.78*
JAN-FEB	3	**6,86**	**5,68**	*6.27*	**5,52**	**5,88**	*5.7*
MRT-APR	4	**5,72**	**5,99**	*5.86*	**5,25**	**4,80**	*5.03*
MAY-JUN	5	**4,05**	**4,29**	*4.17*	**4,35**	**4,21**	*4.28*
JUL-AUG	6	**3,78**	**2,74**	*3.26*	**4,28[a]**	**2,83[b]**	*3.56*
AVE		*4,50*	*4,08*		*5,00*	*4,82*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

During year one no significant differences were seen between treatments (P>0.05).

During the second year, differences between treatments were seen during period six with a higher Cu concentration (4.28mg/kg DM) being recorded for treatment K (P<0.05).

In Table 28, averages for each period were compared with within each treatment. The results showed great variation between period averages.

Table 28 The influence of different period averages within treatments on copper concentration (mg/kg) corrected for organic matter basis in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.302)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**2,74**	**4,08**	*3,41*[a]	**2,25**	**4,11**	*3,18*[a]
NOV-DEC	2	**3,86**	**6,47**	*5,17*[b]	**3,50**	**7,09**	*5,30*[b]
JAN-FEB	3	**6,86**	**5,52**	*6,19*[c]	**5,68**	**5,88**	*5,78*[b]
MRT-APR	4	**5,72**	**5,25**	*5,49*[bc]	**5,99**	**4,80**	*5,39*[b]
MAY-JUN	5	**4,05**	**4,35**	*4,20*[a]	**4,29**	**4,21**	*4,25*[c]
JUL-AUG	6	**3,78**	**4,28**	*4,03*[a]	**2,74**	**2,83**	*2,78*[a]
AVE		*4,50*	*5,00*		*4,08*	*4,82*	

[abc]Column means with different superscripts differ significantly (P ≤ 0.05)

The reason for these differences between periods can be seen from Figure 27, where there seems to be a trend between copper concentration and season. In this trial the copper concentration increased during periods of higher rainfall (periods two, three and four) and then decreased towards periods of low to no rainfall (periods one, five and six). A study done by Jumba *et al*., (1996) showed a tendency for forage concentration of Cu to increase with an increase in altitude in the dry season which is a probable reflection of the covariation in rainfall.

According to the NRC (2016), the Cu requirements for lactating and pregnant cows is 10mg Cu/kg dietary DM. The NRC (2016) does not specify different Cu requirements for different production phases during different parts of the year. The forage Cu concentrations were below this level for both treatments meaning forage alone is not able to supply the Cu requirements for a 400kg cow and supplementation mat be required.

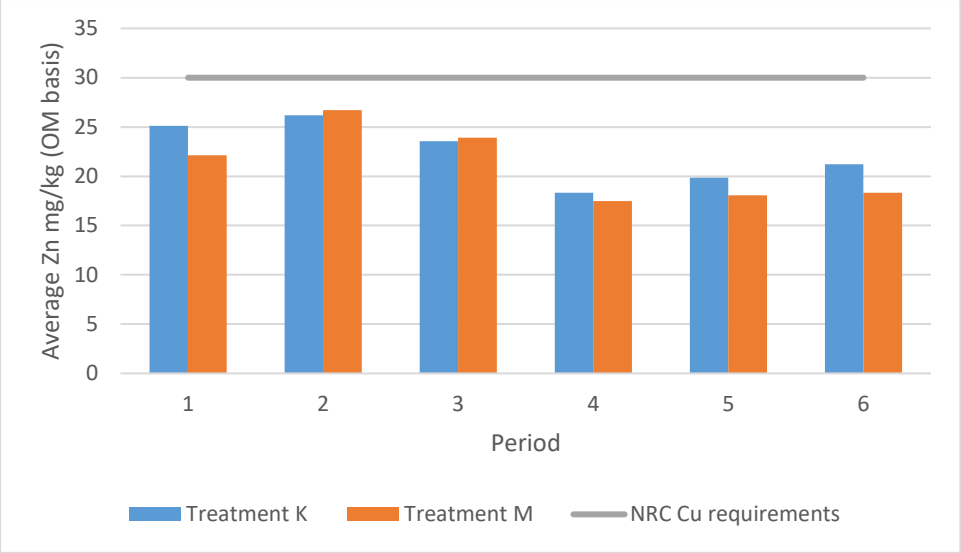

Figure 18 Average copper concentration (mg/kg) corrected for organic matter for treatment K and M over the two year trial period compared to the NRC copper concentration requirement for a 400kg cow with an average milk production of 6.8kg/day at a dry matter intake level of 2.7% of body weight per day (NRC, 2016)

Mo has an antagonistic action on Cu metabolism which is exacerbated when S is high (NRC, 2016). This must be taken into account when Cu requirements are estimated.

4.1.9. MANGANESE

The forage manganese (Mn) concentration ranged from 27.64mg/kg to 51.66mg/kg for treatment K and from 27.08mg/kg DM to 67.79mg/kg for treatment M.

There was a seasonal effect in the Mn concentration of the forage for treatment M with higher values recorded during the wet season. This is depicted in Figure 19. Minson (1990), stated that plant species and state of maturity generally have a small impact on Mn content.

The highest Mn concentrations were recorded during period three for treatment K (average 46.87mg/kg) and during period two for treatment M (average 57.40mg/kg). The lowest concentrations occurred during period one for treatment K (average 29.10mg/kg) and during period six for treatment M (average 28.15mg/kg).

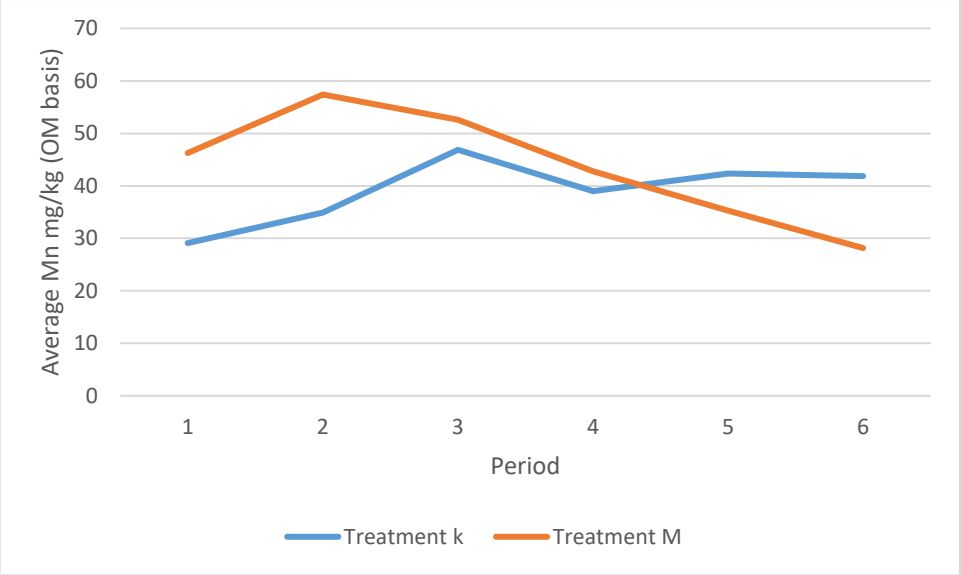

Figure 19 The average manganese concentration (mg/kg) on an organic matter basis of two treatments, over a two year period in north western Namibia as quantified in grazing cattle fitted with oesophageal fistulae

In Table 29, the two years within each treatment were compared to each other. There was more variation between the two years for treatment M compared to treatment K.

Table 29 The influence of different years within treatments on manganese concentration (mg/kg) corrected for organic matter basis in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 5.387)

		TREATMENT - K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**30,56** (1.45)	**27,64** (2.36)	*29,10* (2.37)	**58,34[a]** (25.33)	**34,12[b]** (4.32)	*46,23* (20.98)
NOV-DEC	2	**34,74** (2.63)	**35,03** (8.15)	*34,89* (5.42)	**67,79[a]** (27.89)	**47,00[b]** (7.82)	*57,40* (21.57)
JAN-FEB	3	**51,66** (3.08)	**42,08** (3.53)	*46,87* (6.03)	**57,84** (0.72)	**47,41** (1.67)	*52,62* (5.82)
MRT-APR	4	**36,53** (2.92)	**41,44** (4.91)	*38,98* (4.51)	**48,92** (8.65)	**36,63** (6.33)	*42,78* (9.56)
MAY-JUN	5	**40,67** (3.50)	**44,04** (4.59)	*42,36* (4.09)	**33,02** (9.53)	**37,49** (3.12)	*35,25* (6.80)
JUL-AUG	6	**36,67** (8.98)	**47,10** (10.70)	*41,88* (10.52)	**27,08** (2.49)	**29,22** (0.79)	*28,15* (2.03)
AVE (+/-SD)		*38,47* (7.77)	*39,56 (8.53)*		*48,83* (20.22)	*38,64* (7.86)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

When the two years within each treatment were compared there were no differences between the two years in treatment K P>0.05).

For treatment M, differences between the two years were seen in periods one and two with a higher Mn concentration recorded during year one (58.34mg/kg during period one and 67.79mg/kg during period two) (P<0.05).

In Table 30 the same year between treatments was compared.

Table 30 The influence of the same year between treatments on manganese concentration (mg/kg) corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 5.387)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**30,56[a]**	**58,34[b]**	*44.45*	**27,64**	**34,12**	*30.88*
NOV-DEC	2	**34,74[a]**	**67,79[b]**	*51.27*	**35,03**	**47,00**	*41.02*
JAN-FEB	3	**51,66**	**57,84**	*54.75*	**42,08**	**47,41**	*44.75*
MRT-APR	4	**36,53**	**48,92**	*42.73*	**41,44**	**36,63**	*39.04*
MAY-JUN	5	**40,67**	**33,02**	*36.85*	**44,04**	**37,49**	*40.77*
JUL-AUG	6	**36,67**	**27,08**	*31.88*	**47,10[a]**	**29,22[b]**	*38.16*
AVE		*38,47*	*48,83*		*39,56*	*38,64*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

During year one, differences between the two treatments were seen during periods one and two with a higher Mn concentration being recorded for treatment M (58.34mg/kg during period one and 67.79mg/kg during period two) (P<0.05).

During the second year, differences between the two treatments were seen during period six with a higher Mn concentration being recorded for treatment K (47.10mg/kg) (P<0.05).

In Table 31, the averages of each period were compared to each other within each treatment. There was greater variation between periods in treatment M compared to treatment K.

Table 31 The influence of different period averages within a treatment on manganese concentration (mg/kg) corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north Western Namibia (+/-SE: 3.809)

		TREATMENT - K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**30,56**	**27,64**	*29,10*^{a}	**58,34**	**34,12**	*46,23*^{a}
NOV-DEC	2	**34,74**	**35,03**	*34,89*^{ac}	**67,79**	**47,00**	*57,40*^{b}
JAN-FEB	3	**51,66**	**42,08**	*46,87*^{bc}	**57,84**	**47,41**	*52,62*^{ab}
MRT-APR	4	**36,53**	**41,44**	*38,98*^{abc}	**48,92**	**36,63**	*42,78*^{ac}
MAY-JUN	5	**40,67**	**44,04**	*42,36*^{c}	**33,02**	**37,49**	*35,25*^{cd}
JUL-AUG	6	**36,67**	**47,10**	*41,88*^{c}	**27,08**	**29,22**	*28,15*^{d}
AVE		*38,47*	*39,56*		*48,83*	*38,64*	

^{abcd}Column means with different superscripts differ significantly (P ≤ 0.05)

According to Suttle (2000), plants mature in response to factors such as season and climate and there are associated changes in mineral content. This could be a reason for the variation in Mn concentration between periods.

The Mn requirements for lactating and pregnant cows is 40mg of Mn/kg dietary DM (NRC, 2016). Requirement values were not given for different production stages during different times of the year. The Mn requirements for a 400kg cow are met for the majority of the year. Parts of the year when rainfall is lower (periods one, two and four for treatment K and periods five and six for treatment M), their needs are not met from forage alone. This is depicted in Figure 20.

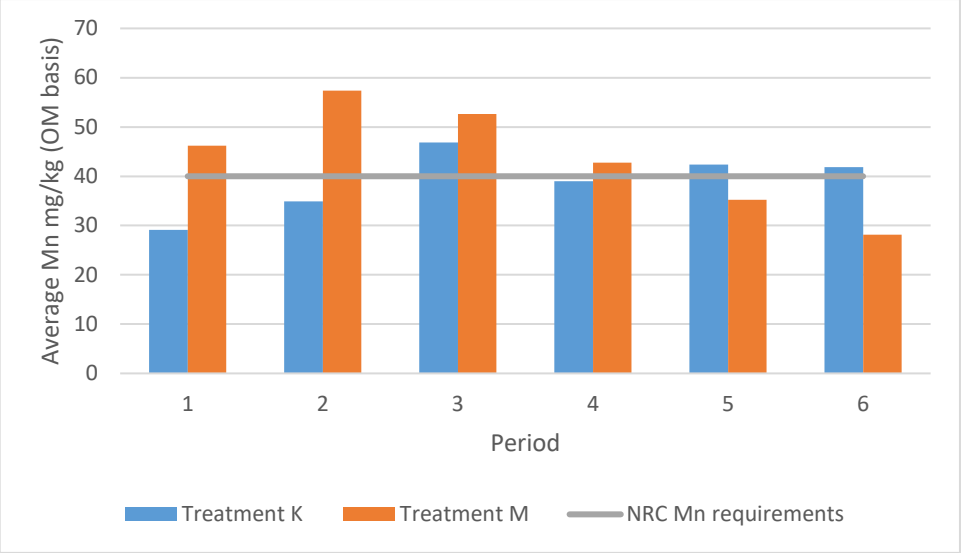

Figure 20 Average manganese concentration (mg/kg) corrected for organic matter for treatment K and M over the two year trial period compared to the NRC manganese concentration requirement for a 400kg cow with an average milk production of 6.8kg/day at a dry matter intake level of 2.7% of body weight per day (NRC, 2016)

High concentrations of dietary Ca and P can interfere with Mn availability (Spears, 2003). This may have an effect on Mn requirements.

4.1.10 NEUTRAL DETERGENT FIBRE

The extrusa samples collected from OF cattle were dried by forced draught oven at 50°C to 60°C as a practical drying method rather than the optimal drying method which was freeze drying, recommended by Engels *et al*. (1981) and Burritt *et al*. (1988). The extrusa samples after squeezing still contained high concentration of moisture that contributed to the chemical reaction known as the Maillard-reaction in which the sugar residues and amino acids condensed to form a brown complex with physical properties similar to lignin (Burritt *et al*., 1988). Burritt *et al*. (1988) found large differences in fibre fraction results and the differences were large enough to lead to erroneous conclusions about the forage quality.

The results for neutral detergent fibre (OM) are recorded in Table 32 below. The values ranged from 49.86% to 64.53% for treatment K and from 53% to 66.20% for treatment M. The NDF values were higher during periods of low rainfall (periods one, four, five and six). The highest values fell during period four for treatment K (average 62.86%) and during period six for treatment M (average 65.76%). The NDF values dropped during periods of higher rainfall (periods two and three), the lowest values occurred during period two for treatment K (average 54.93%) and during period three for treatment M (average 54.88%).

Roodt (2012) recorded values of between 69-83% NDF on OM basis in the tree and shrub savannah of Namibia. Theart (2015) recorded values of between 35-50% DM in the Northern Cape in South Africa. The NDF concentration of the forage recorded in the current trial was lower than the values recorded by Roodt (2012) but higher than the values recorded by Theart (2015).

The seasonal trend in NDF concentration is shown in Figure 21.

The decrease in feed digestibility with advancing dry seasons for grass species is consistent with previous studies conducted in areas with distinct wet and dry seasons (Hassen *et al*., 2007).

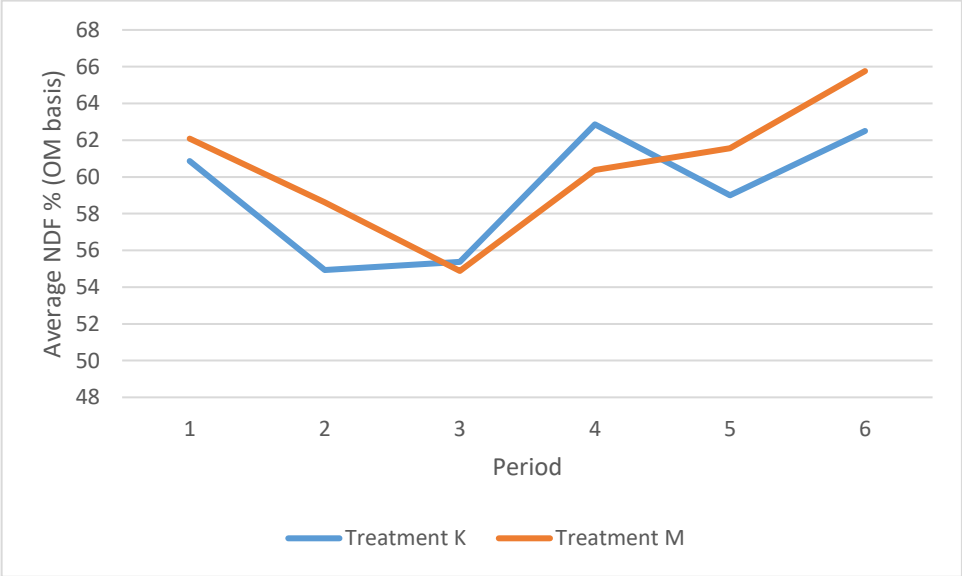

Figure 21 The average neutral detergent fibre percentage corrected for organic matter of two treatments over two years in north western Namibia as quantified in grazing cattle fitted with oesophageal fistulae

In Table 32, the two years were compared within each treatment. There was little variation between the two years for both treatments.

Table 32 The influence of different years within treatments on neutral detergent fibre percentage corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 1.806)

		TREATMENT - K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**58,87** (0.64)	**62,86** (1.27)	*60,86* (2.36)	**59,57** (6.56)	**64,59** (1.80)	*62,08* (5.11)
NOV-DEC	2	**55,67** (4.29)	**54,19** (4.90)	*54,93* (4.20)	**58,70** (9.60)	**58,52** (3.84)	*58,61* (6.54)
JAN-FEB	3	**49,86[a]** (0.74)	**60,88[b]** (1.79)	*55,37* (6.16)	**53,00** (0.86)	**56,76** (1.21)	*54,88* (2.26)
MRT-APR	4	**64,53** (0.51)	**61,18** (2.48)	*62,86* (2.43)	**59,10** (0.97)	**61,65** (1.13)	*60,37* (1.69)
MAY-JUN	5	**56,93** (2.02)	**61,07** (1.95)	*59,00* (2.88)	**62,77** (0.15)	**60,34** (0.95)	*61,56* (1.47)
JUL-AUG	6	**62,27** (2.37)	**62,73** (2.04)	*62,50* (1.99)	**65,32** (1.52)	**66,20** (1.31)	*65,76* (1.36)
AVE (+/-SD)		*58,02* (5.21)	*60,49* (3.76)		*59,74* (5.64)	*61,34* (3.75)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

For treatment K, differences were found between the two years in period three with a higher NDF value (60.88%) occurring in year two (P<0.05).

For treatment M, there were no differences between the two years (P>0.05).

In Table 33, the same year was compared between the two treatments. Again, there was little variation between the recorded values during both years.

Table 33 The influence of the same year between treatments on the neutral detergent fibre percentage corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 1.806)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**58,87**	**59,57**	*59.22*	**62,86**	**64,59**	*63.73*
NOV-DEC	2	**55,67**	**58,70**	*57.19*	**54,19**	**58,52**	*56.36*
JAN-FEB	3	**49,86**	**53,00**	*51.43*	**60,88**	**56,76**	*58.82*
MRT-APR	4	**64,53[a]**	**59,10[b]**	*61.82*	**61,18**	**61,65**	*61.42*
MAY-JUN	5	**56,93[a]**	**62,77[b]**	*59.85*	**61,07**	**60,34**	*60.71*
JUL-AUG	6	**62,27**	**65,32**	*63.8*	**62,73**	**66,20**	*64.47*
AVE		*58,02*	*59,74*		*60,49*	*61,34*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

In year one, there were differences between the two treatments in period four and five (P<0.05). In period four, a higher NDF value (64.53%) was recorded for treatment K. In period five, a higher NDF value (62.77%) was recorded for treatment M.

In year two, there were no differences between the two treatments (P>0.05).

In Table 34, period averages within each treatment were compared. The NDF values showed variation between the periods.

Table 34 The influence of different period averages within each treatment on the neutral detergent fibre percentage corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 1.277)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**58,87**	**62,86**	*60,86^{ac}*	**59,57**	**64,59**	*62,08^{a}*
NOV-DEC	2	**55,67**	**54,19**	*54,93^{b}*	**58,70**	**58,52**	*58,61^{a}*
JAN-FEB	3	**49,86**	**60,88**	*55,37^{b}*	**53,00**	**56,76**	*54,88^{b}*
MRT-APR	4	**64,53**	**61,18**	*62,86^{a}*	**59,10**	**61,65**	*60,37^{a}*
MAY-JUN	5	**56,93**	**61,07**	*59,00^{c}*	**62,77**	**60,34**	*61,56^{a}*
JUL-AUG	6	**62,27**	**62,73**	*62,50^{ac}*	**65,32**	**66,20**	*65,76^{c}*
AVE		*58,02*	*60,49*		*59,74*	*61,34*	

^{abc}Column means with different superscripts differ significantly (P ≤ 0.05)

The reason for these differences between periods are due to the fact that higher NDF values tend to occur during the months of lower rainfall (periods one, four, five and six) whilst lower NDF values occur during the months of higher rainfall (periods two, three). A decrease in NDF content during the wet season is due to an accumulation of non-structural sugars and advancing maturity (Fedenko *et al*., 2013).

Intake may be restricted when forage is high in NDF as it contributes towards the "filling effect" in the rumen due to it being digested more slowly (Van Soest, 1994).

4.1.11. ACID DETERGENT LIGNIN

The acid detergent lignin (ADL) in the extrusa collected by OF cattle is presented in Table 35. The ADL values range from 5.26% to 12.69% for treatment K and from 6.03% to 8.95% for treatment M. Roodt (2012) recorded ADL values of between 7.8-22% OM in the tree and shrub savannah of Namibia and Theart (2015) recorded values of between 8.5-32% DM in the Northern Cape in South Africa. A few of the ADL values in the current trial fell below these ranges.

The general trend seemed to show an increase in ADL values during periods two and three (November – February) when rainfall was higher and forage was more mature. The

highest values were recorded during period three for treatment K (Average 11.37%) and during period two for treatment M (Average 8.16%). This increase in ADL concentration occurred at the same time there was an increase in CP concentration (Table 14). Burritt *et al*., (1988) found that extrusa containing immature forage was the most susceptible to oven drying in terms of the formation of artefact lignin, due to the higher concentrations of protein and soluble carbohydrates contained in immature forages.

Lower ADL concentrations occurred during periods one, four, five and six (March-October). The lowest values were recorded during period four for treatment K (Average 6.24%) and during period six for treatment M (Average 7.06%). This trend is shown in Figure 22.

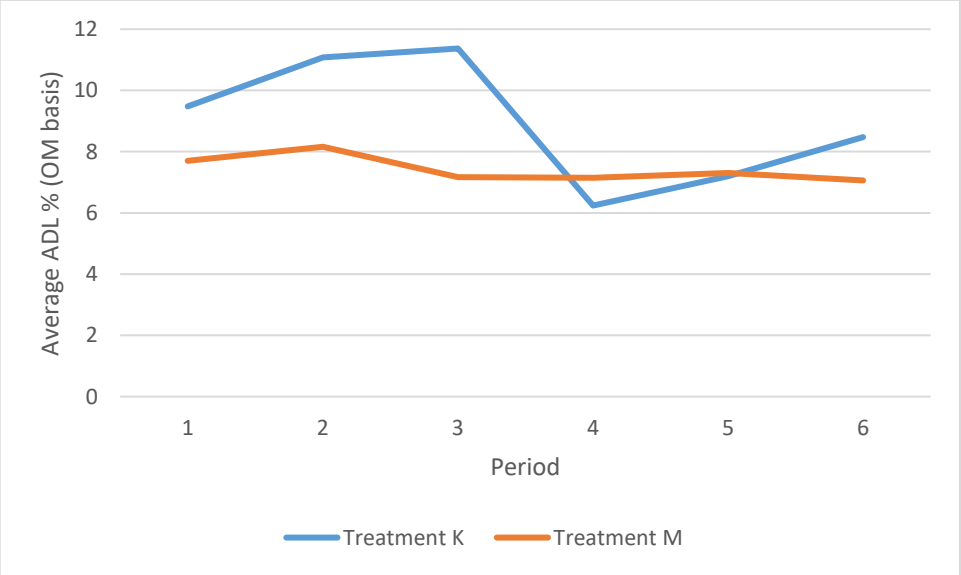

Figure 22 The average acid detergent lignin percentage corrected for organic matter of two treatments over two years in north western Namibia as quantified in grazing cattle fitted with oesophageal fistulae

In Table 35. The two years within each treatment were compared.

Table 35 The influence of different years within treatments on the acid detergent lignin percentage corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.715)

		TREATMENT - K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**12,69[a]** (0.45)	**6,26[b]** (0.71)	*9,48* (3.56)	**7,99** (2.04)	**7,41** (0.36)	*7,70* (1.35)
NOV-DEC	2	**12,58[a]** (1.24)	**9,57[b]** (1.38)	*11,08* (2.02)	**8,95** (1.99)	**7,38** (0.63)	*8,16* (1.57)
JAN-FEB	3	**12,08** (1.61)	**10,66** (0.71)	*11,37* (1.36)	**6,15[a]** (0.56)	**8,20[b]** (2.31)	*7,17* (1.88)
MRT-APR	4	**7,23** (1.69)	**5,26** (0.78)	*6,24* (1.60)	**7,30** (0.61)	**6,99** (2.72)	*7,15* (1.77)
MAY-JUN	5	**8,33[a]** (1.39)	**6,08[b]** (0.73)	*7,20* (1.58)	**8,58[a]** (0.30)	**6,03[b]** (0.48)	*7,30* (1.44)
JUL-AUG	6	**8,35** (0.31)	**8,62** (0.87)	*8,48* (0.60)	**7,55** (0.36)	**6,56** (0.48)	*7,06* (0.66)
AVE (+/-SD)		*10,21* (2.57)	*7,74* (2.18)		*7,75* (1.39)	*7,10* (1.45)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

For treatment K, differences were seen between years in periods one, two and five (P<0.05). In period one, a higher ADL value (12.69%) was recorded in year one. The higher ADL value in this case may be due to the formation of artefact lignin as the corresponding CP value was also higher during this time (Burritt *et al*., 1988). In periods two and five a higher ADL value (12.58% for period two and 8.33% for period five) was recorded in year one.

For treatment M, differences were seen between the two years in periods three and five (P<0.05). In period three, a higher ADL value (8.20%) was recorded in year two which may be due to the formation of artefact lignin as rainfall was higher during this time and so was the corresponding CP value (Burritt *et al*., 1988). For period five, a higher ADL value (8.58%) was recorded during the first year.

In Table 36 each year was compared between treatments.

Table 36 The influence of the same year between treatments on the acid detergent lignin percentage corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.715)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**12,69[a]**	**7,99[b]**	*10.34*	**6,26**	**7,41**	*6.84*
NOV-DEC	2	**12,58[a]**	**8,95[b]**	*10.77*	**9,57[a]**	**7,38[b]**	*8.48*
JAN-FEB	3	**12,08[a]**	**6,15[b]**	*9.12*	**10,66[a]**	**8,20[b]**	*9.43*
MRT-APR	4	**7,23**	**7,30**	*7.27*	**5,26**	**6,99**	*6.13*
MAY-JUN	5	**8,33**	**8,58**	*8.46*	**6,08**	**6,03**	*6.06*
JUL-AUG	6	**8,35**	**7,55**	*7.95*	**8,62[a]**	**6,56[b]**	*7.59*
AVE		*10,21*	*7,75*		*7,74*	*7,10*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

In year one, significant differences between treatments were seen in periods one, two and three (P<0.05). In all three periods a higher ADL value was recorded for treatment K (12.69% during period 1, 12.58% during period two and 12.08% during period three. This could be due to the formation of artefact lignin as rainfall was higher during this time as well as the corresponding CP value being higher (Burritt *et al*., 1988).

In year two, significant differences were seen between treatments in periods two and three with higher ADL values recorded for treatment K (9.57% during period two and 10.66% during period three) (P<0.05).

In Table 37 the different periods within each treatment were compared. There was greater variation between the periods in treatment K compared to treatment M.

Table 37 The influence of different period averages within each treatment on the acid detergent lignin percentage corrected for organic matter in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 0.505)

		TREATMENT - K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**12,69**	**6,26**	*9,48^{ad}*	**7,99**	**7,41**	*7,70^{a}*
NOV-DEC	2	**12,58**	**9,57**	*11,08^{b}*	**8,95**	**7,38**	*8,16^{a}*
JAN-FEB	3	**12,08**	**10,66**	*11,37^{b}*	**6,15**	**8,20**	*7,17^{a}*
MRT-APR	4	**7,23**	**5,26**	*6,24^{c}*	**7,30**	**6,99**	*7,15^{a}*
MAY-JUN	5	**8,33**	**6,08**	*7,20^{cd}*	**8,58**	**6,03**	*7,30^{a}*
JUL-AUG	6	**8,35**	**8,62**	*8,48^{ad}*	**7,55**	**6,56**	*7,06^{a}*
AVE		*10,21*	*7,74*		*7,75*	*7,10*	

^{abcd}Column means with different superscripts differ significantly (P ≤ 0.05)

The differences in treatment K were due to the fact that higher ADL values during periods of higher rainfall (periods two and three) are from the formation of artefact lignin where immature forages containing higher concentrations of protein and soluble carbohydrates are more susceptible to oven drying (Van Soest, 1994).

Other possible reasons for differences in ADL content between periods include the fact that lignin contents in grasses are influenced by climatic conditions (Ramirez *et al*., 2004). In the seasons when rainfall is higher, invariably lignin contents are lower. Conversely, lignin contents in most grasses increase during the drier seasons of winter (Ramirez *et al*., 2004).

Acid detergent lignin is digested more slowly in the rumen and therefore has an effect on rumen fill. Forages high in ADL will reduce feed intake due to this “filling effect”(Van Soest, 1994).

4.1.12. IN VITRO DIGESTIBLE ORGANIC MATTER

The *in vitro* digestible organic matter (IVDOM) of veld collected by OF cattle is presented in Table 38. For treatment K, the values ranged from 35.22% to 48.11% and from 27.30% to 55.87% for treatment M. Roodt (2012) recorded values of between 358-649g/kg OM in the tree and shrub savannah of Namibia. The majority of the IVDOM values recorded in the current trial fell within this range.

The drying of extrusa samples in an oven at 50^{o}C to 60^{o}C had a significant depressing effect on the IVDOM (Engels *et al*., 1981). This is caused by the condensation of carbohydrates and proteins through the non-enzymatic browning reaction in the presence of high moisture levels known as the maillard-reaction.

The two points where the greatest depression in the IVDOM occurred (during period two for both treatments) coincided with high ADL concentrations. The increased formation of artefact lignin caused by oven drying would decrease the IVDOM. This artefact lignin formation pointed out by the ADL concentrations, during oven drying could have a deleterious effect in the analysis of IVDOM in extrusa (Burritt *et al*., 1988).

The general trend observed was that IVDOM values dropped from July to December and then increase from January to April and then decreased towards June. This trend corresponds with the tendencies established by Van Schalkwyk (1978) which showed the IVDOM values had the highest concentration (515g/kg) during the wet season and dropped to a concentration of 419g/kg in the dry season which may be due to advancing plant maturity (Meissner, 1997).

The IVDOM of the forage is linked to digestibility. A higher proportion of IVDOM compared to NDF in forage will result in a higher feed intake due to increased digestibility and passage rate through the gut (Meissner, 1997). (

The highest IVDOM values occurred during period one for treatment K (Average 46.91%) and during period four for treatment M (Average 52.84%). The lowest IVDOM values were recorded during period two for both treatment K (Average 38.21%) and treatment M (Average 37.84%). This trend is depicted in Figure 23.

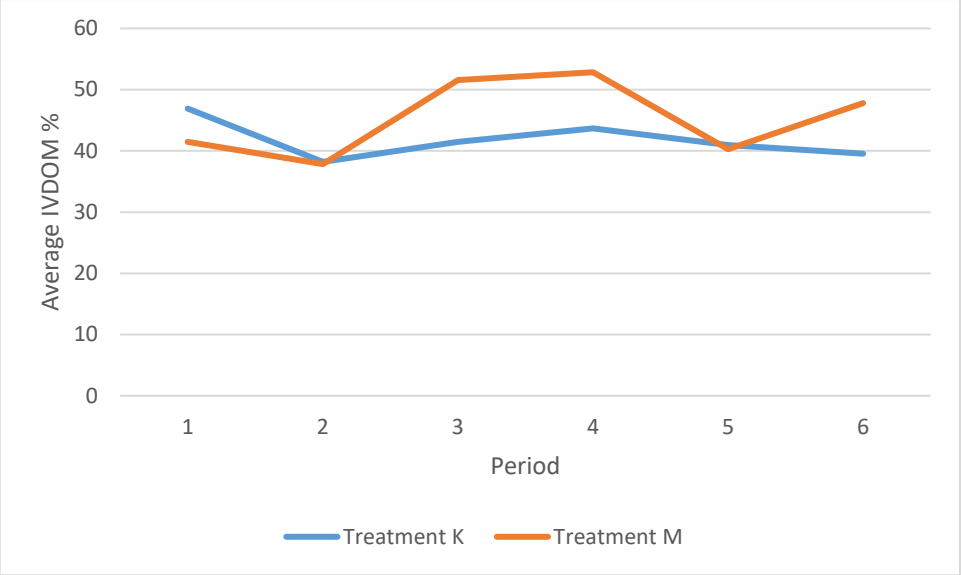

Figure 23 The *in vitro* digestible organic matter percentage of two treatments over two years in north western Namibia as quantified in grazing cattle fitted with oesophageal fistulae

In Table 38, the two years within each treatment were compared. There was greater variation between the two years in treatment M compared to treatment K.

Table 38 The influence of different years within treatments on the *in vitro* digestible organic matter percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 2.307)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**45,71** (2.56)	**48,11** (2.12)	*46,91* (2.48)	**34,36[a]** (4.80)	**48,61[b]** (0.63)	*41,49* (8.38)
NOV-DEC	2	**35,22** (2.74)	**41,19** (3.56)	*38,21* (4.33)	**27,30[a]** (2.48)	**48,39[b]** (1.30)	*37,84* (11.69)
JAN-FEB	3	**40,11** (3.31)	**42,84** (5.82)	*41,47* (4.49)	**47,59[a]** (1.68)	**55,53[b]** (1.92)	*51,56* (4.64)
MRT-APR	4	**47,44[a]** (5.76)	**39,95[b]** (5.79)	*43,69* (6.60)	**55,87** (6.57)	**49,81** (7.98)	*52,84* (7.33)
MAY-JUN	5	**40,12** (3.44)	**41,80** (0.47)	*40,96* (2.38)	**36,96[a]** (4.29)	**43,60[b]** (7.08)	*40,28* (6.38)
JUL-AUG	6	**40,22** (1.73)	**38,91** (2.50)	*39,56* (2.06)	**45,38** (1.97)	**50,25** (1.45)	*47,82* (3.08)
AVE (+/-SD)		*41,47* (5.08)	*42,13* (4.47)		*41,24* (10.26)	*49,37* (5.23)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

Differences between years for treatment K were seen in period four where a higher IVDOM value (47.44%) was recorded in year one (P<0.05).

For treatment M, significant differences between years were seen in periods one, two, three and five with higher IVDOM values recorded during the second year during these periods (48.61% during period one, 48.39% during period two, 55.53% during period three and 43.60% during period five) (P<0.05).

In Table 39, each year between treatments was compared. There was great variation in IVDOM values during both years.

Table 39 The influence of the same year between treatments on the *in vitro* digestible organic matter percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 2.307)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**45,71[a]**	**34,36[b]**	*40.04*	**48,11**	**48,61**	*48.36*
NOV-DEC	2	**35,22[a]**	**27,30[b]**	*31.26*	**41,19[a]**	**48,39[b]**	*44.79*
JAN-FEB	3	**40,11[a]**	**47,59[b]**	*43.85*	**42,84[a]**	**55,53[b]**	*49.19*
MRT-APR	4	**47,44[a]**	**55,87[b]**	*51.66*	**39,95[a]**	**49,81[b]**	*44.88*
MAY-JUN	5	**40,12**	**36,96**	*38.54*	**41,80**	**43,60**	*42.7*
JUL-AUG	6	**40,22**	**45,38**	*42.8*	**38,91[a]**	**50,25[b]**	*44.58*
AVE		*41,47*	*41,24*		*42,13*	*49,37*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

Differences between treatments in year one were seen in periods one, two, three and four (P<0.05). For periods one and two, higher IVDOM values (45.71% and 35.22% respectively) were recorded for treatment K. For periods three and four, higher IVDOM values (47.59% and 55.87% respectively) were recorded for treatment M.

During year two, differences between treatments were found in periods two, three, four and six with higher IVDOM values recorded for treatment M (48.39%, 55.53%, 49.81% and 50.25% respectively) (P<0.05).

In Table 40, the period averages within each treatment were compared. There was greater variation between the periods in treatment M compared to treatment K.

Table 40 The influence of different period averages within treatments on the *in vitro* digestible organic matter percentage in veld selected by oesophageally fistulated cattle during different sampling periods in north western Namibia (+/-SE: 1.632)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**45,71**	**48,11**	*46,91*^{ac}	**34,36**	**48,61**	*41,49*^{a}
NOV-DEC	2	**35,22**	**41,19**	*38,21*^{b}	**27,30**	**48,39**	*37,84*^{a}
JAN-FEB	3	**40,11**	**42,84**	*41,47*^{bc}	**47,59**	**55,53**	*51,56*^{bc}
MRT-APR	4	**47,44**	**39,95**	*43,69*^{c}	**55,87**	**49,81**	*52,84*^{b}
MAY-JUN	5	**40,12**	**41,80**	*40,96*^{bc}	**36,96**	**43,60**	*40,28*^{a}
JUL-AUG	6	**40,22**	**38,91**	*39,56*^{bc}	**45,38**	**50,25**	*47,82*^{c}
AVE		*41,47*	*42,13*		*41,24*	*49,37*	

^{abc}Column means with different superscripts differ significantly (P ≤ 0.05)

The reason for these differences are because during periods of higher rainfall (periods three and four) IVDOM values tend to increase. However even though rainfall may be higher IVDOM values may drop (period two) due to the formation of artefact lignin during the oven drying process of extrusa as is seen by an increase in ADL values.

During periods of low rainfall (periods one, five and six) IVDOM values tend to drop due to a decline in forage quality. Sun *et al.* (2014) also found that the dry matter digestibility of various grass species decreased during the winter months and increased during the summer months.

4.1.13. ENERGY

Equation 6 was used to estimate the energy content of the forage, using the IVDOM values from the current trial, during the different periods throughout the two years for both treatments (Table 41).

Equation 6: ME (MJ/kg DM) = 0.016 DOMD

The drying of extrusa samples in an oven at 50^{o}C to 60^{o}C had a significant depressing effect on the IVDOM due to effects of the maillard reaction (Engels *et al*., 1981). This may in turn have an effect on the energy values.

The metabolisable energy (ME) concentration ranged from 6.3 MJ/kg to 8.4 MJ/kg for treatment K and from 5.4 MJ/kg to 9.9 MJ/kg for treatment M. A seasonal trend was observed where the higher values occurred after or during periods of higher rainfall with the exception of the high value recorded during period one of treatment K.

The highest values were recorded in period one for treatment K (average of 8.2 MJ/kg) and during period three for treatment M (average of 9.6 MJ/kg). Whilst the lowest values were recorded during period two for treatment K (average of 6.9MJ/kg) and during period five for treatment M (average of 7.0 MJ/kg). Evitayani *et al.* (2004) also found that ME content of grasses varied from 6.0 to 8.3 MJ/kg in dry season and increased slightly from 6.4 to 8.6 MJ/kg in rainy season.

In Table 41, the two years within each treatment were compared. There was greater variation between the two years in treatment M compared to treatment K.

Table 41 The influence of different years within treatments on the metabolisable energy concentration (MJ/kg) corrected for organic matter from ruminally cannulated cattle during different sampling periods in north western Namibia (+/-SE: 0.042)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	***AVE*** (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**8.06** (0.05)	**8.36** (0.03)	*8.21* (0.04)	**6.69[a]** (0.13)	**8.45[b]** (0.01)	*7.57* (0.13)
NOV-DEC	2	**6.33** (0.05)	**7.46** (0.06)	*6.89* (0.08)	**5.37[a]** (0.03)	**8.84[b]** (0.01)	*7.11* (0.19)
JAN-FEB	3	**7.64** (0.07)	**7.54** (0.10)	*7.59* (0.08)	**9.22** (0.04)	**9.92** (0.03)	*9.57* (0.05)
MRT-APR	4	**8.27[a]** (0.10)	**6.99[b]** (0.10)	*7.63* (0.11)	**9.78** (0.11)	**8.64** (0.14)	*9.21* (0.13)
MAY-JUN	5	**7.07** (0.06)	**7.55** (0.01)	*7.31* (0.05)	**6.40[a]** (0.06)	**7.63[b]** (0.12)	*7.01* (0.11)
JUL-AUG	6	**7.07** (0.03)	**6.95** (0.04)	*7.01* (0.03)	**7.92** (0.04)	**8.68** (0.03)	*8.30* (0.05)
AVE (+/-SD)		*7.41* (0.09)	*7.48* (0.08)		*7.56* (0.17)	*8.69* (0.09)	

[abc]Row means with different superscripts differ significantly (P ≤ 0.05)

Differences were recorded between the two years in period four for treatment K with a higher ME value occurring in year one (8.27 MJ/kg) (P<0.05).

For treatment M, differences between the two years occurred in periods one, two and five with higher ME values recorded during year two (8.45 MJ/kg in period one, 8.84 MJ/kg in period two and 7.63 MJ/kg in period five (P<0.05).

In Table 42, each year was compared between treatments. There was greater variation within year two compared to the first year.

Table 42 The influence of the same year between treatments on the metabolisable energy concentration (MJ/kg) corrected for organic matter from ruminally cannulated cattle during different sampling periods in north western Namibia (+/-SE: 0.042)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	***AVE***	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**8.06[a]**	**6.69[b]**	*7.38*	**8.36**	**8.45**	*8.41*
NOV-DEC	2	**6.33**	**5.37**	*5.85*	**7.46[a]**	**8.84[b]**	*8.15*
JAN-FEB	3	**7.64[a]**	**9.22[b]**	*8.43*	**7.54[a]**	**9.92[b]**	*8.73*
MRT-APR	4	**8.27[a]**	**9.78[b]**	*9.03*	**6.99[a]**	**8.64[b]**	*7.82*
MAY-JUN	5	**7.07**	**6.4**	*6.74*	**7.55**	**7.63**	*7.59*
JUL-AUG	6	**7.07**	**7.92**	*7.5*	**6.95[a]**	**8.68[b]**	*7.82*
AVE		*7.41*	*7.48*		*7.48*	*8.69*	

[abc]Row means with different superscripts differ significantly (P ≤ 0.05)

In the first year there were differences between treatments in periods one, three and four (P<0.05). There was a higher energy value in treatment K for period one (8.06MJ/kg). During periods three and four a higher energy value was recorded for treatment M (9.22 MJ/kg and 9.78 MJ/kg).

In year two, differences between treatments were recorded during periods two, three, four and six with higher ME values occurring in treatment M (8.84 MJ/kg, 9.92MJ/kg, 8.64MJ/kg and 8.68MJ/kg respectively) (P<0.05).

In Table 43, the period averages of ME were compared within each treatment. There was greater variation between the periods in treatment M compared to treatment K.

Table 43 The influence of different period averages within treatments on the metabolisable energy concentration (MJ/kg) corrected for organic matter from ruminally cannulated cattle during different sampling periods in north western Namibia (+/-SE: 0.030)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	***AVE***	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**8.06**	**8.36**	*8.21*[a]	**6.69**	**8.45**	*7.57*[ac]
NOV-DEC	2	**6.33**	**7.46**	*6.89*[b]	**5.37**	**8.84**	*7.11*[a]
JAN-FEB	3	**7.64**	**7.54**	*7.59*[ab]	**9.22**	**9.92**	*9.57*[b]
MRT-APR	4	**8.27**	**6.99**	*7.63*[ab]	**9.78**	**8.64**	*9.21*[b]
MAY-JUN	5	**7.07**	**7.55**	*7.31*[b]	**6.40**	**7.63**	*7.01*[a]
JUL-AUG	6	**7.07**	**6.95**	*7.01*[b]	**7.92**	**8.68**	*8.30*[c]
AVE		*7.41*	*7.48*		*7.56*	*8.69*	

[abc]Column means with different superscripts differ significantly (P ≤ 0.05)

Differences between periods are due to the seasonal trend in forage energy concentration with higher values occurring during periods three and four which was during and following high rainfall. The ME values recorded then declined during the dry season. Nasrullah *et al*. (2003) also found that forage had a higher dry matter digestibility and thus a higher ME content in the rainy season.

Havstad & Malechek (1982) used the carbon dioxide entry rate technique to estimate that free-ranging heifers had 46% higher energy expenditures than stall-fed heifers consuming similar forages. The maintenance (MJ ME/day) requirement for stall-fed animals plus 50% was estimated to give a reasonable indication of the additional energy requirements of the cattle in this trial, which were under similar conditions to the cited literature (McDonald *et al*.,2011)

In Figure 24, the energy requirements of a 400kg cow are shown at an intake level of 2.7% during lactation and 2.0% during pregnancy of body weight per day (NRC, 2000).

A deficiency of energy will lead to reduced production efficiencies (NRC, 2007). Singh *et al*. (2013) stated that a shortage of energy can also lead to reduced growth, immune response and fertility.

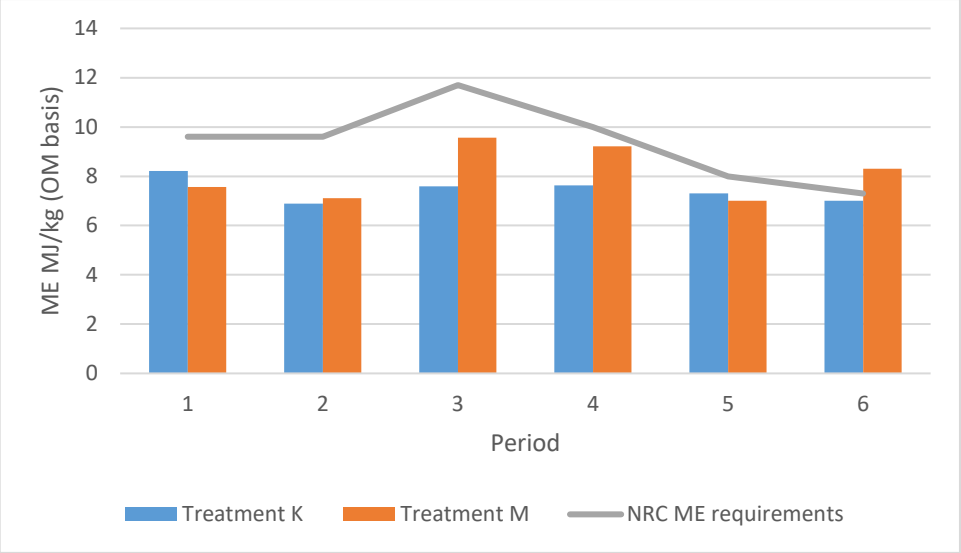

Figure 24 Average metabolisable energy concentration (MJ/kg) corrected for dry matter for treatment K and M over the two year trial period compared to the NRC metabolisable energy concentration requirement for a 400kg cow with an average milk production of 6.8kg/day at a dry matter intake level of 2.0% (during pregnancy) and 2.7% (during lactation) of body weight per day (NRC, 2000)

During pregnancy dry matter intake decreases (NRC, 2000) and so do the ME requirements compared to the requirements needed during lactation. During gestation (periods one, four, five and six) the ME requirements of the cows are not met from the intake of forage alone except for treatment M during period six. As lactation starts in periods two and three the dry matter intake of the cows normalises at 2.7% of body weight. The ME requirements also increase during this time and are not met from forage intake alone so supplementation is needed.

4.2. RUMEN LIQUOR

The production of energy and microbial protein synthesis of free-range cattle was determined from the biochemical analysis of ruminal fluid where both rumen ammonia -N and total volatile fatty acid concentration was measured.

On the previous day, 12 h to 13 h before rumen fluid sample collections the animals were removed from water. The next morning ruminal samples were taken.

4.2.1. AMMONIA-N

The ammonia-N concentrations in the rumen fluid are shown in Table 44. The values ranged from 2.27mg/100ml rumen fluid to 7.30mg/100ml rumen fluid for treatment K and from 3.13mg/100ml rumen fluid to 7.94mg/100ml rumen fluid for treatment M. The highest concentrations for ammonia-N were recorded during the periods of higher rainfall (periods two and three). During the dry season (periods one, five and six), the lowest ammonia-N concentrations were recorded with period one of treatment M being an exception. This trend can be seen in Figure 25.

The highest rumen ammonia- N concentration was recorded during period three for treatment K (average 7.12mg/100ml rumen fluid) and during period two for treatment M (average 7.59mg/100ml rumen fluid). The lowest rumen ammonia-N concentrations occurred during period five for treatment K (average 2.99mg/100ml) and during period six for treatment M (average 3.22mg/100ml).

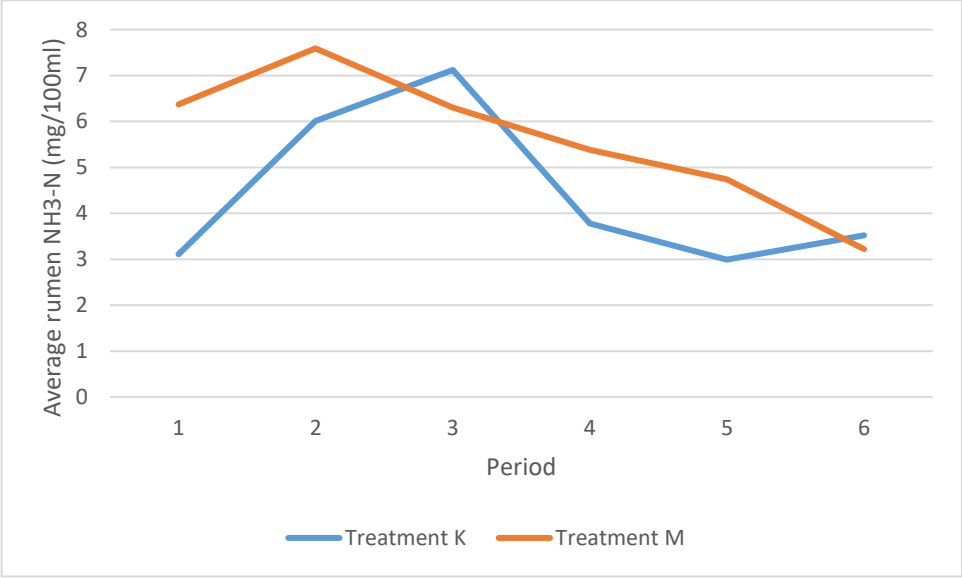

Figure 25 The average ruminal ammonia-N concentrations (mg/100ml) of two treatments over two years in north western Namibia as quantified in grazing cattle fitted with rumen cannulae

In Table 44, the two years within each treatment were compared.

Table 44 The influence of different years within treatments on the ruminal ammonia-N (mg/100ml) from ruminally cannulated cattle during different sampling periods in north western Namibia (+/-SE: 0.327)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**2,27[a]** (0.01)	**3,95[b]** (0.59)	*3.11* (0.99)	**6.47** (1.28)	**6.26** (0.13)	*6.37* (0.82)
NOV-DEC	2	**5.20[a]** (0.16)	**6,82[b]** (0.40)	*6.01* (0.93)	**7.23** (0.63)	**7.94** (0.61)	*7.59* (0.67)
JAN-FEB	3	**6.92** (0.47)	**7.30** (0.48)	*7.12* (0.47)	**6.45** (0.32)	**6.15** (1.15)	*6.30* (0.77)
MRT-APR	4	**4.09** (0.49)	**3,46** (0.98)	*3.78* (0.77)	**6,62[a]** (0.27)	**4.14[b]** (0.20)	*5.38* (1.37)
MAY-JUN	5	**3,50[a]** (0.27)	**2,48[b]** (0.46)	*2.99* (0.65)	**5,54[a]** (0.59)	**3.95[b]** (0.14)	*4.74* (0.95)
JUL-AUG	6	**3,72** (0.60)	**3.32** (0.03)	*3.52* (0.44)	**3,32** (0.63)	**3.13** (0.42)	*3.22* (0.49)
AVE (+/-SD)		*4.28* (1.54)	*4.55* (1.94)		*5,94* (1.43)	*5.26* (1.77)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

Differences between years for treatment K were seen in periods one, two and five (P<0.05). Higher ammonia-N values were recorded for year two of periods one and two (3.95mg/100ml and 6.82mg/100ml respectively). During period five, a higher ammonia-N value was recorded during year one (3.50mg/100ml).

For treatment M, differences between years were seen during periods four and five with higher ammonia-N values being recorded during year one for both periods (6.62mg/100ml and 5.54mg/100ml) (P<0.05).

In Table 45, each year was compared between treatments. There was great variation between the values during both years.

Table 45 The influence of the same year between treatments on the rumen ammonia-N (mg/100ml) from ruminally cannulated cattle during different sampling periods in north western Namibia (+/-SE: 0.327)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	*AVE*	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**2,27[a]**	**6.47[b]**	*2.69*	**3,95[a]**	**6.26[b]**	*5.11*
NOV-DEC	2	**5.20[a]**	**7.23[b]**	*6.23*	**6,82[a]**	**7.94[b]**	*7.38*
JAN-FEB	3	**6.92**	**6.45**	*6.69*	**7.30[a]**	**6.15[b]**	*6.73*
MRT-APR	4	**4.09[a]**	**6.62[b]**	*5.36*	**3,46**	**4.14**	*3.8*
MAY-JUN	5	**3.50[a]**	**5,54[b]**	*4.52*	**2,48[a]**	**3.95[b]**	*3.22*
JUL-AUG	6	**3,72**	**3,32**	*3.52*	**3.32**	**3.13**	*3.23*
AVE		*4.28*	*5,94*		*4.55*	*5.26*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

During year one, differences were seen between treatments during periods one, two, four and five with higher ammonia-N values recorded for treatment M (6.47mg/100ml during period one, 7.23mg/100ml during period two, 6.62mg/100ml during period four and 5.54mg/100ml during period five) (P<0.05).

During year two, differences between treatments were seen during periods one, two, three and five (P<0.05). Higher ammonia-N values were recorded for treatment M during periods one, two and five (6.26mg/100ml, 7.94mg/100ml and 3.95mg/100ml respectively). Higher ammonia-N values were recorded for treatment K during period three (7.30mg/100ml).

In Table 46, the period averages within each treatment were compared.

Table 46 The influence of different period averages within treatments on the rumen ammonia-N (mg/100ml) from ruminally cannulated cattle during different sampling periods in north western Namibia (+/-SE: 0.231)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	*AVE*	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**2,27**	**3,95**	*3.11*[a]	**6.47**	**6.26**	*6.37*[a]
NOV-DEC	2	**5.20**	**6,82**	*6.01*[b]	**7.23**	**7.94**	*7.59*[b]
JAN-FEB	3	**6.92**	**7.30**	*7.12*[c]	**6.45**	**6.15**	*6.30*[a]
MRT-APR	4	**4.09**	**3,46**	*3.78*[d]	**6.62**	**4.14**	*5.38*[c]
MAY-JUN	5	**3.50**	**2,48**	*2.99*[a]	**5,54**	**3.95**	*4.74*[c]
JUL-AUG	6	**3,72**	**3.32**	*3.52*[ad]	**3,32**	**3.13**	*3.22*[d]
AVE		*4.28*	*4.55*		*5,94*	*5.26*	

[abcd]Column means with different superscripts differ significantly (P ≤ 0.05)

The reason for these differences are because of the higher ammonia-N concentrations recorded during periods of higher rainfall (periods two and three) and lower concentrations recorded during periods of low to no rainfall (periods one, four, five and six) with the exception of the high value which occurred in period one of treatment M. Park *et al*. (1994) also found that there is a decrease in ammonia-N concentration as the season progresses with advancing rangeland maturity and a decrease in diet crude protein content.

Leng (1990) suggested that the optimal rumen fluid ammonia-N concentrations range from 6-10mg/100ml rumen fluid for cattle. With only a few values falling within this range in the current trial, the majority of the trial values tended to fall below the minimum concentration of 5.00mg/100ml rumen fluid for cattle as stated by Satter & Roffler (1977). Values that were below this minimum concentration occurred mainly during the periods of no to little rainfall (periods one, four, five and six) and this is indicative of insufficient nitrogenous substrates for microbial growth (Satter & Roffler, 1977).

Detmann (2009) proposed rumen ammonia-N concentrations of 8mg/100ml on a forage based diet for the optimal utilization of NDF which was not achieved in this trial. Detmann (2009) also stated that a rumen ammonia- N concentration of 15mg/100ml would lead to maximum levels of dry matter intake by steers fed *Brachiaria decumbens* hay. These values were also not reached in this trial.

4.2.2. TOTAL VOLATILE FATTY ACID CONCENTRATION

The total volatile fatty acid (VFA) concentrations are shown in Table 47. For treatment K, the values ranged from 52.76mmol/L to 75.93mmol/L for the sum of all the VFA's and from 51.37mmol/L to 82.67mmol/L for treatment M.

The highest total VFA concentrations were recorded during period four for treatment K (Average 71.66mmol/L and during period six for treatment M (Average 73.13mmol/L). The lowest values occurred during period three for treatment K (Average 56.37mmol/L) and during period one for treatment M (Average 59.07mmol/L). Roodt (2012) recorded total VFA values of between 44-78mmol/L rumen fluid in the tree and shrub savannah of Namibia.

According to Koster *et al* (1996), a higher total VFA concentration in the rumen generally reflects increased ruminal microbial fermentation. However total VFA concentration is dependent on diet type, level of intake, frequency of feeding and feed additives (Araba *et al*., 2002). Total VFA concentration should decrease with advancing forage maturity (Park *et al*., 1994). The results recorded in this trial did not show a distinctive seasonal trend, therefore a graph is not shown.

In Table 47, the two years within each treatment were compared. There was greater variation between the two years in treatment M compared to treatment K.

Table 47 The influence of different years within treatments on the total volatile fatty acid concentration (mmol/L) from ruminally cannulated cattle during different sampling periods in north western Namibia (+/-SE: 1.763)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1** (+/-SD)	**Y2** (+/-SD)	***AVE*** (+/-SD)	**Y1** (+/-SD)	**Y2** (+/-SD)	*AVE* (+/-SD)
SEP-OCT	1	**63.45** (2.53)	**63.18** (2.04)	*63.32* (2.06)	**61.85[a]** (2.06)	**56.30[b]** (0.11)	*59.07* (3.31)
NOV-DEC	2	**64.14** (2.00)	**64.72** (1.00)	*64.43* (1.45)	**59.49[a]** (7.68)	**64.84[b]** (1.33)	*62.17* (5.73)
JAN-FEB	3	**58.48** (3.19)	**54.23** (1.25)	*56.37* (3.17)	**67.60[a]** (0.03)	**75.84[b]** (3.83)	*71.72* (5.12)
MRT-APR	4	**75.93 a** (2.99)	**67.40 [b]** (0.05)	*71.66* (5.04)	**62.70[a]** (2.53)	**82.67 [b]** (4.34)	*72.69* (11.39)
MAY-JUN	5	**72.82a** (5.22)	**67.13 [b]** (0.29)	*69.98* (4.54)	**51.37 [a]** (1.45)	**77.33[b]** (2.47)	*64.35* (14.33)
JUL-AUG	6	**75.48 a** (4.66)	**52.76 [b]** (0.6)	*64.12* (12.80)	**74.34** (4.75)	**71.93** (1.56)	*73.13* (3.43)
AVE (+/-SD)		*68.38* (7.51)	*61.57* (6.13)		*62.89* (7.99)	*71.48* (9.23)	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

Differences between years for treatment K were seen in periods four, five and six with higher VFA values recorded during year one (75.93mmol/L during period four, 72.82mmol/L during period five and 75.48mmol/L during period six) (P<0.05).

For treatment M, differences were seen in periods one, two, three, four and five. Higher VFA values were recorded during year two of periods two, three, four and five (64.84mmol/L, 75.84mmol/L, 82.67mmol/L and 77.33mmol/L respectively (P<0.05). A higher total VFA concentration was recorded during year one of period one (61.85mmol/L).

In Table 48, each year between treatments was compared. There was greater variation within year two compared to the first year.

Table 48 The influence of the same year between treatments on the total volatile fatty acid concentration (mmol/L) from ruminally cannulated cattle during different sampling periods in north western Namibia (+/-SE: 1.763)

SEASON	PERIOD	**Y1(K)**	**Y1(M)**	***AVE***	**Y2(K)**	**Y2(M)**	*AVE*
SEP-OCT	1	**63.45**	**61.85**	*62.62*	**63.18[a]**	**56.30[b]**	*59.74*
NOV-DEC	2	**64.14**	**59.49**	*61.82*	**64.72**	**64.84**	*64.78*
JAN-FEB	3	**58.48[a]**	**67.60[b]**	*63.04*	**54.23[a]**	**75.84[b]**	*65.04*
MRT-APR	4	**75.93 [a]**	**62.70[b]**	*69.32*	**67.40 [a]**	**82.67 [b]**	*75.04*
MAY-JUN	5	**72.82[a]**	**51.37 [b]**	*62.1*	**67.13 [a]**	**77.33[b]**	*72.23*
JUL-AUG	6	**75.48**	**74.34**	*74.91*	**52.76 [a]**	**71.93 [b]**	*62.35*
AVE		*68.38*	*62.89*		*61.57*	*71.48*	

[ab]Row means with different superscripts differ significantly (P ≤ 0.05)

During year one, differences between treatments were seen in periods three, four and five (P<0.05). Higher values were recorded for treatment K during periods four and five (75.93mmol/L and 72.82mmol/L respectively). A higher total VFA value was recorded in treatment M during period three (67.60mmol/L).

During year two, differences between treatments were seen in periods one, three, four, five and six (P<0.05). Higher values were recorded for treatment M during periods three, four, five and six (75.84mmol/L, 82.67mmol/L, 77.33mmol/L and 71.93mmol/L respectively). A higher total VFA concentration was recorded for treatment K during period one (63.18mmol/L).

In Table 49, the period averages within each treatment were compared. There was great variation between the periods for both treatments.

Table 49 The influence of different period averages within treatments on the total volatile fatty acid concentration (mmol/L) from ruminally cannulated cattle during different sampling periods in north western Namibia (+/-SE: 1.247)

		TREATMENT – K			TREATMENT – M		
SEASON	PERIOD	**Y1**	**Y2**	***AVE***	**Y1**	**Y2**	*AVE*
SEP-OCT	1	**63.45**	**63.18**	*63.32*^{a}	**61.85**	**56.30**	*59.07*^{a}
NOV-DEC	2	**64.14**	**64.72**	*64.43*^{a}	**59.49**	**64.84**	*62.17*^{ac}
JAN-FEB	3	**58.48**	**54.23**	*56.37*^{b}	**67.60**	**75.84**	*71.72*^{b}
MRT-APR	4	**75.93**	**67.40**	*71.66*^{c}	**62.70**	**82.67**	*72.69*^{b}
MAY-JUN	5	**72.82**	**67.13**	*69.98*^{c}	**51.37**	**77.33**	*64.35*^{c}
JUL-AUG	6	**75.48**	**52.76**	*64.12*^{a}	**74.34**	**71.93**	*73.13*^{bc}
AVE		*68.38*	*61.57*		*62.89*	*76.82*	

^{abc}Column means with different superscripts differ significantly (P ≤ 0.05)

The reason for these differences are due to the fact that Total VFA should decrease with advancing forage maturity (Park *et al*., 1994). The higher value that was recorded during period four of treatment K followed good rainfall in the previous periods and therefore is due to good subsequent forage growth. The same goes for the higher values recorded in periods three and four for treatment M.

Roodt (2012) recorded values of between 44-78mmol/L rumen fluid in the tree and shrub savannah of Namibia. The rumen VFA values in this trial were also within this range.

4.3. FAECAL INDICATORS

Faecal samples were taken from the rectums of 6 animals. Grant (1989) recommended that at least 10 samples of different animals should be collected via rectal collections. Both faecal phosphorus and faecal crude protein were determined from the faecal samples.

4.3.1. FAECAL CRUDE PROTEIN

The faecal CP values ranged from 6.04% to 9.66% for treatment K and from 6.03% to 11.30% for treatment M.

The highest faecal CP values were recorded during period four for both treatment K (average 8.75%) and treatment M (average 9.77%). The lowest values occurred during five for treatment K (average 6.30%) and during period one for treatment M (average 6.81%).

Nunez-Hernandez *et al*. (1992), found that faecal nitrogen concentration was more closely related to the nitrogen balance of the animal than other faecal indicators.

Grant (1989) suggested the use of faecal CP to make certain management decisions. Grant (1989) proposed a faecal CP level of 65g/kg as a minimum, below which deficiencies would occur in cattle. Below the concentration of 65g/kg CP indicated a need for protein supplementation in cattle and above 100g/kg CP indicated that supplementation should be decreased (Grant, 1989).

In Figure 26 the average faecal CP values for each treatment were compared to the upper and lower limit of faecal CP as suggested by Grant (1989).

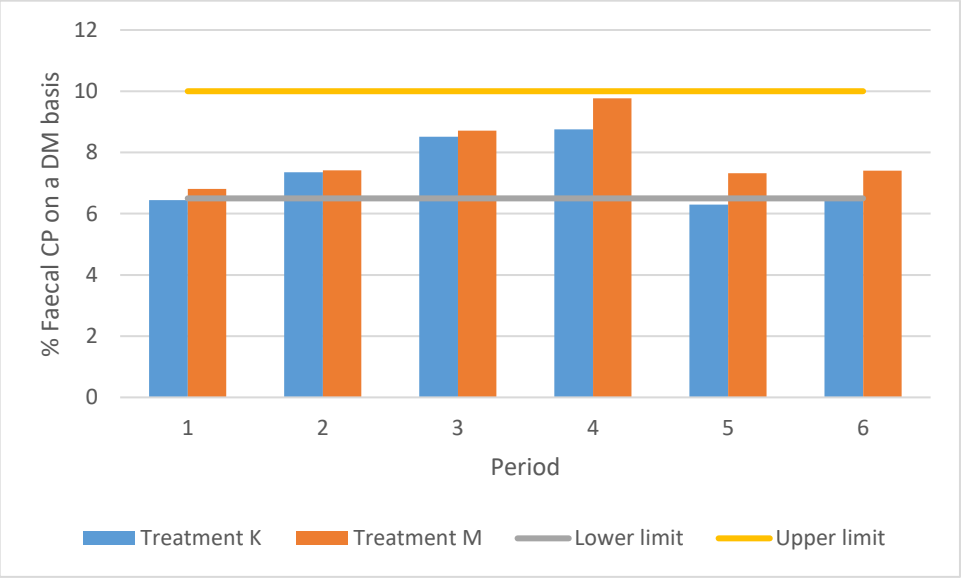

Figure 26 The average faecal crude protein % on a dry matter basis. A lower limit of 6.5% of faecal crude protein and an upper limit of 10% of faecal crude protein as suggested by Grant (1989)

If the values of Grant (1989) are used as a guide, the animals should receive a protein supplement for both treatments especially during the drier months of the year.

In an attempt to test whether faecal CP could be used as a predictor of the CP status of the diet, regressions were determined between the oesophageally collected extrusa crude protein analysis and the faecal crude protein. Figure 27 shows the regression for treatment K and Figure 28 shows the regression for treatment M.

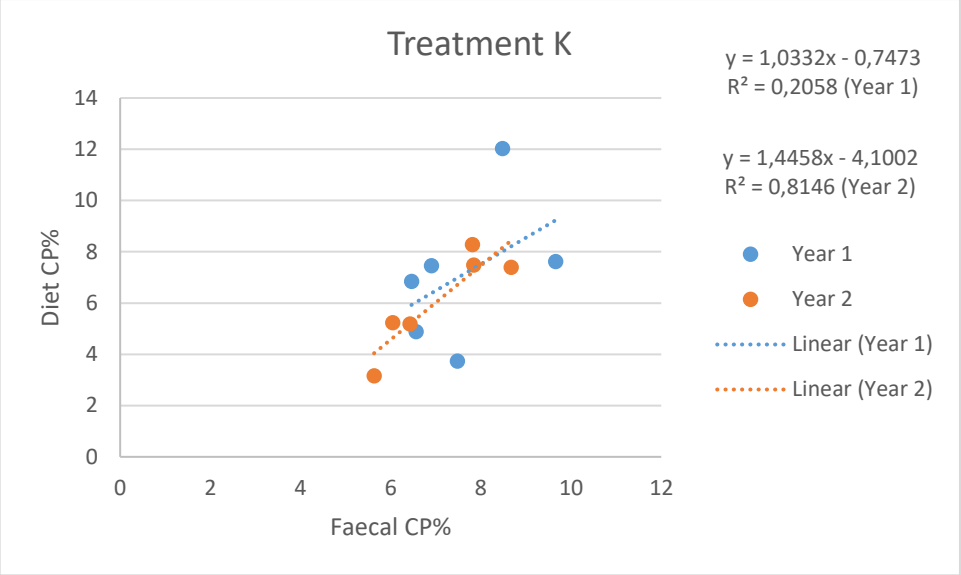

Figure 27 Regression between diet crude protein % collected from OF cattle and faecal crude protein % for treatment K

For treatment K the R^2 value for year 2 (0.8146) is strong enough to show a relationship between the faecal CP% and the diet CP%. However the R^2 value for year 1 (0.2058) was not strong enough to show a relationship between the two variables which casts doubt on the trustworthiness of using faecal CP as an indicator diet CP.

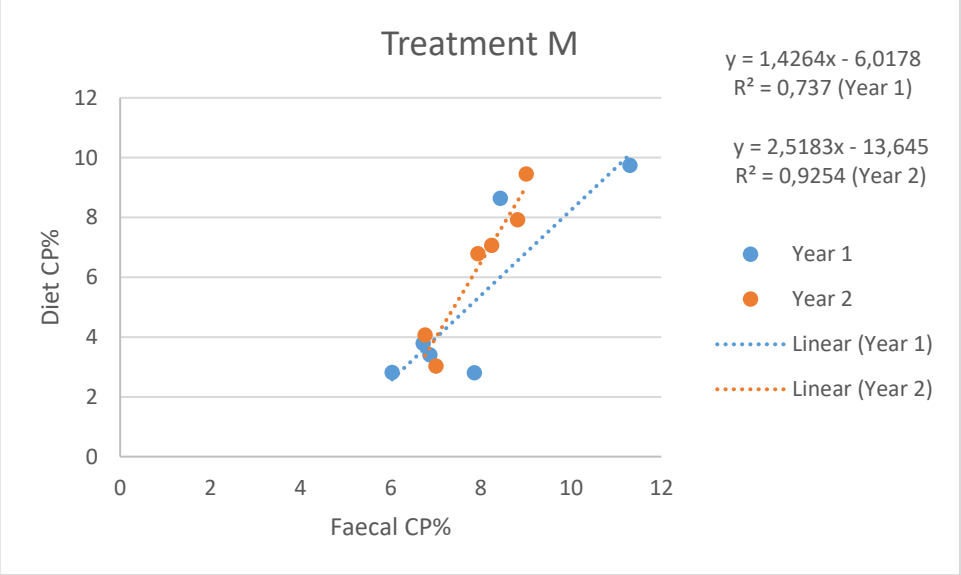

Figure 28 Regression between diet crude protein % and faecal crude protein % for treatment M

For treatment M, the R^2 values for both years (0.737 for year one and 0.9254 for year two) were strong enough to suggest that faecal CP % may be used as an indicator of diet CP % and whether or not nitrogen should be supplemented. However one must take into consideration the use of such relationships needs to be tested under specific conditions.

An overall R^2 predictor was calculated by combining data on both treatments and both years for OF collected and faecal collected crude protein. Figure 29 shows the combined R^2 predictor for the relationship between diet CP% and faecal CP%

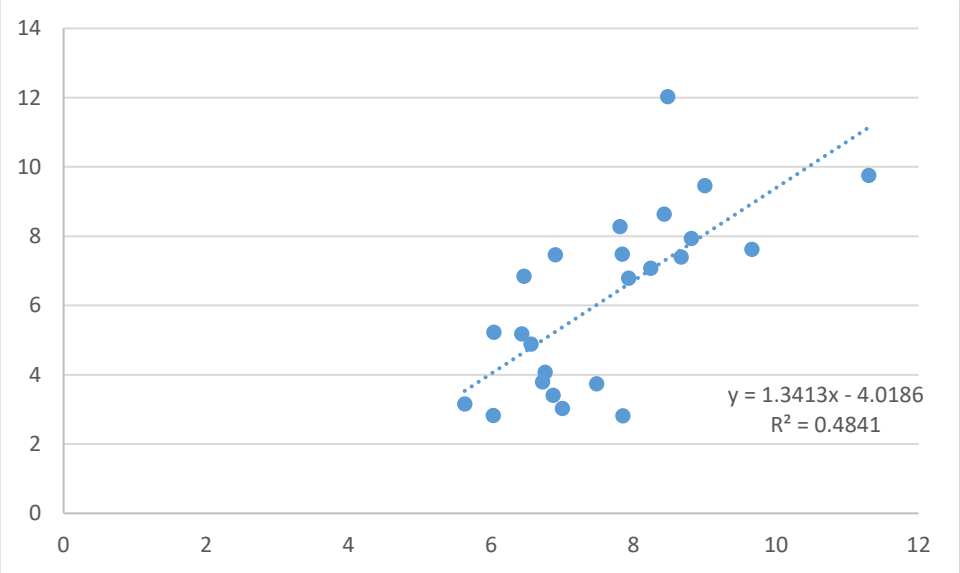

Figure 29 Regression between diet crude protein % and faecal crude protein % for treatment K and M over two years.

The lower R^2 value indicates there is a not so strong relationship between diet CP% and faecal CP% when the values of each treatment and year are combined. This could be due to the low R^2 value (0.2058) recorded during year one of Treatment K. This combined predictor value confirms that such relationships need to be tested under specific conditions and the results may be erroneous due to possible faecal microbial protein contamination.

4.3.2. FAECAL PHOSPHORUS

The faecal P concentrations range from 2.0% to 6.3% for treatment K and from 2.1 % to 6.7% for treatment M. The highest values were recorded during period three for both treatment K (average 5.0%) and treatment M (average 6.5%). The lowest faecal P concentrations occurred during period six for treatment K (average 2.5%) and during periods one and five for treatment M (average 3.5%).

Grant *et* al. (1996) showed that faecal phosphorus concentrations in growing cattle had a very distinct seasonal pattern. The highest faecal P output was during the wet season with a sharp decline during the dry season.

Read *et al.* (1986) indicated that faecal P concentrations are more indicative of an animal's diet P concentration than an indicator of P status. It was recommended by Read *et al.* (1986) that the use of faeces as an indicator of dietary P intake status had to be part of a determination for total volume of faeces due to the influence of P on voluntary feed intake. If total P exretion is measured, it has to be brought in line with total P intake (P-intake g/day and not concentration).

Grant (1989) suggested that faecal P levels of below 2.2g/kg indicated a dietary deficiency and that supplementation was required. Faecal P concentration levels between 2.2 and 3.5g/kg were shown to be normal in cattle. The average faecal P concentration for the trial is shown in Figure 30.

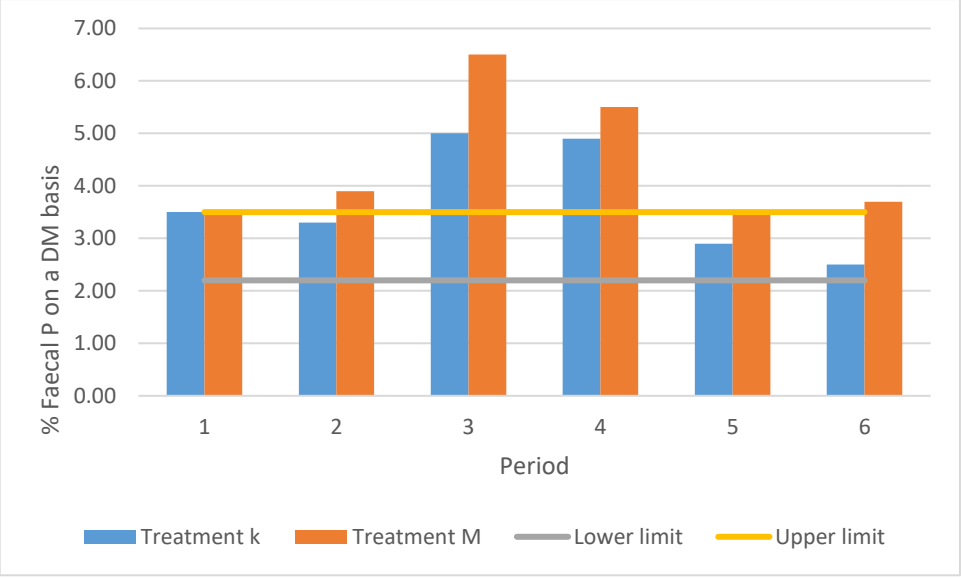

Figure 30 The average faecal phosphorus % on a dry matter basis. A lower limit of 2.2% and an upper limit of 3.5% is suggested by Grant (1989).

According to Figure 30, the faecal P levels are within the normal range although lower during the periods of low rainfall (periods one, two, five and six).

The relationship between faecal P% and diet P% (OF sample) is shown in Figure 31 for treatment K and Figure 32 for treatment M.

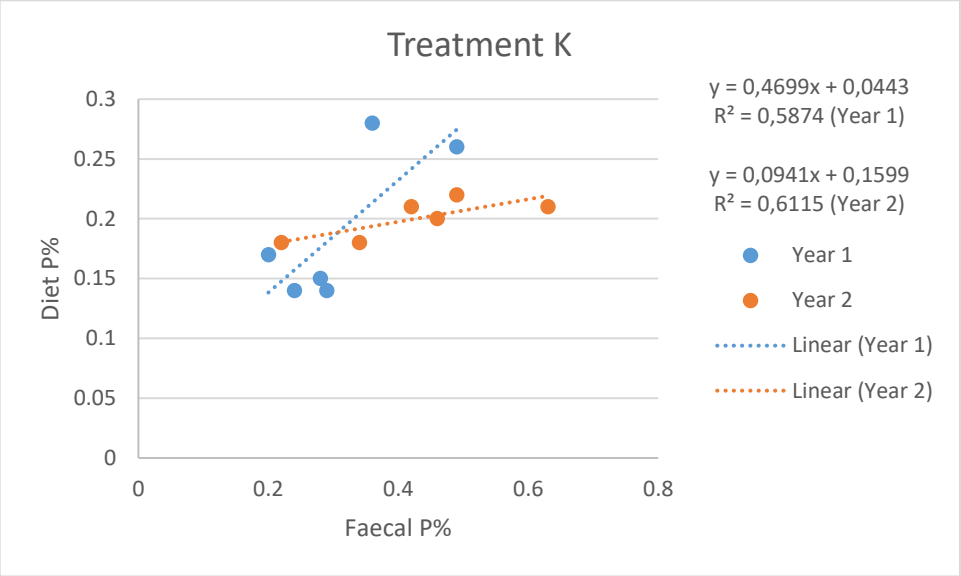

Figure 31 Regression between diet phosphorus % and faecal phosphorus % for treatment K

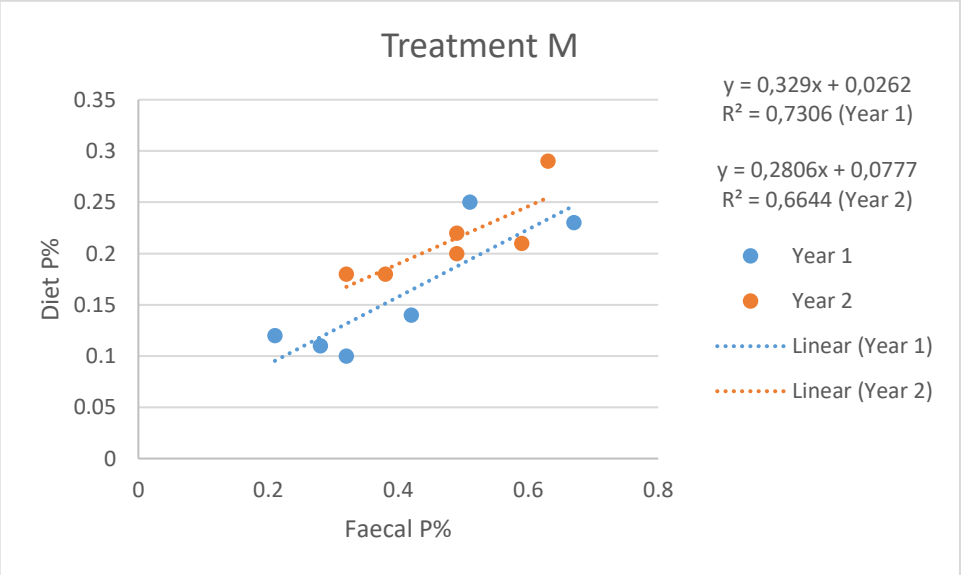

Figure 32 Regression between diet phosphorus % and faecal phosphorus % for treatment M

The R^2 values for both years in treatment K (0.5874 for year one and 0.6115 for year two) and M (0.7306 for year one and 0.6644 for year two) are fairly weak enough to say that there isn't a relationship between faecal P% and diet P% and faecal P% cannot be used as an indicator of the P status of the diet consumed by cattle under these conditions.

In Figure 33 a combined R^2 predictor was calculated to test the relationship between diet P% and faecal P%.

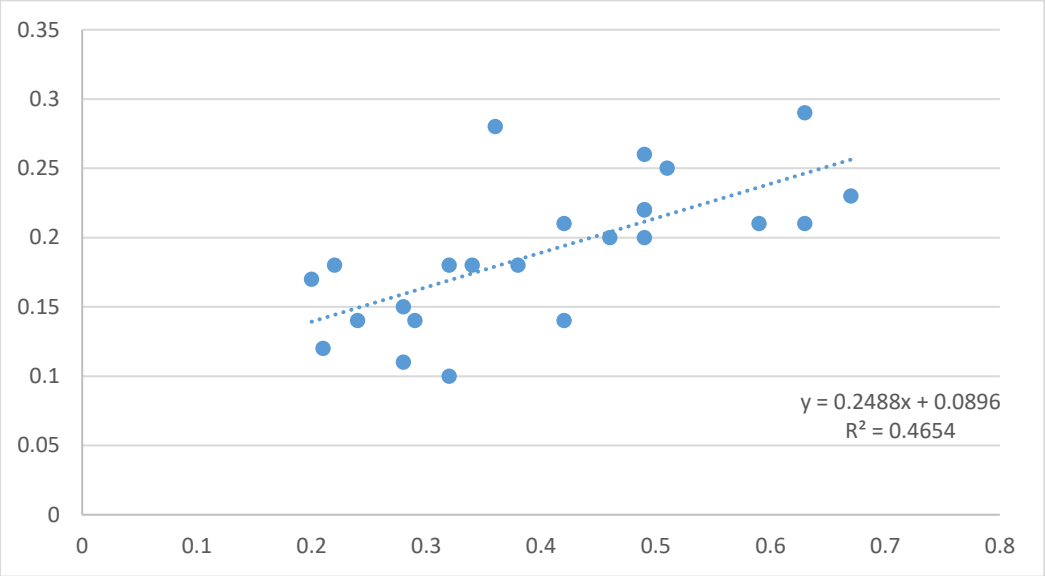

Figure 33 Regression between diet phosphorus % and faecal phosphorus % for treatment K and M over two years.

The lower R^2 value indicates that faecal P% may be used as a weak indicator of an animal's P status provided the data used has been obtained from an area with similar environmental conditions.

CHAPTER 5 GENERAL DISCUSSION

5.1. GENERAL DISCUSSION

The extensive farming of cattle in semi-arid subtropical areas on pastures is limited by the health, management and nutrition of the animals. These factors are predominantly influenced by the prevailing climate, soils and vegetation of the area of which the farmer has little control over.

An animal's production is said to be limited by the nutrient in shortest supply, which in the current trial may be P due to the high levels of Ca in the forage which widens the Ca:P ratio. The second most limiting nutrient was crude protein.

In this trial it was assumed that the intake of forage per animal per day was not a limiting factor thus the quality of the veld selected by the cattle became the main focus of the trial. This said the amount of available veld and stocking rate is one of the most important factors that can be controlled by a farmer. Determination of available veld at the end of the rainy season and the subsequent adjustment of stocking rates is very important as animal performance would be affected much sooner than veld condition when applying heavy stocking rates (Kruger, 1998). Constantly applied high stocking rates could result in deterioration of the forage condition would lead to bush encroachment (De Klerk, 2004).

For this trial, each year was divided into six periods of two months each. During the wet season which fell during periods 2-4 (November-April) there was an average of 176mm of rain across both treatments. During this time veld quality peaked. During the dry season which occurred during periods one, five and six (May-October) an average of 5mm of rain fell across both treatments. Due to this low rainfall, veld quality deteriorated.

For the oesophageally collected samples there were differences between the two years for all the parameters as well as differences between the two veld types (treatments) and periods. Crude protein had a large seasonal variation in both treatments, with treatment K having higher CP concentrations for the majority of the trial period compared to treatment M. Phosphorus also tended to show seasonal variation with higher concentrations during the wet season. According to the NRC (2007), crude protein requirements for a 400kg cow with a peak milk yield of 6.8kg/day and a dry matter intake 2.7% of body weight, were not met from the intake of forage alone during periods one, two, five and six whilst cows are expected to be pregnant. Phosphorus requirements seem to be met during most of the year but not during period one when cows are in the last trimester of pregnancy.

High concentrations of Ca were found in both treatments. The high level of calcium along with the high Ca levels in the drinking water will lead to a Ca:P imbalance. High Ca:P ratios may limit the absorption of phosphorus leading to acute phosphorus deficiencies (Ramirez *et al*., 2001). Treatment K had higher concentrations of Ca, Zn and Cu compared to treatment M, whilst Treatment M had a higher concentration of Mn during the majority of the trial period. The Mn concentration was shown to be adequate during most parts of the year for both treatments however Cu, Zn and Mg were deficient especially during the winter months. High Ca levels found in this trial may reduce the availability of Zn and Mn in the forage.

When estimating mineral intake from forage it is important to take into account the absorbable mineral content of the forage before comparing to requirements. The efficiency of absorption of P from forage collected by OF cattle is 75% (Ternouth *et al*., 1996) and of Ca is 70% (Scott & McLean, 1981).

With P known to be the first limiting nutrient in extensive cattle farming in Namibia especially during periods when animals have high growth requirements (summer/rain season and young animals/weaners etc), it was important to do a soil analysis for P_B which could indicate the expected animal P status as acutely deficient at <4mg/kg, deficient at 4-6mg/kg and marginal at 7-8mg/kg (McCosker & Winks, 1994).

Roodt (2012) recorded monthly liveweight changes as well as average daily gains of the cattle as a measurement of animal performance. This data gave an accurate indicator of the nutritional status of the cattle. Roodt (2012) tracked the performance of the cattle which were provided with different supplementation treatments.

Results from Roodt (2012) indicated that the lick to use during the wet season was a phosphorus and trace mineral containing lick. During the dry and spring seasons a maintenance lick gave the best animal performance, this lick contained phosphorus and protein. In the current trial, even though highest forage P concentrations were found during the wet season it was not enough to meet the requirements of a cow in late gestation and supplementation would be needed.

The effects of P deficiency have been well documented in literature, these include a depressed appetite, suboptimal growth and feed efficiency, depressed fertility and pica which may lead to botulism (Karn, 2001). In serious cases of deficiency the animal will display swollen and stiff joints as well as brittle bones.

The use of a maintenance lick during the spring and dry season helps prevent a primary shortage of P and a secondary CP shortage. The trial done by Roodt (2012)

indicated that phosphorus had a sparing effect on protein as the animals that received a P supplement utilised the protein in circulation for production and performed better. The rumen fluid ammonia-N concentrations of the animals receiving a phosphorus lick during the dry season ranged from 2.9-3.6mg/100ml rumen fluid, the rumen fluid ammonia concentrations of the animals in the current trial which received no supplements ranged from 2.99-6.37mg/100ml rumen fluid in the dry season indicating P might not have been the primary deficiency.

Osteochondrosis is a common joint disorder which affects many species. A number of possible aetiologies and predisposing factors have been proposed to be involved in the cause of osteochondrosis. These include over-nutrition, rapid growth, genetics (Hittmeier *et al.* 2006), ischaemia, excess dietary calcium, hormonal influences and trauma (Trostel *et* al., 2002). Osteochondrosis in cattle is found in all types of husbandry systems, including feedlots (Heinola *et al*., 2006), pure-bred beef (Dutra *et al*., 1999), dairy (Trostle *et al*., 1997) and animals grazing rangelands (Hill *et al*., 1998).

Cattle affected with this disorder develop effusions in the weight-bearing joints, in particular the femoro-tibial (stifle) joint, associated with inflammation and pain, causing lameness of varying degrees (Botha *et al*., 2016). As a result, animals are unable to walk long distances for grazing, have decreased feed intake, have decreased milk production and a loss in body condition, and bulls have decreased mating ability (Persson *et al*., 2007). Animals are often eventually slaughtered as a result of severe lameness and loss of condition.

Calcium deficiency, with a distorted Ca ratio, was associated with an outbreak of osteoarthritis in fattening bulls, this was probably osteochondrosis. Osteoarthritis lesions occurred in more than 80% of the animals with a Ca deficient diet (Heinola *et al*., 2006).

Extensive on-farm trials have confirmed that supplementation with balanced minerals such as Mg, Zn and Mn, bioavailable P and vitamins has a significant impact on preventing and curing the condition in the field. Commercial mineral supplements have been formulated for use in affected areas (Botha *et al*., 2016). From this information an excess of Ca in the forage which could lead to an imbalanced Ca:P ratio in the current trial may lead to joint disorders in the cattle.

Osuji (1974) found that foraging cattle had 25-50% higher energy requirements due to the cost of eating, walking, grazing and the increased work of digestion by the gut caused by the bulky pasture material. According to the NRC (2007), the cattle were rarely able to meet their energy requirements from forage alone. Thus reducing the energy requirements

of grazing cattle through correct nutrition and management practices becomes important for the farm's profitability.

The IVDOM values of the current trial increased during the wet summer months whilst the NDF values decreased. The ADL values increased during the periods of higher rainfall especially in treatment K. This increase in ADL concentration was due to an increase in plant maturity although it occurred at the same time there was an increase in CP concentration. Burritt *et al*. (1988) found that extrusa containing immature forage was the most susceptible to oven drying in terms of the formation of artefact lignin, due to the higher concentrations of protein and soluble carbohydrates contained in immature forages. This lignin formation could have reduced the bio-availability of the forage CP.

The rumen cannulated animals showed differences between years, treatments and periods for total VFA concentration and rumen NH_3-N. The rumen ammonia-N concentrations increased during the periods of higher rainfall whilst the total VFA concentration showed no distinct seasonal trends. Detmann (2009) proposed rumen ammonia-N concentrations of 8mg/100ml for the optimal utilization of NDF which was not achieved in this trial. The faecal CP results indicated that protein supplementation is necessary. The faecal P results fell within the normal range however bioavailability of the P might be affected by the high Ca levels in the forage causing a distorted Ca:P ratio.

Results from correlations done between faecal P% and diet P% as well as between faecal CP% and diet CP% indicate that faecal indicators cannot be used with confidence as an indicator of the selected feed P or CP concentration when both the years and treatments were combined. Correlations would need to be done under specific conditions to improve the accuracy and the relationship between the faecal and diet nutrient values.

5.2. RECOMMENDATIONS

With the forage of both treatments alone not being able to supply all the nutrient and mineral needs of the cattle, supplementation becomes important if the animal's performance and productivity is to be improved.

Recommended supplements for the use in a supplementary feeding program include the following:

Phosphorus lick (P) – The goal with this supplement is to supplement the required P without reducing the total pasture intake. This supplement should be given during the periods when the natural grazing supplies sufficient protein and energy and when phosphorus is suspected to be the first limiting nutrient. This supplement should be made from P-sources containing low levels of Ca. A mineral premix should be included to supply 100% of the required Cu, Zn and Mg for maintenance of a 400kg cow (NRC, 2016).

From the results in the current trial it would only be necessary to supplement P during the last trimester of pregnancy (period one and two) when the P content form the forage alone is not able to supply the needs of a 400kg pregnant cow with a dry matter intake of 2% of body weight per day. An additional concern are the high Ca levels in the forage which may have an effect on the availability of P as well as the Ca:P ratio. This may mean that P supplementation may be necessary during other times of the year as well. Growing animals were not considered in this trial and this may have an effect on when P supplementation is required.

Protein lick (N) – This supplement should be given during periods when the veld is low in crude protein (July-August in this trial). This supplement will supply protein to aid in digestion and production. An ideal situation would be for this supplement to have a complementary effect on the grazing, with subsequently higher forage dry matter intakes. This supplement should contain NPN-sources to serve as a cheap and readily available N source for the ruminal micro-organisms. A mineral premix should be included to supply 100% of the required Cu, Zn and Mg for maintenance of a 400kg cow (NRC, 2016).

In the current trial, forage CP concentration was low during periods one, two, five and six (May – December) and intake from forage alone was not enough to supply the needs of a pregnant 400kg cow with a dry matter intake of 2% of body weight per day during this time and the animals may benefit from a N lick during this time.

Crude protein and energy concentration of the forage was lower during periods one, two (September – December), five and six (May – August) during which the cows are expected to be pregnant. During these periods, intake from forage alone is not able to supply the protein and energy requirements of a 400kg pregnant cow, with a dry matter intake of 2% of body weight per day, and providing them with a production lick during this time may be beneficial.

Production lick (E) – This supplement should be given during periods of high production on low protein and energy containing forage. This supplement should contain NPN-sources as well as sources of energy to ensure the animals are supplied with enough ME. A premix should be included to supply 100% of the required Cu, Zn and Mg for maintenance of a 400kg cow (NRC, 2016).

5.3. CRITICAL EVALUATION

In this trial the forage was analysed in terms of its qualitative value and its ability to provide the nutrient requirements of extensively farmed beef cattle in north western Namibia. It may be worthwhile to evaluate the quantitative value of the forage as well by recording dry matter yields during different times of the year as it is known that during spring, although the forage on offer is of high quality, the plants contain low concentrations of dry matter and cattle are not able to collect enough high quality forage which would only allow minimal improvements in animal performance as was observed by Roodt (2012). Recording dry matter yields would also help to estimate the nutritional status of the animals as well as helping to determine the correct stocking rate.

Daily dry matter intake of forage is important in being able to estimate the animal's daily nutrient intake. Data was used from Van Schalkwyk (1978) in which intake was determined using the chromic oxide technique in cattle. The intake obtained from this method were then also compared to intakes calculated using equation 2 developed form the NRC (2000) and from equations 3 and 4 which relate to wet and dry season forage in Namibia. Being able to determine dry matter intake by external marker methods for this trial would have improved the accuracy of feed intake estimations. Comparing daily dry matter intake estimates during this trial would also have improved the understanding of the influence of the changing veld dry matter availability levels during the trial.

Oesophageally fistulated cattle (OF) used during the trial allowed for quick attachment and removal of the collection bags with less discomfort to the cattle due to the additional surgical establishment of a neck loop as described by Kartchner & Adams (1983). Freeze-drying of OF selected veld samples was not performed. Freeze-drying of OF extrusa samples should have been done at the higher cost and increased effort required for transportation of frozen samples. All analysis results on the fibre fractions in extrusa collected by OF were circumspectly reported due to potential artefact lignin formation (Burritt *et al.*, 1988) resulting from the forced air oven drying that was performed. This may result in equations two, three and four, which required the use of ADF concentrations in order to calculate dry matter intake, being less accurate.

The P concentrations which were determined from forage selected by OF cattle are probably elevated due to salivary contamination of samples (Pinchak *et al*., 1990). The potentially elevated P concentrations in the veld obtained from samples collected from OF

cattle in this trial was still the most important analysis that may indicate a P deficiency in the diet of the cattle in this trial.

The results of this trial gave a clear indication that supplementation is needed especially during the spring and dry seasons with P and CP being the primary and secondary most limiting nutrients respectively. The results from Roodt (2012) gave a good indication of the impact of strategic nutrient supplementation on growing beef cattle in the Okahandja district of Namibia. It would be useful to do future research in different geographic areas of Namibia with different rainfall and soil types in order to establish baseline nutritional data for various cattle production areas in Namibia. An *ad libitum* supply of P containing licks is crucial if P deficiencies are to be prevented along with statistically analysed animal performances (reproduction and weight data) in relation to economic evaluations under extensive cattle farming conditions which would help improve the profitability of cattle farming in Namibia.

The high Ca concentrations of the forage obtained from OF cattle needs to be addressed as along with low P concentrations creates a wide Ca:P as well as other mineral imbalances such as Mn and Zn. This can lead to a condition known as osteochondrosis which is known to cause significant production losses. Research done in providing cattle with a source of P supplementation has been found to help reduce the incidence of osteochondrosis. An effort should be made to help educate farmers on the possible causes of osteochondrosis and the options available to them to help prevent this condition.

REFERENCES

Adegosan, A.T., Givens, D.I. & Owens, E., 2000. Measuring chemical composition and nutritive values in forages. In: t'Mannetje L. & Jones, R.M., eds. Field and laboratory methods for grassland and animal production research. Wallingford, U.K: CAB International, 263-278.

Akin, D.E., 1989. Histological and physical factors affecting digestibility of forages. Agron. J. 81, 17- 25.

AOAC., 2002. Official methods of analysis (17th ed.). Association of Official Analytical Chemists. Inc., Arlington, Virginia, U.S.A.

Araba, A., Byers, F.M. & Guessous, F., 2002. Patterns of rumen fermentation in bulls fed barley/molasses diets. Anim. Feed Sci. Technol. 97, 53-64.

ARC, 1980. The nutrient requirements of farm livestock. Commonwealth Agricultural Bureaux, Farnham Royal, Slough, U.K. Pp 351.

Beauchemin, K.A., Yang, W.Z., & Rode, L.M., 2003. Effects of particle size of alfalfa-based dairy cow diets on chewing activity, ruminal fermentation, and milk production. J. Dairy Sci. 86, 630-643.

Beever, D.E., Dhanoa, M.S., Losada, H.R., Evans, R.T., Cammell, S.B. & France, J., 1986. The effect of forage species and stage of harvest on the processes of digestion occurring in the rumen of cattle. Br. J. Nutr. 56, 439-454.

Bortolussi, G., Ternouth, J.H. & McMeniman, N.P., 1996. Dietary nitrogen and phosphorus depletion in cattle and their effects on liveweight gain, blood metabolite concentrations and phosphorus kinetics. J. Agric. Sci. Camb. 126, 493-501.

Botha, K., Jacobs, L., Köster, H., Meissner, H., Neser, J., Prozesky, L., Shepstone, C., Viljoen, H., de Brouwer, C., van Zyl, J. & van der Veen, G., 2016. Preliminary report on osteochondrosis in cattle in the north-western parts of South Africa. Onderstepoort J. Vet. Res. 83, 1-7.

Bravo, D., Sauvant, D., Bogaert, C. & Meschy, F., 2003. III. Quantitative aspects of phosphorus excretion in ruminants. Reprod. Nutr. Dev. 43, 285-300.

Bredon, R.M. & Short, A.M., 1971. Research note: Oesophageal fistulation of cattle for pasture utilization studies, post-fistulation care and use of animals and sampling procedures. Agroanimalia 3, 141-144.

Bredon, R.M., Lyle, A.D. & Swart, C.E., 1970. The use of oesophageal fistulated cattle on wet veld in East Griqualand. Proc. S. Afr. Anim. Prod. 9, 163-167.

Broderick, G. A. & Kang, J. H., 1980. Automated simultaneous determination of ammonia-N and total amino acids in ruminal fluid and *in vitro* media. J. Dairy. Sci. 63:64-75.

Burritt, E.A, Pfister, J.A. & Malechek, J.C., 1988. Effect of drying method on the nutritive composition of esophageal fistula forage samples: influence of maturity. J. Range Manage. 41, 346-349.

Casey, N.H. & Meyer, J.A., 1996. Interim water quality guidelines for livestock watering. Department of Animal and Wildlife Sciences, University of Pretoria.

Chacon, E. & Stobbs, T.H., 1976. Influence of progressive defoliation of a grass sward on eating behaviour of cattle. Aust. J. Agric. Res. 27, 709-725.

Cilliers, J.W. & Van der Merwe, H.J., 1993. Relationships between chemical components of veld herbage and *in vitro* digestibility and estimated intakes of dry matter and digestible dry matter by sheep and cattle. Anim. Feed. Sci. Technol. 43, 151-163.

Coates, D.B. & Penning, P., 2000. Measuring animal performance. IN: Field and laboratory methods for grassland and animal production research. Eds. Mannetjie, L. & Jones, R.M., CABI Publishing, New York, USA. Pp 353-402.

Coleman, S.W., 2005. Predicting forage intake by grazing ruminants, In: Proceedings of the 16th Florida ruminant nutrition symposium, University of Florida, 72-90.

Cordova, F.J., Wallace, J.D. & Pieper, R.D., 1978. Forage intake by grazing livestock: A review. J. Range Manage. 31(6) 430-438.

Cronje, P.B., 1990. Supplementary feeding of ruminants – A physiological approach. S. Afr. J. Anim. Sci. 20, 110-117.

Davies, I.H. & Munro, R., 1999. Osteochondrosis in bull beef cattle following lack of dietary mineral and vitamin supplementation. Veterinary Record. 145, 232- 233.

De Brouwer, C.H.M., Cilliers, J.W., Vermaak, L.M., Van der Merwe, H.J. & Groenewald, P.C.N., 2000. Phosphorus supplementation to natural pasture grazing for beef cows in the Western Highveld region of South Africa. S. Afr. J. Anim. Sci. 30(1), 43-52.

De Bruin, T.D., 1995. The nutritional value of bana grass, greengold and pennaris for sheep. MSc(Agric) Dissertation, University of Pretoria, Pretoria. South Africa.

De Waal, H.O., 1990. Review – Animal production from native pasture in the Free State region – A perspective of the grazing ruminant. S. Afr. J. Anim. Sci. 27, 76-84.

De Waal, H.O., Engels, E.A.N. & Van der Merwe, F.J., 1980. Supplementing sheep with protein and phosphorus on native pasture of the central Orange Free State. I. Diet composition, digestibility and rumen ammonia concentration. S. Afr. J. Anim. Sci. 10, 203-208.

Decruyenaere, V. Buldgen, A. & Stilmant, D., 2009. Factors affecting intake by grazing ruminants and related quantification methods: a review. Biotechnol. Agron. Soc. Environ. 13(4): 559-573.

DelCurto, T., Heiss, B.W., Huston, J.E. & Olson, K.C., 2000. Optimum supplementation strategies for beef cattle consuming low quality roughages in western United States.J. Anim. Sci. 77, 1-16.

Detmann, E., Paulino, M.F., Hilario, C., Mantovani, H.C., Filho, S.V., Sampaio, C.B., de Souza, M.A., Lazzarini, I & Detmann, K.S.C., 2009. Parameterization of ruminal fibre degradation in low-quality tropical forage using *Michaelis-Menten* kinetics. Livest. Sci. 126: 136-146.

Directorate of Agricultural Administration, 1986. Biomassa vs. Getalle. Ministry of Agriculture, Water and Forestry, Windhoek, Namibia.

Directorate of Planning, 2011. Agricultural Statistics Bulletin, September 201. Ministry of Agriculture, Water and Rural Development, Windhoek, Namibia. http://www.theeis.com/data/literature/AGRICULTURAL%20STATISTICS%20BULLETIN%20April%202011.pdf

Doyle, P.T., 1987. Supplements other than forage. The nutrition of herbivores. Academic press, New York. Pp 429-464.

Dutra, F., Carlsten, J. & Ekman, S., 1999. Hind limb skeletal lesions in 12-month-old bulls of beef breeds. J. Vet. Med. Series A. 46, 489-508.

Els, J.F., 2000. Diet selection of four free ranging breeds of small stock I. Chemical composition. Agricola, 11.33-35.

Engels, E.A.N. & Van der Merwe, F.J., 1967. Application of an *in vitro* technique to South African forages with special references to the effect of certain factors on the results. S. Afr. J. Anim. Sci. 10, 983.

Engels, E.A.N., De Waal, H.O., Biel, L.C. & Malan, A., 1981. Practical implications of the effect of drying and treatment on nitrogen content and in vitro digestibility of samples collected by oesophageally fistulated animals. S. Afr. J. Anim. Sci. 11, 247-254.

Evitayani, Warly, L., Fariani, A., Ichinohe, T. & Fujihara, T., 2004. Seasonal changes in nutritive value of some grass species in West Sumatra, Indonesia. Asian-Aust. J. Anim. Sci. 17, 1663-1668.

Fedenko, J.R., Erickson, J.E., Woodard, K.R., Sollenberger, L.E., Vendramini, J.M.B., Gilbert, R.A., Helsel, Z.R. & Peter, G.F., 2013. Biomass production and composition of perennial grasses grown for bioenergy in a subtropical climate across Florida, USA BioEnergy Res. 6, 1082–1093.

Fukushima, R.S., Dehority, B.A. & Loerch, S.C., 1991. Modification of a colorimetric analysis for lignin and its use in studying the inhibitory effects of lignin on forage digestion by ruminal microorganisms. J. Anim. Sci. 69, 295-304.

Fontenot, J.P., Chester-Jones, H., Veit, H.P. & Webb, K.E., 1989. Physiological effects of feeding high levels of magnesium to sheep. J. Anim. Sci. 67, 1070-1081.

Forbes, J.M. & Provenza, F.D., 2000. Integration of learning and metabolic signals into a theory of dietary choice and food intake. In: Ruminant physiology: Digestion, metabolism growth and reproduction. Ed. Cronje, P.B. CAB International, Wallingford, UK. Pp 3-19.

Galyean, M.L., & Goetsch, A.L., 1993. Utilization of forage fiber by ruminants. Pp. 33-71 in Forage Cell Wall Structure and Digestibility, H.G. Jung, D.R. Buxton, R.D. Hatfield, and J. Ralph, eds. Madison, Wis.: ASA-CSSA-SSSA.

Geiss, W., 1971. A preliminary vegetation map of South West Africa. Dinteria. 4, 5-114.

Goering, H.K. & Van Soest, P.J., 1970. Forage fiber analysis (apparatus, reagents, procedures and some applications). U.S.D.A.-A.R.S. Agriculture Handbook No. 379. Government printing office, Washington DC.

Grant, C.C., 1989. Development of a system classifying and monitoring the availability of minerals to cattle in the ranching areas of S.W.A./Namibia. DVsc. Thesis. University of Pretoria, South Africa.

Grant, C.C., Biggs, H.C. & Meissner, H.H., 1996. Demarcation of potentially mineral-deficient areas in central and northern Namibia by means of natural classification systems. Onderstepoort J. Vet. Res. 63: 109-120.

Groenewald, I.B., 1986. Die invloed van stikstof-, energie- en fosforbevattende lekaanvullings op die reproduksie- en produksievermoë van koeie op natuurlike weiding. PhD. Thesis. University of Free State, South Africa.

Hanna, W.W., Monson, W.G. & Burton, G.W., 1973. Histological examination of fresh forage leaves after in vitro digestion. Crop Sci. 13, 98-101.

Hardy, M.B., Meissner, H.H. & O'Reagain, P.J., 1997. Forage intake and free-ranging ruminants: A tropical perspective. Proceedings of the 1997 Int. Grassl. Conf., Session 2- Animal intake and Grazing Systems. (45-52).

Hart, R.H., 1983. Correcting for salivary contamination of esophageal fistula samples. J. Range Manage. 36. Pp 119-120.

Hart, F.J. & Leibholz, J., 1985. The effect of the species, stage of maturity and level of intake of grass on the efficiency of microbial protein synthesis in the rumen of cattle. Proc. Int. Grassl. Congr. 15th, Kyoto, Japan. 950-952.

Hassen, A., Rethman, NFG., Van Niekerk, W.A. & Tjelele, T.J., 2007. Influence of season/year and species on chemical composition and *in vitro* digestibility of five Indigofera accessions. Anim. Feed Sci. Technol. 92, 149–158.

Havstad, K.M. & Malechek, J.C., 1982. Energy expenditure by heifers grazing crested wheatgrass of diminishing availability. J. Range Manage. 35. 447-450.

Heinola, T., Jukola, E., Näkki, P. & Sukura, A., 2006. Consequences of hazardous dietary calcium deficiency for fattening bulls. Acta Veterinaria Scandinavica 48, 48-25.

Heldt, J.S., Cochran, R.C., Manthis, C.P., Woods, B.C., Olson, K.C., Titgemeyer, E.C., Nagaraja, T.G., Vanzant, E.S. & Johnson, D.E., 1999. Effetcs of level and source of carbohydrate and level of degradable intake protein on intake and digestion of low-quality tallgrass-prairie hay by beef steers. J.Anim. Sci. Vol.77 No.10, p. 2846-2854.

Hill, B.D., Sutton, R.H. & Thompson, H., 1998. Investigation of osteochondrosis in grazing beef cattle. Aust. Vet. J. 76, 171-175.

Hittmeier, L.J., Grapes, L., Lensing, R.L., Rothschild, F. & Stahl, C.H., 2006. Genetic background influences metabolic response to dietary phosphorous restriction. J. Nutr. Bioch. 17, 385-395.

Hodgson, J., Fornes, T.D.A., Armstrong, R.H., Beattie, M.M. & Hunter, E.A., 1991. Comparative studies of the ingestive behaviour and herbage intake of sheep and cattle grazing indigenous hill plant communities. J. Applied Ecol. 28, 205-227.

Holechek, J.L., Vavra, M. & Pieper, R.D., 1982. Methods for determining the nutritive quality of range ruminant diets: A Review. J. Anim. Sci. 54(2), 363-376.

Hooper, A.P. & Welch, J.G., 1985. Effects of particle size and forage composition on functional specific gravity. J. Dairy Sci. 68, 1181-1188.

Hoover, W.H., 1986. Chemical factors involved in ruminal fibre digestion. J. Dairy Sci. 69, 2755-2766.

Hungate, R.E., 1979. Evolution of a microbial ecologist. Annu. Rev. Microbiol. 33, 1-20.

IFAD., 2011. Northern regions livestock development project: Reformulation report, July 2011. IFAD, Rome.

Jones, D.I.H. & Wilson, A., 1987. Nutritive quality of forage. The Nutrition of Herbivores. Academic Press, New York. 27, 65-90.

Jouany, J.P., Demeyer, D.I. & Grain, J., 1988. Effect of defaunating the rumen. Anim. Feed Sci. Technol. 21, 229-265.

Jumba, I.O., Suttle, N.F., Hunter, E.A. & Wandiga, S.O., 1995. Effects of soil origin and mineral composition and herbage species on the mineral composition of forages in the Mount Elgon region of Kenya. 2. Trace elements. Trop. Grassl. 29, 47-52.

Jung, H.G., 1989. Forage lignins and their effects on fibre digestibility. Agron. J. 81, 33-38.

Kartchner, R.J. & Adams, D.C., 1983. Technical notes: An improved method for attaching the esophageal fistula bag. J. Range Manage. 36, 405-406.

Karn, J.F., 1986. Microwave-oven drying of forage samples collected via esophageal 253 fistula. J. Anim. Sci. 63, 595-602.

Karn, J.F., 1991. Chemical composition of forage and faeces as affected by microwave oven drying. J. Range Manage. 44, 512-515.

Karn, J.F., 1995. Phosphorus supplementation of replacement heifers in the Northern Great Plains. J. Range Manage. 48, 493-497.

Karn, J.F., 2001. Phosphorus nutrition of grazing cattle: a review. Anim. Feed Sci. Technol. 89, 133-153.

Kempton, T.J. & Leng, R.A., 1979. Protein nutrition of growing lambs. Responses in growth and rumen function to supplementation of a low protein cellulosic diet with either urea, casein or formaldehyde-treated casein. Br. J. Nutr. 42, 289-302.

Klevesahl, E.A., Cochran, R.C., Titgemeyer, E.C., Wickersham, T.A., Farmer, C.G., Arroquy, J.I. & Johnson, D.E., 2003. Effect of a wide range in the ratio of supplemental rumen degradable protein to starch on utilization of low quality, grass hay by beef steers. Anim. Feed Sci. Technol. 105, 5-20.

Köster, H.H., Cochran, R.C., Titgemeyer, E.C., Vanzant, E.S., Abdelgadir, I. & St-Jean, G., 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, Tallgrass-Prairie forage by beef cows. J. Anim. Sci. 74, 2473-2481.

Kruger, A.S., 1998. The influence of stocking rate and cattle type on veld and animal performance in the camel thorn savannah of Namibia. MSc. dissertation. University of Pretoria, South Africa.

Langlands, J.P., 1966. Studies on the nutritive value of the diet selected by grazing sheep. I. Differences in composition between herbage consumed and material collected from oesophageal fistulae. Anim. Prod. 9, 253-259.

Leng, R.A., 1990. Factors affecting the utilization of poor quality forages by ruminants, particularly under tropical conditions. National research review 3, 277.

Loëst, C.A, Titgemeyer, E.C., Drouillard, J.S., Lambert, B.D. & Trater, A.M., 2001. Urea and biuret as nonprotein nitrogen sources in cooked molasses blocks for steers fed prairie hay. Anim. Feed Sci. Technol. 94, 115-126.

Louw, G.N., 1979. An evaluation of the application of stock licks in South Africa. S. Afr. J. Anim. Sci. 9, 133.

Lukhele, M.S. & Van Ryssen, J.B.J., 2003. The chemical composition and potential nutritive value of the foliage of four subtropical tree species in southern Africa for ruminants. S. Afr. J. Anim. Sci. 33, 132-140.

Marshall, B., Torell, D.T. & Bredon, R.M., 1967. Comparison of tropical forages of known composition with samples of these forages collected by oesophageal fistulated animals. J. Range Manage. 20, 310-313.

Martens, H. & Schweigel, M., 2000. Pathophysiology of grass tetany and other hypomagnesemias. Implications for clinical management. Vet. Clin. North Am. Food Anim. Pract. 16, 339-368.

Masters, D.G. & White, C.L., 1996. Detection and treatment of mineral nutrition problems in grazing sheep. ACIAR. 16-28.

Mathison, G.W., Milligan, L.P. & Weisenburger, R.D., 1986. Ruminant feed evaluation unit: Nutritive value of some Alberta feeds for cattle and sheep. In: The 65th annual feeder's day report: Agriculture and forestry bulletin, Special Issue, Edmonton: University of Alberta, Canada. Pp.55-57

McCosker, T. & Winks, L., 1994. Phosphorus nutrition of beef cattle in northern Australia. Department of Primary Industries. Brisbane, Queensland.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A. & Wilkinson, R.G., 2011. Animal Nutrition. Pearson Education Limited, Essex, England.

McDowell, L.R., Conrad, J.H. & Ellis, G.L., 1984. Mineral deficiencies and imbalances and their diagnosis. In: Symposium on Herbivore Nutrition in the Sub-tropics and Tropics – problems and prspects. (Eds.): Gilchrist, F.M.C. & Mackie, R.I. The Science Press, Johannesburg. 67-68.

McDowell, L.R., 1992. Minerals in Animal and Human Nutrition. Academic Press, San Diego, 524 Pp.

McDowell, L.R, 1996. Feeding minerals to cattle on pasture. Anim. Feed Sci. Technol. 60, 247-271.

McDowell, L.R., 2003. Grazing ruminants require free-choice minerals. Feedstuffs 75 (47).

McFarlane, J.D., Judson, J.D. & Gouzos, J., 1990. Copper deficiency in ruminants in the south east of Australia. Aust. J. Exp. Agric. 30, 187–193.

McIvor, J.G., 1979. Seasonal changes in nitrogen and phosphorus concentrations and *in vitro* digestibility *Stylosanthes* species and *Centrosema Pubescens.* Trop. Grassl. Vol 13, 2.

McKay, A.D., Frandsen, P.E., Odero, J.C., Sondergaard, M. & Nganga, S.P., 1969. Chemical composition of herbage from Themeda grassland in Kenya before and after collection from oesophageal fistulated steers. East African Agric. For. J. 35, 190-196.

McLeod, M.N., Kennedy, P.M. & Minson, D.J., 1990. Resistance of stem and leaf fractions of tropical forage to chewing and passage in cattle. Br. J. Nutr. 105-119.

Meissner, H.H. 1993. Carrying capacity as estimated by the animal unit and biomass methods: Pros and Cons. Proceedings of the workshop on determining grazing norms, Irene, Pretoria.

Meissner, H.H. & Paulsmeier, D.V., 1995. Plant compositional constituents affecting between-plant and animal species prediction of forage intake. J. Anim. Sci. 73, 2447-2457.

Meissner, H.H., 1997. Recent research on forage utilization by ruminant livestock in South Africa. Anim. Feed. Sci. Technol. 69, 103-119.

Mertens, D.R. & Loften, J.R., 1980. The effect of starch on forage fibre digestion kinetics *in vitro*. J. Dairy Sci. 63, 1427-1446.

Miller, W.J., 1975. New concepts and developments in metabolism and homeostasis of inorganic elements in dairy cattle. A review. J. Dairy Sci. 58, 1549-1560.

Ministry of Agriculture, Water and Forestry., 2011. Agricultural Statistics Bulletin. Ministry of Agriculture, Water and Forestry, Windhoek, Namibia.

Minson, D.J., 1990. Forage in ruminant nutrition. In: Animal Feeding and Nutrition. Ed. Cunha, T.J., Academic Press, San Diego, USA. Pp 60-84.

Moore, K.J. & Cherney, J.H., 1986. Digestion kinetics of sequentially extracted cell wall components of forage. Crop Sci. 26, 1230-1235.

Moore, J.E., Brant, M.H., Kunkle, W.E. & Hopkins, D.I., 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. 77 (Suppl. 2), 122-135.

Morris, E.J., 1983. Degradation of the intact plant cell wall of subtropical and tropical herbage by rumen bacteria In: Herbivore Nutrition in the Subtropics and Tropics. The Science Press, Craighall, South Africa. 3, 378-398.

Moseley, G. & Dellow, D.W., 1985. Particle breakdown and chewing activity in sheep fed on fresh perennial ryegrass and white clover. Proc. Nutr. Soc. 44, 52A.

Moseley, G. & Jones, J.R., 1979. Some factors associated with the difference in nutritive value of artificially dried red clover and perennial ryegrass for sheep. Br. J. Nutr. 42, 139-147.

Mphinyane, W.N., 2001. Influence of livestock grazing within biospheres under free range and controlled conditions in Botswana. PhD. Thesis. University of Pretoria, South Africa.

Nasrullah, M., Niimi, R.A. & Kawamura, O., 2003. Nutritive evaluation of forage plants in South Sulawesi, Indonesia. Asian-Aust. J. Anim. Sci. 16, 693-701.

NRC, 1987. National Research Council, Predicting Feed Intake of Food-producing animals. National academy press. Washington D.C.

NRC, 2000. National Research Council, Nutrient Requirements of Beef Cattle. 8th revised edition. National Academy Press, Washington, DC.

NRC, 2001. National Research Council, Nutrient Requirements of Dairy Cattle. 7th revised edition. National Academy Press, Washington, DC.

NRC, 2016. National Research Council, Nutrient Requirements of Beef Cattle. 8th revised edition. National Academy Press, Washington, DC.

Nunez-Hernandez, G., Holencheck, J.L., Artthun, D., Tembo, A. & Wall, J.D., 1992. Evaluation of fecal indicators for assessing energy and nitrogen status of cattle and goats. J. Range Mange. 45: 143-147.

O'Reagain, P.J. & Mentis, M.T., 1988. Seasonal changes in the quality of diet selected by cattle grazing the Natal sour sandveld. J. Grassl. Soc. S.A. 5, 48-51.

Olson, K.C. & Malechek, J.C., 1987. Technical notes: A temporary esophageal cannula that prevents fistula contraction during extrusa collections. J. Range Manage. 40, 282-283.

Olson, K.C., 1991. Diet sample collection by esophageal fistula and rumen evacuation techniques. J. Range Manage. 44, 515-519.

Olszewski, J., 1996. The productivity of rainfall in the Western SARDEP pilot areas. Sustainable animal and range development program. Ministry of Agriculture, Water and Rural Development, Windhoek, Namibia.

Oltjen, R.R., 1975. Fats for ruminants – utilization and limitations, including value of protected fats. Proc. Georgia Nutr. Conf. Pp 31-40.

Osuji, P.O., 1974. The physiology of eating and the energy expenditure of the ruminant at pasture. J. Range Manage. 27, 437-443.

Park, K. K., Krysl, L.J., McCracken, B.A., Judkins, M.B. & Holcombe, D.W., 1994. Steers grazing intermediate wheatgrass at various stages of maturity: effects on nutrient quality, forage intake, digesta kinetics, ruminal fermentation, and serum hormones and metabolites. J. Anim. Sci. 72, 478-486.

Persson, Y., Söderquist, L. & Ekman, S., 1997. Joint disorder; a contributory cause to reproductive failure in beef bulls? Acta Veterinaria Scandinavica, Biomed Central. Pp 49, 31-35.

Pinchak, W.E., Greene, L.W. & Hunt, L.J., 1990, Biases in relative estimates of dietary mineral status from esophageal extrusa. J. Range Manage. 43, 136-138.

Pittroff, W. & Kothmann, M.M., 2001. Quantitative prediction of feed intake in ruminants II. Conceptual and mathematical analysis of models for cattle. Livest. Prod. Sci. 71, 151-169.

Provenza, F.D., Villalba, J.J., Cheney, C.D. & Werner, S.J., 1998. Self-organization of foraging behaviour: From simplicity to complexity without goals. Nutr. Res. Rev. 11, 199-222.

Ramírez, R.G., Haenlein, G.F.W. & Núñez-González, M.A., 2001. Seasonal variation of macro and trace mineral contents in 14 browse species that grow in north-eastern Mexico. Small Rum. Res. 39: 153-159.

Ramírez, R.G., Haenlein, G.F.W., García-Castillo, C.G. & Núñez-González, M.A., 2004. Protein, lignin and mineral contents and in situ dry matter digestibility of native Mexican grasses consumed by range goats. Small Rum. Res. 52, 261–269.

Rayburn, E.B. 1986. Quantitative aspects of pasture management. Seneca Trail RC&D Technical Manual. Franklinville, N.Y.: Seneca Trail RC&D.

Read, M.V.P., Engels, E.A.N. & Smith, W.A., 1986. Phosphorus and the grazing ruminant. 4. Blood and faecal grab samples as indicators of the P status of cattle. S. Afr. J. Anim. Sci. 16, 18-22.

Robertson, J.B. & Van Soest, P.J., 1981. The detergent system of analysis and its application to human foods. In: The analysis of dietary fiber in food. Eds. James, W.P.T. & Theander, O., Marcel Dekker, New York. Pp123-158

Romney, D.L. & Gill, M., 2000. Intake of forags. In: Forage Evaluation in Ruminant Nutrition. Eds. Givens, D.I., Owen, E., Axford, R.F.E. & Omed, H.M. CAB International, Wallingford, UK. Pp 43-62.

Roodt, W., 2012. Nutritional status and performance of lick supplemented beef cattle in the tree and shrub savannah of Namibia. MSc. (Animal Nutrition) dissertation. University of Pretoria.

Rook, A.J., Harvey, A., Parsons, A.J., Orr, R.J. & Rutter, S.M., 2004. Bite dimensions and grazing movements by sheep and cattle grazing homogenous perennial ryegraaa swards. Appl. Anim. Behav. Sci., 88, 227-242.

Rooke, J.A., Lee, N.H. & Armstrong, D.G., 1987. The effects of intraruminal infusions of urea, casein, glucose syrup and mixture of casein and glucose syrup on nitrogen in the rumen of cattle receiving grass-silage diets. Br. J. Nutr. 57, 89-98.

Russell, J.B. & Baldwin, R.L., 1979. Comparison of maintenance energy expenditures and growth yields among several rumen bacteria grown on continuous culture. Appl. Environ. Microbiol. 37, 537-543.

Russell, J.B. & Wallace, R.J., 1988. Energy yielding and consuming reactions. In: Hobson, P.N. (Ed.), The rumen Microbial Ecosystem. Elsevier Science Publishers, New York, NY, USA. Pp 185-216.

Rothauge, A., 2006. The effect of frame size and stocking rate on diet selection of cattle and range condition in the camelthorn savannah of east-central Namibia. PhD. Thesis, University of Namibia, Windhoek, Namibia.

Samuels, M.L., 1989. Statistics for the Life Sciences. Collier Macmillan Publishers, London.

Satter, L.D. & Roffler, R.E., 1977. Influence of nitrogen and carbohydrate inputs on rumen fermentation. In: Recent Advances in Animal Nutrition. Eds. Haresign, W. & Lewis, D., London, Butterworths. Pp 25-49.

Scott, D. & McLean, A.F., 1981. Control of mineral absorption in ruminants, Symposium on mineral nutrition of farm animals. Proc. Nutr. Soc. 40, 257-265.

Seymour, W.M., Campbell, D.R. & Johnson, Z.B., 2005. Relationship between volatile fatty acid concentrations and milk production in dairy cows: a literature review. Anim. Feed Sci. Tech. 119, 155-169.

Sharma, B.K., Erdman, R.A. & Reeves, J.B., 1988. Rate and extent of *in situ* digestion of medium and high quality alfalfa and orchardgrass neutral detergent fibre as determined by extended periods of incubation time. J. Dairy Sci. 71, 3509-3513.

Singh, V.K., Pattanaik, A.K., Goswami, T.K. & Sharma, K., 2013. Effect of varying the energy density of protein adequate diets on nutrient metabolism, clinical chemistry, immune response and growth of Muzaffarnagari lambs. Asian-Aust. J. Anim. Sci. 26, 1089-1101.

Soder, J.K., Gregorini, P., Scaglia, G. & Rook, A.J., 2009. Dietary selection by domestic grazing ruminants in temperate pastures: Current state of knowledge, methodologies and future direction. Range. Ecol. Manage. 62(5): 389-398.

Spears, J.W., 2003. Overview of mineral nutrition in cattle: The Dairy and Beef NRC. Proceedings 13th Annual Florida Ruminant Nutrition Symposium. Dep. of Anim. Sci. North Carolina State University. Pp 113-126.

Sun, W., Goetsch, A.L., Forster, L.A., Galloway, D.L. & Johnson, Z.B., 1992. Feed intake and digestion by Holstein steers consuming warm or cool season grass hay and various supplements. Anim. Feed Sci. Technol. 34, 241-254.

Sun, Z., Wang, Z., Zhong, Q. & Zhou, D., 2014. Seasonal variations in voluntary intake and apparent digestibility of forages in goats grazing on introduced *Leymus chinensis* pasture. Asian-Aust. J. Anim. Sci. 27(6), 818–824.

Suttle, N.F., 1991. The interactions between copper, molybdenum and sulfur in ruminant nutrition. An. Rev. Nutr. 11, 121-140.

Suttle, N.F., 2010. The Mineral nutrition of livestock. 4th ed. CAB International. Pp 54-426.

Sweet, J., 1998. Livestock – Coping with drought: Namibia - a case study. Paper prepared for FAO electronic conference on drought. FAO, Rome.

Sweet, J. & Burke, A., 2002. Country pasture/forage resource profiles: Namibia. Original from 2000, updates by S.G. Reynolds in 2002. Food and Agriculture Organization of the United Nations. Rome, Italy. http://fao.org/ag/agp/agpc/doc/Counprof/namibia.htm

Ternouth, J. H., 2001. Developments in the role of phosphorus in animal nutrition. AFMA Forum 2001, recent developments in animal feeds and feeding. http://www.afma.co.za/Mini_Web_AFMA/Images/20010402120913paper7.htm (3 March 2004).

Ternouth, J.H., Bortolussi, G., Coates, D.B., Hendrickson, R.E. & McLean, R.W., 1996. The phosphorus requirements of growing cattle consuming forage diets. J. Agric Sci., Camb. 126, 503-510.

Theart, J.J., 2015. Forage quality of some Kalahari browse species and its ability to reduce methane emission. MSc. (Animal Nutrition) dissertation. University of Pretoria.

Theiler, A., 1912. Facts and theories about stijfziekte and lamziekte, Second report of the director of veterinary research, Government Printer, Pretoria.

Thomas, P.C. & Rook, J.A.F., 1981. Manipulation of rumen fermentation. In: Recent Developments in Ruminant Nutrition. Eds. Haresign, W. & Cole, D.J.A., Butterworths, London. Pp 83-109.

Tilley, T.M.A. & Terry, R.A., 1963. A two-stage technique for the *in vitro* digestion of forage crops. J. Brit. Grassl. Soc. 18, 104-111.

Trostle, S.S., Nicoll, R.G., Forrest, L.J. & Markel, M., 1997. Clinical and radio graphic findings, treatment, and outcome in cattle with osteochondrosis: 29 cases (1986-1996). J. Am. Vet. Med. Ass. 211, 1566-1570.

Van Dyne, G.M. & Torell, D.T., 1964. Development and use of the esophageal fistula: a review. J. Range Manage. 17, 7-19.

Van Dyne, G.M. & Heady, H.F., 1965. Dietary chemical composition of cattle and sheep grazing in common on a dry annual range. J. Range Manage. 18, 78-86.

Van Ryssen J.B.J., 2000. The multifactorial nature of trace nutrient nutrition and the supplementation of trace elements to livestock in South Africa. Presented at the 38th Congress of the SASAS, Alpine Heath, KwaZulu Natal. 1-6.

Van Ryssen, J.B.J., 2003. Predicting the mineral status of livestock from laboratory analyses. UP-Nutrilab Information Day on Laboratory analyses on feeds and animal tissues. University of Pretoria, 26 February 2003. Pp 84-101.

Van Ryssen, J.B.J., 2006. An evaluation of the trace element nutritional status of grazers in the eastern regions of the Free State and Mpumalanga. S. Afr. J. Anim. Sci. 7, 22-30.

Van Schalkwyk L.P., 1978. Veldevaluasie en voerinname studies met beeste op natuurlike weiding. PhD. Thesis. University of Free State, South Africa.

Van Soest, P.J., 1994. Nutritional Ecology of the Ruminant 2nd ed. Cornell University Press, Ithaca, NY, USA.

Varga, G.A., Tyrrell, H.F., Huntington, G.B., Waldo, D.R. & Glen, B.P., 1990. Utilization of nitrogen and energy by Holstein steers fed formaldehyde and formic acid – treated alfalfa or orchardgrass silage at two intakes. J. Anim. Sci. 68, 3780-3791.

Venter, J.P., 1982. Die regte bestokking: “n wenresep teen droogtes”. Swalurama 12, 18-33.

Waldo, D.R., Varga, G.A., Huntington, G.B., Glenn, B.P. & Tyrrell, H.F., 1990. Energy components of growth in Holstein steers fed formaldehyde and formic acid – treated alfalfa or orchardgrass silages at equilized intakes of dry matter. J. Anim. Sci. 68, 3792-3804.

Wallace, J.D., Hyder, D.N. & Van Dyne, G.M., 1972. Salivary contamination of forage selected by esophageal fistulated steers grazing sandhill grassland. J. Range Manage. 25, 184-187.

Wallis de Vries, M.F., 1995. Estimating forage intake and quality in grazing cattle: A reconsideration of the hand-plucking method. J. Range Manage. 48, 370-375.

Webb. E. C., 1994. Synthesis of long chain fatty acids in ruminants and their effects on meat quality. Ph.D. thesis – University of Pretoria, 1994. Chapter 3, p58-59.

Welch, J.G., 1986. Physical parameters of fibre affecting passage from the rumen. J. Dairy Sci. 69, 2750-2754.

Weston, R.H., 2002. Constraints on feed intake by grazing sheep. Sheep Nutr. CAB International. Chapter 2, 27-49.

Weston, R.H. & Poppi, D.P., 1987. Comparative aspects of food intake. In: The Nutrition of Herbivores. Eds. Hacker, J.B. & Ternouth, J.H., Academic press. 13, 133-161.

Young, V.R., Lofgreen, G.P. & Luick, J.R., 1966. The effects of phosphorus depletion, and of calcium and phosphorus intake, on the endogenous excretion of these elements by sheep. Br. J. Nutr. 20, 795-805.