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Nutritional status and performance of lick supplemented beef cattle in the tree and shrub savannah of Namibia

Walter Roodt

Submitted in partial fulfilment of the requirements for the degree

MSc. (Agric) Nutrition Science (Animal Science)

In the Faculty of Natural and Agricultural Sciences

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DECLARATION

I, Walter Roodt declare that the dissertation, which I hereby submit for the degree MSc (Agric) Nutrition Science (Animal Science) 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.

Walter Roodt

Pretoria

16 July 2012

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SUMMARY

Nutritional status and performance of lick supplemented beef cattle in the tree and shrub savannah of Namibia

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The Namibian meat industry relies on the export of weaners to the South African feedlot industry while the largest part of the cattle population in the communal areas of Namibia remain underutilised. Producing a marketable cattle carcass for slaughter, which contributes the most to the Namibian economy, remains a challenge that needs a high level of understanding of all management variables under control by the rangeland manager. The nutritional requirements of cattle are one the important areas for maximising the return from the land and ensuring long term sustainability of the farming enterprise.

A commercial farming enterprise, with the same climate and sandy soils that were predominantly found in the communal farming areas of Namibia, was chosen as experimental site. Three groupings of cattle were exposed to different experimental techniques and treatments over a 15 month trial period.

The first grouping of cattle was 6 oesophageal fistulated cattle used, to collect veld samples selected by the cattle, every 3 weeks to estimate the contribution of the tree and shrub savannah towards the diet of the cattle.

The second grouping was 110 cattle allocated to different nutrient supplementation treatments for slaughter at 28months of age. Five different nutrient supplementation treatments were chosen for 5 groups of 22 cattle, consisting of steers and heifers, for the duration of the period on an *ad libitum* basis. The 5 treatments were applied to illustrate the economic concept of diminishing marginal returns as the increasing feeding cost progressively deteriorated the amount of profit that would be expected. The optimal supplementation strategy would thus be identified according to the financial resources

available to a farmer. Some of the treatments were also planned to progressively result in negative associative effects on forage intake, as energy containing raw materials in such treatments would replace the intake of natural available forage. The need for replacing forage was a common practice in droughts when the availability of forage was limiting or when the finishing of cattle during a short period before slaughter was planned. The cattle needed to be foraging less to conserve energy and thus increase protein accretion and fat deposition. The control of the experiment was the rock salt treatment group (RST) which only received a rock salt lick throughout the dry and wet seasons of the year. This was generally used for the supplementation of wildlife and cattle on rangeland in Namibia and it placed nearly no strain on the finances of a farmer. The remaining four treatments received commercially manufactured lick products with a diverse set of applications that were not strictly used according to the manufacturer's guidelines. During the wet season it was a well-established practice to only supplement with phosphorus and trace mineral containing licks due to the forage having maximum nutritional value during this time in which no additional benefit would be derived from the supplementation of protein and energy containing licks. All treatments, except for the rock salt treatment group (RST), were thus placed on a phosphorus and trace mineral lick during the wet season as part of the nutrient supplementation treatment programs. Different licks were made available to the cattle in the treatment groups, during the dry season, from which the treatment groups derived their names. One group was placed on a phosphorus and trace mineral lick for the duration of the trial, during the wet and dry season, and defined as the 6% phosphorus treatment group (6%PT). A maintenance treatment group (MTT) received protein in addition to phosphorus in the lick during the dry season. The production treatment group (PDT) received energy containing raw materials in addition to the minerals and protein as established in the MTT. The finisher treatment group (FST) received a larger amount of energy containing materials which diluted the mineral and protein concentration of the dry season lick even further than in the PDT.

The third experimental procedure was to establish a group of 5 ruminally cannulated cattle that would individually be rotated every 3 weeks between the supplement fed treatment groups. The cattle would then be sampled for ruminal fluid, blood and faeces to observe the short term impact of the supplements during the different seasons on these variables and the diagnostic value of these parameters to indicate the nutritional status of cattle.

The results clearly illustrated that the cattle had exhibited "nutritional wisdom". The selection of higher quality plant material than what was on offer in the veld was highlighted in a review of previous oesophageal fistulated cattle research. The strong influence of rainfall on the forage quality (increased phosphorus and protein) was highlighted. During spring the phosphorus and protein reached their maximum concentrations. It was only during the wet season that animal performances were optimised when the quantity of high quality forage increased. The average daily *ad libitum* nutrient supplement consumption per animal on the different treatments was strongly influenced by these seasonal changes in forage quality and quantity. The lick intake increased as the dry season progressed and the quality of the forage the animals were able to select decreased. During spring the lick intake sharply decreased as the forage quality improved. The cattle adapted their intake level with the aim of maximising their energy intake, which resulted in the highest possible performance possible, from the forage and lick that was on offer to them. Monitoring the average monthly lick intake per animal would give valuable information to the farmer on the quality of the forage selected. The trends observed in average lick intake during the year could be used as an inexpensive indicator of veld quality. An upper threshold could be set on lick intakes that would signal that a specific area was optimally grazed and that a camp rotation would aid in conserving the rangeland and optimise animal performance.

The year round supplementation of rock salt lick group (RST), or alternatively no nutrient supplement, under these conditions had clearly shown a minimal contribution to the nutritional status of cattle and that this strategy would lead to certain financial underperformance or ruin of the cattle farmer. From the results presented, the year round supplementation with a phosphorus and trace mineral lick (6%PT) was indicated as the absolute minimum nutrient supplementation strategy that would need to be followed in all communal and commercial cattle farming areas of Namibia and probably similar farming locations around the world. Free access to phosphorus licks throughout the year to growing cattle must be ensured by the farmer to allow the cattle to select the correct amount that it would require to optimise performance. This strategy required the least amount of capital to implement and had the largest return on investment for a newly established farmer. If limited amounts of energy containing materials (molasses, maize, bran) were included in the nutrient supplement on offer it allowed the animal the opportunity to only consume the minimum amount of phosphorus that it required throughout the year to balance the shortages that occurred in the forage that it was selecting from. The finisher lick given during the dry season on the FST clearly illustrated that salt and phosphorus were poor regulators of supplemental intake if the cattle were able to increase their total energy retention by over consuming and probably excreting of minerals. The optimum nutrient supplementation strategy was the MTT that alleviated the primary phosphorus and secondary protein shortages during the dry season. This strategy had a much higher capital requirement and would be most suitable for the established cattle farmer that was able to afford this strategy or had access to credit. The PDT and FST were associated with higher supplementation costs that resulted in the highest turnover for the cattle farmer, although at lower profit than the MTT. The PDT and FST supplementation strategies would be more appropriate if the improved nutritional status of the cattle was utilised in a cow herd for improved reproduction or in stud farming when genetic expression of growth potential would offset the cost of supplementation.

LIST OF ABBREVIATIONS

(DM)	- Dry matter basis calculation
(OM)	- Organic matter basis calculation
6%PT	- 6 % Phosphorus treatment group
ADF	- Acid detergent fibre
ADIN	- Acid detergent insoluble nitrogen
ADL	- Acid detergent lignin
BHB	- Blood serum beta-hydroxy butyrate concentration
BUN	- Blood serum urea nitrogen concentration
BW	- Body weight
Ca	- Calcium
Ca:P	- Calcium to phosphorus ratio
Ca:Pi	- Blood serum calcium concentration to blood serum inorganic phosphorus concentration ratio
CNS	- Central nervous System
CP	- Crude protein (N x 6.25)
DM	- Dry matter
DMI	- Dry matter intake
DOMD	- Digestible organic matter dry matter
eCa	- Estimated available Calcium
eCa:P	- Estimated available Calcium to Phosphorus ratio
eME	- Estimated metabolisable energy
eMP	- Estimated metabolisable protein
eP	- Estimated available phosphorus
FST	- Finisher treatment group
IVDOM	- *In Vitro* digestible organic matter
LW	- Liveweight
ME	- Metabolisable energy
MP	- Metabolisable protein
MTT	- Maintenance treatment group
N	- Nitrogen
NDF	- Neutral detergent fibre
NPN	- Non-protein nitrogen
NSC	- Non-structural carbohydrates

OF - Oesophageally fistulated cattle
OM - Organic matter
P - Phosphorus
P_B - Plant available phosphorus in soil
PDT - Production treatment group
Pi - blood serum inorganic phosphorus concentration
r - Correlation
R^2 - Coefficient of determination
RDP - Rumen degradable protein
RST - Rock salt treatment group
SBW - Shrunk body weight (overnight fast or 96% of full body weight)
SCF - Subcutaneous back fat thickness
SEM - Standard error of least square means
SI - International system of units
TDN - Total digestible nutrients
UDP - Undegradable dietary protein
VFA - Volatile fatty acid concentration

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CHAPTER 1 INTRODUCTION

The Namibian meat industry relied heavily on the export markets and an estimated 80% of its beef and lamb production was exported to foreign countries in 2004. Namibia had around 2.3 million head of cattle, which were classified as 40% communal and 60% commercial herds. Namibia produced around 300 000 marketable cattle annually of which 50% (Lange *et al.*, 1997) were marketed on-the-hoof as weaners to South African enterprises where value was added by fattening, processing and distribution. Since 2000 Namibia had continued exporting meat cuts annually to markets in the European Union (Agricultural Statistics Bulletin, 2005). Under the long-term policy framework of Vision 2030 (Namibia Vision 2030, 2004) the country was in an effort to address and promote value-addition in Namibia with increased focus on the weaner sector.

In semi-arid Namibia the fluctuations in forage availability, due to erratic annual total rainfall, and the subsequent adjustment of stocking rates (Lange *et al.*, 1997) had an important influence on rangeland botanical composition, long-term rangeland sustainability and animal performance (Kruger, 1998; Rothauge, 2006). The loss of land productivity in Namibia, since 1959 on approximately 26 million ha of woodland savannahs of as much as 100% or more, was due to bush encroachment resulting from the over utilisation of the grass layer and the subsequent dominance of trees and bushes (De Klerk, 2004).

The knowledge of quantitative digestion and metabolism has clearly shown that the way toward substantial increases in productivity of ruminants on forage based diets was through the balanced nutrient approach that considered the efficiency of the rumen ecosystem and the availability of dietary nutrients post-ruminally (Leng, 1993). Requirements minus nutrient supply from grazed pastures would define the need for supplementary feeding. The feeding strategy must be aimed at closely matching nutrient supply with requirements, whilst keeping costs as low as possible (Van Niekerk, 1996; DelCurto *et al.*, 2000). Minimizing the use of feed supplements is essential to the economic success of forage-based diets under extensive production systems (Paiva, 2003). The improvement in animal nutrition by feeding supplements and the subsequent improvement in animal performance in Namibia were well documented by Freyer (1967), Van Schalkwyk (1975), Van Schalkwyk (1978), Gressmann (1979), Grant (1989), Kubirske (1989) and Strydom (1991).

The ultimate aim of the Namibian farmer is to increase meat production per hectare of farmland in a profitable and sustainable manner under the stipulations laid down by the Namibian Quality Assurance Scheme (*Farm Assured Namibian Meat Scheme*). Little reference was made to the cost to benefit relationship of implementing different supplementation strategies and many new restrictions (such as regulations on the prohibition of growth promotants, ruminant by-products and GMO feedstuffs) and new opportunities (organic livestock production) could influence the production of beef from natural pastures in Namibia.

The nutritive value of veld (grass, tree and shrub components) and, moreover, its ability to support animal production, as well as the role of supplementary feeding in promoting animal production, should be studied under realistic and practical grazing conditions (Engels, 1983; De Waal, 1990; DelCurto *et al.*, 2000). A wealth of knowledge concerning ruminant nutrition in the subtropics is available internationally. Considerable variability in animal performance observed in practice, under the specific climatic conditions of Namibia, accentuates the need for a comprehensive understanding of the interaction of the nutritive value of veld selected by cattle and different nutrient supplementation strategies on the performance of cattle during the dry, spring and wet season.

The aim of this study was to obtain as many possible measurable parameters at a commercial cattle weaner outgrowing enterprise and relate them to the nutritional status of free-range foraging ruminants during the different seasons in Namibia. From the measured nutritional status indicators a practical recommendation could be made on the use of strategic nutrient supplementation practices and the most practical status indicators that farmers and consultants could use at farm level.

The first of three objectives was to quantify the nutritional quality of the veld selected (Chapter 3.2 Oesophageally fistulated cattle) under commercial farming conditions to quantify the baseline nutrition (CHAPTER 5 VELD QUALITY) that the animals were exposed to and thereby be able to subsequently estimate the relative nutrient supplementary needs of the foraging ruminants during the seasons.

The second objective was to place free-ranging crossbred beef steers and heifers on the veld (natural grazing containing grasses, woody plants and herbs) from weaning to subsequent slaughter and deboning for the European Union export markets (CHAPTER 8

MARKETING OF CATTLE). Five different strategic nutrient supplementation treatments, which were generally used in Namibia at the time, were made available to the cattle during the different seasons (Chapter 3.3 Foraging free-range cattle with lick supplements). The weight gains of the cattle on the treatments were regularly monitored (CHAPTER 4 SEASONAL LIVEWEIGT CHANGE). The *ad libitum* intake of the various nutrient supplementation strategies were recorded and compared to the animal nutrient requirements against the background of the actual animal performances obtained (CHAPTER 6 NUTRIENT INTAKE).

The last objective was to obtain animal related status indicators by measuring metabolites and nutrient concentrations in the blood, rumen and faeces of ruminally cannulated cattle during 3 week exposures to the nutrient supplementation treatments during different seasons (Chapter 3.4 Ruminally cannulated cattle). The results would explain how the nutrient strategies had affected the status indicators and if they would be of diagnostic value (CHAPTER 7 NUTRITIONAL STATUS INDICATORS).

CHAPTER 2 REVIEW OF LITERATURE

Ruminant animals have evolved a large and complex set of stomachs that allow fermentation of fibrous feeds by symbiotic micro-organisms. The rumen is the dominant feature of the digestive tract of cattle. This compartment of the stomach contains the medium that supports a dense and varied population of micro-organisms that produce mainly short chain organic acids of volatile fatty acids (VFA), methane and carbon dioxide (Leng, 1991). Acetic acid and butyric acid are the predominant VFA's and the substrates for oxidation and the precursors of lipids. Propionic acid is the only glycogenic VFA. Rumen concentrations of VFA are measured to characterise the general nature of the rumen fermentation (Seymour *et al.*, 2005).

Supplementation strategies could only evolve once a clear understanding of the nutrient profile of the selected browse and graze components of the veld were established under the specific production conditions encountered. However, without reliable data on the level of intake, quality of the diet and the production response obtained, the determination of the unique nutritional requirements of each individual could not be made.

The general expression that best described the relationship between the foraging animal and the diet it ingested was given by Burns & Sollenberger (2002) in Equation 1:

Equation 1 Animal response (kg.d^{-1}) ƒ Dry matter intake (kg.d^{-1}) x Digestibility (%)

Making accurate estimates of digestibility and intake in grazing animals still presents real difficulties in most situations and remains a challenge. Coates & Penning (2000) stressed that the effective measurement of animal performance depended on choosing the most appropriate technique in relation to the prevailing circumstances and the purpose for which the measurements were to be used, together with the correct application of the chosen method.

2.1. FEED INTAKE OF RUMINANTS ON FORAGE DIETS

2.1.1. Introduction

Intake is arguably the single most important variable determining animal performance (Romney & Gill, 2000) but the factors controlling feed intake are complex and not fully understood (NRC, 2000; Burns & Sollenberger, 2002). Pittroff & Kothmann (2001b) illustrated the astonishing lack of sound knowledge within intake models.

Knowledge of feed intake is necessary for diet formulation, for the prediction of animal performance, for the design and control of production systems and for the assessment of animal-resource interactions in grazing ecosystems (Illius *et al.*, 2000).

It was generally accepted that animals ate to supply the tissues with the nutrients required to fuel physiological processes of maintenance, growth (including fat deposition in mature animals), milk production and work. However, given the variety of feed components eaten by animals, it was unlikely that the composition of the nutrients supplied would exactly meet the ratio of nutrients required by the animal. Thus, meeting the requirements of one nutrient was likely to result in a deficiency or excess of another. Animals stop eating to limit metabolic or physical discomfort and thus the animal has to decide at what point the disadvantages of the deficiencies or excesses of some nutrients outweigh the advantages of trying to meet the animal's energy requirements, which were thought to be the main intake driver (Romney & Gill, 2000).

Feed intake was unlikely to be regulated by any single mechanism and that, through the central nervous system, oropharyngeal sensations, gastric contractions and distension, changes in heat production and changes in the concentrations of circulating metabolites may severally be indicated. One solution was to envisage integration of different signals within the brain, but argument still remains as to how and where such integration would take place (Romney & Gill, 2000).

Different theories have evolved to better explain how the ruminant brain integrates the numerous short term and long-term stimuli it receives via its neural and hormonal network to regulate the level of intake and the selection and avoidance of specific nutrients.

The difference between stall-fed animals, for the determination of the requirements for animals (NRC, 2000), and grazing cattle is important. The difference between the total voluntary feed intakes between the two groups differs according to the palatability of feed, different basal energy requirements and the differences in digestibility that occur due to selective grazing.

2.1.2. Theory of dietary choice

The notion that ruminants had nutritional wisdom to know which minerals were needed and how much of each mineral was required, was seen as an erroneous assumption (Forbes, 1986). From as early as the 1920's Theiler *et al.* (1924) had illustrated that cattle with a P deficiency were seen to be chewing bones which was a good source of P to alleviate the deficiency. Atwood *et al.* (2001) showed that animals could more efficiently meet their individual needs for macronutrients when offered a choice among dietary ingredients than when constrained to a single diet, even if the diet was nutritionally balanced. McDowell (2003) summarised many factors that influenced the feeding of free-choice minerals to grazing ruminants but contended that it was a necessary practice.

Learned associations between the sensory properties of a feed and the metabolic consequences of eating that feed, were demonstrated by experiments showing adaptation to choices of feeds, in order to avoid excessive intakes of toxins and to ensure adequate intakes of essential nutrients (Forbes & Provenza, 2000). The word “toxin” was usually reserved for a substance that caused obvious signs of discomfort or distress. However, all dietary components were capable of acting as toxins, if present in great excess over requirements. Even a mild excess could generate aversion, as toxins did not have to be consciously sensed in order for their effects to be relayed to the central nervous system and to have the potential to influence learned aversion. Equally, a deficiency of an essential nutrient could form the unconditioned stimulus for the development of feed aversions. An example was provided by Hills *et al.* (1998) in which sheep either repleted or depleted in sulphur were offered feeds with different concentrations of sulphur. Repleted sheep given high- and low-sulphur feeds initially ate at random but within 2 days reduced the proportion of the high-sulphur feed to achieve a sulphur concentration in the total diet very close to that thought to be optimal. Conversely, depleted sheep initially ate a high proportion of the high-sulphur feed but later reduced the sulphur concentration chosen until it stabilised at the optimum concentration.

In order to demonstrate that appetites were dependent on learned associations between the sensory properties of the foods and their nutritive value, it was necessary to separate the flavour of the food from its yield of nutrients. This could be done by offering animals a distinctive food and at the same time, giving a nutrient by a route that bypassed the mouth, usually intraruminal infusion. Forbes & Provenza (2000) concluded from experimental results that a single nutrient could induce a preference or an aversion to the flavour of it, if it was paired with it during training, depending on the rate of administration in relation to the animal’s requirements.

From the review on the subject by Forbes & Provenza (2000), they found evidence that a feed that the animal believed to alleviate a deficiency became preferred over other feeds, while one thought to be excessive in the same nutrient the animal became averse. Under natural conditions, such responses would lead to “nutritional wisdom”, i.e. eating a mixture of feeds which most closely meets the animal's nutrient requirements. The above raised the question about the time-scale of conditioning. Conditioned aversions to feeds were unusual in that it was not necessary for the conditioning and the unconditioned stimuli to be very close in time. The shorter the delay between feed ingestion and the post-ingestive feedback, the stronger the preference would be. This explained why non-structural carbohydrates that where rapidly digested in the rumen conditioned a strong feed preference. Sheep actively selected plant parts high in soluble carbohydrates, which led to the improved efficiency of microbial protein synthesis and increased organic matter intake. The stronger the aversion the longer it persisted. It was necessary, on the one hand, for conditioned taste aversions to persist (otherwise they had no function), but also to be flexible (otherwise an animal might be saddled with the unnecessary aversion for the rest of its life).

The animal must balance its intake or choice of feeds in order to trade off the intake of a toxin against the need to obtain nutrients, bearing in mind that the only difference between a toxin and a nutrient was the level in the diet. Many types of forage contain toxic phenolics, but these were sometimes in the available plant species with the highest yield of digestible nutrients and grazing animals traded nutrients off against toxins (Forbes & Provenza, 2000).

Hutchings *et al.* (1999) showed that, despite the advantages of grazing swards with increased nitrogen concentrations that were more digestible, faecal contamination of such swards had a major impact on the grazing decisions of animals. Animals not only avoided grazing the contaminated swards when paired with uncontaminated swards, despite any differences in sward nitrogen concentration, but they also altered their grazing microstructure when contaminated swards were grazed, with a reduction in grazing depth and bite rate. Faecal contamination therefore reduced the attractiveness of swards offering a nutritional advantage to a point where the sward was significantly avoided by most animals. It was only when animals were immune to parasites or had a high level of feeding motivation, that some of this swing in grazing behaviour was redressed. This suggested that, for grazing herbivores, the advantages of faecal and hence parasite avoidance greatly outweighed the advantages of increased nutrient intake in trade-off situations.

Zervas *et al.* (2001) found no clear evidence that lambs could regulate their intake of mineral lick blocks, because the lambs failed to exhibit a "mineral wisdom" related to their physiological needs and mineral status. Despite the fact that the two feeds, lucerne hay and concentrates, differed widely in mineral composition, the ingested quantities of Ca, P, Mg, and Na, via the feed, did not differ significantly among the groups of lambs. This was an interesting observation, if it was also taken into account that the diet selection pattern between hay and concentrates could not be explained and that the daily mineral intake from the ingested mineral lick blocks represented only a very small proportion of the total mineral intake of the animals. The differences among the groups in plasma and liver Cu and Zn concentrations represented the quantities ingested via the diet rather than the mineral lick blocks.

Diet selection was directed towards stabilising conditions in the rumen and the rest of the body, i.e. avoiding disease, metabolic imbalance and upset. Ruminant animals thus learned to associate the post-ingestive consequences of eating a feed with the sensory properties of that feed and that they used such conditioned preferences and aversions to direct their selection between feeds (Forbes & Provenza, 2000).

2.1.3. Afferent pathways for "metabolic discomfort"

There is a complex set of signals coming from many parts of the body, the strength of which was dependent on previous nutrition (i.e. feeding behaviour), both short- and long-term. Short-term excesses of nutrient intake result in over-stimulation of gut and liver receptors, and long-term excesses resulted in over-production of leptin, which generated a state of "metabolic discomfort", otherwise known as "satiety". Conversely, under-stimulation of liver and hindbrain receptors due to under-eating (relative to demands) generated a different type of metabolic discomfort, especially when coupled with low levels of leptin, usually known as "hunger". Forbes & Provenza (2000) viewed the range from extreme hunger to excessive satiety as a continuum. The animal directed its behaviour to achieving the most "comfortable" situation, in which comfort was not only induced by the appropriate supply on nutrients, but also by social pressures to eat or not to eat, and by learned associations.

The taste of feed was adjusted according to that feed's effect on the internal environment; on this basis, animals used thalamic and cortical mechanisms to select feeds that were nutritious and avoided those that were toxic (Provenza *et al.*, 1998).

2.1.4. Body weight

The anatomy of domestic ruminants in relation to the anatomy of ruminants in the wild and the ecological niches occupied by each was the key to understanding forage utilisation (Fisher, 2002). Van Soest (1994) classified animals according to their feeding strategy. The Damara dik-dik (*Madoqua kirkii*), at 0.4 m shoulder height and weighing 5kg, as an extreme concentrate selector (Skinner & Smithers, 1990) in contrast the Giraffe (*Giraffe camelopardalis*), standing up to 5 m high with an average weight of 900kg, also being a concentrate selector utilised different heights and types of forage. Both were predominantly browsers but grazed occasionally. The smaller Damara dik-dik has a higher basal metabolic rate and would therefore need to select a more concentrated diet.

At the other side of the spectrum was comparing animals that were similar in size but select different parts of the same grazing. The largest African antelope, the Eland (*Taurotragus oryx*), which was a highly selective mixed feeder (Hofmann, 1973), required a high protein diet and grazed in the wet season and browsed in the dry cool season (Skinner & Smithers, 1990) and cattle as bulk and roughage eaters that would follow a similar pattern (Mphinyane, 2001).

2.1.5. Changes in the animal

After weaning, the intake of DM usually increased in proportion to energy requirements for growth. As maturity approached and the amount of fat in the body increased, feed intake reached a plateau, although in many ruminants there was an annual cycle of intake and body fat content. These changes occurred slowly and there was plenty of time for animals to learn whether small increases or decreases in intake were necessary to conserve minimal discomfort (Forbes & Provenza, 2000).

2.1.6. Physiological state

Van Schalkwyk (1978) showed that the intakes of different types of animals (Afrikaner vs. Simmental) of physiologically similar animals were not significant, but the differences in intake between animals in different physiological stages were significant.

2.1.7. Cyclicity of feed intake

Feeding behaviour was, by its very nature, cyclical and examination of daily intakes of individual animals showed considerable day-to-day variation, sometimes by as much as twofold, too large to be due simply to any changes in the environment or the physical and chemical properties of the forage. An animal that ate exactly the same amount of feed each day had no opportunity to find out whether its overall comfort would be better served by eating a little more, or a little less, than on the previous day (Forbes & Provenza, 2000).

Changes in feed composition led to changes in feed intake. If the change was in the nutritional value then the animals may well have found that a higher or lower daily dry matter intake (DMI) gave it more comfort than simply continuing to eat the same daily weight as before the change. A particular situation in which it was necessary for animals to learn about feed was when the feed to which they had been accustomed, was suddenly changed to another with different sensory and nutritional properties. In most practical and experimental situations, sudden changes were avoided by a slow change of diet. With a sudden change of diet very little was eaten which suggested that the animals were not familiar with the new feed and were showing neophobia (a wariness of new feed in which only small amounts were consumed in order to assess whether there were unpleasant consequences to eating it). A combination of increasing hunger and the realisation that the new feed did not cause illness, encouraged increased acceptance of the feed and a steadily increasing intake (Forbes & Provenza, 2000).

2.1.8. Distension (Fill feedback)

The digestibility of the feed material selected by the grazing animal played a role in the regulation of the voluntary feed intake of the animal (Van Schalkwyk, 1978; Burns *et al.,* 1997). The four fore stomach compartments (rumen, reticulum, omasum and abomasum) all originate from the same embryological tissue. It is well known that intake was controlled by distension of the rumen (Figure 1) in forage diets due to the slow rate of passage by anatomical restrictions such as the reticulo-omasal orifice and the fluid dynamics of the stratified layers of solid and soluble fractions within the rumen.

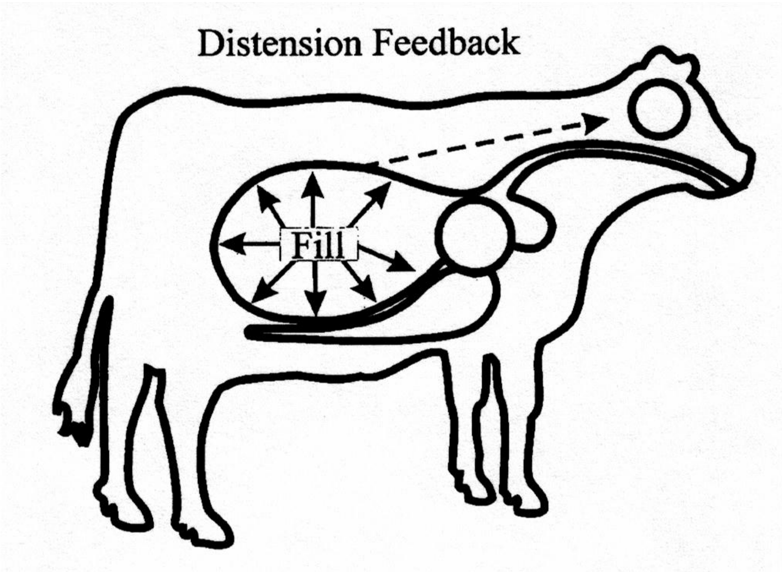


Figure 1 Ruminal fill leading to distension feedback (Fisher, 2002)

The rate of particulate breakdown, through rumination and fibre digesting microbes, was important in the alleviation of rumen fill. Figure 2 shows the relationship between the digestibility of forage and the mean retention time of particles in the rumen as observed by Burns *et al*. (1997).

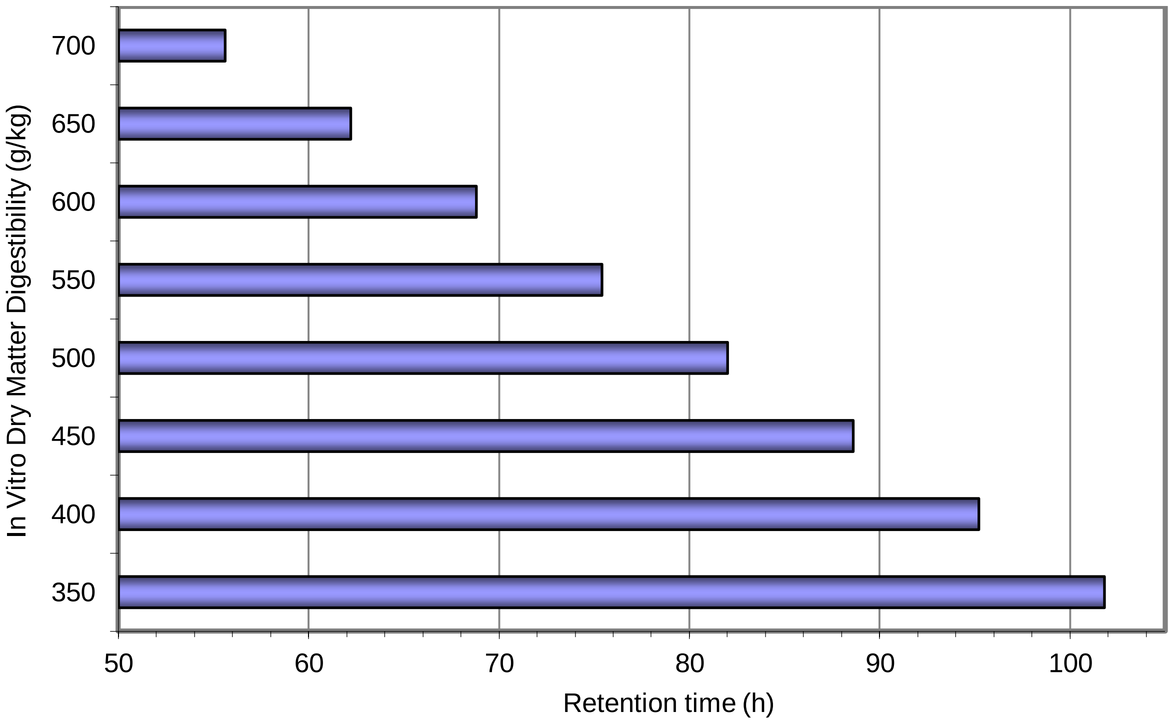


Figure 2 Digestibility in relation to mean retention time of particles in the digestive tract (Burns *et al.*, 1997)

The lower the digestibility of the forage the longer it remained in the rumen and then became limiting to additional intake of forage. For feed particles to leave the reticulo rumen the specific gravity had an upper limit of around 1.3-1.4 and upper size of particles was 2mm in length (Kennedy, 2005).

Neutral detergent fibre (NDF) and acid detergent fibre (ADF) are the most commonly used chemical components to partly account for the cell-wall content and therefore bulkiness of feeds. The NDF fraction best related to feed intake due to it representing the total insoluble fibre matrix (Van Soest, 1994). ADF gave an indication of the total fraction that had cellulose, lignin, silica and acid detergent insoluble nitrogen (ADIN).

2.1.9. Chemostatic control (Voluntary food intake)

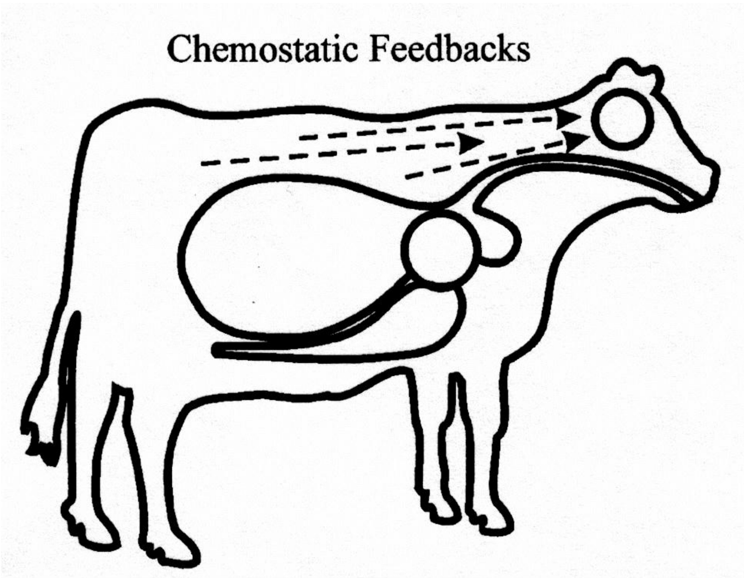


Figure 3 Chemostatic or metabolic feedback (Fisher, 2002)

Metabolic feedback by energy dense diets where total digestible nutrients (TDN) or digestible organic matter (DOM) was used to account for energy density of feeds is illustrated in Figure 3 (Fisher, 2002). Many other factors such as physiological state, body size, social pressures, environmental conditions (heat, cold, wind, mud and humidity), specific nutrients (amino acids, minerals and vitamins), toxins (tannins and glucosidases), disease, forage resource structure and previous experience combined in a multifactorial manner to control feed intake (Romney & Gill, 2000; Forbes, 2003).

2.1.10. Effect of crude protein on feed intake and performance

A dietary protein deficiency in high fibre forage diets decreased intake (Bortolussi *et al.*, 1996; NRC, 2000). Forage intake responses to protein supplementation were generally observed when the forage crude protein (CP) concentration was less than 6 to 8 percent (NRC, 1987).

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 4 that was an adaption from the data of Moore *et al.* (1999).

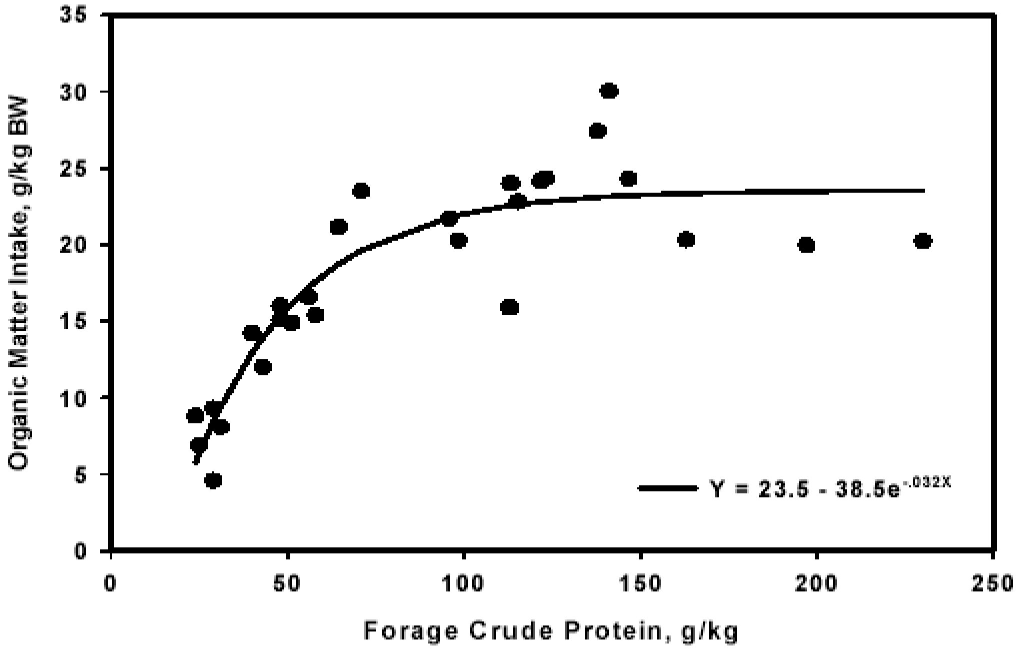


Figure 4 Response of intake to increasing concentrations of crude protein in forages fed alone (Coleman, 2005)

This relationship was also evident when the ratio of digestible organic matter (DOM) to CP exceeded 10-12 (Moore *et al.*, 1999). Under those circumstances ruminal microbes were likely nitrogen limited relative to the energy available and forage intake increased with supplemental nitrogen.

2.1.11. Effect of phosphorus on feed intake and performance

A reduction in voluntary feed intake took place when grazing ruminants were subjected to a primary phosphorus (P) deficiency (McCosker & Winks, 1994; Bortolussi *et al.*, 1996; Ternouth, 2001). The reduction in feed intake due to a P deficiency is poorly understood.

P is a constituent of the crystalline hydroxyapatite in bone and teeth. The bone structures are important storage areas from which phosphorus is sequestered in times of P deficiency. P is essential in energy metabolism, pH and osmolality maintenance and many enzymatic and metabolic reactions.

The reduction of feed intake can, in addition to mentioned functions in the ruminant animal, also be linked to the essential requirement for P by ruminal microbes (Ternouth, 2001) for growth and cellular metabolism (NRC, 2000).

Bortolussi *et al.* (1996) found that a decrease in intake was not due to reduced digestibility of the diet since the dry matter (DM) and NDF digestibility were unaffected by a P deficiency. This observation tended to support the results of Milton & Ternouth (1985), which indicated that the depression of feed intake was 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 (Bortolussi *et al.,* 1996) which could potentially be indicative of a disturbance of protein metabolism pathways in the rumen.

Van Niekerk & Jacobs (1985) showed that P was not the first limiting nutrient when sugarcane tops (P 0.81g/kg DM) were fed to steers and postulate that when only P was supplemented during the dry season it further decreased live mass gain. McCosker & Winks (1994) recommended that phosphorus supplementation should not be undertaken in growing cattle that were losing weight. McCosker & Winks (1994) showed that protein and energy intake was more limiting than P in Australia and that the supplementation of P under a primary N and energy shortage further depressed performance. De Brouwer *et al.* (2000) found the opposite and recommended that when veld, growing under both wet and dry season, was deficient in P the supplementation of P was a recommended practice in South Africa.

2.1.12. Negative associative effects

Goetsch *et al.* (1991) found with Bermuda grass hays (not as low in protein and as highly lignified as tropical grasses) that very little variation in feed intake and digestion was explained by concentrations of NDF, ADF, cellulose, hemicellulose and ADL. Goetsch *et al.* (1991) fed Holstein steer calves (101 to 350kg BW) with *ad libitum* Bermuda grass hay (warm season/temperate grass with average CP 12.4%, NDF 74.5%, ADF 33.9% & ADL 5.4%) without or with supplemental ground maize up to 1.0% of BW. In Equation 2 it is shown that for each kg of maize DM consumed it decreased Bermuda grass DMI by 0.46kg representing a negative associative effect of energy on forage intake.

Equation 2 $\mathbf{DMI = -2.459 + 0.5448\ (BW) - 0.000073\ (BW^2) + .540\ (maize\ DMI)}$

Goetsch *et al.* (1991) concluded that other factors than gut fill had a considerable influence on intake and digestion. In Figure 5 the BW shows a significant influence on intake. As BW increased, total DMI increased quadratically (R^2 = .83).

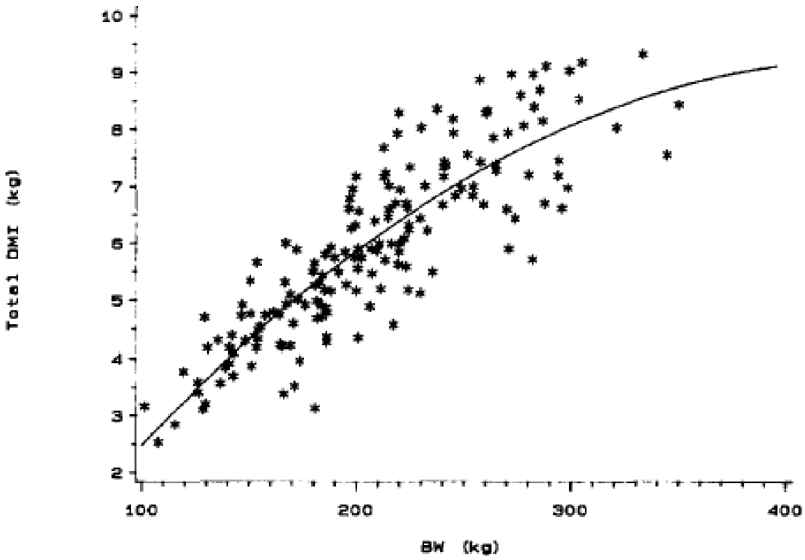


Figure 5 Regression of total dry matter intake (DMI) on body weight (BW) and BW^2 of Holstein steers consuming Bermuda grass hay *ad libitum* with or without supplemental maize (Goetsch *et al.*, 1991)

2.1.13. Structure and distribution of feed

Drescher (2003) explained that natural grasslands were mosaics of patches that differed in availability and quality of forage. The variation was brought about by the differences in nutritional quality between high quality leaves and low quality stems. In natural grasslands theses patches were unevenly distributed consisting of high and low quality forage parts that were intimately mixed. The intimate mixing of leaves and stems decreased the accessibility of the high quality leaves. Foragers were confronted with a trade-off between forage intake and diet quality.

With grazing cattle the quantity of forage available would affect intake (NRC, 2000). When the forage mass available was above 2000kg DM/ha, and the forage was desirable and young, the intake was not limited and maximum quantities of forage were consumed with each bite (Minson, 1990). When the forage mass was reduced to below 2000kg DM/ha there was a reduction in bite size (Minson, 1990) and the intake decreased rapidly to 60% of maximum at 450kg DM/ha (NRC, 1987).

In Figure 6 the structure of the foraging resource could be influenced by foraging as suggested by Drescher (2003). On a short temporal scale foraging caused a local decrease of forage availability and selective foraging could result in a decrease in the proportion of high quality forage parts.

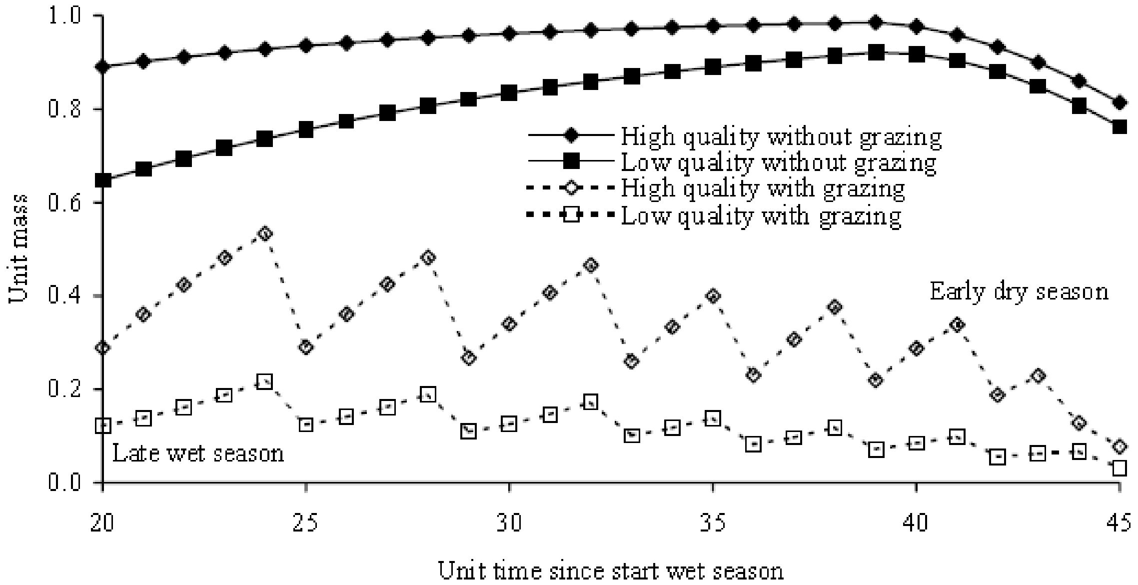


Figure 6 The growth of forage of high quality and of low quality during the late wet and early dry season (Drescher, 2003)

However on a longer temporal scale the foraging could lead to the temporal arresting of a forage resource patch in a state of intermediate forage availability and quality, enabling an optimal compromise between forage intake and diet quality and resulting in the maximisation of long term nutrient intake (Drescher, 2003). Apart from the spatial variation in the forage resources there were also seasonal fluctuations in temperature and rainfall that caused a temporal variation in forage availability and quality.

2.1.14. Empirical feed intake prediction equations

Feed intake varies greatly with environmental conditions, management factors, cattle maturity and dietary factors (NRC, 2000). Any equation should be viewed as providing a guideline to predicting intake and not an absolute prediction of intake. The intake of available forage energy was an important factor affecting animal performance. When forages constituted all or most of the diet in production situations, special considerations were needed for the practical application of nutrient requirement data (NRC, 2000). Pittroff & Kothmann (2001a) found it particularly noteworthy that the two most widely used standard systems for calculating nutrient requirements for cattle, NRC and ARC; seemed not to be adequate for application in grazing situations.

An empirical prediction equation for different animal species and forage types was developed by Meissner & Paulsmeier (1995). The intake of non-lactating ruminant species (sheep, goat, cattle and wildlife) fed on grasses, legumes, hays, silages, shrubs and supplemented forages could be predicted with the same relationship from the ratio between *in vitro* digestibility of organic matter (IVDOM) and NDF as given in Equation 3.

Equation 3 OM intake g/kg / $BW^{0.9}$/day = $70\text{-}97^{-0.975\,(IVDOM\,/\,NDF)}$

Two aspects featured prominently in the equation. The first feature was that the body mass of the animal was raised to the power 0.9 instead of the usual 1.0 (appropriate if intake was primarily controlled by physical constraints within the digestive tract) or 0.75 (appropriate when intake was controlled by absorbed nutrients or energy balance). Intake of most forage's would be controlled by a combination of physical limiting factors and chemical constituents sensed in the blood or at tissue level. The second feature was that the equation conformed to the law of diminishing returns, where intake was severely limited at low ratios of IVDOM to NDF (low digestibility) and less so at medium ratios and even negligible at high levels.

The NRC (2000) concluded that further research was needed to develop more accurate means of predicting intake by beef cattle fed all-forage diets. Equation 4 was developed by 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 typically is 96% of full body weight (NRC, 2000).

Equation 4 NRC DMI (kg) / $SBW^{0.75}$ = 0.002774 x CP%(forage) - 0.000864 x ADF%(forage) + 0.09826

The NRC (2000) warned that conclusions relative to the merit of various equations had to be based on independent validation tests. The validation data sets used for Equation 4, by the NRC (2000), resulted in an under prediction bias of 9.71% for grazing steers and heifers and 10.83% for cows.

Weston & Poppi (1987) postulated that few meaningful comparisons could be made of the herbage dry matter intake between different herbivore genotypes apart from those of sheep and cattle. Thus there was no precise scalar available with respect to body size. Conventional estimates of maintenance energy requirements for animals housed indoors were 25-50% lower than what was observed in foraging ruminants (Osuji, 1974). The increased basal metabolic rate of foraging ruminants was due to the energy cost of eating, walking to graze and the work of digestion done by the gut in handling bulky pasture material (Osuji, 1974).

The research by Blaxter *et al.* (1966), Frisch & Vercoe (1984) and Stanley Price (1985a &1985b) showed that intakes of different breed genotypes of cattle and sheep were more closely related to basal metabolic rate than to metabolic body weight ($BW^{0.75}$). But what was generally found was that cattle and sheep had comparable basal metabolic rates and intakes per unit of $BW^{0.9}$ (Weston & Poppi, 1987).

2.1.15. Conclusion

It is not at all clear how the principles of metabolic control over intake are actually expressed by the animal, in terms of meal size and frequency, and daily intake; although it is clear that the cessation of eating a single meal is not controlled by post-absorptive signals (Illius *et al.,* 2000). Throughout the animal kingdom, the satiation process appears to be under tight, pre-absorptive sensory control. Most animals eat discrete meals, which end before absorption of all the ingested nutrients can take place, suggesting that the origin of satiety signals is the gastrointestinal tract. Meals are terminated in expectation of the post-absorptive consequences rather than being solely the result of them, and thus satiety is a state partly specified by the stimulus conditions. For example, the sense of taste plays a role in the termination of feeding (Illius *et al.,* 2000).

The complexity of these responses emphasizes why voluntary intake is so difficult to predict from first principles: it is, ultimately, a psychological phenomenon. It involves the neural integration of many signals and is subject to not only the interplay of positive and negative physical and metabolic signals, but is also a psychological phenomenon such as perceptual constraints and learning. The elucidation of how the integration of signals is affected by the animal's physiological and mental state remains an important challenge (Illius *et al.,* 2000).

2.2. OESOPHAGEAL FISTULA TECHNIQUE

2.2.1. Introduction

Selective grazing often resulted in a diet being different from the pasture on offer. Consequently, the major limitation in accurately estimating dietary chemical composition of grazing animals was obtaining samples that truly represent the diet. The difficulty increased as species diversity, spatial heterogeneity and paddock size increased (Coates & Penning, 2000).

The inability of hand-cut samples to represent the diet selected by grazing ruminants was well documented in Uganda (Bredon *et al.*, 1967), Mexico (Kiesling, *et al.*, 1969), South Africa (Bredon *et al.*, 1970; Engels, 1983; De Waal, 1990), Botswana (Pratchett *et al.*, 1977) and Namibia (Van Schalkwyk, 1978).

Two basic approaches were available for obtaining representative samples of the diet selected by range ruminants. The first approach involved the manual collection of forage by the experimenter by following and observing what the animals grazed and then attempted to mimic their selection manually. The method was rapid, inexpensive and simple. The hand-plucking method was subject to a mostly unknown bias, as the simulation of the grazing animal was likely to be imperfect (Langlands, 1974; Wallis de Vries, 1995). The method appeared successful if an elaborated stratified sampling approach was used (Wallis de Vries, 1995).

The second approach used surgically altered (rumen or oesophageal fistula) animals. Rumen evacuation through a ruminal cannula provided satisfactory results and direct comparisons with oesophageal fistulated cattle (OF) results could be made (Olson, 1991). The disadvantage of the rumen fistula above the OF was 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).

2.2.2. 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). The OF technique for the collection of feed and fluid samples from domestic animals had been used from as early as 1855 with horses, and for ruminants as early as 1939 with cattle (Van Dyne & Torrel, 1964). Many modifications and alterations to the equipment used for collections had been proposed (Bredon & Short, 1971; Osbourn & Bredon, 1971; Denney, 1981; Kartchner & Adams, 1983; Center & Jones, 1984; Olson & Malechek, 1987; Raats *et al.*, 1996; Robertson & Van den Heuvel 1997).

Primary problems associated with OF sampling were surgery, salivary contamination, rumen content contamination, incomplete collections and obtaining a representative sample in a large pasture (Holechek *et al.*, 1982). Another disadvantage was the cost in labour and time in properly caring for the animals (Coates & Penning, 2000).

2.2.3. Saliva contamination

Marshall *et al.* (1967) and Mckay *et al.* (1969) studied the effect of saliva on extrusa (i.e. sample of forage collected from OF) and found the impact to be minimal, but Holechek *et al.* (1982) warned that fistula samples should not be used for phosphorus analysis because salivary contamination increased the phosphorus content. Researchers that used extrusa mineral concentrations in forage samples to obtain estimates on the nutritional value of forages included Kalmbacher *et al.* (1984), Grant (1989), Pinchak *et al.* (1989), Coates & Ternouth (1992) and Hendrickson *et al.* (1994).

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 deleterious effects on results and discouraged the practice. Hart *et al.* (1983) noted that rinsed samples were consistently lower in crude protein and IVDOM and usually higher in fibre components.

Although urea was recirculated in saliva, the nitrogen concentration of extrusa provided a reliable estimate of the nitrogen concentration of herbage consumed (Langlands, 1966; Mckay *et al.*, 1969; Little, 1972; Pinchak *et al.*, 1990). 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). Engels *et al.* (1981) found that squeezing the extrusa through 4 layers of cheese cloth and discarding the liquid fraction together with oven drying or freeze drying of extrusa samples collected from cattle, did not significantly affect the protein concentration recorded.

Similarly the sulphur, copper, molybdenum (Little, 1975), calcium, magnesium and zinc concentrations in extrusa could be used to predict the dietary concentrations (Pinchak *et al.*, 1990). Pinchak *et al.* (1990) conversely found that the Na, P, K, and Cu dietary concentrations could not be determined from extrusa samples. Mayland & Lesperance (1977) found that the errors were greatest for animals consuming a wide range of forages with different mineral concentrations. The prediction error from extrusa could be less than 10% with homogenous forage samples.

Although the extrusa phosphorus concentrations were elevated due to salivary contamination (Little, 1975; Pinchak *et al.*, 1990), it still represented the most readily accepted method of sampling pasture forage phosphorus for chemical analysis (Karn, 1995). Karn (1997) demonstrated that the P status of cows appeared to be estimated more reliably by forage phosphorus than by serum or faecal phosphorus. De Brouwer *et al.* (2000) obtained forage extrusa samples showing phosphorus deficiency during the dry cold months for beef cow production and the deficiency was subsequently verified by bone density and production results.

2.2.4. 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). Except for ether extract, six or fewer animals were sufficient to sample all dietary chemical constituents within 10% of the mean with 95% confidence (Van Dyne & Heady, 1965; Torell *et al.*, 1967).

Van Schalkwyk (1978) subsequently found in Namibia that 3 animals would be sufficient to sample natural pastures for the determination of CP, IVDOM and ADF.

2.2.5. Drying

Rapid and efficient drying of forage materials without chemical change or dry matter loss was a fundamental concern (Karn, 1991). Burritt *et al.* (1988) found that the method of drying could lead to erroneous conclusions about forage quality and that the nutritive value of forages harvested by OF that had not been freeze-dried had to be interpreted with great care. When accurate fibre concentrations in extrusa were to be determined, it should be done by freeze-drying but where N (Engels *et al*., 1981) and ash (Karn, 1991) were to be determined the drying by microwave (Karn, 1991) or conventional oven was acceptable.

Engels *et al.* (1981) found a significant depression in IVDOM (Two stage technique by Tilley Terry, 1963; as modified by Engels & Van der Merwe, 1967) values obtained in total extrusa collected from sheep and cattle that were either dried in a forced draught oven at 50°C or where freeze-dried. No significant differences were observed when the saliva was removed, by squeezing it through 4 layers of cheese cloth, from the samples and the solid fraction of samples obtained by OF which were dried at 50°C or freeze dried.

Karn (1986 & 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, 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 were typically saturated with saliva, which resulted in increased moisture and pH, which increased the nonenzymatic browning reaction. Burritt *et al.* (1988) named the resulting substance artefact lignin.

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. The results were obtained from the extrusa collected from sheep and goats browsing forage at different stages of maturity. Faber *et al.* (1995) suggested that freeze-drying was the preferable drying method due to significant IVDOM, ADF, NDF and ADIN alterations found in browse samples for drying temperatures above 35 ºC.

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.

2.2.6. Reporting of results (Organic matter basis)

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 and shown in Table 1 (Wallace *et al.*, 1972).

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

Table 1 Example of an organic matter basis calculation (Wallace *et al.*, 1972)

	Dry matter basis	Organic matter basis
Ash (%)	11	-
Organic matter (%)	89	100
Protein (%)	8.4	9.4

2.3. FORAGE QUALITY AND INTAKE IN SOUTHERN AFRICA

2.3.1. Animal performance related to forage quality

Variation in DM yield of veld, primarily due to variation in rainfall, occurred in different years at any site in Southern Africa and was confirmed by animal performance results (De Waal, 1994; Kruger, 1998). The relationship between annual rainfall and the DM yield of veld was not very strong and the distribution of rainfall during the growing season was probably one of the more important factors in determining DM yield of veld (De Waal, 1994).

In addition to the natural occurrence of drought, injudicious grazing practices and especially high stocking rates ultimately caused veld deterioration. These increased the frequency and intensity of droughts and created man-made droughts. Kruger (1998) observed that animal performance was affected much sooner than veld condition when applying heavy stocking rates. Kruger (1998) recommended that the determination of available forage at the end of the rainy season and the subsequent adjustment of the stocking rate was much more important than trying to define an optimum long-term stocking rate.

The seasonal change in the quality of forage in Southern Africa during a given year had a marked effect on animal performance (Freyer, 1967; Van Schalkwyk, 1978; Gressmann, 1979; Groenewald, 1986).

The CP concentrations of forage obtained from oesophageally fistulated cattle (OF) were directly dependent on rainfall distribution (McKay & Frandsen, 1969; Karn & Lorenz, 1983; De Waal, 1990). Maximum rainfall coincided with the flowering stage of most grasses and was followed by the seed-set and subsequent translocation of nutrients in the plant to the roots, resulting in the low nutritional quality of aerial parts of the grass being left during the dry season (Louw, 1979). Nutritional value of forage decreased after the month of maximum rainfall (Cronjé, 1990) but with erratic rainfall patterns the decrease in nutritional value tended to generally occur as the season progressed from wet season to the end of the dry season (De Brouwer *et al.*, 2000).

The timing of the CP concentration of the forage at its highest did not fully explain why production parameters were not always also recorded at their highest during this time and seemed to lag behind. De Waal (1990) found that a low point in monthly dry matter production was observed during December/January in most years when 80% of the annual rainfall was recorded between October and April. The low and varying DM yields of veld early in the growing season were often insufficient to maintain animal production and required DM reserves, carried over from the previous growing season (De Waal, 1990).

2.3.2. Seasonal trends in plant selection by cattle

McKay & Frandsen (1969) found that the CP content of grasses was consistently higher under overgrazed conditions and high CP concentrations were found in the leaves and pods of browse plants. Browsing was much commoner in overgrazed areas and dietary CP was significantly higher in these areas and mainly during the driest season.

A great deal of browsing was observed by Zimmerman (1980) during October (One species represented roughly 20% of intake) while the browse contributed less than 1% during the remainder of the year (Zimmerman, 1980). A stronger tendency for browsing was found by Mphinyane (2001) in Botswana where the plant species observed in dung of cattle was extrapolated to the diet containing 16% browse in the wet season, 24% in the dry cool season and the browse component increased to 38% in the dry warm season at the expense of the decreasingly available grass component.

Rothauge (2006) monitored the dietary abundance of plants in the diets of cows in Namibia (bite-count technique) and found a significant increase in the utilisation of browse species at the expense of grasses as the season progressed from wet season to the dry hot season. Cattle were forced to make increasing use of browsed forage during the dry season when grasses were dormant and did not regrow after defoliation. Yates *et al.* (1982) found that as the availability of forage declined the ability of OF to selectively graze was reduced. This was confirmed by low weight gains of steer calves stocked on the area by continues grazing.

The selection of different plant parts by OF, in a predominant grass sward, is shown in Figure 7 in the temperate areas of South Africa (Natal sour sandveld) as the seasons progressed (O'Reagain & Mentis, 1988). The progression of animals diets from a peak in dietary quality early in the season (November in Spring, with a CP (DM) content of around 100g/kg), to the late part of the season (May in Winter, where the CP (DM) declines to 50g/kg), was associated with a decrease in leaf intake and a concomitant increase in dead and stem material of the grass on offer.

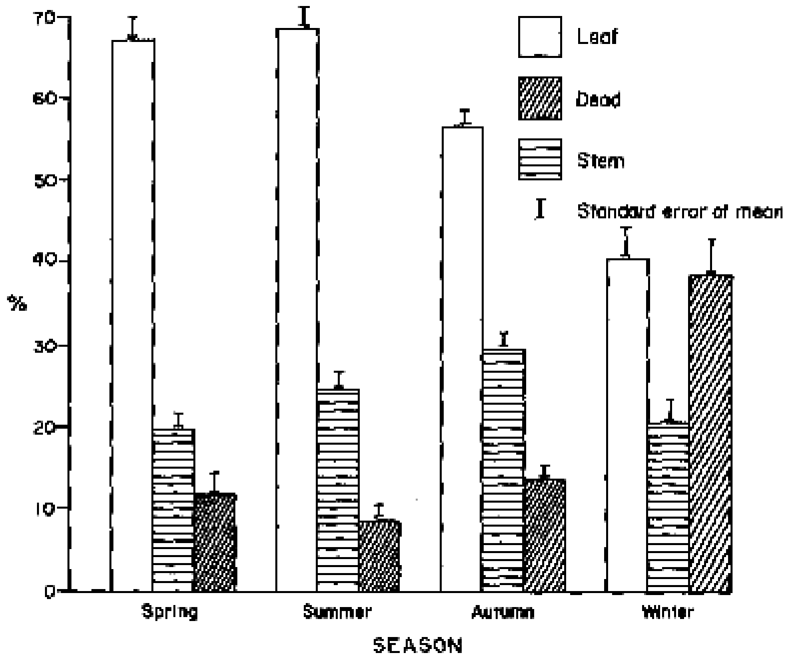


Figure 7 Percentage composition of oesophageal fistula cattle diets over four seasons on the Natal sour sandveld (O'Reagain & Mentis, 1988)

During the seasonal progression, the sward became increasingly stemmy with increased leaf dispersion and a decline in leaf accessibility. Cattle were therefore forced to consume increasing amounts of dead material and stem. To maintain intake levels, due to their wide and deep bite depth with fairly upright incisors, they were limited to relatively unselective cropping of grass tufts. This inability for fine level selection led to a decline in dietary quality (O'Reagain & Mentis, 1988).

A strong relationship existed between the physical structure of grass and the acceptability to cattle. The preferred grass species were generally non-stemmy with high leaf accessibility, high leaf CP content and intermediate leaf tensile strength. Conversely cattle avoided grass species that were generally stemmy with low leaf accessibility, low CP content and had leaves of high tensile strength (O'Reagain & Mentis, 1989).

2.3.3. Oesophageally fistulated cattle (OF) results in Namibia and Botswana

Two studies were reviewed that where conducted under similar climatic conditions with OF. The first study was located in Namibia (Van Schalkwyk, 1978) at Omatjenne experimental station which was located 120km from the current experimental site on the commercial farm Burgkeller. The second was in the Eastern neighbouring country Botswana (Pratchett *et al.*, 1977).

Figure 8 shows the rainfall trends during the collection periods. In Namibia the total rainfall recorded was 521mm and the month of maximal rainfall occurred in January with 78% of total rainfall being recorded during January to March and 93% during December to April.

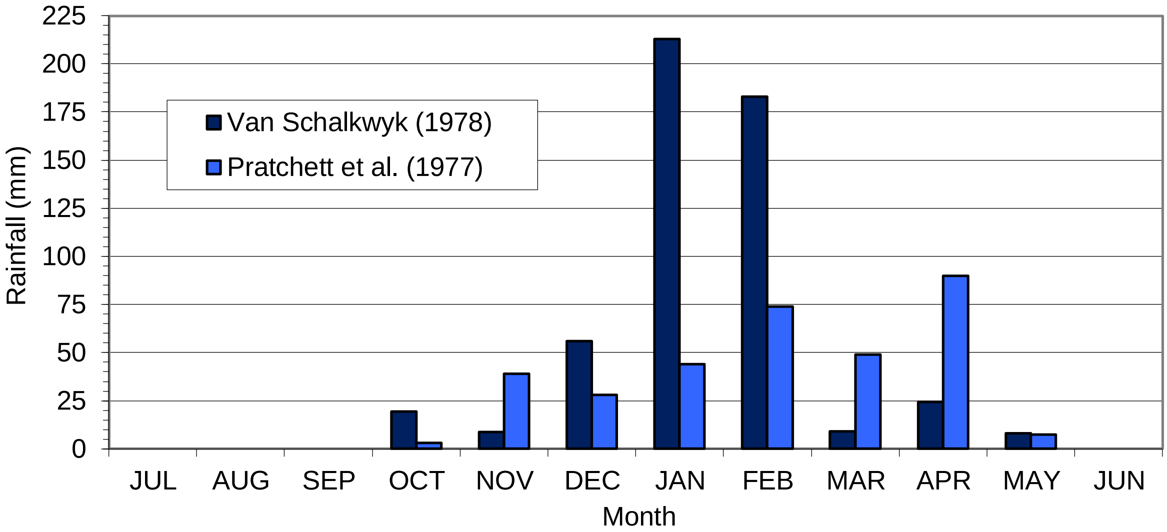


Figure 8 Monthly rainfall during oesophageally fistulated cattle sample collections in Southern Africa

The total rainfall recorded in Botswana was 334mm and the month of maximal rainfall was April with 50% of total rainfall being recorded during January to March and 85% being recorded from December to April.

The CP concentrations are shown in Figure 9. The CP concentrations were low compared with those of temperate regions. Botswana (Pratchett *et al.*, 1977) had a mean CP concentration for the year of 85g/kg rising from a mean of 57g/kg in the dry season to a mean of 94g/kg in the wet season.

The results for forage CP (DM) from Namibia (Van Schalkwyk, 1978) were similar to those of Botswana (Pratchett *et al.*, 1977) in Figure 9. The mean CP concentration for the year was 82g/kg rising from a mean of 62g/kg in the dry season to a mean of 103g/kg in the wet season. The CP (OM) results showed that a higher ash component was present during the wet season compared to the dry season.

Protein was identified as a major limiting nutrient on animal production during the dry season when adequate phosphorus and salt supplementation occurred (Van Schalkwyk, 1978). Young growing heifers (18 months old) and pregnant heifers (30 months) could maintain body weight during the winter months, but lactating cows had large weight losses.

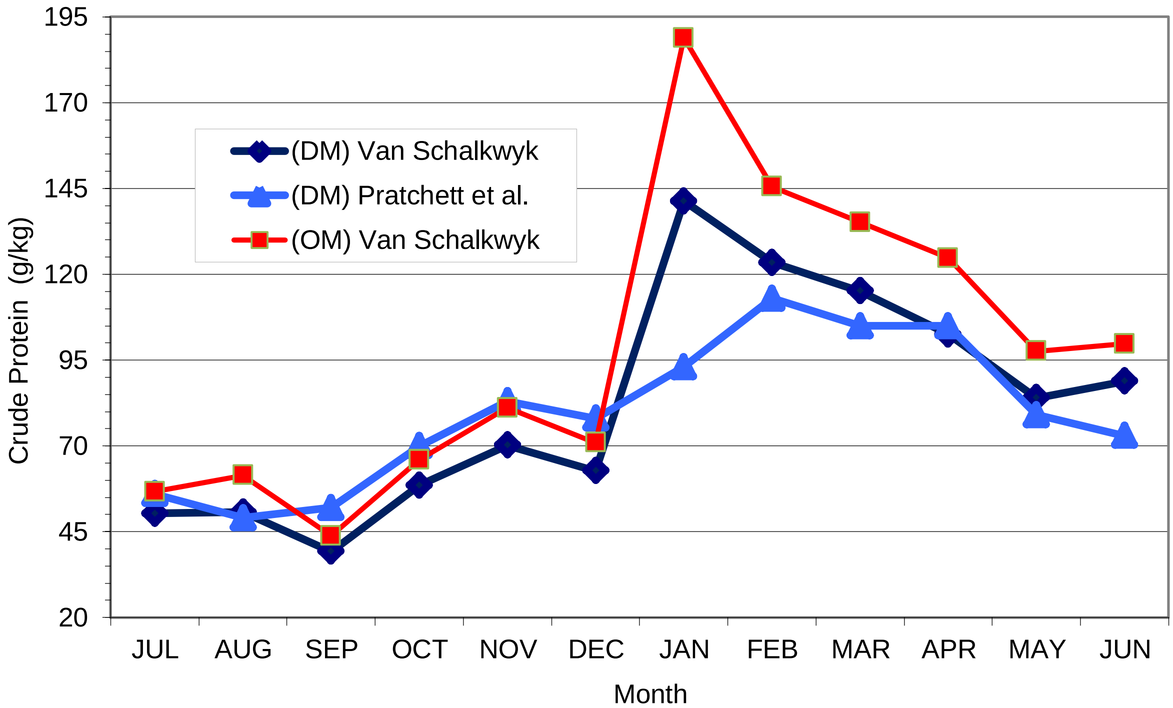


Figure 9 Crude protein (g/kg) in extrusa samples from Namibia (Van Schalkwyk, 1978) on a dry matter (DM) and organic matter basis (OM) and Botswana (Pratchett *et al.*, 1977) on a dry matter basis (DM)

The IVDOM values shown in Figure 10 established the same trend for both data sets with the highest concentrations recorded during the wet season (January to April) and decreased during the following dry cool season. The lowest point was recorded during the dry hot season (August to November) just before the wet season again commenced. The range of values (DM) recorded by Van Schalkwyk (1978) was higher from 419g/kg to 515g/kg than Pratchett *et al.* (1977) from 345g/kg to 470g/kg.

The *in vivo* digestibility of veld samples collected by hand in an adjacent camp to the OF, obtained by Van Schalkwyk (1978), is illustrated in Figure 10. The concentrations showed the same seasonal tendency, but at a higher range starting at 473g/kg during September to 737g/kg during February.

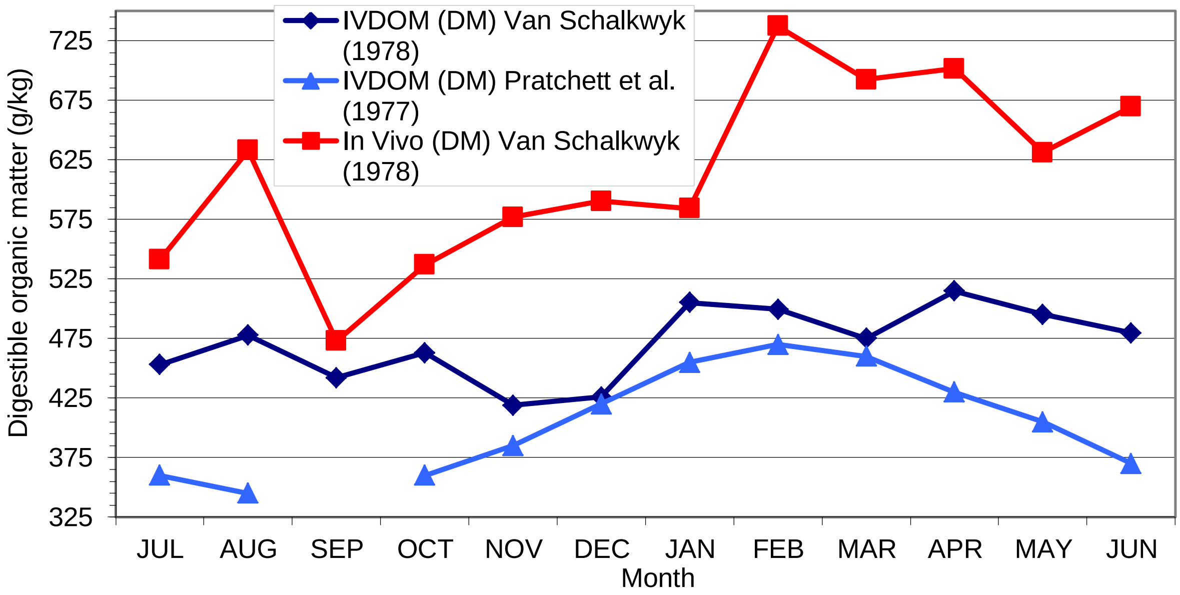


Figure 10 *In vitro* and *in vivo* digestible organic matter (g/kg) of extrusa samples in Namibia (Van Schalkwyk, 1978) on a dry matter basis (DM) and in Botswana (Pratchett *et al.*, 1977) on a dry matter basis (DM)

The ADF recorded in the extrusa collected and freeze dried in Namibia shown in Figure 11 had a strong negative correlation (r = 0.85) with the IVDOM shown in Figure 10 and also a negative correlation with the CP concentration shown in Figure 9. The ADF concentrations showed a distinctive pattern of low values (ranging from 319 to 347g/kg) being recorded during the wet season (February to June) and higher concentrations (397 to 469g/kg) during the dry season (July to January). The highest ADF was recorded during September.

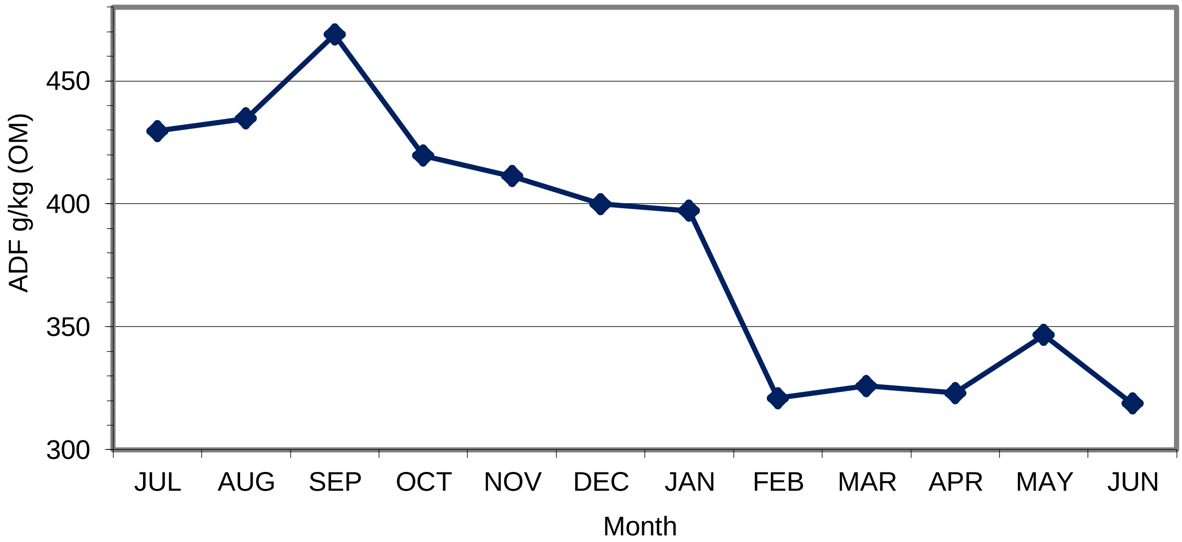


Figure 11 Acid detergent fibre (g/kg) in pasture fistula samples in Namibia (Van Schalkwyk, 1979) on an organic matter basis (OM)

2.3.4. Oesophageally fistulated cattle (OF) results in South Africa

The nutrient content of forage sampled by OF in South Africa showed similar seasonal tendencies in nutrient content and animal performance (Zimmerman, 1980; Engels, 1983; De Waal, 1990; De Brouwer, 1993) as Namibia and Botswana.

The range for CP found by Van Schalkwyk (1978) in Namibia corresponded well to the results by Zimmerman (1980) in the Transvaal where the CP concentration was 54g/kg at the end of the dry season and it increased to 127g/kg at the beginning of the wet season.

The peaks in the CP concentration recorded in Namibia in January (123g/kg) and in Botswana in February (113g/kg) were three to four months later than recorded by Zimmerman (1980) in October (127g/kg). The month of maximal CP concentration in extrusa was recorded by De Brouwer (1993) in December 1985 (140g/kg CP), November 1986 (125g/kg CP), March 1987 (120g/kg CP) and January 1988 (120g/kg CP). The rainfall distributions during the trials were erratic and illustrated the effect of rainfall on the month of maximal CP in forage. The month of maximal CP in forage selected by cattle was December (95g/kg) by De Waal (1990). Engels (1983) found the crude protein on an organic matter basis to be maximal during January 1977 (160g/kg CP), December 1978 (180g/kg CP) and March 1979 (135g/kg CP). These results collectively showed that the month of maximal CP would be recorded during the wet season.

2.3.5. Intake predictions and forage quality parameters in Namibia

Van Schalkwyk (1978) published intake guidelines (Table 2 and Table 3) derived by the chromic oxide marker method for growing cattle, in the same climate as the present study in Namibia, together with forage quality parameters determined by OF. The experimental site was Omatjenne Agriculture Research station, 20km north-west of Otjiwarongo, situated 1381 m above sea level at South latitude 20° 24' and East longitude 16°29' (120km from the current research site).

Average intakes for two different cattle breeds (Afrikaner and Simmental) with three different physiological stages with 4 replications each were used under free grazing management (24 animals per breed). No significant differences ($P<0.05$) in intakes were found between breeds of the same physiological state although significant differences were found between different physiological states. All cattle had *ad libitum* access to a phosphorus and salt nutrient supplement.

The chromic oxide marker was dosed two times a day at the same time as faecal grab samples were taken for chromic oxide recovery. The first sampling time was at 10H00 in the morning and the second at 18H00 in the evening, which caused the least disruption to the natural foraging behaviour of the cattle. The morning chromic oxide recovery resulted in a greater than 100% recovery and the evening collection a lower than 100% recovery. The use of the average values of the two collections, separated by at least 8 hours, gave a chromic oxide recovery of 100.86%.

Monthly digestibility trials were undertaken with 6 oxen (3 Afrikaner and 3 Simmental) starting at the age of 15months and ending at 27 months at the end of the trial. Forage collected by hand was used in the stall-fed digestibility trials to develop a regression line that explained the relationship between *in vitro* and *in vivo* digestibility of the material fed. Forage collected by the 6 OF oxen each month was used for *in vitro* digestibility determinations. The *in vivo* digestibility of OF collected material was then estimated from the developed regressions. No significant differences were found between the digestibility's of forage collected by different breeds during the same months of the year.

Table 2 Rainfall and forage CP (DM) concentrations collected by oesophageally fistulated cattle on a quarterly basis 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, under free grazing management, without a phosphorus deficiency (Van Schalkwyk, 1978)

Period	Rainfall (mm)	CP (DM)	Afrikaner	Simmental	Average
Apr, May, Jun 1977	33	9.2	33.6	31.5	32.6
Jul, Aug, Sep 1977	0	4.7	25.8	26.2	26.0
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

The rainfall from January 1976 to March 1976, which preceded the experimental period April 1977 to June 1977, recorded a total rainfall of 367mm. The change from dry to wet season occurred in December 1977 with a total rainfall of 56mm recorded. The long-term average rainfall was 400mm for the area.

Every month OF samples were collected over three consecutive days. Three Afrikaner and three Simmental oxen were used. The subsamples were squeezed to remove excess saliva and pooled per animal. The samples were then freeze dried.

The average dry matter intake for growing cattle in Table 2 ranged between 26.0 and 32.6g/kg liveweight. These were generally higher levels than found by Coleman (2005) in Figure 4 with a range of 5 to 30g/kg liveweight with only two points above 25g/kg.

In Table 3 the intake of heifers in gestation on to first lactation were from 21.4 to 46.9g/kg liveweight. The intakes of cows in their second lactation were from 29.0g/kg during the dry period up to 43.1g/kg during the start of the third lactation. The ranges of intakes from 21.4 to 46.9g/kg liveweight were higher than found by Coleman (2005) in Figure 4.

Table 3 Average daily dry matter intake in g/kg liveweight on combined data from Afrikaner and Simmental cows determined by 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	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	.	.	29.0
Jan, Feb, Mar 1978	.	46.9	43.1	.

2.3.6. Intake prediction based on seasonal forage quality in Namibia

NRC (2000) suggested that intake prediction equations optimally would have to be developed for the specific beef cattle production situation it was intended to be used in. No single general intake prediction equation would apply to all situations. Such an equation would have to account for a greater percentage of variation in intake than would be possible with a generalised equation (NRC, 2000).

In this section the intake prediction equation developed by the NRC (2000) (Equation 4) was rendered into two new intake prediction equations (Equation 6 & Equation 7) that could be used to more accurately estimate intake in Namibia from forage quality parameters collected by OF during the dry and wet seasons. The intake prediction equations alluded to in this section were validated by the data, forage quality parameters (collected by OF) and estimated actual intakes (determined by the chromic oxide marker method), generated by Van Schalkwyk (1978).

The principles established on the differential scalars used for body weight, in the allometric equations in Equation 3 (Meissner & Paulsmeier, 1995) with $BW^{0.9}$ and Equation 4 (NRC, 2000) as $SBW^{0.75}$, suggested that the variable was specific to the environment and type of animals used. The regulation of intake was controlled by a combination of fill feedback (physical size and digestibility of feed) and chemostatic factors (Fisher, 2002) that could be adjusted for by the bodyweight scalar and should ideally be between $SBW^{0.9}$ and $SBW^{0.75}$.

Protein was an important forage component, influencing intake, if no primary phosphorus shortage was prevalent. Equation 4 would be best suited for determining intake in Namibian forage due to both the CP and ADF concentrations could easily be determined by OF. The extrusa samples would however need to be freeze-dried (Engels *et al.*, 1981; Karn, 1986; Burritt *et al.*, 1988) to ensure that oven drying did not affect the ADF concentrations as indicated in Chapter 2.2.5. The intake prediction equations developed in this section were eventually not used to estimate daily dry matter intake during this trial due to oven drying of extrusa OF samples.

Equation 4 with scalar values for SBW between 0.75 (chemostatic) and 0.90 (physical fill) were analysed for applicability under these similar climatic circumstances in Namibia during the wet and dry season. The range of scalar values were systematically mapped as a range of inputs, as suggested by Pittroff & Kothmann (2001b), on growing Afrikaner and Simmental cattle (Van Schalkwyk, 1978) from forage quality values and shrunk body weight (SBW). The resulting intake estimations were compared with the observed intake data derived by the chromic oxide marker method (Van Schalkwyk, 1978) and only the best-fit equations are reported below.

The scalar for shrunk body weight in Equation 4 is differently set between the wet and dry seasons. Equation 6 with a shrunk bodyweight scalar set at 0.795 has the best fit during the wet season with extrusa CP concentrations above 8%.

Equation 6 Wet season DMI (kg) / SBW$^{0.795}$= 0.002774 X CP(OM%) - 0.000864 x ADF(DM%) + 0.09826

Equation 7 with a shrunk bodyweight scalar set at 0.815 has the best fit during the dry season with extrusa CP concentrations of less than 8%. The increased energy expenditure on foraging and digesting fibrous material during the dry season would be higher than during the wet season. This was in agreement with the findings of Osuji (1974) that found there was a higher maintenance energy component involved in animals foraging compared to stall-fed animals.

Equation 7 Dry season DMI (kg) / SBW$^{0.815}$= 0.002774 X CP(OM%) - 0.000864 x ADF(DM%) + 0.09826

The variation in the resulting intake calculated by Equation 6 and Equation 7 was compared to the data of Van Schalkwyk (1978) for validation in Table 4 for Afrikaner cattle and in Table 5 for Simmental cattle. The different intake levels are illustrated for Afrikaner cattle in Figure 12 and for Simmental cattle in Figure 13.

In Table 4 the average intake for Afrikaner cattle determined by the chromic oxide marker method over a one year period was 8.96kg (Van Schalkwyk, 1978). The average intake calculated in Equation 4 (NRC, 2000) from forage quality parameters determined by Afrikaner OF (Van Schalkwyk, 1978) was 6.60kg, presenting a 26.5% under estimation.

In Table 4 the average intake calculated by Equation 6 for the wet season, from April to June and January to February, and Equation 6 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 4 (Mathison *et al*., 1986) and decreased bias from Equation 6 and Equation 7

Month	CP (OM)[1]	ADF (DM)[2]	SBW[3]	Intake[4]	NRC[5]	Bias	Equation 6 & 7	Bias
April	12.12	33.92	289	**10.1**	7.2	-28.9%	9.3[6]	-8.2%
May	9.94	34.80	286	**8.6**	6.7	-22.8%	8.6[6]	-0.4%
June	9.59	32.95	289	**10.2**	6.8	-34.1%	8.7[6]	-14.9%
July	4.84	43.94	286	**7.0**	5.1	-26.3%	7.4[7]	6.5%
August	5.94	43.03	289	**8.8**	5.4	-38.1%	7.9[7]	-10.5%
September	4.21	47.60	285	**6.5**	4.8	-26.5%	6.9[7]	6.2%
October	6.78	41.54	295	**8.4**	5.8	-31.3%	8.4[7]	-0.6%
November	7.81	40.99	294	**8.9**	6.0	-32.9%	8.7[7]	-2.9%
December	6.68	39.64	295	**7.7**	5.9	-23.7%	8.5[7]	10.5%
January	18.48	39.63	310	**9.9**	8.5	-13.8%	11.0[6]	11.6%
February	13.33	32.69	348	**10.7**	8.6	-19.6%	11.2[6]	4.7%
March	11.89	32.74	355	**10.6**	8.4	-20.4%	11.0[6]	3.7%
Average				**8.95**	**6.60**	**-26.5%**	**8.96**	**0.5%**

[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 4 developed by NRC (2000) from data generated by Mathison *et al.* (1986).

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

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

Figure 12 illustrates that intake calculated from forage quality parameters determined by OF in Equation 6 and Equation 7 would result in intake estimates that would be suitable for growing Afrikaner cattle in the tree and shrub savannah of Namibia.

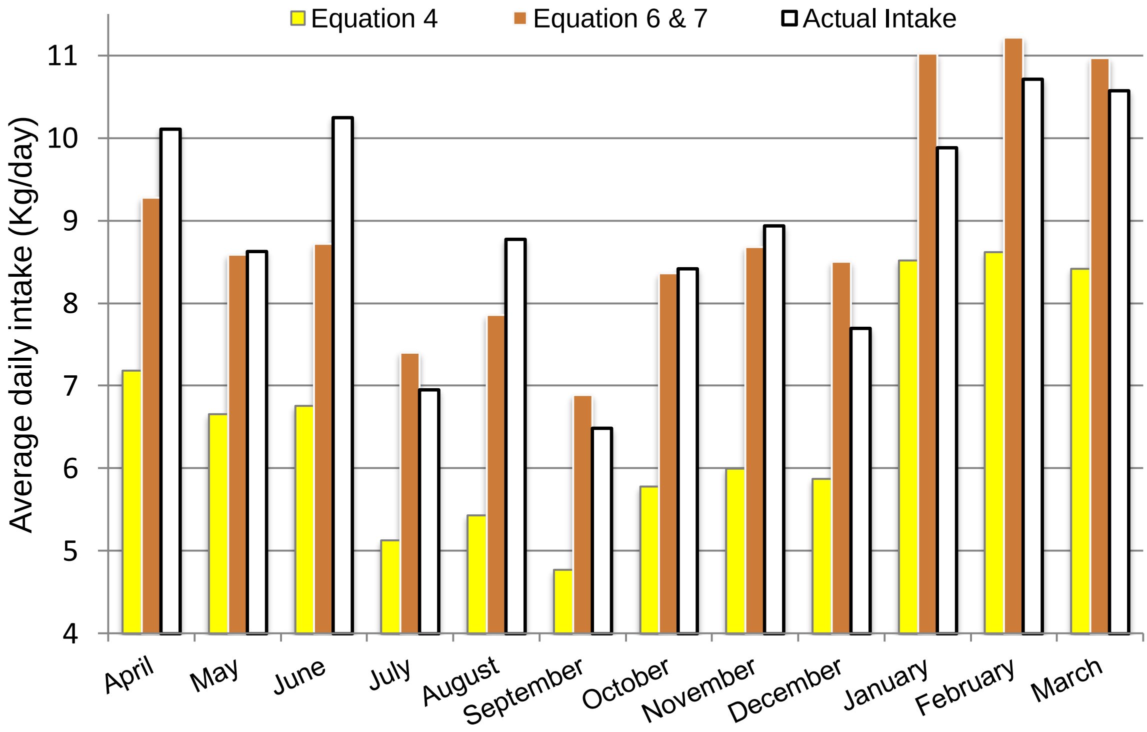


Figure 12 Intake of growing Afrikaner cattle determined by chromic oxide marker method (Van Schalkwyk, 1978) in comparison to results obtained by using parameters from forage collections by oesophageally fistulated cattle (Van Schalkwyk, 1978) in Equation 4 (Mathison *et al*., 1986) and Equation 6 and Equation 7

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 4 (NRC, 2000) from forage quality parameters determined by Simmental OF (Van Schalkwyk, 1978) was 8.24kg, presenting a 28.0% under prediction of intake.

In Table 5 the average intake calculated by Equation 6 for the wet season, from April to June and January to February, and Equation 7 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.

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 4 (Mathison *et al*., 1986) and decreased bias from Equation 6 and Equation 7

Month	CP (OM)[1]	ADF (DM)[2]	SBW[3]	Intake[4]	NRC[5]	Bias	Equation 6 & 7	Bias
April	12.83	30.71	375	**15.0**	9.1	-39.1%	11.9[6]	-20.5%
May	9.57	34.52	374	**8.9**	8.1	-9.6%	10.5[6]	18.0%
June	10.36	30.80	375	**11.5**	8.6	-25.5%	11.2[6]	-2.7%
July	6.50	41.98	360	**8.3**	6.6	-20.6%	9.7[7]	16.4%
August	6.34	43.89	375	**11.3**	6.6	-41.3%	9.8[7]	-13.8%
September	4.55	46.17	368	**9.3**	6.0	-35.9%	8.8[7]	-5.9%
October	6.41	42.38	383	**10.5**	6.9	-34.6%	10.1[7]	-3.7%
November	8.41	41.25	388	**11.3**	7.5	-33.7%	11.1[7]	-2.3%
December	7.51	40.34	388	**10.8**	7.4	-31.6%	10.8[7]	0.7%
January	19.30	39.80	396	**13.8**	10.4	-24.5%	13.6[6]	-1.2%
February	15.78	31.51	423	**14.6**	10.7	-26.5%	14.1[6]	-3.5%
March	15.15	32.46	452	**12.6**	11.0	-12.6%	14.5[6]	15.1%
Average				**11.50**	**8.24**	**-28.0%**	**11.34**	**-0.3%**

[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 4 developed by NRC (2000) from data generated by Mathison *et al.* (1986)

[6] Intake calculated by Equation 6 for wet season forage that contains >8% CP

[7] Intake calculated by Equation 7 for dry season forage that contains <8% CP

Figure 13 illustrates that intakes calculated from forage quality parameters determined by OF in Equation 6 and Equation 7 would result in intake estimates that would be suitable for growing Simmental cattle in the tree and shrub savannah of Namibia.

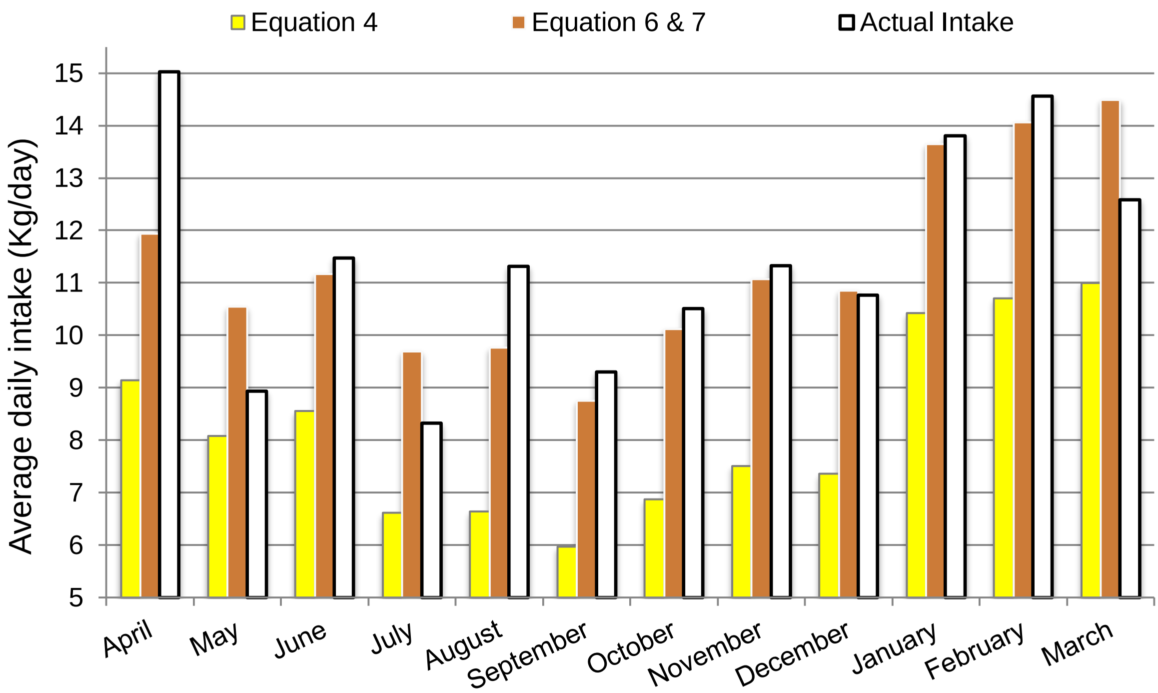


Figure 13 Intake of growing Simmental cattle determined by chromic oxide marker method in comparison to results obtained by using parameters from forage collections by oesophageally fistulated cattle (Van Schalkwyk, 1978) in Equation 4 (Mathison *et al*., 1986) and Equation 6 and Equation 7

There was a strong linear relationship (r=0.78) between the intake determined by chromic oxide marker method and forage samples collected by OF in equation 5 during the wet season. In Figure 14, the intercept for the linear relationship was set at 0, which resulted in a near direct linear relationship with a 0.52 correlation. Figure 14 illustrates that intakes calculated from forage quality parameters determined by OF in Equation 6, during the dry season, would result in intake estimates that would be suitable for growing cattle in the tree and shrub savannah of Namibia.

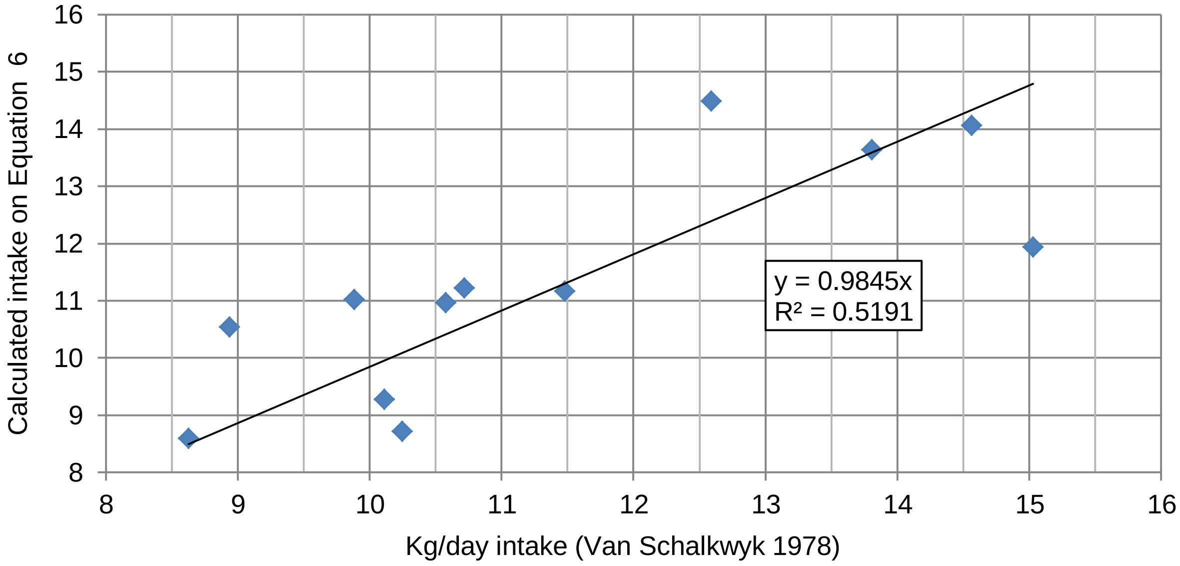


Figure 14 The combined intake of Afrikaner and Simmental cattle determined by the chromic oxide marker method during the wet season (January to June) plotted against the result from the calculated intake from Equation 6 from CP and ADF concentrations determined by oesophageally fistulated cattle

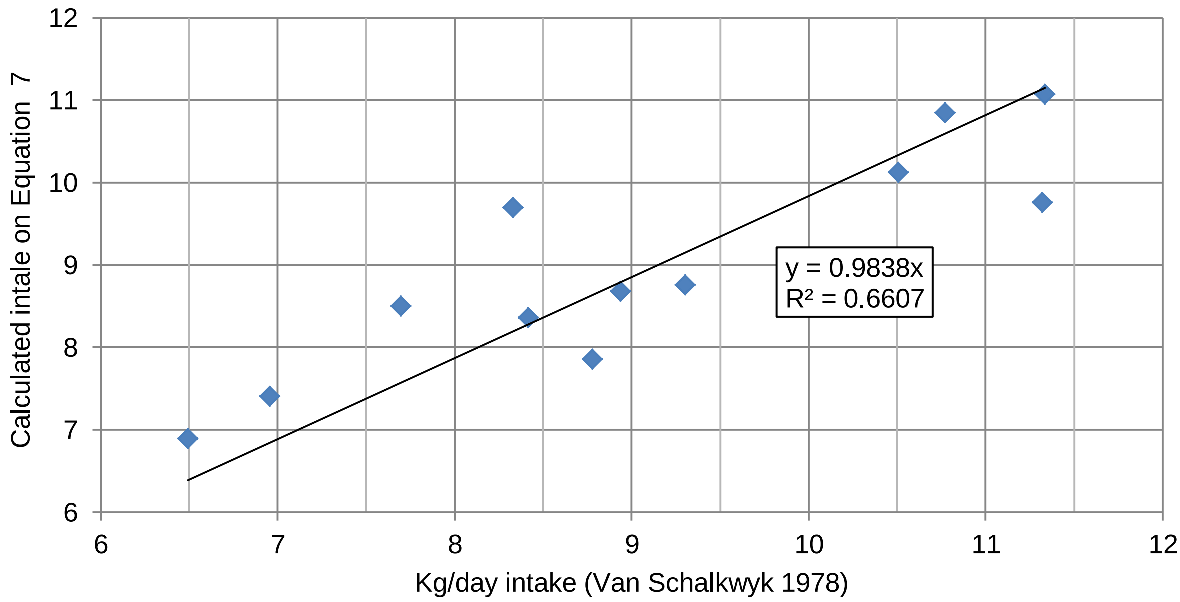


Figure 15 The combined intake of Afrikaner and Simmental cattle determined by the chromic oxide marker method during the dry season (August to November) plotted against the result from the calculated intake from Equation 7 from CP and ADF concentrations determined by oesophageally fistulated cattle showing a direct linear relationship

There is a strong linear relationship (r=0.88) between the intake determined by chromic oxide marker method and forage samples collected by OF in Equation 7 during the dry season. In Figure 15, the intercept for the linear relationship was set at 0 which resulted in a near direct linear relationship with a 0.66 correlation. Figure 15 illustrates that intakes calculated from forage quality parameters determined by OF in Equation 7 during the dry season would result in intake estimates that would be suitable for growing cattle in the tree and shrub savannah of Namibia.

2.4. NUTRIENT SUPPLEMENTATION ON FORAGE DIETS

2.4.1. Phosphorus

Phosphorus deficiency was the most prevalent mineral deficiency throughout the world in grazing livestock and large improvements in production were observed with P supplementation (NRC, 2000). The earliest local investigations to the causes of poor production, due to P deficiencies, in Africa were reported by Theiler (1912) and subsequent national publication (Theiler *et al.*, 1924) and international publication (Theiler *et al.*, 1927) brought it to the attention of nutritionists worldwide.

Karn (2001) and Ternouth (2001) published in depth reviews on phosphorus nutrition of grazing cattle and concluded that a great deal of confusion and disagreement still existed concerning many aspects of P nutrition in grazing cattle. There was no single reliable P status indicator available and the only reasonable guide on when to supplement P was obtained by previous experience on a grazing area in conjunction with forage P, forage crude protein concentrations and possibly blood Pi (Karn, 2001).

Ruminants excrete phosphorus mainly in the faeces and Bravo *et al.* (2003) illustrated that on average 85% of total faecal phosphorus resulted from faecal endogenous phosphorus being constituted mainly from the P in saliva, intestinal cells and digestive secretions. The remaining part of faecal P was derived from unabsorbed dietary phosphorus. An alternative pathway for phosphorus excretion was via urine when the dietary supply became higher than the requirement and aided in the homeostasis of blood plasma phosphorus (Bravo *et al.*, 2003).

A significant relationship existed between crude fibre content of the diet and the ratio of endogenous faecal phosphorus to the total faecal phosphorus (Bravo *et al.*, 2003). The AFRC (1991) had implemented the principle by attributing a higher net phosphorus requirement for maintenance for forage-based diets compared to concentrate-based diets.

Estimates of the requirements of growing cattle consuming forage diets (Ternouth *et al*., 1996) are given in Table 6 and were comparable to those of the NRC (2000). The efficiency of absorption from inorganic phosphate sources could be taken as 85% (NRC, 2001) and from forages 75% (Bortolussi *et al*., 1996; Ternouth *et al*., 1996). The absorbed phosphorus requirement for maintenance was shown to be 19 mg/kg LW (Ternouth *et al*., 1996) and for growth additionally the result of Equation 8 (AFRC, 1991).

Equation 8 Allometric equation to predict phosphorus (P) requirements for growing cattle (AFRC, 1991)

$$\text{P requirement (g/day)} = (1.2+4.635A^{0.22} x LW^{-0.22}) \text{ x LWG}$$

where LW = Live weight (kg),
A = mature LW (kg),
LWG = LW gain (kg per day).

Table 6 Phosphorus requirements (g/d) of growing cattle consuming roughage diets at differential diet qualities (q) (Ternouth *et al.*, 1996)

Live weight (kg)	Diet quality (q)	LW gain (kg/day)		
		0.0	0.5	1.0
100	0.4	2.1	9.0	-
	0.5	1.7	8.3	15.3
200	0.4	3.6	10.2	-
	0.5	2.9	9.0	15.6
300	0.4	5.0	11.4	-
	0.5	4.1	10.1	16.6
400	0.4	6.2	12.8	-
	0.5	5.2	11.0	17.8
500	0.4	7.4	14.2	-
	0.5	6.2	12.1	19.0
600	0.4	8.5	15.5	-
	0.5	7.2	13.2	20.3

Table 7 Required phosphorus concentrations (g/kg dry matter) in roughage diets consumed by grazing cattle at differential diet qualities (q) (Ternouth *et al.*, 1996)

LW (kg)	Diet quality (q)	LW gain (kg/day)		
		0.0	**0.5**	**1.0**
100	0.4	0.9	2.3	-
	0.5	1.0	2.9	3.4
200	0.4	0.9	1.7	-
	0.5	1.0	2.1	2.4
300	0.4	1.0	1.5	-
	0.5	1.1	1.8	2.0
400	0.4	1.0	1.4	-
	0.5	1.1	1.6	1.8
500	0.4	1.0	1.3	-
	0.5	1.1	1.5	1.6
600	0.4	1.0	1.3	-
	0.5	1.1	1.5	1.5

2.4.2. Calcium

Calcium is the most abundant mineral in the animal body with approximately 98% in the bones and teeth of the ruminant and the remaining 2% is distributed in extracellular fluids and soft tissues. Older cattle could be fed calcium-deficient diets for extended periods without developing deficiency signs if previous calcium intake was adequate. Calcium deficiency in young animals prevents bone growth and retards growth and development (NRC, 2000).

Cattle are tolerant of high dietary calcium concentrations but it may affect the metabolism of phosphorus, magnesium and certain trace minerals (NRC, 2000). Dietary calcium concentrations of 4.4% decreased the digestibility of protein and energy (NRC, 2000).

The efficiency of absorption used by the NRC (2001) for limestone was 70% and forage 30%. Scott & McLean (1981) indicated that the ruminant, to meet a change in requirements, would alter the efficiency of absorption of Ca from the gut. Thus, an efficiency of absorption for forage could be used at 70% due to the ability of the ruminant to secrete increased levels of parathyroid hormone when plasma Ca concentration was lower than the Ca demand to eventually accelerate the Ca absorption (Scott & McLean, 1981). The absorbed calcium requirement for maintenance was 15.4mg/kg LW and for growth additionally the result of Equation 9 (AFRC, 1991).

Equation 9 Allometric equation to predict calcium (Ca) requirements for growing cattle (AFRC, 1991)

$$\text{Ca requirement (g/day)} = (9.83 \times (A^{0.22}) \times (LW^{-0.22})) \times LWG$$

where LW =Current live weight (kg),
A = mature LW (kg),
LWG = LW gain (kg per day).

2.4.3. Calcium to phosphorus ratio

Dietary calcium to phosphorus ratio (Ca:P) of 1:1 to 7:1 has been shown to give similar performance, provided that the phosphorus intake was adequate in meeting requirements (NRC, 2000). Extremely wide Ca:P resulted in the exacerbation of a P deficiency (Ternouth, 2001).

Geophagia (searching for and eating suitably mineralised soil) or Osteophagia (bones) or generally called pica was commonly seen in giraffe during the dry season where they attempt to gain a balanced ratio of Ca and P in the diet (Langman, 1978). Lukhele & Van Ryssen (2003) found the Ca concentrations in the foliage of subtropical tree species had exceptionally high concentrations of Ca and lower P concentrations.

AFRC (1991) recommended that separate requirements for Ca and P should be met in the diet and that a desirable limit on Ca:P was unnecessary and even misleading.

2.4.4. Rumen degradable protein

The rumen degradable protein (RDP) contributed to maximal ruminal bacterial crude protein production which could supply from half to essentially all the metabolisable protein required by beef cattle (NRC, 2000).

During the months of no rainfall the forage available to ruminants in Southern Africa had low N concentrations (Pratchett *et al.*, 1977; Van Schalkwyk, 1978; De Waal, 1990). The supplementation of N to animals consuming poor quality forages with low N , with sufficient P being fed, improved both intake and digestibility in stall-fed ruminants (Köster *et al.*, 1996; Klevesahl *et al.*, 2003; Nolte *et al.*, 2003).

Zuntz, in 1891, was the first to be credited for suggesting that rumen microflora played a role in non-protein nitrogen (NPN) utilisation (Huntington & Archibeque, 2000). Ruminants predominantly received NPN from supplements that contained economically available raw materials such as feed grade urea, ammonium sulphate and mono-ammonium phosphate. These sources were readily soluble and were readily converted to ammonia in the rumen. Essentially all ammonia in ruminants or their gastrointestinal tract was in the protonated (NH_4^+) form because the physiological pH is, usually 2 ph units or more, less than the ammonia-ammonium pKa. The protonation and deprotonating of ammonia provided the mechanism for the movement of the molecule across membranes and is readily diffused into and out of all sections of the digestive tract of animals and the blood circulating to the liver. The liver removes ammonia from the blood by producing urea and this is then subsequently removed from the blood by the kidneys via urine or the urea re-enters the digestive tract by diffusion into saliva or directly diffuses across the gastro-intestinal tract wall. NPN poisoning occurs when the ability of the liver to remove ammonia from the blood was exceeded and the ammonia interfered with the functioning of the central nervous system. The data quantifying the sites and rates of urea production, excretion and recycling showed that these processes were linked to the diet composition, intake and productive priorities of the animal and were not constants (Huntington & Archibeque, 2000).

Figure 16 graphically depicts the RDP needs of cattle on low-quality forage. The minimum crude protein needed from a supplement to obtain a positive effect on forage intake and digestibility for supplemented cattle (Equation 10) and the optimum total diet RDP intake level for production in beef steers (Equation 11) and mature, non-pregnant beef cows (Equation 12) are illustrated.

Equation 10 Supplemental CP intake > 0.05% of BW (Moore *et al.*, 1999)
Equation 11 Total RDP intake (Steer) = 5.2 g/kg $BW^{0.75}$ (Klevesahl *et al.*, 2003)
Equation 12 Total RDP intake (Cow) = 4 g/kg $BW^{0.75}$ (Köster *et al.*, 1996)

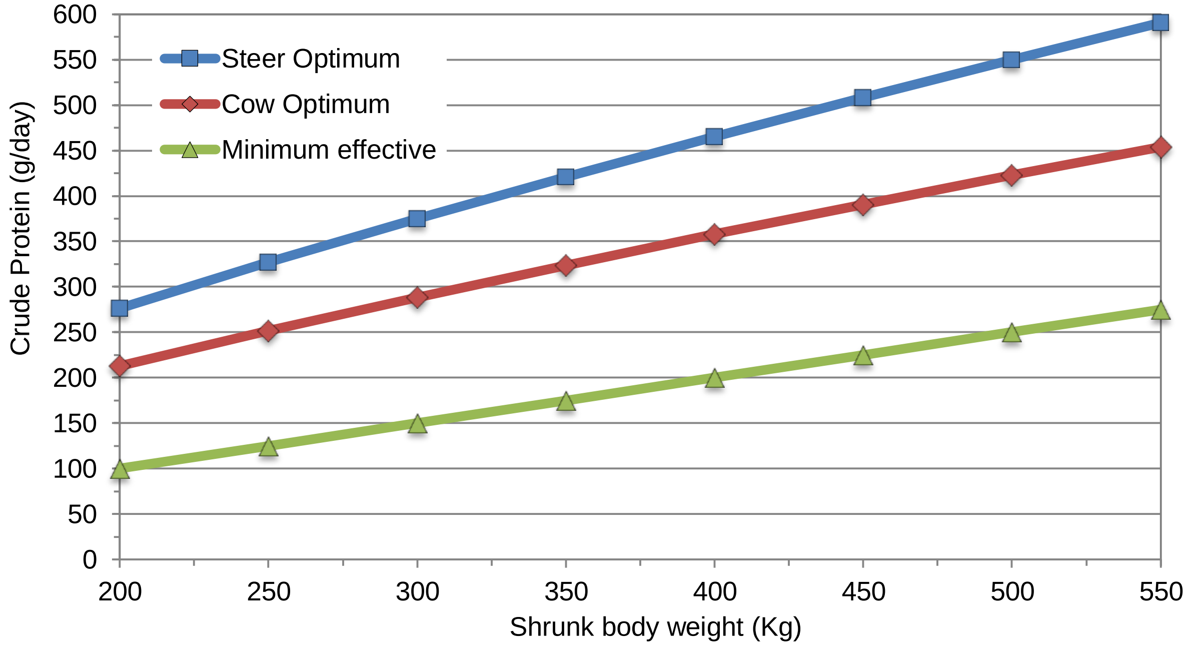


Figure 16 Minimum effective (Moore *et al.*, 1999), cow optimum (Köster *et al.*, 1996) and steer optimum (Klevesahl *et al.*, 2003) rumen degradable protein intake required on low quality forage

The primary sources of nitrogen for fibrolytic bacteria (ammonia and NPN) were able to substitute a portion of the total RDP requirement. The substitution of NPN was done on a RDP equivalent basis (CP = N x 6.25) and was expressed as the percentage CP contributing to the total RDP. Köster *et al.* (1997) indicated that supplementation with urea alone, to steers on low-quality forage, resulted in 85% of the forage intake response achieved by using all true protein. Supplements based on NPN would be more effective in achieving maximal forage utilisation if 25% of the RDP was from true protein (Cochran *et al.* 1998). Cochran *et al.* (1998) warned that reduced performance started to become evident for beef cows when the NPN contribution to total RDP exceeded 25% of the total requirement. Mlay *et al.* (2003) reported soybean oilcake to be equally good as urea in improving plant fibre digestion. For most of the measured parameters soybean cake was slightly superior to urea. The results were possibly due to slower CP degradation in the rumen and thereby matching the slow degradation of hay. Additionally through the provision of pre-formed amino acids, branched chain fatty acids, energy and some minerals not supplied with non-protein nitrogen (Mlay *et al.*, 2003).

Moore *et al.* (1999) suggested that the RDP raw materials, contributing NPN and true protein from oilcake meals, were apparently equivalent for increasing intake on low-quality forages. Wheat bran (47% RDP) with urea (53% RDP), fed at 0.95% of BW, could completely replace the more costly oil cakes (UDP) in growing crossbred bulls (Giri *et al.*, 2005) without affecting rumen fermentation pattern too much and could be used on low-quality forages. No actual animal production results were available to substantiate the author's conclusion. Jacobs (2005) found in steers and Bareki (2010) in pregnant beef cows that urea (in a high-molasses mix) could supply all the supplemental N required when consuming low quality grass hay.

2.4.5. Undegradable dietary protein

Undegradable dietary protein (UDP) is available in the form of plant seed oil extraction by-products (sunflower oilcake, cotton oilcake, soya oilcake and canola oilcake), marine derived protein products (fish meal) or starch extraction by-products from maize (gluten meal).

Under extensive beef production situations, the cost of supplementation is a primary determinant of the raw materials used in licks. The use of undegradable dietary protein (UDP) is largely restricted to intensive production units in Namibia due to the high cost per unit crude protein involved and large transportation costs from production plants.

The specific amino acid requirements of grazing cattle have been scarcely studied, but the limiting amino acids for growing cattle would most probably be methionine and lysine but also histidine, leucine and valine. Grazing cattle rarely demonstrated significant performance responses to supplemental UDP when ruminal nitrogen needs were met (Titgemeyer & Loëst, 2001). Amino acid requirements were related to dietary energy supply due to protein deposition being considered an energy-dependent process. Amino acid supply was also an energy-dependent process as a result of ruminal synthesis of microbial protein. Titgemeyer & Loëst (2001) concluded that supply and demand for amino acids was both linked to dietary energy such that, under most grazing situations, deficiencies of amino acids were unlikely to be severe.

Growing cattle may experience limitations in amino acid supply and were capable of responding to supplementation with UDP (Titgemeyer & Loëst, 2001) but significant animal responses with UDP supplementation in practice remain elusive (Paiva, 2003).

2.4.6. Carbohydrates

The effective use of supplemental carbohydrate sources in supplementation programs requires knowledge of its effects on forage use and how these carbohydrates interact with sources of degradable N (Heldt *et al.*, 1999). Different sources such as high-sugar products (molasses), starch (maize, wheat and sorghum) and fermentable fibre (wheat bran, soya hulls and citrus pulp) could be included. Dixon & Stockdale (1999) defined the outcomes on the intake of metabolisable energy due to changes in intake and/or digestibility of fibrous components when feeding grains to ruminants. Positive associative effects resulted when grains increased voluntary intake and/or digestion of forage, and were usually due to the provision of a limiting nutrient (e.g. nitrogen, phosphorus) in the grain that was deficient in the forage. Negative associative effects resulted where grains decreased voluntary intake and/or digestion of forage and could cause low efficiency of utilisation of grain (forage substitution).

Pate (1983) reviewed the feeding of molasses and described a general negative associative effect when feeding high levels of molasses with low quality roughages, containing low concentrations of crude protein. The supplementation of maize to diets, consisting of forage, with more than 0.25% of body weight resulted in depressed forage intake and fibre digestibility (Sanson & Clanton, 1989; Sanson *et al.*, 1990). Vanzant *et al.* (1990) found that negative associative effects were observed by supplementing more than 0.35% BW (steers) of maize, wheat or sorghum grain based-supplements.

Bodine & Purvis (2003) found intake and digestibility of forage OM was reduced when steers were supplemented with maize (1.0% BW) compared with supplements not containing maize. Grazing time, intensity, and harvesting efficiency were significantly reduced by maize supplementation and the number of grazing sessions per day were significantly increased.

The percentage of urea N excreted in urine was dependent on the N intake relative to nutrient requirements, but also the fermentability of dietary carbohydrates. Numbers ranging from none to 80% of ammonia from urea degradation were incorporated into bacterial N. Availability of energy was the major determinant of that percentage (Huntington & Archibeque, 2000).

Moore *et al.* (1999) suggested that supplements increased forage intake when forage DOMD:CP>7 (Deficit of N relative to available energy) and that supplements decreased intake when forage DOMD:CP <7 (Adequate N). Bodine *et al.* (2000) showed that when adequate supplemental RDP was fed to meet total diet RDP needs, it seemed to overcome negative associative effects typically found from supplementing low-quality forages with large quantities of low-protein and high starch feeds. A negative associative effect of course cracked maize (0.67% BW on an OM basis) on forage intake was observed by Fieser & Vanzant (2004) and that a positive associative effect on forage intake was obtained by supplementing soybean hulls in place of the cracked maize at an equal amount of OM.

Baumann *et al.* (2004) found that intake and digestion responded differently to RDP addition, depending on supplemental energy source. Maize (intake 0.4% BW steers) and soya hulls (intake 0.4% BW steers) were found to be suitable supplements. Osuji & Khalili (1994) found that the energy from cane molasses (intake 0.6% BW steers) fermentation in RDP supplements for animals on low quality forages (56.3g/kg CP) was utilised equally by rumen microbes compared with wheat bran (intake 0.8% BW steers).

Klevesahl *et al.* (2003) found that when the effects of supplement plus forage (49g/kg CP) consumption and digestion were combined, the supplemental RDP and starch did not improve total digestible OM intake compared with offering the supplemental RDP alone. Hennessey & Williamson (1990a) significantly improved the intake and LW gain of cattle on subtropical native pasture (42.5g/kg CP) sprayed with graded amounts of a urea solution without a fermentable energy source.

Bodine & Purvis (2003) illustrated that feeding large amounts of supplement that provided both energy and adequate RDP to cattle allowed greater rates of gain while grazing low-quality forages (74g/kg CP) than either similar levels of grain alone or low-level protein supplementation.

The effect of level of non-structural carbohydrate (NSC) supplementation on intake and digestibility of low-quality forage (55g/kg CP) was investigated by Bowman *et al.* (2004). A control (no supplement) and 0.3% of cow BW supplementation (soybean hulls & soybean meal, wheat middlings and barley & soybean meal) with increasing NSC contributions (320g/day, 640g/day and 960g/day) were provided to contribute 340g CP/day and 21.4 MJ of ME/day. Significant linear decreases in forage DM, NDF and CP intakes were observed with increasing NSC supplementation.

Bowman *et al.* (2004) observed that the forage and supplement DOMD:CP seemed to be superior predictors of response to supplementation with NSC compared with forage CP concentrations alone. Supplements containing NSC and CP improved forage digestion and intake when heifers consumed forage deficient in CP relative to energy (DOMD:CP>7), but decreased forage digestion and intake when cows grazed forage with adequate CP relative to energy (DOMD:CP <7).

Kunkle *et al.* (2000) suggested that when NSC in a supplement was offered above 0.4% of BW, forage intake and digestibility were reduced. In this situation, choosing a highly digestible supplement low in NSC gave 15-30% better performance per unit of supplemental TDN. Fibrous by-product feedstuffs that had high TDN (>75% TDN in DM) and low NSC (<30% NSC in DM) included soybean hulls, wheat bran, corn gluten feed, beet pulp, citrus pulp, distillers grains and brewers grains.

Ørskov (1999) reminded that supplements with easily fermentable fibre improved the rumen environment. This was due to greater numbers of bacteria being present to rapidly invade new substrate entering the rumen. It thereby reduced the lag phase, increased the degradation rate and thus increased rumen turnover.

The inclusion of readily fermentable carbohydrates (>30% NSC in DM) at increasing amounts with a concomitant decrease in intake and digestion, of the fibrous portion of the diet, was generally not as a result of a decline in the number of cellulolytic bacteria in the rumen. It was rather a lag time in the digestion due to a preferential digestion of starch before cellulose by bacteria such as *Bacteriodes succinogenes* (Van Gylswyk & Schwartz, 1984).

2.4.7. Sulphur

Sulphur (S) is an essential element in the diet for ruminants, where sulphur in its reduced form, namely sulphide (SO_3), is needed for the synthesis of cysteine and methionine. Sulphur is also required by ruminal microorganisms for their growth and normal cellular metabolism (NRC, 2000). Sources of sulphur in ruminant diets are elemental sulphur and ammonium sulphate from concentrates, molasses and water sulphate (SO_4). Estimating the total sulphur intake is made by the addition of the quantity of sulphur consumed in the diet and from the water. Water intake could be roughly estimated as 0.95l/10kg body weight (Loneragen *et al.*, 2001). The water sulphate concentration is divided by three to obtain the amount of sulphur (sulphur constitutes a third of molecular weight of sulphate).

The recommended concentration of sulphur in beef cattle diets was 0.15% and toxicity was estimated at around 0.4% (NRC, 2000). Polioencephalomalacia is a neuropathologic condition which was strongly associated with diets and water containing high concentrations of sulphur compounds (Gould, 1998).

Loneragen *et al.* (2001) found that a water sulphate concentration of 583mg/kg, equivalent to 0.22% S (dry matter basis) in the total diet was optimal and that higher concentrations (0.29% and greater) decreased feedlot performance of steers.

2.4.8. Salt

Salt consists of the two major electrolytes, namely sodium and chloride, which are involved in maintaining osmotic pressure, controlling water balance, and regulating acid-base balance. Cattle have evolved without abundant dietary sodium in their diet and their bodies have developed a tenacious ability to conserve sodium by their kidneys and the efficient absorption form the lower small intestine and large intestine. Feeding sodium in excess of needs directly resulted in increased excretion (NRC, 2001). Ruminants have an appetite for sodium and would consume more salt than they actually require (Morris, 1980).

Salt was used to regulate feed intake and cattle could tolerate high-dietary concentrations if an adequate supply of water was available (Morris, 1980; NRC, 2000). Where large amounts of salt are naturally present in drinking water or forage, the amount of salt in the supplement should be reduced. There was a marked seasonal effect in forage concentration of Na and K and were positively correlated with each other; both were maximal while the plants were growing and minimal during the dry period (Morris *et al.*, 1980).

Kattnig *et al.* (1992) found that cattle could ingest water, on a short-term basis, containing up to 2300ppm total dissolved solids with no negative effects. Rogers *et al.* (1979) found that DMI was reduced when steers received a 1kg salt intraruminal infusion. The maximum tolerable concentration for dietary salt in cattle diets was estimated at 9% in the NRC (1980). Excess salt in the diet of Merino wethers resulted in decreased production and De Waal *et al.* (1989a; 1989b) postulated that the increased energy expenditure by the ion transport mechanism across membranes could defer energy away from other productive metabolic processes.

Walker (1957) reported that the daily feeding of 28g of salt resulted in a marked increase in weight gains for grazing steers in Zambia. Murphy & Plasto (1973) noted dramatic responses in beef cows supplemented with salt. Morris *et al.* (1980) found no production response when salt was given as a treatment and questioned the practice of using it as a vehicle to supply trace minerals and universally giving it free-choice to grazing cattle.

Manipulation of salting points in grazing areas with rock salt to increase the utilisation of these under-utilised areas has also been shown not to be effective (Ganskopp, 2001), although shifting watering points was shown to be a very effective way of altering cattle distribution.

The requirement of absorbed sodium for maintenance was 1.5g/100kg BW (NRC, 2001) and for growth was around 1.4g/kg of average daily gain for animals weighing between 150 and 600kg live BW (Gueguen *et al.*, 1989). The NRC (2001) set the efficiency of sodium absorption from the diet at 90%. The daily sodium chloride loss through perspiration could amount to 5g/100kg BW (Kuthe, 1976).

2.5. NUTRITIONAL STATUS INDICATOR: RUMINAL FLUID

A deficiency of any nutrient that was needed by micro-organisms in the rumen also reduced the microbial efficiency, which in turn lead to decreased microbial biomass and eventually reduced the digestibility and ultimately the feed intake, particularly with fibrous feeds (Leng, 1991).

2.5.1. Rumen pH

Acids produced during fermentation of grains generally keep rumen pH slightly below neutral (7.0) or above 7.0 if high forage diets were consumed. High forage diets stimulate the release of large amounts of saliva as they stimulate mastication and the salivary secretion neutralise acids (NRC, 2001).

2.5.2. Ammonia

The concentration of ammonia in the rumen is critical for efficient microbial fermentation. The ammonia concentrations should be above a minimum level for prolonged periods on fibrous diets which are slowly digested. Ruminal ammonia concentration normally fluctuates throughout a day. Animals supplemented with NPN rich feeds reached a peak concentration about one to two hours following feeding and then decreased thereafter (Loëst *et al.*, 2001). The time of sampling in the rumen should be at least 4 to 6 hours post feeding or immediately before feeding.

Satter & Roffler (1977) reported that the concentration of ammonia (NH_3-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).

Hennessy & Williamson (1990b) reported that when cattle fed low quality forage (42.5g/kg CP) were supplemented with increasing amounts of urea, without a source of fermentable carbohydrates, they showed a maximum rumen ammonia concentration where no further response in intake and weight gain was observed. The basal diet concentration was 0.8mg/100ml rumen fluid (0.47mmol/l). When the rumen ammonia concentration increased to higher than 5.4mg/100ml rumen fluid (3.17mmol/l) no further response was observed.

Huntington *et al.* (2001) observed that the level of protein supplementation, two hours after being fed, had a highly significant ($P < 0.01$) linear response in the ammonia concentrations in the rumen of steers. The source of protein was also shown to have a significant effect on the ammonia concentration found in the rumen.

2.5.3. Volatile fatty acids

The energetics of rumen fermentation were best presented by the fractional losses from the energy pool presented by the escape of microbial wastes, the short-chain fatty acids (VFA), methane and fermentation heat loss. VFA accounted for 60-70% of metabolisable energy in ruminants (Van Soest, 1994) and as such were of great importance in beef production. Variations in microbial metabolism caused substantial changes in the partitioning of energy between the VFA, methane and heat of fermentation. Total VFA concentration depended 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 (Thomas & Clapperton, 1972; Klevesahl *et al.*, 2003).

Murphy *et al.* (1982) constructed a model of rumen fermentation that predicted increases in butyric acid and propionic acid concentrations, with a small reduction in acetic acid concentration, as the grain content of a diet was increased up to around 50% of intake. The model predicted that in the transition from forage-based diets to concentrate diets the proportion of soluble carbohydrates converted to propionic acid would increase at the expense of acetic acid production. The model also predicted that the proportion of cellulose fermented to acetic acid increased as more forage was fed in place of concentrate.

Osuji & Khalili (1994) found a significant linear increase in propionic acid and butyric acid at the expense of acetic acid, with increasing substitution of wheat bran with sugar cane molasses as a supplement on low quality forage (56.3 g/kg CP).

Araba *et al.* (2002) found that increasing levels of molasses in cattle diets significantly increased butyric acid at the expense of propionic acid concentrations. Diets containing increasing concentrations of molasses, from 0 to 20% and then to 40%, the acetic acid:propionic acid ratio increased (Araba *et al.*, 2002).

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).

2.6. NUTRITIONAL STATUS INDICATOR: BLOOD METABOLITES

Plasma concentrations of blood metabolites have shown to be sensitive to seasonal changes in nutrient supply of free-ranging goats (Pambu-Gollah *et al.*, 2000) and free-ranging cattle (Hammond, 1997; Long *et al.*, 1999). Metabolic profile tests required a minimum of seven animals (Ingraham & Kappel, 1988). Morris *et al.* (2002) highlighted that attention to proper blood handling, avoidance of haemolysis, storage procedures and processing were important in blood clinical analysis and in the proper interpretation of experimental results.

2.6.1. Phosphorus

Karn (2001) reviewed all status indicators for phosphorus and found that current techniques were not able to accurately determine the dry matter and P intake of grazing cattle from which to determine the total dietary P concentration. Read *et al.* (1986b), De Waal & Koekemoer (1997) and Karn (2001) concluded that blood P had more value as an indicator of dietary P levels, than as a P status indicator.

Blood serum and blood plasma inorganic phosphorus concentration (Pi) were similar and indicated Pi concentrations in the blood (Read *et al.*, 1986b; McCosker & Winks, 1994). The blood serum Pi concentration was significantly higher than the blood plasma Pi in dairy cattle (Monteil *et al.,* 2007). The NRC (1984) gave the normal range for serum Pi as 40mg/l (1.29mmol/l) to 80mg/l (2.58mmol/l).

McCosker & Winks (1994) did not recommend serum as a general substrate to test for Pi because the breakdown of organic phosphate compounds occurred during the clotting process that could result in false high readings. The extent of breakdown depended on the time between collection and separation, and air temperature.

The AFRC (1991) investigated the relative merit and critical range for plasma Pi as a measure of dietary adequacy in comparison to the newly tabulated dietary requirement for P. The relationship between the plasma Pi concentration and the estimated requirement in feeding trials was presented in Equation 13 for growing cattle (r=0.71) and Equation 14 for growing lambs on high roughage diets (r=0.61).

Equation 13 Growing cattle (All Diets) = 2.14 + 18.60 (P intake –P requirement)

Equation 14 Growing lambs (Roughage diets) = 1.89 + 15.6 (P intake –P requirement) -68.6 (P intake –P requirement)^2

Figure 17 illustrates that the tendency for plasma Pi to be higher in cattle than in sheep for a given P deficit or surplus/unit body weight. This may indicate that bovine requirements had been overestimated by AFRC (1991). The optimal plasma Pi concentration for cattle was at 2.14mmol/l (66.3mg/l) and for sheep was 1.89mmol/l (58.5mg/l) and that higher concentrations of P in the blood plasma would show a P surplus in the animal’s diet.

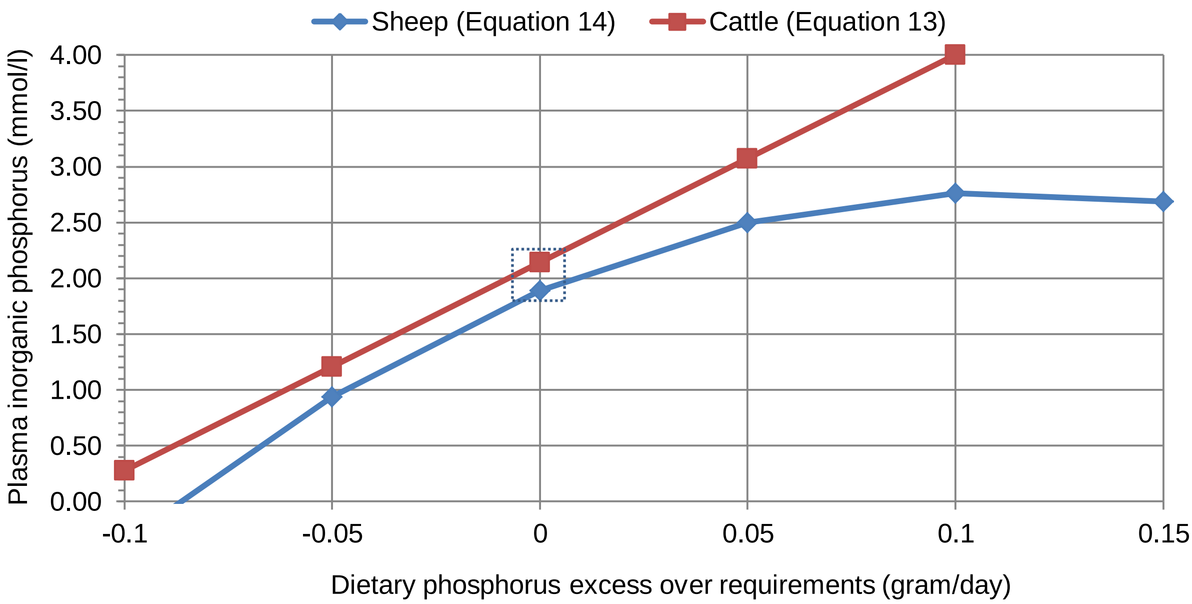


Figure 17 Relationship between plasma inorganic phosphorus in mmol/l and excess phosphorus intake over phosphorus requirement (AFRC, 1991)

Bortolussi *et al.* (1996) reported absorption efficiencies of >0.75 for P intakes in the normal dietary range for roughage diets (70-80%) and found it was at variance with the absorption coefficient of 0.58 used by AFRC (1991) which resulted in the P requirements being excessively high. Ternouth *et al.* (1996) subsequently calculated the requirements of growing cattle and found that the AFRC (1991) requirements were 40-50% over estimated for grazing cattle. The optimal blood plasma Pi concentration could thus be lower and be more closely related to the intercept value of sheep on forage diets.

When plasma Pi were <50mg/l (1.62mmol/l) for growing cattle consuming forage diets the urinary P and endogenous faecal P losses were low (Ternouth *et al.*, 1996). Food intake was depressed when plasma Pi concentrations fell below 40mg/l (1.29mmol/l) (Ternouth *et al.*, 1996). Puls (1994) gave the plasma Pi of below 4.5mg/dl (1.45mmol/l) as being indicative of a P deficiency. Very little P was normally excreted in the urine of ruminants, even if the dietary intake was in excess of requirements, until the concentration of Pi was raised to over 2.25mmol/l (Scott & McLean, 1981).

Groenewald (1986) concluded after 8 years of lick supplementation of beef cows in Kwazulu Natal (South Africa) that a deficiency in P intake (receiving only salt as lick) was occurring at plasma Pi concentrations of <35.6mg/l (1.15mmol/l). Plasma Pi concentrations of 62.2mg/l (2.01mmol/l) were regarded as normal in cows receiving various P containing licks.

Hendrickson *et al.* (1994) observed clinical signs of depraved appetite with cattle chewing bones, stones and yard rails at plasma Pi concentrations of less than 35mg/l (1.13mmol/l). Plasma Pi concentrations below a critical level of 20mg/l (0.65mmol/l) was considered to be indicative of a P deficiency (Read *et al.*, 1986b).

McCosker & Winks (1994) gave diagnostic concentrations for blood Pi and faecal CP for steers and lactating cows in Table 8. When the faecal CP concentrations were less than 81g/kg the cattle would be losing weight or be at maintenance. The recommendation from the authors was that P supplementation would not be required. The only exceptions were for lactating cows and cows in the last third of pregnancy that would respond to P supplementation.

Table 8 Diagnostic concentrations of jugular blood inorganic phosphorus concentration (Pi) and faecal crude protein (CP) for steers and lactating cows (McCosker & Winks, 1994)

Blood Pi (mg/l)	Blood Pi (mmol/l)	Faecal CP (g/kg)	The P status is
Steers and Dry stock			
<28	<0.90	>81	acute
28-39	0.90-1.26	81-113	deficient
28-39	0.90-1.26	>113	acute
39-50	1.26-1.62	>81	marginal
39-50	1.26-1.62	81-113	deficient
>50	>1.62	>113	adequate
Lactating cows			
<28	<0.90	>81	acute
28-39	0.90-1.26	81-131	deficient
28-39	0.90-1.26	>131	acute
39-50	1.26-1.62	81-113	adequate
39-50	1.26-1.62	113-150	marginal
39-50	1.26-1.62	>150	deficient
>50	>1.62	>81	adequate

Bortolussi *et al.* (1996) fed steers (187kg BW) over a period of 15 weeks with different N and P concentrations and measured their Pi concentrations shown in Table 9. During the trials the steers showed an initial reduction in feed intake due to P deficiency after 7 weeks and the maximum feed intake reduction occurred after 10 weeks.

Table 9 Plasma inorganic phosphorus concentration concentrations in mmol/l for steers fed different nitrogen (N) and phosphorus (P) diets over time (Bortolussi *et al.*, 1996)

Diet fed	Week 2	Week 6	Week 10	Week 15
Low P, Low N	1.46	1.26	1.12	1.17
Low P, High N	1.24	1.10	0.92	0.96
Medium P, Low N	2.45	2.15	1.89	2.30
High P, High N	2.40	2.20	2.15	2.24

The results from Bortolussi *et al.* (1996), as measured in terms of LW change and feed intake, imply that the provision of additional dietary N to a P-deficient diet (Table 9 – Low P, High N) would exacerbate the P-deficiency and would further reduce the Pi and bone thickness. Under low dietary N conditions (Table 9 – Low P, Low N and Medium P, Low N) the effects of a dietary P deficiency were reduced and there was a sparing on P due to a decreased demand on the reserves of the animal.

2.6.2. Calcium

Blood calcium concentration was not a good indicator of Ca status because plasma Ca was maintained between 9mg/dl (2.2mmol/l) and 11mg/dl (2.75mmol/l) by homeostatic mechanisms (NRC, 2000; NRC, 2001).

2.6.3. Calcium to phosphorus ratio

Due to the insensitivity of the blood calcium concentrations to dietary calcium intake, the Ca to P ratio (Ca:P) is a more appropriate measure for diagnostic interpretation and is a more sensitive and stable measure than Pi alone (Groenewald, 1986). Groenewald (1986) proposed that a P deficiency was indicated by a ratio wider than 2:1 and that animals receiving adequate P supplementation would have a 1.5:1 ratio as a normal value. Groenewald (1986) determined, with a 2:1 relationship, the minimum normal concentration of Ca in blood at 8mg/dl (2mmol/l) and and P in blood at 4mg/dl (1.29mmol/l). When the guideline was changed to SI, a P deficiency would be indicated by a ratio wider than 1.55 and adequate P in diet was at 1.16 or narrower.

Underwood (1981) suggested that the lower normal limit for serum Ca in cattle was 90mg/l (2.25mmol/l) and a similar value was given by NRC (2000) for plasma Ca. The concentration at which P was still determined to be normal for cattle was 50mg/l (1.62mmol/l) (Ternouth *et al.*, 1996) and the intake of P indicated a deficiency at less than

45mg/l (1.45mmol/l) (Puls, 1994). The guideline for P-deficiency remained for a ratio wider than 1.55 and a ratio narrower than 1.39 would be adequate.

2.6.4. Urea nitrogen

The blood plasma/serum urea nitrogen (BUN) was a useful tool for monitoring the protein-energy status of cattle (Hammond, 1997). Low dietary N intakes rapidly and significantly reduce BUN concentrations (Bortolussi *et al.*, 1996). It could be used to appropriately manage the changeover between wet and dry season supplementation programs. BUN concentrations that would indicate when cattle were likely to respond to further protein supplementation were given by Preston *et al.* (1978) for finishing steers < 7 mg/dl (2.50mmol/l) and Byers & Moxon (1980) for rapidly growing cattle < 11 mg/dl (3.93mmol/l).

In a review Hammond (1997) recommended that a dietary deficiency in protein occurred when beef cows and finishing steers had BUN < 7 mg/dl (2.50mmol/l) and rapidly growing cattle or high producing dairy cows had BUN < 15mg/dl (5.36mmol/l).

Demand for protein to support growth was affected by urea synthesis and the blood concentrations in steers (Huntington & Archibeque, 2000). Increased dietary postruminal N supply increased the BUN in steers (Figure 18) but dietary sources and amounts of energy and CP alter the relationship (Huntington *et al.*, 2001). Breed differences for BUN were observed by Valencia *et al.* (2001) and related it to differences in protein utilisation between breeds.

Huntington *et al.* (2001) found the CP intake (kg/day), with supplemented soya bean meal and a 2:1 mixture of corn gluten meal:blood meal, was also related to the average daily gain (ADG kg/d). The control diet had an ADG of 0.35 at a CP intake of 0.388kg/day. Both protein supplements linearly increased ADG, compared to control, until reaching a plateau for total CP intake at 0.671kg/day (soybean meal) and 0.589kg/day (corn gluten meal:blood meal) where maximal ADG was observed. Relating the plateau for ADG back to the BUN data in Figure 18 it would appear that an optimal BUN concentration for this trial would be around 3mmol/l but that the growth of the control group at 0.35kg/day with 0.399kg/day CP intake would be satisfactory under grazing conditions where the BUN was recorded under 1 mmol/l.

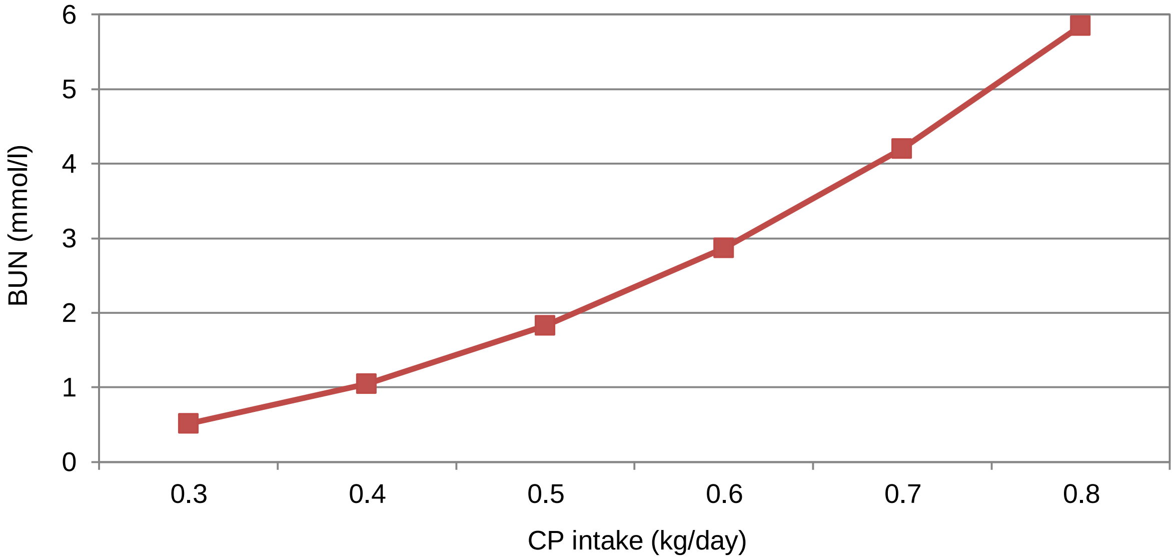


Figure 18 Quadratic regression (R^2=0.73) of blood urea nitrogen (BUN) as a function of crude protein intake (CP) for steers (302kg body weight)(Huntington *et al*,. 2001)

Bortolussi *et al.* (1996) fed steers (187kg BW) over a period of 15 weeks with different N and P levels and measured their BUN concentrations (Table 10). Low dietary N intakes rapidly and significantly reduce the BUN concentration.

Table 10 Plasma urea nitrogen in mmol/l for steers fed different nitrogen (N) and phosphorus (P) diets over time (Bortolussi *et al.*, 1996)

Diet fed	Week 2	Week 6	Week 10	Week 15
Low P, Low N	1.80	1.08	1.01	1.56
Low P, High N	1.97	5.15	4.80	5.49
Medium P, Low N	1.42	0.92	0.62	1.29
High P, High N	3.59	2.13	1.99	2.28

2.6.5. Beta-hydroxybutyrate

The most predominant ketone body in all species is beta-hydroxybutyrate (BHB) and elevated concentrations indicated short-term negative energy balance and adipose tissue catabolism (Bergman, 1971). Shaw & Tume (1992) found that BHB could assist in evaluating nutritional stress prior to slaughter of livestock.

Blum *et al.* (1985) studied the effects of feed restriction for 5 months and then refeeding the steers. During the restriction period the BHB concentrations were elevated to 131µmol/l, which was well below concentrations where mild ketosis was suspected. Mild ketosis were shown to be >900µmol/l (Al-Rawashdeh, 1999) and <1440µmol/l (Santos *et al.*, 2004) in dairy cattle. Concentrations of BHB tended to decrease during the first two days of refeeding (111µmol/l) and then increased to 232µmol/l on day 24. The increase in BHB after about 10 days of refeeding (190µmol/l) was related to BHB synthesis in the rumen wall.

Significant linear increases were found in BHB concentrations by Murphy (1999), and are shown in Table 11, where increasing amounts of molasses were fed. This could have been due to a higher proportion of butyric acid in the rumen VFA due to molasses and subsequent metabolism of butyric acid to BHB in rumen epithelium and liver.

Table 11 The effect of increasing levels of molasses in the diet of dairy cows on beta-hydroxybutyrate (BHB) (Murphy, 1999)

Molasses (g/kg DM basis)	BHB (mmol/L)
0 g/kg	0.56
139 g/kg	0.61
254 g/kg	0.65
351 g/kg	0.65

This effect had also been observed by Shingfield *et al.* (2002) where lower BHB was observed in animals with rumen fermentation relatively rich in propionic acid.

2.7. NUTRITIONAL STATUS INDICATOR: FAECAL NUTRIENTS

2.7.1. Phosphorus

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 forage content of the diet (high fibre diets) 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.* (1986b) 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.* (1986b) and Groenewald (1986) found that faecal P concentrations were insensitive for distinguishing between supplemented and unsupplemented cattle due to a depression in 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.

2.7.2. Calcium

Young *et al.* (1966) found that the rate of metabolic faecal Ca excretion was not correlated with intake or absorption of the element but increased Ca intake tended to slightly increase the amount of Ca excreted in faeces. Urinary excretion of Ca was significantly influenced by dietary Ca and P concentrations. The urinary contribution to total endogenous loss of Ca was low when the intake of P was adequate but it increased significantly when P intake was deficient.

Faecal Ca represented unabsorbed dietary Ca and endogenous unabsorbed Ca, therefore any factor that affected the absorption would affect the amount of Ca excreted in faeces as well (McDowell, 1992).

2.7.3. Crude protein and phosphorus

Hennessy & Williamson (1990a) found that where the cattle were fed increasing amounts of urea on low quality forage (42.5g/kg) the faeces N content was not increased but rather the urine N was increased. Bodine & Purvis (2003) suggested that particular caution had to be taken when using faecal N concentrations as an indicator of N status for cattle grazing low-quality forages and receiving energy-based supplements without RDP. Increased faecal N, less BUN and decreased N intake was observed when supplemented with energy.

Grant (1989) found that the P and N concentrations in faeces could be a practical tool to indicate the P and N status of the diet consumed. At least 10 animals needed to be sampled and should not have been under any form of metabolic stress. Grant (1989) recommended that faecal P below 2.2g/kg showed a dietary deficiency in P and that supplementation of P was recommended. Faecal CP concentrations of below 65g/kg showed a deficiency and that the supplementation of CP was recommended. The upper critical value for faecal P was 3.5g/kg and for CP was 100g/kg and should the values have been higher than this the supplementation of these nutrients could have been decreased. The intermediate range for P at 2.2 to 3.5g/kg was shown to be normal and the faecal CP concentration was between 65 to 100g/kg.

McCosker & Winks (1994) developed a list of diagnostic concentrations for faecal P at a range of faecal nitrogen concentrations in Table 12. McCosker & Winks (1994) postulated that at higher dietary nitrogen levels the faeces required higher dietary P levels. Higher faecal CP concentrations would normally occur on forage with higher legume contents and on forage from soils that were more fertile.

Table 12 A range of faecal crude protein (CP) concentrations with diagnostic concentrations for faecal phosphorus (McCosker & Winks, 1994)

Acute	Deficient	Marginal	Adequate
Faecal CP 81 to 94 g/kg			
< 1.5	1.5 - 2.0	2.0 - 2.5	> 2.5
Faecal CP 94 to 125 g/kg			
< 2.0	2.0 - 2.5	2.5 - 3.0	> 3.0
Faecal CP 125 to 156 g/kg			
< 2.5	2.5 - 3.0	3.0 - 3.5	> 3.5
Faecal CP 156 to 188 g/kg			
< 3.0	3.0 - 3.5	3.5 - 4.0	> 4.0

CHAPTER 3 EXPERIMENTAL DESIGN

The design of this study was based on the principles and guidelines presented by Bransby & Maclaurin (2000). The research was conducted in participation with producers, extension personnel and input suppliers for maximum first hand technology transfer (see Figure 148 and Figure 149 in the Photo Appendix).

3.1. EXPERIMENTAL UNIT

3.1.1. Location

The study area was 1710ha of the South-West part of the farm Burgkeller Nr. 234 situated next to the Osire settlement for refugees, in the central Namibian interior, 120km south east from the town Otjiwarongo. The location is situated 1354m above sea level at South latitude 21° 02' and East longitude 17°26'.

3.1.2. Climate

The long-term annual rainfall mean (Figure 19) recorded on Burgkeller from 1967 to 2004 (38 years) was 387mm, ranging from an annual minimum of 90mm (1995) to an annual maximum rainfall of 688mm (1974).

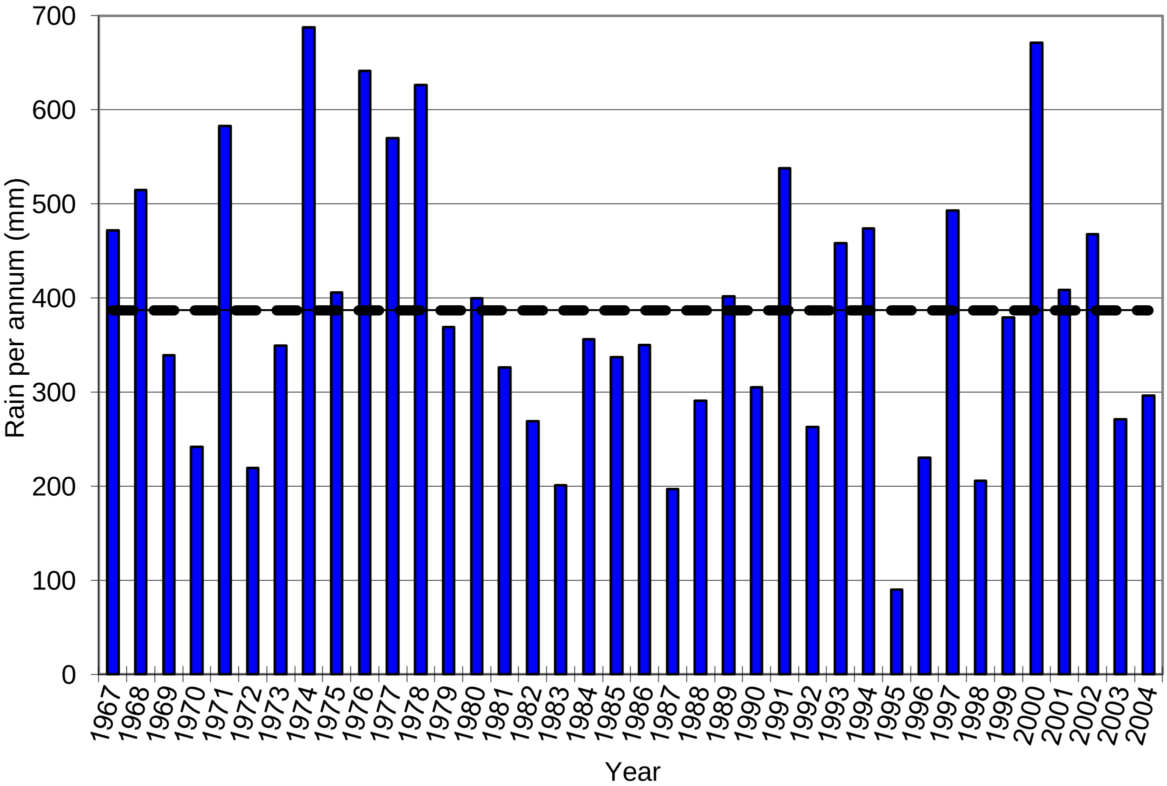


Figure 19 Burgkeller annual average rainfall from 1967 to 2004

The average annual rainfall recorded for Burgkeller (387mm) in Figure 19 closely resembles the long-term average rainfall range (350-400mm) recorded for the area in

Figure 20 that shows the rainfall mean for the study area from close to the start of the decade at weather stations.

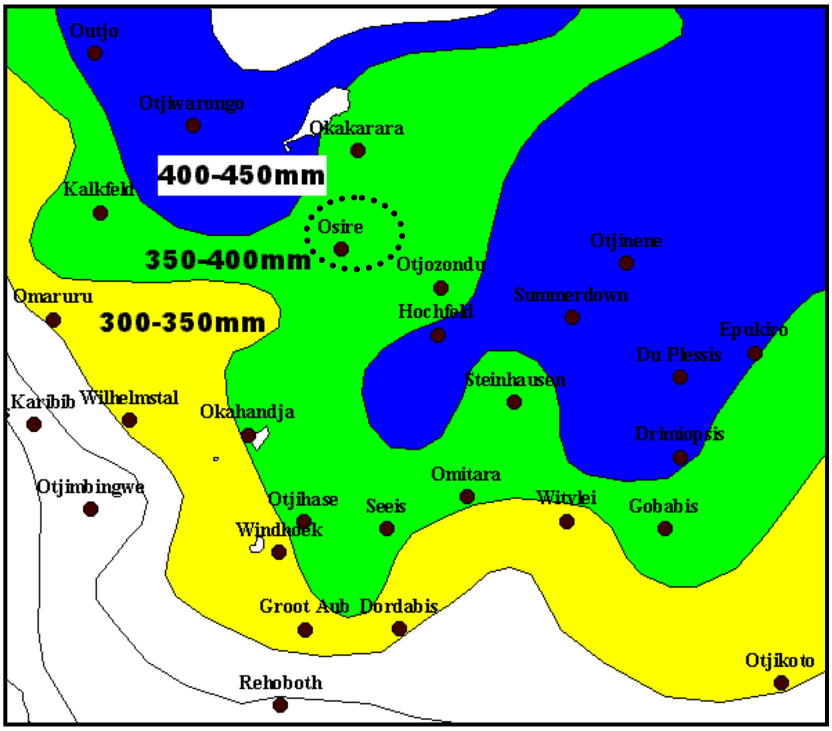


Figure 20 Long-term average annual rainfall from weather stations (Namibia Resource Consultants, 1999)

Figure 21 gives the monthly average rainfall for the period of 1966 to 2004 on Burgkeller. The period of maximal rainfall was normally recorded from December to March (97%) on Burgkeller. The month of maximal rainfall was normally recorded during January (37%) or alternately during February (29%). The peak of the rainy season occurred over January, February and March which were defined as the core rainfall months (Olszewski, 1996) that accounted for 68% of the season's rainfall. If the associated months (Olszewski, 1996) were added to the core months, December and April, it accounted for 90% of the total rainfall that was recorded during the rainy season.

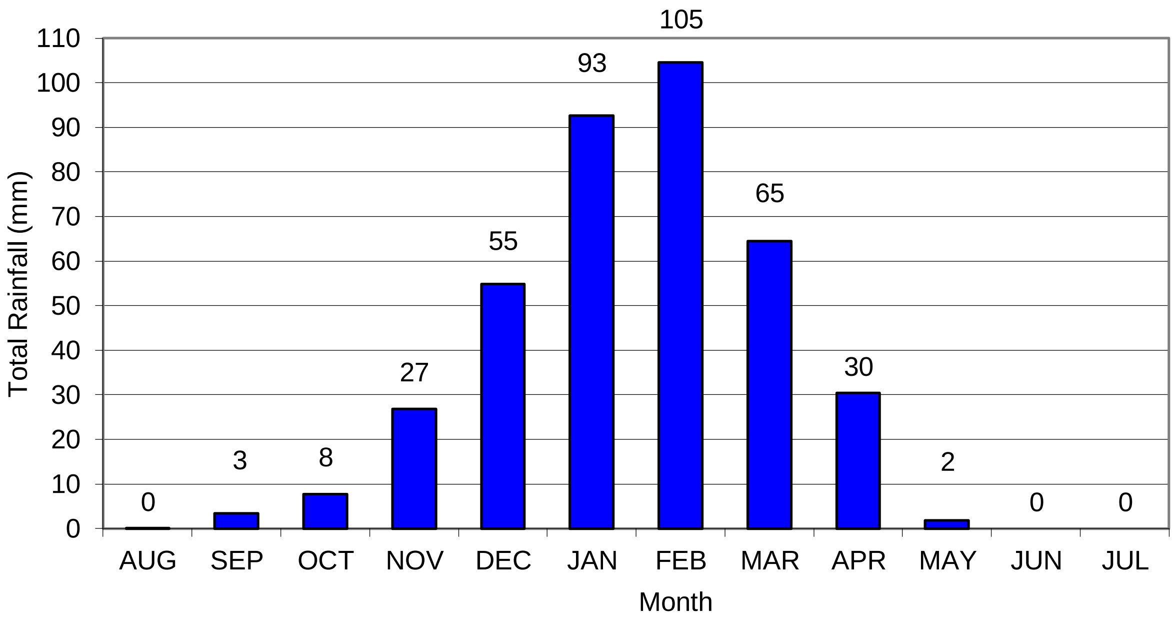


Figure 21 Burgkeller monthly average rainfall from 1967 to 2004

In Figure 22 the total rainfall recorded in the year before commencement of the experimental period was 271mm (2003) which represented only 70% of average annual rainfall recorded for Burgkeller. During the experimental period in 2004 the total rainfall was 296mm which represented only 77% of the long-term average annual rainfall recorded for Burgkeller. The rainfall records showed a period of below average rainfall that proceeded the experimental period and during the experimental period that would have placed pressure on the nutritive quality of forage on the experimental area.

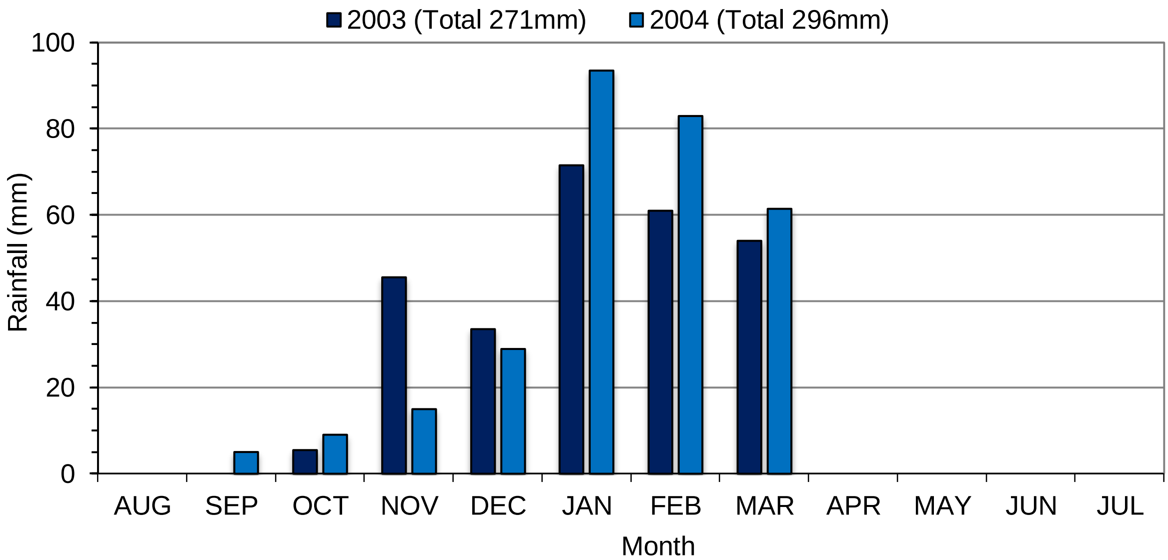


Figure 22 Monthly rainfall records on Burgkeller for the year preceding (2003/04) and the year during (2004/05) the experimental period

The month of maximal rainfall was recorded in January in both of these years. Over the years 2003 to 2004 the average rainfall during the core rainfall months (January to March) was 75% of the season's total rainfall. Including the associated rainfall months to the core rainfall months (December to April) it accounted for 86% of the seasonal total rainfall.

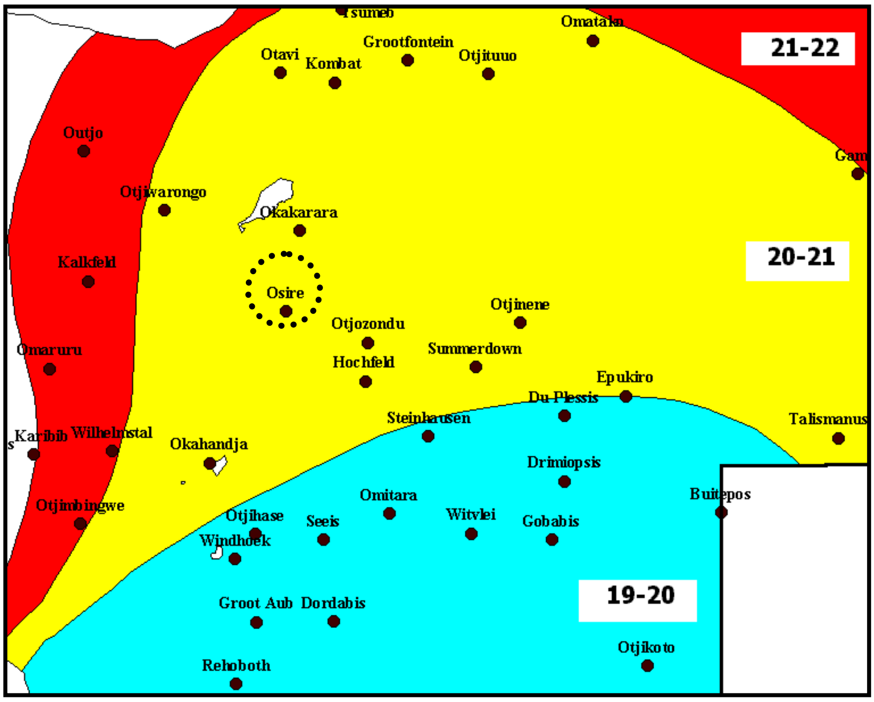


Figure 23 Namibia long-term average annual temperature in °C (Hutchinson, 2002)

The annual temperature averages for each area in Figure 23 were calculated from the average of every day's maximum and minimum temperature during a year and showed a long-term average temperature for the experimental area of 20-21°C. During the experimental period the mean daily maximum temperatures in the wet season (November/December) regularly exceeded 30 °C at Burgkeller and the minimums in the dry cool season were recorded as -3.5 °C in June 2004 and -4.6 °C in July 2004.

The classification of the general area as a subtropic is illustrated in Figure 24 by Peel *et al.* (2007).

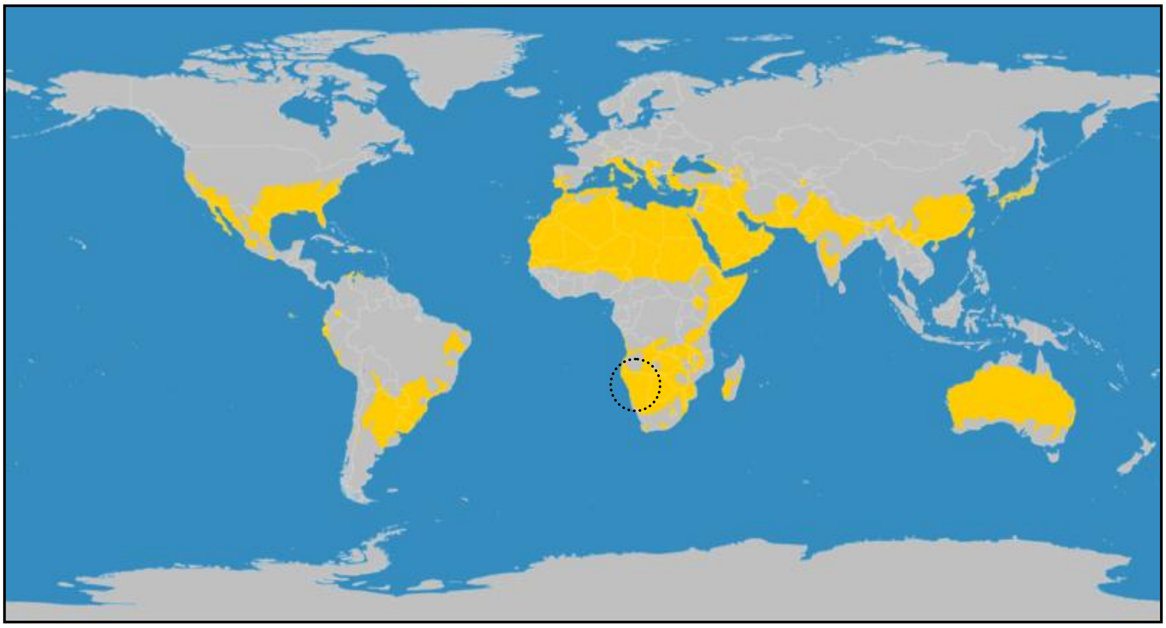


Figure 24 The subtropic areas of the world are highlighted in yellow (Peel *et al.*, 2007) with a circle around Namibia showing the country in relation to other subtropical areas around the world

3.1.3. Vegetation

In Africa the biome is classified as "Tree and Shrub Savannah" (White, 1983). The vegetation type in Namibia is "Thornbush Shrubland" (Giess, 1971; Atlas of Namibia, 2002).

The range condition was in a degraded state with bush encroachment present. This represented the situation on the majority of the farms in woodland savannahs with 26 million ha of Namibia being negatively affected by bush encroachment (De Klerk, 2004).

The relative abundance of plants, presented in Table 13, in the six camps on Burgkeller where determined at the end of the rainy season. The botanical survey was done by using a 2.5m falling rod over 1 kilometre diagonal transects across each camp with a total of 2679 points being identified. The minimum number of points per camp was 300 as suggested by Hardy & Walker (1991). The average canopy cover of the soil was 78% which was determined by classifying the exact point of impact of the rod either as "bare" or "covered". The total vegetation abundance on average compromised of 58% grass species, 21% woody plants and 21% ephemeral plant species. The most abundant species, representing at least 80% of the total recorded in each botanical grouping, are listed in descending order of abundance. The grasses were *Urochloa brachyura, Stipagrostis* *uniplumis, Eragrostis annulata* and *Melinis repens grandiflora*. Mphinyane (2001) observed that *S. uniplumis* was one of the less preferred species by cattle and was similarly one of the most frequently occurring and most available (g/m^2) of all herbaceous species throughout the year in Botswana. The predominant woody plants were *Terminalia sericia, Acacia mellifera, Dichrostachys cineria* and *Acacia erioloba.* The predominant dicotyledonous forbs were *Tylosema esculentum, Indigofera spp*., *Kohautia spp*. & *Cleome spp.*, *Evolvolus alsinoides* and *Talinum caffrum*.

Kruger (1998) and Rothauge (2006) postulated that the grass *Schmidtia pappophoroides* could be used as an ecological indicator species for beef ranching in the camelthorn tree savannah of Eastern Namibia. It was preferentially selected by cattle at all stocking rates and relatively tolerant of the associated defoliation, maintaining a noticeable presence in the grass sward even at high stocking densities (Rothauge, 2006). Mphinyane (2001), under similar conditions in Botswana, also observed that *S. pappophoroides* was one of the most highly preferred in the diet of cattle but was also among the least common on the rangeland and also one of the least available in terms of phytomass. On Burgkeller the grass *S. pappophoroides* was only on average 0.34% of the grass abundance in contrast to the 21% found on Sandveld Research station (Rothauge, 2006).

The principle diet components (70% of bites taken) and preferred dietary components of free-ranging cattle in the camelthorn savannah of Eastern Namibia were the perennial grasses *S. pappophoroides*, *Anthephora pubescens*, *Eragrostis lehmanniana, Eragrostis trichophora* and *Melinis repens repens* (Rothauge, 2006). On Burgkeller the two grasses, *A. pubescens* and *M. repens repens* were not found. The relative abundance of *S. pappophoroides*, *E. lehmanniana* and *E. trichophora* was only 3.28% on Burgkeller which was in contrast to the 35% abundance on Sandveld research station. The camps on Burgkeller were ranked in decreasing order by the relative abundance of the most preferred grass species (Rothauge, 2006) in Table 13.

Camp 4 was used by the oesophageally fistulated cattle (OF) due to its proximity to the house and facilities that were essential in the daily care of these animals. The camp had a total grass dry matter biomass of 737kg/ha with a 73% palatable grass component and a 27% unpalatable grass component with a 79% plant canopy cover.

Table 13 Relative abundance of the most preferred grass species on Burgkeller with reference to the camp used by the oesophageally fistulated cattle (OF)

	Average (244ha)	Camp 9 (275ha)	Camp 4 **OF** (200ha)	Camp 3 (270ha)	Camp 2 (255ha)	Camp 1 (294ha)	Camp 7 (246ha)	Camp 8 (170ha)
S. pappophoroides	0.34%	0.44%	0.00%	1.01%	1.13%	0.31%	0.00%	0.00%
E. lehmanniana	2.76%	12.01%	3.32%	1.42%	0.65%	1.42%	1.33%	1.03%
E. trichophora	0.17%	0.00%	0.00%	0.41%	0.32%	0.31%	0.00%	0.00%
	3.28%	12.45%	3.32%	2.84%	2.11%	2.05%	1.33%	1.03%

This compares well with the work done by Kruger (1998) on the Sandveld research farm with variable stocking rates which on average had a range of total grass availability of 263kg/ha (1985) and 702kg/ha (1992). Kruger (1998) observed that rainfall had a larger influence on grass availability than either stocking rate or cattle type.

3.1.4. Soil and water properties

The experimental site was classified as being Kalahari Sandveld landscape with the dominant soil group being classified as Hypoferralic Arenosols (Atlas of Namibia, 2002). Arenosol soils (Figure 25) have a strongly weathered horizon and the sand fraction is dominated by resistant minerals such as iron-, aluminium-, manganese- and titanium oxides. These soils have a low water-storage capacity and low biological activity (Coetzee, 2004).

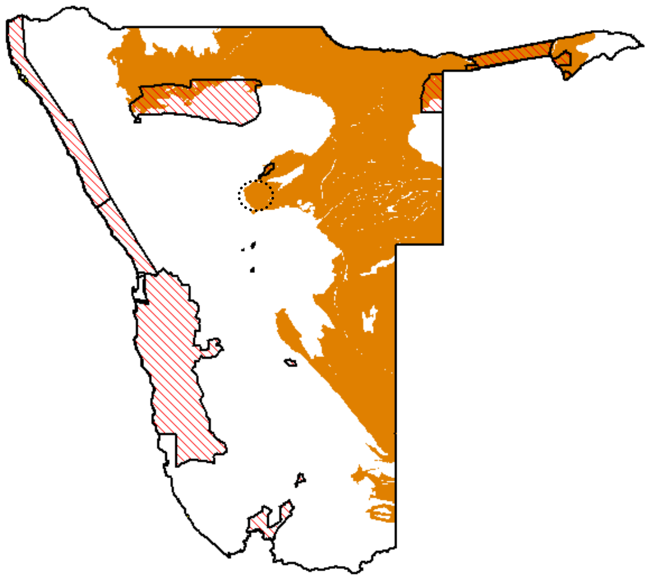


Figure 25 Map of Namibia with arenosol soil type and National parks in relation to experimental site (Simmonds, 2002)

Arenosols cover about 13% in Sub-Saharan Africa and are widely spread in the southern part of the continent (Hartemink & Huting, 2008), as illustrated in Figure 26. P deficiencies in cattle were usually associated with P deficient soils (Karn, 2001).

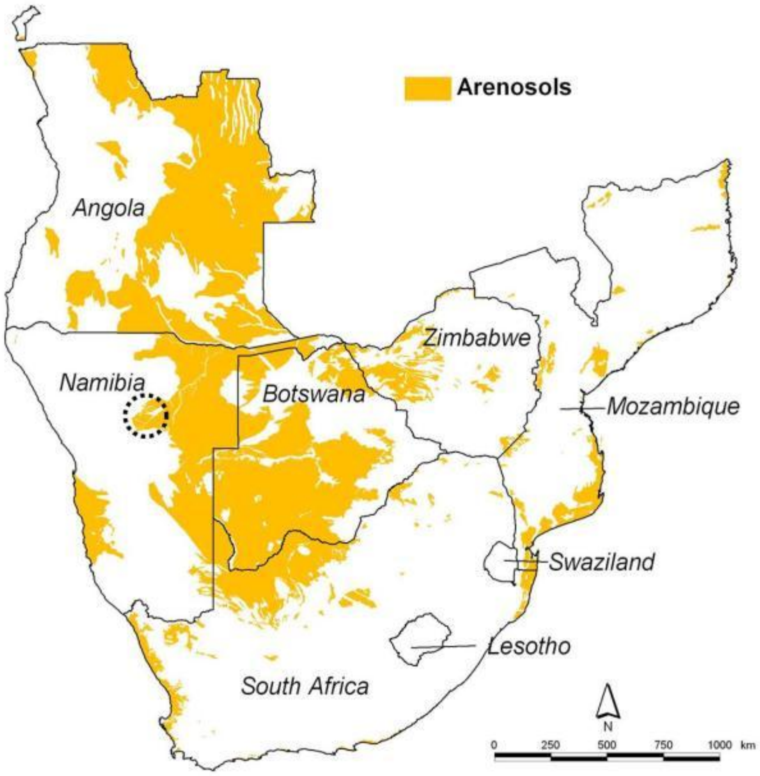


Figure 26 Simplified land-cover map of arenosols in Southern Africa (Hartemink & Huting, 2008)

The availability of P to the plant from soil is measured by P_B (Bray 1 or bicarbonate extractable method) in soils that have a pH<7.4. The available P was 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.

Soil analysis was done in camp 4 where the OF were kept. The area in camp 4 used for sampling covered 25 hectares with 20 points being sampled at a depth of 30cm and 100g samples being collected. The sub-samples were mixed and a representative sample was submitted for soil analysis (Table 14).

Table 14 Soil analysis results (elements expressed as mg/kg dry soil or mg/l for saturation extract)

pH (KCl)	4.88
P_B mg/kg	2
K mg/kg	65
Ca mg/kg	168
Mg mg/kg	42
Na mg/kg	7

Zn mg/l	0.04
Cu mg/l	0.2
Mn mg/l	7.96
Fe mg/l	8.12
Clay %	<10%

Results showed low concentrations of phosphorus and zinc in the soil and that it was a highly permeable soil due to the low clay content. The P_B recorded at 2mg/kg was the same low concentration tested by Hendrickson *et al.* (1994) in Northern Australia where both P fertilizer application and P supplementation of cattle increased dry matter intake and LW gain of cattle.

The water of the central watering point was analysed and the results are presented in Table 15.

Table 15 Water analysis

Total dissolved solids	384 mg/l
Sulphate (as SO_4)	21 mg/l
Nitrate	3.2 mg/l
Fluoride	0.6 mg/l
Iron	0.04 mg/l

Sodium	34 mg/l
Potassium	5 mg/l
Calcium (as $CaCO_3$)	103 mg/l
Copper	0.02 mg/l
Zinc	0.01 mg/l

The data reflects that the water was suitable for stock watering (Department of Water Affairs and Forestry, 1996a) and human consumption (Department of Water Affairs and Forestry, 1996b).

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. The stocking rate was used for the cattle on supplementation treatments (Chapter 3.3) together with ruminally cannulated cattle (Chapter 3.4) rotated through the same camps at the same time and separately the OF (Chapter 3.2) in Camp 4. The biomass stocking rate that was actually recorded at the end of the trial in the 6 nutrient supplementation treatment camps is shown in Table 16.

Table 16 Variation in biomass stocking rate (Kg/ha) for 116 cattle on the 1510ha experimental area during seasonal periods

Period	Kg/ha
'04 Dry (3 Jun '04 to 17 Nov '04)	18
Spring (18 Nov '04 to 26 Jan '05)	19
Wet (27 Jan '05 to 12 May '05)	24
'05 Dry (13 May '05 to 9 Sep '05)	27
Average	22

The actual average stocking rate that was recorded at 22kg/ha was slightly lower than the 25kg/ha that was targeted during the planning of the trial. The stocking rate during the 2004 dry season at 18kg/ha was much lower than the subsequent 2005 dry season at 27kg/ha. The stocking rate during the wet season ranged from 19kg/ha to 24kg/ha.

Significant numbers of Red Hartebeest (*Alcelaphus buselaphus*, average weight 130kg, predominantly grazers), Gemsbok (*Oryx gazelle*, average weight 220kg, 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) and Kudu (*Tragelaphus strepsiceros*, average weight 220kg, predominantly browsers) freely roamed the area and where not included in the calculation of the stocking rate.

3.1.6. Method

Three different groups of animals were used for data collection in this trial and were allocated to camps as presented in Table 17.

Table 17 Experimental site usage by different groupings of cattle and camp sizes

		Experimental outlay		
Camp number	Size (ha)	Oesophageally fistulated	Ruminally cannulated	Free-range foraging cattle
Camp 1	294		X	X
Camp 2	255		X	X
Camp 3	270		X	X
Camp 4	200	X		
Camp 7	246		X	X
Camp 8	170		X	X
Camp 9	275		X	X
Average	244	200	252	252

The first group in Chapter 3.2 were selected for oesophageal fistulation to determine forage quality. The group was kept in Camp 4 (200 ha) with 10 milking cows. The milking cows were in the camp for only 8 months of the year during the dry season and were rotated out of the camp for 4 months during the wet season. This brought the annual stocking rate to 25kg cattle live mass/ha and allowed the camp to recover during the wet season. The second group in Chapter 3.3 received five nutrient supplementation treatments (Table 19 and Table 20) and were subsequently slaughtered. The supplemented cattle were rotated through five of the six camps allocated (camp 1, 2, 3, 7, 8 and 9), which was situated around the seventh camp (camp 4) used by the OF. The last group of cattle in Chapter 3.4 were procured for ruminal cannulation and rotated with the cattle on the nutrient supplementation treatments.

The 119 crossbred (F1 and F2) cattle born on the farm Burgkeller, from May 2003 to July 2003, were weaned January/February 2004 at an average age of 7 months. They continued on a 6% phosphorus, salt and trace mineral lick mixture up to June 2004 (Table 18).

Table 18 Management of cattle in the time before the experimental period started

Age (Months)	Date	Management
0	May-03	BIRTH
1	Jun-03	
2	Jul-03	
3	Aug-03	SUCKLING FROM DAMS
4	Sep-03	
5	Oct-03	
6	Nov-03	
7	Dec-03	
8	Jan-04	WEANED
9	Feb-04	
10	Mar-04	6% phosphorus lick
11	Apr-04	
12	May-04	

The herd received the recommended vaccinations as prescribed by the local veterinarian. During April 2004 the cattle were removed from water and food for 24 hours and weighed. The six heaviest animals (267 ± 6kg; mean ± SD), from the starting group of 119 animals, were removed for taming and later were oesophageally fistulated (Chapter 3.2) and the lightest 3 animals were removed from the trial.

The remaining 110 cattle (Chapter 3.3) at an age of 12 months were weighed a consecutive month and the two weightings were used to determine an average starting live mass (224 ± 26Kg, mean ± SD). The group was sequentially stratified firstly by sex (50 steers 232 ± 23kg and 60 heifers 217 ± 26kg) and secondly by live weight and finally by breed type (22 Hereford 243 ± 20kg; 30 Charolais 232 ± 20kg; 58 Brahman 213 ± 24kg) and randomly allocated to one of five supplementation treatments (Chapter 3.3, Table 19).

Six crossbred cattle (360±18kg; mean ± SD) from an adjacent farming unit to the experimental unit were procured and ruminally fistulated (Chapter 3.4) during the same time when the oesophageal fistulations (Chapter 3.2) 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.

3.2. OESOPHAGEALLY FISTULATED CATTLE (OF)

3.2.1. Method

The cattle, described in Chapter 3.1.6, were given copper nose rings and were hand tamed before they were oesophageally fistulated as described by Osbourne & Bredon (1971). The OF were kept on kraal, at the farm house, over four weeks for recovery with daily supervision and fed a 6mm pelleted balanced maintenance diet (12% CP) and grass.

The OF then surgically received a neck loop as described by Kartchner & Adams (1983) shown in Figure 129, Figure 130 and Figure 131 in the Photo Appendix. The neck loop was an expensive part of the surgical establishment of the OF. The neck loop was well worth the investment because it negated the use of girth straps that substantially reduced the time required for the fitting and removal of collection bags. The OF were kept in the recovery kraal at the house for another two weeks to recover from the second set of surgeries. During the six week period of recovery the animals showed good recovery from the procedures and had gained weight. After the experimental period was concluded, the subsequent year, a steer was born to the heifer in the group of OF reflecting that the surgical procedures had no ill effects on production.

The spatulas for the fistula plugs were made from parts of PVC pipe and a 6mm stainless steel rod which was fastened with a quick drying chemical bonding cement (Q-bond™) and steel wire, so that the steel rod had longitudinal movement (Van Dyne & Torell, 1964). The bonding cement needed regular replacement due to wear and tear (Figure 133, Photo Appendix). Twice a week, the plugs were removed and the holes cleaned (Figure 128, Photo Appendix). 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.

The collection bags were made to the specifications of Bredon & Short (1971) and constructed from canvas material. The bottom of the bag had a permeable screen which was made of shadecloth with an 80% weaving density. At both sides, parallel to the animal's neck, 20 mm wide aluminium strips were stitched in to keep the bag from collapsing during collections (Figure 129, Figure 130 and Figure 131 in the Photo Appendix). Two fastener strips with buckles were stitched in to secure the bag around the animal's neck.

The temporary tubular oesophageal cannula devised by Olson & Malechek (1987) to prevent fistula contraction while the plug was out, was further refined by constructing the cannula from an ultra-light Teflon (fluoro polymer material) on a lathe. The tubular oesophageal cannula did not give satisfactory results with the animals used in this experiment and were later discarded. It took extra time to apply and remove the cannula which added to the animal's discomfort. The cannula was 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 and 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 cannula. The problem of the fistula constricting during collections was overcome by only inserting the bottom narrow part of the plug into the fistula opening 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 fully secured the next day, without much discomfort to the animal. A smaller diameter tapered plug was first inserted if the fistula closed more than normal and subsequently replaced by a wider plug.

3.2.2. Sampling periods

Every 3 weeks sampling with the 6 OF took place in camp 4. These collections were synchronised with the weighing of cattle on treatments (Table 19) and the collections of samples from the ruminally cannulated cattle (Chapter 3.4.1).

3.2.3. Sampling procedure

In the afternoon, 12h before the morning of scheduled collections, access to water and supplements were restricted. The morning of the collections the screen-bottomed canvas collection bags were fitted to the neck, through the neck loop as described by Kartchner & Adams (1983), after removal of the plug and spatula. The cattle were herded, in camp four, away from the more trampled parts around the water source with horses (Figure 132, Photo Appendix). The collections took place for 45-60 minutes and the animals were then again herded to the crush pen facilities (Figure 128, Photo Appendix). The bags were removed and any samples containing regurgitated rumen contents were discarded.

Due to the constriction of the fistula during the collections, the spatula and plug were reinserted with enough pressure to secure the plug in place but without causing the animal discomfort. The next day the plug and spatula was then secured in place after the fistula had time to adjust to its original position.

3.2.4. Sample preparation

The whole extrusa sample was removed from the screen bottomed collection bag. The extrusa was subdivided into smaller manageable parts and strained through a very fine cotton cloth and the excess saliva was discarded. The whole strained extrusa sample was placed in a plastic bag and frozen until the sample could be dried.

Freeze-drying, as suggested by Burritt *et al.* (1988) and Faber *et al.* (1995), of extrusa samples was not possible due to the remote location of the experimental site and the cost involved in the transport of frozen samples to the closest forage research laboratory with suitable equipment in neighbouring South Africa. The second factor that precluded freeze-drying was the cost of the technique with so many samples that needed to be processed.

Extrusa samples were dried in a forced draught oven at 50ºC for 48 to 52 hours. The use of a lower temperature setting for the oven, as suggested by Engels *et al.* (1981) and Faber *et al.* (1995) was found to be problematic for samples collected during the wet season due to high moisture levels in the extrusa that led to fungal growth on the samples. The oven temperature had to be increased to 60ºC for samples collect during the summer months to reduce the fungal growth during drying.

The dried samples were packaged and sent to the nutritional analysis lab of the University of Pretoria. The dried samples were ground to pass through a 1mm sieve screen of a Beaver mill before further lab procedures took place.

3.3. FORAGING FREE-RANGE CATTLE WITH LICK SUPPLEMENTS

3.3.1. Nutrient supplementation treatments

Five different nutrient supplementation treatment plans (Table 19) were allocated to the 5 groups of 22 cattle. The licks were changed according to the seasons within the treatment plans and were made available on an *ad libitum* basis. The trial period ran over 15months, from June 2004 until slaughter in September 2005. The treatment programs with different licks were planned to replicate existing supplementation practices that were in use in the extensive cattle farming areas in Namibia with different licks being made available during the dry and wet seasons.

Making available lick supplements on an *ad libitum* basis during the wet season was restricted to rock salt lick and 6% phosphorus lick due to high concentrations of nutrients in the newly grown vegetation that did not require any additional protein or energy containing raw materials to be supplemented in the diets of cattle. Supplements containing protein and energy were restricted to the dry season.

Rock salt treatment group (RST) served as the control in the experiment (Table 19). Rock salt lick was made available *ad libitum* to the RST during the dry and wet season and it only contributed electrolytes (sodium & chloride) to the diets of cattle. The physical presentation of the supplement was in block form as it was extracted from salt deposits along the Namibian coast and was predominantly licked by cattle to extract the electrolytes.

Six percent phosphorus treatment group (6%PT) primarily received phosphorus from the lick that was made available to them during the dry and wet season. A 6% phosphorus lick (Table 20) was obtained by mixing 50kg coarse salt with a 50kg phosphate concentrate manufactured in South Africa from de-fluorinated phosphoric acid to contain a minimum 120g/kg phosphorus (containing a vitamin and mineral premix, no molasses was used during the manufacture process). The 6% phosphorus lick was made available *ad libitum* during the dry and wet season to the 6%PT.

Table 19 Nutrient supplementation treatment programme for the experimental period with different licks used during the dry/spring season and wet season

Age (Months)	Date	Nutrient Supplementation Treatment[1] RST	6%PT	MTT	PDT	FST
13	Jun-04	Rock salt lick	6% Phosphorus lick	Maintenance lick	Production lick	Finisher lick
14	Jul-04					
15	Aug-04					
16	Sep-04					
17	Oct-04					
18	Nov-04					
19	Dec-04					
20	Jan-05					
21	Feb-05		6% phosphorus lick		6% Phosphorus lick	
22	Mar-05					
23	Apr-05					
24	May-05					
25	Jun-05		6% phosphorus lick	Maintenance lick	Production lick	Finisher lick
26	Jul-05					
27	Aug-05					
28	Sep-05					

[1] Treatment description:

RST: Rock salt treatment group – Rock salt lick available *ad libitum* as experimental control.
6%PT: Six percent phosphorus treatment group – Salt and trace-mineralised inorganic phosphorus lick available *ad libitum* during the dry and wet season.
MTT: Maintenance treatment group – Maintenance lick available *ad libitum* during the dry season and a salt and trace-mineralised inorganic phosphorus lick containing 6% phosphorus available *ad libitum* during the wet season.
PDT: Production treatment group – Production lick available *ad libitum* during the dry season and a salt and trace-mineralised inorganic phosphorus lick containing 6% phosphorus available *ad libitum* during the wet season.
FST: Finisher treatment group – Finisher lick available *ad libitum* during the dry season and a salt and trace-mineralised inorganic phosphorus lick containing 6% phosphorus available *ad libitum* during the wet season.

The maintenance treatment group (MTT) started with a maintenance lick (composition shown in Table 20) on an *ad libitum* basis during the dry season from June 2004 to January 2005. The maintenance lick primarily consisted of phosphorus (20g/kg) and crude protein (431g/kg) although a minimal quantity of energy (4MJ/kg ME) from molasses and wheat bran was also available. From February 2005 to May 2005, during the wet season, the MTT were changed over to the 6% phosphorus lick (composition shown in

Table 20) on an *ad libitum* basis. During the following dry season, from June 2005 to September 2005, the MTT was again given free access to the maintenance lick until slaughter.

Table 20 Lick supplements nutrient composition in g/kg (Dry matter basis) containing a standard trace mineral premix unit not presented in the table

Parameter	6% Phosphorus lick	Maintenance lick[1]	Production lick[2]	Finisher lick[3]
Dry matter	959	914	914	907
Ash	.	397	254	190
CP	.	431	274	210
NPN*	.	50	25	16
CP *ex* NPN		311	156	97
ADIN	.	7	8	10
IVDOM	.	799	828	833
FAT	.	9	24	25
NDF	.	132	196	212
ADF	.	54	67	79
ADL	.	27	27	29
Phosphorus**	60	20	8	7
Calcium	142	40	13	8
Na	.	106	80	58
ME (MJ/kg)***	.	4.0	7.3	8.5

* Sources: Urea, Mono-Ammonium Phosphate & Ammonium Sulphate
** Sources: Mono-Ammonium Phosphate, Dicalcium Phosphate & Mono Calcium Phosphate
*** Summed value from proportions of individual components within lick
<u>Organic raw materials included in descending order</u>
[1] Wheat Bran, Cane Molasses, Sunflower Oilcake
[2] Wheat Bran, Yellow Maize Meal, Hominy Chop, Cane Molasses & Sunflower Oilcake
[3] Wheat Bran, Yellow Maize Meal, Hominy Chop, Cane Molasses and Sunflower Oilcake

The Production treatment group (PDT) started with a production lick (composition shown in Table 20) on an *ad libitum* basis during the dry season from June 2004 to January 2005. The production lick had a higher concentration of energy containing raw materials in it with the addition of maize meal and hominy chop to the list of ingredients as set out for the maintenance lick. The production lick had lower concentrations of sodium (80g/kg), phosphorus (8g/kg), crude protein (274g/kg) as they were diluted by a higher inclusion of energy (7.3MJ/kg ME). From February 2005 to May 2005, during the wet season, the PTT group were changed over to the 6% phosphorus lick (composition shown in Table 20) on an *ad libitum* basis. During the following dry season, from June 2005 to September 2005, the PTT group was again given free access to the production lick until slaughter.

The Finisher treatment group (FST) started with a finisher lick (composition shown in Table 20) on an *ad libitum* basis during the dry season from June 2004 to January 2005. The finisher lick had the highest concentration of energy containing raw materials in it. The finisher lick had even lower concentrations of sodium (58g/kg), phosphorus (7g/kg), crude protein (210g/kg) compared to the production and maintenance licks and the highest concentration of energy (8.5MJ/kg ME). From February 2005 to May 2005, during the wet season, the FST were changed over to the 6% phosphorus lick (composition shown in Table 20) on an *ad libitum* basis. During the following dry season, from June 2005 to September 2005, the FST was again given free access to the finisher lick until slaughter.

All treatment groups received *ad libitum* access to a single lick at a time to maximise forage intake and animal performance (Beaty *et al.*, 1994). All licks were manufactured in Windhoek by a commercial feed compounder (Voermeester Pty. Ltd.) with a standard trace mineral premix, the only exception being the rock salt that contained no additional trace minerals which was sourced from Swakopmund.

The licks were placed in specifically designed closed lick troughs which cattle were trained to use at the start of the experimental period (Figure 145, Photo Appendix). The areas were regularly monitored by micro-light plane to verify that no wildlife learned to use the new lick troughs placed in the camps (Figure 144, Photo Appendix). Wildlife learned to open the closed lick troughs if sufficiently exposed to the devices. Personal communication with farmers in Namibia and personal experience has shown that wild ruminants consume considerable amounts of nutrient supplements placed for cattle.

3.3.2. Management of cattle

The camp rotation program for treatment groups is presented in Table 21 with the sizes of the camps and the duration between rotations. Randomised camp rotations took place on average every 21 days and each treatment was allocated nearly three periods in every available camp.

The experimental unit (1510ha) consisted of six from the available seven camps (1710ha) and the average camp size for nutrient supplementation treatment groups was 252ha with the largest camp at 294ha (Camp 1) and the smallest camp 170ha (Camp 8).

During the 2004 dry season (3 Jun ’04 to 15 Dec ‘04), spring season (16 Dec ’04 to 26 Jan ’05) and the 2005 dry season (13 May ‘05 to 13 Sep ‘05) six camps were continuously grazed by 5 treatment groups totalling 110 *Bos indicus* (Brahman) x *Bos taurus* (Charolais & Hereford) crossbred steers and heifers and 5 ruminally cannulated cattle (Chapter 3.4). One random camp was always rested between rotations.

During the wet season (27 Jan ‘05 to 12 May ’05) the supplementation treatment groups received only two from the five available licks, which allowed the opportunity to rest three camps per rotation during the active growth period of the vegetation. The treatment herds were combined 6%P & MTT and PDT & FST and the RST kept separately forming only three herds.

Table 21 Camp rotation program for nutrient supplementation treatment groups with the number days between rotations

Sampling date	RST	6%PT	MTT	PDT	FST	Rested Camps	Days
21-Jun-04	Camp 3	Camp 9	Camp 8	Camp 2	Camp 1	Camp 7	18
14-Jul-04	Camp 9	Camp 3	Camp 7	Camp 1	Camp 2	Camp 8	23
04-Aug-04	Camp 2	Camp 8	Camp 1	Camp 9	Camp 3	Camp 7	21
25-Aug-04	Camp 1	Camp 7	Camp 2	Camp 3	Camp 9	Camp 8	21
16-Sep-04	Camp 7	Camp 1	Camp 3	Camp 9	Camp 8	Camp 2	22
06-Oct-04	Camp 1	Camp 2	Camp 9	Camp 8	Camp 7	Camp 3	20
27-Oct-04	Camp 2	Camp 3	Camp 8	Camp 7	Camp 1	Camp 9	21
17-Nov-04	Camp 3	Camp 9	Camp 7	Camp 2	Camp 8	Camp 1	21
16-Dec-04	Camp 9	Camp 8	Camp 1	Camp 3	Camp 7	Camp 2	29
07-Jan-05	Camp 8	Camp 7	Camp 2	Camp 9	Camp 1	Camp 3	22
26-Jan-05	Camp 7	Camp 1	Camp 3	Camp 8	Camp 2	Camp 9	19
16-Feb-05	Camp 1	Camp 8		Camp 7		Camp 2 Camp 3 Camp 9	21
10-Mar-05	Camp 3	Camp 9		Camp 2		Camp 8 Camp 7 Camp 1	22
31-Mar-05	Camp 7	Camp 1		Camp 8		Camp 2 Camp 3 Camp 9	21
21-Apr-05	Camp 9	Camp 2		Camp 3		Camp 8 Camp 7 Camp 1	21
12-May-05	Camp 8	Camp 7		Camp 1		Camp 2 Camp 3 Camp 9	21
02-Jun-05	Camp 8	Camp 2	Camp 9	Camp 7	Camp 3	Camp 1	21
21-Jun-05	Camp 7	Camp 3	Camp 8	Camp 1	Camp 9	Camp 2	19
14-Jul-05	Camp 1	Camp 9	Camp 7	Camp 2	Camp 8	Camp 3	23
04-Aug-05	Camp 2	Camp 8	Camp 1	Camp 3	Camp 7	Camp 9	21
23-Aug-05	Camp 3	Camp 7	Camp 2	Camp 8	Camp 9	Camp 1	19
09-Sep-05	Camp 9	Camp 1	Camp 3	Camp 7	Camp 2	Camp 8	17

3.3.3. Data collection

The individual LW of each animal in the treatment group was recorded, before rotation to a new camp occurred, after the feed and water was withheld at least 12 hours before weighing. The difference between full and fasted weight has implications in comparing results across experiments because LW gain could be up to 8% lower and dressing percentage around 4% higher when fasted rather than full LW was recorded (Coates & Penning, 2000). LW could vary substantially over short periods without any change in body composition (Coates & Penning, 2000). This variation was due to gut fill (could account for over 20% of LW) and changes in body water volume (water intake may exceed 20% of LW).

Average daily nutrient supplement intake was calculated for every period by subtracting the remaining supplement in lick troughs from the total recorded supplement given to the treatment group over each period divided by the number of animals and number of days during the period.

All treatment groups were slaughtered at a time estimated when the PDT was on average ready to receive an optimum grading for export markets. Strydom (2002) proposed a minimum carcass weight of 230kg and a fat cover of 1 mm (Grade 1). An average LW of 460kg at around 27 months of age (A or AB grade) with a dressing percentage of 50% (Du Plessis & Hoffman, 2004) was found to be most likely to give the desired result. All treatment animals were slaughtered at a Meatco Pty. Ltd. Abattoir (Okahandja, Namibia) certified for European export and carcasses were graded by a qualified grader from the Meatboard of Namibia.

3.4. RUMINALLY CANNULATED CATTLE

3.4.1. Treatments

In Table 22 five of the six ruminally cannulated cattle were allocated one each to a nutrient supplement treatment group (Table 19) during the normal random camp rotations (Table 21) undertaken by the grazing free-range cattle. The ruminally cannulated cattle were significantly heavier than the treatment animals and the social hierarchy was easily re-established after introduction of the ruminally cannulated cattle into the supplementation treatment herd after each rotation.

Table 22 Camp rotation program by animal number for ruminally cannulated cattle

Sampling date	RST	6%PT	MTT	PDT	FST
21-Jun-04					
14-Jul-04					
04-Aug-04					
25-Aug-04	503: Camp 1	596: Camp 7	587: Camp 2	526: Camp 3	589: Camp 9
16-Sep-04	589: Camp 7	503: Camp 1	596: Camp 3	587: Camp 9	526: Camp 8
06-Oct-04	526: Camp 1	589: Camp 2	503: Camp 9	596: Camp 8	587: Camp 7
27-Oct-04	587: Camp 2	526: Camp 3	589: Camp 8	503: Camp 7	596: Camp 1
17-Nov-04	596: Camp 3	587: Camp 9	526: Camp 7	589: Camp 2	503: Camp 8
16-Dec-04					
07-Jan-05					
26-Jan-05					
16-Feb-05					
10-Mar-05		503, 526, 587, 589, 596: Camp 3			
31-Mar-05	503, 526, 587, 589, 596: Camp 1				
21-Apr-05					
12-May-05					
02-Jun-05	503: Camp 8	596: Camp 2	587: Camp 9	526: Camp 7	589: Camp 3
21-Jun-05	589: Camp 7	503: Camp 3	596: Camp 8	587: Camp 1	526: Camp 9
14-Jul-05	526: Camp 1	589: Camp 9	503: Camp 7	596: Camp 2	587: Camp 8
04-Aug-05	587: Camp 2	526: Camp 8	589: Camp 1	503: Camp 3	596: Camp 7
23-Aug-05	596: Camp 3	587: Camp 7	526: Camp 2	589: Camp 8	503: Camp 9
09-Sep-05					

A 5x5 Latin square design was used for the rumen cannulated animals during the dry season with 5 treatments (RST, 6%PT, MTT, PDT and FST) and 5 periods (every 21 days rotation between randomised camp allocations). This was duplicated by doing collections during the dry hot season (5 August to 17 November 2004) and the dry cool season (13 May to 23 August 2005). During the wet season (17 February and 31 March 2005) an incomplete block design was used with the treatment (RST or 6%PT) as the blocking variable.

3.4.2. Sampling procedure

The rumen cannulated cattle were collect together with the nutrient supplement treatment group cattle (Chapter 3.3) after each 21 day treatment period in randomly allocated camps. In the morning, 48h before sampling, access to water points were restricted but the forage and licks were still accessible to the rumen cannulated cattle and supplementation treatment cattle. The next morning, 24h before sampling, the cattle were allowed access to water before being moved to the central point of sampling. The cattle were then kept separately in their treatment groups with access to their lick, without water and feed. The afternoon, 12h before sampling, the licks were removed. On the morning of the sample collections the ruminally cannulated cattle were caught up from their individual supplementation groups and placed together in the crush pen and subsequently sampled.

The rumen cannulated cattle were sampled first, before the nutrient supplementation groups were weighed and oesophageal fistula collections took place, early in the morning of the day on which data collections took place. The blood was collected from the jugular vein, by jugular venapuncture shown in Figure 141 (Photo Appendix), before sampling of the ruminal fluid and faeces took place to ensure the minimum stress to the animal before blood collection. The blood sample (10ml) was taken in a gold topped Pathcare vacutainer with gel (the gel has a density intermediate to blood cells and serum) and five inversions of the vacutainer were done to mix blood with clot activator and placed in a refrigerator directly after collection and maintained between 2-5 degrees Celsius. The blood samples were transported, to the Windhoek Pathcare Laboratory within 8-16 hours after sampling, and centrifuged to separate the serum and blood cells. The serum sample was then packaged and sent by courier to the Pathcare Laboratory in Cape Town for further analysis. The parameters tested in the serum of the blood were inorganic phosphorus (Pi), calcium (Ca), blood serum urea nitrogen (BUN) and beta-hydroxybutyrate (BHB).

The plastic stopper of the Bar Diamond ruminal cannula was removed from the outer cannula that remained fitted in the rumen fistula. Two pieces of equipment were then used to obtain ruminal fluid samples. A 50 ml syringe was attached to a 4 mm wide and 550mm long plastic catheter to withdraw fluid samples. The syringe with catheter extension was then inserted into a 10mm wide by 500 mm long PVC pipe, for structural support, while probing different parts of the rumen (Figure 137). The PVC pipe had multiple 1 mm holes drilled into the bottom 50 mm part of the PVC pipe, 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 (Figure 136). 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. The pH of the rumen fluid was taken immediately. Duplicate 18ml rumen fluid samples were pipetted into 35ml urine plastic sample collection jars (Figure 140). One sample was preserved with 2 ml of a 50% H_2SO_4 solution for the determination of rumen ammonia-nitrogen (NH_3-N). The other sample was preserved with 2 ml of a 10% (m/v) NaOH solution for the determination of rumen volatile fatty acids. 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.

Faecal grab samples were collected from the rectum and the animals released from the crush pen.

3.4.3. Lab 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 (NH_3-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.

3.5. DETERMINATION OF RESULTS

3.5.1. Lab procedures

The dry matter (DM) and ash concentrations were determined according to the AOAC (2002) methods. Crude protein (CP) was calculated as 6.25 times the nitrogen (N) concentration 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 fibre (ADF), acid detergent lignin (ADL) and acid detergent insoluble nitrogen (ADIN) were determined according to Goering and Van Soest (1970).

After wet digestion with a nitric-perchloric acid mixture the calcium (Ca) concentration was measured using an atomic absorption spectrophotometer and the sodium (Na) concentration using a flame emission spectrophotometer. The photometric method using molybdovanadate was used to measure phosphorus (P) concentrations (AOAC, 2002). The SO_4 concentration was determined using atomic absorption spectrophotometry (Plant analysis) and converted to sulphur (S) by calculation.

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.

3.5.2. Units of measure

The units of measure were adopted as suggested by the American Institute of Nutrition (1997) and are reported as determined by the international system of units (SI) (Young, 1987). The results received from the Pathcare Laboratory were partly reported in SI units. The conversion of results received from commercial laboratories in the SI to traditional values for blood and rumen analysis results are given in Table 23 for comparison to previous referenced results.

Table 23 Conversion factor table for analysis results of inorganic phosphorus (Pi), calcium (Ca), blood urea nitrogen (BUN) and ammonia between SI units of measure (mmol/l) and traditional measures (mg/dl or mg/100ml) adopted from Young (1987)

	Conversion factor	
Parameter	SI to Old	Old to SI
Phosphorus (Inorganic)	3.096	0.323
Calcium	4.000	0.250
Urea Nitrogen	2.801	0.357
Ammonia	1.704	0.587

The beta-hydroxy butyrate was measured to a 10^{-3} smaller unit and converting the old unit of mg/dl to µmol/l a conversion factor of **96.05** was used. To convert back to the old unit a conversion factor of **0.0104** was used (Young, 1987).

3.5.3. Statistical design

An analysis of variance with the Proc GLM model (SAS, 1994) was used to determine the significance (5%) between variables. Least square means and standard deviations (s.d.) were calculated (Samuels, 1989).

3.6. GROUPING OF DATA BY SEASON

The distribution of sampling dates into semi-arid subtropical seasons was done according to major trends observed in liveweight (LW) change of foraging free-range cattle (CHAPTER 4) and forage quality collected from oesophageally fistulated cattle (OF) (CHAPTER 5) as defined by Table 24.

Table 24 Seasonal grouping by sampling dates at deflection points in average liveweight gain and forage quality compared to the length of these seasonal periods and the rainfall recorded

Period	Season	Days	Rainfall (mm)
3 Jun '04 to 17 Nov '04	2004 Dry	167	19
18 Nov '04 to 26 Jan '05	Spring	70	109.5
27 Jan '05 to 12 May '05	Wet	106	167.5
13 May '05 to 9 Sep '05	2005 Dry	120	0

w

The 2004 dry season was fully under way by the time the trial started and the last rainfall was recorded during March 2004. Very little green veld could be seen in the camps.

The spring season was confirmed by the data collections on 16 Dec ’04 when the grasses and herbs started becoming green due to growth. Some trees had already started flowering during October 2004 and many of the bushes and smaller trees were becoming green due to the first leave growth visible by 18 Nov ‘04 (Figure 143). By the time the collection on 17 Nov ’04 had occurred a total of 19mm rain had been recorded. The rain consisted of an early 5mm (16 Sep ’04) rain shower which was followed by the first productive rainfall of 14mm recorded over 6 days before this collection on 17 Nov ’04 (4mm on 28 Oct ’04, 5mm on 29 Oct ‘04, 2mm on 1 Nov ’04 and 3mm on 2 Nov ’04). During the period up to the collection on 16 Dec ’04 a further 10mm was recorded in two showers of 6mm (18 Nov ’04) and 4mm (29 Nov ’04). The spring season seemed to follow one to two months after the first "productive rainfall" (defined as 10mm rain over 24 hours by Olzewski, 1996 and Kruger, 1998) was recorded with a total rainfall of 29mm recorded during this period.

From 17 Dec ’04 to 26 Jan ’05 an additional 99.5mm over 41 days was recorded in 10 rain showers. The first "substantial rainfall" (defined as 25mm over 24hours by Olzewski, 1996 and Kruger, 1998) occurred from 30 Dec ’04 to 31 Dec ’04 which contributed 27mm of rain. The wet season was identified by the data collections on 16 Feb ’05 by which time the camps were covered in green veld. During the wet season the total rainfall recorded was 167.5mm from 27 Jan ’05 to 31 Mar ’05 which was 64 days. The last rain recorded during the wet season was a "substantial rainfall" event of 32mm on 31 Mar ’05. No rain was recorded from 1 Apr ’05 to the end of the wet season on 12 May ‘05.

The 2005 dry season was identified by data collections on 2 Jun ’05 which was 63 days after the last rain was recorded during the wet season. The green colour of the forage in the camps had disappeared and the range vegetation was again mostly yellow and brown of colour.

Figure 27 illustrates that spring occurred 4 to 6 weeks after the first productive rainfall (4mm on 28 Oct ’04 and 5mm on 29 Oct ’04) was recorded. The start of the wet season occurred 4 to 6 weeks after the first substantial rainfall (7mm on 30 Dec ’04 and 20mm on 31 Dec ‘04) was recorded. The dry season started 6 to 8 weeks after the last substantial rainfall (32mm on 31 Mar ‘05) was recorded during the wet season.

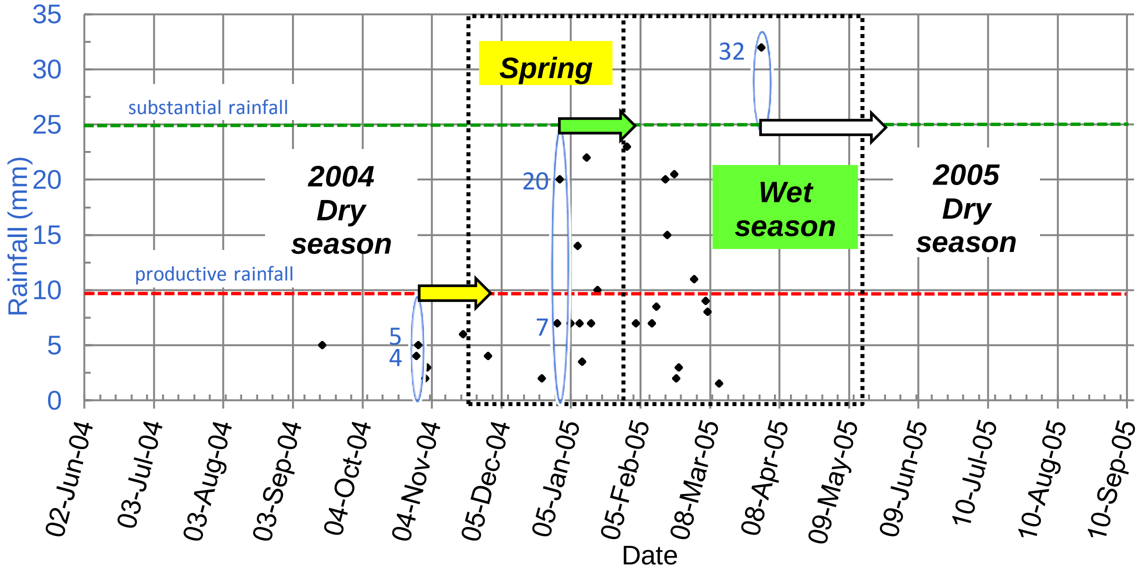


Figure 27 Productive (10mm/day) and substantial (25mm/day) rainfall events recorded during the trial period followed by latent periods before the first animal liveweight data from free-range cattle and forage quality results from oesophageally fistulated cattle responded to the seasonal progression from dry season to spring to wet season and back to dry season.

CHAPTER 4 SEASONAL LIVEWEIGT CHANGE

It is absolutely necessary to measure animal performance to apply results obtained to similar production situations (Van Niekerk, 1996; Coates & Penning, 2000). The average liveweight (LW) (Table 25) of 22 cross-bred heifers and steers per nutrient supplementation treatment group were monitored for 15 months from 3 June 2004 to 9 September 2005.

Table 25 Average liveweight (LW) in kilogram after overnight fasting on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Date	RST	6%PT	MTT	PDT	FST	S.E.M
03-Jun-04	222	224	229	225	221	6
14-Jul-04	228	221	230	225	229	6
04-Aug-04	218	234	233	221	230	6
25-Aug-04	213^{a}	232^{b}	243^{b}	232^{b}	238^{b}	6
16-Sep-04	218^{a}	237^{b}	246^{b}	233^{ab}	241^{b}	6
06-Oct-04	220^{a}	239^{b}	254^{b}	241^{b}	254^{b}	6
27-Oct-04	211^{a}	245^{b}	247^{b}	243^{b}	254^{b}	6
17-Nov-04	208^{a}	247^{b}	252^{b}	247^{b}	264^{b}	6
16-Dec-04	211^{a}	237^{b}	251^{b}	253^{b}	270^{c}	6
07-Jan-05	214^{a}	245^{b}	268^{c}	267^{c}	285^{d}	6
26-Jan-05	209^{a}	252^{b}	270^{c}	265^{bc}	289^{d}	6
16-Feb-05	225^{a}	273^{b}	291^{c}	288^{bc}	313^{d}	7
10-Mar-05	257^{a}	299^{b}	318^{bc}	310^{b}	337^{c}	7
31-Mar-05	267^{a}	313^{b}	330^{bc}	324^{b}	348^{c}	7
21-Apr-05	287^{a}	332^{b}	351^{bc}	339^{b}	361^{c}	7
12-May-05	300^{a}	351^{b}	369^{bc}	362^{bc}	384^{c}	8
02-Jun-05	302^{a}	358^{b}	376^{bc}	356^{b}	384^{c}	8
21-Jun-05	294^{a}	351^{b}	365^{bc}	355^{bc}	373^{c}	8
14-Jul-05	286^{a}	348^{b}	365^{bc}	359^{bc}	374^{c}	8
04-Aug-05	285^{a}	357^{b}	368^{b}	357^{b}	399^{c}	7
23-Aug-05	279^{a}	349^{b}	369^{bc}	371^{cd}	392^{d}	8
09-Sep-05	276^{a}	349^{b}	377^{c}	370^{bc}	401^{d}	8

^{abcd} Row means with different superscripts differ significantly ($P<0.05$)
S.E.M: Standard error of means

The LW were compared on the various nutrient supplementation treatment strategies to determine if the 6%PT, MTT, PDT and FST would result in increased performances, through higher body weights, than the control to the experiment (RST).

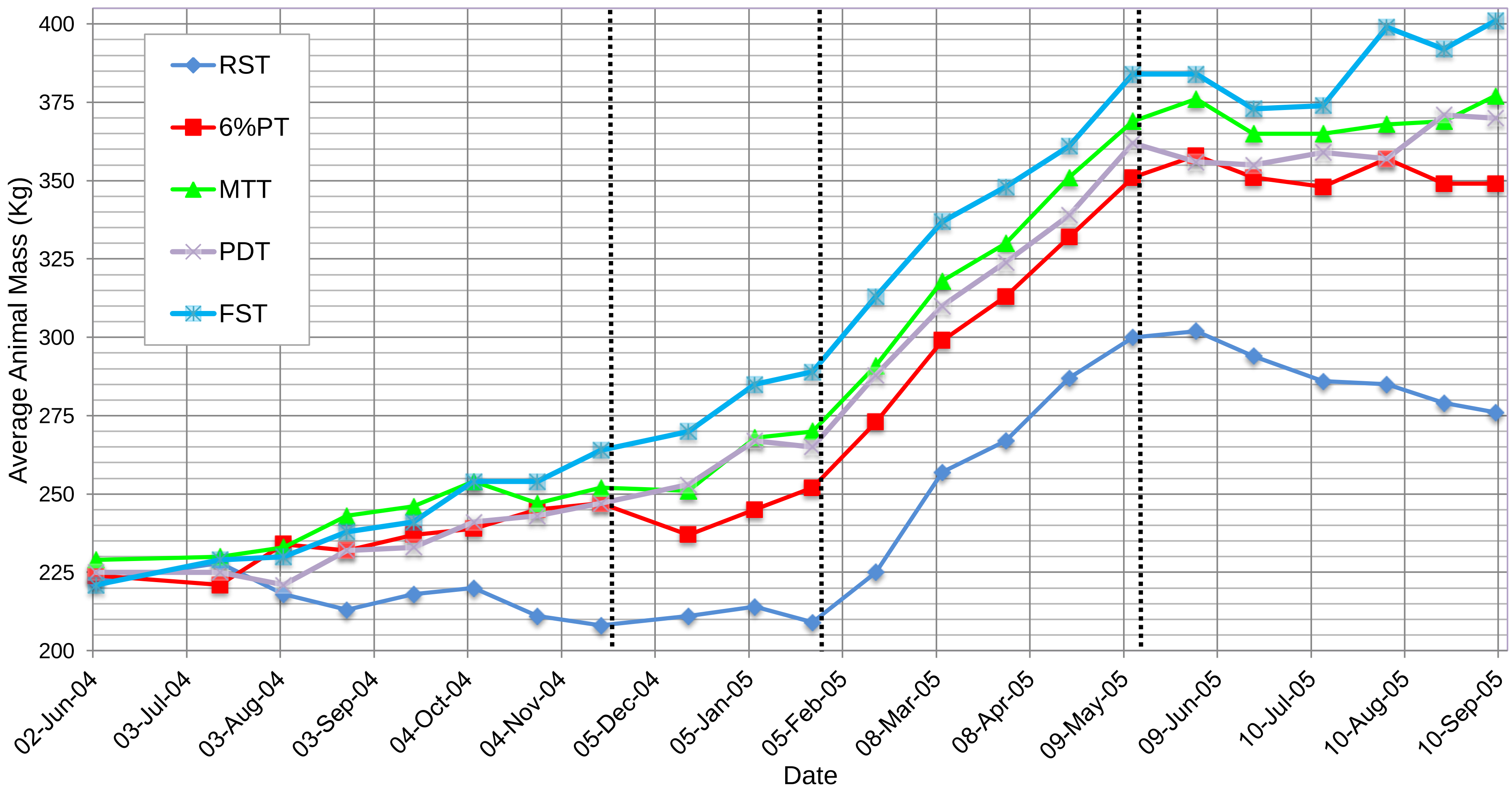


Figure 28 Average cattle liveweight in kilogram after overnight fasting on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST). Dotted vertical lines show seasonal groupings for interpretation (Table 24)

The seasonally averaged LW (Table 26) and change in LW over the season was calculated as the average 30 day kg LW change per treatment in Table 27.

Table 26 Average liveweight in kilogram over different periods of the trial for groups of cattle on different supplementation treatments defined as rock salt treatment (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Period	RST	6%PT	MTT	PDT	FST
3 Jun '04 to 17 Nov '04	217	235	242	233	241
18 Nov '04 to 26 Jan '05	211	245	263	262	281
27 Jan '05 to 12 May '05	267	314	332	325	349
13 May '05 to 9 Sep '05	287	352	370	361	387

Table 27 Kilogram average monthly (30 days) weight change per animal over different periods of the trial for groups of cattle on different supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Period	RST	6%PT	MTT	PDT	FST
3 Jun '04 to 17 Nov '04	-2.5	4.1	4.1	4.0	7.7
18 Nov '04 to 26 Jan '05	0.4	2.1	7.7	7.7	10.7
27 Jan '05 to 12 May '05	25.8	28.0	28.0	27.5	26.9
13 May '05 to 9 Sep '05	-6.0	-0.5	2.0	2.0	4.3

4.1. ROCK SALT TREATMENT GROUP (RST)

In the absence of substantial nutrients being supplemented, by only making available rock salt, the productivity of the RST was directly related to the quantity and quality of the veld consumed by the treatment group (Coates & Penning, 2000). The interpretation of the OF results obtained in the following Chapter with the LW changes of the RST in this Chapter help to fully understand the pasture-animal relationship to manage the feeding of supplements.

In Figure 28 the RST started to lose weight 41 days into the trial from 15 Jul ’04 and continued the overall trend in losing weight for 196 days until 26 Jan ’05 where the average weight loss was 19kg per animal and the daily weight loss was 97g. During this period the RST became significantly lower in weight compared with the other treatments on 25 Aug ’04 which was 84 days after the start of the trial. The cattle LW graph in Figure

28 showed that the RST could not maintain LW during the 2004 dry season and declined at 84g/day over this period. The general trend for weight loss during the dry seasons was established for the duration of the trial, but during a short period, minimal growth was recorded. The period of positive gain was recorded over 42days from 26 Aug ’04 to 6 Oct ’04 where there was a total average weight gain of 7kg/animal, which represented an average daily gain of 166g.

During the spring season, there was very little change in LW. With improved veld quality, from 27 Jan ’05 to 12 May ’05, the RST was able to sustain growth of 858g/day. This was the lowest recorded average weight gain of all supplementation treatments during the wet season.

During the next 21 days to the weighing on 2 Jun ’05 there was a small gain of only 2kg per animal where after the weight loss of the group again commenced. The next 99 days until 9 Sept ’05 the total average weight loss per animal recorded was 26kg and the average daily weight loss was 262g. During the 2005 dry season the RST had the highest average LW losses recorded at 200g/day.

During the whole trial period the RST had gained an average of 54kg/animal and had a significantly lower weight than all the other treatment groups. The RST was regularly observed chewing foreign objects, also called pica, which was a symptom of a P deficiency in the diet.

4.2. SIX PERCENT PHOSPHORUS TREATMENT GROUP (6%PT)

The 6%PT gained weight from 3 Jun ’04 to 17 Nov ’04 with an average 23kg weight gain per animal over 167 days representing average daily gain of 138g during the 2004 dry season. On 25 Aug ’04 the 6%PT became significantly heavier than the RST with no significant differences being observed with other treatment groups.

During the next period of 29 days to 16 Dec ’04 into the spring season the group lost an average of 10kg/animal representing an average daily weight loss of 345g. This allowed the FST to become significantly heavier on 16 Dec ’04 and continued to be heavier than the 6%PT until the end of the trial. After this period of weight loss the group regained an average of 8kg/animal up to 7 Jan ’04 and recovered another average of 7kg/animal until 26 Jan’05. Gut fill was affected by herbage quality, being least when herbage was lush and highly digestible and increasing as herbage became fibrous. Gut fill was likely to increase progressively as the pasture matured and its quality declined (Coates

& Penning, 2000). The change in body weight due to gut fill was illustrated by the retention time of digesta of different digestibility's in Figure 1 and was illustrated by the difference in observed gut fill in Figure 137 (dry season on RST) and Figure 138 (wet season) in the Photo Appendix. This could explain the sudden drop in LW by the 6%PT occurring from 17 Nov '04 to 16 Des '04 and the persistent weigh deficit compared to the MTT, PDT and FST which was again reduced at the onset of the dry cool season with lower quality material being consumed with increased gut fill. The 6%PT showed no weight change for 72 days during this period from 27 Oct '04 to 7 Jan '05. On 7 Jan '05 the MTT and PDT become significantly heavier than the 6%PT for the first time.

The rate of weight gain improved from 27 Jan '05 to 12 May '05, which represented a period of 106 days. The group showed an average weight gain of 99kg/animal that translated into an average daily gain of 934g. At the end of this period, the 6%PT was significantly heavier than the RST but also significantly lower in weight than the FST and no significant differences were observed with the MTT and PDT.

The next phase from 13 May '05 to the end of the trial on 9 Sep '05, which extended over 120 days, the group barely maintained their weight and lost an average of 2kg/animal. The total weight gain over the experimental period recorded was an average of 125kg/animal. The 6%PT ended with a significantly higher weight than the RST. The 6%PT ended at a significantly lower weight than the MTT and FST with no significant difference being recorded in comparison to the PDT.

4.3. MAINTENANCE TREATMENT GROUP (MTT)

The MTT had a modest growth rate from the onset of the trial until the 26 Jan '05 with the period lasting 237 days with the average weight gain per animal in the group being recorded at 28kg, which represented a daily average gain of 118g. On 25 Aug '04 the MTT became significantly heavier than the RST and on 7 Jan '05 become significantly heavier than the 6%PT. The FST become significantly heavier than the MTT on 16 Dec '04 but by 10 Mar '05 the difference again became non-significant.

During the wet season over a period of 106 days from 27 Jan '05 to 12 May '05 the group recorded an average weight gain of 99kg/animal which represented an average daily gain of 934g which was the same as that recorded by the 6%PT.

The last phase of 120 days, from 13 May '05 to 9 Sep '05, the group gained an average of 8kg/animal at an average daily gain of 67g. The total average weight gain over the trial period was 148kg/animal and the group was significantly heavier than the RST and 6%PT. The MTT weighted significantly less than the FST on 4 Aug ’05 and did not recover this deficit during the remainder of the trial. No significant difference in weight was recorded against the PDT.

4.4. PRODUCTION TREATMENT GROUP (PDT)

The PDT established a modest growth rate from the onset of the trial until 26 Jan ’05 with the period lasting 237 days with the average weight gain per animal in the group being recorded at 40kg, which represented a daily average gain of 169g. On 25 Aug ’04 the PDT became significantly heavier than the RST and on 7 Jan ’05 become significantly heavier than the 6%PT. The FST became significantly heavier than the PDT on 16 Dec ’04 but by 12 May ’05 the difference again became non-significant.

During the wet season over a period of 106 days from 27 Jan ’05 to 12 May ’05 the group recorded an average weight gain of 97kg/animal which represented an average daily gain of 915g, which was slightly lower than that recorded by the 6%PT and MTT.

The last phase of 120 days, from 13 May ’05 to 9 Sep ’05, the group gained an average of 8kg/animal at an average daily gain of 67g. At the end of the trial on 9 Sept ’05 the PDT had gained an average of 145kg/animal and weighed significantly less than the FST, but significantly more than the RST and 6%PT. The PDT had no significant difference compared to the MTT at the end of the trial.

4.5. FINISHER TREATMENT GROUP (FST)

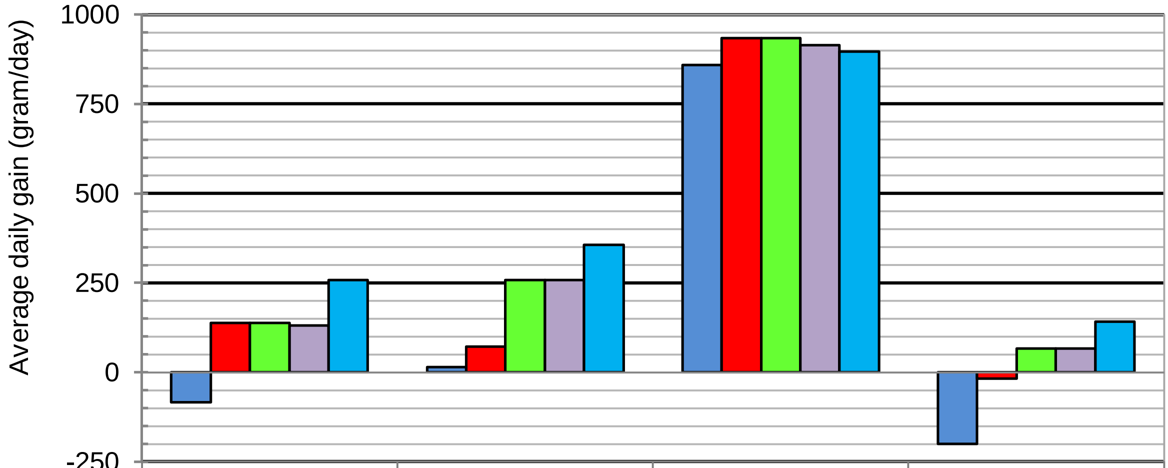
The FST (Figure 28) established the highest growth rate from the onset of the trial until 26 Jan ’05 with the period lasting 237 days with the average weight gain per animal in the group being recorded at 68kg/animal, which represented a daily average gain of 287g. On 25 Aug ’04 the FST became significantly heavier than the RST and on 16 Dec ’05 became significantly heavier than the remainder of the treatments.

During the wet season over a period of 106 days from 27 Jan ’05 to 12 May ’05 the group recorded an average weight gain of 95kg/animal which represented an average daily gain of 896g which was slightly lower than that recorded by the 6%PT, MTT and PDT.

The last phase of 120 days, from 13 May ’05 to 9 Sep ’05, the group gained an average of 17kg/animal at an average daily gain of 142g. At the end of the trial on 9 Sept ’05 the PDT had gained an average of 180kg/animal and weighted significantly more than all the other treatment groups.

4.6. CONCLUSION

Distinctively different periods in the rate of weight gain, recorded at intervals of three weeks after a camp rotation, were observed during the trial and these were grouped according to the season in Figure 29. The first improvement seen in the LW gain was the month after the onset of the rain season that was defined as the spring season. The second deflection point in LW gain was the month after the month in which maximal rainfall was recorded. The duration of the wet season (last rain shower was 32mm on 31 March ’05) had very little influence on the LW changes and it seemed that within 7 to 9 weeks after the last rain the LW gain reached a turning point (13 May ’05 to 2 June ’05). During the 2004 and 2005 dry seasons the cattle had great difficulty in gaining weight.



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
RST	-84	14	858	-200
6%PT	138	71	934	-17
MTT	138	257	934	67
PDT	132	257	915	67
FST	257	357	896	142

Figure 29 Average daily weight change in grams per animal over different periods of the trial for groups of cattle on different supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The LW of the RST fell behind all other treatment groups during the early part of the 2004 dry season and continued to record significantly lower weights for the duration of the trial. The RST indicated the baseline nutritional value of the forage available to the cattle during the trial against which all other nutrient supplementation strategies could be measured. The forage was not able to maintain cattle weight during the dry season although high growth rates were supported during the wet season. The group showed clear signs of pica during the dry season, which indicated a P deficiency in their diet. It was easy to identify the group from a distance when weighing them, at the central watering point in the presence of other supplementation groups, as they were the group always restless and chewing anything available in their surroundings.

The 6%PT had similar LW gains as recorded by the MTT, PDT and FST up to end of the 2004 dry season on 17 Nov ’04. The 6%PT had a sudden unexpected drop in LW of 10kg, from 18 Nov ’04 to 16 Dec ’04, as the spring season started. The FST became significantly heavier in weight than the 6%PT at the onset of the spring season on 16 Dec ’04 and the difference was maintained up to the end of the trial. The MTT and PDT became significantly heavier than the 6%PT during the next weighing on 7 Jan ’05. This drop in weight by the 6%PT could have occurred due to increased amounts of highly digestible green forage being consumed that would have caused a reduction in gut fill that was more pronounced than the MTT, PDT and FST which had higher diet digestibility’s due to the nutrients these supplements contributed. As the spring season passed onto the wet season and then changed into the 2005 dry season the weight differences between the 6%PT and the MTT and PDT again became non-significant.

At the end of the trial the RST was significantly lower in weight and the FST heavier than the other three treatments that were ranked in between. The PDT had similar weights to the 6%PT and MTT, although the MTT was significantly heavier than the 6%PT. These results had clearly shown that there was a phosphorus deficiency in the veld consumed during the dry season (RST) and that the supplementation of phosphorus throughout the year (6%PT, MTT, PDT and FST) resulted in significantly higher animal performances during the experimental period compared to the RST. MTT with both P and CP supplementation gave an improvement in production above 6%PT, but the improvement was not of the same magnitude as observed between the 6%PT and RST.

Compensatory growth (growth continues at an accelerated rate after a long period of feed restriction) was probably occurring in all groups during the wet season due to the lower quality forage on offer during the dry season. During the wet season, the RST seemed to record a slightly higher level of compensatory growth compared to the 6%PT, MTT, PDT and FST. Table 28 estimates the growth rates for the treatment groups over the different seasons expressed as the average daily growth in grams per kilogram LW.

Table 28 Grams average daily animal weight gain per kilogram liveweight during different periods of the trial for groups of cattle on different supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Period	RST	6%PT	MTT	PDT	FST
3 Jun '04 to 17 Nov '04	-0.39	0.59	0.57	0.56	1.07
18 Nov '04 to 26 Jan '05	0.07	0.29	0.98	0.98	1.27
27 Jan '05 to 12 May '05	3.21	2.98	2.81	2.82	2.57
13 May '05 to 9 Sep '05	-0.70	-0.05	0.18	0.18	0.37

Due to the significantly lower LW at the start of the wet season, the RST could not catch up to the other treatment groups by the end of the wet season, although they had a slightly higher rate of gain at 3.21g/kg LW/day. The 6%PT (2.98g/kg LW/day) also seemed to be gaining weight at a slightly higher rate than the MTT (2.81g/kg LW/day), PDT (2.82g/kg LW/day) and the FST (2.57g/kg LW/day), which recorded the lowest rate of gain during the wet season.

CHAPTER 5 VELD QUALITY

Six oesophageally fistulated cattle (OF), supplemented with a 6% phosphorus and trace mineral lick throughout the trial period, were used to collect forage selected by cattle every 3 weeks. The quality of the forage was used to estimate the contribution of the tree and shrub savannah (veld) towards the diet of the cattle on lick supplementation treatments. The nutritional status and performance of free-range foraging ruminants could then be evaluated against the estimated baseline nutrition, which the OF were able to select from the veld, in addition to the average nutrient intakes from different *ad libitum* nutrient supplementation treatment programs. The rock salt treatment group (RST), receiving only rock salt lick, would present the baseline diet as only electrolytes were contributed to this groups dietary requirements from the licks. The RST would reflect the nutritional status and performance that could be expected in cattle that fully relied on the quality of veld selected by the OF reported in this chapter.

The change in the quality of the veld selected by OF was strongly influenced by the rainfall distribution. The seasons were defined in Table 24 (Chapter 3.6) by grouping the collection dates according to rainfall in conjunction with the major changes in LW, which coincided with changes in the quality of the veld selected by the OF in this Chapter.

5.1. MOISTURE AND ASH

The veld selected by free-ranging ruminants contained different concentrations of moisture throughout the year with the highest moisture concentrations during the wet active growing season and the lowest moisture concentrations during the senescent phase in the dry season. The OF technique used to collect the veld samples resulted in the samples being soaked in the cattle's saliva and the moisture concentrations could therefore not be determined. The results on the OF collected veld were obtained on a dry matter basis (DM). In Table 29 the values were corrected for ash (Chapter 2.2.6) to an organic matter basis (OM) due to saliva containing small amounts of minerals and also the ingestion of soil during times where animals were foraging close to the soil surface.

The organic matter and ash concentrations are presented in Table 29. The ash had a range of 42g/kg to 128g/kg. The organic matter concentrations of the samples were between 872g/kg to 958g/kg during the year (Figure 30). The samples collected during the dry season, from 4 Aug '04 to 17 Nov '04 and again from 2 June '05 to 9 Sept '05, had low ash values that ranged from 42g/kg to 78g/kg.

Table 29 Average g/kg ash and g/kg organic matter (OM) selected by oesophageally fistulated cattle during different sampling periods

Date	Ash	OM
04-Aug-04	71	929
25-Aug-04	78	922
16-Sep-04	69	931
06-Oct-04	65	935
27-Oct-04	44	956
17-Nov-04	44	956
16-Dec-04	70	930
07-Jan-05	75	925
26-Jan-05	114	886
16-Feb-05	128	872
10-Mar-05	73	927
31-Mar-05	109	891
21-Apr-05	65	935
12-May-05	55	945
02-Jun-05	52	948
21-Jun-05	65	935
14-Jul-05	53	947
04-Aug-05	49	951
23-Aug-05	42	958
09-Sep-05	46	954

The three highest ash concentrations recorded where 26 Jan ‘05 at 114g/kg, 16 Feb ’05 at 128g/kg and 31 Mar ’05 at 109g/kg during the spring and wet season. These high ash concentrations depressed the organic matter concentration of samples during the wet season as seen in Figure 30.

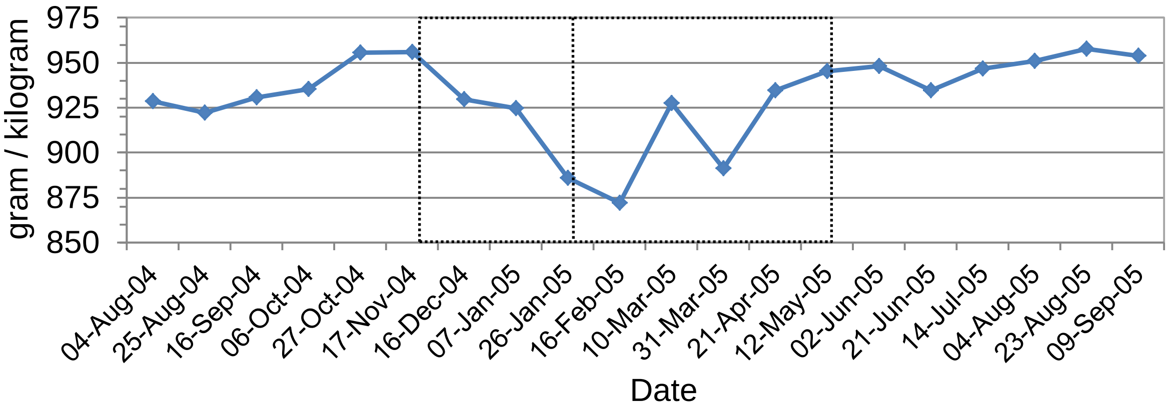


Figure 30 Average organic matter in veld selected by oesophageally fistulated cattle during different sampling periods

Soil mineral contamination of extrusa samples (Wallace *et al.*, 1972) was at the highest during this period due to animals foraging close to the soil surface where the new plant growth was located.

5.2. CRUDE PROTEIN

The crude protein (CP) concentrations of veld (Table 30) selected by OF are shown in Figure 31. The highest values for CP (OM) occurred during the spring and wet season. The CP (OM) had a seasonal tendency with the CP concentrations increasing from 36g/kg at the end of the 2004 dry season to 190g/kg at the end of the spring season and subsequently decreasing to 63g/kg at the end of the wet season.

Table 30 Average g/kg crude protein (CP) of veld selected by oesophageally fistulated cattle during different sampling periods reported on an organic matter basis (OM)

Date	CP (OM)
04-Aug-04	43
25-Aug-04	50
16-Sep-04	43
06-Oct-04	41
27-Oct-04	30
17-Nov-04	36
16-Dec-04	103
07-Jan-05	105
26-Jan-05	190
16-Feb-05	150
10-Mar-05	96
31-Mar-05	105
21-Apr-05	65
12-May-05	63
02-Jun-05	59
21-Jun-05	64
14-Jul-05	33
04-Aug-05	41
23-Aug-05	37
09-Sep-05	40

The 2004 dry season from 4 Aug 04’ to 17 Nov ’04 had a CP (OM) range from 30g/kg to 50g/kg. The 2005 dry season from 2 Jun ’05 to 9 Sept ’05 had a CP (OM) range from 33g/kg to 64g/kg. The range during both dry seasons was from 30g/kg to 64g/kg. The combined ranges during the spring and wet seasons were from 63g/kg to 190g/kg.

The CP concentrations showed a declining trend from after the highest concentrations recorded during the wet season until the next rainy season commenced, which was in agreement with Cronjé (1990) that the nutritional value of veld decreased after the month of maximum rainfall. Van Schalkwyk (1975) similarly found that the CP concentration increased towards the month of maximal rainfall in January after which it decreased to the lowest point in the late winter (July to October) in Namibia.

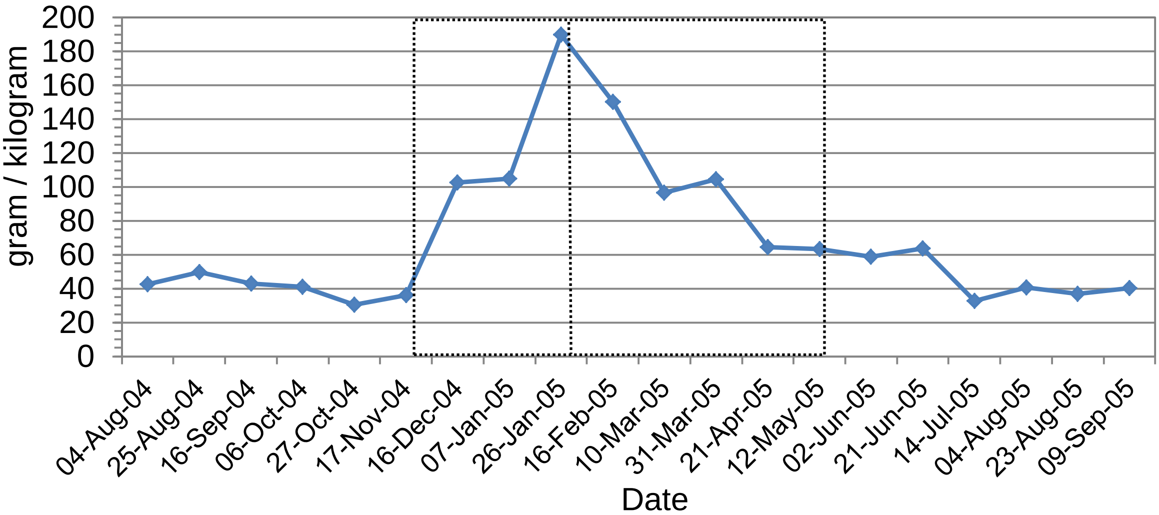


Figure 31 Average crude protein concentration in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis

The CP concentrations of below 63g/kg (OM) during the dry season suggested that there was not enough N to meet the needs of rumen microbial populations (Van Soest, 1994) and decreased performance would be observed due to decreased intake (Coleman, 2005). Forage intake responses to protein supplementation were generally observed when the forage crude protein concentration was less than 60 to 80g/kg (NRC, 1987).

The quantity and distribution of rainfall had a marked influence on the CP concentration of the selected forage as confirmed by McKay & Frandsen (1969). A strong positive correlation existed between rainfall per month and CP in veld selected by OF on an organic matter basis (r = 0.92). An equation for the linear regression between rainfall per month and CP on an organic matter basis (R^2 = 0.85) is shown in Figure 32.

The strong relationship observed in Figure 32 was in agreement with McKay & Frandsen (1969), Karn & Lorenz (1983) and De Waal (1990) who found that the CP concentrations of forage obtained from OF were directly dependent on the rainfall distribution.

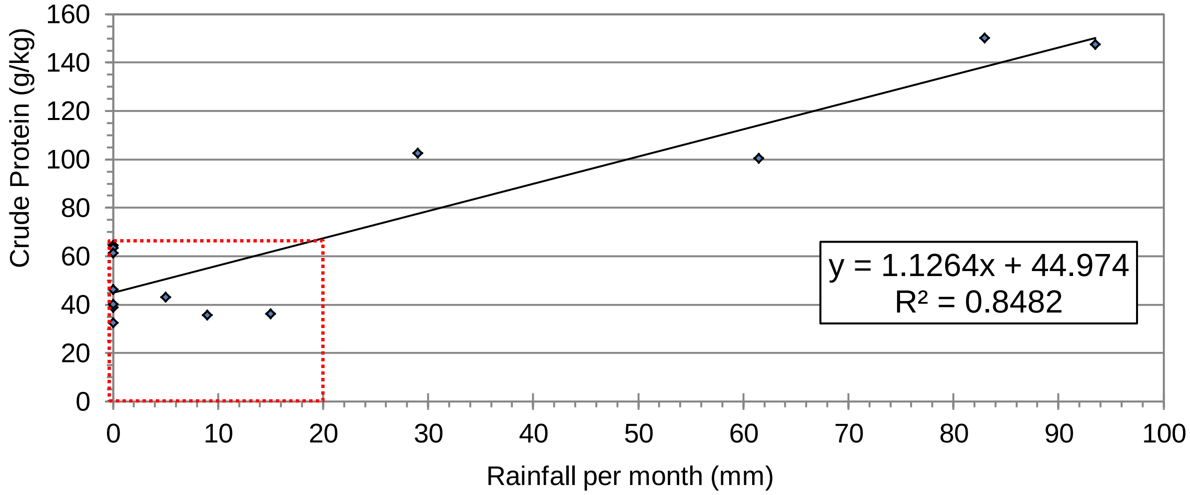


Figure 32 Linear regression line between monthly total rainfall and crude protein in veld selected by oesophageally fistulated cattle on an organic matter basis

The linear regression in Figure 32 suggested that with a monthly rainfall of at least 20mm the veld selected by OF would reach a minimum 68g/kg CP (OM) concentration that would have resulted in improved feed intake by cattle (NRC, 1987; Coleman, 2005), if the volume of forage on offer was not limiting.

5.3. PHOSPHORUS

The phosphorus (P) concentrations of veld (Table 31) selected by OF are shown in Figure 33. The P had a seasonal tendency with the P (OM) concentrations increasing from 1.02g/kg at the end of the 2004 dry season to 3.07g/kg at the end of the spring season and subsequently decreasing to 1.33g/kg at the end of the wet season.

The 2004 dry season, from 4 Aug 04’ to 17 Nov ’04, had a P (OM) range from 0.83g/kg to 1.19g/kg. The 2005 dry season, from 2 Jun ’05 to 9 Sept ’05, had a P (OM) range from 0.66g/kg to 1.12g/kg.

Table 31 Average g/kg phosphorus (P) concentration of veld selected by oesophageally fistulated cattle during different sampling periods reported on an organic matter basis (OM)

Date	P (OM)
04-Aug-04	0.83
25-Aug-04	1.19
16-Sep-04	1.07
06-Oct-04	1.02
27-Oct-04	0.85
17-Nov-04	1.02
16-Dec-04	1.90
07-Jan-05	1.62
26-Jan-05	3.07
16-Feb-05	2.57
10-Mar-05	1.65
31-Mar-05	1.83
21-Apr-05	1.47
12-May-05	1.33
02-Jun-05	1.12
21-Jun-05	0.95
14-Jul-05	0.93
04-Aug-05	0.96
23-Aug-05	0.66
09-Sep-05	0.76

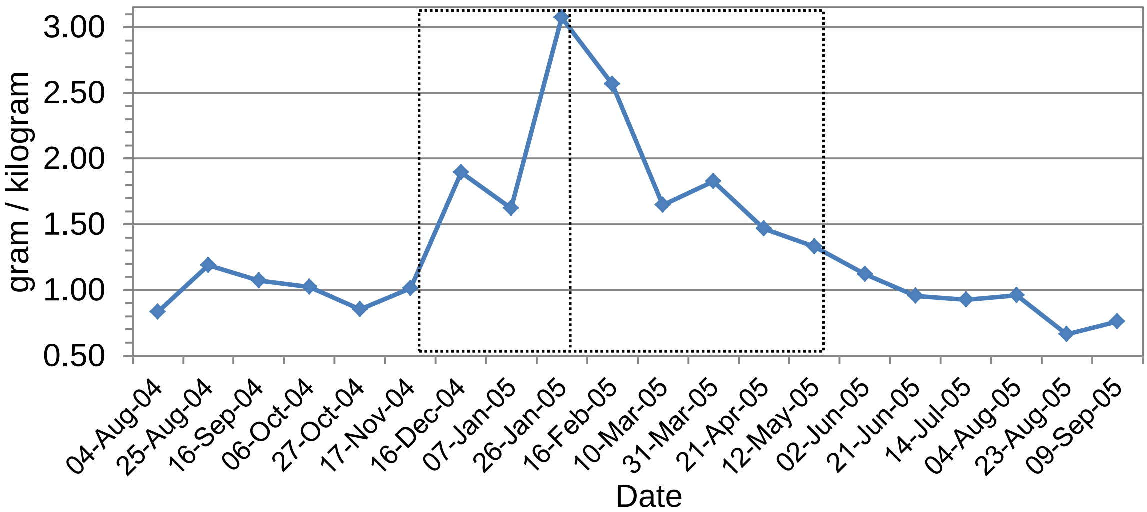


Figure 33 Average phosphorus concentration in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis

The combined range for P (OM), during the dry seasons, was from 0.66g/kg to 1.19g/kg. The combined ranges during the spring and wet seasons were from 1.33g/kg to 3.07g/kg.

A strong positive correlation existed between rainfall per month and P in veld selected by OF on an organic matter basis (r=0.89). An equation for the linear regression between rainfall per month and P on an organic matter basis (R^2 = 0.78) is presented in Figure 34.

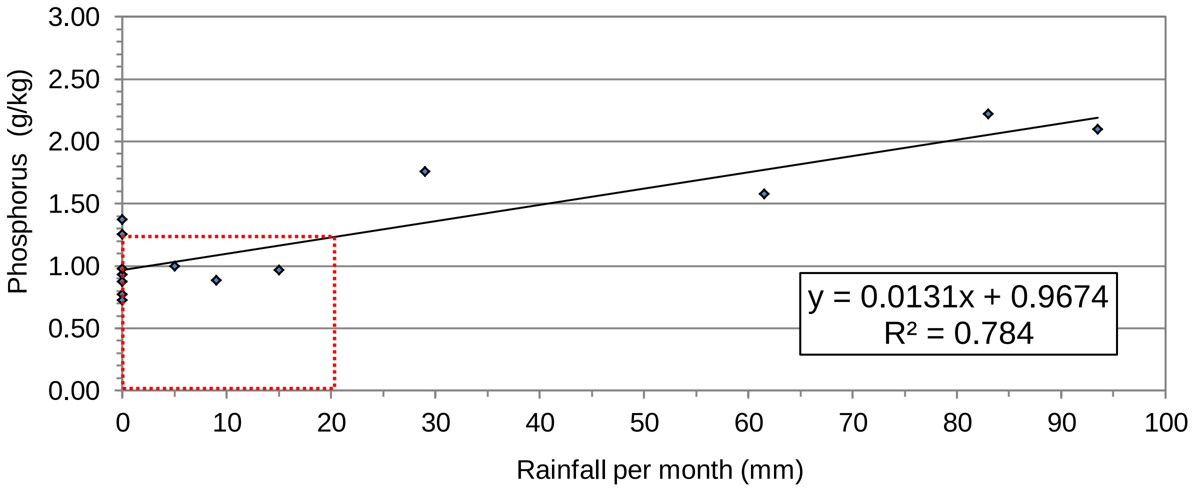


Figure 34 Linear regression line between monthly total rainfall and phosphorus in veld selected by oesophageally fistulated cattle on an organic matter basis.

A monthly rainfall minimum of 20mm, illustrated by Figure 32, indicated that the CP (68g/kg CP (OM)) selected by OF from veld would be sufficient for optimal feed intake. The 20mm rainfall level in the linear regression in Figure 34 estimated the minimum OF P (OM) concentration of 1.23g/kg, which corresponded with the estimated 68g/kg CP (OM) minimum concentration for optimal feed intake. This was in agreement with Ternouth *et al.* (1996) that published that a forage concentration of 1.5g/kg P was required for 0.5kg/day growth in 300kg cattle and that a concentration below 1.2g/kg P would only allow maintenance of body weight. The lowest P (OM) concentration measured during the experimental period during the wet season was recorded at 1.33g/kg, which allowed for body maintenance and growth, if the volume of forage on offer was not limiting.

An equation for the linear regression (R^2 = 0.95) between P (OM) and CP (OM) is presented in Figure 35. A stronger positive correlation (r = 0.97) existed between P and CP in veld selected by OF than the relationship between rainfall per month and P in veld selected by OF (Figure 34).

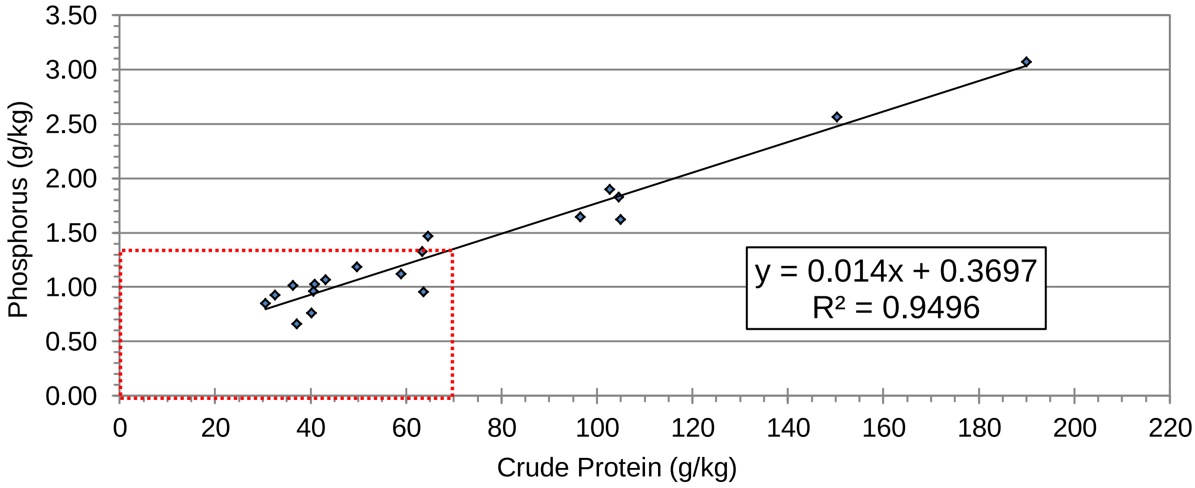


Figure 35 Linear regression line between phosphorus and crude protein in veld selected by oesophageally fistulated cattle on an organic matter basis

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 onset of spring and an improvement in LW gain during the wet season seemed to occur at a minimum OF veld CP concentration of 70g/kg (OM). This suggested that the veld selected by OF in the linear relationship (Figure 35) would have a minimum P (DM) concentration of 1.35g/kg. These estimates were similar to the concentrations derived by the linear relationship between the rainfall and P (OM) in Figure 34 at 1.23g/kg.

The P concentration of forage selected by cattle was a useful diagnostic tool in determining the P status of cattle (Karn, 1995; Karn, 1997; 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).

Ternouth *et al.* (1996) suggested that the forage selected by cattle, weighing from 100 to 500kg, needed to contain a minimum P concentration of 0.9 to 1.0g/kg for the animals to maintain LW on a low quality diet (q=0.4 in Table 7) as found during the dry season in this trial. The recorded P (OM) values for the dry season periods ranged from 0.66g/kg to 1.19g/kg. The rock salt treatment group (RST) in Figure 29, which only received rock salt lick, recorded bodyweight maintenance or loss during this period as suggested by Ternouth *et al.* (1996).

Ternouth *et al.* (1996) suggested that the forage selected by cattle, on high quality diets (q=0.5 in Table 7) as found during the wet season of the trial, to grow 0.5kg/day was from 2.9 g/kg P (100kg LW) to 1.5g/kg P (500kg LW). For cattle to grow 1.0kg/day was from 3.4 g/kg P (100kg LW) to 1.6g/kg (500kg LW). The recorded P (OM) values for the spring and wet season's period ranged from 1.33g/kg to 3.07g/kg. These concentrations supported between 0.5kg to 1.0kg/day growth rates, during the wet season in this trial, by the RST in Figure 29. During the spring season, the P (OM) levels were 1.62g/kg to 3.07g/kg, but the volume of forage on offer was probably limiting which did not allow for optimal growth rates in the RST.

5.4. CALCIUM AND CALCIUM TO PHOSPHORUS RATIO

The calcium (Ca) concentrations of veld (Table 32) selected by OF are shown in Figure 36. The range of values in Ca (OM) recorded during the year was the lowest at 1.94g/kg recorded on 23 Aug '05 during the dry season and the highest at 8.54g/kg recorded on 26 Jan '05 at the end of the spring season.

During the dry seasons the Ca (OM) concentrations had a very wide range of 1.94g/kg to 6.88g/kg. During the spring season the Ca (OM) concentrations were at the higher range of the maximum concentrations recorded during the year where the Ca (OM) range was 6.49g/kg and 8.54g/kg. The ranges recorded during the wet season Ca (OM) was lower at 2.81g/kg to 4.52g/kg.

Table 32 Average g/kg calcium (Ca) concentrations and the calcium to phosphorus ratio (Ca:P) of veld selected by oesophageally fistulated cattle during different sampling periods reported on an organic matter basis (OM)

Date	Ca (OM)	Ca:P (OM)
04-Aug-04	3.18	3.9
25-Aug-04	6.88	5.5
16-Sep-04	4.54	4.3
06-Oct-04	6.58	6.5
27-Oct-04	3.78	4.6
17-Nov-04	5.06	5.0
16-Dec-04	7.21	3.9
07-Jan-05	6.49	4.0
26-Jan-05	8.54	2.7
16-Feb-05	4.52	1.8
10-Mar-05	3.55	2.2
31-Mar-05	4.21	2.3
21-Apr-05	2.81	1.9
12-May-05	4.49	3.4
02-Jun-05	5.71	5.1
21-Jun-05	5.51	5.7
14-Jul-05	2.66	3.0
04-Aug-05	2.66	2.8
23-Aug-05	1.94	2.9
09-Sep-05	2.86	3.8

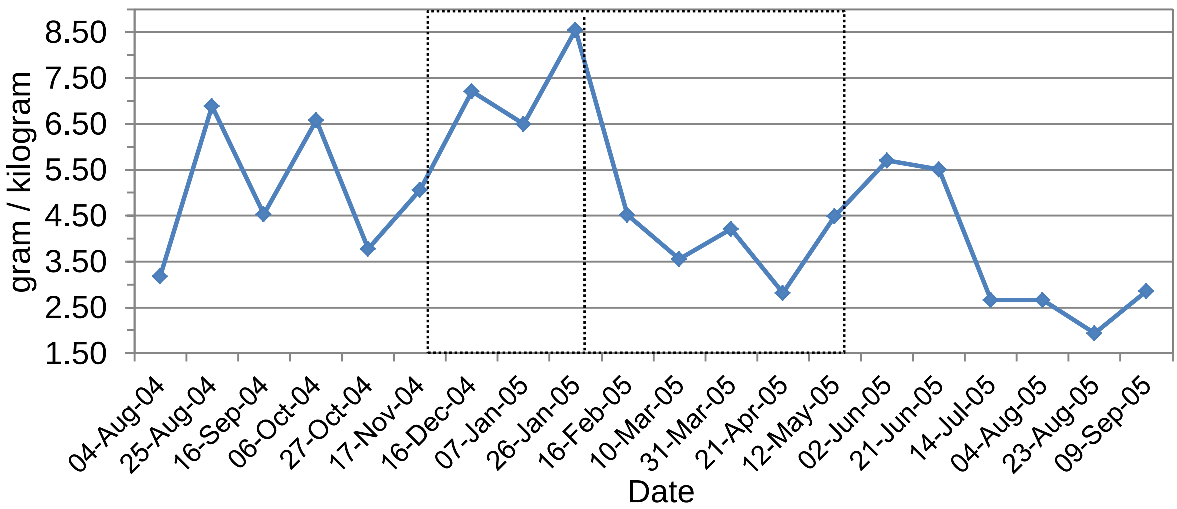


Figure 36 Average calcium concentration in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis

Ca concentrations in the diets of cattle, between 200kg to 400kg LW, with 1.8g/kg to 2.5g/kg would be adequate for maintenance of body weight (NRC, 2000). Ca concentrations in diets from 2.5g/kg to 5.0g/kg would be adequate for growth of between 0.1kg/day to 1kg/day. The NRC (2000) stated that similar animal performance would be expected with a Ca to P ratio of 1:1 to 7:1.

The calcium to phosphorus ratio (Ca:P) in the veld (Table 32) is illustrated in Figure 37. The Ca:P corresponded well to the diet selection patterns of cattle, which showed a seasonal tendency in the relative contributions of grass and browse to the total diet of cattle, as observed by Mphinyane (2001) in Botswana under similar climatic conditions of this trial. The seasonal plant class distribution in cattle diets found by Mphinyane (2001) 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.

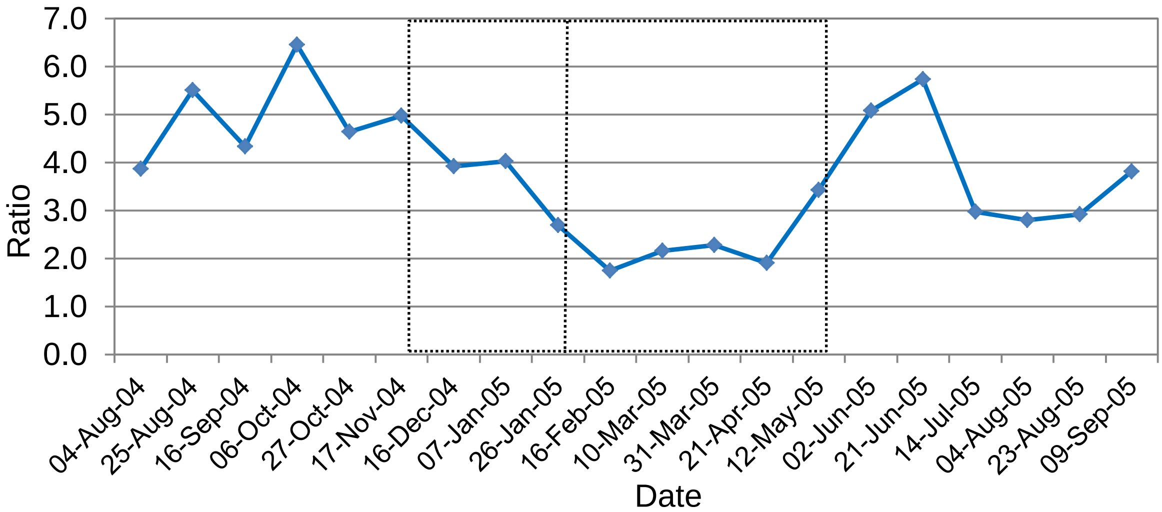


Figure 37 Average calcium to phosphorus ratio in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis (OM)

The Ca:P (OM) showed an increasing trend during the 2004 dry season from a low at 3.9 up to 6 Oct '04 where it had reached a maximum ratio of 6.5. During the end of the 2004 dry season the OF were observed selecting more bush and less grass due to reduced availability. The trend observed in the Ca:P in the diet selected by OF in Figure 37 corresponded with the maximal inclusion of browse in the diet during the middle of the dry hot season (Mphinyane, 2001). Rothauge (2006) similarly found that the nutritional nadir towards the end of the grazing period resulted in cattle being forced to make increasing use of browsed veld when the grasses were dormant and did not regrow after defoliation.

Lukhele & Van Ryssen (2003) found no consistent seasonal pattern in the Ca concentrations in the foliage of subtropical tree species, ranging from 7.9g/kg (DM) to 16.0g/kg (DM), but warned that all species that were investigated had exceptionally high concentrations of Ca and lower P concentrations. Havenga *et al.* (2004) also reported high Ca:P levels of *Boscia* spp found in the subtropical parts of southern Africa. The inclusion of increasing levels of the foliage of these tree species would increase the Ca:P in cattle diets during the end of the dry season when they would start growing leaves.

From the widest Ca:P, recorded in the dry hot season, it had a decreasing trend towards end of the 2004 dry season at 5.0 and continued decreasing during spring to 2.7. During the start of the wet season on 16 Feb ’05 it reached the lowest recorded Ca:P of 1.8 after which it increased towards the end of the wet season. The first frost was recorded during the month of June 2005 and another bout of frost occurred during July 2005. The Ca:P decreased sharply during the months where frost was recorded to 3.0 and then again steadily increased towards the end of the 2005 dry season.

5.5. FORAGE QUALITY AFFECTED BY OVEN DRYING

The extrusa samples were dried by forced draught oven at 50ºC to 60ºC 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 concentrations 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 from the analysis for NDF (Robertson & Van Soest, 1981), ADF, ADL, ADL, ADIN (Goering & Van Soest, 1970) and IVDOM (Tilley & Terry, 1963 modified by Engels & Van der Merwe, 1967) are presented in Table 33.

Table 33 Average g/kg neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), acid detergent insoluble nitrogen (ADIN), *in vitro* digestible organic matter (IVDOM) concentrations of veld selected by oesophageally fistulated cattle during different sampling periods reported on an organic matter basis (OM)

Date	NDF (OM)	ADF (OM)	ADL (OM)	ADIN (OM)	IVDOM (OM)	IVDOM: CP(OM)*
04-Aug-04	784	518	78	5.6	592	14.0
25-Aug-04	772	556	90	6.7	655	13.2
16-Sep-04	762	564	95	6.0	614	14.3
06-Oct-04	786	546	90	5.9	588	14.5
27-Oct-04	818	567	85	4.5	521	17.2
17-Nov-04	822	546	100	10.1	523	15.0
16-Dec-04	769	540	154	24.4	464	4.6
07-Jan-05	768	561	176	24.6	411	4.1
26-Jan-05	699	544	220	25.2	358	1.9
16-Feb-05	725	493	113	13.5	599	4.0
10-Mar-05	791	484	84	10.1	606	6.3
31-Mar-05	763	475	92	11.8	649	6.2
21-Apr-05	819	486	84	8.3	588	9.1
12-May-05	785	517	113	8.1	590	9.6
02-Jun-05	795	537	141	9.7	575	9.9
21-Jun-05	754	540	158	10.6	462	7.6
14-Jul-05	830	545	96	4.7	516	16.3
04-Aug-05	795	805	91	4.3	589	14.9
23-Aug-05	825	798	100	4.6	545	14.7
09-Sep-05	824	749	119	4.7	477	11.9

* Ratio

The neutral detergent fibre (NDF) in the extrusa (Table 33) collected by OF is illustrated in Figure 38. During the dry seasons the range of values recorded for the NDF was 754g/kg to 830g/kg. The highest NDF values were recorded at the end of the dry seasons with a range of 818g/kg and 825g/kg.

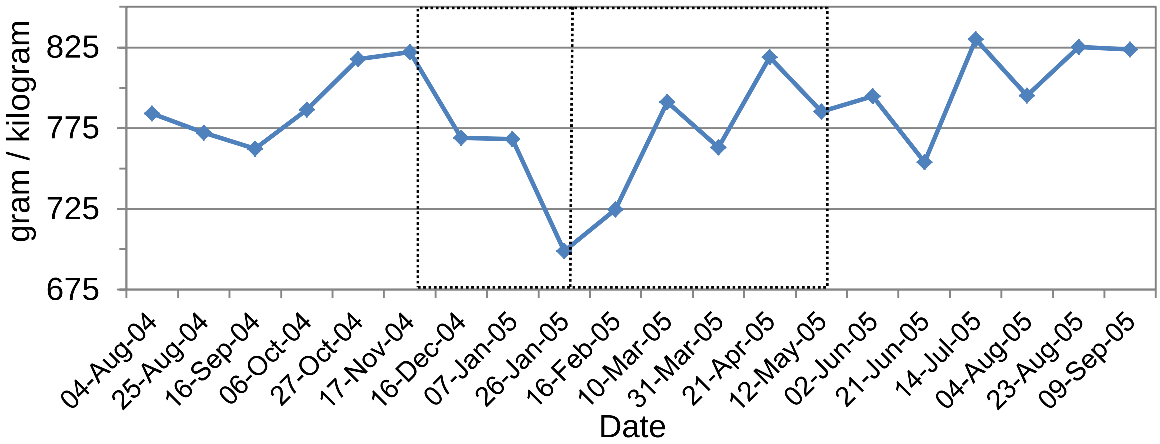


Figure 38 Average neutral detergent fibre concentration in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis

During the spring and wet season the NDF trend was the inverse of the CP (Figure 31) and P (Figure 33) trends. The NDF values decreased to the lowest recorded value of 699g/kg at the end of the spring season and then started increasing during the wet season ending at 785g/kg.

The trend established in NDF values in the extrusa collected by OF during seasonal changes of forage (Figure 38) was similar to the seasonal trends established in results obtained by Burritt *et al.* (1988) in sheep and goats with extrusa samples being freeze dried, presented in Figure 39. The NDF (Freeze) had an increasing trend, starting at 350g/kg to 450g/kg NDF, as the dry season progressed with lower quality forage remaining in the veld, to around 500g/kg, and then dropped during spring as the plants started growing (350g/kg) and increased as the wet season progressed (towards 400g/kg). The oven-dried samples at 40ºC showed no drop during the wet season by Burritt *et al.* (1988), which was the opposite of the current trial results. The range of values in NDF for Burritt *et al.* (1988) was 350g/kg to 550g/kg, which was much lower than the 699g/kg to 825g/kg observed in Figure 38.

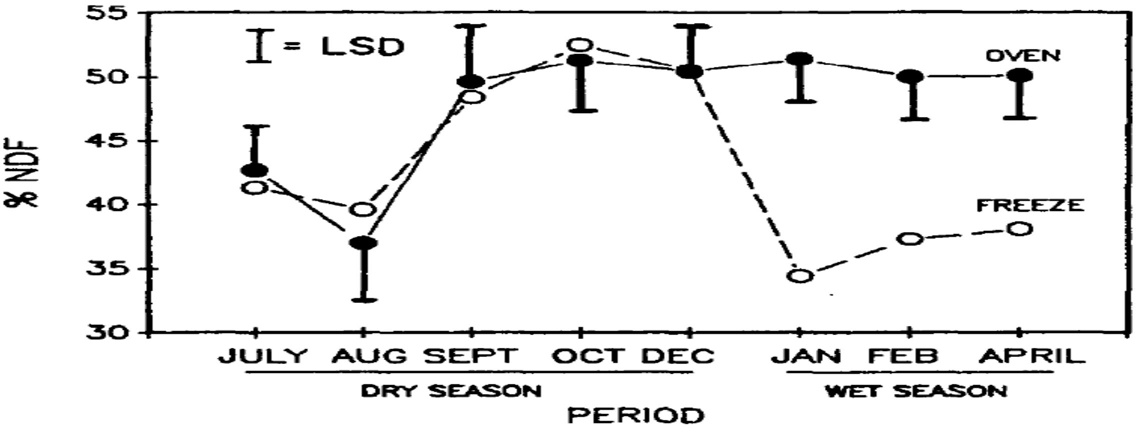


Figure 39 Effect of oven (40°C) and freeze-drying on the neutral detergent fibre (NDF) concentration of extrusa from browsing oesophageally fistulated sheep and goats (Burritt *et al.*, 1988)

These trends were also in agreement with O'Reagain & Mentis (1988) finding that as the season progressed from the start of the rainy season the dietary quality declined as the veld became increasingly stemmy with higher concentrations in NDF.

The acid detergent fibre (ADF) in the extrusa samples (Table 33) as collected by OF is illustrated in Figure 40. The range of values during the 2004 dry season for the ADF was 518g/kg to 567g/kg. The next dry season the last three collections had a range of 749g/kg to 805g/kg, which were much higher than expected and could have been a result due to forage availability becoming limited and very low quality plant material being selected.

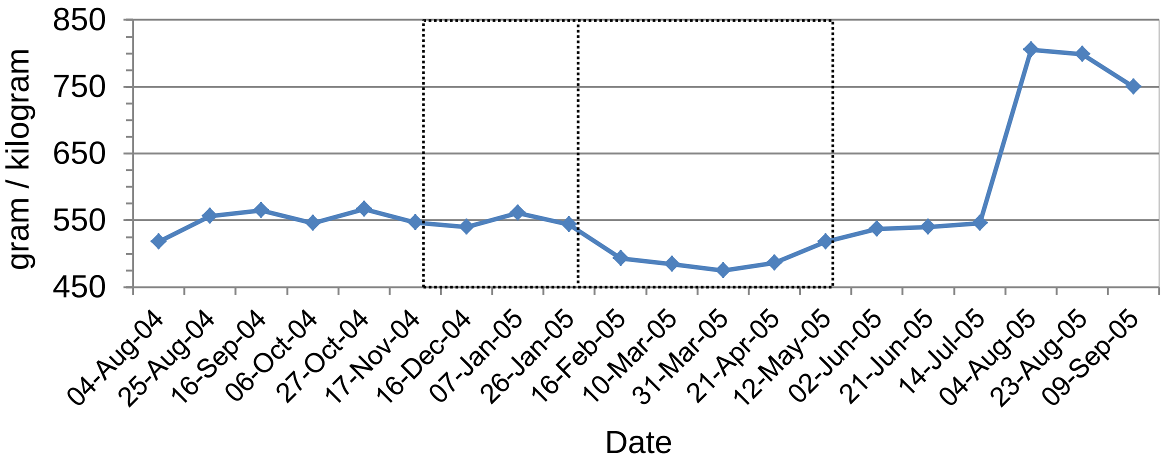


Figure 40 Average acid detergent fibre concentration in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis

The ADF concentrations decreased during spring to a low point on 16 Feb ’04 at 544g/kg at the start of the wet season. The ADF values then again started increasing into the 2005 dry season.

The trend observed in Figure 40 was comparable to the trend observed by Van Schalkwyk (1978) in Figure 11 with the highest ADF values being recorded during the dry season and the lowest values recorded during the wet season, with the highest values being recorded towards the end of the dry season. The ranges of values from 319g/kg to 469g/kg recorded in ADF by Van Schalkwyk (1978) in Figure 11 were much lower than the range of 489g/kg to 766g/kg recorded in Figure 40. The three highest points recorded over 550g/kg confirmed increased dead and stemmy material being selected by cattle towards the end of the season (O’Reagain & Mentis, 1988) as the dry material availability decreased due to grazing pressure as observed by Kruger (1998). The trends established above, regarding decreased concentrations in ADF during the wet season, would result in improved dry matter intakes as illustrated in Figure 12 and Figure 13 from Van Schalkwyk (1978). Lower ADF during the wet season and increased dry matter intakes would result in improved animal performance, if sufficient dry matter was available.

The acid detergent lignin (ADL) in the extrusa (Table 33) collected by OF is illustrated in Figure 41. During the 2004 dry season the range of values recorded for ADL were from 78g/kg to 100g/kg and showed an increasing trend. During the spring season the ADL concentrations in the selected veld had an increasing trend ending at a maximum of 220g/kg.

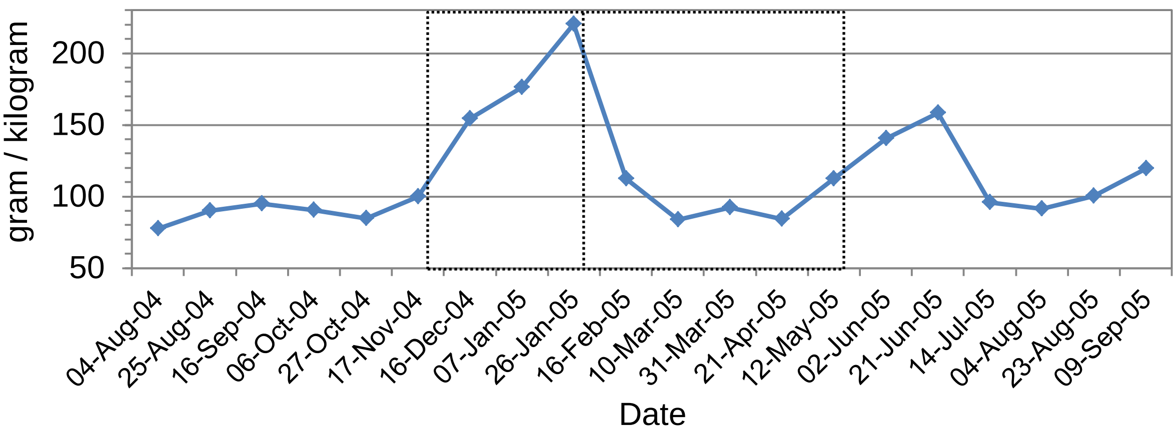


Figure 41 Average acid detergent lignin concentration in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis

The increase in ADL concentrations during spring with a concomitant increase in ash concentrations (Table 29) and CP concentrations (Table 30) was in agreement with Burritt *et al.* (1988). The authors found that extrusa containing immature forage was the most susceptible to oven drying due to higher concentrations of protein and soluble carbohydrates contained in immature forages. O'Reagain & Mentis (1988) confirm that less mature plant parts were selected during spring into the early wet season.

In Figure 42 the formation of artefact lignin due to oven drying was clearly illustrated during the spring and wet season (Burritt *et al.*, 1988). The actual lignin concentrations should have decreased significantly as illustrated by Burritt *et al.* (1988) by freeze drying extrusa samples.

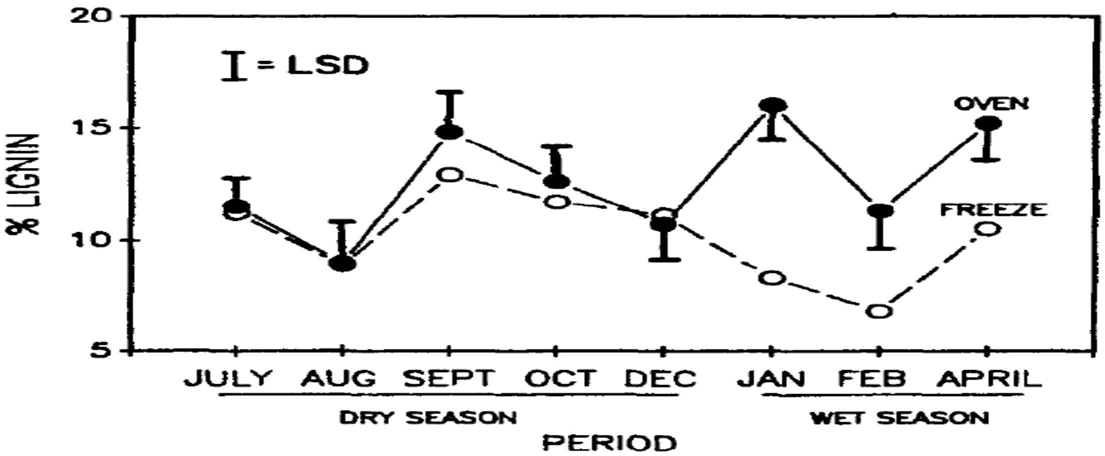


Figure 42 Effect of oven (40°C) and freeze-drying on the lignin (dry matter basis) concentration of extrusa from browsing oesophageally fistulated sheep and goats (Burritt *et al.*,1988)

In Figure 41, during the wet season, the range in ADL concentrations decreased to 84g/kg to 113g/kg. During the 2005 dry season, the ADL concentrations again rose until reaching a maximum on 21 Jun '05 at 158g/kg after frost occurred. The ADL again decreased to 91g/kg after which it rose towards the end of the 2005 dry season.

The acid detergent insoluble nitrogen (ADIN) in the veld (Table 33) as collected by OF is illustrated in Figure 43. During the dry seasons the range of ADIN was 4.3g/kg to 10.6g/kg.

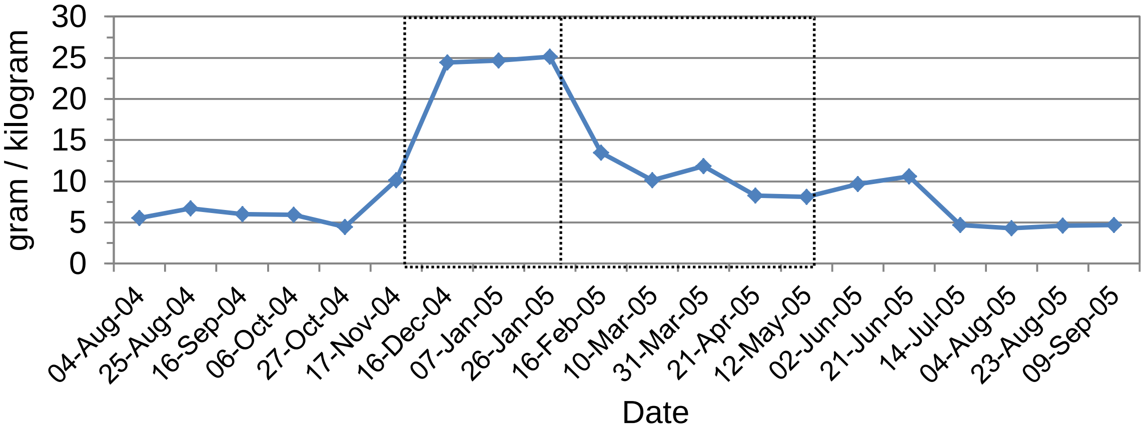


Figure 43 Average acid detergent insoluble nitrogen concentration in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis

During spring the ADIN range increased to 24.4g/kg and 25.2g/kg. During the wet season there was a decrease in ADIN to a range of 8.1g/kg to 13.5g/kg. During the early part of the 2005 dry season, from 2 Jun ’05 to 21 Jun ’05 the range of values in ADIN were from 9.7g/kg to 10.6g/kg. The range of values further decreased to 4.3g/kg to 4.7g/kg during the remainder of the 2005 dry season.

Faber *et al.* (1995) suggested that freeze-drying was the preferable drying method due to significant ADIN alterations found in browse samples for drying temperatures above 35 ºC. The increase in ADIN concentrations during spring with a concomitant increase in ash concentrations (Table 29) and CP concentrations (Table 30) was in agreement with Burritt *et al.* (1988). Burritt *et al.* (1988) found that extrusa containing immature forages was the most susceptible to oven-drying due to higher concentrations of protein and carbohydrates. 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. O’Reagain & Mentis (1988) confirm that less mature plant parts were selected during spring into the early wet season. 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 were typically saturated with saliva, which resulted in increased moisture and pH, which increased the nonenzymatic browning reaction. Burritt *et al.* (1988) named the resulting substance artefact lignin.

The *in vitro* digestible organic matter (IVDOM) in the veld (Table 33) as collected by OF is illustrated in Figure 44. The range of values recorded for IVDOM from the highest value at 655g/kg on 25 Aug '04 to the lowest at 358g/kg on 26 Jan '05 was at odds with results obtained by Van Schalkwyk (1978) and Pratchett *et al.* (1977) in Figure 10.

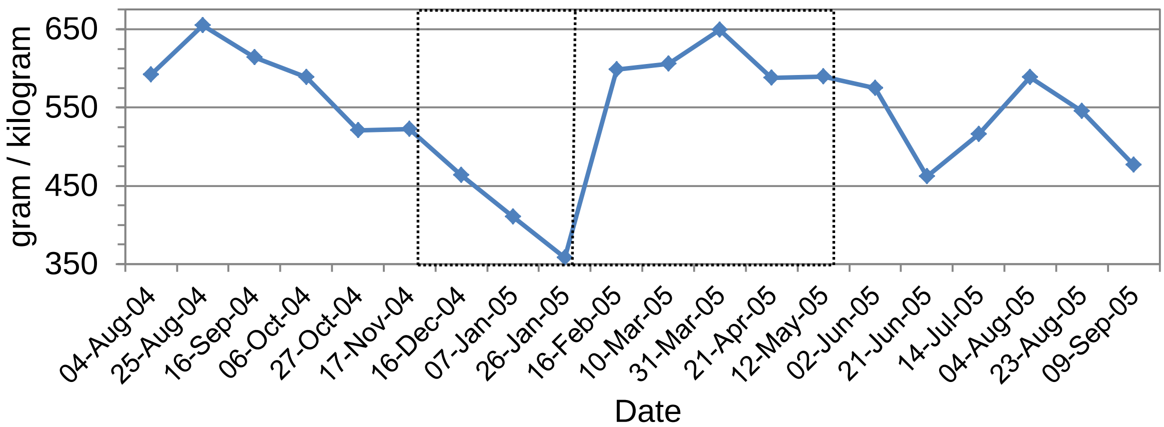


Figure 44 Average *in vitro* digestible organic matter concentration in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis

The drying of extrusa samples in an oven at 50ºC to 60ºC had a significant depressing effect on the IVDOM (Engels *et al*., 1981). This was apparently caused by the condensation of carbohydrates and proteins through the non-enzymatic browning reaction in the presence of high moisture levels.

The two points where the greatest depressions in IVDOM occurred on 26 Jan '05 and 21 Jun '05 coincided with the maximum ADL concentrations recorded in Figure 41. Increased concentrations of artefact lignin due to oven drying of samples would decrease the IVDOM as observed in Figure 44. The artefact lignin formation pointed to by the ADL (Figure 41) and ADIN (Figure 43), during oven drying was shown to have a deleterious effect on the analysis of the IVDOM (Figure 44) in the extrusa.

The general trend and range of values correspond with the tendencies established by Van Schalkwyk (1978) in Figure 10 where the dry matter IVDOM values decreased, from 453g/kg in July to 426g/kg in December, and then rose during the months of January to March with a range of 475g/kg to 505g/kg and then decreased towards June.

In Figure 45 the IVDOM (OM) analysis values from Table 33 and CP (OM) values from Table 30 form the basis of the IVDOM to CP ratio calculated in Table 33. Probably the greatest and most uniform relationship of forage chemistry to intake occurred when the crude protein concentration was below 80g/kg (Coleman, 2005). Moore *et al.* (1999) suggested that the ratio at which the digestible organic dry matter (DOMD) to CP exceeded 10-12 would reflect this.

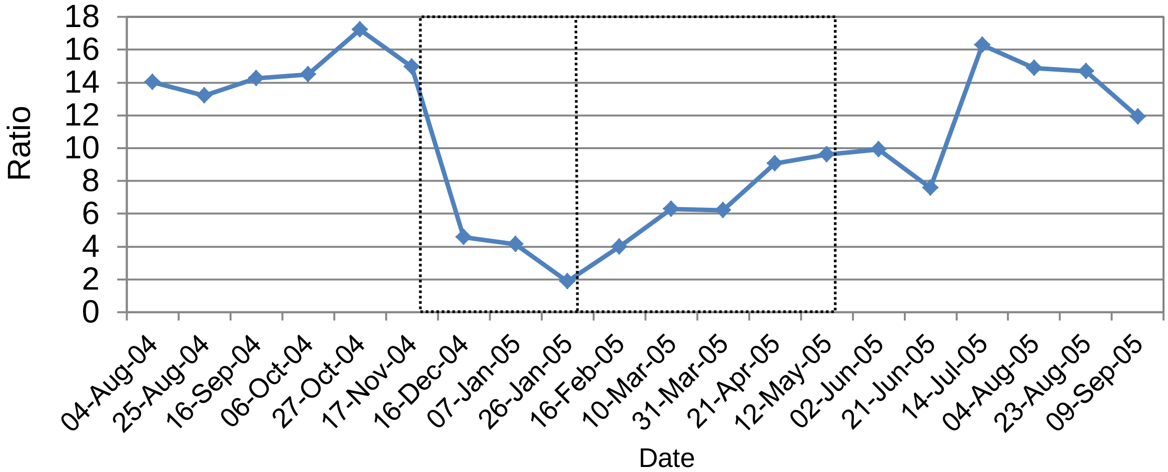


Figure 45 Average *in vitro* digestible organic matter to crude protein ratio calculated from parameters tested in veld selected by oesophageally fistulated cattle during different sampling periods on an organic matter basis

Moore *et al.* (1999) suggested that supplements contributing protein increased forage intake when forage had a deficit of N relative to available energy (DOMD:CP>7). Supplements had no effect on intake when the forage had inadequate available energy (DOMD:CP <7).

In Figure 45 the 2004 dry season IVDOM:CP indicated that the ruminal microbes were likely nitrogen limited relative to the energy available and forage intake would increase with supplemental nitrogen. Similar concentrations were recorded during the 2005 dry season. The wet season would not have benefited from supplementing nitrogen due to sufficient CP concentrations being available in relation to energy. The results obtained still allow the IVDOM:CP ratio to be used and was able to show a nitrogen shortage in the veld selected. The variation in the digestibility values in this trial and from the results obtained by Van Schalkwyk (1978) and Pratchett *et al.* (1977) show a narrow range and no additional benefit was derived from using IVDOM in comparison to using only the CP concentrations analysed in the extrusa samples dried in an oven.

5.6. CONCLUSION

The largest influence of the ash on results was on the data during the spring and early wet season where the nutrient concentrations were already elevated above minimum animal performance thresholds. 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 Wallace *et al.* (1972).

A positive linear relationship was established between monthly rainfall and respectively CP and P, which were the most important nutrients for animal performance as set out by average nutrient values over seasonal periods in Table 34. A strong positive linear relationship was established between CP and P.

Table 34 Summary of average forage quality results on an organic matter basis as selected by oesophageally fistulated cattle according to the season defined by rainfall and cattle liveweight change in Table 24

Parameter	2004 Dry 4 Aug '04 to 17 Nov '04	Spring 18 Nov '04 to 26 Jan '05	Wet 27 Jan '05 to 12 May '05	2005 Dry 13 May '05 to 9 Sep '05
OM (g/kg) [1]	876	846	850	883
Ash (g/kg) [1]	62	87	86	51
CP (g/kg OM) [2]	41	133	96	46
P (g/kg OM) [3]	1.00	2.20	1.77	0.90
Ca (g/kg OM) [4]	5.00	7.42	3.92	3.56
Ca:P [4]	5.0	3.6	2.3	3.9
NDF (g/kg OM) [5]	791	745	777	804
ADF (g/kg OM) [5]	550	548	491	662
ADL (g/kg OM) [5]	90	184	97	118
ADIN (g/kg OM) [5]	6.5	24.7	10.3	6.4
IVDOM (g/kg OM) [5]	582	411	606	527
IVDOM:CP(OM) [5]	14.7	3.5	7.0	12.5

[1] Table 29, [2] Table 30, [3] Table 31, [4] Table 32, [5] Table 33

The minimum thresholds for veld selected by OF on an organic matter basis for changed animal performance seemed to be indicated at inflection points at 70g/kg CP (OM) and 1.3g/kg P (OM).

In the dry season when the quality of veld selected by OF decreased, to below 70g/kg CP (OM) and 1.3g/kg P (OM), the animal performance (indicated by Rock salt treatment group (RST) in Chapter 4.1) decreased towards maintenance of body weight or loss of body weight.

During spring, animal performance was not supported although the quality of veld selected by OF where above the indicated minimum thresholds. This was most likely due to low dry matter yield of veld early in the growing season that would be insufficient to maintain animal production (De Waal, 1990). The dry matter availability would only improve after a lag phase after veld quality improved as indicated by De Waal (1994) and Kruger (1998). The quality of veld selected by OF was a leading indicator of animal performance. Only after the improvement in veld quality reached the maximum point at the end of spring and started declining during the wet season did the animal performance reach optimal levels.

In the wet season when the quality of veld selected by OF increased, to above 70g/kg CP (OM) and 1.3g/kg P (OM), the animal performances (indicated by Rock salt treatment group (RST) in Chapter 4.1) had recorded increased growth rates between 0.5kg/day and 1.0kg/day.

The IVDOM (together with other fibre fraction) results obtained from oven dried extrusa samples have no practical value for evaluation due to the formation of artefact lignin. Engels *et al.* (1981) found that oven drying of extrusa samples collected from cattle did not affect the total protein concentration recorded. The elevated ADIN concentrations during the spring season with new plant growth were in agreement with the elevated ADL concentrations recorded that proved that protein was involved in the formation of artefact lignin as suggested by Burritt *et al.* (1988).

There seemed to be higher concentrations of NDF, ADF, ADL and lower IVDOM in the extrusa collected by OF (Table 34) during the 2005 dry season compared to the 2004 dry season. During the 2005 dry season, the sward seemed to become increasingly stemmy with increased leaf dispersion and a decline in leaf accessibility, which therefore forced the cattle to consume increasing amounts of dead material and stem (O’Reagain & Mentis, 1988).

CHAPTER 6 NUTRIENT INTAKE

The rock salt treatment group (RST), receiving only rock salt lick, indicated the animal performance (CHAPTER 4) that was as a result of only the nutritional quality of the selected veld (CHAPTER 5). The RST only contributed electrolytes to the forage based diet, which resulted in very low levels of nutrient supplementation. The RST would thus indicate the baseline nutrition and performance expected of a forage based diet against which all other treatment groups could be measured. The improved animal performances above the RST, reported in CHAPTER 4, by the 6% Phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST) would need to be explained by evaluating the estimated total dietary nutrient contents. The estimated dietary nutrient levels of each treatment group would then also guide the evaluation of potential nutritional status indicators in CHAPTER 7.

The average daily *ad libitum* supplement consumption per animal, on each nutrient supplementation treatment group over the seasons, was measured on sampling dates between camp rotations every 3 weeks. The average supplement intake, from each of the five strategic nutrient supplementation treatments, and the contribution it made to the total daily nutrient intake is presented in Chapter 6.2. The total daily nutrient intake was estimated by using the total daily dry matter forage intake determinations, obtained by chromic oxide marker method, in the same area as the experimental site in Namibia (Van Schalkwyk, 1978).

The total dietary contribution of the estimated available nutrients from each of the individual supplement treatments, together with the estimated available veld intake nutrients, was evaluated against the estimated available dietary nutrient requirements for the animals (Chapter 6.3 to Chapter 6.7) based on their average liveweight and growth rates in CHAPTER 4.

6.1. ESTIMATED TOTAL DAILY DRY MATTER INTAKE

The estimated daily total dry matter intake per animal from the data generated by Van Schalkwyk (1978) in Table 35 was used to estimate the total intake under the current trial conditions.

Table 35 Rainfall, veld crude protein g/kg on an organic matter basis (CP(OM)) collected by oesophageally fistulated cattle on a quarterly basis in comparison to average daily kilogram dry matter intake expressed as a percentage of kilogram liveweight (LW) for growing cattle (15 months to 27 months of age) determined by chromic oxide marker method, under free grazing management, without a phosphorus shortage (Van Schalkwyk, 1978)

Month	Rainfall (mm)	CP (OM)	Intake (% of LW)
JUL	0	56.7	2.60%
AUG	0	61.4	2.60%
SEP	0	43.8	2.60%
OCT	**19.5**	66.0	2.83%
NOV	8.6	81.1	2.83%
DEC	**56**	71.0	2.83%
JAN	212.9	188.9	3.16%
FEB	183	145.6	3.16%
MAR	9	135.2	3.16%
APR	24.3	124.7	3.26%
MAY	8.2	97.6	3.26%
JUN	8.2	99.8	3.26%

The data generated in the present trial was as closely as possible matched to the rainfall, extrusa CP(OM) and season in Table 35 to derive the most suitable forage based total dry matter intake estimates on a percentage of liveweight (LW) basis for the current trial in Table 36.

Table 36 Matching the season, rainfall, crude protein g/kg on an organic matter basis (CP(OM)) of oesophageally fistulated cattle with liveweight (LW) gains of cattle on nutrient supplement treatments during the Burgkeller trial to the most suitable estimates of average kilogram daily dry matter intake as a percentage of kilogram cattle liveweight as described by Van Schalkwyk (1978) under similar conditions

Date	Rainfall (mm)	CP (OM)	Intake (% of LW)
04-Aug-04		43	2.60%
25-Aug-04		50	2.60%
16-Sep-04	5	43	2.60%
06-Oct-04		41	2.60%
27-Oct-04		30	2.60%
17-Nov-04	**14**	36	2.60%
16-Dec-04	10	103	2.83%
07-Jan-05	**36**	105	2.83%
26-Jan-05	64	190	2.83%
16-Feb-05	66	150	3.26%
10-Mar-05	69	96	3.26%
31-Mar-05	34	105	3.26%
21-Apr-05		65	3.26%
12-May-05		63	3.26%
02-Jun-05		59	2.60%
21-Jun-05		64	2.60%
14-Jul-05		33	2.60%
04-Aug-05		41	2.60%
23-Aug-05		37	2.60%
09-Sep-05		40	2.60%

The lick intakes recorded above 500g/day by PDT & FST when receiving the production and finisher licks during the dry season would have been subject to negative associative effects during these periods with the substitution of veld intake by the consumption of energy rich supplements (Dixon & Stockdale, 1999). The effect would have been more marked in the FST due to higher intakes being recorded (Goetsch *et al.*, 1991).

6.2. AVERAGE DAILY LICK INTAKE

The daily average lick intake per animal on an *ad libitum* basis, over each collection period, recorded by each treatment group is presented in Table 37. The treatment groups received their respective dry season licks from 21 Jun ’04 to 26 Jan ’05. On 27 Jan ’05, at the start of the wet season, the 6% Phosphorus lick was only made available to the

6%PT, MTT, PDT and FST. The treatment groups were then reduced from 5 separate foraging groups to only 3 groups by keeping the RST separately on rock salt lick and grouping the 6%PT and MTT into one group and PDT and FST together to allow the regrowth of plant material during the wet season due to less camps being stocked.

Table 37 Average daily *ad libitum* lick intake between camp rotations measured in gram per animal per day on an as-fed basis. Supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Date	RST	6%PT	MTT	PDT	FST
21-Jun-04	51	64	283	760	1496
14-Jul-04	34	91	252	958	1663
04-Aug-04	49	51	377	744	2325
25-Aug-04	69	87	432	813	2230
16-Sep-04	57	101	387	740	2916
06-Oct-04	67	133	266	1003	2725
27-Oct-04	78	144	490	1234	2871
17-Nov-04	70	164	465	1430	3194
16-Dec-04	23	103	293	764	2658
07-Jan-05	59	69	198	570	1824
26-Jan-05	30	45	114	605	1401
16-Feb-05	66	61	61	83	83
10-Mar-05	64	59	59	83	83
31-Mar-05	73	87	87	51	51
21-Apr-05	55	70	70	141	141
12-May-05	89	107	107	104	104
02-Jun-05	73	159	201	1090	2874
21-Jun-05	80	70	578	1267	3312
14-Jul-05	74	98	358	1611	4319
04-Aug-05	84	137	729	1207	3967
23-Aug-05	80	141	751	1717	3852
09-Sep-05	63	128	631	1470	4143

The treatment groups (Table 19) were split into 5 separate foraging groups and started receiving their selected dry season licks on 13 May ’05 when the nutrient quality of the veld had deteriorated. The decision to start placing dry season licks, in accordance with the treatment plan, was taken when very little green material was observed in the paddocks, the faeces became hard and the faeces colour changed to brown.

6.2.1. Rock salt treatment group (RST)

The RST received rock salt lick throughout the trial to serve as a control treatment to the experiment. The RST had a narrow range of rock salt lick intake per animal from 23g/day to 89g/day (Figure 46). Lower values where recorded during the spring season. This could have been possible due to decreased number of visits to the lick points, as the availability of new growing plant parts would have forced the cattle to spend more time foraging to collect the sparsely distributed high quality plant material with low dry matter values. This period was also associated with the lowest measured body weights, which allowed for the lowest electrolyte requirement per unit body mass. The intakes increased as the season progressed from the wet season to the dry season.

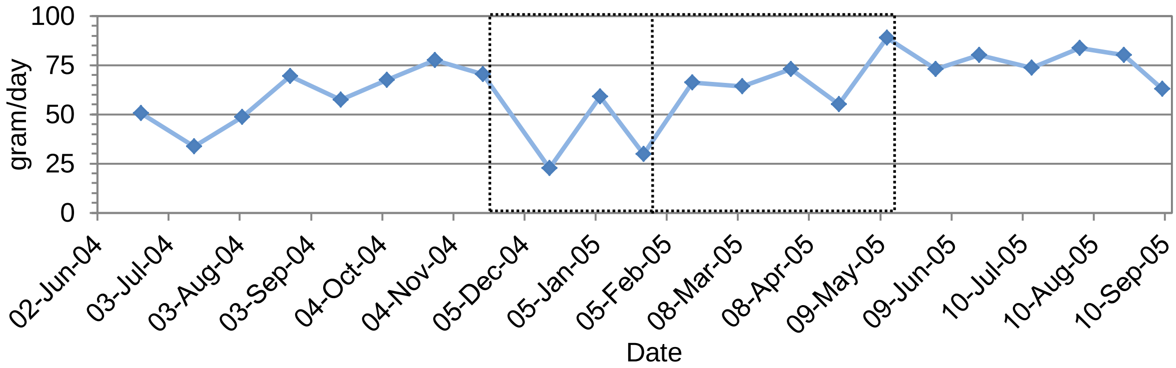


Figure 46 Average daily *ad libitum* rock salt treatment group (RST) intake in gram per animal per day by free-ranging cattle between camp rotations on an as-fed basis

The estimated total intake of veld (Table 36) and rock salt lick in Figure 47 reflects that the maximum estimated veld intake occurred during the wet season, which could be confirmed by improved LW gains during this period.

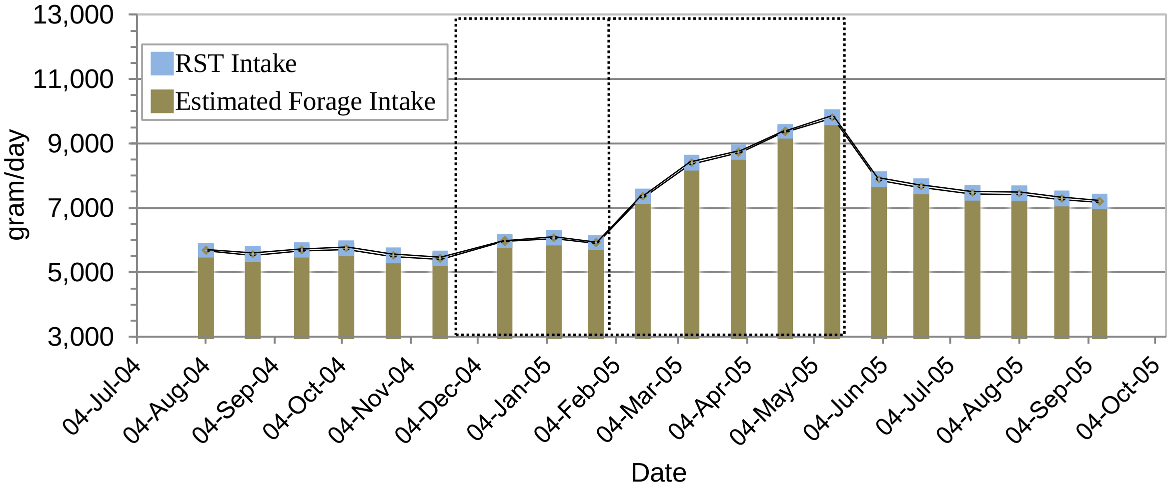


Figure 47 Estimated average daily total dry matter intake of the rock salt treatment group (RST) indicating the contribution of the rock salt lick with an estimate of the veld intake (Van Schalkwyk, 1978)

6.2.2. Six percent phosphorus treatment group (6%PT)

The 6%PT received a mixture of a 12% phosphorus concentrate supplement containing trace minerals and calcium, which was mixed with equal parts iodated coarse salt to obtain a 6% phosphorus lick. The 6% phosphorus lick was made available throughout the experimental period (Figure 48). The average intake per animal had a range of 45g/day to 164g/day.

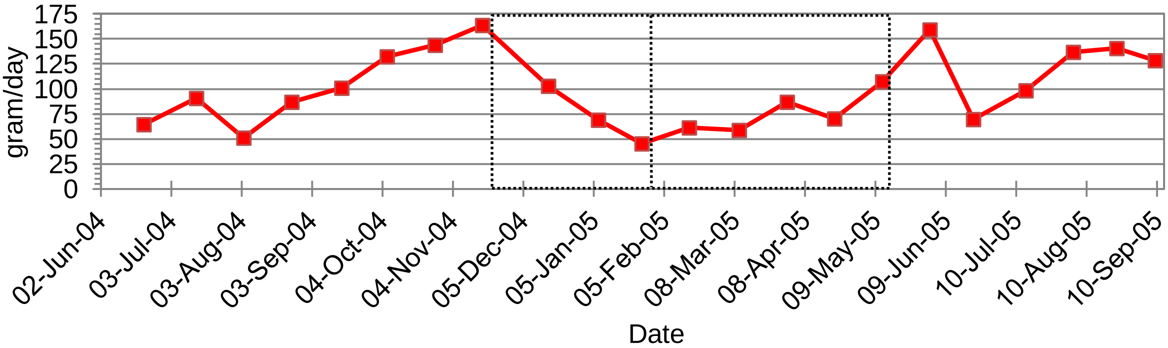


Figure 48 Average daily *ad libitum* 6% phosphorus treatment group (6%PT) intake in gram per animal per day by free-ranging cattle between camp rotations on an as-fed basis

The lowest intakes of 6% phosphorus lick were recorded during the wet season with a tendency for increasing intakes during the dry season and the highest intakes recorded during the dry season just before the spring season. The maximum intake at 164g/day recorded on 17 Nov ’04 was the turning point for increasing intakes during the dry season to decreasing intakes in the spring season.

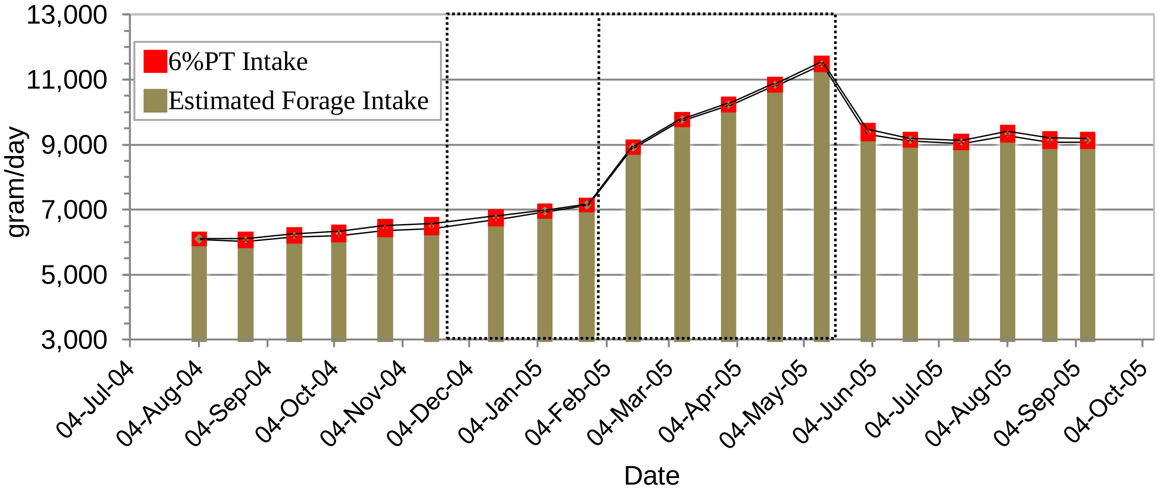


Figure 49 Estimated average daily total dry matter intake of the 6% phosphorus treatment group (6%PT) indicating the contribution of the 6% phosphorus lick with an estimate of the veld intake (Van Schalkwyk, 1978)

A decrease in lick intake occurred during the spring season from 16 Dec ‘04 and continued to decrease up to the month of highest rainfall, which was January. The total lick and estimated veld intake in Figure 49 showed an increase in estimated veld intake in the spring season up to maximal estimated veld intake during the wet season, which indicated an inverse relationship between lick intake and estimated veld intake. The cattle were able to collect a better quality diet from the veld at the onset of the spring season and started decreasing lick intakes in reaction to this improvement in their dietary nutritional content. As the veld quality deteriorated into the next dry season, the cattle started consuming increasing levels of lick.

6.2.3. Maintenance treatment group (MTT)

The MTT received a maintenance lick contributing mainly P and CP during the dry season and spring season of the experimental period. During the wet season, starting the day after the collection of 26 Jan ’05 and ending on 12 May ’05, the group was changed to a 6% phosphorus lick in accordance with the treatment plan.

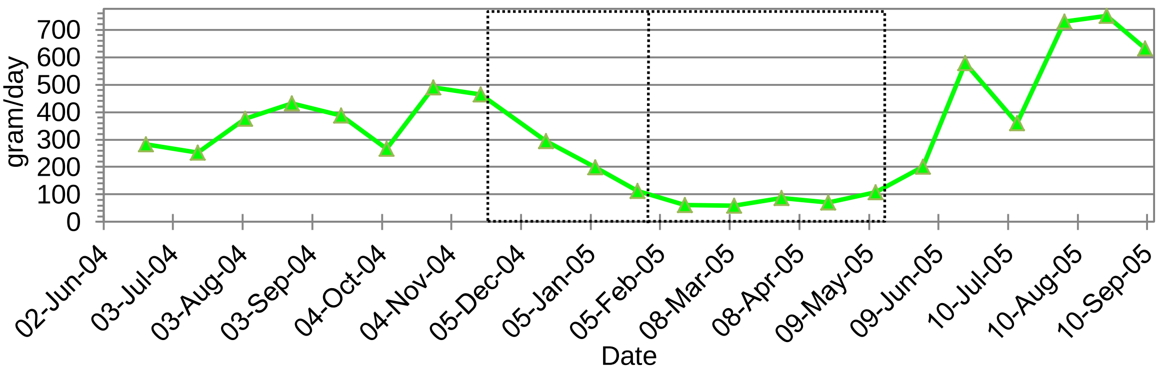


Figure 50 Average daily *ad libitum* maintenance treatment group (MTT) intake in gram per animal per day by free-ranging cattle between camp rotations on an as-fed basis

The *ad libitum* daily average intake for each period on the different licks for the MTT is shown in Figure 50. The intake on the maintenance lick during the 2004 dry season started at a low point of 252g/day in the period ending 14 Jul '04. The intake increased to a maximum of 490g/day during the period ending 27 Oct '04, which then progressively declined to the lowest intake of 114g/day for the maintenance lick in the period ending 26 Jan '05 at the end of spring. The decrease in *ad libitum* lick intakes started as the veld quality improved and the estimated veld intakes increased before the final change to the 6% phosphorus lick occurred on the 16 Feb '05 as indicated by the total intake in Figure 51.

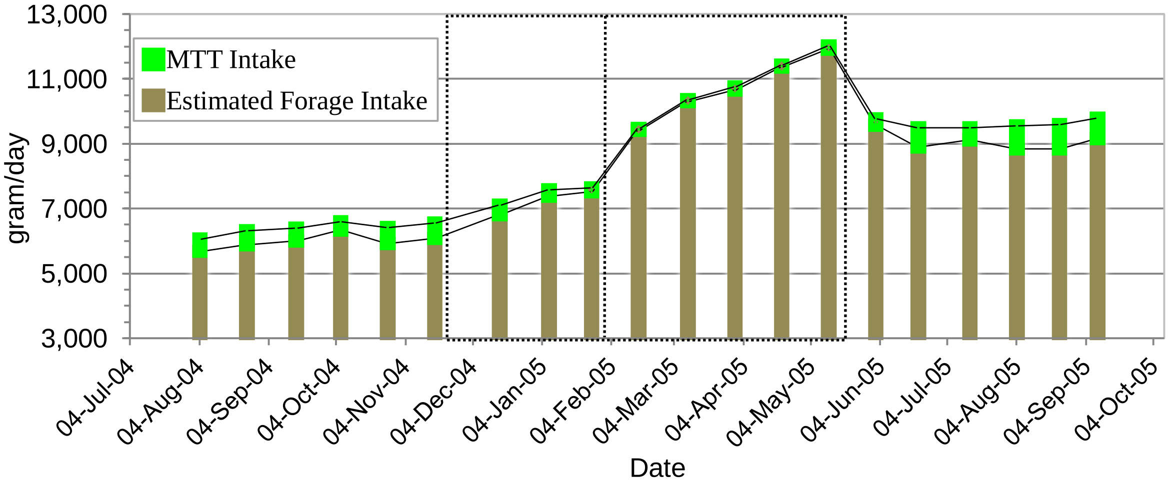


Figure 51 Estimated average daily total dry matter intake of the maintenance treatment group (MTT) indicating the contribution of the maintenance lick during the dry and spring season, 6% phosphorus lick during the wet season with an estimate of the veld intake (Van Schalkwyk, 1978)

During the wet season the MTT was combined with the 6%PT and given the 6%

phosphorus lick. The intake range recorded a low at 59g/day early in the wet season and then moved up to 107g/day at the highest recorded during the period ending 12 May ’05 at the end of the wet season. The day after this collection the combined treatment group herds were again split into separate camps and the maintenance lick was given to the MTT. During the dry season the intake on the maintenance lick started at the lowest point of 201g/day during the period ending 2 Jun ’05 and increased to the highest value recorded at 751g during the period ending 23 Aug ’05.

6.2.4. Production treatment group (PDT)

The *ad libitum* average daily lick intake for the PDT is illustrated in Figure 52. The PDT received a production lick contributing mainly P and CP but also a moderate amount of energy during the experimental period, except during the wet season where a 6% phosphorus lick was only made available for consumption. The intake on the production lick during early 2004 dry season had a low level of intake ranging from 740g/day to 958g/day.

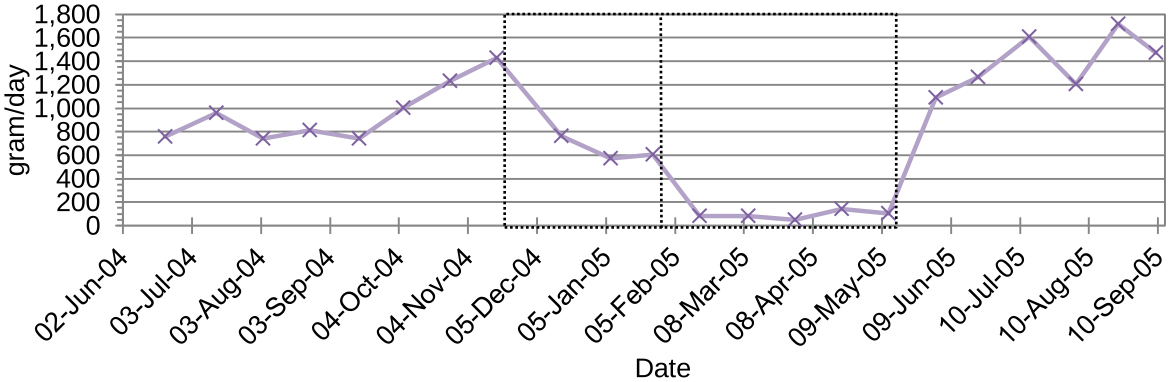


Figure 52 Average daily *ad libitum* production treatment group (PDT) intake in gram per animal per day by free-ranging cattle between camp rotations on an as-fed basis

Towards the end of the dry season intakes increased to a range of 1003g/day (6 Oct ’04) and 1430g/day (17 Nov ’04). The intake on the production lick started declining during the onset of the spring season to the lowest point in the period ending 7 Jan ’05 with 570g/day and remained at around this level at 605g/day during the next period ending 26 Jan ’05 at the end of the spring season.

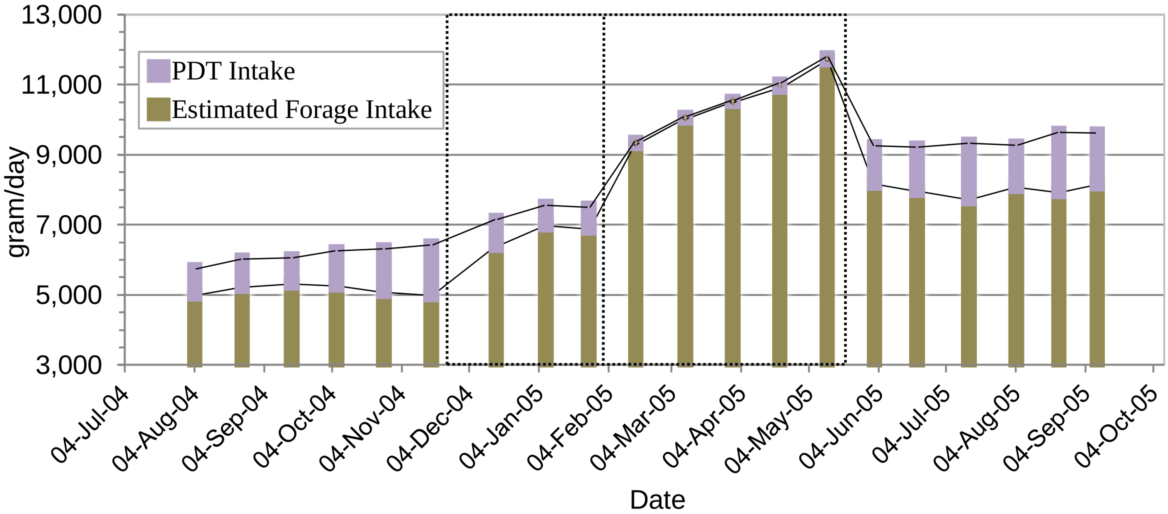


Figure 53 Estimated average daily total dry matter intake of the production treatment group (PDT) indicating the contribution of the production lick during the dry and spring season, 6% phosphorus lick during the wet season with an estimate of the veld intake (Van Schalkwyk, 1978)

In Figure 53 the decrease in the *ad libitum* production lick is illustrated against the increase in estimated veld intakes during the spring season. During the wet season the PDT were combined with the FST into one group and given the 6% phosphorus lick. The recorded intake range for the 6% phosphorus lick during the wet season was from 51g/day to 104g/day due to increasing weight gains requiring increasing levels of supplemented minerals as the season progressed. The onset of the dry season occurred after the data collection of 12 Mary '05. The PDT and FST were again split into separate groups in separate camps and the production lick was made available to the PDT. The intake on the production lick started at the lowest point of 1090g/day in the period ending 2 Jun '05 and increased to the highest value recorded at 1717g/day during the period ending 23 Aug '05.

6.2.5. Finisher treatment group (FST)

The average daily lick intake for the FST is illustrated in Figure 54. The FST received a finisher lick contributing mainly energy but also P and CP during the experimental period, except during the wet season where they received the same 6% phosphorus lick as the 6%PT, MTT and PDT.

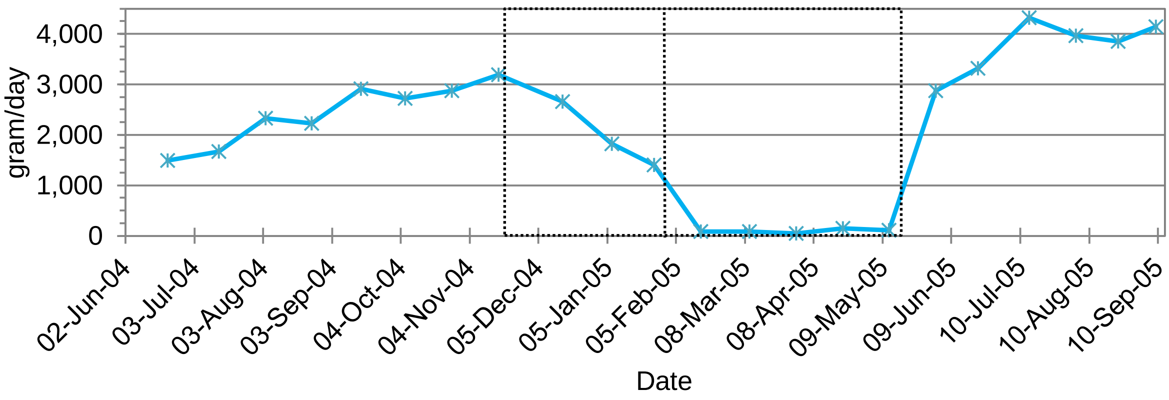


Figure 54 Average daily *ad libitum* finisher treatment group *(*FST) intake in gram per animal per day by free-ranging cattle between camp rotations on an as-fed basis

The intake on the finisher lick started at the lowest point in the dry season at 1496g/day (3 Jun ’04). The *ad libitum* intakes increased to a maximum at 3194g/day (17 Nov’04). At the onset of the spring season the voluntary intake on the finisher lick started declining to the lowest intake recorded from the start of the trial at 1401g/day (26 Jan ’05).

Figure 55 shows the decrease in dry matter contribution of the finisher lick to the diet with increasing levels of dry matter from the estimated veld intake during the spring season.

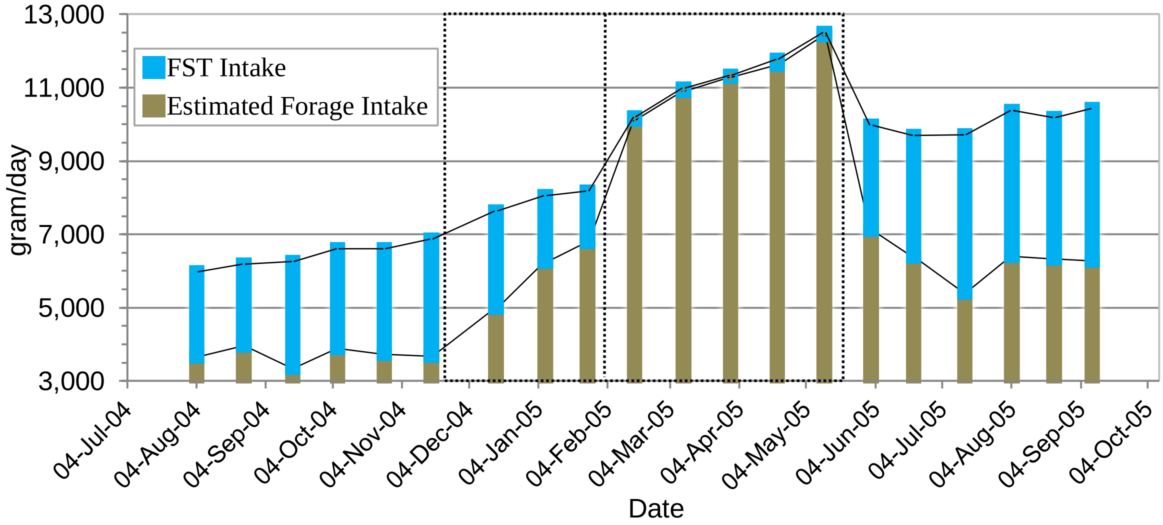
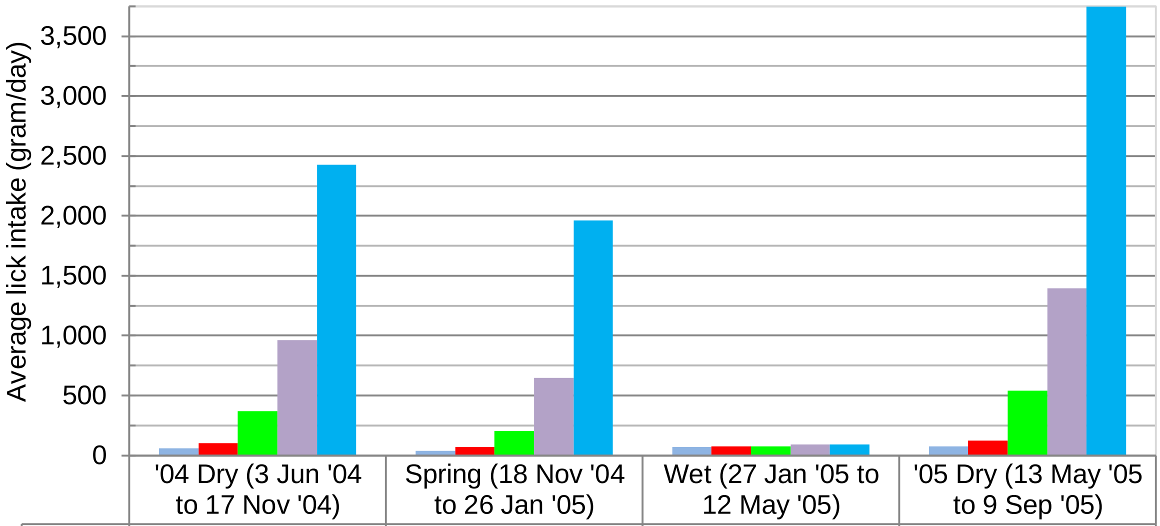


Figure 55 Estimated average daily total dry matter intake of the finisher treatment group (FST) indicating the contribution of the finisher lick during the dry and spring season, 6% phosphorus lick during the wet season with an estimate of the veld intake (Van Schalkwyk, 1978)

During the wet season the FST were combined with the PDT and given the 6% phosphorus lick. The intake range recorded had a low at 51g/day in the period ending 31 Mar ’05 and had the highest intake at 104g/day during the period ending 12 May ’05. From the onset of the dry season, after the 12 May ’05 collection, the FST was split from the PDT into separate camps and the finisher lick was again made available to the FST. During the dry season the intake on the finisher lick started at the lowest point of 1090g/day (2 Jun ’05) and increased to the highest level recorded at 1717g/day (23 Aug ’05).

6.2.6. Seasonal *ad libitum* lick intake trends

The average daily intake of licks for all treatments (Figure 56) over the 2004 dry season (3 Jun ’04 to 17 Nov ’04) had an increasing trend. The average daily intake of licks, between camp rotations, from the onset of the trial on 3 Jun ‘04 to a point of maximum lick intakes occurred on 27 Oct ’04 (146 days from the onset of the trial) for RST & MTT and 17 Nov ’04 (167 days from the onset of the trial) for the 6%PT, PDT & FST. The average lick intakes per animal during the 2004 dry season was 59g/day (RST), 104g/day (6%PT), 369g/day (MTT), 960g/day (PDT) and 2427g/day (FST).



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
RST	59	37	69	76
6%PT	104	72	77	122
MTT	369	202	77	541
PDT	960	647	92	1394
FST	2427	1961	92	3744

Figure 56 Average daily *ad libitum* lick intake in grams per animal over seasons of the trial for groups of cattle on different supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST).

The average daily intake of licks on all treatments decreased rapidly during the spring season when the veld quality had been increasing towards a maximum point on 26

Jan ’05. The average *ad libitum* supplement intake per animal during the spring season was 37g/day (RST), 72g/day (6%PT), 202g/day (MTT), 647g/day (PDT) and 1961g/day (FST).

The removal of the dry season licks, specific to each treatment group, occurred on 26 Jan ’05. Most treatment groups were combined and placed on a 6% phosphorus lick, with the exception of the RST that continued on the rock salt lick. During the remainder of the wet season from 26 Jan ’05 to 12 May ’05 the average intake of rock salt lick by RST was 69g/day and the intake of a 6% phosphorus lick by the 6%MT & MTT was 77g/day and for the PDT & FST was 92g/day.

On 12 May ’05, when the dry season started, the treatment groups were split and commenced on their supplementation treatment specific licks in different camps after it was observed that a reduction in the amount of green material had occurred and the faeces of animals had become firm and brown. The average lick intake per animal during the 2005 dry season was considerably higher than the 2004 dry season with 76g/day (RST), 122g/day (6%PT), 541g/day (MTT), 1394g/day (PDT) and 3744g/day (FST).

The higher nutrient supplement intakes, recorded during the second dry season (2005), could be related to the higher average LW of the groups (Figure 28) after the wet season in which high growth rates were recorded. The increased average group liveweights had increased average stocking rates (Table 16) on the experimental unit from 18kg/ha, over the 2004 dry season, to 27kg/ha over the subsequent 2005 dry season. The increased stocking rates would result in reduced availability of veld dry matter from which the cattle could select their dietary nutrient intake and result in reduced animal performance (Yates *et al.*, 1982). In Figure 29 the RST confirmed this by losing weight at 84g/day during the 2004 dry season and increasing their rate of weight loss to 200g/day during the 2005 dry season.

6.3. SALT INTAKE

The salt in the supplements on offer contributed to the requirement for sodium and chloride in the diet of cattle but was also included as a cheap ingredient that aided in the regulation of lick intake.

Table 38 Average daily *ad libitum* salt intake between camp rotations measured in gram per animal per day on a dry matter basis. Supplementation treatments were defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Date	RST	6%PT	MTT	PDT	FST
21-Jun-04	48	31	86	157	210
14-Jul-04	32	43	77	198	234
04-Aug-04	46	24	115	154	327
25-Aug-04	66	41	132	168	313
16-Sep-04	54	48	118	156	412
06-Oct-04	64	63	81	211	385
27-Oct-04	74	68	149	259	406
17-Nov-04	67	78	142	300	451
16-Dec-04	22	49	89	161	376
07-Jan-05	56	33	61	120	258
26-Jan-05	28	22	35	127	198
16-Feb-05	63	29	29	39	39
10-Mar-05	61	28	28	40	40
31-Mar-05	69	41	41	24	24
21-Apr-05	52	33	33	67	67
12-May-05	84	51	51	49	49
02-Jun-05	69	76	61	229	397
21-Jun-05	76	33	176	266	458
14-Jul-05	70	47	109	338	597
04-Aug-05	80	65	222	254	549
23-Aug-05	76	67	229	361	533
09-Sep-05	60	61	193	309	573

The average daily salt intake on a dry matter basis for the RST is illustrated in Figure 57.

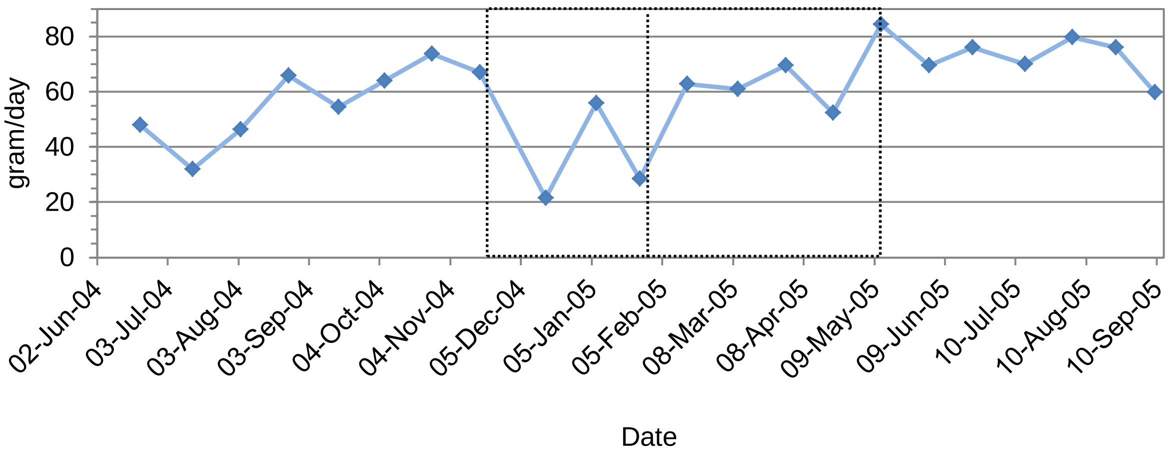


Figure 57 Average daily *ad libitum* salt intake by free-ranging cattle in the rock salt treatment group (RST) between camp rotations in gram per animal per day on a dry matter basis

The RST had a narrow range of salt intakes per animal from 22g/day to 84g/day over the experimental period. Lower values where recorded during the spring and wet season with increased intakes being recorded as the season progressed towards the end of the dry season. This was in agreement with Morris *et al.* (1980) that sodium levels were maximal while the plants were growing and minimal during plant dormancy. The NRC (2001) sets the requirement for sodium for 200kg to 400kg cattle growing at 1kg/day at around 5g/day to 8g/day of sodium (salt contains 38% sodium). The range of salt intakes established by the RST translated into a sodium contribution to the diet ranging from 8.3g/day to 31.9g/day (excluding any veld-derived electrolytes). These levels obtained from the RST would indicate the minimum requirements for sodium and chloride as there were no other nutrients in this supplement to confound the voluntary intake decisions made by the cattle. The dry matter sodium requirement per kg LW for the RST was the lowest during spring.

The average daily salt intake on a dry matter basis for the 6%PT is illustrated in Figure 58. The 6%PT had a similar narrow range in salt intake compared to the RST with a salt intake per animal from 22g/day to 78g/day over the experimental period. The highest salt intake at 78g/day was recorded during the period ending 17 Nov ’04 just before the spring season started. From the onset of the wet season the salt intake steadily declined to the lowest level of 22g/day recorded during the period ending 26 Jan ’05.

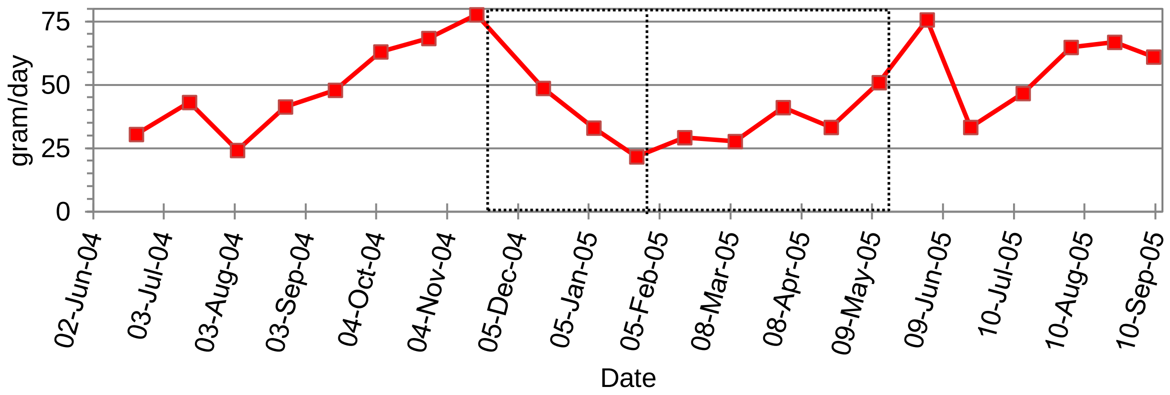


Figure 58 Average daily *ad libitum* salt intake by free-ranging cattle in the 6% phosphorus treatment group (6%PT) between camp rotations in gram per animal per day on a dry matter basis

The average daily salt intake on a dry matter basis for the MTT is illustrated in Figure 59. The MTT had a wider range in salt intake per animal than the RST and 6%PT, which was 28g/day to 229g/day over the experimental period.

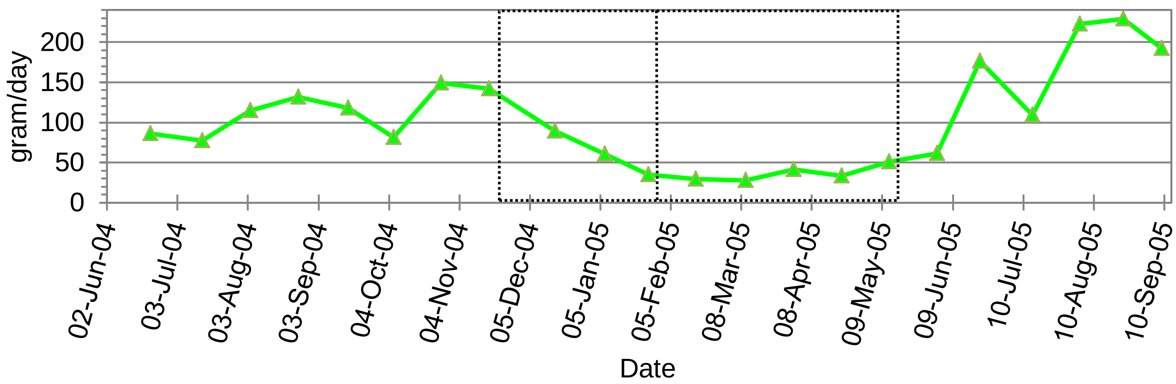


Figure 59 Average daily *ad libitum* salt intake by free-ranging cattle in the maintenance treatment group (MTT) between camp rotations in gram per animal per day on a dry matter basis

The average salt intake on a dry matter basis for cattle on a MTT during the 2004 dry season started at a low point of 77g/day in the period ending 14 Jul '04. The salt intake then increased to a maximum of 149g/day during the period ending 27 Oct '04 after which it then steadily declined to the lowest average salt intake at 28g/day during the period ending 10 Mar '05 in the early wet season. The average salt intake then increased during the dry season to the highest level recorded at 229g/day during the period ending 23 Aug '05.

The average daily salt intake on a dry matter basis for the PDT is illustrated in Figure 60. The PDT had a wider range in salt intake per animal than the RST, 6%PT and

MTT from 24g/day to 361g/day over the experimental period.

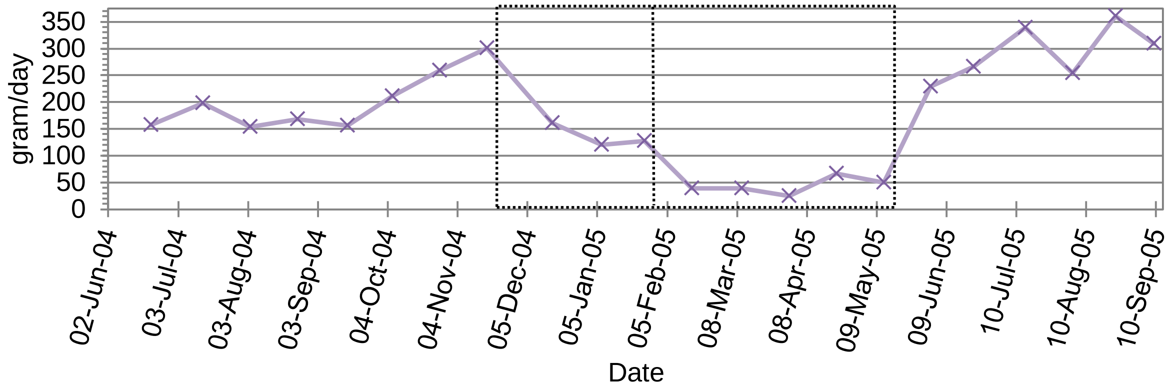


Figure 60 Average daily *ad libitum* salt intake by free-ranging cattle in the production treatment group (PDT) between camp rotations in gram per animal per day on a dry matter basis

The average salt intake on a dry matter basis for cattle on a PDT during the 2004 dry season ranged from a minimum of 154g/day on 4 Aug '04 and continued to increase to a maximum of 300g/day in the period ending 17 Nov '04. The salt intake on the PDT then steadily declined during the spring season. The lowest intake was recorded at 24g/day during the period ending 31 Mar '05 in the middle of the wet season. The average salt intake then increased during the dry season to the highest level recorded at 361g/day during the period ending 23 Aug '05.

The average daily salt intake on a dry matter basis for the FST is illustrated in Figure 61. The FST had the widest range in salt intake per animal between all treatment groups from 24g/day to 597g/day over the experimental period.

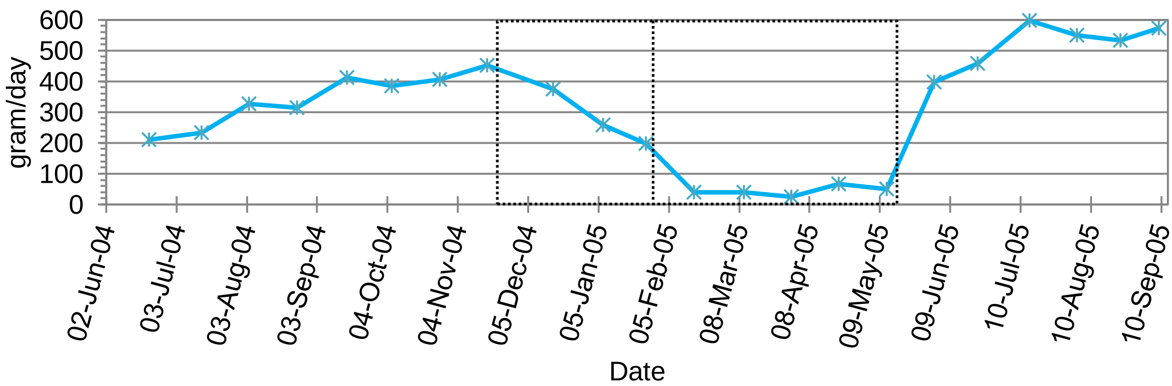
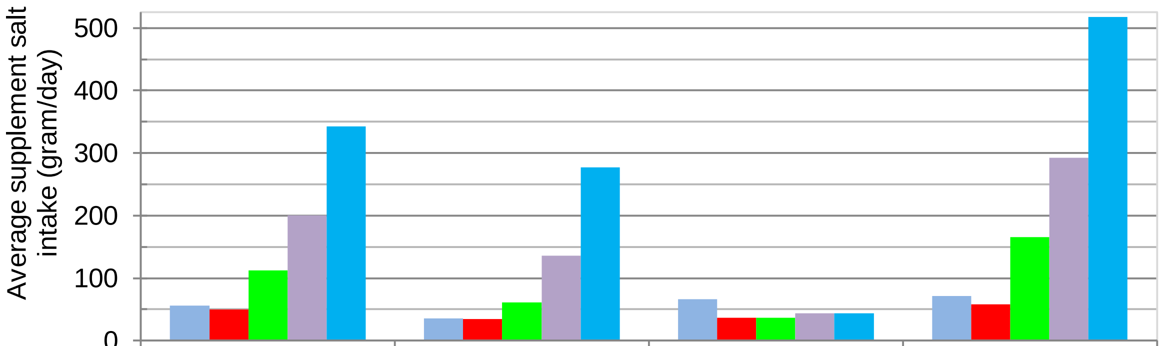


Figure 61 Average daily *ad libitum* salt intake by free-ranging cattle in the finisher treatment group (FST) between camp rotations in gram per animal per day on a dry matter basis

The average salt intake on a dry matter basis for cattle on the FST started at the lowest point of 210g/day in the 2004 dry season on 21 Jun ’04 and increased to the maximum of 451g/day in the period 17 Nov’04 at the end of the dry season. The salt intake on the FST then changed its increasing trend and declined to the lowest intake recorded at 24g/day during the period ending 31 Mar ’05 in the middle of the wet season. The average salt intake then again started to increase during the dry season towards the highest value recorded at 597g/day on 14 Jul ’05 and maintained these elevated levels until the end of the recording period.

6.3.1. Seasonal *ad libitum* lick intake trends

The average daily salt consumption of free-range cattle diets from *ad lib* consumption of different licks during the main seasonal periods identified in Table 24 is illustrated in Figure 62.



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
RST	56	35	66	72
6%PT	50	34	36	58
MTT	113	62	36	165
PDT	200	136	44	293
FST	342	277	44	518

Figure 62 Average daily *ad libitum* salt intake from the lick in grams per animal over seasons of the trial for groups of cattle on different supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

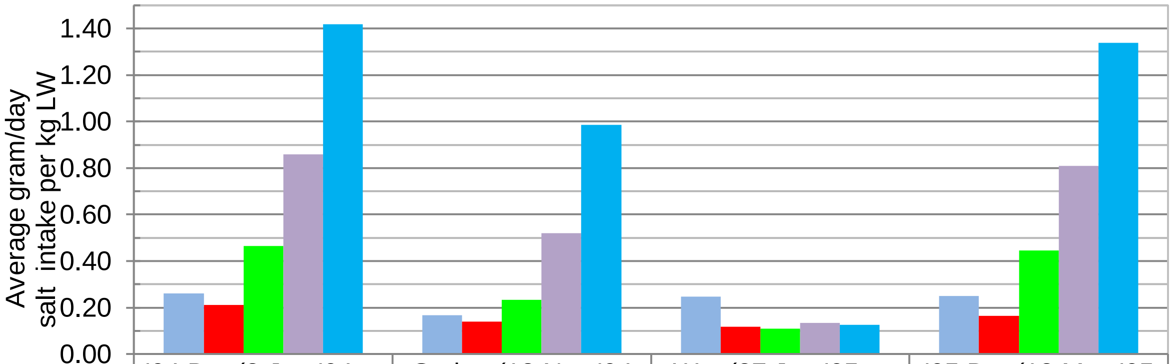
The average daily salt intake per animal from the supplement treatments during the 2004 dry season was 56g/day (RST), 50g/day (6%PT), 113g/day (MTT), 200g/day (PDT) and 342g/day (FST). During the spring season the average salt intakes shifted from an increasing trend towards a decreasing trend and the averages decreased to 35g/day (RST), 34g/day (6%PT), 62g/day (MTT), 136g/day (PDT) and 277g/day (FST). During the wet season the salt intake for the treatment groups had a range of 36g/day to 66g/day. The average daily salt intake during the 2005 dry season was higher than the previous dry season with 72g/day (RST), 58g/day (6%PT), 165g/day (MTT), 293g/day (PDT) and 518g/day (FST).

The average *ad libitum* daily intake of salt from the licks over the whole period recorded by the RST (60g/day) and the 6%PT (47g/day) were comparable to the estimates made by De Waal *et al.* (1996) on the data from Read *et al.* (1986a) where cows consumed salt on average 59g/day over 5 years. The average daily salt intakes from the MTT (103g/day) and PDT (181g/day) were more comparable to the results obtained by De Waal *et al.* (1996) with cows supplemented with P on a higher average salt intake of 110g/day over 5 years.

The detrimental effects on animal performance due to high salt intakes, as observed by De Waal *et al.* (1989a); De Waal *et al.* (1989b) and De Waal *et al.* (1996), would most probably have been demonstrated in the present trial where the average salt intake for the FST was recorded at an average of 313g/day but also to a lesser degree by the MTT (103g/day) and PDT (181g/day) with higher intakes than the RST or 6%PT. The animal performance results presented in Figure 28 however showed that the reverse of this expected trend and reflected that the salt intake did not negatively affect animal performance at increasing levels up to a maximum of 597g/day recorded by the FST during the period 14 Jul '05.

The increasing levels of salt intake presented by the MTT, PDT and FST during the dry seasons (Figure 62), above the required salt intake levels established by the RST and 6%PT, seemed to be related to increasing levels of ME intake from the dry season licks that were on offer (Chapter 6.7, Table 44). The increased growth rates (Figure 29) that resulted during the dry seasons from progressively higher energy intakes, would seem to suggest that cattle were consuming the licks to maximise their energy intake for growth. The negative stimuli generated by the detrimental effects of increased salt intakes were being offset against the larger positive effects of increased performances relating to increased energy available in the diet of the cattle.

Comparisons between the *ad libitum* salt intakes of supplemental groups during the seasons were best made if they were recalculated back to grams of salt consumed from the supplement on offer per kg average LW of the group (Figure 63).



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
RST	0.26	0.17	0.25	0.25
6%PT	0.21	0.14	0.12	0.16
MTT	0.47	0.23	0.11	0.45
PDT	0.86	0.52	0.14	0.81
FST	1.42	0.98	0.13	1.34

Figure 63 Average daily gram *ad libitum* salt intake from the lick per kilogram animal liveweight (LW) over seasons of the trial for groups of cattle on different supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The RST obtained only sodium and chloride as electrolytes from the rock salt that was on offer. During the dry season and wet season, the RST consumed 0.25g/kg LW to 0.26g/kg LW, which was in contrast to only 0.17g/kg LW during the spring season. The 6%PT additionally had phosphorus and calcium in the lick, which relieved the primary phosphorus deficiency observed as pica in the RST. The 6%PT recorded lower levels of salt consumption than the RST at 0.16g/kg LW to 0.21g/kg LW during the dry seasons and the spring and wet season from 0.12g/kg LW to 0.14g/kg LW.

The RST had rock salt lick available during the wet season with the salt intake at 0.25g/kg LW that was in contrast to the 6% phosphorus lick on offer to all of the remaining treatments (6%PT, MTT, PDT and FST) with similar salt intake levels from 0.11g/kg LW to 0.14g/kg LW during the wet season.

6.4. PHOSPHORUS INTAKE

The average *ad libitum* phosphorus intake in gram per animal per day obtained from the supplementation treatments, over each period between rotations in camps, is tabulated in Table 39.

Table 39 Average daily *ad libitum* phosphorus intake between camp rotations from different nutrient supplement treatments measured in gram per animal per day on a dry matter basis. Supplementation treatments were defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Date	RST	6%PT	MTT	PDT	FST
21-Jun-04	.	3.9	5.3	5.6	9.8
14-Jul-04	.	5.5	4.7	7.0	10.9
04-Aug-04	.	3.1	7.0	5.5	15.2
25-Aug-04	.	5.2	8.1	6.0	14.6
16-Sep-04	.	6.0	7.3	5.5	19.2
06-Oct-04	.	8.0	5.0	7.5	18.0
27-Oct-04	.	8.6	9.2	9.2	18.9
17-Nov-04	.	9.8	8.7	10.7	21.0
16-Dec-04	.	6.2	5.5	5.7	17.5
07-Jan-05	.	4.2	3.7	4.3	12.0
26-Jan-05	.	2.7	2.1	4.5	9.2
16-Feb-05	.	3.7	3.7	5.0	5.0
10-Mar-05	.	3.5	3.5	5.0	5.0
31-Mar-05	.	5.2	5.2	3.1	3.1
21-Apr-05	.	4.2	4.2	8.4	8.4
12-May-05	.	6.4	6.4	6.2	6.2
02-Jun-05	.	9.6	3.8	8.1	18.9
21-Jun-05	.	4.2	10.9	9.5	21.8
14-Jul-05	.	5.9	6.7	12.0	28.4
04-Aug-05	.	8.2	13.7	9.0	26.1
23-Aug-05	.	8.4	14.1	12.8	25.3
09-Sep-05	.	7.7	11.9	11.0	27.2

The phosphorus intakes for the 6%PT, MTT and PDT are illustrated in Figure 64 and for FST in Figure 65. The trend and range of values recorded for the average phosphorus intake on a dry matter basis for the 6%PT, MTT and PDT were similar, which was in contrast to the large differences observed in the total lick intake (Figure 56) and salt intake (Figure 62). The variability observed between the results of periods following one another and between treatments could be associated to the random allocation of different camps between sampling intervals. The LW differences observed between treatment groups towards the end of the experimental period would also have had an influence on intake. Figure 64 suggested that the phosphorus intake would have been a nutrient that was actively selected for in the 6%PT, MTT and PDT treatment plans and could have influenced the intake regulation to a greater degree than the salt concentration of the supplements.

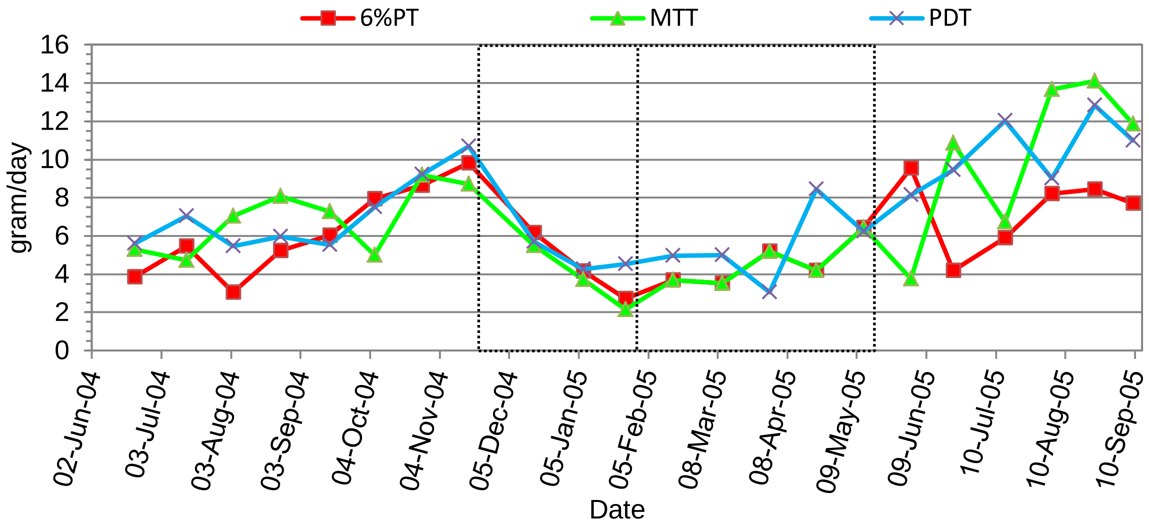


Figure 64 Average daily *ad libitum* phosphorus intake by free-ranging cattle in the 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT) and production treatment group (PDT) between camp rotations in gram per animal per day on a dry matter basis

The range in average P intakes recorded by the 6%PT, MTT and PDT during the first half of the dry season was 3.1g/day to 8.1g/day. The P intakes increased up to the highest levels ranging from 8.6g/day to 10.7g/day during last two periods of the dry season in 2004. The intakes simultaneously then decreased during the spring season to the lowest values recorded on 26 Jan '04 ranging from 2.1g/day to 4.5g/day. With the start of the wet season all treatments, except the RST, were grouped and placed on 6% phosphorus lick as part of the treatment plans. The intakes of P remained low and increased up to the end of the wet season with the P intakes ranging from 6.2g/day to 6.4g/day.

The specific dry season licks (6% phosphorus lick, maintenance lick, production lick and finisher lick) replaced the wet season period feeding of only the 6% phosphorus lick and started directly after the 12 May '05 collection. The intakes showed a high degree of variability between camp rotations but with an overall increasing trend in values towards the end of the experimental period with the highest intakes recorded during the 2005 dry season at 9.6g/day (6%PT), 14.1g/day (MTT) and 12.8g/day (PDT) respectively.

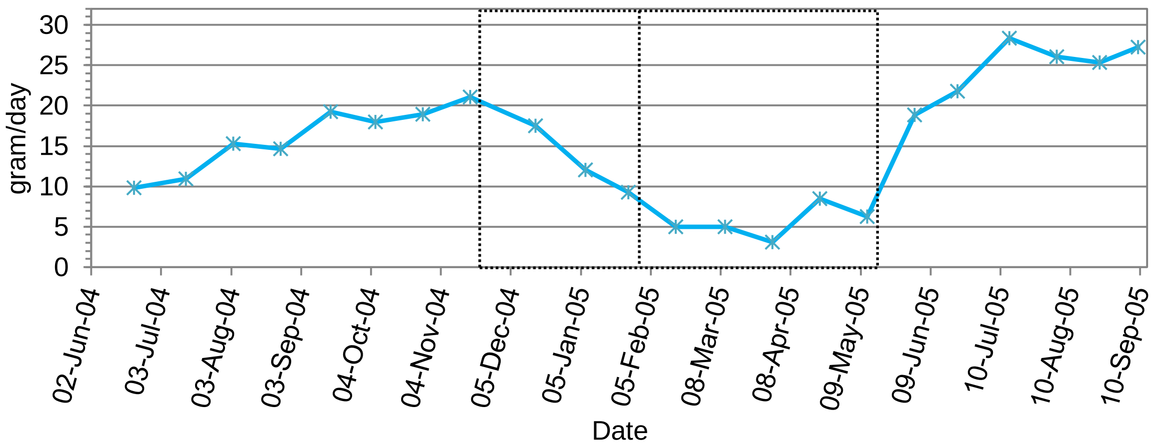
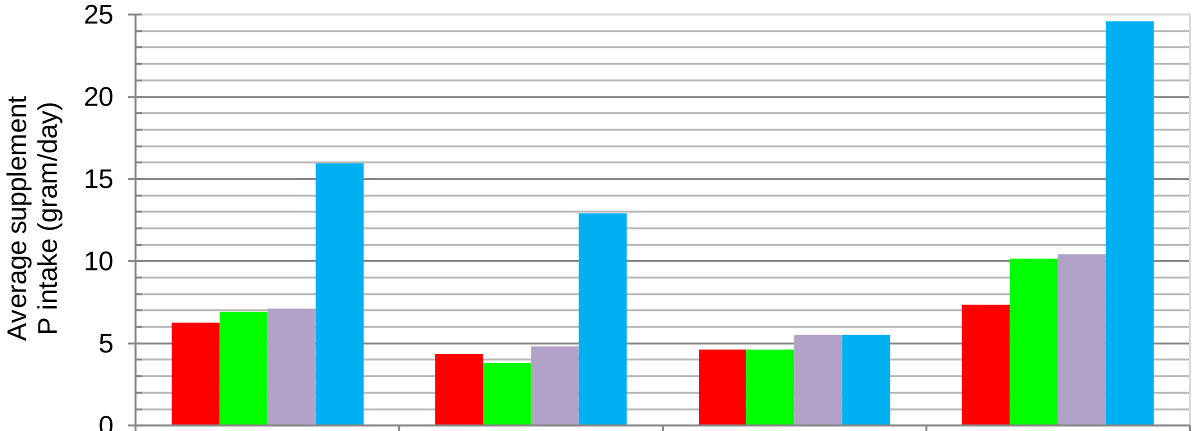


Figure 65 Average daily *ad libitum* phosphorus intake by free-ranging cattle in the finisher treatment group (FST) between camp rotations in gram per animal per day on a dry matter basis

The average P intake for the FST (Figure 65) had a higher maximum at 28.4g/day compared to the other P containing licks in Figure 64 (6%PT, MTT and PDT). The P intake started at 9.8g/day and increased up to the end of the dry season to 21.0g/day. The P intake decreased during the spring season until it reached the lowest level of 3.1g/day in the middle of the wet season on 31 Mar ’05. The P intakes increased to a range of 18.9g/day and 28.4g/day during the 2005 dry season.

6.4.1. Seasonal *ad libitum* lick intake trends

The seasonal average daily *ad libitum* P intakes selected from the licks on offer to free-range cattle are illustrated in Figure 66.



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
6%PT	6	4	5	7
MTT	7	4	5	10
PDT	7	5	6	10
FST	16	13	6	25

Figure 66 Average daily *ad libitum* phosphorus (P) intake from the lick in grams per animal over seasons of the trial for groups of cattle on different supplementation treatments defined as 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

During the 2004 dry season, from the start on 3 Jun ’04 to the final collection on 17 Nov ’04, there was a trend for increasing quantities of P being consumed by the treatment groups receiving supplements containing various concentrations of P. The average intake was similar for the 6%PT (6g/day), MTT (7g/day), PDT (7g/day) but was much higher for the FST at 16g/day.

The general trend in the P intake, derived from different supplements, reversed to decreasing quantities of P being consumed, from 18 Nov ’04 to 26 Jan ’05, during the spring season. The average intake during the spring season was lower than the preceding 2004 dry season. Similar intakes were recorded by the 6%PT, MTT and PDT at 4g/day. The FST again recorded a much higher average P intake than the other treatments at 13g/day but it had also decreased during this season from the preceding season. During November 2004 the veld P concentration selected by OF increased to above 1.5g/kg

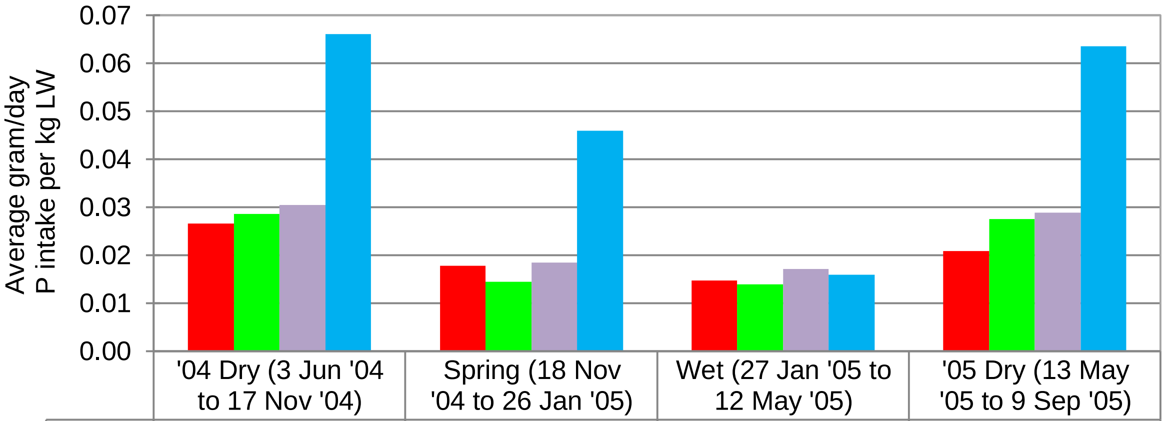
(Figure 33). The improvement in veld P concentrations selected by OF and the concomitant improvement in animal performance during the spring season (Figure 29) with a decrease in their *ad libitum* P intakes during the season suggested that P was a nutrient influencing the intake of the supplements by cattle.

During the wet season, from 27 Jan ’05 to 12 May ’05, the MTT, PDT and FST received the same 6% phosphorus lick as was made available to the 6%PT during the dry season (as set out in the treatment plan in Table 19). 6%PT and MTT were grouped into one group and consumed on average 5g/day P. The PDT and FST were grouped and consumed slightly more at 6g/day P, due to the higher average LW of the second combined group, than the first combined group during the wet season.

During the 2005 dry season, from 13 May ’05 to 9 Sep ’05, the groups consumed higher concentrations of P than the 2004 dry season. The lowest intake during the 2005 dry season was recorded by the 6%PT (7g/day) and similar intakes by the MTT and PDT (10g/day) and a much higher P intake for the FST at 25g/day.

The best comparisons between the *ad libitum* P intakes of nutrient supplemented groups during the seasons were made if they were recalculated back to grams of P consumed from the supplement on offer per kilogram average LW of the group (Figure 67). During the dry and wet seasons of the year the 6%PT obtained primarily macro-minerals (P and Ca) and secondarily electrolytes in combination with micro-minerals from the 6% phosphorus lick on offer.

The 6%PT had no observable signs of pica as was identified in the RST and this group would have been the most likely to primarily fulfil their P and Ca requirements from the treatment on offer without other nutrients confounding supplement intake decisions. The 6%PT consumed P at 0.06g/kg LW during the 2004 dry season which decreased to 0.04g/kg LW during the spring season and further decreased to 0.03g/kg LW during the wet season. During the 2005 dry season the P intakes increased to 0.05g/kg LW.



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
6%PT	0.03	0.02	0.01	0.02
MTT	0.03	0.01	0.01	0.03
PDT	0.03	0.02	0.02	0.03
FST	0.07	0.05	0.02	0.06

Figure 67 Average daily gram *ad libitum* phosphorus (P) intake from the lick per kilogram animal liveweight (LW) over seasons of the trial for groups of cattle on different supplementation treatments defined as 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The 6%PT, MTT and PDT had similar P intakes per kilogram LW, which was in contrast to the elevated P intake levels observed in the FST. During the dry seasons the FST intakes of P ranged from 0.06g/kg LW to 0.07g/kg LW and during the spring season the P intake was also higher at 0.05g/kg LW. This would indicate that other nutrients were influencing the *ad libitum* total supplement intakes of FST.

6.4.2. Estimated available phosphorus (eP) compared to requirements

The estimated available phosphorus (eP) of the total dry matter intake could only be evaluated against animal requirements after determining the absorbable phosphorus content of each constituent of the diet and adding them together (NRC, 2000; NRC, 2001). The efficiency of absorption from the licks containing inorganic sources of mono-calcium phosphate and mono-ammonium phosphate was taken as 85% (NRC, 2001) and from the forage collected by OF at 75% (Bortolussi *et al.*, 1996; Ternouth *et al.*, 1996). The available phosphorus requirement for maintenance was taken to be 19mg/kg LW (Ternouth *et al.*, 1996) and for growth additionally the result of Equation 8 (AFRC, 1991) at 0.5kg/day and 1.0kg/day gain. The average LW of treatment groups on every collection date, as presented in Table 25, was used together with the intake estimate made in Table 36, which was based on Van Schalkwyk (1978).

The RST only had the veld contributing eP to the diet and Figure 68 indicated that the eP intake during the dry season would barely be enough for maintenance of body weight.

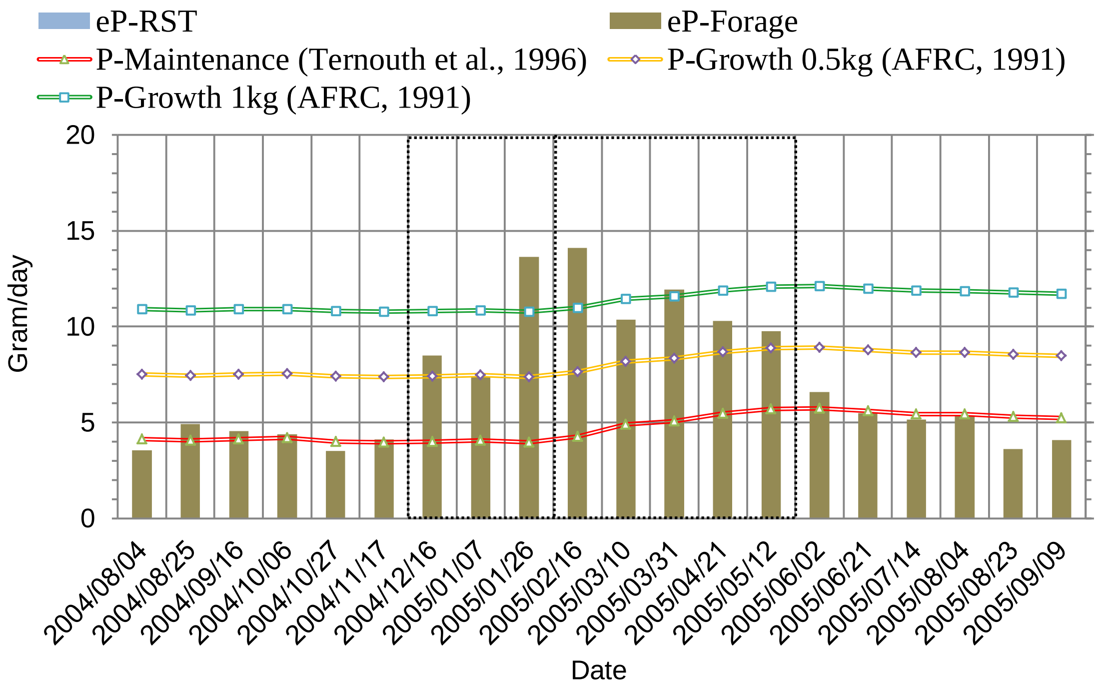


Figure 68 Estimated available phosphorus (eP) of the total intake by free-ranging cattle in the rock salt treatment group (RST), receiving only a rock salt lick between camp rotations, in gram per animal per day on a dry matter basis compared to the requirements for maintenance (Ternouth *et al*., 1996) and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

The animal performance recorded in Figure 29 in CHAPTER 4 indicated that the RST lost 84g/day during the 2004 dry season and lost 200g/day during 2005 dry season. During the spring season Figure 68 suggested that the RST would have gained between 0.5-1.0kg/day but the actual gain recorded was only 14g/day. P was most probably not the most limiting nutrient during this period. This suggested that the dry matter availability during this period was still a problem or that the P was used to replenish the depleted hydroxyapatite in bone before LW gain could be recorded.

During the wet season the eP suggested that it would support LW gain between 0.5kg/day and 1kg/day. This was confirmed by Figure 29 at 858g/day.

The 6%PT received P from the lick in combination to the veld P in the diet shown in Figure 69. The eP during the dry seasons and spring season suggested that it would support growth of between 0.5kg/day to 1kg/day.

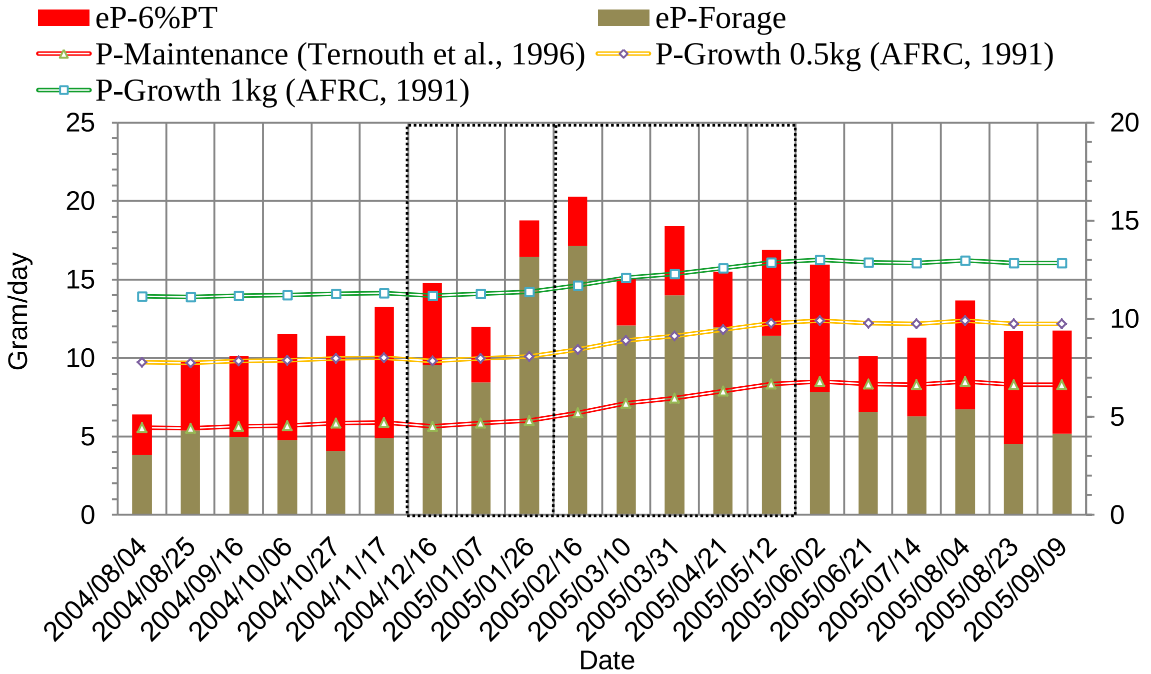


Figure 69 Estimated available phosphorus (eP) of the total intake by free-ranging cattle in the 6% phosphorus treatment group (6%PT), receiving only a 6% phosphorus lick between camp rotations, in gram per animal per day on a dry matter basis compared to the requirements for maintenance (Ternouth *et al.*, 1996) and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

The actual LW gain observed during the 2004 dry season was 138g/day, spring season 71g/day and during 2005 dry season the 6%PT had trouble maintaining weight, and lost 17g/day. This indicated that another dietary deficiency was restricting animal performance after the primary P deficiency, confirmed by the RST, was alleviated. During the wet season, there were sufficient eP to support in excess of 1kg/day LW gains which translated into actual gains of 934g/day.

The MTT (Figure 70), PDT (Figure 71) and FST (Figure 72) received P from the lick in combination to the veld P in the diet. The eP during the dry seasons and spring season would support growth of between 0.5kg/day to 1kg/day. The actual growth recorded during the 2004 dry season was 138g/day (MTT), 132g/day (PDT) and 257g/day (FST) and only 67g/day (MTT and PDT) and 142g/day (FST) during the 2005 dry season.

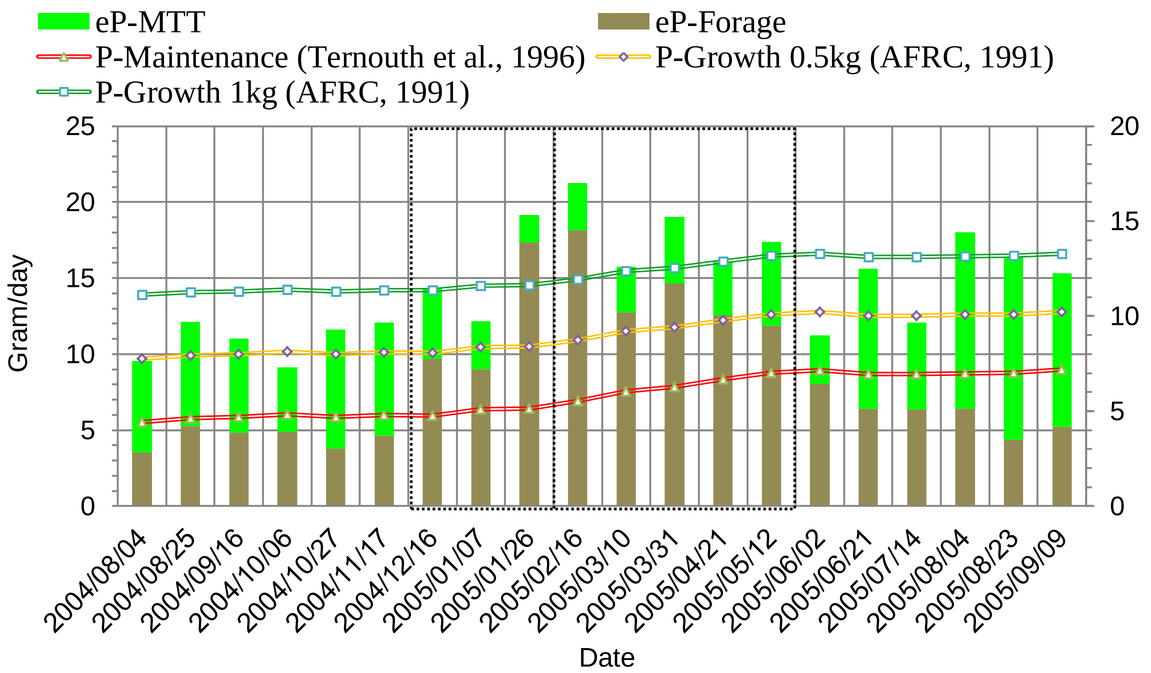


Figure 70 Estimated available phosphorus (eP) of the total intake by free-ranging cattle in the maintenance treatment group (MTT) between camp rotations in gram per animal per day on a dry matter basis compared to the requirements for maintenance (Ternouth *et al.*, 1996) and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

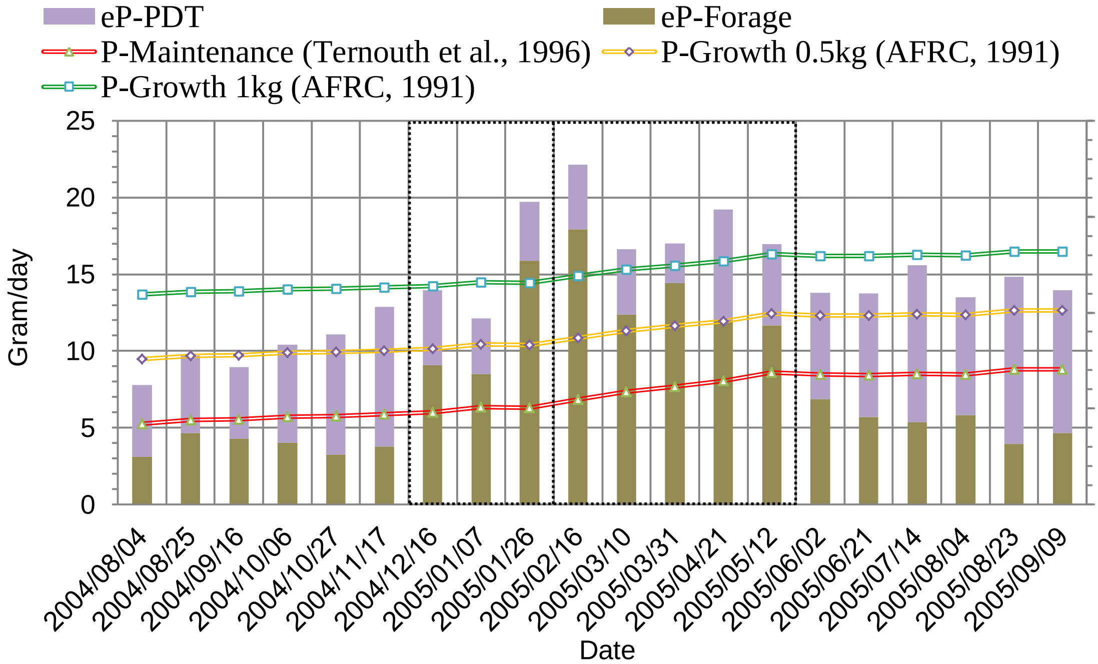


Figure 71 Estimated available phosphorus (eP) of the total intake by free-ranging cattle in the production treatment group (PDT) between camp rotations in gram per animal per day on a dry matter basis compared to the requirements for maintenance (Ternouth *et al*., 1996) and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

A higher growth rate at 257g/day (MTT and PDT) and 357g/day (FST) was recorded during the spring season. These results suggested that P was not the limiting nutrient at these intake levels during the dry and spring seasons as it was consumed in sufficient quantities for the requirements of 0.5kg/day growth.

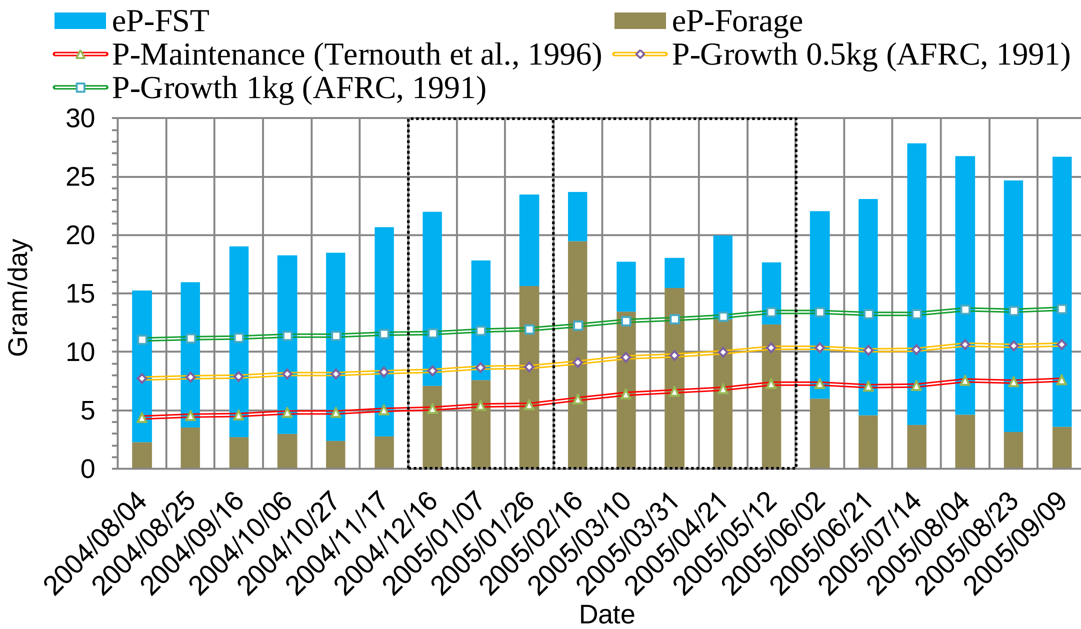


Figure 72 Estimated available phosphorus (eP) of the total intake by free-ranging cattle in the finisher treatment group (FST) between camp rotations in gram per animal per day on a dry matter basis compared to the requirements for maintenance (Ternouth *et al*., 1996) and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

The *ad libitum* P intake levels observed in this trial by the 6%PT, MTT and PDT as established by the strong seasonal trends in Chapter 6.4.1 gave a good indication of the levels required by growing cattle under these trial conditions.

The very high level of phosphorus intake presented by the FST during the dry seasons (Figure 62), above the required eP intake levels established by the 6%PT, MTT and PDT seemed to be related to the high level of ME intake from the finisher lick that was on offer (Chapter 6.7, Table 44). The increased growth rate (Figure 29) that resulted during the dry seasons from the high energy intake, would seem to suggest that the cattle were consuming the lick to maximise their energy intake for growth. The negative stimulus generated by the overconsumption of phosphorus was being offset against the larger positive effect of increased performance relating to increased energy available in the diet of the cattle.

6.5. CALCIUM AND CALCIUM TO PHOSPHORUS RATIO

The average Ca intake per animal per day over each period between rotations in camps in Table 40 are shown in Figure 73 for the 6%PT, MTT and PDT and in Figure 74 for the FST.

Table 40 Average daily *ad libitum* calcium intake between camp rotations from different nutrient supplement treatments measured in gram per animal per day on a dry matter basis. Supplementation treatments were defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Date	RST	6%PT	MTT	PDT	FST
21-Jun-04	.	9	11	9	11
14-Jul-04	.	13	9	11	12
04-Aug-04	.	7	14	9	17
25-Aug-04	.	12	16	10	17
16-Sep-04	.	14	15	9	22
06-Oct-04	.	19	10	12	21
27-Oct-04	.	20	18	15	22
17-Nov-04	.	23	17	17	24
16-Dec-04	.	15	11	9	20
07-Jan-05	.	10	7	7	14
26-Jan-05	.	6	4	7	11
16-Feb-05	.	9	9	12	12
10-Mar-05	.	8	8	12	12
31-Mar-05	.	12	12	7	7
21-Apr-05	.	10	10	20	20
12-May-05	.	15	15	15	15
02-Jun-05	.	23	8	13	22
21-Jun-05	.	10	22	15	25
14-Jul-05	.	14	13	20	32
04-Aug-05	.	19	27	15	30
23-Aug-05	.	20	28	21	29
09-Sep-05	.	18	24	18	31

The trends in the average *ad libitum* Ca intake from supplements on offer on a dry matter basis for the 6%PT, MTT, PDT and FST were similar to the trends observed in the P consumption due to the Ca inclusion in the supplements being done at constant Ca:P ratios.

The average Ca intake for 6%PT, MTT and PDT increased during the dry season from 3 Jun ’04 to the end of 17 Nov ’04 with a range of 7g/day to 23g/day. The Ca intakes simultaneously then started decreasing during the spring season to the lowest values recorded on 26 Jan 2004 ranging from 4g/day to 7g/day. The treatments were grouped and placed on the 6% phosphorus lick from 18 Nov ’04 during the wet season. Ca intakes increased towards the end of the wet season with a maximum range of 15g/day to 20g/day.

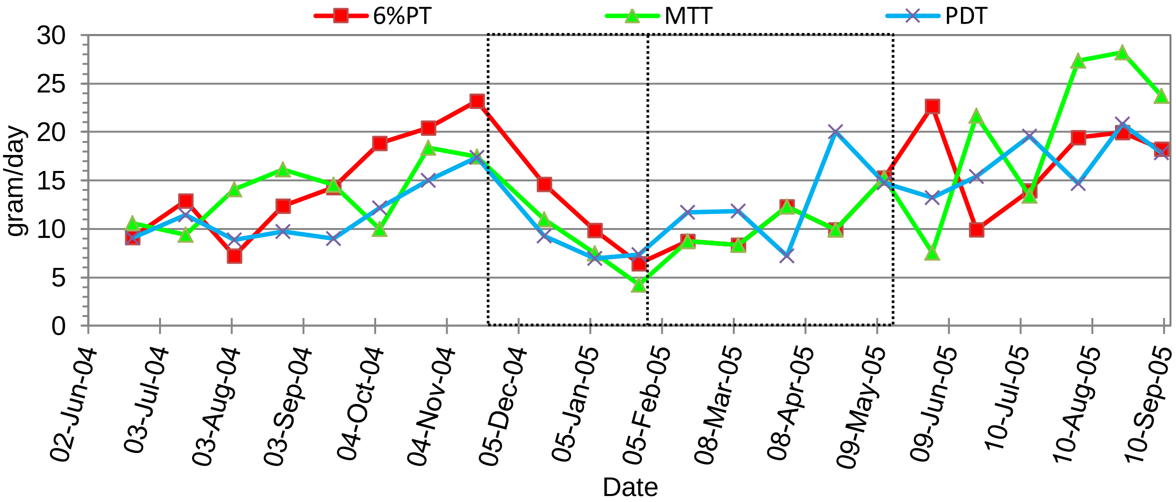


Figure 73 Average daily *ad libitum* calcium intake by free-ranging cattle in the 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT) and production treatment group (PDT) between camp rotations in gram per animal per day on a dry matter basis

From 13 May ’05 the individual specific licks (6% phosphorus lick, maintenance lick and finisher lick) were given and the intakes showed a high degree of variability with an overall increase in values towards the end of the experimental period. The highest intakes recorded during the 2005 dry season were at 23g/day (6%PT), 28g/day (MTT) and 21g/day (PDT) respectively.

The average Ca intakes recorded by the FST (Figure 74) had a similar trend as established by the 6%PT, MTT and PDT in Figure 73. The Ca intake started at 11g/day and increased during the dry season to 24g/day. The Ca intake then decreased during the spring season to a low of 11g/day. The Ca intake increased during the wet season and continued the increasing trend during the 2005 dry season to a maximum of 32g/day during the period ending 14 Jul ’05 and persisted at elevated levels until the end of the experimental period.

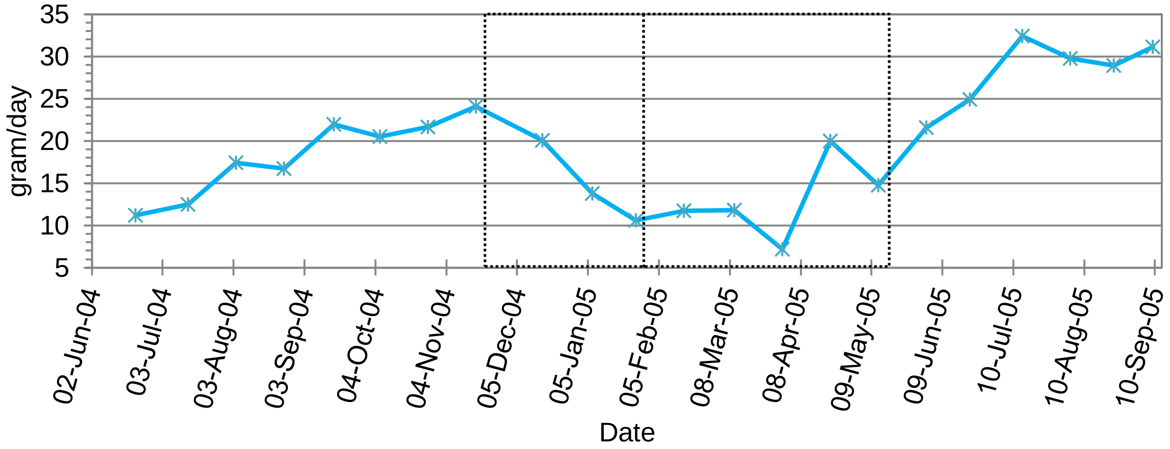
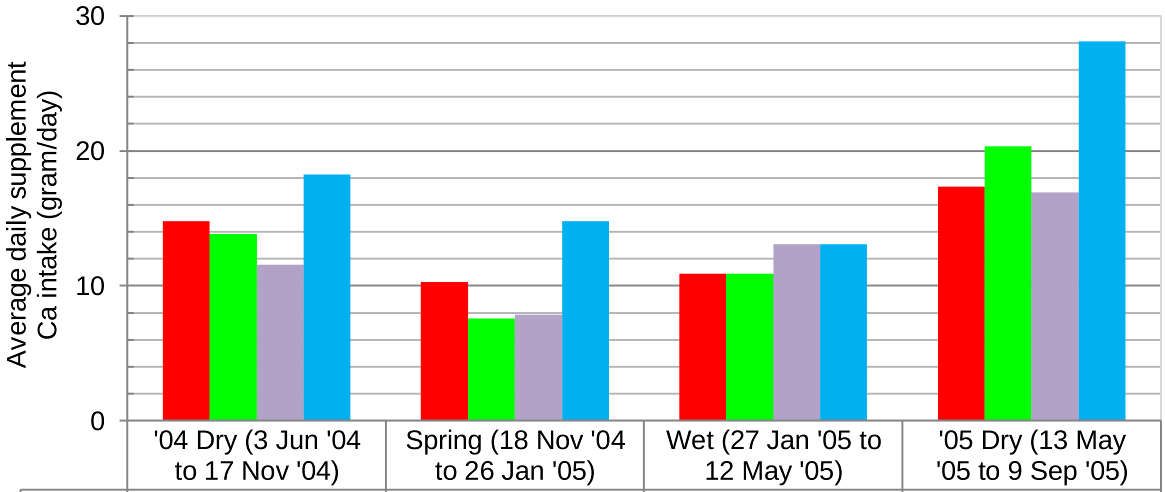


Figure 74 Average daily *ad libitum* calcium intake by free-ranging cattle in the finisher treatment group (FST) between camp rotations in gram per animal per day on a dry matter basis

6.5.1. Seasonal *ad libitum* lick intake trends

The seasonal average daily Ca contribution to the diet of free-range cattle diets from *ad libitum* consumption of different licks is illustrated in Figure 75.

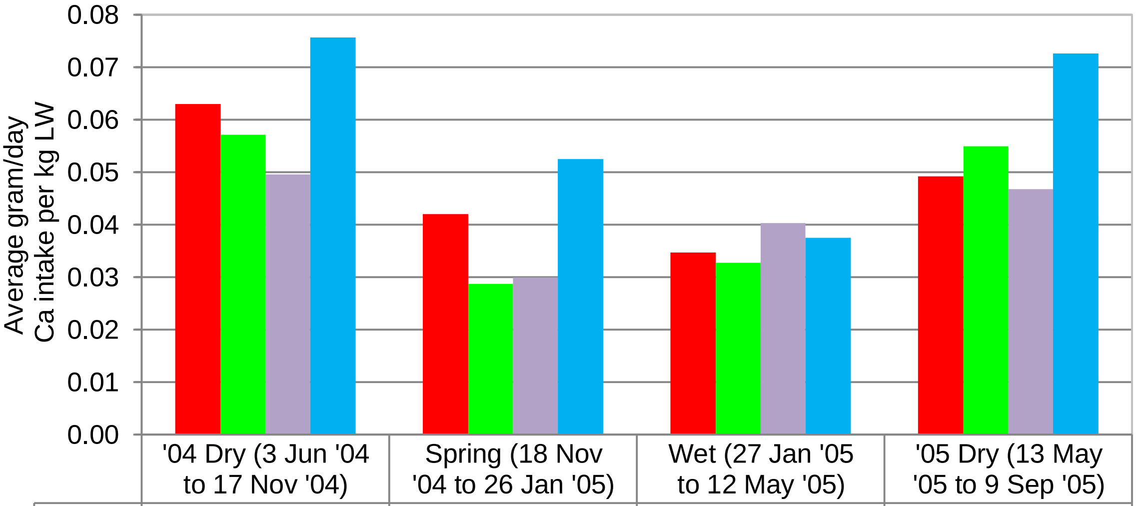


	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
6%PT	15	10	11	17
MTT	14	8	11	20
PDT	12	8	13	17
FST	18	15	13	28

Figure 75 Average daily *ad libitum* calcium (Ca) intake from the lick in grams per animal over seasons of the trial for groups of cattle on different supplementation treatments defined as 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The Ca intakes from the nutrient supplement treatments directly followed the trends established in the P intakes due to a fixed Ca to P ratio in all supplemental treatments. During the 2004 dry season there was a trend for increasing quantities of Ca being consumed by the treatment groups receiving supplements containing various concentrations of Ca. The range in average intakes during the 2004 dry season was from 12g/day to 18g/day.

There was a trend reversal during the spring season in the Ca intakes with lower levels being recorded. The average intakes during the spring season ranged from 8g/day to 15g/day. During the wet season the Ca intakes started increasing with a range from 11g/day to 13g/day. During the 2005 dry season the treatment groups consumed higher levels of Ca than the 2004 dry season with a range of 17g/day to 28g/day.



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
6%PT	0.06	0.04	0.03	0.05
MTT	0.06	0.03	0.03	0.05
PDT	0.05	0.03	0.04	0.05
FST	0.08	0.05	0.04	0.07

Figure 76 Average daily gram *ad libitum* calcium (Ca) intake from the lick per kilogram animal liveweight (LW) over seasons of the trial for groups of cattle on different supplementation treatments defined as 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The 6%PT, MTT and PDT had similar Ca intakes per kilogram LW, which was in contrast to the elevated Ca intake levels observed in the FST. During the dry seasons, the FST intakes of Ca ranged from 0.07g/kg LW to 0.08g/kg LW and during the spring season, the Ca intake was also higher at 0.05g/kg LW.

6.5.2. Estimated available calcium (eCa) compared to requirements

The efficiency of Ca absorption was taken as 70% from limestone in the lick treatments (NRC, 2001) and veld (Scott & McLean, 1981) to establish the estimated available calcium (eCa) of the total dry matter intake. The available calcium requirement for maintenance was set at 15.4mg/kg LW (AFRC, 1991) and for growth additionally the result of Equation 9 (AFRC, 1991). The average LW of treatment groups on every collection date, as presented in Table 25, was used together with the intake estimate made in Table 36, which was based on Van Schalkwyk (1978).

The RST only had the veld contributing Ca to the diet and Figure 77 indicated that the eCa during the dry months would be sufficient for 0.5kg/day gain and would sustain 1kg/day gain during the spring and wet season. The animal performance shown in Figure 29 (CHAPTER 4) indicated that the Ca would not have been a limiting nutrient in the diet of cattle on the RST.

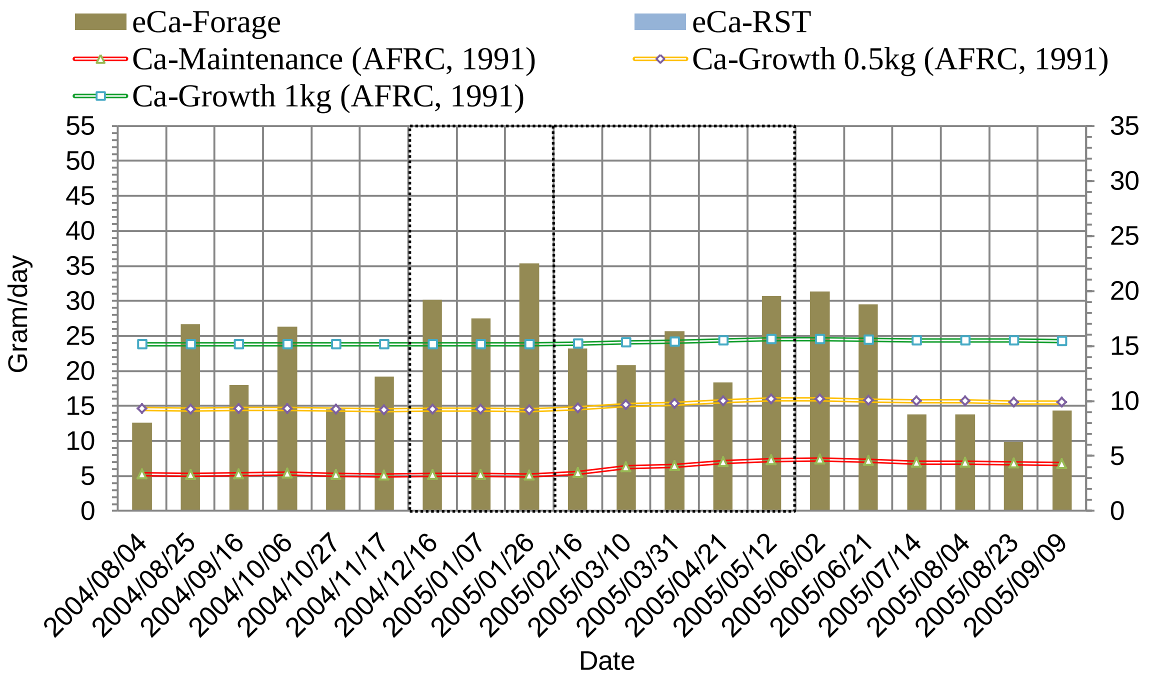


Figure 77 Estimated available calcium (eCa) of the total intake by free-ranging cattle in the rock salt treatment group (RST), receiving only a rock salt lick between camp rotations, in gram per animal per day on a dry matter basis compared to the requirements for maintenance and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

The eCa of the 6%PT (Figure 78), MTT (Figure 79), PDT (Figure 80) and FST (Figure 81) were all in excess of requirements as indicated by the actual LW gain recorded in Figure 29 (CHAPTER 4).

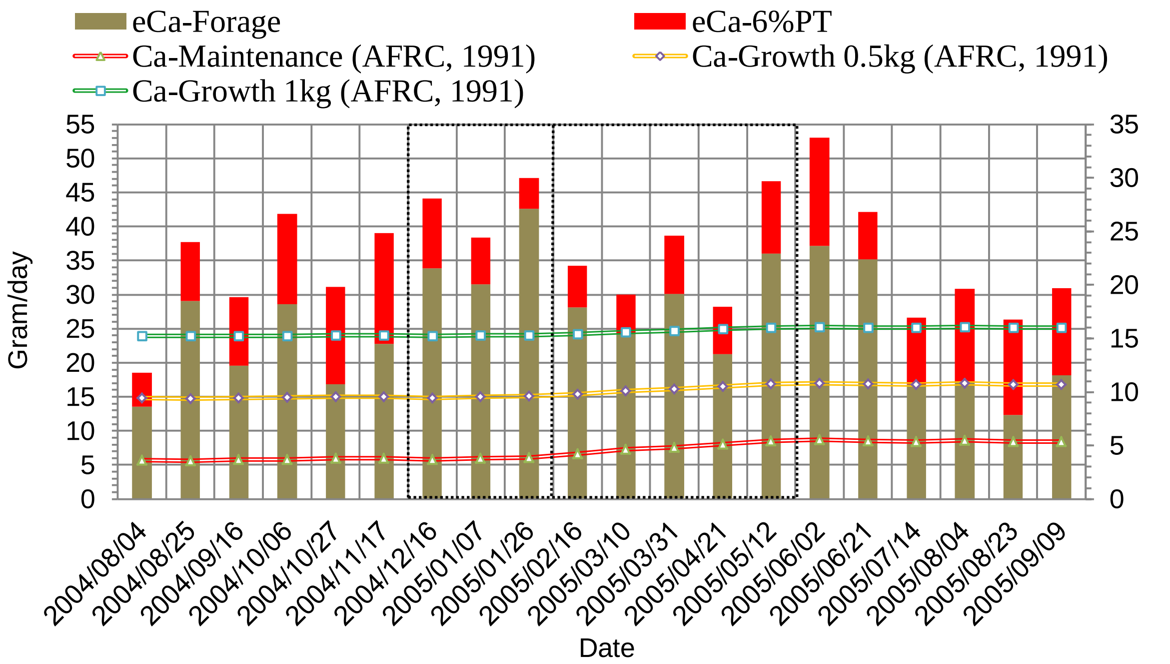


Figure 78 Estimated available calcium (eCa) of the total intake by free-ranging cattle in the 6% phosphorus treatment group (6%PT), receiving only a 6% phosphorus lick between camp rotations, in gram per animal per day on a dry matter basis compared to the requirements for maintenance and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

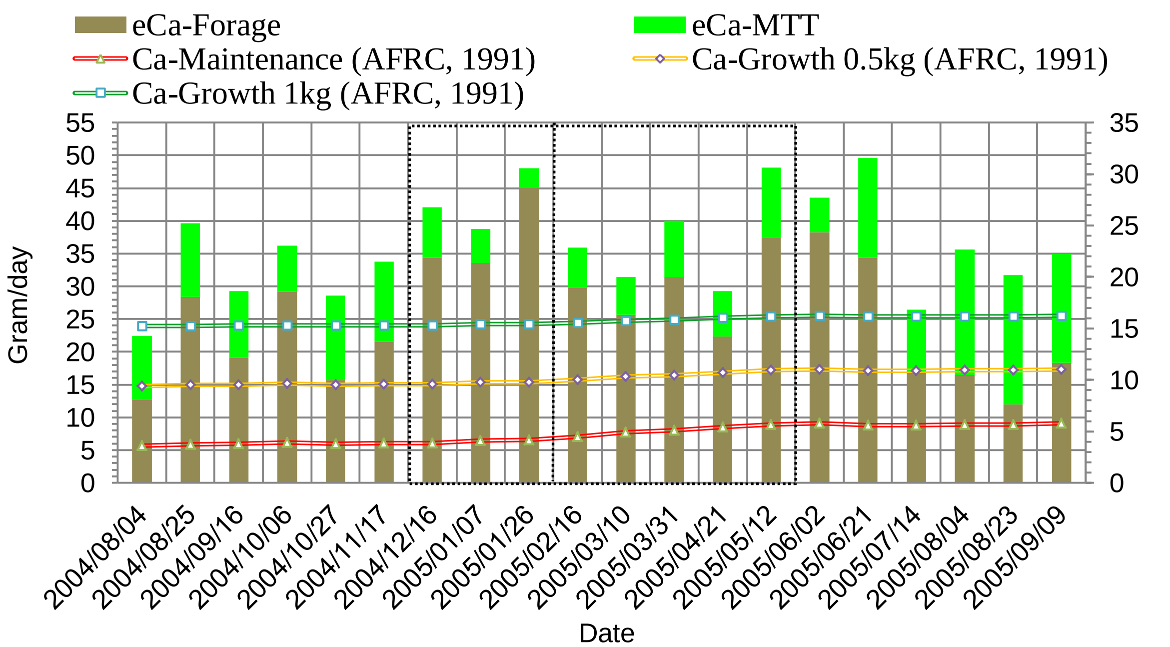


Figure 79 Estimated available calcium (eCa) of the total intake by free-ranging cattle in the maintenance treatment group (MTT) between camp rotations in gram per animal per day on a dry matter basis compared to the requirements for maintenance and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

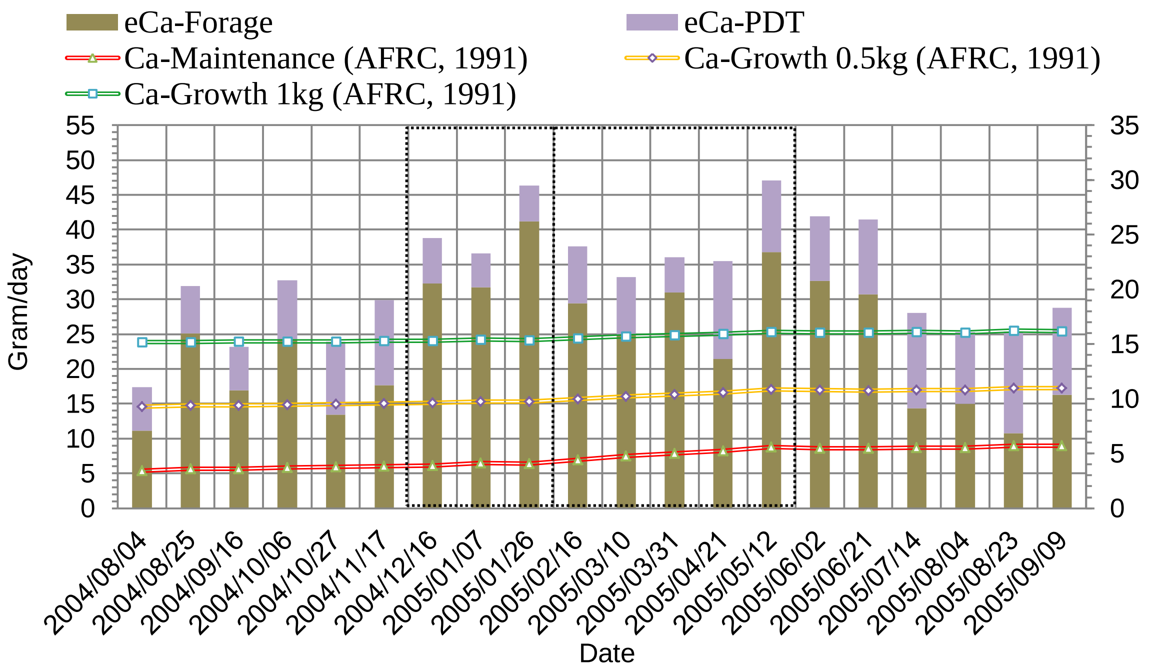


Figure 80 Estimated available calcium (eCa) of the total intake by free-ranging cattle in the production treatment group (PDT) between camp rotations in gram per animal per day on a dry matter basis compared to the requirements for maintenance and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

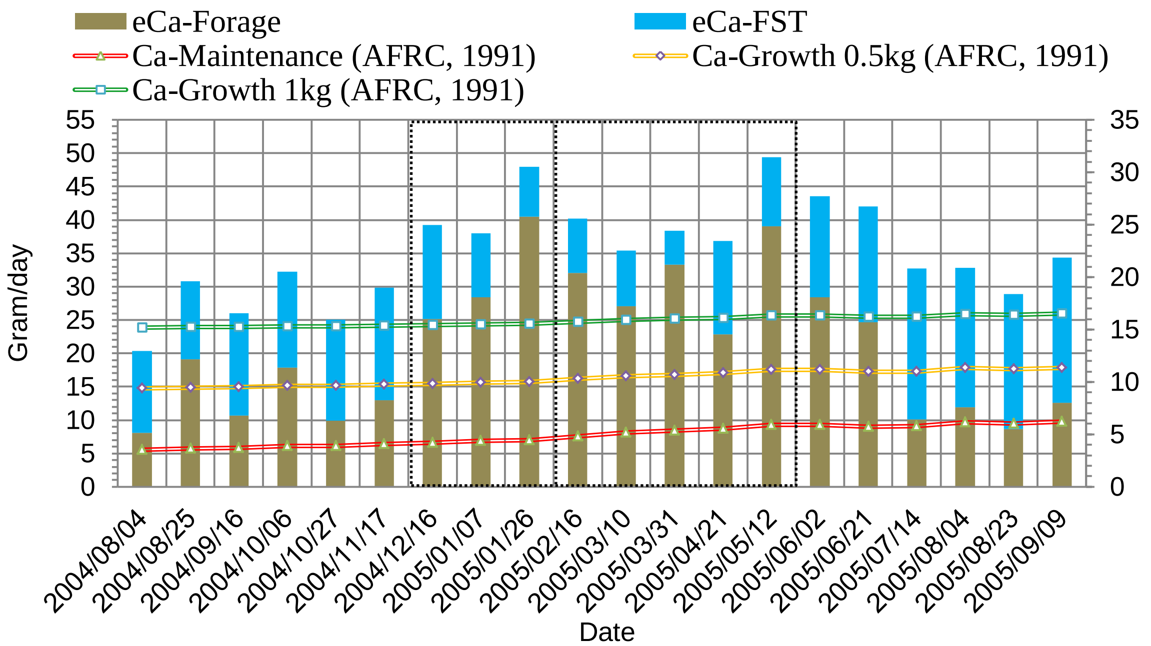


Figure 81 Estimated available calcium (eCa) of the total intake by free-ranging cattle in the finisher treatment group (FST) between camp rotations in gram per animal per day on a dry matter basis compared to the requirements for maintenance and growth at 0.5kg/day and 1.0kg/day (AFRC, 1991)

6.5.3. Estimated available calcium to phosphorus ratio (eCa:P) of total daily intake

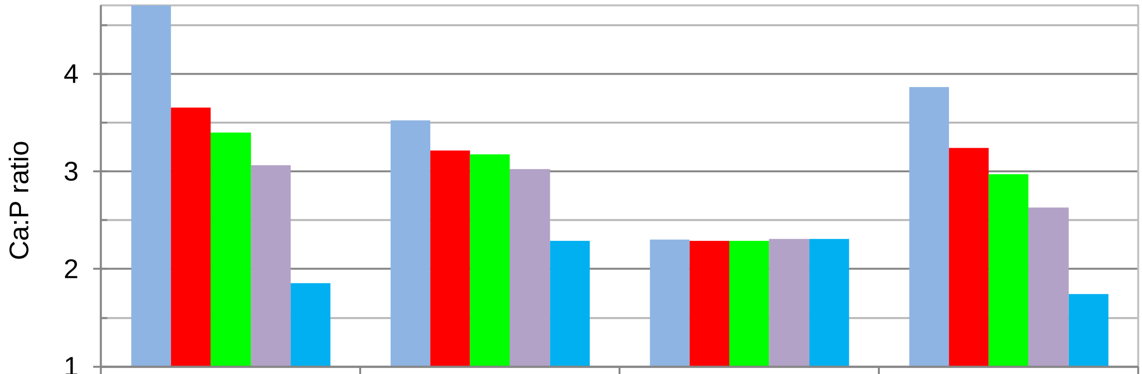
The ratio between the estimated total dietary available P and Ca (eCa: P) is presented in Table 41 and the eCa:P is illustrated in Figure 82.

Table 41 The calcium to phosphorus ratio for the estimated total dietary intake of available calcium and available phosphorus after the absorption coefficients for veld and concentrate were accounted for

Date	RST	6%PT	MTT	PDT	FST
04-Aug-04	3.8	3.3	2.8	2.6	1.6
25-Aug-04	5.8	4.4	3.8	3.8	2.3
16-Sep-04	4.2	3.4	3.1	3.0	1.7
06-Oct-04	6.4	4.2	4.6	3.7	2.1
27-Oct-04	4.4	3.2	2.9	2.6	1.6
17-Nov-04	5.0	3.5	3.3	2.8	1.8
16-Dec-04	3.8	3.4	3.3	3.1	2.1
07-Jan-05	4.0	3.6	3.5	3.4	2.5
26-Jan-05	2.8	2.7	2.7	2.6	2.3
16-Feb-05	1.8	1.8	1.8	1.9	1.9
10-Mar-05	2.2	2.2	2.2	2.2	2.2
31-Mar-05	2.3	2.3	2.3	2.3	2.3
21-Apr-05	1.9	2.0	2.0	2.1	2.1
12-May-05	3.4	3.1	3.1	3.1	3.1
02-Jun-05	5.1	3.8	4.3	3.5	2.4
21-Jun-05	5.8	4.7	3.7	3.5	2.2
14-Jul-05	2.9	2.7	2.5	2.1	1.4
04-Aug-05	2.8	2.6	2.3	2.2	1.5
23-Aug-05	2.9	2.6	2.3	2.0	1.4
09-Sep-05	3.8	3.1	2.7	2.4	1.6

The dietary average eCa:P ratios for all treatments over all seasons had a range of 1.4 to 6.4. The RST had the highest recorded eCa:P values compared to the FST with the narrowest ratios.

NRC (2000) sets the guideline for the dietary Ca:P at 1:1 to 7:1, which had been shown to give similar performances provided that the P and Ca intakes were adequate in meeting the minimum dietary requirements for each element. An extremely wide Ca:P could exacerbate a P deficiency (Ternouth, 2001).



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
RST	4.9	3.5	2.3	3.9
6%PT	3.7	3.2	2.3	3.2
MTT	3.4	3.2	2.3	3.0
PDT	3.1	3.0	2.3	2.6
FST	1.9	2.3	2.3	1.7

Figure 82 Estimated average daily total dietary available phosphorus (P) to calcium (Ca) ratio over seasons of the trial for groups of cattle on different supplementation treatments defined as 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The RST with all the dietary Ca and P supplied by the selected veld tended to have the highest seasonal eCa:P ratio ranging from 2.3 to 4.9. The 6%PT, MTT and PDT had a eCa:P ratio, averaged over seasons, ranging from 2.3 to 3.7. The FST with the highest Ca and P contributions from the lick tended to have the lowest eCa:P range from 1.7 to 2.3.

6.6. PROTEIN INTAKE

6.6.1. Crude protein intake from dry season licks

The average daily crude protein (CP) intake per animal over each sampling period during the dry season between rotations in camps (Table 42) for the MTT, PDT and FST are shown in Figure 83. The results showed that clear differences were observed in the amount of CP consumed on the different licks provided during the dry season.

Table 42 Average daily *ad libitum* crude protein intake between camp rotations from different nutrient supplement treatments measured in gram per animal per day on a dry matter basis. Supplementation treatments were defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Date	RST	6%PT	MTT	PDT	FST
21-Jun-04	.	.	114	191	294
14-Jul-04	.	.	101	241	327
04-Aug-04	.	.	152	187	457
25-Aug-04	.	.	174	205	439
16-Sep-04	.	.	157	189	577
06-Oct-04	.	.	108	257	539
27-Oct-04	.	.	198	316	568
17-Nov-04	.	.	188	366	632
16-Dec-04	.	.	119	196	526
07-Jan-05	.	.	80	146	361
26-Jan-05	.	.	46	155	277
16-Feb-05	.	.	.	.	.
10-Mar-05	.	.	.	.	.
31-Mar-05	.	.	.	.	.
21-Apr-05	.	.	.	.	.
12-May-05	.	.	.	.	.
02-Jun-05	.	.	81	279	567
21-Jun-05	.	.	234	324	653
14-Jul-05	.	.	145	412	852
04-Aug-05	.	.	295	309	782
23-Aug-05	.	.	304	440	760
09-Sep-05	.	.	256	376	817

The RST and 6%PT did not have any protein sources in the licks that were offered and during the wet season all treatments, except the RST, were changed to a 6% phosphorus lick. During the 2004 dry season, from 3 Jun ’04 to 17 Nov ’04, there was a trend for increasing amounts of CP being consumed by treatment groups receiving supplements containing various concentrations of CP (Table 20).

The MTT had a range of CP intakes from 46g/day to 304g/day. During the 2004 dry season the CP intake started at 114g/day and increased up to 198g/day, during the period ending 27 Oct ’04, and subsequently decreased to 46g/day in the period ending 26 Jan ’05 at the end of the spring season. The 2005 dry season the intake started at 81g/day and increased to a maximum of 304g/day during the period ending 23 Aug ’05.

The PDT had a range of CP intakes from 155g/day to 440g/day. During the 2004 dry season, the CP intake started at 191g/day and increased up to 366g/day at the end of the dry season. The CP intake decreased during the spring season to 155g/day. The 2005 dry season CP intake started at 279g/day and increased to a maximum of 440g/day during the period ending 23 Aug '05.

The FST had a range of CP intakes from 277g/day to 852g/day. During the 2004 dry season, the CP intake started at 294g/day and increased up to 632g/day at the end of the dry season. The CP intake subsequently decreased to 277g/day in the spring season. The 2005 dry season CP intake started at 567g/day, increased to a maximum of 852g/day during the period ending 14 Jul '05, and persisted at these elevated levels up to the end of the trial.

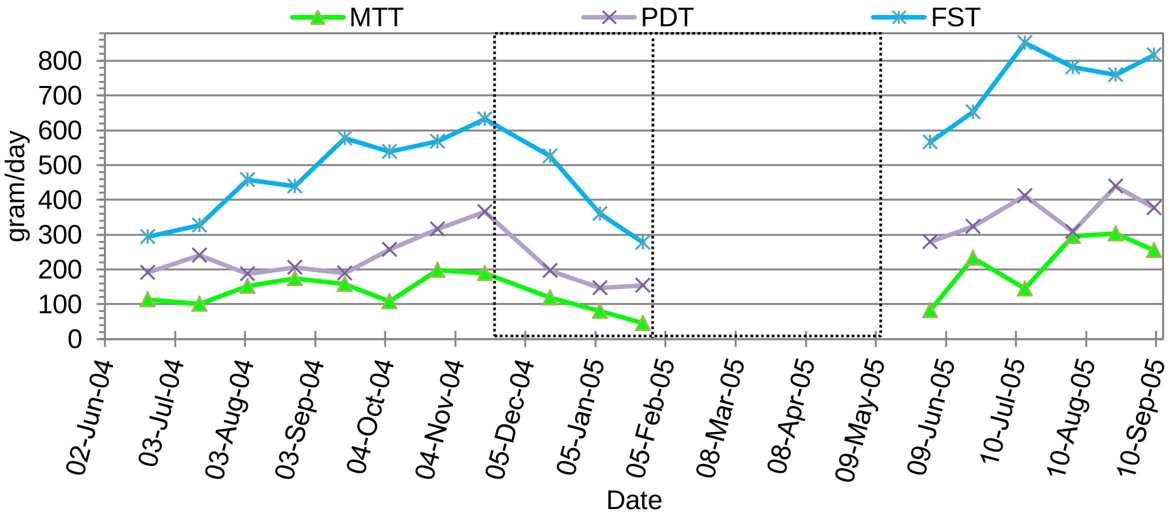
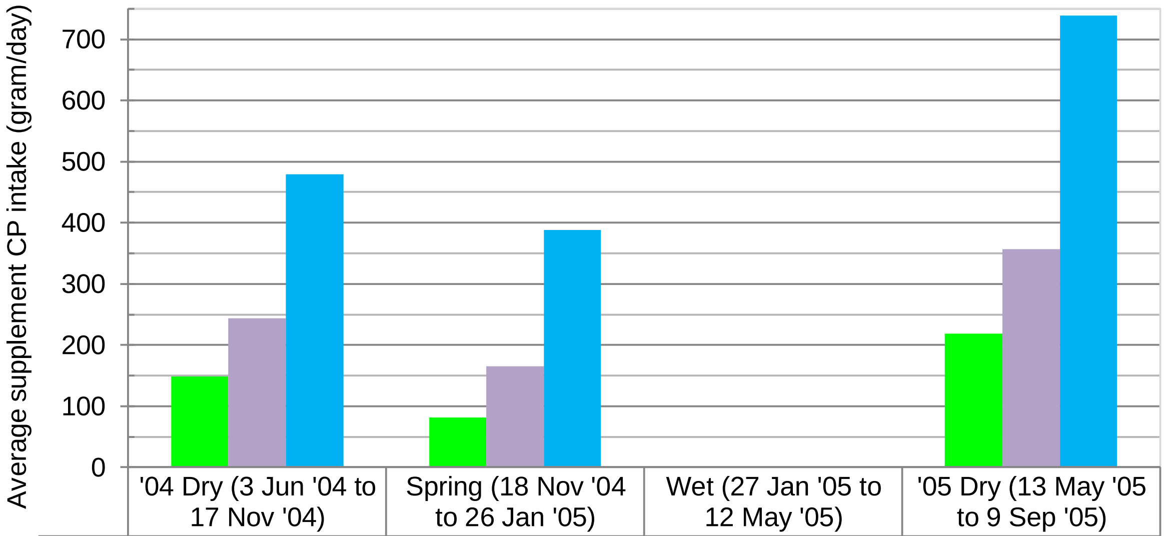


Figure 83 Average daily *ad libitum* total crude protein intake by free-ranging cattle in the maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST) between camp rotations in gram per animal per day on a dry matter basis

The seasonal average daily CP contribution to the diet of free-range cattle diets from *ad libitum* consumption of different licks is illustrated in Figure 84. The average daily CP intake from supplements per animal decreased from the 2004 dry season (MTT 149g/day, PDT 244g/day and FST 479g/day) to the spring season (MTT 82g/day, PDT 165g/day and FST 388g/day).



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
MTT	149	82	0	219
PDT	244	165	0	357
FST	479	388	0	738

Figure 84 Average daily *ad libitum* crude protein (CP) intake from the lick in grams per animal over seasons of the trial for groups of cattle on different supplementation treatments defined as maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The average daily CP intakes from supplements were higher during the 2005 dry season at MTT 219g/day, PDT 357g/day and FST 738g/day than the preceding 2004 dry season.

6.6.2. Crude protein contribution from non-protein nitrogen sources (CP ex-NPN) in dry season licks

The average daily CP that was contributed by NPN (CP ex-NPN) raw material sources (Urea, Mono-Ammonium Phosphate & Ammonium Sulphate) in the lick are presented in Table 43 and illustrated in Figure 85.

Table 43 Average daily *ad libitum* crude protein derived from non-protein nitrogen source intake between camp rotations from different nutrient supplement treatments measured in gram per animal per day on a dry matter basis. Supplementation treatments were defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Date	RST	6%PT	MTT	PDT	FST
21-Jun-04	.	.	82	109	136
14-Jul-04	.	.	73	137	151
04-Aug-04	.	.	109	107	211
25-Aug-04	.	.	125	116	203
16-Sep-04	.	.	113	108	266
06-Oct-04	.	.	78	146	249
27-Oct-04	.	.	143	180	262
17-Nov-04	.	.	136	208	292
16-Dec-04	.	.	86	111	243
07-Jan-05	.	.	58	83	167
26-Jan-05	.	.	33	88	128
16-Feb-05	.	.	.	.	.
10-Mar-05	.	.	.	.	.
31-Mar-05	.	.	.	.	.
21-Apr-05	.	.	.	.	.
12-May-05	.	.	.	.	.
02-Jun-05	.	.	59	159	262
21-Jun-05	.	.	169	185	302
14-Jul-05	.	.	105	235	393
04-Aug-05	.	.	213	176	361
23-Aug-05	.	.	219	250	351
09-Sep-05	.	.	184	214	377

The intake ranges of CP ex-NPN during the 2004 dry season were 73g/day to 143g/day MTT, 107g/day to 208g/day PDT and 136g/day to 292g/day FST. The maximum intakes increased during the 2005 dry season to 219g/day MTT, 250g/day PDT and 393g/day FST.

During the onset of the wet season, all CP ex-NPN levels had a trend reversal to decreasing intake levels from increasing intake levels during the dry season. The minimum intakes recorded during the spring season were 33g/day MTT, 83g/day PDT and 128g/day FST.

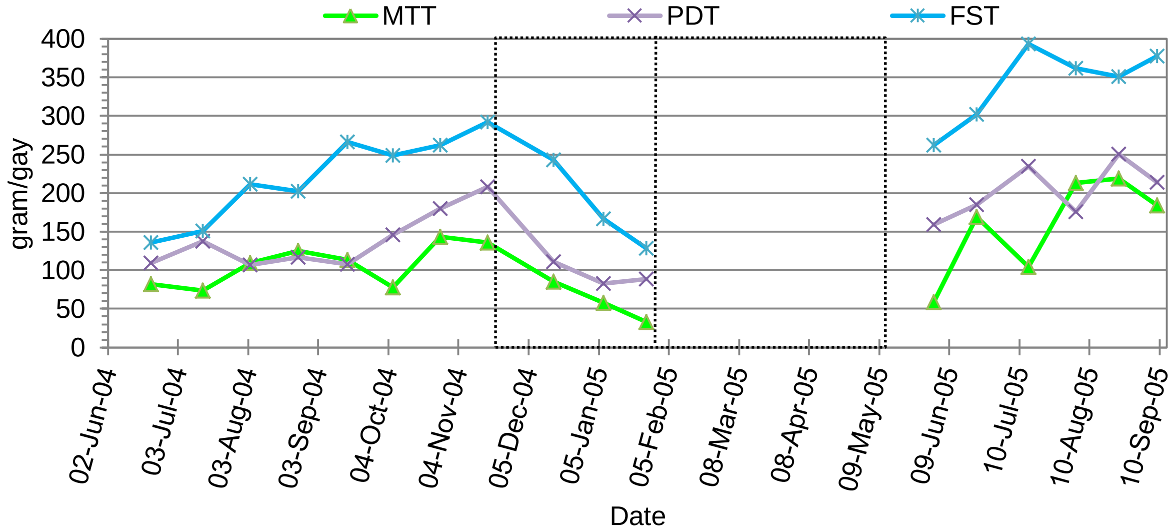
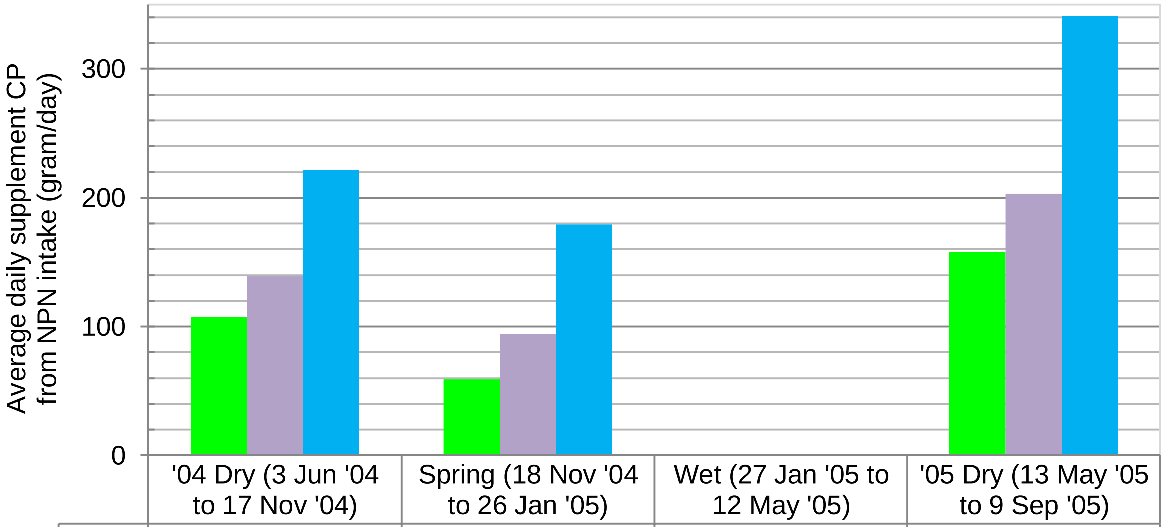


Figure 85 Average daily *ad libitum* crude protein contributed by non-protein nitrogen intake by free-ranging cattle in the maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST) between camp rotations in gram per animal per day on a dry matter basis

The seasonal average CP ex-NPN contributed to the diet of free-range cattle diets from *ad libitum* consumption of different licks is illustrated in Figure 86. The average daily CP ex-NPN intake from supplements per animal decreased from the 2004 dry season (107g/day MTT, 139g/day PDT and 221g/day FST) to the spring season (59g/day MTT, 94g/day PDT and 179g/day FST).



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
MTT	107	59	0	158
PDT	139	94	0	203
FST	221	179	0	341

Figure 86 Average daily *ad libitum* crude protein (CP) intake that originates from non-protein nitrogen (NPN) sources in the lick in grams per animal over seasons of the trial for groups of cattle on different supplementation treatments defined as maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The average daily CP ex-NPN intakes from supplements were higher during the 2005 dry season with MTT 158g/day, PDT 203g/day and FST 341g/day than the preceding 2004 dry season.

The CP contributed by NPN sources (CP ex-NPN) had a similar trend than the CP intake, but the ranges were lower for the FST and higher for the MTT with the PDT in between. The nitrogen released by these sources were all contributing to the rumen degradable protein (RDP) fraction which could lead to NPN poisoning if over consumed (Huntington & Archibeque, 2000). The CP ex-NPN could replace up to 85% of the natural protein sources in the diet of cattle to stimulate dry matter intake (Köster *et al.*, 1997) or replace 100% of the natural protein without dry matter intake (Jacobs, 2005) or animal performance deteriorations (Bareki, 2010; Van der Merwe, 2010).

During the spring season the decrease in lick intakes by all nutrient supplementation treatments seemed to be indicated by the improvement in the veld selected by OF, indicated by increases in P and CP concentrations in the selected veld. The CP that would be available during the early regrowth of grass would primarily be contributing RDP. The veld RDP together with CP ex-NPN could have had a negative sensory feedback to cattle resulting in potential decreased lick intakes. The FST with the highest CP ex-NPN levels in the diet did not seem to be more effected, in decreased lick intakes during the spring season, than the MTT and PDT.

Different NPN percentage contributions to the total CP in the licks (Table 20) were used at 72% MTT, 57% PDT and 46% FST. These levels were still below the suggested 85% maximum level suggested by (Köster *et al.*, 1997). Research by Jacobs (2005), Bareki (2010) and Van der Merwe (2010) have shown that 100% replacement of natural RDP materials by NPN sources in high-molasses supplements was possible. The FST had the highest total intake levels of CP ex-NPN from their finisher lick, but they were also receiving a larger proportion of natural CP protein sources in their total diet than the other supplementation treatments. The PDT contained a slightly higher concentration of CP ex-NPN in the dry season production lick, but consumed a lower total level than the FST. The MTT had the highest concentration of CP ex-NPN in the maintenance lick but consumed the lowest level, compared to the PDT and FST.

6.6.3. Estimated metabolisable protein (eMP) compared to requirements

The average LW of treatment groups on every collection date, as presented in Table 25, was used together with the intake estimate made in Table 36, which was based on Van Schalkwyk (1978). The crude protein concentration of veld selected by OF together with the estimated intake gave the estimated crude protein intake from forage. The crude protein intake from the licks was added to the estimated forage CP intake and an estimate of the total crude protein intake was made for each treatment group.

The estimated total dietary protein was estimated to be fully utilised for microbial protein synthesis. The microbial protein, that was the result of the ruminal degradable protein (RDP) input and veld crude protein contributed from the diet, was assumed to be 80% true protein and 80% digestible (NRC, 2000). The total estimated protein intake was thus multiplied by 0.64 to obtain the estimated metabolisable protein (eMP) of the total daily intake (NRC, 2000). The requirement for maintenance was set at 3.8g MP/kg $BW^{0.75}$ (NRC, 2000) and for growth 279.85g MP/kg gain (NRC, 2001).

The RST only had the veld contributing CP to the diet and Figure 87 indicated that the eMP intake during the 2004 and 2005 dry season would not have been enough for the maintenance of body weight. Animal performance recorded in Figure 29 in CHAPTER 4 confirmed that the RST lost 84g/day during the 2004 dry season and lost 200g/day during 2005 dry season.

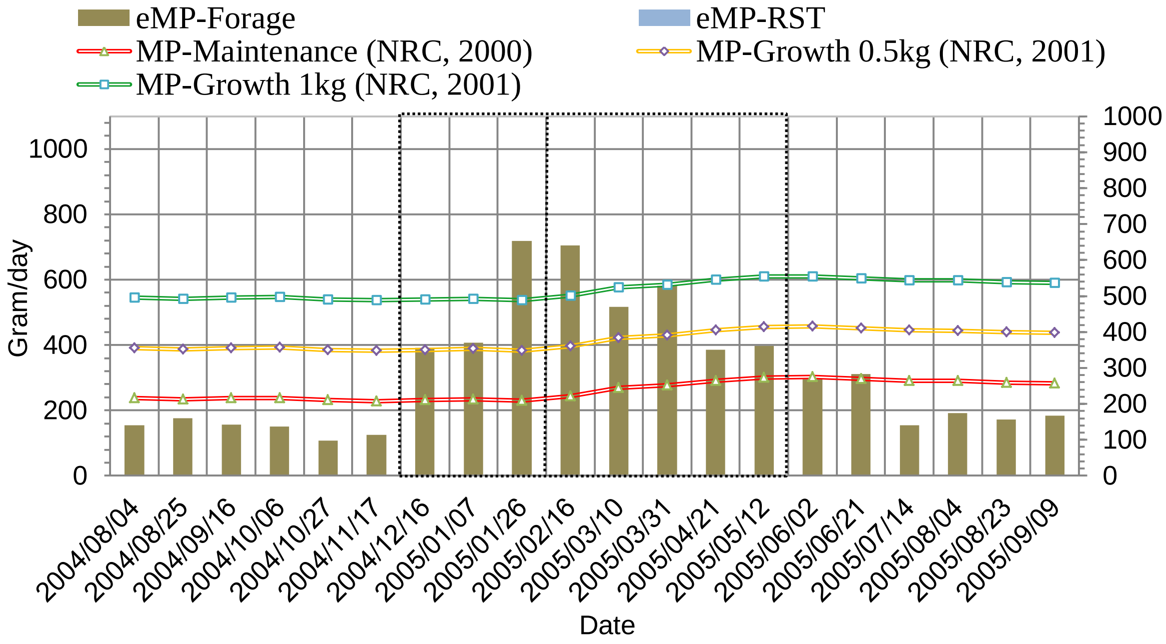


Figure 87 Estimated metabolisable protein (eMP) of the total intake by free-ranging cattle in the rock salt treatment group (RST), receiving only a rock salt lick between camp rotations, in gram per animal per day on a dry matter basis compared to the requirements for maintenance (NRC, 2000) and growth at 0.5kg/day and 1.0kg/day (NRC, 2001)

During the spring season Figure 87 suggested that the RST would have gained between 0.5-1.0kg/day but the actual gain recorded was only 14g/day. CP was most probably not the most limiting nutrient during this period. This suggested that the dry matter availability during this period would have been limiting. During the wet season the eMP intakes suggested that it would support LW gain between 0.5kg/day and 1kg/day. This was confirmed by Figure 29 at 858g/day.

This seemed to indicate that CP intake was the first limiting nutrient to performance of the RST during the dry season and that the P intake indicated in Chaper 6.4 would be sufficient for body weight maintenance. This however was not confirmed by the 6%PT that was also not receiving sufficient quantities of CP in the diet but did receive adequate quantities of P and had significantly higher performance levels.

The 6%PT only had the veld contributing CP to the diet and Figure 88 indicated that the eMP intake during the 2004 and 2005 dry season would not have been enough for bodyweight maintenance. The animal performance recorded in Figure 29 (CHAPTER 4) did not confirm this and the 6%PT gained 138g/day during the 2004 dry season and only lost 17g/day during 2005 dry season. This indicated that CP intake was not the most limiting factor to LW gain although the intakes clearly seemed suboptimal. P seemed to be the first most limiting nutrient to animal production when comparing the RST and 6%PT with each other.

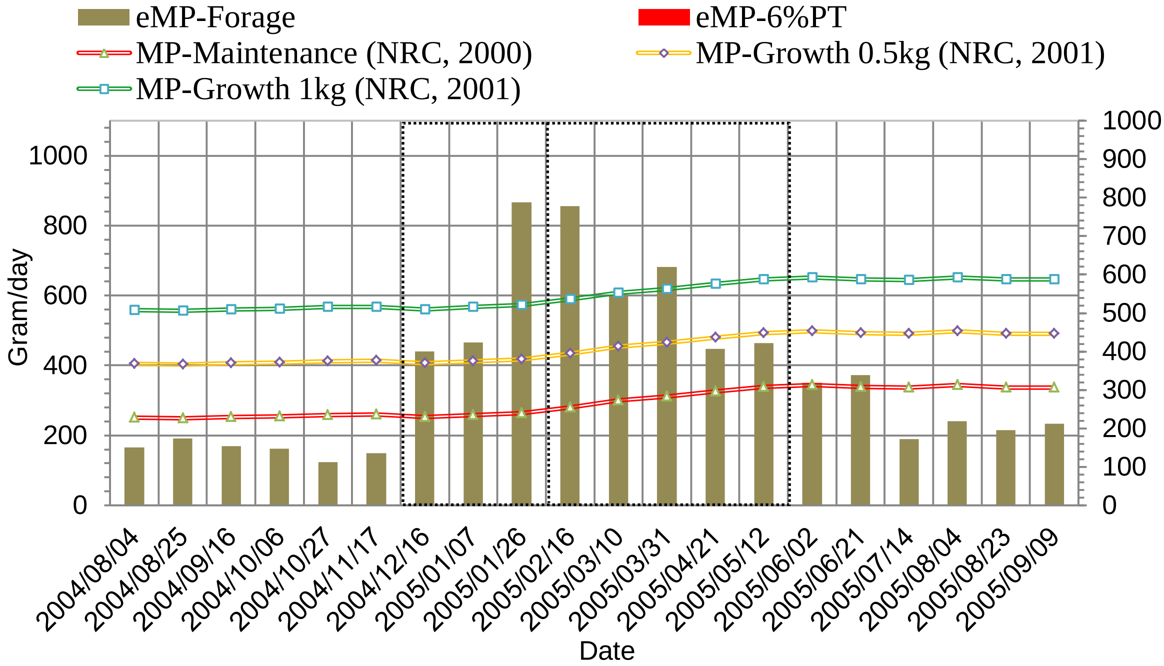


Figure 88 Estimated metabolisable protein (eMP) of the total intake by free-ranging cattle in the 6% phosphorus treatment group (6%PT), receiving only a 6% phosphorus lick between camp rotations, in gram per animal per day on a dry matter basis compared to the requirements for maintenance (NRC, 2000) and growth at 0.5kg/day and 1.0kg/day (NRC, 2001)

During the spring season there was sufficient eMP in the total daily intake to support 0.5kg/day to 1kg/day LW gain. The LW gain recorded in Figure 29 (CHAPTER 4) did not confirm this with only 71g/day being recorded. This could indicate that dry matter intake was lower than estimated. During the wet season the eMP intakes indicated that it would support growth of between 0.5-1.0kg/day LW gains which were confirmed by actual gains of 934g/day.

The MTT (Figure 89), PDT (Figure 90) and FST (Figure 91) received CP from the lick in combination to the veld CP in the diet. The MTT and PDT had similar eMP intakes from the diet during the dry seasons, which would support maintenance and gain of up to 0.5kg/day.

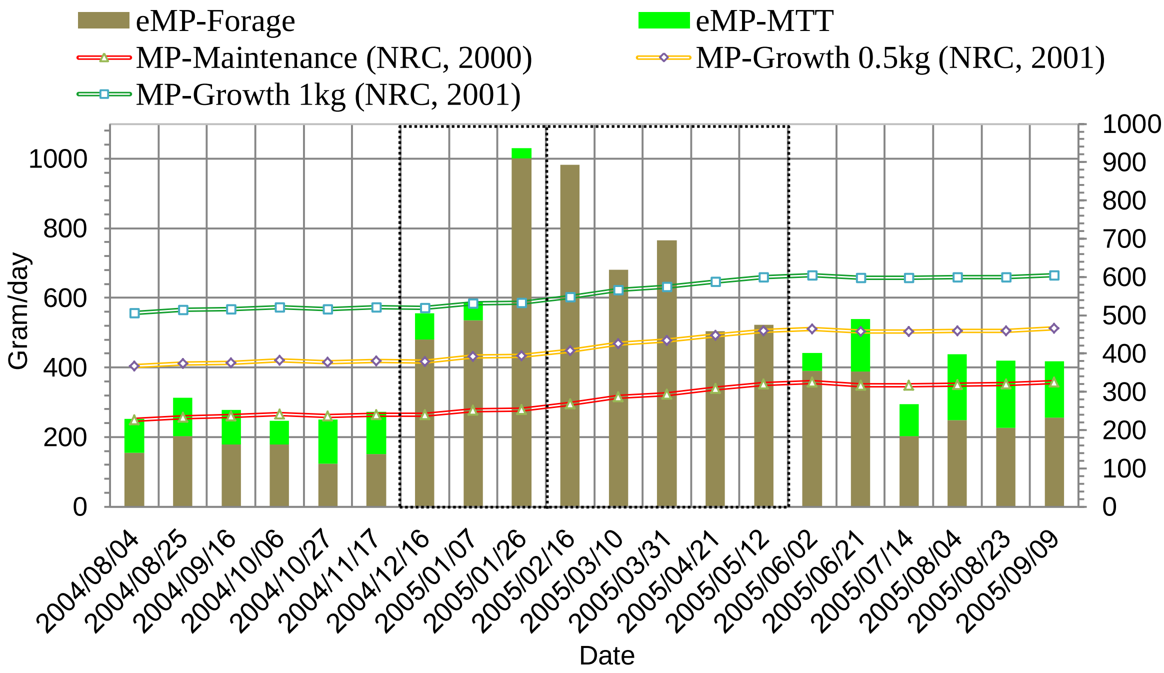


Figure 89 Estimated metabolisable protein (eMP) of the total intake by free-ranging cattle in the maintenance treatment group (MTT) between camp rotations in gram per animal per day on a dry matter basis compared to the requirements for maintenance (NRC, 2000) and growth at 0.5kg/day and 1.0kg/day (NRC, 2001)

The actual growth recorded during the 2004 dry season was 138g/day (MTT) and 132g/day (PDT) and only 67g/day (MTT and PDT) during the 2005 dry season. The eMP intake during the spring season and wet season indicated that LW gain of 0.5kg/day to 1.0kg/day would be supported which was confirmed by the animal performance data in Figure 29 (CHAPTER 4). During the spring season the LW gain recorded by MTT and PDT were similar at 257g/day, which was lower than the indicated eMP levels that were available. It seemed that the dry matter availability of veld was limiting during this period. During the wet season the LW gain recorded by the MTT at 934g/day and PDT at 915g/day agreed with MP requirements for LW gain of 0.5kg/day to 1kg/day.

The FST had persistently high eMP levels in Figure 91 which would indicate LW gain of 0.5kg/day to1.0kg/day throughout the dry and wet seasons would be possible.

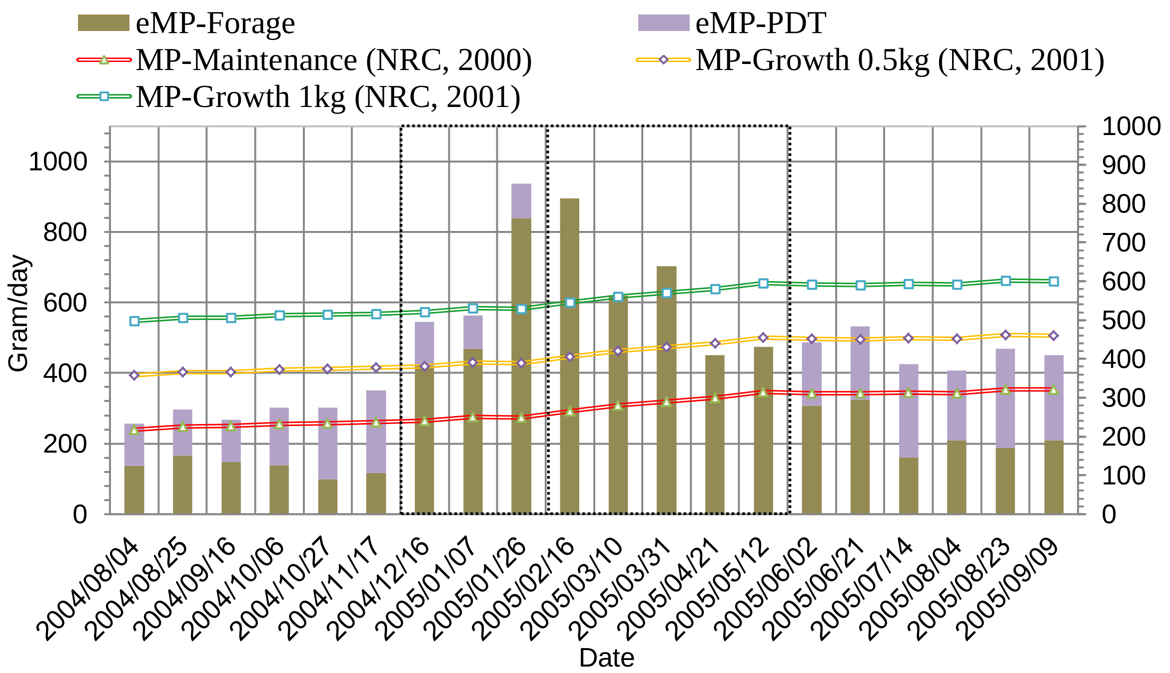


Figure 90 Estimated metabolisable protein (eMP) of the total intake by free-ranging cattle in the production treatment group (PDT) between camp rotations in gram per animal per day on a dry matter basis compared to the requirements for maintenance (NRC, 2000) and growth at 0.5kg/day and 1.0kg/day (NRC, 2001)

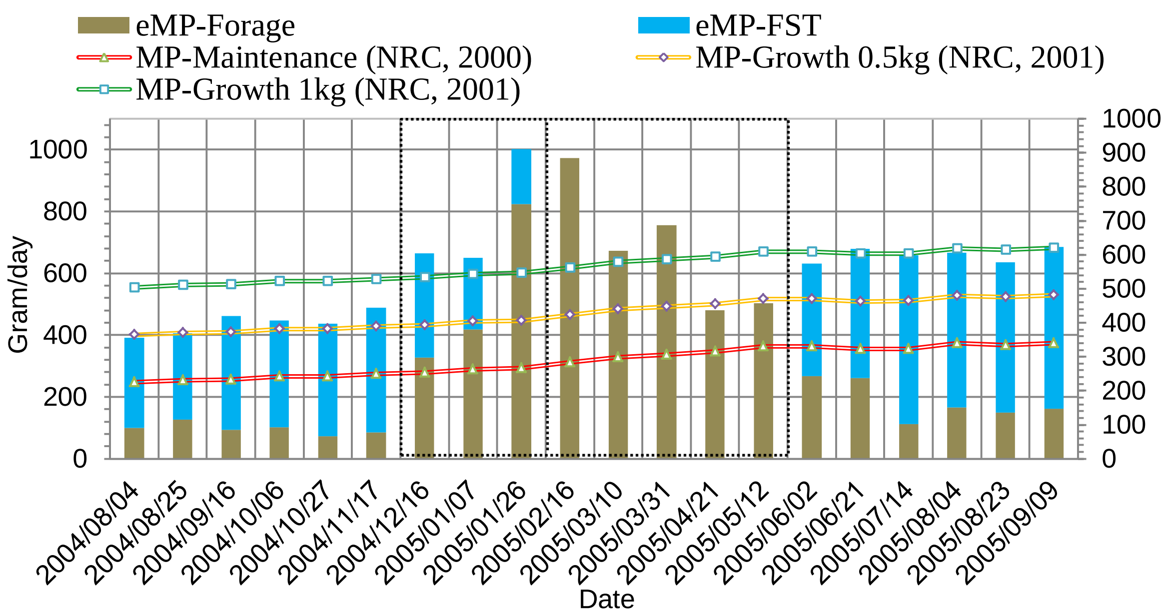


Figure 91 Estimated metabolisable protein (eMP) of the total intake by free-ranging cattle in the finisher treatment group (FST) between camp rotations in gram per animal per day on a dry matter basis compared to the requirements for maintenance (NRC, 2000) and growth at 0.5kg/day and 1.0kg/day (NRC, 2001)

The animal performance data in Figure 29 (CHAPTER 4) did not confirm this during the 2004 dry season at 257g/day, 357g/day during the spring season and 142g/day during the 2005 dry season. LW gain estimates during the wet season at 986g/day were in agreement with eMP levels. This indicated that surplus eMP levels were available to the FST for gain but that other dietary factors restricted LW gain.

6.6.4. Lick crude protein intake compared to minimum recommendations by Moore *et al*. (1999) and Klevesahl *et al*. (2003)

The minimal CP intake from supplements at 0.05% of BW (Equation 10) recommended for forage based diets for the largest increases in daily LW gain was presented by Moore *et al.* (1999). The minimum requirement for supplemental RDP in the diet of steers to maximise digestible OM intake (Equation 11) was given by Klevesahl *et al.* (2003). Köster *et al.* (1996) found that diminishing responses in forage organic matter intake to higher levels of RDP were probably set by the fermentability of the forage and the protein requirements of the animal. Klevesahl *et al.* (2003) found that offering a supplement that was a combination of supplemental RDP and starch did not improve total digestible OM intake compared to only offering supplemental RDP alone. Jacobs (2005), Bareki (2010) and Van der Merwe (2010) found that 100% replacement of natural RDP materials by NPN in high-molasses supplements would not affect cattle performance.

The minimum level of CP supplemental intake for optimal LW gain (Moore *et al.*, 1999) and the minimum RDP supplementation level for maximising intake (Klevesahl *et al.*, 2003) are presented for the supplemental treatments that contributed CP to the diet during the dry season in the MTT (Figure 92), PDT (Figure 93) and FST (Figure 94).

The MTT was barely maintaining this minimum level of supplementation suggested by Moore *et al.* (1999) during the 2004 dry season and fell below this level during the spring season. During the early part of the 2005 dry season it was also below the recommended minimum level.

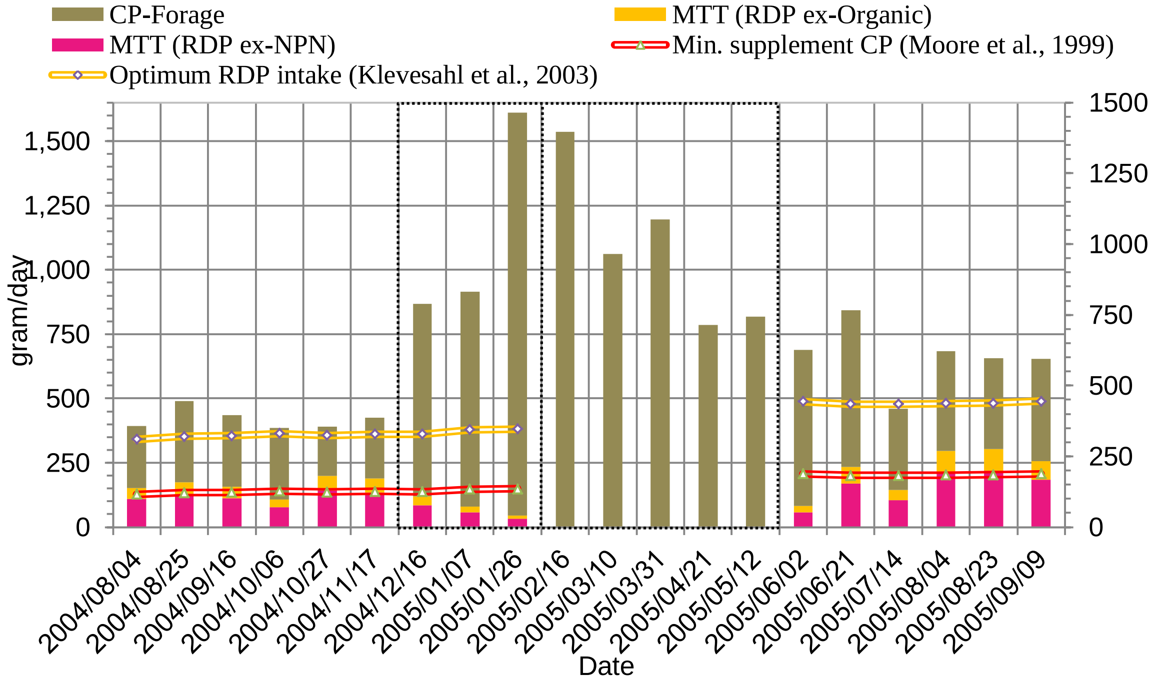


Figure 92 Estimated crude protein (CP) intake by free-ranging cattle in the maintenance treatment group (MTT) consisting of the veld CP and the rumen degradable protein (RDP) within the maintenance lick derived from non-protein nitrogen (NPN) and organic sources. The data is presented per camp rotation in gram per animal per day on a dry matter basis compared to the minimum CP level for maximum liveweight gain (Moore *et al.*, 1999) and the minimum RDP level for maximising intake (Klevesahl *et al.*, 2003)

Comparing these identified months of lower than minimum CP levels for maximum liveweight gain to the eMP in the previous section it is evident that sufficient eMP intake occurred during these periods. The higher protein levels originated from the selected veld and not just body weight maintenance was possible as suggested by the eMP during these periods, but also growth.

The optimum RDP supplement intake level suggested by Klevesahl *et al.* (2003) was not reached during any stage of the trial by the MTT. The eMP during the dry seasons indicated that higher levels of MP in die diet could have increased growth rates and the RDP from the maintenance lick could be increased for further improvements in organic matter intake. The strong influence P seemed to have on lick intake rates (Figure 64) would require that the P concentration in the MTT would need to be lowered (while higher salt intakes could occur) or alternatively the CP concentration in the lick needed to be higher to allow for increased levels of RDP to be consumed for improved growth rates.

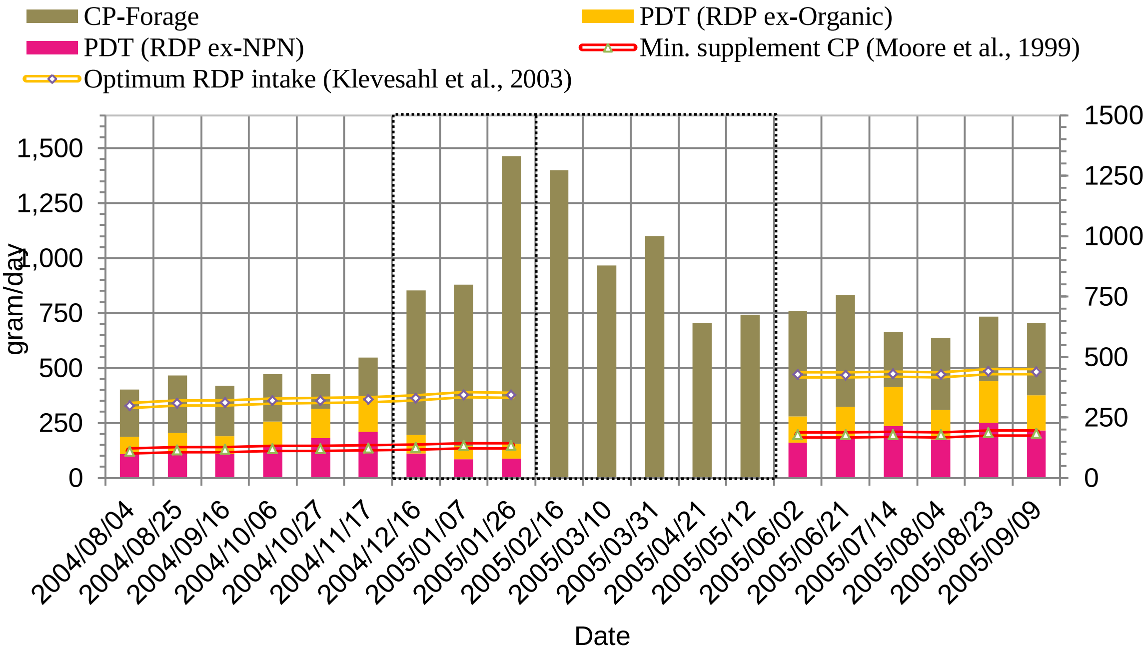


Figure 93 Estimated crude protein (CP) intake by free-ranging cattle in the production treatment group (PDT) consisting of the veld CP and the rumen degradable protein (RDP) within the production lick derived from non-protein nitrogen (NPN) and organic sources. The data is presented per camp rotation in gram per animal per day on a dry matter basis compared to the minimum CP level for maximum liveweight gain (Moore *et al.*, 1999) and the minimum RDP level for maximising intake (Klevesahl *et al.*, 2003)

The PDT was able to reach the minimum level of supplementation suggested by Moore *et al.* (1999) during the dry seasons as well as the spring season. The optimum RDP supplement intake level suggested by Klevesahl *et al.* (2003) was on average out of reach to the PDT. From the eMP in Figure 90 it was evident that the PDT was only consuming sufficient levels of CP in their diet for body weight maintenance during the 2004 dry season and growth between 0kg/day to 0.5kg/day during the 2005 dry season. Higher levels of RDP during the dry seasons could have improved organic matter intake and subsequently animal performance.

The eMP in the PDT (Figure 90) reached comparable levels to those recorded by the MTT (Figure 89), but was able to perform better in relation to the benchmarks set in Figure 93 (PDT) in comparison to the MTT (Figure 92). The average daily weight gain over seasonal periods (Figure 29) did however not seem to indicate any additional benefits derived from higher RDP levels on the PDT compared to the MTT, and both treatments ended on similar weights (Table 25) at the end of the experimental period at 377kg MTT and 370kg PDT.

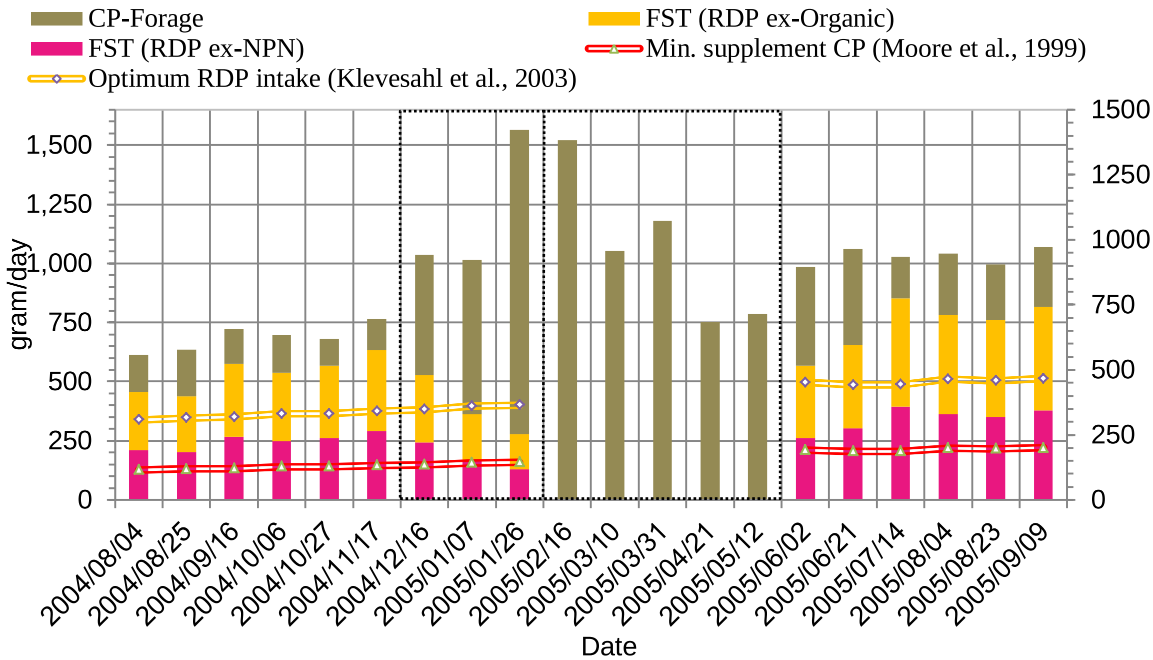


Figure 94 Estimated crude protein (CP) intake by free-ranging cattle in the finisher treatment group (FST) consisting of the veld CP and the rumen degradable protein (RDP) within the finisher lick derived from non-protein nitrogen (NPN) and organic sources. The data is presented per camp rotation in gram per animal per day on a dry matter basis compared to the minimum CP level for maximum liveweight gain (Moore *et al.*, 1999) and the minimum RDP level for maximising intake (Klevesahl *et al.*, 2003)

The FST was able to reach the minimum level of supplementation suggested by Moore *et al.* (1999) during the dry seasons as well as the spring season with only taking into account the CP ex-NPN fraction in Figure 94. Combining the CP originating from organic raw materials in the finisher lick to the CP ex-NPN in the FST, it was able to surpass the optimum RDP supplement intake level suggested by Klevesahl *et al.* (2003), except towards the end of the spring season.

The eMP (Figure 91) of the FST illustrated that the CP intake of the group should have resulted in growth rates of between 0.5kg/day to 1kg/day. This however did not realise as the group could only gain 257g/day during the 2004 dry season, 357g/day during the spring season and then dropped to 142g/day during the subsequent 2005 dry season.

In addition to optimal CP supplementation levels in the FST, indicated by Figure 91 and Figure 94, the finisher lick would have also substituted low digestibility forage from the diet by higher digestible energy raw materials derived from the finisher lick, which should have allowed optimal production to be reached. The intake of salt (Figure 62) and eP (Figure 72) above requirements could have had a negative effect on the growth performances observed in the FST.

6.7. ENERGY INTAKE

The average daily metabolisable energy (ME) intake per animal over each sampling period during the dry season between rotations in camps (Table 44) for the MTT, PDT and FST are shown in Figure 95. The results showed that clear differences were observed in the amount of ME consumed on the different licks provided during the dry season.

Table 44 Average daily *ad libitum* metabolisable energy intake between camp rotations from different nutrient supplement treatments measured in mega-joule per animal per day on a dry matter basis. Supplementation treatments were defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Date	RST	6%PT	MTT	PDT	FST
21-Jun-04	.	.	1.06	5.10	11.91
14-Jul-04	.	.	0.94	6.42	13.24
04-Aug-04	.	.	1.41	4.99	18.50
25-Aug-04	.	.	1.61	5.45	17.75
16-Sep-04	.	.	1.46	5.05	23.36
06-Oct-04	.	.	1.00	6.84	21.83
27-Oct-04	.	.	1.84	8.42	22.99
17-Nov-04	.	.	1.75	9.75	25.58
16-Dec-04	.	.	1.10	5.21	21.29
07-Jan-05	.	.	0.75	3.89	14.61
26-Jan-05	.	.	0.43	4.13	11.22
16-Feb-05	.	.	.	.	.
10-Mar-05	.	.	.	.	.
31-Mar-05	.	.	.	.	.
21-Apr-05	.	.	.	.	.
12-May-05	.	.	.	.	.
02-Jun-05	.	.	0.76	7.43	22.93
21-Jun-05	.	.	2.17	8.64	26.43
14-Jul-05	.	.	1.35	10.98	34.46
04-Aug-05	.	.	2.74	8.23	31.66
23-Aug-05	.	.	2.82	11.71	30.74
09-Sep-05	.	.	2.37	10.03	33.06

The rock salt lick and 6% phosphorus lick did not have any energy sources included. During the wet season all treatments, except the RST, were changed to a 6% phosphorus lick containing no energy. During the 2004 dry season, from 3 Jun ’04 to 17 Nov ’04, there was a trend for increasing amounts of ME being consumed by treatment groups receiving supplements containing increasing concentrations of ME (Table 20).

The MTT had a range of ME intakes from 0.43MJ/day to 2.83MJ/day. During the 2004 dry season the CP intake started at 1.06MJ/day and increased up to 1.84MJ/day, during the period ending 27 Oct ’04, and subsequently decreased to 0.43MJ/day in the period ending 26 Jan ’05 at the end of the spring season. The 2005 dry season the intake started at 0.76MJ/day and increased to a maximum of 2.82MJ/day during the period ending 23 Aug ’05.

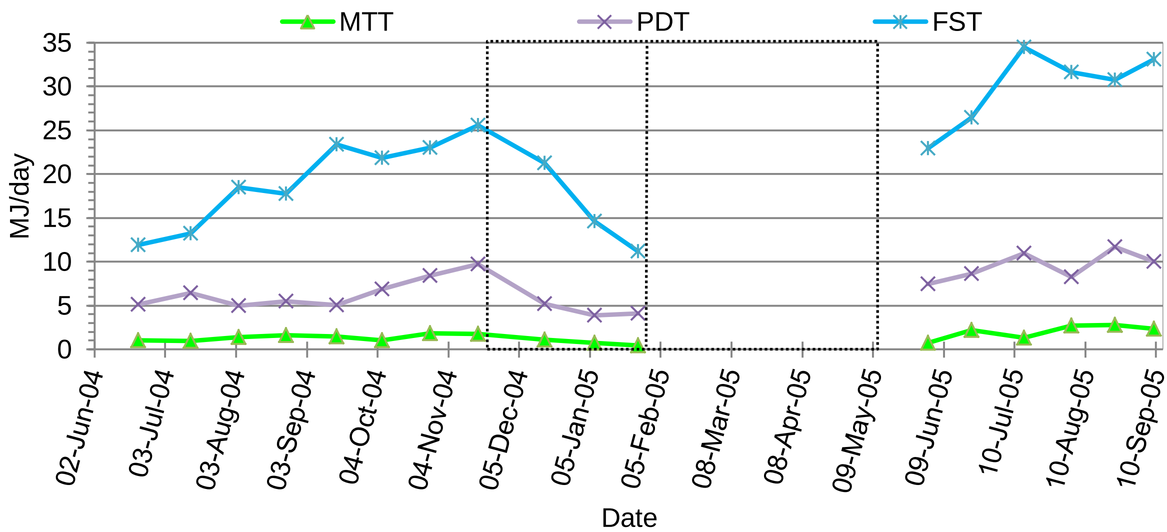


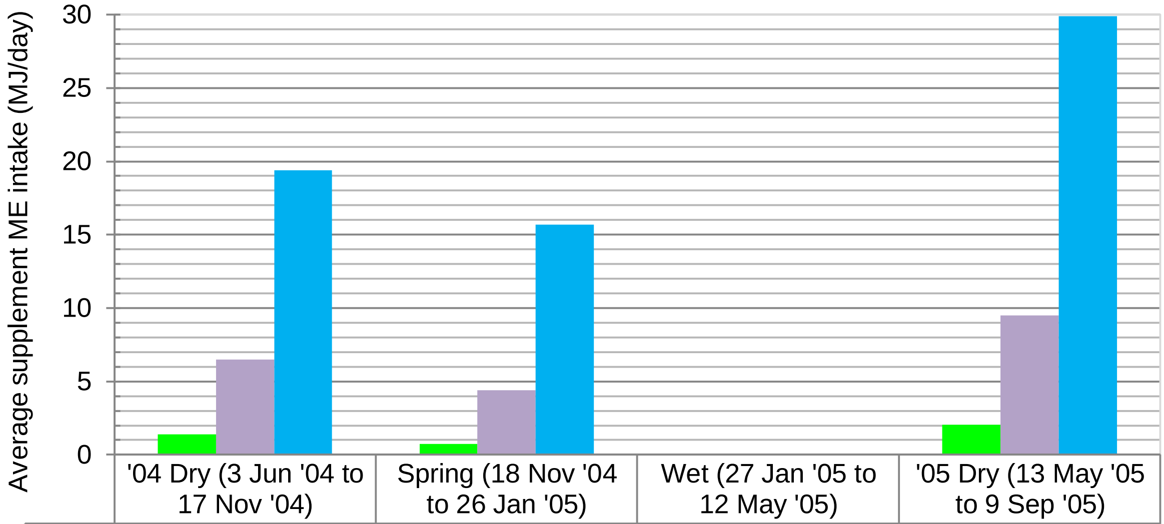
Figure 95 *Ad libitum* average daily calculated metabolisable energy (ME) intake by free-ranging cattle in the maintenance treatment group (MTT), production treatment group (PDT) and finisher group (FST) between camp rotations in mega-joules (MJ) per animal per day on a dry matter basis

The PDT had a range of ME intakes from 4.13MJ/day to 11.71MJ/day. During the 2004 dry season the ME intake started at 5.10MJ/day and increased up to 9.75MJ/day at the end of the dry season. The ME intake decreased during the spring season to 4.13MJ/day. The 2005 dry season ME intake started at 7.43MJ/day and increased to a maximum of 11.71MJ/day during the period ending 23 Aug ’05.

The FST had a range of ME intakes from 11.22MJ/day to 34.46MJ/day. During the 2004 dry season the ME intake started at 11.91MJ/day and increased up to 25.58MJ/day at the end of the dry season. The ME intake subsequently decreased to 11.22MJ/day in the spring season. The 2005 dry season ME intake started at 22.93MJ/day and increased to a maximum of 34.46MJ/day during the period ending 14 Jul '05 and persisted at these elevated levels up to the end of the trial.

6.7.1. Seasonal *ad libitum* lick intake trends

The seasonal average daily ME contribution to the diet of free-range cattle diets from *ad libitum* consumption of different licks is illustrated in Figure 96. The average daily ME intake from supplements decreased from the 2004 dry season (MTT 1.4MJ/day, PDT 6.5MJ/day and FST 19.4MJ/day) to the spring season (MTT 0.8MJ/day, PDT 4.4MJ/day and FST 15.7MJ/day).



	'04 Dry (3 Jun '04 to 17 Nov '04)	Spring (18 Nov '04 to 26 Jan '05)	Wet (27 Jan '05 to 12 May '05)	'05 Dry (13 May '05 to 9 Sep '05)
MTT	1.4	0.8	0.0	2.0
PDT	6.5	4.4	0.0	9.5
FST	19.4	15.7	0.0	29.9

Figure 96 Average daily *ad libitum* metabolisable energy (ME) intake from the lick in mega-joules (MJ) per animal over seasons of the trial for groups of cattle on different supplementation treatments defined as maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The average daily ME intakes from supplements were higher during the 2005 dry season at MTT 2.0MJ/day, PDT 9.5MJ/day and FST 29.9MJ/day than the preceding 2004 dry season.

6.7.2. Estimated metabolisable energy (eMP) compared to requirements

The energy required by growing cattle (0.5kg/day and 1kg/day) in addition to their basal metabolic energy requirement and energy required for foraging will be estimated in this section to give some insight on the actual growth rates that were recorded by the treatment groups. The most suitable estimates for these measures together with the estimated intakes of energy from the forage and supplements will be graphically presented.

The average LW of treatment groups on every collection date, as presented in Table 25, was used together with the intake estimate made in Table 36, which was based on Van Schalkwyk (1978). Digestible energy (DE) values and total digestible nutrients (TDN) were practically similar (NRC, 2000). The relationship between DE and ME could vary considerably due to energy losses in faecal, urinary and gaseous forms on different diets. The NRC (2000) used 82% to account for energy losses from DE down to ME as a generalised estimate for forages.

The TDN for dry season veld was estimated as 500g/kg based on Figure 10 (*In vivo* results on hand-cut grass samples and IVDOM results from freeze-dried OF samples published by Van Schalkwyk, 1978), which equated to 7.5MJ/kg ME (NRC, 2000). The TDN for wet season veld was estimated as 600g/kg based on Figure 10 (*In vivo* results on hand-cut grass samples and IVDOM results from freeze-dried OF samples published by Van Schalkwyk, 1978), which equated to 9MJ/kg ME (NRC, 2000).

The total maintenance ME requirement was estimated to be 0.5 $LW^{0.75}$ MJ ME (NRC, 2000) for stall-fed animals. The ME requirement for growth was calculated as 0.5 $LW^{0.75}$ MJ ME/kg LW gain (NRC, 2000).

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 basal MJ ME/day maintenance 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 foraging in large camps.

The higher energy requirement for foraging was in agreement with observations made by Van Schalkwyk (1978) that observed growing cattle required 74.38% more ME than the tabular nutrient requirements tables, which were available at the time (NRC, 1976) accounted for. 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. NRC (2000) and NRC (2001) make provisions in the prediction models for activity as an additional burden to maintenance energy when cattle were on pasture and include factors for sloped terrain, veld availability and ambient temperature.

Van Schalkwyk (1978) found that young growing heifers at an average age of 16months needed 0.243MJ ME/kg LW to maintain weight and needed 0.305MJ ME/kg LW for 0.5kg/day gain. The ME calculations suggested above resulted in the growing cattle at an age of 16months during September 2004 to be estimated as 0.190MJ ME/kg LW for maintenance and 0.254MJ ME/kg LW for 0.5kg gain. The ME level thus currently suggested for maintenance and for 0.5kg/day gain was respectively 21.8% and 16.7% lower than determined by Van Schalkwyk (1978).

The RST had only the veld contributing ME to the diet and Figure 97 indicates that the ME intake during the 2004 and 2005 dry season would have been enough for maintenance. Animal performance recorded in Figure 29 in CHAPTER 4 did not confirm this and the RST lost 84g/day during the 2004 dry season and lost 200g/day during 2005 dry season. The primary P (Bortolussi *et al.*, 1996; Ternouth, 2001) and secondary CP (Bortolussi *et al.*, 1996; Coleman, 2005) deficiencies during the dry season in the RST diet would have reduced intake which would have resulted in lower ME intakes not account for by the current ME intake levels.

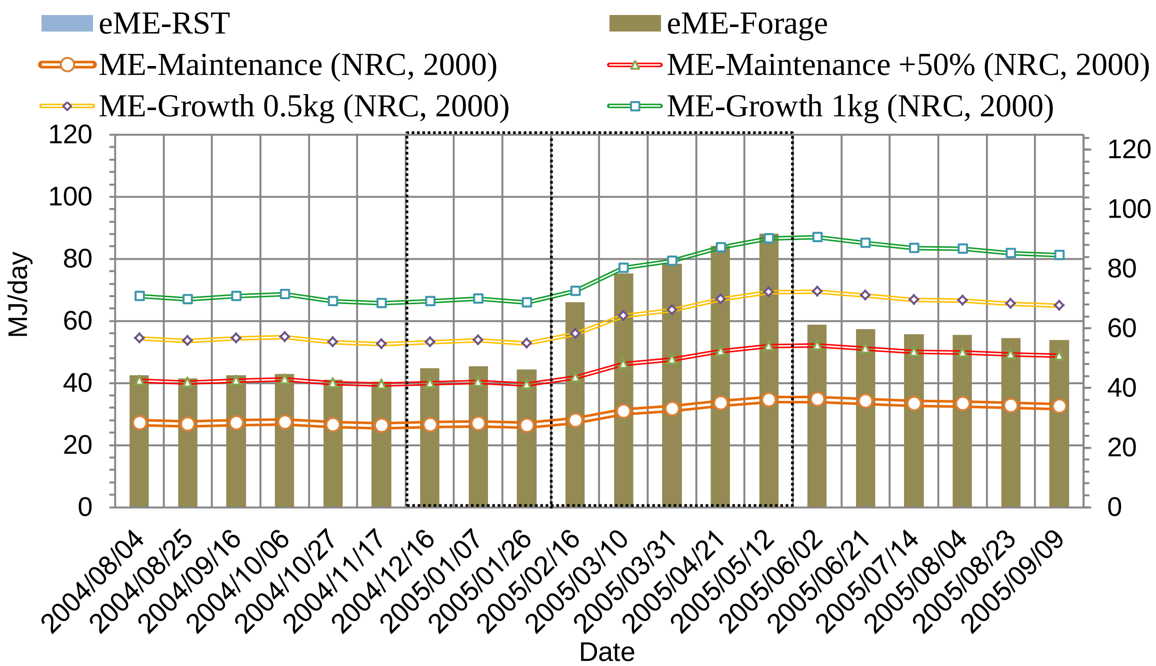


Figure 97 Estimated metabolisable energy (eME) of the total intake by free-ranging cattle in the rock salt treatment group (RST), receiving only a rock salt lick between camp rotations, in mega-joule (MJ) per animal per day on a dry matter basis compared to the requirements for basal metabolism (Maintenance of stall-fed cattle) published by the NRC (2000), maintenance increased by 50% for foraging activity, growth at 0.5kg/day and growth at 1.0kg/day (NRC, 2000)

During the spring season Figure 97 suggested that the RST would have slightly gained weight which was confirmed at only 14g/day. During the wet season the ME intakes suggested that it would support LW gain between 0.5kg/day and 1kg/day. This was confirmed in Figure 29 at 858g/day.

The 6%PT only had the veld contributing ME to the diet and Figure 98 indicated that the ME intake during the 2004 and 2005 dry season would be enough for maintenance. The animal performance recorded in Figure 29 confirmed this and the 6%PT gained 138g/day during the 2004 dry season and only lost 17g/day during 2005 dry season. This indicated that ME intake was a limiting factor to LW gain.

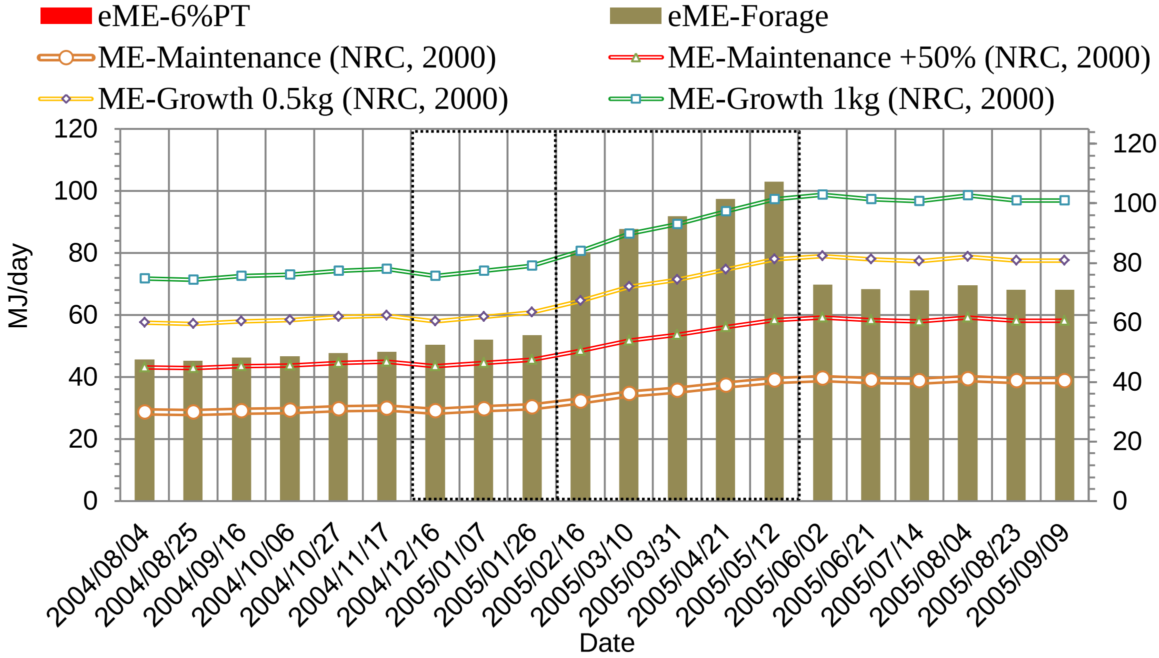


Figure 98 Estimated metabolisable energy (eME) of the total intake by free-ranging cattle in the 6% phosphorus treatment group (6%PT), receiving only a 6% phosphorus lick between camp rotations, in mega-joule (MJ) per animal per day on a dry matter basis compared to the requirements for basal metabolism (Maintenance of stall-fed cattle) published by the NRC (2000), maintenance increased by 50% for foraging activity, growth at 0.5kg/day and growth at 1.0kg/day (NRC, 2000)

During the spring season there was sufficient ME levels in the diet to support a small LW gain. The LW gain recorded in Figure 29 confirmed this with 71g/day. During the wet season the ME intakes indicated that it would support growth of between 0.5-1.0kg/day LW gain which was confirmed by an actual LW gain of 934g/day.

The MTT (Figure 99), PDT (Figure 100) and FST (Figure 101) received ME from the lick treatment during the dry and spring season in combination to the veld ME in the diet. The MTT,PDT and FST had similar relative ME intakes from the diet during the dry seasons, which would support maintenance during the 2004 dry season, but would be restricted to under 0.5kg/day LW gain during the 2005 dry season.

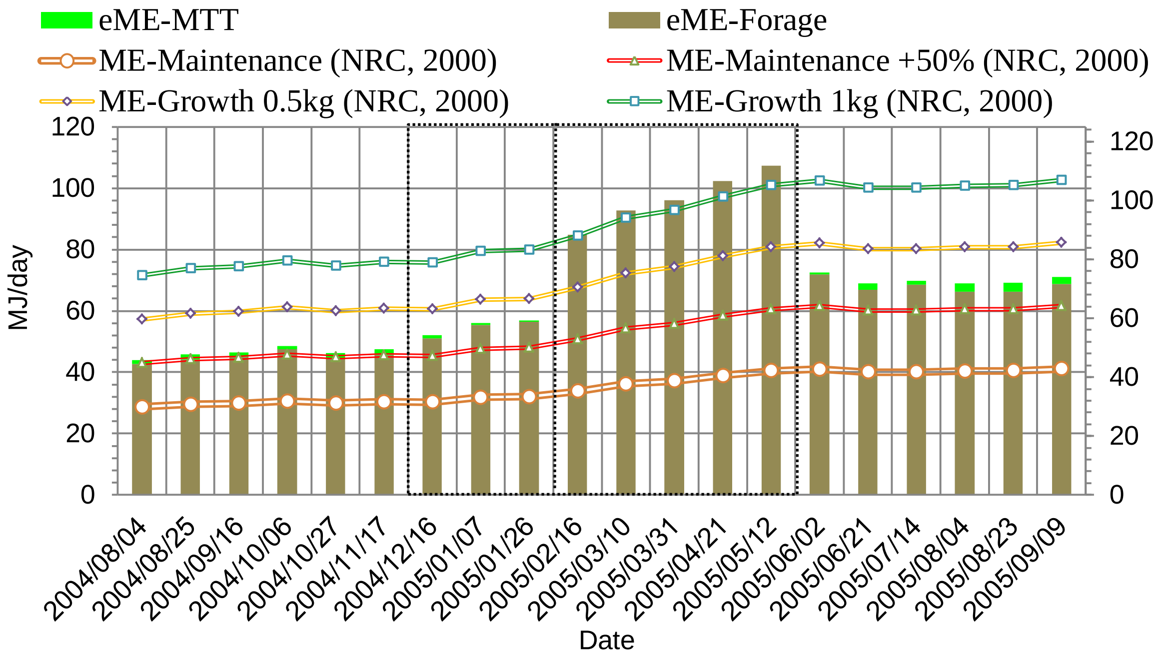


Figure 99 Estimated metabolisable energy (eME) of the total intake by free-ranging cattle in the maintenance treatment group (MTT) between camp rotations in mega-joule (MJ) per animal per day on a dry matter basis compared to the requirements for basal metabolism (Maintenance of stall-fed cattle) published by the NRC (2000), maintenance increased by 50% for foraging activity, growth at 0.5kg/day and growth at 1.0kg/day (NRC, 2000)

The actual growth recorded during the 2004 dry season was higher than estimated by the ME intake at 138g/day (MTT) and 132g/day (PDT) while during the 2005 dry season it was lower at 67g/day (MTT and PDT).

The ME intake during the spring season indicated that LW gain was restricted to below 0.5kg/day which was confirmed by the animal performance data in Figure 29. During the spring season the LW gain recorded by MTT and PDT were similar at 257g/day.

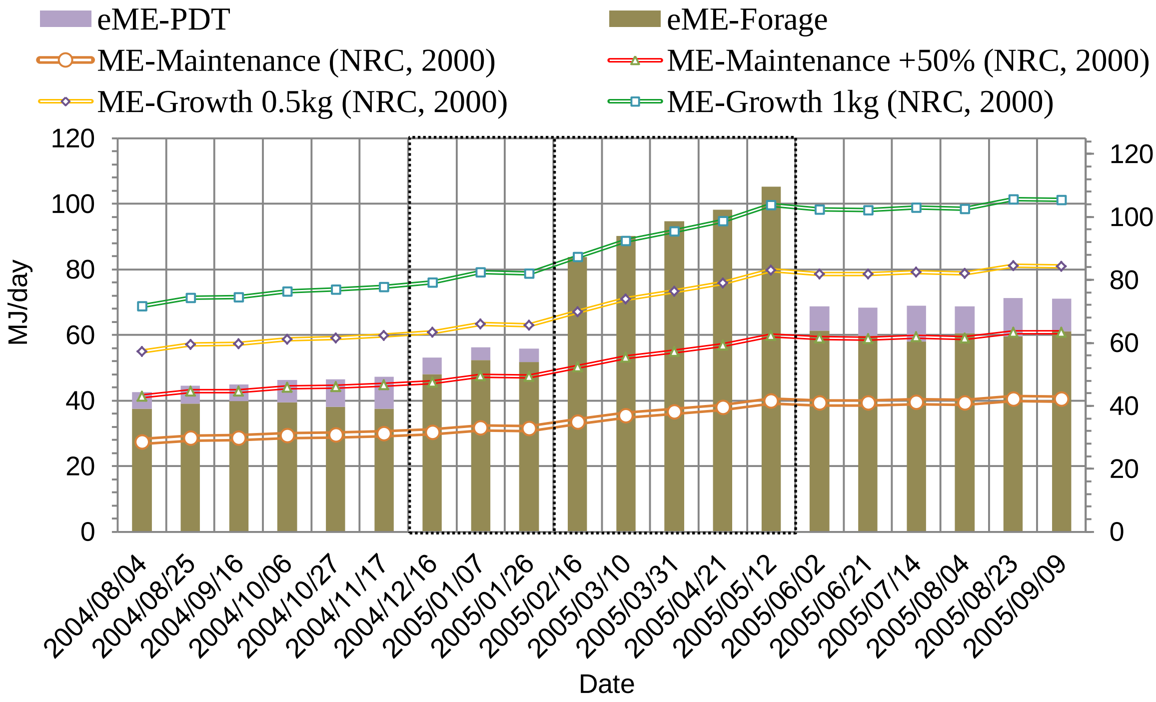


Figure 100 Estimated metabolisable energy (eME) of the total intake by free-ranging cattle in the production treatment group (PDT) between camp rotations in mega-joule (MJ) per animal per day on a dry matter basis compared to the requirements for basal metabolism (Maintenance of stall-fed cattle) published by the NRC (2000), maintenance increased by 50% for foraging activity, growth at 0.5kg/day and growth at 1.0kg/day (NRC, 2000)

During the wet season the ME intake estimates suggested that LW gain of around 1.0kg/day would be possible. Figure 29 confirmed the LW gain for MTT at 934g/day and PDT at 915g/day.

The FST had a similar trend in ME levels in Figure 101 to the MTT (Figure 99) and PDT (Figure 100) which would allow for body maintenance during the 2004 dry season and would support gain of around 0.25kg/day in the 2005 dry season. The animal performance data in Figure 29 (CHAPTER 4) confirmed that the FST had higher ME levels in the diet during the 2004 dry season with LW gain being recorded at 257g/day. During the 2005 dry season the ME level was lower than indicated in Figure 101 with only 142g/day LW gain being supported.

LW gain results (Figure 29) obtained during the wet season at 986g/day was in agreement with the estimated ME levels in the diet that LW gain of 1.0kg/day was possible.

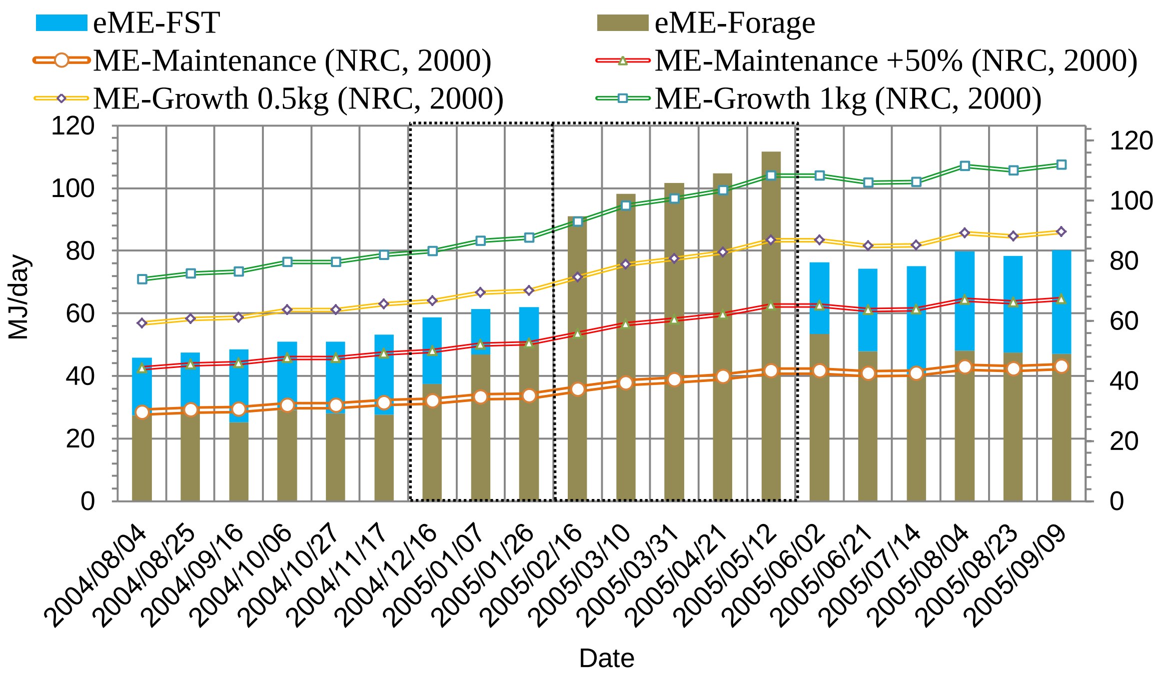


Figure 101 Estimated metabolisable energy (eME) of the total intake by free-ranging cattle in the finisher treatment group (FST) between camp rotations in mega-joule (MJ) per animal per day on a dry matter basis compared to the requirements for basal metabolism (Maintenance of stall-fed cattle) published by the NRC (2000), maintenance increased by 50% for foraging activity, growth at 0.5kg/day and growth at 1.0kg/day (NRC, 2000)

6.8. CONCLUSION

A general trend for increasing *ad libitum* strategic nutrient supplement intake was observed as the dry season progressed. Freyer (1967) found a similar trend in increasing lick intakes as the dry season progressed with concomitant decreases in CP and P concentrations in hand-cut pasture samples. During spring a trend reversal occurred and the nutrient supplement intake decreased while the veld quality increased to a maximum point. The animal performance did not respond in the same magnitude during spring to these increases in veld quality. The animal performance only improved at the onset of the wet season after the veld quality had peaked during spring. The quantity of veld available probably was limiting during spring (De Waal, 1994; Kruger, 1998). The trends in supplement intake were directly related to the veld quality and as such a practical on farm indicator for the farmer to use to monitor the quality of veld available to his cattle in a specific camp.

The levels of *ad libitum* salt intake recorded in this trial, with (6%PT) or without sufficient phosphorus (RST) being available in the diet, suggested that 0.11g/kg LW to 0.25g/kg LW salt intake from the supplement during the wet season would be sufficient to meet the animal's maintenance requirements for sodium and chloride and a minimum of 850g/day gain. The levels of *ad libitum* salt intake recorded in this trial, with (6%PT) or without sufficient phosphorus (RST) being available in the diet, suggested that 0.16g/kg LW to 0.26g/kg LW salt from the supplement during the dry season would be sufficient to meet the animal's maintenance requirements for sodium and chloride. The higher levels of salt supplementation during the dry season compared to the spring season with 0.14g/kg LW to 0.17g/kg LW was in agreement with the observations made by Morris *et al.* (1980) that there was a marked seasonal effect in veld electrolyte concentration, being maximal while the plants were growing and minimal during the dry period. Elevated levels of salt above requirements, as compared to the RST and 6%PT, were observed during the dry and spring season on the MTT, PDT and FST ranging from 0.23g/kg LW to 1.43g/kg LW. There was a trend for higher salt intake levels as the energy concentration in the licks increased from no energy (rock salt lick and 6% phosphorus lick) to little energy (maintenance lick) to more energy (production lick) to the highest energy concentration (finisher lick) during the dry and spring seasons. The current trial showed that salt could be consumed in excess of requirements with the FST consuming 5 (RST) to 8 (6%PT) times the required salt in gram per kilogram LW during the dry season. High levels of salt intake

(397g/day to 597g/day FST) still allowed for the highest levels of animal performance. Rogers *et al.* (1979) found that DMI was only reduced when steers received a 1kg salt intraruminal infusion, which was double the level recorded by the FST during the dry seasons of this trial.

Although the extrusa phosphorus concentrations were elevated due to salivary contamination (Little, 1975; Pinchak *et al.*, 1990), it still represented the most readily accepted method of sampling pasture forage phosphorus for chemical analysis (Karn, 1995; Karn, 1997). The levels of *ad libitum* P intake from the 6%PT, MTT and PDT recorded in this trial suggested that 0.01g/kg LW to 0.02g/kg LW during the wet season would be sufficient to meet the animal's maintenance requirements for P and a minimum of 850g/day gain. The levels of *ad libitum* P intake from the 6%PT, MTT and PDT recorded in this trial suggested that 0.02g/kg LW to 0.03g/kg LW during the dry season would be sufficient to meet the animal's maintenance requirements for P. NRC (2000) confirmed that a strong sensory feedback would occur from a phosphorus deficiency due to reduced growth, reduced feed efficiency and decreased appetite. The signs of deficiency would occur rather quickly if dietary phosphorus was insufficient (NRC, 2001) as observed in the RST. An oversupply of P in the diet, as observed in the FST, would decrease the efficiency of absorption of P from the diet (NRC, 2001). P toxicity would most likely only occur with an oversupply of P in the diet together with a low dietary Ca level compared to animal requirements (NRC, 2001). P in large oral doses obtained from supplements would not be considered toxic as they only result in mild diarrhoea and abdominal distress (NRC, 2001).

There seemed to be a stronger sensory feedback from P than from the salt in the licks on lick intake regulation in the groups of cattle in this trial. P seemed to be a nutrient that was actively selected for and thus controlling the intake of the supplements to a greater degree (as indicated by 6%PT, MTT and PDT in Figure 64 and Figure 67) than the salt in the licks (Figure 62 and Figure 63). If the energy contribution of the supplement to the diet became too high, as was the case with the FST, the salt (Figure 63) and P (Figure 72) would not be able to limit the intake and excessive quantities would be consumed. The excess quantities above requirements still allowed the cattle to maximise energy intake from their diet as they were still able to perform the best during the trial.

The levels of *ad libitum* Ca intake from the 6%PT, MTT and PDT recorded in this trial suggested that 0.03g/kg LW to 0.04g/kg LW during the wet season would be sufficient to meet the animal's maintenance requirements for P and a minimum of 850g/day gain. The levels of *ad libitum* Ca intake from the 6%PT, MTT and PDT recorded in this trial suggested that 0.04g/kg LW to 0.06g/kg LW during the dry season would be sufficient to meet the animal's maintenance requirements for Ca.

The RST and 6%PT obtained only protein from the selected veld, due to no additional protein being part of the lick treatments, and it was not sufficient to maintain body weight during the dry season. The 6%PT showed a possible protein sparing affect and were able to perform better than the MP intakes were suggesting. The RST indicated that P was the most limiting nutrient and the 6%PT indicated that protein the second most limiting nutrient in the diets of cattle in this trial. The MTT and PDT received sufficient MP for the maintenance of LW during the dry season. FST received sufficient MP to sustain 0.5kg/day gain during the 2004 dry season and 1.0kg/day gain during the 2005 dry season, which was not realised and as such meant that this group consumed excess protein. During the dry seasons, all licks contributing protein to the diet (MTT, PDT and FST) were able to supply more than the minimum 0.05% of BW supplemental CP recommended by Moore *et al.* (1999), from where the largest increases in LW gain would start occurring. The RDP contribution from supplements at which intake would be maximised, as suggested by Klevesahl *et al.* (2003), would suggest that the maintenance lick contributed marginal protein levels to the diet of cattle. The production lick contributed sub-optimal protein levels to the diets of cattle and that the finisher treatment contributed protein in excess of what was required to reach optimal intake levels.

The higher than anticipated LW gains during the 2004 dry season by the 6%PT, MTT, PDT and FST would suggest that the maintenance energy requirements were slightly less than the estimated 50% above basal metabolism made at the start of the chapter. When using an estimate of 40% above basal metabolism it would have been more accurate in explaining the LW gain results observed. During the 2005 dry season lower than anticipated LW gains were recorded compared to dietary ME intake levels suggested. There seemed to be a higher energy cost to maintenance than the estimated 50% increase above basal metabolism made at the start of the chapter. An estimate of 65% higher than basal maintenance requirement for ME, due to foraging, would have been more accurate for the MTT and PDT to explain actual LW gains recorded.

The cattle in the FST consumed a much larger proportion of its dietary ME from the supplements that were offered and these replaced veld intake due to negative associative affects (Goetsch *et al.*, 1991). Less time spent foraging would have lowered the dietary ME requirement for foraging which was required above basal maintenance requirement for ME. An estimated 55% higher than basal maintenance requirement for ME would have been more accurate to explain the LW gain results obtained by the FST during the 2005 dry season, which was in contrast to the higher estimated requirement of 65% for the MTT and PDT.

The originally estimated higher energy requirement for foraging, set in this chapter at 50% above basal metabolism ME, was based on Havstad & Malechek (1982) that found that free-ranging heifers had 46% higher energy expenditures than stall-fed heifers consuming similar forages. The subsequently suggested changes in the preceding paragraphs for each of the treatment groups during the seasons ranged from 40% to 65% (mean 52.5%). The estimated increases in energy maintenance requirements above basal metabolism for foraging activities, compared to actual animal performances recorded in Figure 29 in CHAPTER 4, indicated that 50% was a reasonable estimation.

The stocking rate (Table 16; Chapter 3.1.5) during the 2005 dry season (27Kg/ha) was 50% higher than the 2004 dry season (18Kg/ha) which meant increased effort was required to harvest plant material from the heavier stocked camps than the previous season when the average cattle weights were much lower. Kruger (1998) found that increasing stocking rates tended to result in decreasing availability of desirable grass species and total available grass, which would resulted in lower animal production. There seemed to be higher concentrations of NDF, ADF, ADL and lower IVDOM in the extrusa collected by OF (Table 34) during the 2005 dry season compared to the 2004 dry season. During the 2005 dry season, the sward seemed to become increasingly stemmy with increased leaf dispersion and a decline in leaf accessibility, which therefore forced the cattle to consume increasing amounts of dead material and stem (O'Reagain & Mentis, 1988).

CHAPTER 7 NUTRITIONAL STATUS INDICATORS

Predicting the nutritional status of free-range cattle, that were consuming different *ad libitum* nutrient supplementation treatments, from the chemical analysis of faeces and the biochemical analysis of blood and ruminal fluid collected from ruminally cannulated cattle is presented in this chapter.

Each ruminally cannulated animal was placed on a treatment for an average of three weeks before being moved to another treatment group on the subsequent camp rotation (Table 22) until each animal had been on all five treatments during each of the three seasons collections were made.

The animal had to adapt to the new group of cattle, new lick and new camp within 3 weeks after which the sampling took place. The management technique employed to be able to collect cattle from camps with a 24 hour feed restriction and then moving them to a central point with a 12 hour lick and water restriction was used to ensure all measured metabolites were comparable at their baseline concentrations. The long delay between veld intake and then subsequently the shorter restriction of lick intake and testing would have had a strong influence on the results obtained in Table 45.

Table 45 Metabolites in the ruminal fluid collected from ruminally cannulated cattle on different nutrient supplementation treatments during different seasons measure as pH, milligram ammonia in 100ml ruminal fluid, millimole volatile fatty acids in 100ml ruminal fluid and individual volatile fatty acids as percentages and ratios within 100ml ruminal fluid. Supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Parameter	RST	6%PT	MTT	PDT	FST	S.E.M
DRY HOT SEASON (5 Aug '04 – 17 Nov '04)						
pH	7.36^{a}	7.32^{ab}	7.40^{a}	7.16^{b}	7.23^{ab}	0.06
NH_3-N (mg/100ml)	4.2^{ab}	2.9^{b}	5.1^{ac}	5.7^{ac}	6.0^{c}	0.5
VFA (mmol/100ml)	7.0^{a}	6.6^{ab}	5.3^{bc}	6.8^{ab}	4.4^{c}	0.5
Acetic acid (%)	73.3^{a}	72.8^{ab}	73.9^{a}	70.6^{b}	70.4^{b}	0.9
Propionic acid (%)	17.6	18.8	17.1	18.0	17.5	0.6
Butyric acid (%)	8.2^{a}	7.7^{a}	8.2^{a}	10.5^{b}	10.9^{b}	0.5
Valeric acid (%)	0.9^{ac}	0.7^{ab}	0.9^{ac}	0.9^{c}	1.2^{d}	0.1
Acetic/Propionic acid	4.2	3.9	4.4	4.0	4.1	0.2
Acetic/Butyric acid	9.1^{a}	9.4^{a}	9.3^{a}	6.9^{b}	6.6^{b}	0.5
WET SEASON (17 Feb '05 – 31 Mar '05)						
pH	7.36	7.36	.	.	.	0.05
NH_3-N (mg/100ml)	7.2	7.8	.	.	.	0.3
VFA (mmol/100ml)	5.8	4.9	.	.	.	0.6
Acetic acid (%)	74.0	74.8	.	.	.	0.8
Propionic acid (%)	14.1	13.8	.	.	.	0.4
Butyric acid (%)	10.5	9.8	.	.	.	0.4
Valeric acid (%)	1.4	1.5	.	.	.	0.1
Acetic/Propionic acid	5.3	5.5	.	.	.	0.2
Acetic/Butyric acid	7.1	7.7	.	.	.	0.4
DRY COOL SEASON (13 May '05 – 23 Aug '05)						
pH	7.32	7.28	7.28	7.28	7.38	0.04
NH_3-N (mg/100ml)	3.8^{ab}	3.6^{a}	5.0^{b}	4.7^{ab}	5.0^{b}	0.4
VFA (mmol/100ml)	7.8^{a}	7.4^{a}	6.0^{b}	6.0^{b}	6.0^{b}	0.4
Acetic acid (%)	72.7	74.3	72.6	72.5	73.6	1.3
Propionic acid (%)	16.7	16.2	16.2	15.2	14.7	0.7
Butyric acid (%)	9.7^{ab}	8.6^{a}	10.2^{ab}	11.3^{b}	10.7^{b}	0.7
Valeric acid (%)	0.9^{a}	0.9^{a}	1.1^{b}	1.0^{ab}	1.0^{ab}	0.1
Acetic/Propionic acid	4.4	4.6	4.6	4.8	5.1	0.3
Acetic/Butyric acid	7.5	8.7	7.4	6.5	7.2	0.6

[abcd] Row means with different superscripts differ significantly ($P<0.05$)

S.E.M: Standard error of means

7.1. RUMINAL FLUID

7.1.1. pH

The pH recorded in Figure 102 from Table 45 had a narrow neutral to slightly alkaline range over the experimental period of 7.16 at the lowest and 7.40 at the highest. During the dry hot season the PDT had a significantly lower pH than the RST and MTT. No significant differences in pH where observed between treatments during the other sampling periods. The treatments did not appear to affect ruminal pH.

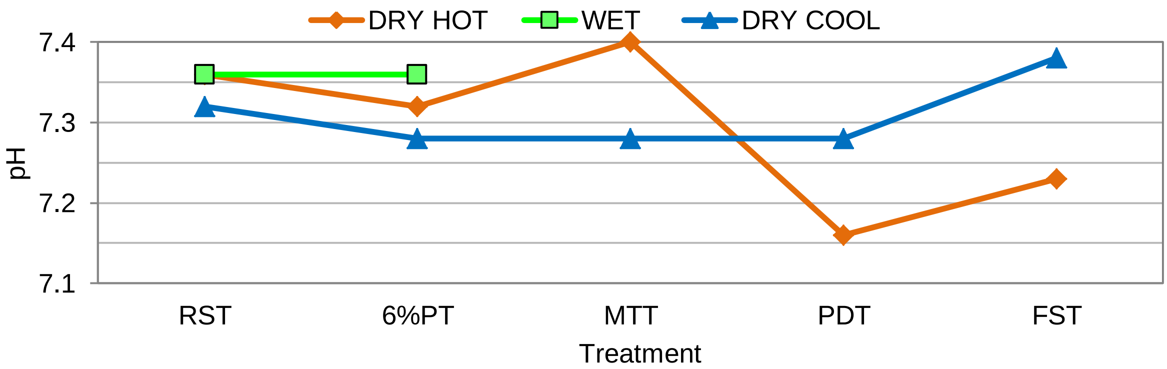


Figure 102 Ruminal fluid pH of cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The ruminal pH was within a narrow range during all recorded periods and only during the first dry hot season did the two supplement treatments with the highest energy concentrations have slightly depressed values. High forage diets tended to be higher than 7.0 and if higher levels of acids were produced during the fermentation of grains it would tend to depress the pH (NRC, 2001).

7.1.2. Ammonia

Ammonia concentrations recorded in the rumen fluid are shown in Figure 103 from the data in Table 45. During the two dry seasons the 6%PT had the lowest ammonia concentrations at 2.9mg/100ml rumen fluid (1.70mmol/l) in the dry hot season and 3.6mg/100ml rumen fluid (2.11mmol/l) in the dry cool season. The highest concentrations for ammonia were recorded during the wet season in a range of 7.2mg/100ml rumen fluid (4.23mmol/l) for RST and 7.8mg/100ml rumen fluid (4.58mmol/l) for the 6%PT.

During the dry hot season the 6%PT was significantly lower than the MTT at 5.1mg/100ml rumen fluid (2.99mmol/l), PDT at 5.7mg/100ml rumen fluid (3.35mmol/l) and FST at 6.0mg/100ml rumen fluid (3.52mmol/l). During the dry cool season the 6%PT was only significantly lower from the MTT at 5.0mg/100ml rumen fluid (2.94mmol/l) and FST 5.0mg/100ml rumen fluid (2.94mmol/l). The rumen ammonia concentration tended to identify the cattle with no source of protein in their licks.

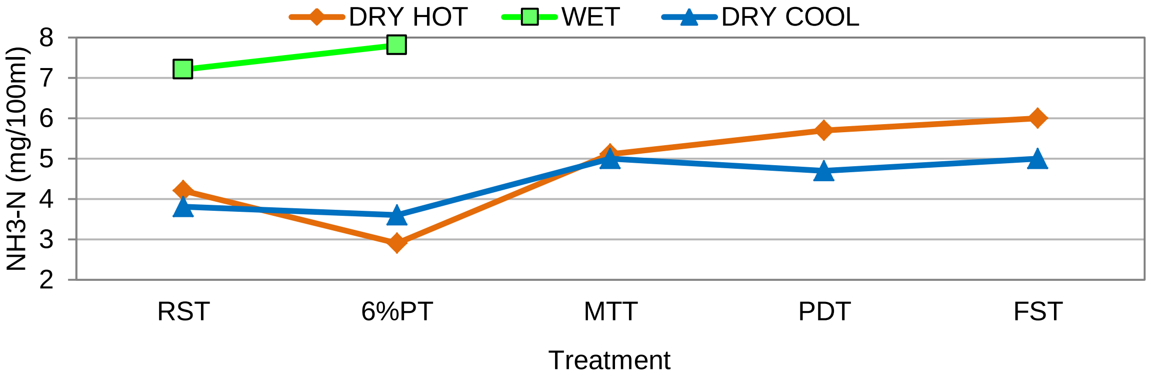


Figure 103 Ruminal fluid ammonia concentrations in milligram per 100ml rumen fluid (mg/100ml) of cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST) in comparison to optimal (Leng, 1990),

The rumen fluid ammonia concentrations recorded during the wet season at 7.2-7.8mg/100ml rumen fluid (4.23-4.58mmol/l) were much higher than the values recorded during the dry season and corresponded to the optimal range of 6-10mg/100ml rumen fluid (3.52-5.87mmol/l) as suggested by Leng (1990).

The rumen fluid ammonia concentrations recorded by the 6%PT had the lowest values at 2.9-3.6mg/100ml rumen fluid (1.70-2.11mmol/l) during the dry season, which was followed by the RST with slightly higher values at 3.8-4.2mg/100ml rumen fluid (2.23-2.47mmol/l). The 6%PT and RST concentrations fell within the lower part of the range of ammonia concentrations of 2.0-5.0mg/100ml rumen fluid (1.17-2.94mmol/l) that signalled insufficient nitrogenous substrates for microbial growth being available (Satter & Roffler, 1977). The lower ammonia concentrations found in the 6%PT (P sufficient and N deficient animals) compared to the RST (P and N deficient animals) were indicative of a disturbance of protein metabolism pathways of the rumen microbes in the RST due to a P deficiency (Petri *et al.*, 1988; Gunn & Ternouth 1994).

During the dry hot season the nutrient treatments contributing protein to the diet of the cattle (MTT, PDT & FST) recorded values ranging between 5.1-6.0mg/100ml rumen fluid (3.00-3.52mmol/l). The above concentrations were higher than the 5.0mg/100ml rumen fluid (2.94mmol/l) under which an N deficiency would have been suspected in the diet (Satter & Roffler, 1977).

This was not the case during the dry cool season with the PDT at 4.70mg/100ml rumen fluid (2.76mmol/l) being below this suggested minimum concentration and the MTT and FST values recorded at 5.00mg/100ml rumen fluid (3.52mmol/l) being on the minimum rumen ammonia concentration recommended by Satter & Roffler (1977). The results suggested that the PDT had suboptimal protein intake levels in their diets contributing to the microbial demand for ammonia during the dry cool season (21 Jun to 9 Sep 2005). All other dry season ammonia concentrations were on or above the minimum concentration of 5.0mg/100ml rumen fluid (Satter & Roffler, 1977) and below or on the optimal ruminal ammonia concentration of 6.0mg/100ml rumen fluid (Leng, 1990).

The marginal rumen ammonia concentrations in the protein supplemented cattle in the dry season would have occurred due to the delay of 12h in supplement intake before sampling and indicated that supplemental protein feeding at regular intervals was necessary.

7.1.3. Volatile fatty acid concentrations (VFA)

The total volatile fatty acid concentrations (VFA), from Table 45 illustrated in Figure 104, ranged between 4.4-7.8mmol/100ml rumen fluid during the experimental period. The lowest total VFA of 4.4mmol/100ml rumen fluid was recorded by the FST during the dry hot season and was significantly lower than the RST (7.0mmol/100ml rumen fluid), PDT (6.8mmol/100ml rumen fluid) and 6%PT (6.6mmol/100ml rumen fluid).

During the wet season the total VFA tended to be at the lower range of concentrations recorded during the experimental period at 4.9-5.8mmol/100ml rumen fluid. The total VFA during the dry cool season of the RST (7.8mmol/100ml rumen fluid) and 6%PT (7.4mmol/100ml rumen fluid) where significantly higher than the MTT, PDT and FST (6mmol/100ml rumen fluid).

The general trend observed in total VFA during the dry season was for the RST and 6%PT to be in the higher part of the range at 6.6-7.8mmol/100ml rumen fluid. During the dry season the MTT, PDT and FST where generally recorded at the lower end of the range at 4.4-6.8mmol/100ml rumen fluid.

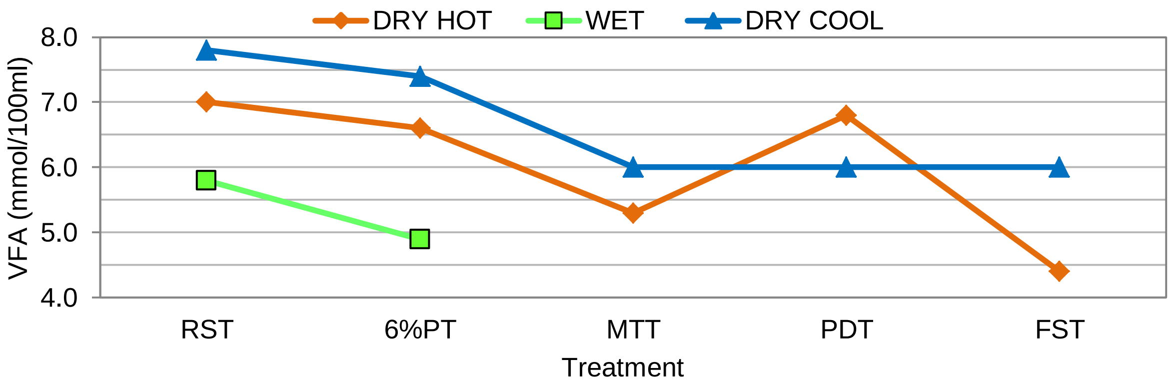


Figure 104 Ruminal fluid total volatile fatty acid concentrations (VFA) in millimole per 100ml rumen fluid (mmol/100ml) of cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The total VFA in the rumen was the highest for the RST throughout each of the experimental seasons compared to the other treatments. These results do not follow the general reasoning that higher total VFA in the rumen generally reflect increased ruminal microbial fermentation as observed by Köster *et al* (1996) where increases in total VFA were recorded with increasing levels of RDP being supplemented to forage-fed cattle. The RST had a total VFA of 7.0mmol/100ml rumen fluid during the dry hot season that coincided with weight losses recorded by the cattle. During the dry cool season the total VFA of RST at 7.8mmol/100ml rumen fluid and the 6%PT at 7.4mmol/100ml rumen fluid had both recorded weight losses. Total VFA depended on type of diet, level of intake, frequency of feeding and feed additives (Araba *et al.*, 2002). Araba *et al.* (2002) found that total VFA were lower for molasses based diets and the presence of protozoa in the rumen of molasses fed cattle could contribute to the decrease in total VFA. The MTT, PDT and FST contained cane molasses which could have resulted in lower total VFA during the dry season. During the wet season the total VFA were lower than most of the levels recorded by the treatment groups in the dry season. This was not in agreement with Park *et al.* (1994) and McCollum *et al.* (1985) that found that the total VFA decreased with advancing forage maturity. Results obtained during the wet season indicated that cattle could have had access to water or that samples were incorrectly taken from the rumen.

The high molar acetic acid concentration contribution to VFA, in Table 45 as illustrated in Figure 105, during all periods of the year ranged from 70.4% to 74.8% on all treatments that indicated the primary dietary component was forage (>65% acetic acid suggested by Thomas & Rook, 1981).

The acetic acid contribution to VFA tended to show maximum concentrations during the wet season (RST at 74.0% and 6%PT at 74.8%) when the lowest lick intakes where recorded and tended to decrease as the total lick intake increased with increasing amounts of grain and molasses materials being present.

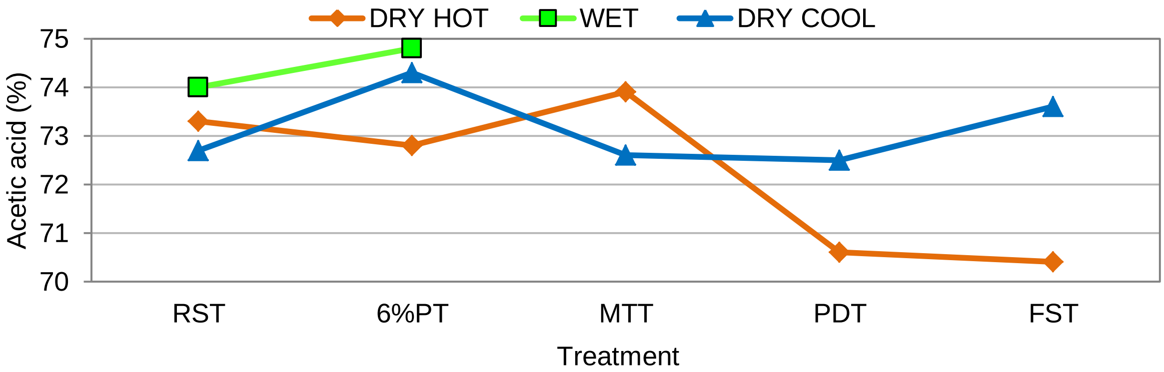


Figure 105 Ruminal fluid acetic acid percentage contribution (%) to volatile fatty acid concentrations of cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The low molar propionic acid concentration contribution to VFA, in Table 45 and illustrated in Figure 106, during all periods of the year ranging from 13.8% to 18.8% on all treatments reflect that low starch concentrations were maintained in the diet of cattle (<25% propionic acid suggested by Thomas & Rook, 1981).

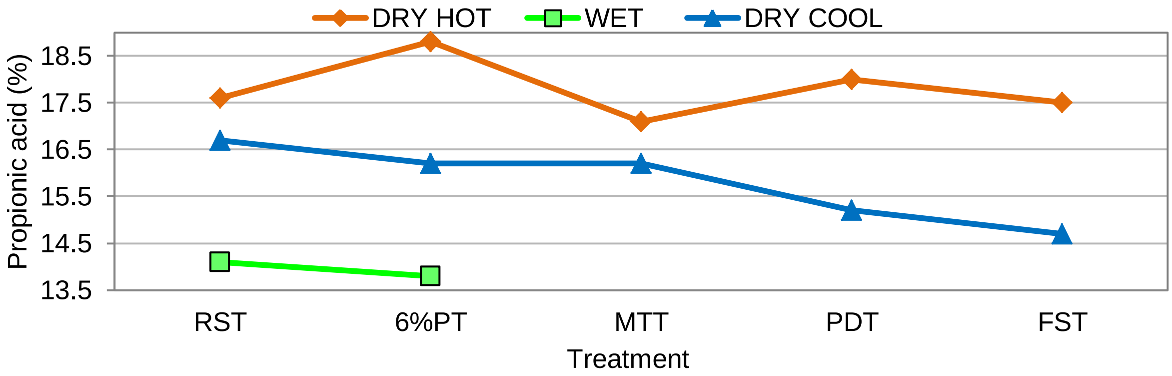


Figure 106 Ruminal fluid propionic acid percentage contribution (%) to volatile fatty acid concentrations of cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The propionic acid contribution to VFA composition showed no significant variations between treatments although different ranges of values were recorded during the different seasons. Park *et al.* (1994) similarly found this unusual pattern for elevated propionic acid contributions in VFA during the dry season compared to the lower contributions during the wet season when plants were actively growing.

The low molar butyric acid concentration contribution to VFA, in Table 45 illustrated in Figure 107, during all periods of the year ranging from 8.2% to 11.3% on all treatments reflect that moderate feeding levels were maintained (<18% Butyric acid suggested by Thomas & Rook, 1981).

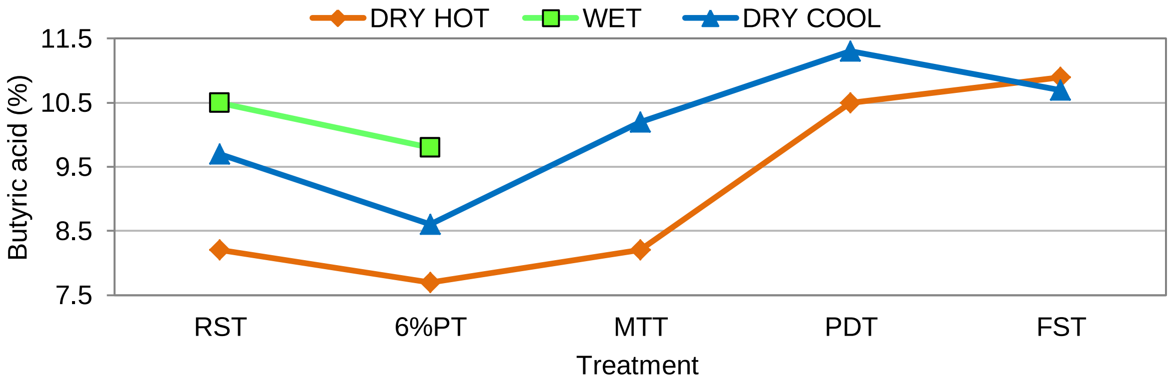


Figure 107 Ruminal fluid butyric acid percentage contribution (%) to volatile fatty acid concentrations of cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

During dry hot season the butyric acid contribution to total VFA measured in the PDT (10.5%) and FST (10.9%) were significantly higher than RST (8.2%), 6%PT (7.7%) and MTT (8.2%). This was not repeated during the dry cool season where the PDT (11.3%) and FST (10.7%) were only significantly higher than the 6%PT (8.6%). The MTT, PDT and FST contained molasses and Araba *et al.* (2002) found that increasing concentrations of molasses significantly increased butyric acid contributions to total VFA.

The 6%PT had the lowest butyric acid concentrations during all three seasons of the year compared to other treatments during the dry hot (7.7%) wet (9.8%) and dry cool (8.6%) seasons. The butyric acid fraction had a positive relationship with dry matter intake that led to improved production (Seymour *et al.*, 2005). This could not be established in the current trial as the RST had the most depressed animal performances and the 6%PT had higher intakes and production levels that were not indicated by the butyric acid fractions.

The valeric acid contribution to VFA, from Table 45 and illustrated in Figure 108, was very low with a range of 0.7% to 1.5% being recorded during the study. During the dry hot season the FST (1.2%) had a significantly higher valeric acid contribution to VFA when compared with the range of 0.7 to 0.9% observed for the other treatments. During the dry cool season the valeric acid contribution to VFA by the RST (0.9%) and 6%PT (0.9%) were significantly lower than the MTT (1.1%) but were comparable with the PDT (1%) and FST (1%).

The wet season resulted in higher valeric acid contributions to VFA ranging from 1.4-1.5% that were also the highest concentrations recorded for the experimental period.

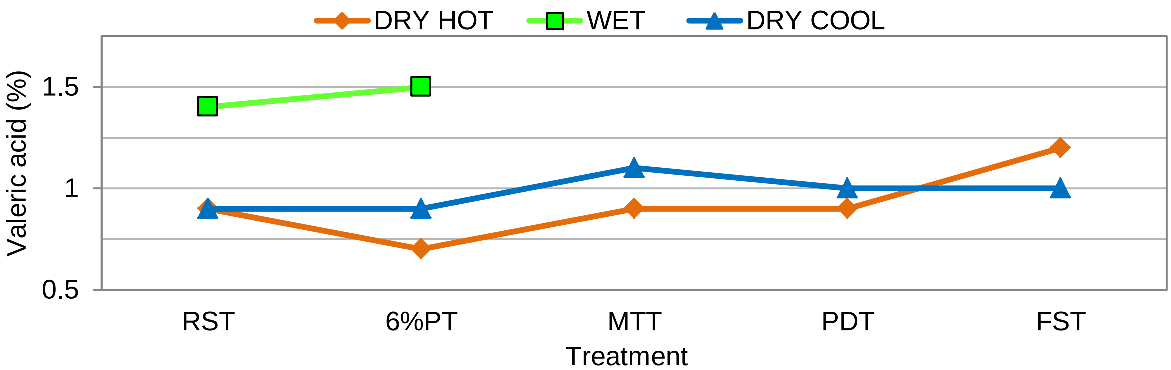


Figure 108 Ruminal fluid valeric acid percentage contribution (%) to volatile fatty acid concentrations of cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The model by Murphy *et al.* (1982) predicted that with the increased feeding of concentrates to animals consuming forage the acetic acid proportion of VFA would decrease and an increase in the proportion of butyric acid and or propionic acid could be expected.

The molar contribution of acetic acid to propionic acid in VFA, in Figure 109 from data in Table 45, resulted in no differences being observed between treatments. The range of ratios recorded during the combined data of the dry season was 3.9 to 5.1. The highest range of values recorded for the ratio by treatments occurred during the wet season at 5.3-5.5. The ratios were higher due to less propionic acid being present in the VFA and there were comparatively higher concentrations contributed by the butyric acid.

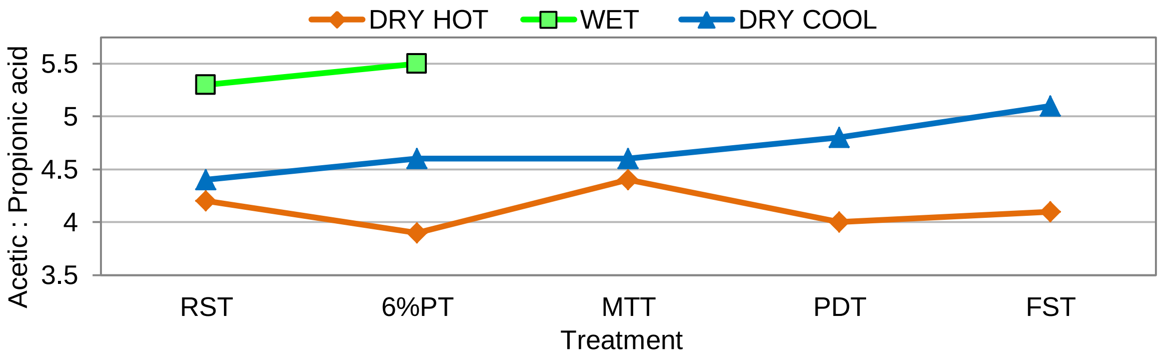


Figure 109 Ruminal fluid acetic acid to propionic acid ratio in volatile fatty acid concentrations in cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The molar contribution ratio of acetic acid to butyric acid in the VFA, from data in Table 45 and illustrated in Figure 110, showed that during the dry hot season the PDT (6.9) and FST (6.6) had significantly lower ratios than the RST (9.1), 6%PT (9.4) and MTT (9.3). Park *et al.* (1994) found the ratio for acetic acid to butyric acid in the VFA decreased from 3.09 to 2.62 as the forage matured and became dormant, which was in agreement with the higher ratios recorded during the wet season compared to the dry season.

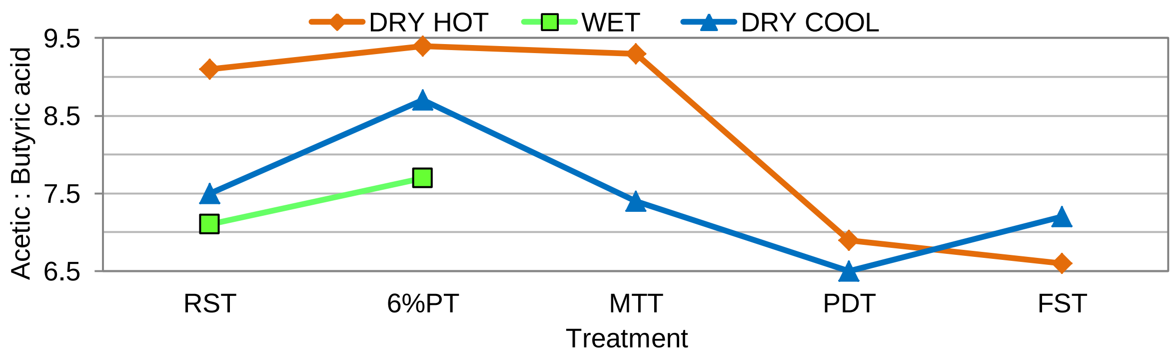


Figure 110 Ruminal fluid acetic acid to butyric acid ratio in volatile fatty acid concentrations in cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The dry cool season and wet season record no significant differences between treatments and range between the highest acetic acid to butyric acid ratio recorded for the 6%PT (8.7) in the dry cool season and the lowest ratio for the PDT (6.5) in the dry cool season.

Increasing levels of nutrition tended to decrease the molar contribution ratio of acetic acid to butyric acid in the VFA due to increased concentrations of butyric acid being produced at the expense of lactate in the ruminal fluid. The butyric acid contribution to VFA composition tended to increase as the acetic acid contribution decreased. The ratio was most depressed during the dry season on the treatments with the highest energy contributions in the diet. The inclusion of molasses in the supplements and the increasing trend for supplement intake would result in larger quantities of molasses being consumed in the diet of the cattle as the supplement intake increased and led to increased butyric acid concentrations in the rumen at the expense of propionic acid (Araba *et al.*, 2002).

7.2. Blood metabolites

The number of animals tested in this trial was only five compared to the minimum of seven animals recommended by Ingraham & Kappel (1988). The blood was collected from the jugular vein by venapuncture and metabolites in the serum were tested with the results presented in Table 46.

A seasonal trend in circulating blood serum Pi and BUN in the RST was similar to results obtained from unsupplemented free-ranging Wildebeest (*Connochaetes taurinus*) in the Etosha National Park by Berry & Louw (1982). Wet season Pi concentrations at 1.73mmol/l, where significantly higher than the dry season Pi concentrations of 1.33mmol/l, which represented an observed marginal deficiency of P in the diet of the Wildebeest (Berry & Louw, 1982). The blood plasma calcium concentrations were 2.37mmol/l during the wet season and similarly 2.44mmol/l during the dry season. The Ca:P in blood plasma during the wet season was 1.37 and during the dry season 1.83. The plasma BUN for the wet season was 8.06mmol/l and was significantly lower during the dry season at 5.78mmol/l.

Table 46 Metabolite concentrations in the serum of blood collected by venapuncture from ruminally cannulated cattle on different nutrient supplementation treatments during different seasons of the year. Supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Parameter	RST	6%PT	MTT	PDT	FST	S.E.M
DRY HOT SEASON (5 Aug '04 – 17 Nov '04)						
BUN (mmol/l)	4.2^{ab}	3.2^{a}	4.5^{b}	4.0^{ab}	4.2^{ab}	0.4
BHB (mg/dl)	5.7^{a}	4.1^{b}	4.3^{ab}	4.2^{b}	4.4^{ab}	0.5
Phosphorus (mmol/l)	1.65^{a}	2.77^{b}	2.43^{b}	2.74^{b}	2.47^{b}	0.1
Calcium (mmol/l)	2.36^{ab}	2.24^{a}	2.27^{ab}	2.36^{ab}	2.37^{b}	0.04
Ca/P	1.51^{a}	0.82^{b}	0.96^{b}	0.88^{b}	0.96^{b}	0.08
WET SEASON (17 Feb '05 – 31 Mar '05)						
BUN (mmol/l)	8.7^{a}	6.9^{b}	.	.	.	0.4
BHB (mg/dl)	3.1	4.7	.	.	.	0.5
Phosphorus (mmol/l)	2.47	1.91	.	.	.	0.26
Calcium (mmol/l)	2.44	2.54	.	.	.	0.11
Ca/P	1.03	1.39	.	.	.	0.14
DRY COOL SEASON (13 May '05 – 23 Aug '05)						
BUN (mmol/l)	4.2^{ab}	3.4^{a}	4.6^{b}	4.2^{ab}	5.1^{b}	0.3
BHB (mg/dl)	5.3^{a}	3.5^{b}	5.2^{a}	4.8^{ab}	4.6^{ab}	0.5
Phosphorus (mmol/l)	1.83^{a}	2.67^{ab}	2.97^{b}	2.57^{ab}	2.95^{b}	0.27
Calcium (mmol/l)	2.43	2.31	2.38	2.40	2.45	0.05
Ca/P	1.45^{a}	0.91^{b}	0.81^{b}	1.12^{ab}	0.83^{b}	0.17

^{ab} Row means with different superscripts differ significantly (P<0.05)

S.E.M: Standard error of means

7.2.1. Blood serum urea nitrogen concentration (BUN)

The blood serum urea nitrogen concentration (BUN) in Figure 111 showed a clear difference between the dry season with a range of 3.2mmol/l to 5.1mmol/l and the wet season with a range of 6.9mmol/l to 8.7mmol/l for all treatments. The 6%PT had the lowest concentrations during all seasons but was particularly low during the dry season. The BUN of the 6%PT during the dry hot season was the lowest at 3.2mmol/l and was only significantly lower than the MTT at 4.5mmol/l. During the dry cool season it was once again significantly lower than the MTT (4.6mmol/l) but also the FTT (5.2mmol/l). The BUN of 6%PT (6.9mmol/l) was significantly lower than the RST (8.7mmol/l) during the wet season.

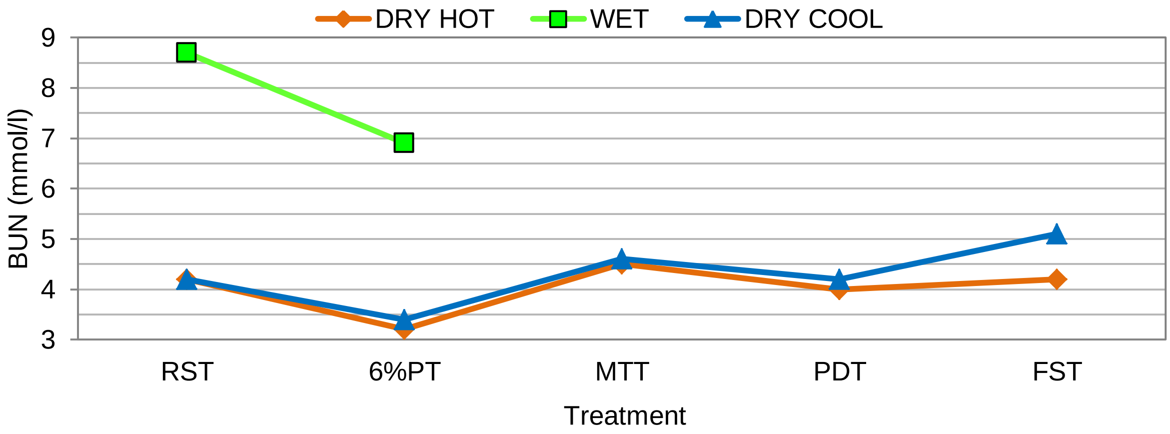


Figure 111 Blood serum urea nitrogen concentration (BUN) in millimole per litre (mmol/l) from ruminally cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The BUN measured during the dry season had a range of 3.2mmol/l to 5.1mmol/l and during the wet season at 6.9mmol/l to 8.7mmol/l. Hammond (1997) recommended that protein supplementation would give positive results if the BUN was less than 5.36mmol/l in rapidly growing cattle. The BUN during the wet season reflected that the dietary protein levels were conducive to high levels of growth and rapid growth rates would be expected and these animals would not benefit from additional protein supplementation. The BUN suggested by Hammond (1997) could potentially be used to monitor the change over from P and CP containing supplements during the dry season to primarily P containing supplements during the wet season.

During the dry season the CP supplemented treatments (MTT, PDT and FST) had a BUN range of 4.0mmol/l to 5.1mmol/l which was higher than the value of 3.93mmol/l determined by Byers & Moxon (1980) below which additional protein supplementation would improve performance in rapidly growing cattle. The BUN for the CP supplemented cattle indicate that adequate CP supplementation occurred.

During the dry season the RST and 6%PT, which did not receive additional protein from licks on offer, had a BUN range of 3.2 to 4.2mmol/l. The RST had recorded a BUN of 4.2mmol/l during the two dry seasons, which indicated that protein supplementation would not have increased production according to Byers & Moxon (1980). The free-range cattle on the RST had been losing weight during these periods, which was attributed to a primary P shortage and a secondary CP shortage. The 6%PT had a range of values from

3.2mmol/l to 3.4mmol/l that indicated a protein shortage in the diet of the animals and was consistent with results obtained which showed that the primary P shortage was not present in this group and the next deficient nutrient was CP.

The above results were in accordance with the results obtained by Bortolussi *et al.* (1996) who found that under conditions of P deficiency a reduction in feed intake was not due to reduced digestibility of the diet, since DM and NDF digestibility where found to be unaffected. The depression in intake could have been the result of a disturbance in the intracellular metabolism (Milton & Ternouth, 1985). Bortolussi *et al.* (1996) found that such a disturbance could potentially have been in protein metabolism pathways and this was suggested by a significantly higher BUN found on N-adequate and low P groups. The results by Bortolussi *et al.* (1996) and Milton & Ternouth (1985) established that when a primary P shortage was alleviated the ammonia concentrations in the rumen decreased and a decrease in BUN resulted due to cellular protein metabolism being restored which utilised the available N in circulation.

7.2.2. Beta-hydroxy butyrate concentration (BHB)

The blood serum beta-hydroxy butyrate concentration (BHB) in Figure 112 showed a range of 3.5mg/dl (336µmol/l) to 5.2mg/dl (500µmol/l) during the dry season for all treatments receiving P containing nutrient supplements (6%PT, MTT, PDT and FST). The BHB of the RST during the dry season was significantly higher than the 6%PT with a range of 5.3mg/dl (509µmol/l) in the dry cool season and 5.7mg/dl (547µmol/l) during the dry hot season. The lowest concentration for BHB was recorded during the wet season by the RSS at 3.1mg/dl (298µmol/l).

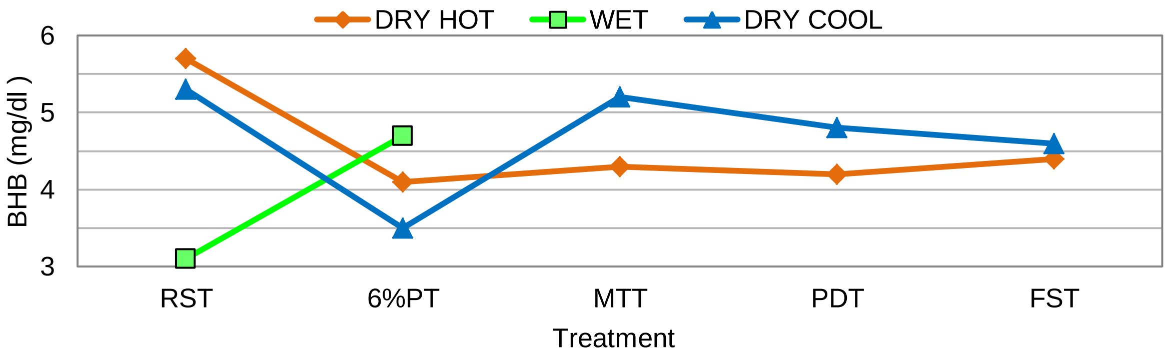


Figure 112 Blood serum beta-hydroxy butyrate concentration (BHB) in milligram per decilitre (mg/dl) from ruminally cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The BHB recorded in the RST during the dry season were the highest values recorded during the experimental period that ranged from 5.3mg/dl (509µmol/l) to 5.7mg/dl (547µmol/l). The remaining treatments that received P in their nutrient supplements (6%PT, MTT, PDT and FST) during the dry season together with results from the wet season with adequate P concentrations in the veld had a range of 3.1mg/dl (298µmol/l) to 5.2mg/dl (500µmol/l).

Elevated BHB was an indicator for short-term negative energy balance and adipose tissue catabolism in cows (Bergman, 1971) and an indicator of nutritional stress in pre-slaughter cattle (Shaw & Tume, 1992). According to the current results a BHB above 5.2mg/dl (500µmol/l) after a 21 day P depletion period could indicate nutritional stress and would aid in identifying animals that had a P deficiency in their diet.

Molasses tends to linearly increase BHB (Murphy, 1999; Shingfield, 2002) and should be guarded against. The increasing levels of molasses consumed from supplementation intakes, from the lowest by the MTT and increasing to the PDT and highest by the FST, during the dry seasons of the trial seemed to have no effect on the BHB results obtained.

7.2.3. Blood serum inorganic phosphorus concentration (Pi)

In Figure 113 the blood serum inorganic phosphorus concentration (Pi) in the dry hot season for the RST at 1.65mmol/l (51.1mg/l) was significantly lower than the P containing nutrient supplement treatments (6%PT, MTT , PDT and FST) that ranged from 2.43mmol/l (75.2mg/l) to 2.77mmol/l (85.8mg/l).

During the wet season there were no significant differences between the RST at 2.47mmol/l (76.5mg/l) and 6%PT at the lower Pi of 1.91mmol/l (59.1mg/l). During the wet season the veld contained sufficient P concentrations to maintain high levels of growth.

During the dry cool season the RST again showed lower Pi at 1.83mmol/l (56.7mg/l) but was only significantly lower than the MTT at 2.97mmol/l (92.0mg/l) and FST at 2.95mmol/l (91.3mg/l). There were no significant differences between the P supplemented groups (6%PT, MTT, PDT and FST) with a Pi range of 2.57mmol/l (79.6mg/l) to 2.97mmol/l (92.0mg/l).

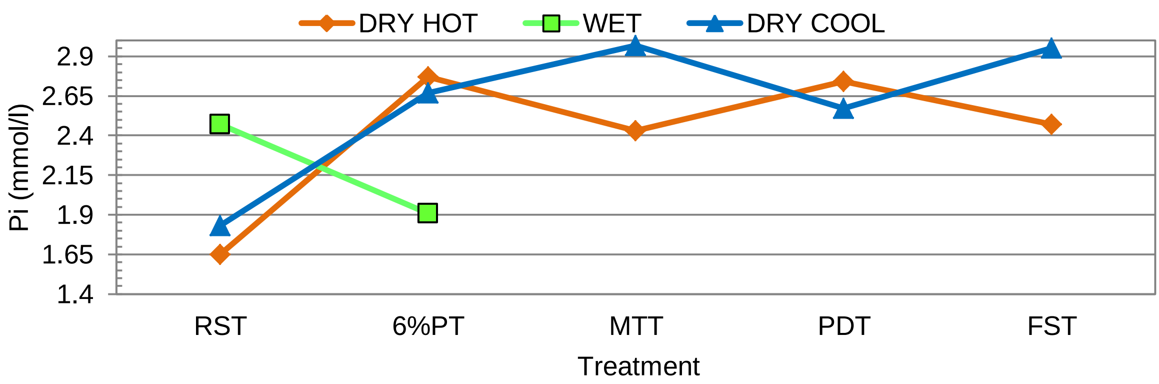


Figure 113 Blood serum inorganic phosphorus concentrations (Pi) in millimole per litre (mmol/l) from ruminally cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The ruminally cannulated cattle where randomly shifted from adequate phosphorus levels (6%PT, MTT, PDT and FST) to inadequate phosphorus levels (RST) and sampled after three weeks on the treatment during the dry season. The depletion of P levels over three weeks of the dry season were significant for most treatments and would be a leading indicator of P status when a dietary P deficiency was occurring.

The Pi recorded by the RST during the dry season, with a range of 1.65mmol/l to 1.83mmol/l, was higher than the 1.45mmol/l (45.0mg/l) concentration suggested by Puls (1994) and McCosker & Winks (1994) below which a P deficiency would be suspected. The Pi in the RST was also higher than the acute P deficiency level that was observed in beef cows at 1.15mmol/l (35.6mg/l) found by Groenewald (1986) and 1.13mmol/l (35.0mg/l) found by Hendrickson *et al.* (1994) and McCosker & Winks (1994).

Bortolussi *et al.* (1996) showed that when a high N and high P diet was fed over 15 weeks it resulted in a Pi of 69.4mg/l (2.24mmol/l). When steers were depleted over 15 weeks with a medium N and medium P diet the Pi dropped to 58.8mg/l (1.90mmol/l) although after 2 weeks on the treatment the Pi had initially dropped to 51.4mg/l (1.66mmol/l). When a low P diet was offered with high, medium and low N levels the Pi was consistently reduced to below 40.0mg/l (1.29mmol/l).

Groenewald (1986) found the Pi at 2.01mmol/l (62.2mg/l) was regarded as normal for beef cows which were receiving P containing supplements and was higher than the range recorded by the RST during the dry season. Bortolussi *et al.* (1996) found in P depleted cattle that received medium to high containing P diets from 2 to 15 weeks had a range of Pi values from 1.89mmol/l (58.5mg/l) to 2.45mmol/l (75.9mg/l).

The results obtained in the present study with the results from Bortolussi *et al.* (1996) would suggest that a P deficiency in the diet of cattle, which were not supplemented with an *ad libitum* P containing supplement for 21 days, could be indicated at Pi below 1.90mmol/l (58.8mg/l).

7.2.4. Calcium and calcium to phosphorus ratio (Ca:Pi)

The blood serum calcium concentration (Ca) in Figure 114 in the dry hot season had a narrow range with the lowest concentration at 2.24mmol/l (89.6mg/l) for the 6%PT and the highest concentration of 2.37mmol/l (94.8mg/l) for the FST. These were the only treatments that were significantly different from each other.

The highest blood Ca concentrations were recorded during the wet season at 2.44mmol/l (97.6mg/l) on RST and 2.54mmol/l (101.6mg/l) on 6%PT.

During the dry cool season the narrow range of concentrations for Ca persisted for 6%PT being the lowest at 2.31mmol/l (92.4mg/l) and the highest was also recorded by the FST at 2.45mmol/l (98.0mg/l).

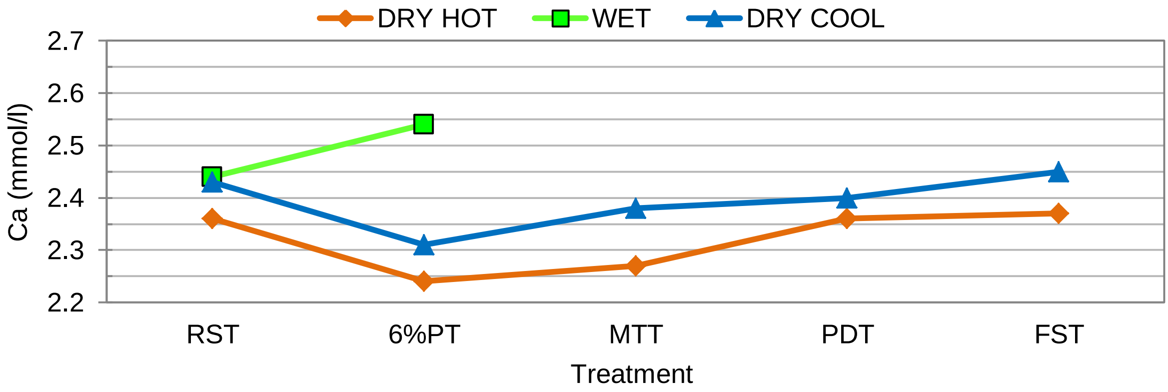


Figure 114 Blood serum calcium concentrations (Ca) in millimole per litre (mmol/l) from ruminally cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The blood serum Ca concentrations ranged from 2.24mmol/l to 2.54mmol/l throughout the experimental period due to tight homeostatic control and compared well to the narrow range of 2.2mmol/l to 2.75mmol/l suggested by the NRC (2000, 2001).

During the dry hot season the RST had a blood serum concentration with a calcium to phosphorus ratio (Ca:Pi) of 1.51, as illustrated in Figure 115. The Ca:P for the RST was significantly higher than the nutrient supplement treatments receiving phosphorus with the lowest being recorded by the 6%PT at 0.82 the widest at 0.96 for both MTT and FST supplements. The same trend was established by the treatments during the dry cool season where the widest ratio was recorded by the RST at 1.45 and this was significantly wider than most treatments, except the PDT at 1.12. The remaining treatments were significantly narrower than the RST and had the narrowest value of 0.81 recorded by the MTT and the widest at 0.91 for the 6%PT. During the wet season the RST had an intermediate ratio of 1.03 and the 6%PT had a wider ratio at 1.39.

Underwood (1966) indicated that there existed an inverse relationship between blood Pi and Ca and this was a result of the mobilisation of these elements from the hydroxyapatite in bone to supply the needed P, with the corresponding Ca remaining as an excess in the blood. Read *et al.* (1986b) found a slight tendency for the calcium to be higher in the groups with the lowest Pi concentrations.

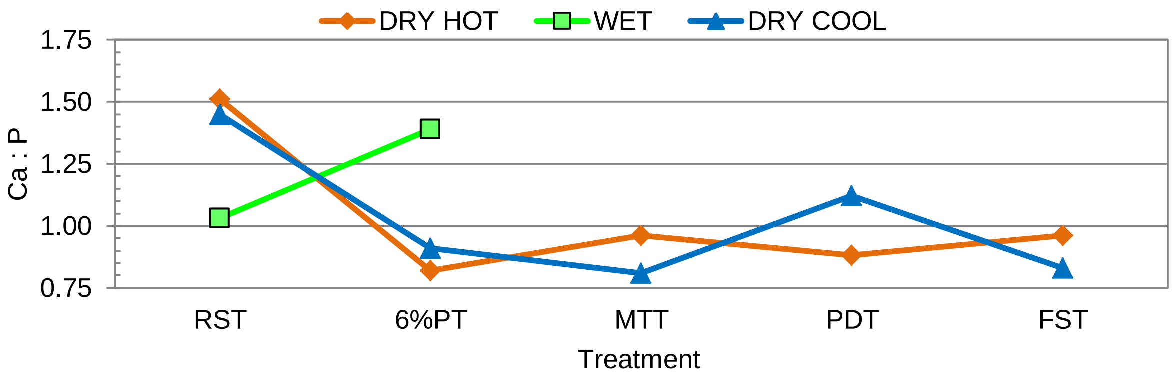


Figure 115 Blood serum calcium to phosphorus ratio (Ca:Pi) from ruminally cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The RST recorded the highest Ca:Pi levels during the dry season where a P deficiency was confirmed with the foraging cattle group losing weight (Figure 29). The ratio ranged from 1.45 to 1.51. The groups receiving P nutrient supplements (6%PT, MTT, PDT and FST) had significantly lower Ca:Pi during the dry hot season with a range of 0.82 to 0.96. During the dry cool season the range was 0.81 to 1.12 and the highest ratio was recorded by the PDT at 1.12, which was the only treatment that was not significantly lower than the RST. During the wet season the 6%PT had a higher Ca:Pi at 1.39, compared to the 1.03 recorded by the RST. The highest blood Ca concentrations during the trial where recorded by the 6%PT during the wet season at 2.54mmol/l and the highest faecal Ca concentration, which was recorded in the next section, suggested that high Ca intakes increased the Ca:Pi.

Due to the insensitivity of the blood calcium concentrations to dietary calcium intake, the Ca:Pi was a more appropriate measure for diagnostic interpretation and was a more sensitive and stable measure than Pi alone (Groenewald, 1986). Underwood (1981) suggested that the lower normal limit for serum Ca in cattle was 2.25mmol/l and a similar value was given by NRC (2000) for plasma Ca. This would translate into a normal Ca:Pi of 1.18 (2.25Ca:1.90P). The Pi at which cattle diets seemed to become deficient was 1.90mmol/l (Bortolussi *et al.*, 1996) which would result in a Ca:Pi of 1.42 (2.7Ca:1.90Pi) if the upper normal blood serum Ca concentration of 2.7mmol/l was used (NRC 2000; NRC 2001).

7.3. FAECAL NUTRIENTS

The number of animals tested in this trial was only 5. This did not follow the recommendations by Grant (1989) for the collection of 10 samples via rectal collections or McCosker & Winks (1994) for sampling at least 15 to 20 animals from dung voided when they were still in the paddock.

Table 47 Faecal nutrients in gram per kilogram during different seasons in ruminally cannulated cattle on different supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Parameter	RST	6%PT	MTT	PDT	FST	S.E.M
DRY HOT SEASON (5 Aug '04 – 17 Nov '04)						
Protein	65.8^{a}	71.4^{ab}	72.6^{ab}	71.4^{ab}	74.1^{b}	2.3
Phosphorus	1.4^{a}	2.9^{b}	2.9^{b}	2.4^{ab}	2.5^{ab}	0.4
Calcium	7.6^{a}	13.7^{b}	13.0^{b}	11.8^{ab}	7.9^{a}	1.4
WET SEASON (17 Feb '05 – 31 Mar '05)						
Protein	104.2	106.3	.	.	.	5.9
Phosphorus	2.5	2.4	.	.	.	0.2
Calcium	12.5	16.5	.	.	.	1.8
DRY COOL SEASON (13 May '05 – 23 Aug '05)						
Protein	83.0	84.5	90.0	83.9	93.4	6.5
Phosphorus	1.6^{a}	2.1^{ab}	2.3^{bc}	1.8^{ab}	2.4^{bc}	0.2
Calcium	12.2	15.4	13.9	11.6	13.0	1.3

[abc] Row means with different superscripts differ significantly ($P<0.05$)
S.E.M: Standard error of means

The results presented, with limited sampling numbers, do not support the findings by Grant (1989) and McCosker & Winks (1994) which used the faecal P and CP concentrations in combination as diagnostic indicators of nutritional status. The recommendations by Grant (1989) would classify the 6%PT and PDT during the dry cool season as P deficient and the dietary protein levels of RST during the dry season as normal, although they were subject to a primary P and secondary CP deficiency. The recommendations by McCosker & Winks (1994) would have wrongly classified the RST and 6%PT as obtaining marginal P during the wet season, PDT as obtaining marginal P during the dry hot season, 6%PT obtaining marginal P during the dry cool season and the PDT as P deficient during the dry cool season.

7.3.1. Crude protein

The highest CP concentrations in the faeces (Figure 116) where recorded during the wet season. The RST was at 104.2g/kg and the 6%PT was the highest for all collections during the trial at 106.3g/kg.

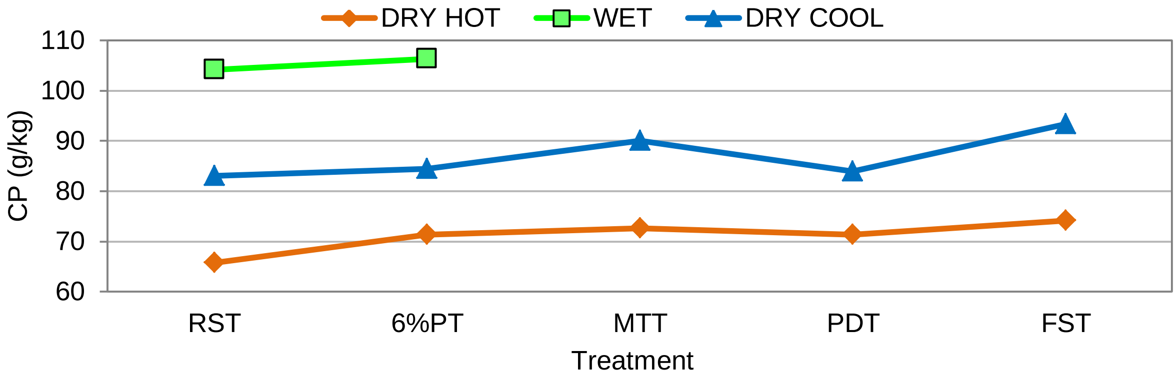


Figure 116 Crude protein (CP) in faeces in gram per kilogram (g/kg) from ruminally cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The lowest concentration for CP in faeces was recorded by the RST during the dry hot season at 65.8g/kg and 83.9g/kg during the dry cool season. During the dry hot season the FST was the only treatment with a significantly higher CP concentration than the RST at 74.1g/kg.

No significantly different levels in CP where observed between treatments during the wet season and during the dry cool season. The range of CP concentrations in the dry cool season was 83g/kg to 93.4g/kg, which was higher than the range of CP concentrations in the faeces during the dry hot season that ranged from 65.8g/kg to 74.1g/kg.

7.3.2. Phosphorus

The P present in the faeces (Figure 117) was the lowest in the RST during dry hot season with 1.4g/kg and the dry cool season with 1.6g/kg. During the dry hot season the faecal P concentration of RST was significantly lower than the 6%PT and MTT at 2.9g/kg. The PDT faecal P at 2.4g/kg and FST at 2.5g/kg were not significantly lower than the RST during the dry hot season.

The PDT and FST had similar ranges of faecal P concentrations as obtained by the 6%PT during the wet season at 2.4g/kg and the RST at 2.5g/kg. During the dry cool season the RST at 1.6g/kg was significantly lower than the MTT at 2.3g/kg and the FST at 2.4g/kg. The PDT at 1.8g/kg and the 6%PT supplement at 2.1g/kg were not much different than the RST during the dry cool season.

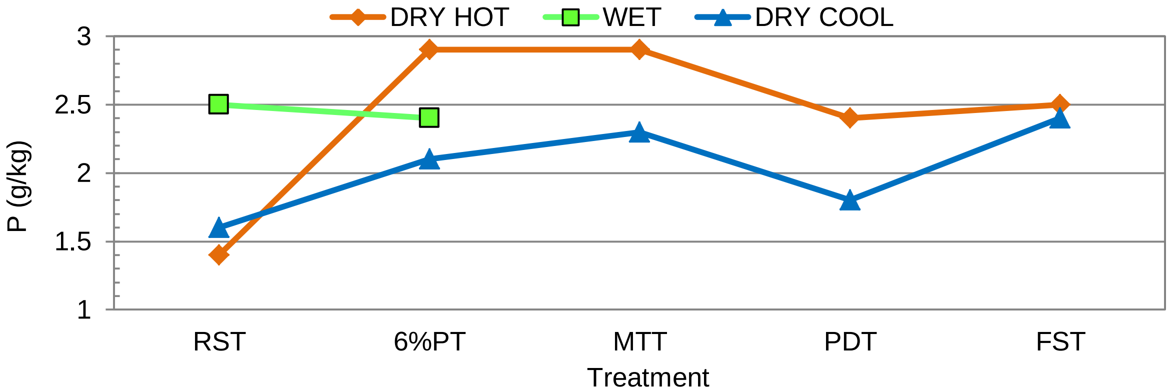


Figure 117 Phosphorus (P) in faeces in gram per kilogram (g/kg) from ruminally cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The P concentration of faeces of cattle on the RST recorded the lowest values in the dry season and had a range of 1.4g/kg to 1.6g/kg. The RST results tended to be significantly lower than the P concentration at 1.8g/kg to 2.9g/kg of P supplemented cattle (6%PT, MTT, PDT and FST) and cattle on veld in the wet season with no P deficiency. From this data, the P deficient group (RST) could be identified by faecal P concentrations that were below 1.8g/kg.

This was in accordance with results obtained by Groenewald (1986) who found that beef cows on a salt supplement had the lowest faecal P concentrations in the dry season and had shown that the P faecal concentrations had a seasonal influence. The concentrations recorded by Groenewald (1986) would most accurately have indentified a deficient group below 2.0g/kg faecal P which was also given by McCosker & Winks (1994) as a level where deficiency would be observed. Groenewald (1986) recommended that the use of faeces as an indicator of P status had to be part of a determination for total volume of faeces due to the influence of P on voluntary feed intake.

7.3.3. Calcium and calcium to phosphorus ratio

The highest Ca concentrations in the faeces where recorded throughout the seasons by the 6%PT. The faecal Ca concentration (Figure 118) during dry hot season for the RST at 7.6g/kg was significantly lower than the 6%PT at 13.7g/kg and MTT at 13.0 g/kg. It was not significantly different from the PTT at 11.8g/kg and FST at 7.9g/kg. No significant differences between treatments were observed during the wet or during the dry cool season.

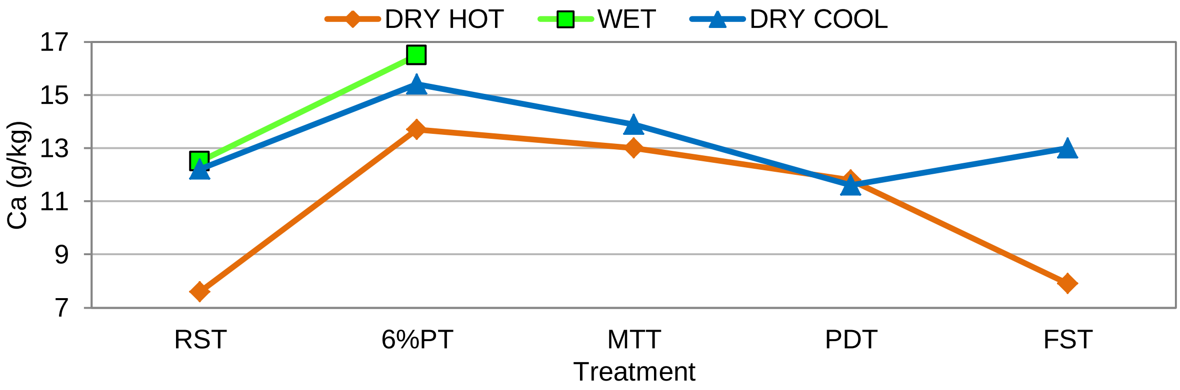


Figure 118 Calcium (Ca) in faeces in gram per kilogram (g/kg) from ruminally cannulated cattle during seasons on different nutrient supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The range of faecal Ca excretion values recorded during the wet season were 12.5g/kg to 16.5g/kg and for the Ca supplemented groups (6%PT, MTT, PDT and FST) during the dry hot and dry cool season were 7.9g/kg to15.4g/kg. The calcium concentrations recorded in the faeces show no clear trends.

7.4. CONCLUSION

The use of ruminal fluid as nutritional status indicators would be of limited use to the farmer as they would only indicate the dietary nutrient level intakes at the point of testing and were dependent on time after testing on the interpretation of results. The method would be difficult to run on farms as results were obtained from ruminally cannulated cattle. The treatment groups in which the ruminally cannulated cattle were kept had to be captured at the watering points from 24 hours before the sampling was scheduled to take place and 12 hours before sampling water and licks were restricted. The cattle then had to be moved to the central point on the farm to gain access to crush facilities. The restrictions of water and licks was required due to the cattle in nutrient supplementation groups had to be weighed as shrunk body weight and the dilution of nutrients in the ruminal fluid of ruminally cannulated cattle could have had negative effects on the results. Ammonia concentrations recorded in the rumen fluid seemed to be able to identify the groups that had a protein deficiency during the dry season (<4.5mg/100ml rumen fluid), received supplemental protein during the dry season (4.5 to 6.5mg/100ml rumen fluid) and had optimal protein for maximum growth during the wet season (>6.5mg/100ml rumen fluid). The volatile fatty acid concentrations in the ruminal fluid would indicate that it was taken during the wet season when the acetic to propionic acid ratio was >5.2.

The sampling of blood is a practical method for farmers to obtain indications on the nutritional intake levels of their cattle. Morris *et al.* (2002) highlighted that attention to proper blood handling, avoidance of haemolysis, storage procedures and processing were important in blood clinical analysis and in the proper interpretation of experimental results. The sampling and analysis of a minimum of seven animals (Ingraham & Kappel, 1988) was suggested for general metabolic profile tests. During this longer term latin square design collection of five animals had indicated that five tests would allow for significant differences to be found between blood metabolites. Read *et al.* (1986b), De Waal & Koekemoer (1997) and Karn (2001) concluded that blood P had more value as an indicator of dietary P levels, than as a P status indicator. A P deficiency in the diet of cattle in this trial that were not supplemented with *ad libitum* P containing supplements for 3 week periods could be indicated at Pi <1.90mmol/l and the result would be confirmed with a Ca:Pi that was >1.42. The BUN determined from blood that were collected from the jugular vein identified the groups during the wet season, that would be receiving optimal protein levels in their diets for maximum growth, at >5.36mmol/l. The treatment groups that would not respond economically to further protein supplementation during the dry season seemed to have BUN from 3.93mmol/l to 5.36mmol/l (RST, MTT, PDT and FST). The groups that would respond economically to further protein supplementation (6%PT) during the dry season would be identified by BUN <3.93mmol/l. BHB results from blood samples >5.2mg/dl indicated nutritional stress and would aid in identifying animals that had a P deficiency in their diet.

The use of faecal nutrient levels as nutritional status indicators, from grab samples of faeces in camps or rectal samples, is practically very easy for farmers to do. Read *et al.* (1986b) indicated that faecal P concentrations were likely more indicative of an animal's diet P concentration than an indicator of P status. Groenewald (1986) and Read *et al.* (1986b) recommended that the use of faeces as an indicator of P dietary intake status had to be part of a determination for total volume of faeces due to the influence of P on voluntary feed intake. This would result in the status indicator becoming unpractical at farm level. The number of animals tested by rectal grab samples at five in the current trial was half that was recommended by Grant, (1989). McCosker & Winks, 1994 recommended the use of 15-20 grab samples if samples of dung in camps were to be used. During the movement of cattle to the central crush facilities, the potential existed for the cattle being stressed if moved to quickly and increased faecal discharge could occur. From the current trial it seemed that faecal P below 1.8g/kg could potentially identify animals with a P deficiency.

CHAPTER 8 MARKETING OF CATTLE

Animal production with the main management goal of maximizing economic returns, as a result of selling livestock products in free economies (Bransby & Maclaurin, 2000), necessarily would include an evaluation of the marketing system in place and the profitability of each strategic nutrient supplementation treatment.

McCosker & Winks (1994) stated that cattle needed to be supplemented with P on soils indicating an acute P deficiency (Soil P_b <4mg/kg) and that the gross margins would be high in northern Australia. If the cattle were on soils indicating a deficient P status (Soil P_b 4-6mg/kg) the economic returns would be lower, but would still result in attractive returns. McCosker & Winks (1994) established that short-term borrowing to finance P supplementation programs would be economical and could be covered by increased sales within 2 years.

Freyer (1967) did nutrient supplementation (P, Ca, Urea, energy and salt) compared to a control (P, Ca and salt) during the dry season. The trial was done in the “Palmvlakte” of Namibia (South- Eastern area of South latitude 19° to 20° and East longitude 18° to 19°) that bordered on the arenosol soils as depicted in Figure 25. The soil had a P_B of 1mg/kg and a 70% sand component that classified it as an acutely P deficient area (McCosker & Winks, 1994). Cattle were slaughtered at the ages of 30 months (3 permanent incisors) and 36 months (3.6 to 4.3 permanent incisors) respectively. Freyer (1967) concluded that year round P supplementation was accordingly recommended and that in general the practice of P supplementation was already observed as a general management practice in the area, as without it farmers knew about the direct and indirect economic losses. The feeding of urea during the dry season was concluded to be a profitable and practical method of increasing beef production.

Van Schalkwyk (1975) tested various inclusion levels of Mopane tree (*Colophospermum mopane*) twigs and leaves (branches harvested up to 2 cm) with molasses meal and lucerne as an alternative feed resource during drought years in Namibia. The financial evaluation illustrated that it was not a feasible solution.

Gressmann (1979) did a nutrient supplementation (P, Ca, CP, energy and salt) trial during the dry season in the “Ovamboland” of Namibia (South latitude 17.5° to 18.5° and East longitude 14° to 18°) with low soil P concentrations, as depicted in Figure 25, with the indigenous Ovambo cattle breed (Sanga). Significant increases in growth rates and final liveweight (LW) of the cattle were recorded. The increased animal production was evaluated against the nutrient supplementation costs and marketing structures at the time and it was established the practice would clearly be profitable for farmers.

Groenewald (1986) established that improved biological performance of cows was linked to improved profitability in a long term (8 years) nutrient supplementation trial (P, CP and energy) undertaken in the Kwazulu-Natal province of South Africa (South latitude 28.12° and East longitude 29.58°). The study showed that incremental additions in nutrients from treatments starting with only salt as control to fixed feeding of 6g/day P, 12g/day P, CP and Energy, during the winter only, and then finally year round supplementation resulted in step wise improvements in conception rates, weaning percentages and weaning weights and concomitant increases in margin over supplementation cost. Annual mortality rates increased between groups as their level of nutrient supplementation reduced with the salt group recording the highest mortality at 4.4% against the next group, which only received 6g/day P with an annual mortality of 1.3% and the optimally supplemented cows with no mortalities recorded.

8.1. MARKETING RESULTS

Marketing results for the foraging free-range cattle with *ad libitum* nutrient supplementation treatments are presented in Table 48. All treatment groups were weighted the last time on Friday 9 September 2005 to determine the LW on the farm. Wednesday 14 September 2005 the cattle were loaded on trucks and transported 180km to the Meatco Pty. Ltd. Abattoir in Okahandja (Namibia) at an average age of 28 months.

The cattle from different treatments were mixed and were held overnight in pens before slaughtering occurred on Thursday 15 September 2005 at which time the LW was determined by the abattoir. The cattle were presented at random for slaughtering and the carcasses were cut down the middle and classified by a qualified grader from the Meatboard of Namibia as described by Strydom & Smith (2005). The grader classified the carcass for age by looking at the number of permanent incisors that were visible, fatness by looking at the subcutaneous back fat thickness (SCF) and the conformation by looking at how flat or round the carcass was according to the South African classification system (Government notice 1748, 1992) as it was also being used in Namibia.

Table 48 Marketing results for cattle groups supplemented on different strategic nutrient treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Parameter	RST	6%PT	MTT	PDT	FST	S.E.M
Liveweight at abattoir (Kg)	267.4[a]	328.1[b]	353.7[c]	348.6[bc]	374.9[d]	7.5
Warm dressing weight (Kg)	141.0[a]	180.8[b]	195.8[c]	197.0[c]	222.6[d]	4.5
Cold dressing weight (Kg)	137.5[a]	176.2[b]	190.9[c]	192.1[c]	217.1[d]	4.4
Dressing (%)	51.5[a]	53.6[b]	54.0[b]	55.1[c]	57.9[d]	0.4
Permanent teeth classification	1.3	1.2	1.2	1.0	1.2	0.2
Fat cover classification	0.6[a]	1.5	1.6	2.0	2.1	0.2
Conformation classification	2.1[a]	2.8[b]	3.0[b]	3.0[b]	3.2[c]	0.1
96-hour cold room weight (Kg)	135.9[a]	175.1[b]	190.5[c]	191.4[c]	216.3[d]	4.3
96-hour cooler shrink (%)	3.63[a]	3.12[b]	2.70[c]	2.84[bc]	2.85[bc]	0.11
Average marketing price (R/kg)	10.20[a]	12.30[b]	12.59[bc]	12.88[bc]	13.12[c]	0.22
Gross income received (R/Unit)	1406.34[a]	2184.11[b]	2411.83[c]	2484.20[c]	2852.5[d]	78.72

[abcd] Row means with common superscripts do not differ significantly (P>0.05)
S.E.M: Standard error of means

After grading the warm dressing weight was determined before being stored in cold rooms. The warm dressing weight was then decreased by 2.5% to obtain the cold dressing weight on which the producer would then be paid and the dressing percentage would be determined from the LW measured at the abattoir. Monday 19 Sep 2005 the 96-hour cold room weight was recorded as the halved carcasses were transferred to the deboning plant to determine the 96-hour cooler shrink percentage.

8.2. DRESSING PERCENTAGE

The dressing percentages in Figure 119 started from a low of 51.5% for the RST which was significantly lower than the 6%PT at 53.6% and MTT at 54.0%. The PDT at 55.1% was significantly higher than the 6%PT and MTT, and significantly lower than the FST at 57.9%. The general linear trend for the increase in dressing percentage as the nutrition improved was in agreement with results obtained by Schroeder *et al.* (1980). Increasing quality of veld feeding treatments fed to cattle resulted in dressing percentages improving from 53.4% to 58.0%, and if these animals were then subsequently feedlotted the dressing percentages would further improve to between 60.8% and 61.4%.

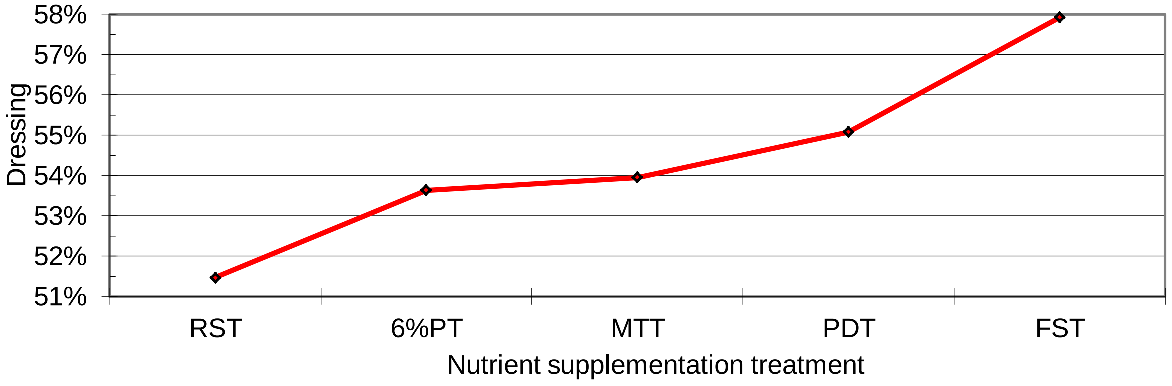


Figure 119 Dressing percentage obtained by supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The average dressing percentage of the RST at 51.5% was similar to the result obtained by Du Plessis & Hoffman (2004) at 51.33% for 30 month old mixed breed cattle not receiving supplementary feeds. The PDT at 55.1% had similar dressing percentages to Camfield *et al.* (1999) with 55.3% to 56.9% at an age of 20 months for cattle that were raised on improved pastures. FST at 57.9% was the closest to feedlotted cattle as recorded by Camfield *et al.* (1999), which had dressing percentages of 58.4% to 59.7% at 14 months of age.

8.3. CARCASS WEIGHT

Meatco Namibia exported vacuum packed deboned meat cuts by sea to the European Union. The European marketing strategy influenced the payment system offered to Meatco producers. Carcass weight had a positive effect on yield for all carcass cuts and accounted for most of the variation in total yield (Strydom & Smith, 2005). Strydom (2002) explained that the optimum income would be earned on cold carcasses weighing more than 220kg and a premium of R0.01/5kg would be paid to weights above 220kg. A pricing penalty of R0.02/5kg in weights of between 219kg down to 160kg with larger penalties in price for cold carcasses weighing lower than 160kg.

The FST weight of 217.1kg, illustrated in Figure 120, was the closest to the anchor point in the payment system explained above as it was only penalised by R0.02/kg from the optimum weight of 220kg. The MTT (190.9kg) and PDT (192.1kg) were penalised by R0.12/kg and the 6%PT (176.2kg) was penalised by R0.18/kg. The RST at 137.5kg was heavily penalised for falling under the 160kg weigh class.

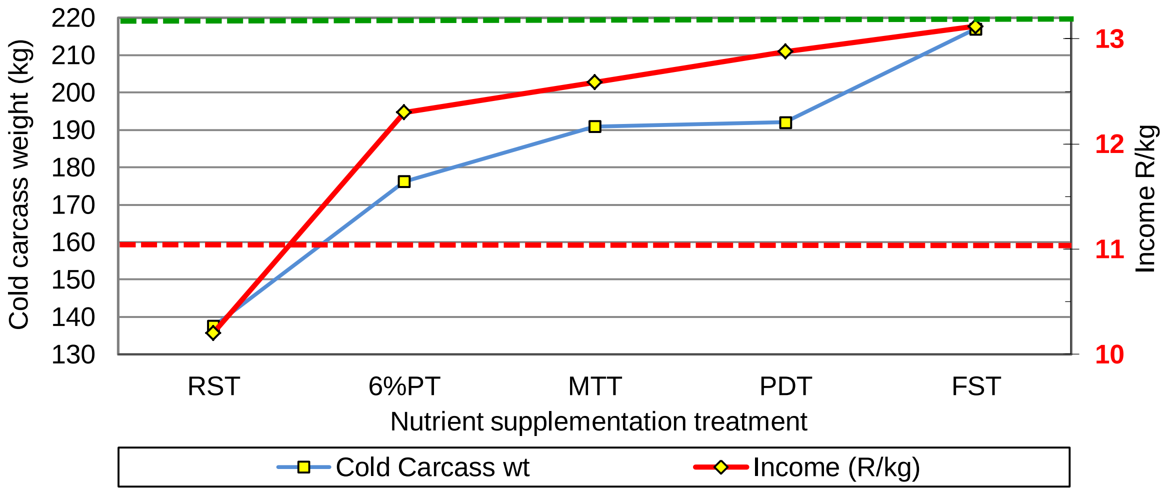


Figure 120 Average income in Rand per kilogram compared to the average total kilogram of cold carcass marketed for the supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST). Optimum premium paid for cold carcass weight at 220kg down to lowest point of escalating decreases in prices paid at 160kg indicated

8.4. CARCASS GRADING

The pricing structure at Meatco paid a premium of R0.70/kg (6%) for A grades above AB grades which in turn received a premium of R1.10 (11%) above B grades. Du Plessis & Hoffman (2004) found 23.8% of animals graded as B (3 or 4 permanent incisors visible) at the age of 30 months. The author's recommended that animals needed to be marketed at a marginally earlier age of 27months that could result in no B grades being obtained.

No significant age differences were observed between the treatment groups with a range of values between 1.0 and 1.3 permanent incisors being visible which classified the cattle on average as AB grades (between 1 and 2 permanent incisors being visible to the grader). All cattle slaughtered in the trial had no more than two visible permanent incisors at the age of 28 months which meant that all cattle were either graded as A (36.36% animals with no permanent incisors visible) or AB (63.63% animals with between 1 and 2 permanent incisors being visible) which ensured optimum returns under the marketing scheme for the age grades (Figure 121).

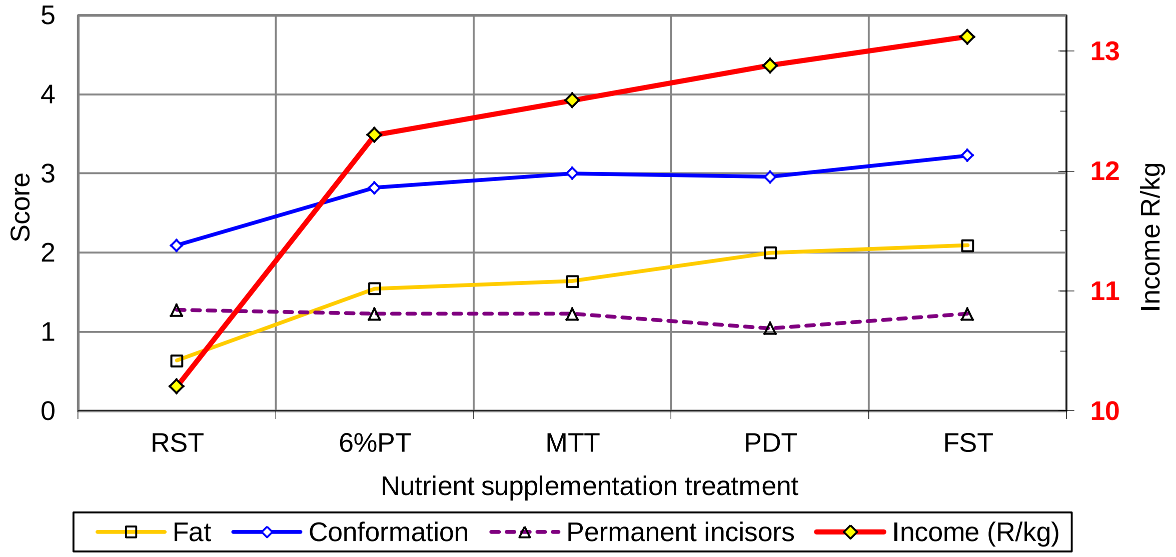


Figure 121 Average income in Rand per kilogram compared to the scoring results by a Meatboard of Namibia qualified grader on the South African classification system (Government notice 1748, 1992) for the supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

Producers receive the highest price for carcass fatness grades determined by the subcutaneous back fat thickness (SCF) that graded between 1 (very lean, <1mm SCF), 2 (lean, 1-3mm SCF), 3 (medium fat, 3-5mm SCF) and 4 (fat, 5-7mm SCF) with a 6% price penalty on a 0 classification (no fat, 0mm SCF) and a 4% price penalty on 5 (over-fat, 7-10mm SCF) or 6 classification (Excessively over-fat, >10mm SCF) (Strydom, 2002). The 6 fat classification as a rule needed to be trimmed down to around 10mm of subcutaneous fat to be able to export the cuts. The RST had 50% of the carcasses receive a fat grade of 0 which resulted in an average fat grade of 0.6 which was significantly leaner than the other nutrient supplementation treatments that ranged from 1.5 to 2.1.

Carcasses with a conformation grade of 3 (medium), 4 (round) and 5 (very round) received a R0.10/kg (A grades) to R0.20/kg (AB grades) premium above carcasses that only received a 1 (very flat) or 2 (flat) score (Strydom, 2002). In Figure 121 the RST had 90.9% of the classifications as a 2 (flat) which was in the lower paying grades which resulted in a significantly lower average grading score at 2.1 compared to other treatments. The 6%PT had only 18.18% graded as 2 which were in the low paying grades. The 6%PT (2.8), MTT (3.0) and PDT (3.0) had similar conformation grades and the FST was significantly better with an average 3.2 conformation grade. The FST was the only group to attain grades for 4 (round) and had 18.18% of the group obtain the grade which was in contrast to all other groups that could at best receive a 3 (medium) classification.

8.5. COOLER SHRINK

The <u>2.5%</u> theoretically calculated reduction of the warm dressing weight to the cold dressing weight compares well to the 24-hour cooler shrink percentages measured by Schroeder *et al.* (1980). Schroeder *et al.* (1980) recorded a range of 2.2% to 3.3% in the 24-hour cooler shrink on veld fed cattle. Cattle that were feedlotted on concentrates had a lower 24-hour cooler shrink, which ranged from 2.1% to 2.4%, due to a higher total fat content of the carcasses that ranged from 24.3% to 27.9% compared to the veld fed cattle ranging from 5.0 to 7.0%.

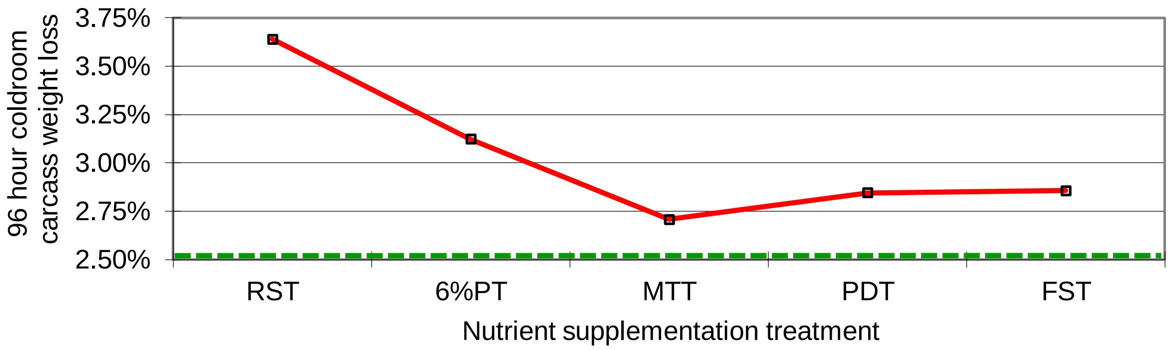


Figure 122 The 96-hour cooler carcass weight shrink percentage due to moisture loss for supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST). The theoretical 2.5% reduction line for 24-hour cooler shrink used to determine cold carcass weights

The 96-hour cooler shrink values recorded during the trial (Figure 122) showed a significantly higher moisture loss in the RST at 3.63% compared to the other treatments that ranged from 2.7% to 3.12%. Schroeder *et al.* (1980) obtained 72-hour cooler shrink values for veld fed cattle that ranged from 3.3% to 3.9%, which was much higher than the feedlotted cattle from 2.4% to 2.9%. Camfield *et al.* (1999) measured 96-hour cooler shrink on pasture fed cattle that ranged from 2.42% to 3.15%, which was higher than that obtained in feedlotted cattle ranging from 2.18% to 2.53%.

8.6. ECONOMIC EVALUATION

Improved nutritional state from increasing levels and quality of *ad libitum* strategically supplemented nutrients to free-range foraging cattle resulted in increasing levels of income earned per animal under the Namibian marketing system used by Meatco to remunerate its producers as depicted in Figure 123.

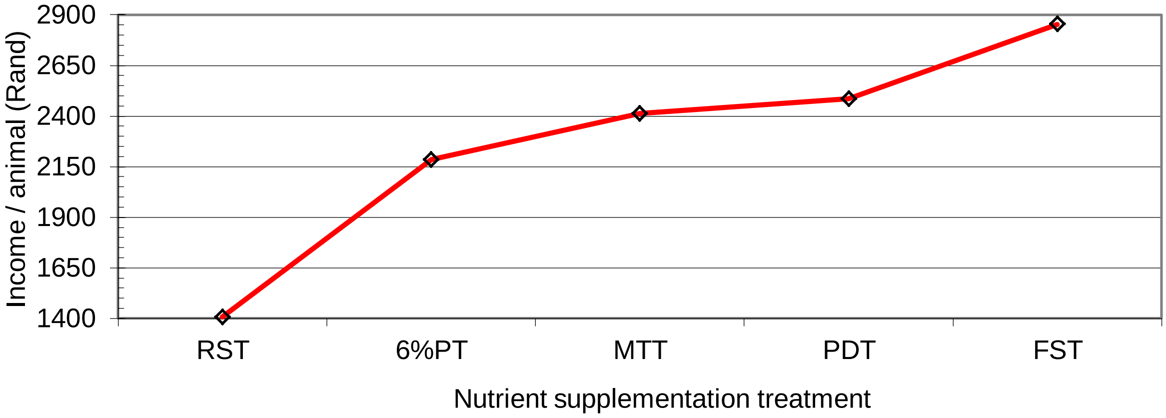


Figure 123 Gross average income in Rand per carcass after slaughtering supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The RST had the lowest return at R1406.34/animal, which was significantly less than all other treatments in Table 48. The 6%PT had the second lowest return at R2184.11/ animal, which was significantly higher than the RST. The MTT with R2411.83/ animal and PDT with R2484.20/ animal received similar incomes that were significantly higher than the 6%PT but were paid significantly lower than the FST at R2852.50/ animal.

The income received by the nutrient treatment strategy (Figure 123) had to be offset against the cost of supplementation (Table 49) to establish if there was sufficient profit to merit the use of such a strategy by the livestock producer in Namibia (Figure 124).

Table 49 Total supplement intake in kilogram and cost in Rand per animal over the 15 month duration of the feeding trial and the gross margin calculated from the carcass income less the total cost of supplementation per treatment defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

	RST	6%PT	MTT	PDT	FST
Total supplement intake (kg/animal)	31	47	152	395	1028
Total supplement cost (R/animal)	14.17	66.61	190.64	525.32	1411.06
Gross margin (R/animal)	1392.17	2117.50	2221.19	1958.88	1441.44

With each progressive nutrient supplementation strategy (from RST up to FST), the total cost of supplementation per animal over the trial period increased (Table 49). The RST represented the lowest cost of supplementation at R14.17/animal and the cost of supplementation increased by 470% to R66.61/animal for the 6%PT. The cost of supplementation on the 6%PT increased by 286% to the MTT at R190.64/animal. The cost of supplementation on the MTT increased by 276% to the PDT at R525.32/animal. The highest cost of supplementation was recorded by the FST at R1411.06 which was 269% higher than the PDT and 10 170% higher than the RST.

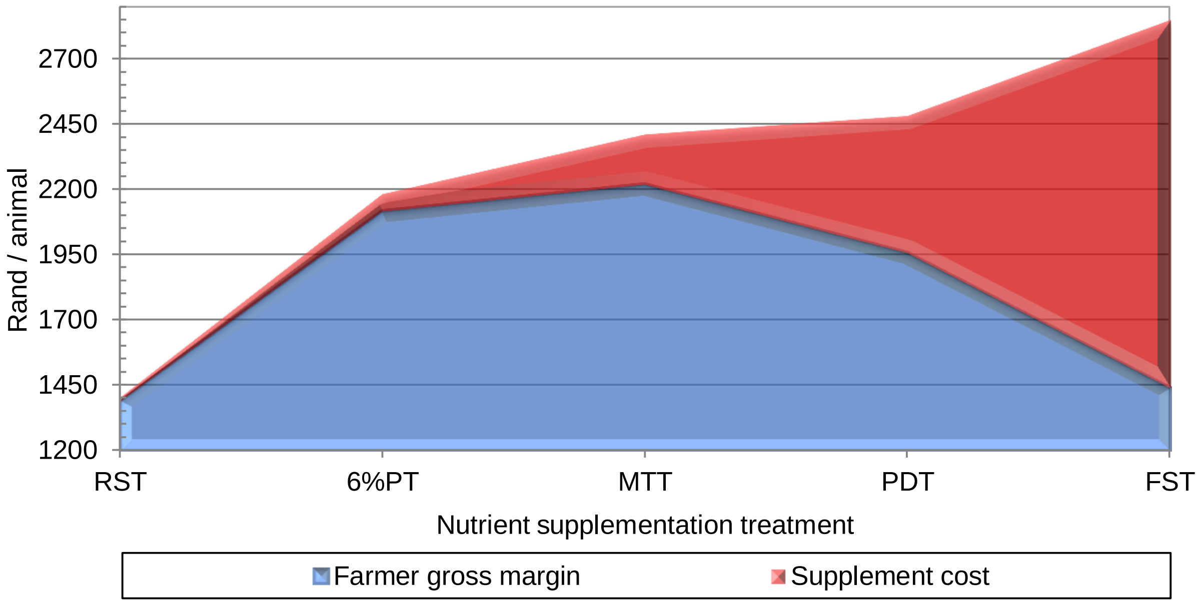


Figure 124 Farmer total income in Rand per carcass stacked as the total cost of the nutrient supplementation strategy on the gross income earned per carcass for supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

In Figure 124 the total income earned per carcass less the total supplementation cost per animal results in the gross profit left to the farmer as income from which all other farming expenses would need to be paid before the net profitability of the farming enterprise could be determined. By using the RST as the easiest and most basic of nutrient supplementation strategies used in Namibia, and as the control of the current experiment, the increased gross margin that was generated by different supplementation strategies is illustrated in Figure 125 and Figure 126.

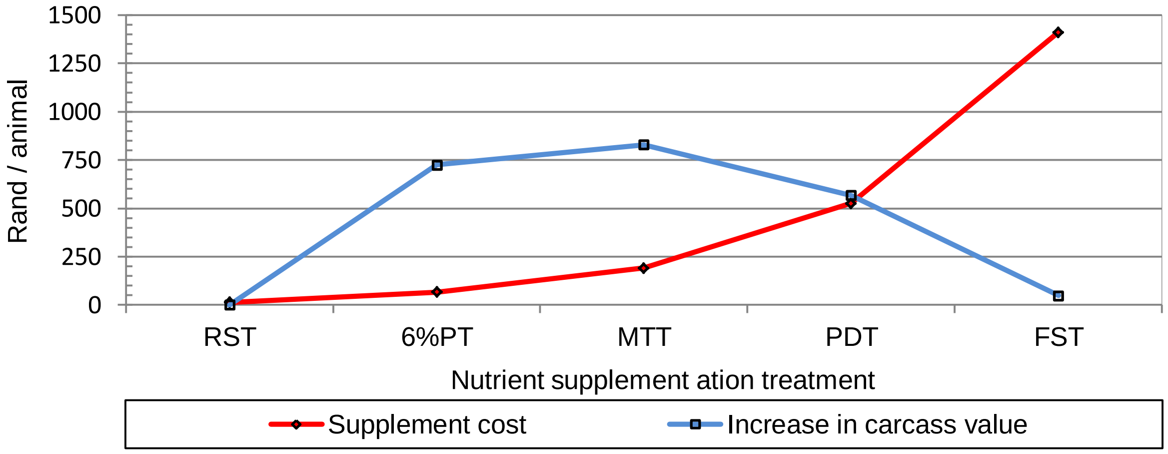


Figure 125 The diminishing marginal returns graph of the strategic nutrient supplementation costs of the treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST)

The 6%PT generated a 52% higher gross profit than the RST by consuming a total of 47kg of lick per animal, which was only 16kg of lick consumed more than the RST. The 6%PT generated an additional income of R13.95 for every additional R1 spent on the nutrient supplementation cost. The 6%PT realised the highest return on investment and would be most suited for farmers with limited financial resources. The MTT generated a 60% higher gross profit than the RST by feeding 121kg more supplement per animal with a return on investment of R4.70 per additional R1 spent on supplementation. This level of supplementation was the most profitable for the farmer but would require higher levels of financing.

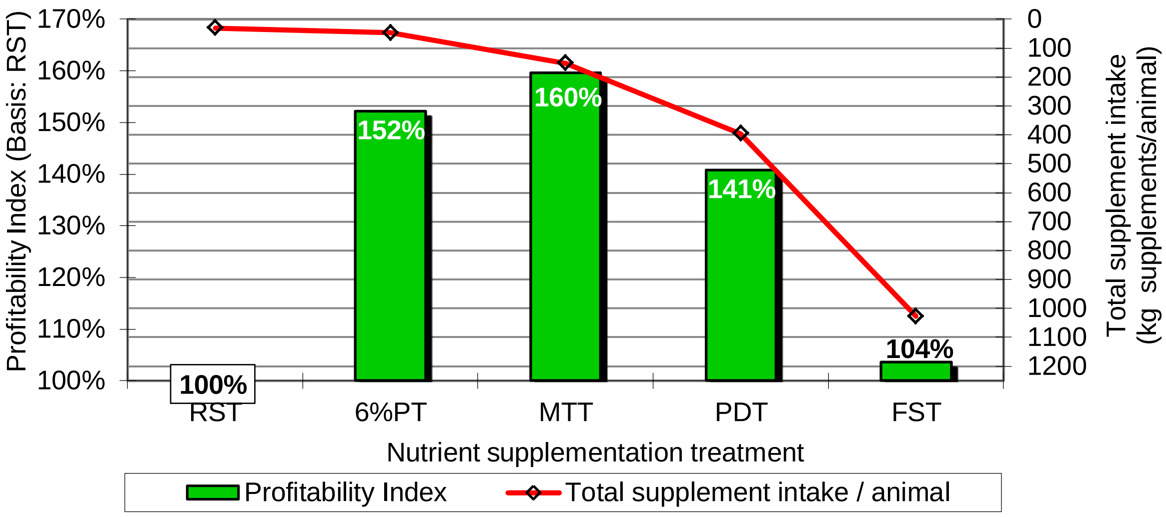


Figure 126 The profitability index of nutrient supplementation treatments with the rock salt treatment group (RST) as the basis of comparison to the 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST) compared to the total supplement intake in Kilogram per animal over the 15month duration of the trial

The PDT generated a 41% higher gross profit than the RST by feeding 364kg more supplement per animal with a return on investment of R1.11 per additional R1 spent on supplementation. The FST generated only a 4% higher gross profit than the RST by feeding 997kg more supplement per animal with a return on investment of only R0.04 per additional R1 spent on supplementation.

CHAPTER 9 GENERAL DISCUSSION

The management by farmers of extensive ruminant production from semi-arid subtropical pastures is limited to the health, genetics and nutrition that are predominantly influenced by the prevailing climate, soils and vegetation of the area that are not under the control of the farmer.

Liebig's barrel illustrates (Figure 127) that as the capacity of a barrel with staves of unequal length was limited by the shortest stave, so a plant (UNIDO & IFDC, 1998) and subsequently an animal's production (Van Niekerk, 1996) was limited by the nutrient in shortest supply. The most limiting nutrient to animal production for the current trial, as defined by Liebig's law of the minimum (UNIDO & IFDC, 1998), would be phosphorus.

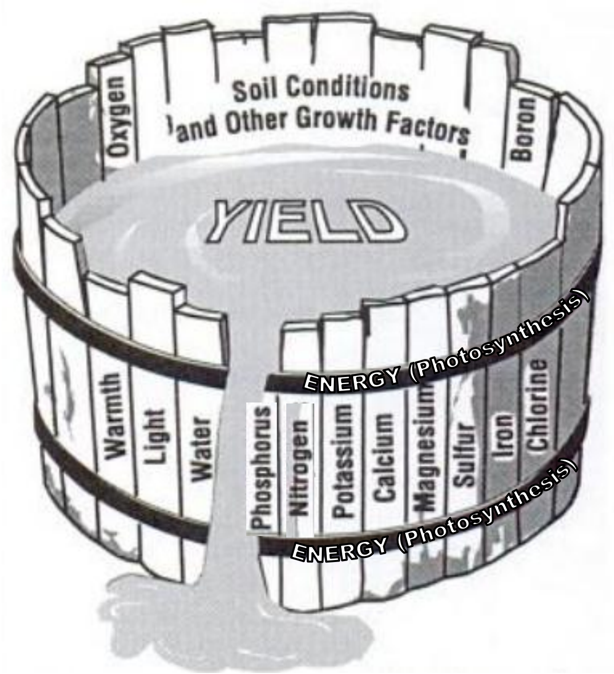


Figure 127 Liebig's law of the minimum illustrated in a barrel analogy (UNIDO & IFDC, 1998)

The second most limiting nutrient would be crude protein. The energy that drives the system, which was primarily derived from plants that harvested the energy by photosynthesis, would be the main supporting rib's keeping all the barrel staves in place. The sun energy locked into plant structures and subsequently assimilated by the animal was what ultimately allowed a farmer to make a living. Phosphorus being the most important nutrient in the transfer of energy from the plant to the animal in energy metabolism (adenosine phosphates) and the structural support in bones highlights why it is of great importance to the Namibian cattle farmer.

9.1. NUTRITIONAL QUALITY OF VELD

Only when the amount of veld per animal was not a limiting factor, did the quality of the veld selected by the ruminant enter as a matter of great importance. The stocking rate was probably the most important factor managed by the cattle farmer. Kruger (1998) concluded that the determination of available veld at the end of the rainy season and the subsequent adjustment of stocking rates was very important as animal performance would be affected much sooner than veld condition when applying heavy stocking rates. If high stocking densities were constantly applied, the veld condition would permanently deteriorate which would lead to bush encroachment (De Klerk, 2004).

During spring, the month after the first productive rainfall (min of 10mm/day) was recorded, the plants started growing and contained very low concentrations of dry matter and cattle were not able to collect enough high quality veld which only allowed minimal improvements in animal performance. The dry matter on offer and therefore animal performance only improved in the wet season, the month after the first substantial rainfall (min of 25mm/day) was recorded, which followed after the veld quality had peaked and the month of maximum rainfall had been recorded. This was also the time that the greatest damage to range plants could occur due to the plants being busy in strengthening their roots and ultimately being able to produce seed. The dung of cattle became green and watery due to the high digestibility of the plant material on offer. The onset of the dry season was two months after the last substantial rainfall for the season was recorded. During the dry season, nearly no green material could be seen in the veld and no active growth of plants occurred. The dung of cattle became firm and brown during this period. This was the time when the dry dead grass needed to be harvested by cattle as it would minimally affect the vigour of the grass plants. This was also the time that the nutritional quality of the veld on offer was at its lowest. The cattle selected the highest quality material available to them and as such, the quality of veld deteriorated as the season progressed until the next spring season would arrive.

The strong positive linear relationship between CP and P concentrations, in OF collected veld samples on sandy soils, and their combined relationships with seasonal rainfall was established. The animal performance results suggested that under circumstances of low protein concentrations in veld (CP<7%, found in the dry season) there would be a P deficiency (P<0.13%, found in the dry season).

9.2. ANIMAL PERFORMANCE ON TREATMENTS

The RST as control treatment received rock salt throughout the trial period and resulted in the lowest LW (276kg), return (R1406.34) and gross margin (R1392.17) for the cattle farmer. The RST exhibited symptoms of pica and had a wiry and coarse hair coat indicating a phosphorus deficiency. During the dry season the group lost weight, maintained weight during the spring and gained 858g/day during the wet season. The group consumed sufficient salt (sodium and chloride) levels of 0.1g/kg LW to 0.2g/kg LW during the wet season to meet maintenance and growth requirements. The ruminally cannulated cattle that were cycled through this treatment after 3 weeks of adaption confirmed a primary P deficiency indicated in the blood by Pi of <1.90mmol/l and the result was confirmed by a Ca:Pi in blood that was >1.42. The faecal P concentrations of below 1.8g/kg were a further indication of a P deficiency. A secondary protein shortage was confirmed by ammonia concentrations recorded in the rumen fluid at <4.5mg/100ml rumen fluid. BHB results from blood samples that were >5.2mg/dl had indicated that the group were under nutritional stress.

The 6%PT received a basic P mineral supplement throughout the dry and wet seasons. The 6%PT recorded a significantly higher LW (349kg), significantly higher return (R2184.11), highest marginal return (R13.95/R1 spent on supplementation) and the second highest gross margin (R2117.50) in the trial. The group indicated to be consuming sufficient salt (sodium and chloride) levels of 0.2g/kg LW to 0.3g/kg LW to meet the animal's maintenance requirements during the dry season and 0.1g/kg LW to 0.2g/kg LW during the wet season seemed to be sufficient for 934g/day growth. The levels of *ad libitum* P intake of 0.01g/kg LW to 0.02g/kg LW during the wet season and 0.02g/kg LW to 0.03g/kg LW during the dry season indicated to be required for optimal performance. The BUN tested in the blood at <3.93mmol/l indicated that the group would respond economically to further protein supplementation during the dry season. Ammonia concentrations recorded in the rumen fluid were also able to identify the groups protein deficiency during the dry season at <4.5mg/100ml rumen fluid.

The MTT received additional protein in the dry season. The MTT recorded a further significant improvement in LW (377kg), significantly higher return (R2411.83), second highest marginal return (R4.70/R1 spent on supplementation) and the highest gross margin (R2221.19) recorded in the trial. The supplemental protein allowed sufficient quantities of estimated metabolisable protein (eMP) to be consumed to maintain LW during the dry season but was not sufficient to optimise intake levels.

The PDT received additional protein and energy in the dry season. The PDT had a slightly lower LW (370kg), comparable return (R2484.20), lower marginal return (R1.11/R1 spent on supplementation) and a reduced gross margin (R1958.88). The protein intake was optimised in this treatment with additional energy being contributed to the diet.

The FST received excessive levels of protein and much higher energy in the dry season, which replaced a large part of the veld that should have been consumed in the diet. The FST had the highest LW (401kg), highest return (R2852.5), lowest marginal return (R0.04/R1 spent on supplementation) and the gross margin (R1441.44) was only slightly higher than the RST. Excessive mineral intakes were recorded due to the cattle trying to maximise their intake of energy that would replace veld intake. This would reduce the grazing pressure and increase the period over which the foraging resource could be utilised, but this came at a significant cost to the cattle farmer.

9.3. *AD LIBITUM* FEEDING OF SUPPLEMENTS

Forbes & Provenza (2000) found evidence that a feed that the animal believed to be alleviating a deficiency became preferred over other feeds; while one thought to be excessive in the same nutrient, it would become averse off. Under natural conditions, such responses would lead to “nutritional wisdom”, i.e. eating a mixture of foods which most closely meets the animal’s nutrient requirements. This was clearly observed in the seasonally averaged total available nutrient concentrations in the diets of the treatment cattle summarised in Table 50.

The cattle had the ability to alleviate nutrient deficiencies in the consumed veld by consuming different nutrient supplements at different increasing rates of intake to match the trends in declining veld quality as the dry season progressed. This trend was reversed during the spring season when the veld quality was improving and the supplement intakes plummeted, although animal performances only slightly improved during this period. During the wet season the licks for most treatment groups were changed to only contain 6% phosphorus and trace minerals, except for the RST, and as the wet season progressed the intakes steadily increased as the P concentrations in the veld selected by OF decreased.

The primary nutrient selected for by cattle in the 6%PT, MTT and PDT seemed to be P (Table 50) although there were a wide range of different nutrients obtained from the supplements.

Table 50 Average daily estimated available nutrient concentration in the estimated total diets, consisting of veld and nutrient supplement intakes, over the seasonal periods of the trial for the supplementation treatments defined as rock salt treatment group (RST), 6% phosphorus treatment group (6%PT), maintenance treatment group (MTT), production treatment group (PDT) and finisher treatment group (FST). Single underline indicating deficiencies and double underline indicating excessive nutrients

Nutrient	**RST**	**6%PT**	**MTT**	**PDT**	**FST**
DRY SEASON (2 Jun '04 – 17 Nov '04)					
Supplement % of diet	1%	2%	6%	16%	42%
ME (MJ/day) ex. Supplement	.	.	**1.5**	**6.7**	**21.7**
Salt	1.11%	0.86%	1.93%	**3.36%**	**5.94%**
CP	**4.3%**	**4.3%**	6.6%	7.8%	10.8%
P	**0.11%**	0.21%	0.22%	0.21%	**0.34%**
Ca	0.53%	0.79%	0.73%	0.64%	0.63%
Ca:P	4.9	3.7	3.4	3.1	1.9
SPRING SEASON (18 Nov '04 – 26 Jan '05)					
Supplement % of diet	1%	1%	3%	9%	25%
ME (MJ/day) ex. Supplement	.	.	**0.8**	**4.4**	**15.7**
Salt	0.59%	0.50%	0.84%	**1.84%**	**3.51%**
CP	14.4%	14.4%	15.1%	15.4%	16.0%
P	0.23%	0.29%	0.27%	0.27%	**0.34%**
Ca	0.76%	0.91%	0.84%	0.80%	0.76%
Ca:P	3.5	3.2	3.2	3.0	2.3
WET SEASON (27 Jan '05 – 12 May '05)					
Supplement % of diet	1%	1%	1%	1%	1%
ME (MJ/day) ex. Supplement	.	.	.	.	.
Salt	0.76%	0.35%	0.33%	0.41%	0.38%
CP	10.3%	10.3%	10.2%	10.2%	10.2%
P	0.18%	0.23%	0.22%	0.23%	0.23%
Ca	0.40%	0.51%	0.50%	0.52%	0.52%
Ca:P	2.3	2.3	2.3	2.3	2.3
DRY SEASON (13 May '05 – 9 Sep '05)					
Supplement % of diet	1%	1%	6%	15%	37%
ME (MJ/day) ex. Supplement	.	.	**2.0**	**9.5**	**29.9**
Salt	0.96%	0.63%	1.72%	**3.11%**	**5.14%**
CP	**4.9%**	**4.9%**	6.9%	8.0%	10.5%
P	**0.10%**	0.18%	0.20%	0.19%	**0.31%**
Ca	0.38%	0.57%	0.57%	0.51%	0.52%
Ca:P	3.9	3.2	3.0	2.6	1.7

The P deficiency observed in the RST seemed to result in strong sensory feedback signals to cattle in the 6%PT, MTT, PDT and FST, which influenced the *ad libitum* intake rates on licks that were made available. A reduction in voluntary feed intake took place when grazing ruminants were subjected to a primary P deficiency (McCosker & Winks, 1994; Bortolussi *et al.*, 1996; Ternouth, 2001).The RST lost weight during the dry season and showed symptoms of a P deficiency in the form of pica. The RST had to extract P from the hydroxyapatite bone structure with a surplus Ca being left to circulate in the blood.

On the opposite side of the intake feedback signalling spectrum the FST consumed two to three times the required levels of P. The PDT followed by the MTT to a lesser extent also consuming P in excess of requirements as the 2005 dry season progressed. The energy contributions from the licks seemed to indicate the reason for less P being consumed in excess of requirements by these nutrient supplement treatments. The graded increases in surplus P consumptions as the energy contributions of the supplements increased indicated that the cattle were trying to maximise their energy intake from the supplements. The energy cost of excreting surplus minerals (P, Ca and salt) ingested had to be offset against the total additional energy consumed which would improve production levels. The excreted P was not found in faecal P concentrations due to the surplus most probably being excreted via the alternative route in the urine under these circumstances (Shiraz-Beechey *et al.*, 1996; Bravo *et al.*, 2003). It was clear that salt was a poor intake regulator as no trend was observed in salt intake levels as was observed in the P intakes. The FST consumed excessive quantities of salt (five to eight times their requirement) while still outperforming the other supplementation groups. The total dietary inclusion of salt in the FST during dry season (Table 50) at around 5% to 6% was still much lower than the estimated total diet maximum tolerable concentration at 9% (NRC, 1980). These observations had two primary negative consequences for the farmer. Firstly the replacement of relatively inexpensive energy contained in the veld by expensive energy containing raw materials (bran, maize meal and molasses) and secondly the excretion of surplus minerals (P, Ca and salt). This explained the deterioration in the economic evaluation where the PDT and FST resulted in progressively reduced marginal returns and profits although the highest animal performances were recorded.

Romney & Gill (2000) explain that it was generally accepted that animals ate to supply the tissues with the nutrients required to fuel the physiological processes of maintenance and growth. However, given the variety of feed components eaten by animals, it was unlikely that the composition of the nutrients supplied would exactly meet the ratio of nutrients required by the animal. Thus, meeting the requirements of one nutrient was likely to result in a deficiency or excess of another. Animals stopped eating to limit metabolic or physical discomfort and thus the animal had to decide at what point the disadvantages of the deficiencies or excesses of some nutrients outweigh the advantages of trying to meet the animal's energy requirements, which were thought to be the main intake driver.

The MTT seemed to have resulted in the optimum nutrient supplementation strategy. The primary P and secondary CP shortages in the selectively consumed veld were best alleviated, compared to the other treatment groups, by this strategy while minimal negative associative effects on intake would occur due to no energy rich grains being included in the maintenance lick during the dry season. The economic evaluation confirmed that the MTT resulted in the optimal utilisation of the veld and licks on offer to the cattle in this trial.

CHAPTER 10 OVERALL CONCLUSION

The first indicator that a primary P shortage in the diet of cattle could be prevalent was if sandy soils (Arenosols) were found in the area. A basic soil analysis for $P_{B,}$ used in general crop fertiliser requirement determinations, 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).

The monthly rainfall pattern was an important indicator of the nutritional value of the veld. A strong linear relationship existed between monthly rainfall and the CP and P concentrations in samples selected by oesophageally fistulated cattle (OF) in this trial. Rainfall data was thus a good nutritional status indicator of cattle, which signalled when changes in the veld quality were expected as the seasons changed. The DM yield (kg/ha) of the grass plants at the end of the wet season (May) needed to be determined by cutting one meter quadrates and weighing the amount of grass available (kg/ha). Total rainfall was a good indicator of the quantity of veld available and this would influence the annual decision on the biomass stocking rates (kg LW/ha) that would have to be targeted as detailed by Kruger (1998).

Monthly animal LW change and the average daily gain calculated from this data was the most accurate indicator of the nutritional status of cattle. Monthly determining the average daily *ad libitum* nutrient supplement intake (kg/day per animal) was a valuable indicator of the quality of veld on offer. The recommended lick to use during the wet season was a phosphorus and trace mineral containing lick. During the dry and spring seasons it was a maintenance lick which contained phosphorus and protein (with minimal energy containing raw materials). The supplement on offer was the only buffer for the animal when nutritional shortages occurred in the diet selected from the veld. The phosphorus and protein intake could be expressed as gram nutrient per kilogram LW for comparisons in groups of cattle with different weights in the same physiological status. If the same lick was made available to similar cattle groups over different years and over different areas (farms/camps) it would clearly have shown trends relating to increases (decreased supplement intakes) and decreases (increased supplement intakes) in the veld quality and quantity that the cattle were able to select. These results could be recorded and indexed for comparison together with animal performance and rainfall records. The decision to rotate cattle herds between different sized camps over different terrains could also be managed by using this data. Setting a maximum intake threshold for lick intakes at which point it would signal that the quality and quantity of veld, which was selected by cattle, was no longer suitable and the cattle had to be moved to new camps.

The use of RST as a nutrient supplementation strategy would most probably result in financial ruin and is strongly advised against. A significant improvement in productivity and hence profitability of the farmer could be obtained by using a P containing supplement throughout the year (6%PT). This practice should be implemented as a minimum requirement for animal health and welfare and ultimately for financial viability of the extensive free-range cattle farming enterprise in the sandy soils of Namibia. The risks of cattle obtaining suboptimal P levels in their diet were well documented in literature, with emaciation and botulism being but some of the negative effects. The rock salt group had depraved appetites and were regularly observed chewing twigs, stones, fence posts and other strange objects which were characteristic of pica. Farmers have in the past observed that rock salt would wear down the teeth of cattle. After regular close observation of the animals in this trial it seemed that all the strange objects that were chewing would be the cause of the teeth wear, rather than the physical form in which the salt was applied. The regular picking up of stones (limestone) and chewing them by the RST would shorten the longevity of these animals due to accelerated wear of their teeth. The cattle were also seen chewing bones, from wild animals that had died in the veld, which could lead to botulism. Potential exists to make available a rock salt lick in combination with a separate phosphorus lick during the wet season. Cattle or wildlife could potentially be able to balance their own diet electrolyte and phosphorus intake levels during the wet season if constantly exposed to the licks but this should not be encouraged during the dry or spring season.

The P levels consumed from different nutrient supplementation treatments in this trial, during different seasons of the year, seemed to indicate that the nutrient was actively selected for by cattle. If the licks had limited quantities of energy containing materials in them, it indicated that limited quantities would be consumed in excess of requirements. Minimal risk to animal health and profitability would occur by feeding P supplements *ad libitum* if low concentrations of energy containing raw materials were present in the supplements. The practice of increasing the palatability of P containing supplements by the addition of molasses or other energy rich by-products due to perceived low intakes was a practice that was highly questionable in the Southern African region. If cattle consume low levels of P from nutrient supplements, as would be the case during the wet season and dry season in areas with sufficient P levels in the soils, there would be no need for the cattle to be forced to increase their consumption levels.

The use of a maintenance lick to buffer the animal from the primary shortage of P and a secondary CP shortage is recommended during the spring and dry season. Part of the reason that the protein was observed to be a secondary deficiency was explained by the protein sparing effect that was observed in one of the two the protein deficient diets. The 6%PT, in contrast to the RST, utilised the protein in circulation for production and performed significantly better. The rumen fluid ammonia concentrations during the dry season recorded by the 6%PT were the lowest values recorded at 2.9-3.6mg/100ml rumen fluid. The RST counter intuitively had slightly higher values recorded at 3.8-4.2mg/100ml rumen fluid. The lower ammonia concentrations found in the 6%PT (P sufficient and N deficient animals) compared to the RST (P and N deficient animals) indicated a disturbance of protein metabolism pathways of the rumen microbes in the RST due to a P deficiency (Petri *et al.*, 1988; Gunn & Ternouth 1994). The BUN confirmed this as the 6%PT had the lowest concentrations during the dry season ranging from 3.2mmol/l to 3.4mmol/l. The RST recorded higher BUN of 4.2mmol/l during the dry seasons, which indicated that protein supplementation would probably not have increased production (Byers & Moxon, 1980), although this could not be confirmed due to no treatment being included with adequate protein and no phosphorus.

The use of the production lick (used during the dry and spring season for the PDT) and the finisher lick (used during the dry and spring season for the FST) would be feasible strategies if they were used as short term strategies (3 to 6 months) to improve cattle performance. This would be feasible if the 24 to 28month old slaughter cattle had reached their marketing weights and additional fat cover was needed to optimise the fat grading. The use of these licks in the cow herd to improve their energy status would improve their fertility, weaning and liveability parameters as found by Groenewald (1986). The growing out of stud animals, under these conditions, would also require production or finisher type licks to maximise the expression of their genetic potential. Under these specific management conditions, the economics of supplementation change and the increased returns would be expected to offset the additional supplementation costs.

These strategies (PDT & FST) have been shown to be wasteful of the minerals (P, Ca and salt) that were required to limit the *ad libitum* intake of these supplements. To further improve the economics of these higher return farming enterprises (eg. finishing of cattle before slaughter, breeding herd nutrition and stud farming) on extensively managed free-range pastures additional management efforts could further save costs. Reducing the energy burden of foraging seemed to be the largest strain on available energy in the cattle of this trial. The estimated ME requirements, illustrated from Figure 97 to Figure 101, in which the energy requirements of stall-fed cattle and foraging cattle just maintaining body weight was illustrated. If the cattle were constrained to a feedlot or veldlot, a saving of around 20MJ/day of energy could be assumed that would add around 0.5kg/day growth rates due to the saving of the 40-65% additional energy requirement for foraging. By using improved pastures (eg. eradicate invader bush, fertilizer application on natural veld, irrigation or reduced stocking densities for the recovery of palatable grass species) the energy burden on the cattle would be reduced. By having these improved range areas close to the central farming infrastructure it would be feasible to rather daily feed cattle 20-40% of their total intake (which should be around 0.5% to 1% of LW) in concentrated energy and protein containing feeds, without the inclusion of intake limiters that were consumed excessively in this trial. By reducing the quantity of forage required, due to substitution of energy rich raw materials in the diet, there would be a further saving in the energy requirement of foraging for a smaller quantity of veld. The improved forage resources could thus be utilised by more animals at a time or extend the period over which a certain group of animals could utilise the range. This becomes especially important if below normal rainfall was received during drought periods when forage resources needed to be stretched for longer periods until destocking could take place.

CHAPTER 11 CRITICAL EVALUATION

Research with ruminants under commercial extensive production systems are difficult to undertake due to large tracks of land being required, high financial outlays, obtaining committed financiers and researchers for long term studies, availability of committed staff to run research on these farms and the availability of suitable facilities on such farms. Few published research works are available to reference which do fulfil these criteria. An unexpected limitation that was initially encountered was obtaining copies of the scattered dissertations and thesis's by Southern African researchers, which were mostly reported in Afrikaans. The research of Van Schalkwyk (1978) and Groenewald (1986) were good examples of research works that would be well worth translating into English and made available electronically to ensure much wider referencing by regional and international researchers.

Determining grass dry matter yields in each camp, during each collection period or more specifically during each season, should have been a parameter for inclusion as a potential nutritional status indicator during this trial. Stocking rate and rainfall were important factors affecting grass dry matter availability (Kruger, 1998). During the spring season, with the first rains resulting in early plant growth, it was observed that the OF extrusa samples collected contained high nutrient levels. The high diet quality did not seem to match sufficient quantities of the veld being available to cattle as indicated by only slightly improved cattle liveweight changes during spring. Towards the end of the experimental period, during the 2005 dry season, there were higher stocking densities recorded than at the onset of the trial (Table 16; Chapter 3.1.5). The availability of less grass dry matter in camps for selection would probably have had a more pronounced depressing effect on animal performance during this period. The increased estimated energy requirement above maintenance for foraging, of 40% during the 2004 dry season and the higher estimate for 65% during the 2005dry season, was alluded to in Chapter 6.8.

Daily dry matter intake was one the most important variables determining animal performance (Romney & Gill, 2000), although there was no way to obtain a direct intake measurement of a grazing animal (Burns & Sollenberger, 2002). Van Schalkwyk (1978) published data on seasonal intake determinations made by chromic oxide marker method, in physiologically similar cattle in the direct vicinity, which allowed for reasonable estimates of daily dry matter intake to be made during the evaluation of the current trial. The dry matter intake determinations by external marker method during this trial would have greatly improved the accuracy of feed intake estimations. Comparing the estimated intakes between a primary phosphorus deficiency (RST), secondary CP deficiency (6%PT), progressively negative associative effects caused by the PDT and FST and the potentially optimal intake levels in the MTT would have elucidated how these licks influenced voluntary feed intake. Comparing the daily dry matter intake estimates during this trial, derived from an external marker method, would have also improved the understanding of the influence of the changing veld dry matter availability levels during the trial. Variable dry matter intakes over all treatments would probably have been observed in the early part of the trial at lower stocking rates (2004 dry season), spring season with early plant growth, optimal animal performance during the wet season and subsequent lower animal performance during the 2005 dry season with the highest stocking densities 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. Great effort went into developing intake prediction equations in Chapter 2.3.6 to be able to directly use forage quality parameter results obtained from OF extrusa samples in this trial. By making use of intake estimations determined by Equation 4, developed by NRC (2000) from data generated by Mathison *et al*. (1986), new equations were derived from data generated by Van Schalkwyk (1978) in Namibia. Using the CP and ADF concentrations in the extrusa collected in OF, in the newly derived Equation 6 (wet season) and Equation 7 (dry season), would have allowed for daily dry matter intake estimates specific for this trial. These equations were subsequently not used to estimate daily dry matter intake in the current trial due to extrusa samples not being freeze-dried and the potential formation of artefact lignin influencing the ADF results obtained. Data comparisons, of rainfall and CP from extrusa collected by OF, in the current trial with the data generated by Van Schalkwyk (1978) in Chapter 6.1 were eventually used for the seasonal estimation of total daily dry matter intake in this trial. P concentrations, determined in OF extrusa samples, would probably have resulted in elevated levels of P being analysed due to salivary contamination (Little, 1975; Pinchak *et al.*, 1990). The potentially elevated P concentrations in the veld obtained from samples collected by OF in this trial was nevertheless still the most important analysis pointing towards a P deficiency in the diet of the cattle in this trial.

The results of this study gave a good indication of the impact of strategic nutrient supplementation on growing beef cattle on the sandy soils in lower than average rainfall years in Namibia. Future research would have to be undertaken in different geographic areas of Namibia with different rainfall and geological classifications. Future research should focus on the collection of extrusa samples from OF cattle together with rainfall, soil analysis and dry matter yields to establish baseline nutritional data for various cattle production areas in Namibia. The current trial seemed to indicate that growing cattle had the ability to consume strategic nutrient supplements at variable intake rates to maximise energy retention, from their selected diet of veld and licks, during the different seasons of the year. The evaluation of *ad libitum* monthly lick intake data on the most important strategic nutrient supplementation treatments (6%PT and MTT) across different areas of Namibia over different years and the subsequent calculations of nutrient intake per kg LW would be able to generate valuable data on the requirements of growing cattle in Namibia. The research would give insight into the nutritional baseline of growing cattle from the quality and quantity of veld available in different geographical areas, cattle breeds, veld management practices, rainfall events experienced in the cattle farming areas of Namibia. This would allow large quantities of data to be collected with the help of the network of existing well-organised and skilled farmers groupings across Namibia.

The five treatment groups consisted of 22 mixed breed steers and heifers and only the 21day period average lick intake per average weight of the cattle in the group could be determined. The data thus generated from the *ad libitum* lick intakes across the different seasons and different strategic nutrient supplementation treatments could not be statistically analysed. Titanium dioxide could be used in future research as an indigestible marker for large scale supplementation studies in commercial production situations to estimate supplement intake (Kincheloe, 2004). Titanium dioxide could legally be added to feeds at 1% as a colour additive (Titgemeyer *et al.*, 2001) and a rapid method for accurate analysis (Myers *et al.*, 2004) was available.

The statistical analysis of the liveweight changes over each collection period, running over different seasons of the grow-out of the weaner cattle on an extensively managed commercial farm, together with the statistical analysis of the marketing results on the nutrient supplementation treatments were strong anchoring points to this research project. The veld quality, nutrient intake and nutritional status indicators reported on the trial were all used to elucidate the animal performances obtained. The economic evaluation of any nutrient supplementation treatment is critical to increase the profitability of the Namibian cattle farmer through local value addition of their product. The relevance of scientific research must be measured against the potential increase in the value to the industry it was related to. Many research results statistically proven to potentially improve animal performance, from laboratory run trials or in stall-fed ruminants, have in practice been observed to have limited practical or economic relevance to extensive farming operations. NRC (2000) advised that caution had be used when using urea in low protein high forage diets and that the use of NPN was more appropriate in high-grain diets because of the rapid rumen degradation of starch. DelCurto *et al.* (2000) concluded that in general, natural protein seemed to be the most beneficial supplement for high-fibre, low quality roughages in ruminant diets and that NPN did not seem to be as beneficial as natural protein supplementation. Klevesahl *et al.* (2003) found that offering a supplement that was a combination of supplemental RDP and starch did not improve total digestible OM intake compared to only offering supplemental RDP alone. Bareki (2010) and Van der Merwe (2010) found that natural protein raw materials could be 100% substituted by NPN in high-molasses supplements with cattle on low quality grass pastures. Future research in the value addition of weaners would have to focus on nutrient supplements of natural rumen degradable protein raw materials of low cost seed oilcakes (sunflower, cotton and canola), with graded levels from 0% to 100% being replaced by non-protein nitrogen sources. This would have to be done with low non-structural carbohydrate sources (wheat bran, soybean hulls, citrus pulp or brewers grains as described by Kunkle *et al.*, 2000) compared to high-molasses based supplements. These combinations would have to be tested while a primary P deficiency had to be negated by a fixed concentration of P and salt being included in the licks or feeds to be tested. Making available to cattle these supplements through *ad libitum* presentation of these licks during the spring and dry season together with their statistically analysed animal performances in relation to economic evaluations under extensive cattle farming conditions would further promote value-addition of the weaner sector in Namibia.

The use of a P supplement throughout the year seemed to be a minimum biological and financial necessity for the value addition of weaners in the Namibian cattle industry. If significant strides were to be made in the local value addition of cattle in the communal farming areas, which consisted of the majority of land surface covering potentially P deficient soils located north and south of the veterinary cordon fence, the nutrient P would have to receive serious attention from policy makers in Namibia. Options that would be available to policymakers to enhance the industry would have to be evaluated. Making available financial assistance to farmers for year round use of phosphorus concentrated nutrient supplements (containing a minimum of 6% P with trace minerals) would assist in weaner value addition. Limited subsidies on imported P concentrated raw materials (containing a minimum 18% P) for local value addition by feed manufacturers would directly support the beef industry. Policy support for companies involved in the development of the industries in the mining and the subsequent value addition of the offshore Namibian marine sediment phosphate reserves would support both the cattle and cropping industries in Southern Africa.

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CHAPTER 13 PHOTO APPENDIX

Figure 128 A tame oesophageally fistulated Brahman steer with copper nose ring after a routine cleaning session shows minimal discomfort to the animal

Figure 129 Neckloop replaces girth straps as recommended by Kartchner & Adams (1983) during a foraging episode. The collection bag collapsed at the top without structural support sown in

Figure 130 Aluminium reinforcement strip stitched into the top of the collection bag so that the bag did not collapse. Three straps around the neck due to the fistula being established very low in the neck

Figure 131 Animals freely foraging during a collection episode in a 210 ha camp (Camp 4) without girth straps

Figure 132 Two horses where used to guide the six OF animals back to the pen to remove the collection bags

Figure 133 Spatula made from PVC pipe with steel wire keeping the steel rod in place. The wire loosened due to strain from tightening. The spatula was ready to be cleaned and again bonded with Q-Bond™ to the PVC pipe for further use

Figure 134 A green coloured extrusa sample collected by OF in the screen bottomed canvas bag during the wet season (26 Jan '05)

Figure 135 A brown coloured extrusa sample collected by OF during the dry season (4 Aug '04) on the thin cotton cloth used to express saliva by hand

Figure 136 Collection of ruminal liquor from the rumen of a cannulated animal after a three week period on a nutrient supplementation treatment

Figure 137 Rumen distension due to low digestibility of forage consumed by a ruminally cannulated animal on rock salt during the late dry season (17 Nov '04)

Figure 138 The lack of rumen distension due to high digestibility of forage consumed by a ruminally cannulated animal during the wet season (10 Mar '05)

Figure 139 The remaining fine forage particles from the rumen on a fine cotton cloth after the sample taken from the rumen was filtered through it (2 Jun '05)

Figure 140 Two sub samples of the filtered rumen fluid were preserved in sample bottles before being frozen for later analysis of ammonia and VFA

Figure 141 Blood samples were taken by venapuncture into Vacutainers™ supplied by Pathcare

Figure 142 A steer from the MTT at the start of the dry season (13 May '05) busy foraging and browsing

Figure 143 Selectively browsing animal from FST at the start of spring (18 Nov 2004)

Figure 144 The free-ranging group of cattle on the 6%PT during the dry season 2004

Figure 145 The FST at the automatically closing nutrient supplementation bins at the watering point

Figure 146 All animals on the nutrient supplementation treatments were weighed between camp rotations every 3 weeks

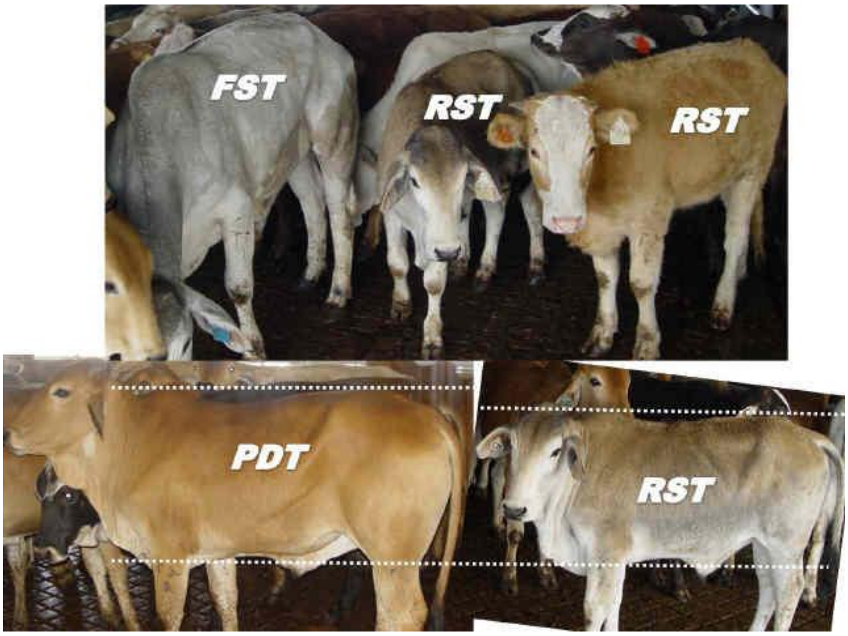

Figure 147 Size comparisons between some individuals in the different treatments at slaughter. Note the rough hair coat of RST animals

Figure 148 Practical demonstration of rumen distension during a farmer day with preliminary data being presented on the project

Figure 149 Farmers receive explanations on the principals involved in setting up the experimental procedures