

**FEEDLOT PERFORMANCE OF DORPER LAMBS ON
OPUNTIA-BASED DIETS WITH DIFFERENT NITROGEN
SOURCES**

by

Katrina Lugambo Shiningavamwe

Dissertation submitted in accordance with the requirements for the degree

Magister Scientiae Agriculturae

to the

Department of Animal, Wildlife and Grassland Sciences

Faculty of Natural and Agricultural Sciences

University of the Free State, Bloemfontein

Supervisor: Prof. H.O. de Waal (University of the Free State)

Co-supervisor: Dr. L.M.J. Schwalbach (University of the Free State)

Co-supervisor: Mr. J. Els (Ministry of Agriculture, Water & Forestry, Namibia)

November 2009

Table of Contents

	Page
Abstract	i
Declaration	iv
Dedication	v
Acknowledgements	vi
List of Figures	viii
List of Tables	ix
1. Introduction	1
2. Materials and Methods	7
2.1 Study area	7
2.2 Experimental feeds	7
2.3 Experimental animals	8
2.4 Experimental design and treatment diets	9
2.5 Trials	11
2.5.1 Adaptation period	11
2.5.2 Growth trials	11
2.5.2.1 Trial period	11
2.5.2.2 Feed intake	12
2.5.2.3 Water intake	12
2.5.3 Digestibility trials	12
2.5.3.1 Trial period	12
2.5.3.2 Feed intake	13
2.5.3.3 Water intake	13
2.5.3.4 Feeds and refusals	14
2.5.3.5 Faeces	14
2.5.3.6 Urine collection	14
2.6 Chemical analysis of feeds, refusals and faeces	15
2.6.1 Sample preparations	15
2.6.2 Dry matter (DM)	15
2.6.3 Ash or inorganic matter	15
2.6.4 Organic matter (OM)	16
2.6.5 Crude protein (CP)	16
2.6.6 Lipids (Ether extract, EE)	16
2.6.7 Neutral-detergent fibre (NDF)	17
2.6.8 Acid-detergent fibre (ADF)	18
2.6.9 Gross energy (GE)	18
2.6.10 Apparent digestibility coefficients	19
2.7 Carcass evaluation	19
2.7.1 Slaughter technique	19
2.7.2 Carcass grading	20
2.7.3 Carcass weight	20
2.7.4 Carcass measurements	20
2.7.5 pH measurements	21
2.7.6 Carcass length	21
2.7.7 Shoulder and buttock circumferences	21

2.7.8	Fat thickness	22
2.7.9	<i>Musculus longissimus dorsi</i> depth and width	23
2.7.10	Estimation of carcass composition	23
2.8	Statistical analysis	24
3.	Feed intake by Dorper wether lambs in the feedlot and digestibility trials	25
3.1	Chemical composition of the three treatment diets	26
3.2	Feed and water intake of Dorper wether lambs in the feedlot	27
3.2.1	Feed intake of Dorper wether lambs in the feedlot	28
3.2.2	Water intake of Dorper wether lambs in the feedlot	28
3.3	Intake during the digestibility trials	29
3.3.1	Dry matter and nutrient intake and apparent digestibility of treatment diets	29
3.3.1.1	Cage Period 1	30
3.3.1.2	Cage Period 2	31
3.3.1.3	Cage Period 3	32
3.4	Water intake and urine excretion	35
3.5	Faecal excretion	36
3.6	Conclusions	37
4.	Growth performance and carcass characterisation	38
4.1	Growth performance of Dorper wether lambs	39
4.2	Carcass evaluation	42
4.2.1	Carcass weight and dressing percentage	42
4.2.2	Carcass value characteristics (grading)	43
4.2.3	Carcass measurements	45
4.2.4	Fat thickness	46
4.2.5	Carcass composition	46
4.3	Conclusions	47
5.	Conclusions and recommendations	48
6.	References	51

Abstract

Feedlot performance of Dorper lambs on *Opuntia*-based diets with different nitrogen sources

by

Katrina Lugambo Shiningavamwe

Supervisor: Prof. H.O. De Waal

Co-supervisor: Dr. L.M.J. Schwalbach

**Department of Animal, Wildlife and Grassland Sciences
University of the Free State, Bloemfontein, South Africa**

Co-supervisor: Mr. J. Els

Ministry of Agriculture, Water & Forestry, Namibia

Degree: Magister Scientiae Agriculturae

Three feedlot diets were evaluated with Dorper wether lambs at Bergvlug Experimental Farm, Khomas Region, Namibia. Bergvlug is located about 35 km east of Windhoek. The three treatment diets consisted of a conventional feedlot diet (treatment diet T0) and two *Opuntia*-based treatment diets (T1 and T2) containing different additional nitrogen sources, namely a non-protein nitrogen (NPN; feed grade urea) or natural protein (sunflower oilcake meal). Treatment diet T0 was based on coarsely ground lucerne hay, yellow maize meal, feed grade urea and molasses meal. The *Opuntia*-based treatment diets (T1 and T2) were reformulated and part of the lucerne was replaced by sun-dried and coarsely ground *Opuntia* cladodes at levels of 330 or 300 g/kg. In treatment diet T1 additional nitrogen was included as feed grade urea (non-protein nitrogen; NPN) and for treatment diet T2 the additional nitrogen was included as sunflower oilcake meal (a natural protein).

The feed intake and water intake, the growth performance and carcass characteristics of the Dorper wether lambs were evaluated in the feedlot. Forty-five newly weaned Dorper wether

lambs, weighing on average about 22 kg, were randomly allocated to the three treatment diets. The 15 Dorper wether lambs per treatment diet were further subdivided into three subgroups or replicates of five lambs each. For the duration of the trial the lambs were kept in small pens in a shaded area (open-sided roofed shed). The Dorper wether lambs were fed the treatment diets until a target average slaughter weight of 35 kg per treatment diet was reached.

During the feeding period in the feedlot, one replicate of five Dorper wether lambs per treatment diet was moved from the feedlot pens to metabolism cages for a week every third week to determine their individual daily feed and water intake and apparent digestibility of the three treatment diets. The daily urine and faecal excretions were also monitored.

Chemical analysis of the three treatment diets used in this study showed that acid-detergent fibre (ADF), neutral-detergent fibre (NDF), organic matter (OM) and gross energy (GE) have decreased with inclusion of sun-dried and coarsely ground *Opuntia* cladodes, which is ascribed to the lower ADF, NDF, OM and GE content of the *Opuntia* cladodes. On the other hand, the ash and lipids increased with inclusion of sun-dried and coarsely ground *Opuntia* cladodes in the treatment diets.

The inclusion of sun-dried and coarsely ground *Opuntia* cladodes at 330 or 300 g/kg in the treatment diets in general had little or no effect on the feed intake and digestibility of the treatment diets by Dorper wether lambs. Exceptions were observed for the intake and apparent digestibility of ADF and NDF as a result of the difference in fibre content of the treatment diets. Similar water intake and urine excretion were observed for Dorper wether lambs fed any one of the treatment diets during the three cage feeding periods.

The results of the study confirmed that the feed intake and apparent digestibility of the treatment diets for Dorper wether lambs were not affected by: (1) the inclusion of sun-dried and coarsely ground *Opuntia* cladodes at 330 and 300 g/kg; or (2) two nitrogen sources used (NPN or natural protein) in the *Opuntia*-based diets.

Considering the results of the Cage Periods 1 to 3, it can be summarised that the daily intake and apparent digestibility of DM and other chemical constituents of the Dorper wether lambs increased as the trial progressed, regardless of the treatment diets. It suggests that the

reticulo-rumen of Dorper wether lambs were getting better adapted over time to the diets and consequently digestibility improved.

The average daily gain and feed conversion efficiency of Dorper wether lambs fed the *Opuntia*-based diet supplemented with natural protein were comparable to those fed the conventional feedlot diet. The Dorper wether lambs fed the *Opuntia*-based diet supplemented with NPN had a lower growth rate than those fed the conventional feedlot diet and the *Opuntia*-based diet supplemented with natural protein. Thus, although feed conversion efficiency was not significantly ($P>0.05$) different among treatment diets, Dorper wether lambs fed the conventional diet and the *Opuntia*-based diet supplemented with natural protein required less feed to gain weight than those fed the *Opuntia*-based diet supplemented with NPN. This suggests that supplementing an *Opuntia*-based feedlot diet with a natural protein source will markedly improve feed efficiency and average daily gain of lambs. This may reduce the feeding period required to reach the target slaughter weight and increase the economic benefit associated with the use of sun-dried and coarsely ground *Opuntia* cladodes in feedlot diets.

Most of the carcass characteristics considered were not significantly different ($P>0.05$) among treatments. It suggests that carcass quality or grading is not markedly affected by inclusion of sun-dried and coarsely ground *Opuntia* cladodes in feedlot diets (up to 330 or 300 g/kg) for Dorper wether lambs or by the nitrogen source used to balance the diets. The carcasses of the Dorper wether lambs fed the three different treatment diets fetched very similar prices per kg. However, the Dorper wether lambs fed treatment diet T1, the *Opuntia*-based diet with the inclusion of feed grade urea (an NPN source), did not reach the average target slaughter weight of 35 kg, even after 91 days in the feedlot. Therefore, their lighter carcasses and poorer carcass grading at slaughter fetched a lower total price per carcass.

The results of this study, the fourth study under the auspices of the UFS, opened the prospect of formulating affordable *Opuntia*-based diets for specific application to ruminant species of different ages and production classes. However, more research is needed to evaluate the growth performance, carcass characteristics and profitability of other small stock breeds and ruminant species fed sun-dried and coarsely ground *Opuntia* cladodes in feedlot diets, balanced with different nitrogen sources.

DECLARATION

I hereby declare that this dissertation submitted by me for the degree of Magister Scientiae Agriculturae (M.Sc. Agric.) at the University of the Free State is my own independent work and has not previously been submitted by me to another University/Faculty. I furthermore cede copyright of the thesis in favour of the University of the Free State.”

.....

Katrina Lugambo Shiningavamwe

Bloemfontein

November 2009

.....

Date

DEDICATION

In memory of my Mother, **Tuuliki Martin**, 1938-2003, who was my hero, a woman of faith and who was always proud of me.

This work is also dedicated to my father, **Kleopas Negongo**, who by the grace of God is my remaining source of strength. The two of you have taught me the gift of love and joy.

Furthermore, this thesis is dedicated to my mother-in-law, **Luise Nambala** with her in my life I still feel I have a mother around me. She has installed many values in my life since I met her that I still live up to in my daily life.

Finally, to the most precious gift of the Almighty, my children, **Ndahekeleka Katrina** and **Tangi Kiandre**. Whatever challenges I went through during my studies, your smiles kept me going. You are my inspiration. This is for you with all my love.

ACKNOWLEDGEMENTS

For the successful completion of this study, there are many people to thank for their contribution and for making this project possible:

I would like to acknowledge and thank my supervisor **Prof. H.O. de Waal** and co-supervisors **Dr. Luis Schwalbach** and **Mr. Jaque Els** for their continuous guidance and assistance on the design of the project and support to see this project through to completion.

SADC-ICART without their financial support, this dream was never going to be a reality.

The farmer who supplied the *Opuntia cladodes*, **Mr. James Bassingthwaighte** for ensuring the continuous and timely supply of the *Opuntia cladodes*.

Neudamm Experimental Farm, Namibia for kindly granting me the permission to use their milling machine.

The Manager of Bergvlug Veterinary Experimental Farm for making it possible to set up my trials on their farm and availing the farmhands (**Joseph, Thomas, Lamba & Cornelius**) who generously assisted me with my daily activities on the farm. You all made my time while working at Bergvlug an incredible and unforgettable experience.

The Head of the Nutrition Laboratory for granting me permission to use the lab facilities during the chemical analysis. To the Nutrition Laboratory technicians (**Werner, Peter and Jeffrey**) for tirelessly assisting and guiding me during the analysis. I appreciated getting to work with you; thanks for generously sharing your experience with me.

My thanks go to my colleagues at work who took time to help me during the feeding trials of this project.

Mr. Jaque Els, Ministry of Agriculture Water and Forestry, Namibia is thanked for the construction of the metabolism cages for sheep used in this study at Bergvlug Experimental Farm.

Ministry of Agriculture Water and Forestry, Namibia for assisting me with transport during the feeding trials of this project, availing funds for the construction of metabolic cages and purchasing of feed. In addition I would also like to thank the Ministry for providing the animals for my project.

Prof. Arno Hugo, Department of Microbial, Biochemical and Food Biotechnology at the UFS, for guidance and mentoring on the carcass dissection and carcass evaluation.

Mr. Mike Fair, Department of Animal, Wildlife and Grassland Sciences at the UFS, for the statistical analysis of the data.

Mrs. Hester Linde, Department of Animal, Wildlife and Grassland Sciences at the UFS, for preparing and printing the final copies of the dissertation.

My sincere thanks to my sisters, nieces, nephew, cousins, in-laws and friends for their love, support and for their unwavering faith when I needed it most.

Most importantly, I am especially grateful to my husband **Andreas Ndafudifwa Shiningavamwe**, who has been there for our children during my studies. You have been my source of constant encouragement, your patience and understanding gave me strength to accomplish the success I have achieved.

I wish you happiness and I wish you peace and may God Bless you all.

List of Figures

	Page
Figure 2.1 <i>Opuntia</i> cladode strips drying in the sun on corrugated zinc iron sheets.	8
Figure 2.2 Mixing of treatment diets using spades.	10
Figure 2.3 Some of the Dorper wether lambs housed individually in metabolism cages.	13
Figure 2.4 pH of the carcass measured in the <i>musculus longissimus dorsi</i> .	21
Figure 2.5 Three-ribs sample cut removed from the left side of a carcass.	22
Figure 2.6 Marked positions on the cut where the fat thickness was measured.	23
Figure 2.7 The width and depth of the <i>musculus longissimus dorsi</i> measured with a calliper.	23
Figure 2.8 Muscle, fat and bone tissues dissected from the 3-rib cut.	24
Figure 3.1 Average daily water intake (ml/lamb) of Dorper wether lambs in the feedlot during the study period.	29
Figure 4.1 Average live body weight of Dorper wether lambs during the feeding period in the feedlot.	39

List of Tables

		Page
Table 2.1	Composition of the three treatment diets (T0, T1 and T2) fed to Dorper wether lambs	10
Table 3.1	Chemical composition of the three treatment diets (T0, T1 and T2)	26
Table 3.2	The average (mean±s.e.) daily feed intake by Dorper wether lambs in the feedlot during the study period	28
Table 3.3	The daily intake (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 1	30
Table 3.4	Apparent digestibility coefficients (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 1	31
Table 3.5	The daily intake (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 2	32
Table 3.6	Apparent digestibility coefficients (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 2	33
Table 3.7	The daily intake (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 3	33
Table 3.8	Apparent digestibility coefficients (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 3	34
Table 3.9	The average (mean±s.e.) daily water intake during the three cage periods by Dorper wether lambs	35
Table 3.10	The average (mean±s.e.) daily urine excreted during the three cage periods by Dorper wether lambs	36
Table 3.11	The average (mean±s.e.) faecal DM excreted during the three cage periods by Dorper wether lambs	36
Table 4.1	Performance of the Dorper wether lambs during the feeding period in the feedlot and the cost of diets	40
Table 4.2	Slaughter weight and carcass characteristics of the Dorper wether lambs fed three treatment diets in a feedlot	44
Table 4.3	Carcass grades and prices per kg obtained by the Dorper wether lambs fed the three treatment diets	45
Table 4.4	Proportion of the muscle, bone and fat of the 3-rib cut from carcasses of the Dorper wether lambs	47

1. Introduction

In most tropical livestock production systems, sheep are raised under range conditions, predominantly without any feed supplement. During the dry season, grazing material becomes scarce and pastures are deficient in protein and minerals. In addition, the natural rangeland or veld, which is the basic diet for sheep, is often overgrazed. According to Ben Salem *et al.* (2002), rapid increases in flock size associated with a lack of an appropriate management strategy (stocking rate, grazing period and duration, rangeland management), are the major causes of continuous degradation of rangelands. Under such unfavourable conditions, animals have low productivity due to low feed availability and quality. Coupled to that, it takes longer for animals to reach slaughter weight and often produce carcasses of a lower quality.

Mutton and lamb producers especially in Namibia and South Africa use diets mostly containing lucerne and maize to fatten animals in feedlots. However, high prices of lucerne available on the market often limit its use as good quality roughage in feedlot diets. Most importantly, the aim of feedlot enterprises should be to produce animals of a particular weight and carcass quality or grade over a relatively short period.

There is a need to investigate alternative feed sources for livestock to augment limited or scarce feed sources, thus enabling livestock to survive critical periods of feed shortages and still be able to produce good quality meat. These alternative feeds must be affordable but they must also be adapted to drought and harsh conditions in the tropical and subtropical areas (Nefzaoui & Ben Salem, 2001).

In recent years, there has been an increasing interest in cactus pear (*Opuntia*) as an alternative feed for livestock in the tropical and subtropical regions of the world. According to Santos *et al.* (2003) and Khalafalla *et al.* (2007), the increased importance of cactus pear in these regions is mainly due to their drought resistance, high biomass yield, palatability, salinity tolerance and soil adaptability. These factors make *Opuntia* species an important feed source for livestock, particularly during periods of drought and seasons of low feed availability. Furthermore, *Opuntia* converts water to dry matter or digestible energy far more efficiently than grasses and legumes (De Kock, 1980; 2001; Azocar, 2001) and can be fed to livestock as

fresh forage or stored as silage. These good characteristics of *Opuntia* species are of particular interest to animal scientists and livestock producers amidst the climatic changes predicted for coming decades.

Opuntia cladodes are now widely used as animal feed (fodder and forage) in Mexico (Russel & Felker, 1987; Misra *et al.*, 2006), Ethiopia (Tegegne, 2001; 2002) and South Africa (Zeeman, 2005; Einkamerer, 2008; Menezes, 2008).

Opuntia cladodes are highly digestible by sheep (Felker, 1995; Nefzaoui & Ben Salem, 1996; 2001; De Waal *et al.*, 2006; Zeeman, 2005; Einkamerer, 2008; Menezes, 2008) and can be used as part of a complete diet (Firew, 2001; De Waal *et al.*, 2006) or as a supplement to improve the feeding value of low quality roughage, such as cereal straw (Ben Salem *et al.*, 1996; 2004; Tegegne *et al.*, 2005). However, digestibility depends on the age of the cladodes and decreases in older plant material (Nefzaoui, 1995).

The nutritional value of *Opuntia* as livestock feed has been examined by several workers (De Kock, 1980; Retamal *et al.*, 1987; Sirohi *et al.*, 1997; Fuentes-Rodriguez, 1997; Tegegne, 2001; Tegegne *et al.*, 2002; 2005; Gebremariam *et al.*, 2006; Misra *et al.*, 2006; Vieira *et al.*, 2007; Felker *et al.*, 2006; De Waal *et al.*, 2006; Tien & Beynen, 2005; Zeeman, 2005; Tegegne *et al.*, 2007; Einkamerer, 2008; Menezes, 2008). Moreover, the nutritive quality of *Opuntia* is highly variable depending on plant type (species and variety), cladode age, sampling season, part of the plant and agronomic conditions (soil type, climate, growing conditions) (Sirohi *et al.*, 1997; Misra *et al.*, 2006). In addition, the nutritive value of a feed also depends on its chemical composition, the intake by animals and its digestibility (De Waal *et al.*, 2006).

Generally, *Opuntia* has a high moisture content of 70-93% (Lopez-Garcia *et al.*, 2001; Tegegne, 2001) and apparent digestibility of about 75% (Einkamerer, 2008). In addition, analysis of chemical composition shows that *Opuntia* cladodes (on dry matter basis) are rich in vitamin A, ash, calcium (Ca) (Tegegne *et al.*, 2002), and readily available carbohydrates and it may serve as a good source of fermentable metabolizable energy (ME) (Tegegne *et al.*, 2005).

Several workers (De Kock, 1980; Tegegne *et al.*, 2002; Ben Salem *et al.*, 2002) have concluded that *Opuntia* cladodes are low in crude protein (CP), fibre, sodium (Na), and phosphorus (P). Therefore, in order to meet both maintenance and production requirements of animals, it is recommended that the diet is balanced with supplementary protein, e.g. oilseed cakes or non-protein nitrogen (NPN) such as urea (Nefzaoui & Ben Salem, 1996; Nefzaoui *et al.*, 1995; Ben Salem *et al.*, 2002; Misra *et al.*, 2006), and fibre (straws or hay) (Nefzaoui *et al.*, 1993). Failure to use a nitrogen supplement in *Opuntia*-based diets consumed by ruminants, may limit the ingestion of a diet and its efficient utilization, resulting in a low intake of energy (Steenkamp & Hayward, 1981). Ben Salem *et al.* (2002) concluded that protein supply improved the nutritive value of *Opuntia*-based diets fed to lambs and increased daily body weight gain. There was a further improvement when the level of bypass protein in the diet was increased.

Opuntia has recently been receiving attention from scientists and growers alike in South Africa (Brutsch & Zimmerman, 1993; 1995). Studies in a research programme based at the University of the Free State, (Zeeman, 2005; De Waal *et al.*, 2006; Einkamerer, 2008; Menezes, 2008) have extensively investigated increased inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes up to 360 g/kg in diets for Dorper wether lambs on feed and water intake, apparent digestibility, and growth performance. These studies showed that sun-dried and coarsely ground *Opuntia* cladodes have a great potential as animal feed with no apparent detrimental effects on Dorper wether lambs.

The performance and carcass characteristics of Dorpers and that of their crosses have been studied and reported by a number of authors (Milne, 2000; Cloete *et al.*, 2000; Staab *et al.*, 1999; Notter *et al.*, 2004; Snowden & Duckett, 2003; Daniel & Held, 2005) under feedlot conditions. However, none of these studies have used *Opuntia*-based diets.

The method and system of carcass grading practiced in different countries varies depending on the objectives of the system and on the degree of uniformity that exists among types and species of animals (Jeremiah, 1998). For example, in South Africa and Namibia, the grading system is based on external fat covering and age of the animal (South African meat classification system for beef, lamb, mutton and goat meat; Government notice no. R.863, 1 September 2006). Countries have established the system that best allows consistency of product for their consumers. Based upon the findings

obtained by Jeremiah (1998) on development of a quality classification system for lamb carcasses, only carcasses from lambs weighing 32 kg live or more and with no more than two permanent incisors can be classified as lambs.

As mentioned previously, there is a need to help lamb producers to provide optimum nutrition for marketable animals to improve live weight and carcass grade at slaughter and thus the total edible meat produced. The production of quality lean meat involves many aspects of animal production especially nutrition (Sebsibe, 2009). The effect of nutrition on carcass composition is complicated as it involves the interactions between level of intake, the composition of the feed, and nutrient requirements of the animal (Momani Shaker *et al.*, 2003).

Changing market demands for leaner meat is an increasing challenge because consumers regard fat as unhealthy and associate it with high cholesterol levels and a higher risk for heart disease. The ideal carcass can be described as one that has a minimum amount of bone, a maximum amount of muscle and an optimum amount of fat (Schilling, 2005). A certain proportion of fat is desirable to reduce drying out of the carcass (Sebsibe, 2009). On the other hand, too much fat is undesirable.

Carcasses of animals are classified after slaughter for a number of characteristics. Carcass evaluation should be able to provide as much information as possible about the quality of the carcass as well as to identify characteristics that assist in placing monetary value on a carcass. Important factors or measurements used singly or in combination to assess the carcass value are: carcass weight, *musculus longissimus dorsi* area and fat thickness (Einkamerer, 2008).

General information on the effect of nutritional level on fattening performance and carcass quality of lambs has been published and confirmed by several authors (Schoeman, 2000; Momani Shaker *et al.*, 2003; Gruber *et al.*, 2007; Snowden & Duckett, 2003). It was stated by Mareko *et al.* (2006) that the nature, yield and composition of a carcass at slaughter are affected by the production system under which the animal was reared. These authors described the intensive feeding system (fattening) with an *ad lib.* regime as the best method for lambs, specifically for meat production (Momani Shaker *et al.*, 2003; Gokdal *et al.*, 2004; Mareko *et al.*, 2006; Daskiran *et al.*, 2006; Louvandini *et al.*, 2006). In his study Horak

(1999, cited by Momani Shaker *et al.*, 2003) concluded that the high growth potential of lambs could not be achieved without concentrate feeds in the diet.

In South Africa, increasing numbers of lambs and sheep are being finished off in feedlots (Van der Westhuizen *et al.*, 2009). The question is then posed how these composite formulated diets change the proportion of the main body tissues?

Although the studies mentioned previously (Zeeman, 2005; Einkamerer, 2008; Menezes, 2008) have shown the high potential for the utilization of sun-dried and coarsely ground *Opuntia* cladodes as feed source, the performance of sheep on *Opuntia*-based diets under intensive feeding (feedlot) in terms of growth and carcass quality or grading need to be evaluated.

Generally, it can be concluded that *Opuntia* is a good, affordable feed source which may reduce the use of expensive feeds and therefore reduce the feeding costs and raise the level of sheep production in the arid and semi-arid zones. Such *Opuntia*-based diets requires a low input of cereal grains and forage crops and can thus be recommended to use during the feed shortages prevailing in the arid and semi-arid areas of Southern Africa (Nefzaoui & Ben Salem, 1996; Nefzaoui & Ben Salem, 1996; Ben Salem *et al.*, 2002; Misra *et al.*, 2006; De Waal *et al.*, 2006).

However, for the *Opuntia*-based diets to become a viable alternative feed source for the mutton and lamb production industry, it must be able to maintain the carcass value or quality.

This study is a therefore a follow up of other studies by Zeeman (2005), Einkamerer (2008) and Menezes (2008) which used different inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes substituting lucerne hay, but with the same nitrogen source (urea). Zeeman (2005) tested four different inclusion levels namely 0, 120, 240 and 360 g/kg of sun-dried and coarsely ground *Opuntia* cladodes. However, in the studies by Einkamerer (2008) and Menezes (2008), the treatment diet containing 120 g/kg *Opuntia* cladodes was omitted since the result of the preceding study by Zeeman (2005) showed that this diet, in comparison with zero *Opuntia* was too low an inclusion level. Moreover, this diet did not have a significant effect on feed and water intake, apparent digestibility and the live body weight of the Dorper wether lambs.

The inclusion levels of 300 to 330 g/kg *Opuntia* in this study was therefore based on the fact that previous studies have investigated the effect of incremental levels of sun-dried and coarsely ground *Opuntia* cladodes up to 360 g/kg in diets on intake, digestibility, and growth without causing any negative effect on the performance of Dorper wether lambs.

As mentioned previously, all three above mentioned studies (Zeeman, 2005; Einkamerer, 2008; Menezes, 2008) used the same nitrogen source, namely the NPN source feed grade urea. Therefore, in addition to the inclusion of sun-dried and coarsely ground *Opuntia* cladodes in feedlot diets, this study aimed also to look at the effect of different nitrogen sources in *Opuntia*-based diets on lambs. This information is important because no research has been carried out using *Opuntia*-based diets in high production systems for Dorper lambs. Furthermore, the Dorper wether lambs used in the present study were also younger and weighed less (± 22 kg) than in previous studies. This body weight of about 22 kg is usually recommended as an appropriate weaning entry weight for lambs in the feedlot.

This study was conducted with Dorper wether lambs of about 22 kg to evaluate:

- two *Opuntia*-based production diets containing levels of 300 to 330 g/kg compared to a conventional feedlot diet.
- the effects of a non-protein nitrogen (NPN) source (feed grade urea) compared to a natural protein source (sunflower oilcake meal) in the two *Opuntia*-based diets.

2. Materials and Methods

2.1 Study area

The study was conducted at Bergvlug Experimental Farm, Ministry of Agriculture, Water and Forestry, Directorate of Veterinary Services, Khomas Region, Namibia. Bergvlug is located about 35 km east of Windhoek. The field work lasted from February to June 2009 with the approval of the **Interfaculty Animal Ethics Committee** of the UFS (**Animal experiment nr. 02/09; dated 27 May 2009**).

2.2 Experimental feeds

The *Opuntia ficus-indica* var. Algerian cladodes used in this study were collected from a fruit producing *Opuntia* orchard, on the farm Graceland near Okahandja in the Otjozondjupa region of Namibia. Graceland is about 70 km north of Windhoek and about 100 km from Bergvlug. Based on the assumption that 300 to 330 g/kg of sun-dried and coarsely ground *Opuntia* cladodes would be incorporated in the two treatment diets, it was estimated that about 1 063 kg of sun-dried *Opuntia* cladodes would be required for a trial period of about 70 days. Therefore, about 11 000 kg fresh *Opuntia* cladodes were harvested, considering that the dry matter (DM) content is about 100 to 150 g/kg.

The fresh *Opuntia* cladodes were harvested from February to May 2009. About 1 000 kg fresh cladodes were transported every week. The harvesting period was extended because of the rainy season which prevailed especially during February and March. Longer periods (about 14 to 18 days) were thus needed to dry the cladodes because of more cloudy days and less sunshine. In accordance with the procedures described by Zeeman (2005), Einkamerer (2008) and Menezes (2008), fresh *Opuntia* cladodes were harvested, cut into strips of about 15 to 20 mm and dried in the sun. Cutting of fresh cladodes into strips was done on the farm Graceland using an electric cutter and packed in containers before being transported to Bergvlug to be dried in the sun.

Corrugated zinc iron sheets were laid flat on the ground to dry the cladode strips in the sun. This procedure instead of drying the cladode strips on a roof top enabled the speedy removal of the cladode strips when it started raining and returning them outdoors after the rain has

stopped. The cladode strips were spread by placing them in a single layer to allow space between strips and enhance air movement around them for faster drying (Figure 2.1).



Figure 2.1 *Opuntia* cladode strips drying in the sun on corrugated zinc iron sheets.

The sun-dried cladode strips were then ground in a hammer mill to pass through a 20 mm sieve. In agreement with Zeeman (2005), Einkamerer (2008) and Menezes (2008), experience showed that sun-dried *Opuntia* cladodes still tended to clog up the hammer mill during the grinding process and thus required the hammer mill to be opened and cleaned regularly.

Apart from the sun-dried *Opuntia* cladodes, lucerne hay was also ground in a hammer mill to pass through a 20 mm sieve in order to have homogeneous mixed diets. Other feed ingredients used in the diets were yellow maize meal, sunflower oilcake meal, molasses meal (Enermol), feed grade urea and feed lime. These feeds were included in the physical form as purchased.

2.3 Experimental animals

The Dorper wether lambs used in this study were the property of the Ministry of Agriculture, Water and Forestry, Directorate of Agricultural Research and Training, Namibia. Forty five (45) newly weaned Dorper wether lambs with an average live weight of 22 kg were transferred from the Hardap Research Station, near Mariental, to Bergvlug Experimental Farm where the trials were conducted. Upon arrival at Bergvlug, the Dorper wether lambs

were kept on the veld for one week before the commencement of the trial. This allowed them to acclimatise to the new environment and to recover from any weaning shock, because they were just weaned from their mothers on the day they were transferred to Bergvlug.

The Dorper wether lambs were vaccinated with Multivax P at the beginning of the trials to protect them against botulism, black quarter, pulpy kidney and clostridium. They were also treated against internal parasites.

The 45 Dorper wether lambs were stratified according to live weight into nine (9) groups of five (5) lambs, thus ensuring comparable mean initial weights for groups. Three (3) replicates or subgroups of five lambs were then randomly allocated to each of the three treatment diets. For the duration of the trial the Dorper wether lambs were kept in a shaded area (open-sided roofed shed) and received the different treatment diets.

2.4 Experimental design and treatment diets

The experiment lasted for 90 days and was conducted using a complete randomized design with fifteen (15) Dorper wether lambs per treatment, divided into three (3) replicates or subgroups with five lambs each. This provided the minimum, but yet sufficient, number of animals for an accurate analysis of data.

A conventional feedlot diet was used as the control diet (T0), consisting of coarsely ground lucerne hay, yellow maize meal, feed grade urea and molasses meal (Enermol). In the other two treatment diets (T1 and T2), the lucerne was replaced partly by sun-dried and coarsely ground *Opuntia* cladodes at levels of 300 to 330 g/kg (Table 2.1). Additional nitrogen was supplied in both treatment diets T0 and T1 in the form of non-protein nitrogen (NPN; feed grade urea) and in treatment diet T2 as a natural protein source (sunflower oilcake meal).

The composition of the three treatment diets is presented in Table 2.1.

Table 2.1 Composition of the three treatment diets (T0, T1 and T2) fed to Dorper wether lambs

Feed ingredient (kg air dry)	Treatment diets*		
	T0	T1	T2
Sun-dried and coarsely ground <i>Opuntia</i> cladodes	-	330	300
Coarsely ground lucerne hay	577	255	190
Yellow maize meal	358	340	275
Feed grade urea	10	20	-
Sunflower oilcake meal	-	-	180
Molasses meal (Enermol)	40	40	40
Feed lime	15	15	15

* T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

The treatment diets used in this study were mixed at the project site. The diets were mixed in batches every week, following the sun-drying and processing of *Opuntia* cladode strips. Mixing of diets was done on a plastic sheet using spades (Figure 2.2).



Figure 2.2 Mixing of treatment diets using spades.

This study is a follow up of previous studies by Zeeman (2005), Einkamerer (2008) and Menezes (2008) which used different inclusion levels of sun-dried and coarsely ground

Opuntia cladodes. Zeeman (2005) used four different inclusion levels namely 0, 120, 240 and 360 g/kg sun-dried and coarsely ground *Opuntia cladodes*. However, in studies by Einkamerer (2008) and Menezes (2008), the treatment diet T12 (containing 120 g/kg) was omitted because the result of the preceding study showed that this treatment diet did not result in any significant differences in terms of feed and water intake, and the apparent digestibility or live weight of the Dorper wether lambs when compared to control diets without *Opuntia*. The decision of a 300 to 330 g/kg inclusion level in the treatment diets of this study was, therefore, based on previous studies that have investigated the effect of incremental sun-dried and coarsely ground *Opuntia cladodes* in diets for Dorper wether lambs on intake, digestibility, and growth without finding any negative effect on their performance.

2.5 Trials

The study consisted of two facets, namely a growth trial in a feedlot and three digestibility trials of one week each in metabolism cages.

2.5.1 Adaptation period

The Dorper wether lambs were adapted separately in the three groups of 15 animals each in large open kraals to their respective treatment diets for two weeks. The regime for provision of water and feed for the remainder of the trial, as described in section 2.5.2.2 and 2.5.2.3, was implemented.

2.5.2 Growth trials

2.5.2.1 Trial period

All 45 Dorper wether lambs were used in the growth trial to evaluate their growth performance and the feed and water intake on the three treatment diets. After the adaptation period of fourteen (14) days (see 2.5.1), each of the nine subgroups (three replicates per treatment) were randomly allocated and confined to smaller pens (4 m x 3 m) with concrete floors in an open-sided roofed shed where they received water on an *ad libitum* basis and the treatment diets.

Initial body weight was obtained by weighing the Dorper wether lambs at the start of the adaptation period of the trial. Thereafter, the lambs were weighed every week on

Wednesdays at 10h00 during the trial until they reached an average target weight for slaughtering of 35 kg live body weight. All weighing was done without the lambs being withheld from feed and water.

2.5.2.2 Feed intake

The daily food was offered in three portions, namely at 08h30, 14h00 and 16h30. The feed offered and feed refused at two-day intervals for the nine subgroups were recorded to determine the average daily feed intake. Feed spilled on the floor by lambs in each pen when eating were picked up during the next hour after feeding and collected in plastic bags as part of feed refused. The lambs were fed at a 15% refusal level as calculated with a 3-days moving average (Einkamerer, 2008).

2.5.2.3 Water intake

Water was provided in each pen in a plastic trough with a capacity of about 16 litres. The water troughs were refilled with a known quantity of water when its content dropped to half or less. The refilled quantity of water was added to the volume of water provided earlier to calculate the total quantity of water provided for that particular day. The volume of water remaining the next morning was poured out and measured and the trough was refilled with clean water. The daily water intake was recorded as the difference between water provided the previous day and water remaining the next morning when the troughs were cleaned.

2.5.3 Digestibility trials

2.5.3.1 Trial period

Digestibility trials were conducted at set intervals during the growth trials. The same replicate of five (5) Dorper wether lambs per treatment diet (randomly selected) was moved from the pens to metabolism cages for a week, every third week, namely during weeks 1, 5 and 8 (as determined from being fed in the small subgroups of five lambs). The metabolism cages were also housed in the open-sided shed (Figure 2.3).



Figure 2.3 Some of the Dorper wether lambs housed individually in metabolism cages.

Initially the growth trial period was planned to run for 70 days. Based on the information collected in the feedlot, the projected growth rates of some treatment groups, especially treatment diet T2, indicated that they would reach the target average slaughter weight of 35 kg before the planned time. Therefore, the third digestibility trial was rescheduled a week earlier in order for the data of Cage Period 3 to be collected before the Dorper wether lambs had to be slaughtered at an average of about 35 kg live weight.

2.5.3.2 Feed intake

The daily feed was offered to each Dorper wether lamb in three portions in the metabolism cages, namely at 08h30, 14h00 and 16h30. On day one, the lambs were offered 1 500 g feed. On the second and third day the amount of feed offered to lambs was calculated at a 15% refusal level, namely 15% more feed than ingested the previous day or days. From the fourth day and the days after, the feed for a 24-hour period was offered at a 15% refusal level of intake, calculated on a daily basis by using a 3-day moving average of the feed intake of each lamb during the preceding three days.

2.5.3.3 Water intake

Water was provided to each Dorper wether lamb in plastic buckets of about 5 litres. The water buckets were refilled with a known quantity of water when its content dropped to half or less. The refilled quantity of water was added to the volume of water provided earlier to get the total quantity of water provided for that particular day. The volume of water remaining in the bucket the next morning was poured out, measured and the bucket was refilled with clean water. The daily water intake was recorded as the difference between

water provided the previous day and water remaining the next morning when the buckets were cleaned.

2.5.3.4 Feeds and refusals

Daily feed refusals were removed and weighed before the morning feeding, then dried in a force draught oven at 100°C. At the end of the collection period, the feed refusals for each Dorper wether lamb were mixed and pooled. Representative samples were taken, ground to pass a 1 mm sieve and stored in plastic bottles for chemical analysis.

During the first period in the metabolism cages, data were collected only for six (6) days (not seven) because the Dorper wether lambs were adapted to the new housing conditions in the metabolism cages for one day before the collection period started.

During the trial periods, random samples of each treatment diet (T0, T1 and T2) were taken every day and pooled separately in marked paper bags. At the end of the trial period, all treatment diet samples were dried in a force draught oven at 100°C, ground to pass a 1 mm sieve and stored in plastic bottles for chemical analysis.

2.5.3.5 Faeces

Faeces from individual Dorper wether lambs were collected separately on a daily basis, pooled in marked paper bags and dried in a force draught oven at 100°C. At the end of the trial period of seven (7) days the total dry matter (DM) of faeces was weighed and recorded per lamb. The oven dried faeces for each lamb were mixed and pooled. Representative samples were taken by means of the quartering technique (H.O. de Waal, 2009; personal communication), ground to pass a 1 mm sieve, and stored in plastic bottles for chemical analysis.

2.5.3.6 Urine collection

Individual total daily urine excretion for each Dorper wether lamb was collected in glass bottles and the volumes recorded. The urine was collected on a sheet metal chute from the base of the metabolism cages and directed via urine collection plates into the bottles. Every morning before feeding, the urine for each lamb was collected into a plastic measuring cylinder, the total urine volume recorded and the urine flushed away. The empty bottles were then properly placed back under the urine collection plates of the metabolism cages.

2.6 Chemical analysis of feeds, refusals and faeces

2.6.1 Sample preparations

All composite samples (faeces, feeds and refusal) were prepared for analysis by grinding it in a hammer mill to pass through a 1 mm sieve. Some particles did not readily pass through the sieve. These particles were collected and mixed thoroughly with the rest of the milled samples as homogenous as possible before being stored in plastic bottles. The prepared samples were stored in clean and clearly labeled plastic bottles pending analysis.

2.6.2 Dry matter (DM)

The dry matter (DM) content of the treatment diets, individual feed refusals and faeces collected during the digestibility trials were determined by weighing about 2 g of samples ground to pass a 1 mm sieve into previously weighed crucibles and dried overnight in a force draught oven at 100°C (AOAC, 2000). The dried samples were removed from the oven and cooled to room temperature in desiccators before being weighed again.

The DM of samples was calculated as follows:

$$\text{DM (g/kg)} = \frac{\text{Weight of sample (g) after drying}}{\text{Weight of sample (g) before drying}} \times 1000$$

2.6.3 Ash or inorganic matter

The samples used to determine DM were also used to determine the ash or inorganic matter content of each sample. After weighing the dried samples, the crucibles plus dry samples were placed in a muffle furnace and incinerated overnight at 550°C (AOAC, 2000). Finally, crucibles plus ash were cooled to room temperature in desiccators and weighed again.

The ash content of each sample was determined as follows:

$$\text{Ash (g/kg DM)} = \frac{\text{Weight of sample after incineration (g)}}{\text{Weight of dried sample before incineration (g DM)}} \times 1000$$

2.6.4 Organic matter (OM)

Organic matter was calculated by subtracting the ash content from 1 000 or using the following formula:

$$\text{OM (g/kg DM)} = \frac{\text{Weight of sample (g)} - \text{weight of ash (g)}}{\text{Weight of sample (g DM)}} \times 1000$$

2.6.5 Crude protein (CP)

Crude protein was determined by the Kjeldahl method as described by AOAC (2000) and according to the standardized analytical procedures of the Agri Laboratory Association of Southern Africa (AgriLASA, 2007). Approximately 0.2 g DM of each sample was weighed on a filter paper and introduced into a digestion tube. Two Kjeldahl selenium catalyst tablets and 20 ml concentrated sulphuric acid were added to each digestion tube. The set-up digestion tubes, manifold and exhaust tubes connected to the scrubber were then introduced into the digestion block and the samples were digested at maximum heat for 1 hour. The samples were then digested with sulphuric acid (H₂SO₄) in the presence of the catalyst that increased the boiling point of sulphuric acid. After the digestion process, the samples are allowed to cool for 15 to 20 minutes before distillation.

The digestion tubes with samples were then introduced to the preheated Distillation unit of a BUchi 339. Steam was introduced into the sample tube to facilitate the transfer of nitrogen to the receiving flask. During the distillation, ammonia that was formed during the digestion process was liberated by adding sodium hydroxide (NaOH) to the digested materials, distilled off and collected in boric acid (H₃BO₄). The quantity of nitrogen collected was then determined by titration of the borate formed with 0.1 N hydrochloric acid (HCl).

After titration was completed, the results were automatically calculated and printed out by the machine. The percentage protein of the diets, refusals and faeces was calculated by multiplying the nitrogen value with a factor of 6.25.

2.6.6 Lipids (Ether extract, EE)

Ether extract (EE) was determined according to the standardized analytical procedures of the Agri Laboratory Association of Southern Africa (AgriLASA, 2007). The ether extract (EE)

content of each sample was determined by weighing about 2 g of samples ground to pass a 1 mm sieve into clean dried extraction thimbles. Glass cotton wool was inserted in a thimble to keep the sample in place during extraction and then place the extraction thimbles containing the samples in the extractor. A clean and dried Soxhlet flask was weighed and connected to the extraction apparatus after being filled to about 2/3 of its capacity with petroleum ether. The cooling water supply and heating mantle were turned on and the temperature was adjusted to achieve a condensation rate of ether at 5-6 drops per hours for at least 4 hours. As the cool water condensed the ether vapours, it dropped onto the sample placed into the extraction thimble and the fat extracted by the ether dropped back into the flask.

After the extraction period, the remaining ether was evaporated and the flasks were placed in a drying oven at 100°C to dry overnight. The flasks were then cooled in desiccators and weighed again to determine the extracted residues.

The EE fraction of samples was determined as follows:

$$\text{EE (g/kg DM)} = \frac{[\text{Flask (g) + Ether extract}] - \text{Flask (g)}}{\text{Sample (g DM)}} \times 1000$$

2.6.7 Neutral-detergent fibre (NDF)

Neutral-detergent fibre (NDF) of feed, refusals and faeces were determined according to procedures described by Goering and Van Soest (1970) and Robertson and Van Soest (1981). This procedure was used to determine the insoluble portion of the analysed samples (feeds and faeces), consisting of hemicellulose, cellulose, lignin, cutin and silica (cell wall fraction). Respective samples of about 1 g were weighed into sintered glass crucibles and placed in the extraction unit. The machine and cooling system were turned on and 100 ml cold neutral detergent solution (NDS) was added to each crucible, and boiled for 1 hour. The NDS was drained out by suction and the samples were washed with hot water and then rinsed with acetone.

After completing the drying process with vacuum extraction, samples were placed in a drying oven to dry overnight at 100°C. Dry samples were removed from the oven and placed in desiccators to cool and weighed again before being placed in a muffle furnace and incinerated

overnight at 550°C. The incinerated samples were taken from the furnace, cooled in a desiccator, and weighed again.

The NDF content was calculated as follows:

$$\text{NDF (g/kg DM)} = \frac{[\text{Sample (g DM)} - \text{Sample after boiling \& drying (g)}] - \text{Ash (g)}}{\text{Sample (g DM)}} \times 1000$$

2.6.8 Acid-detergent fibre (ADF)

Acid-detergent fibre (ADF) was determined according to procedures described by Goering and Van Soest (1970) and Robertson and Van Soest (1981). This procedure was used to determine lignocelluloses and silica of the analysed samples (feeds and faeces). Respective samples of about 1 g were weighed into sintered glass crucibles and placed in the extraction unit. The machine and cooling system were turned on and 100 ml cold acid detergent solution (ADS) was added to each crucible with the sample residue and then boiled for an hour.

The solution was drained out by suction and the samples were washed three times with boiling water and then rinsed twice with acetone. The remaining residues were dried overnight in a drying oven at 100°C. Dried samples were taken from the oven and transferred in a desiccator to cool before being weighed. The samples were incinerated overnight at 550°C in a muffle furnace. The ash samples were removed from the furnace, allowed to cool in desiccators, and weighed.

The ADF content of samples was calculated as follows:

$$\text{ADF (g/kg DM)} = \frac{[\text{Sample (g DM)} - \text{Sample after boiling (g)}] - \text{Ash (g)}}{\text{Sample (g DM)}} \times 1000$$

2.6.9 Gross energy (GE)

The gross energy (GE) content of the respective sampled material was determined on a DM basis using an adiabatic bomb calorimeter (AOAC, 2000). Gross energy (GE) was measured in joule (J).

The procedure described by Menezes (2008) was used to determine GE. About 0.2 g samples were used for faeces and for other materials a sample of about 0.4 g was used. All samples were weighed accurately before being analysed.

2.6.10 Apparent digestibility coefficients

The apparent digestibility coefficient of a feed or nutrient is calculated by the following formula (McDonald *et al.*, 2002):

$$\text{Apparent digestibility} = \frac{\text{Feed or nutrient intake (g DM)} - \text{feed or nutrient excreted in faeces (g DM)}}{\text{Feed or nutrient intake (g DM)}}$$

Where intake (kg) = kg feed or nutrient presented - kg feed or nutrient refused.

Note that in this study the apparent digestibility was presented as a coefficient.

2.7 Carcass evaluation

The Dorper wether lambs were fed three treatment diets until a target average live weight of 35 kg for the treatment group was reached. When the treatment group reached the target weight, lambs were individually weighed to obtain the Final Live Weight (FLW). They were transported the same day to the registered commercial abattoir MEATCO, in Windhoek, Namibia which is about 35 km from Bergvlug. The Dorper wether lambs were fasted for a period of 18 to 24 hours with water available, at the abattoir before being slaughtered.

2.7.1 Slaughter technique

As Namibia is a net exporter of meat to the European Union (EU) and to some Muslim countries, animals have to be slaughtered in accordance with the EU laws of ethics and welfare, combined with Halaal slaughter method. It is required by law that an animal is electrically stunned before being slaughtered. This is in order to ensure that the animal does not suffer pain during slaughter (Anil *et al.*, 2004). Therefore, on the slaughter day the Dorper wether lambs were brought into a stunning box one by one, whereby a low voltage alternating electric current was applied by means of two electrodes. The electrodes were placed on either side of the head using tongs to render the animal unconscious before it is slaughtered. After stunning, the animals were Halaal slaughtered by the Muslim expert by cutting the carotids, jugular vessels, oesophagus and trachea in a single cut in order to allow

blood to drain from the carcass. The carcasses were hanged on the bleeding rail and the dressing operations began after the animals were completely dead.

2.7.2 Carcass grading

Hot dressed carcasses were immediately graded after slaughter by experienced meat grader officials from MEATBOARD of Namibia. Carcass grading was done according to the South African Meat Classification System for beef, lamb, mutton and goat meat (Government notice no. R.863, 1 September 2006). Quality grades as done by the Meat Board grader combines three separate factors that affect the palatability and tenderness of the meat namely maturity, subcutaneous fat and muscle conformation:

- The carcass grading system uses three maturity groups, referred to by letters – A (indicating the carcass from the youngest animals with no permanent teeth) to C (indicating carcasses from old animals with more than six permanent teeth).
- Fat was measured by means of visual appraisal into fat classes on an increasing scale varying from score 0 (no visible subcutaneous fat on the carcass) to score 6 (excessively overfat – obese – carcass surface covered with subcutaneous fat).
- Conformation grading was also done by visual assessment of the muscular and skeletal formation of the carcass. The conformation codes range between 1 (very flat) to 5 (very round). Thus, the conformation descriptions in the grade specifications referred to the thickness of muscling and the fullness of the carcass (Strydom & Smith, 2005).

2.7.3 Carcass weight

After dressing and evisceration procedures, carcasses were weighed to obtain hot carcass weight (HCW). The final live weight and the hot carcass weight were used to determine dressing out percentage (DOP). The dressing out percentage of a hot carcass was calculated using the formula suggested by Mareko *et al.* (2006): $DOP = (HCW/FLW) \times 100$. Carcasses were chilled in a cooler at a temperature of 0 to 2°C for 24 hours to obtain the cold carcass weight.

2.7.4 Carcass measurements

The chilled carcass of each Dorper wether lamb was divided down the spinal column by a longitudinal cut on the vertebral column into two half-carcasses using a meat band saw and the left side of the carcass was used for further measurements (Gokdar *et al.*, 2004). The

carcasses were measured for carcass characteristics including meat pH, carcass length, shoulder and buttock circumferences, fat thickness and the width and depth of the *musculus longissimus dorsi*.

2.7.5 pH measurements

The pH determination of the carcasses was carried out 1 hour (pH1) and 24 hours (pH24) after slaughtering in the left *musculus longissimus dorsi* (Jones *et al.*, 1995). A portable digital pH meter with a penetration electrode was used (Figure 2.4).



Figure 2.4 pH of the carcass measured in the *musculus longissimus dorsi*.

2.7.6 Carcass length

The individual carcass length of each Dorper wether lamb (distance between the base of the tail and the base of the neck) was measured using a calliper before the carcasses were split into halves.

2.7.7 Shoulder and buttock circumferences

The shoulder and buttock circumferences were measured with a flexible tape measure (A. Hugo, 2009; personal communication).

2.7.8 Fat thickness

After the chilled carcass of each Dorper wether lamb was divided down the spinal column into half-carcasses, a fraction of ribs (10th -12th ribs) was taken by transverse cuts between the 12th and 13th ribs and between the 9th and 10th ribs from the left side of each carcass (Figure 2.5).



Figure 2.5 Three-ribs sample cut removed from the left side of a carcass.

Fat thickness was measured at $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ positions on the 12th rib from the chine bone end, with a vernier calliper (Figure 2.6) and the average of three measurements taken (Jones *et al.*, 1995; A. Hugo, 2009; personal communication).



Figure 2.6 Marked positions on the cut where the fat thickness was measured.

2.7.9 *Musculus longissimus dorsi* depth and width

The depth and the width of the *musculus longissimus dorsi* exposed by cutting the carcass between the 12th and 13th ribs, were measured with a vernier calliper (Figure 2.7).

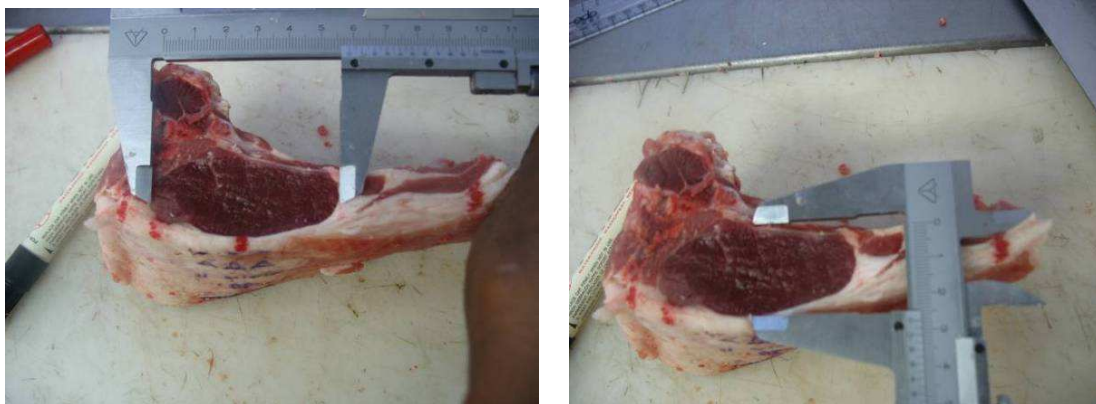


Figure 2.7 The width and depth of the *musculus longissimus dorsi* measured with a calliper.

2.7.10 Estimation of carcass composition

A 3-rib cut (9th through to 11th ribs) was removed from the left side of each carcass and was physically separated by blunt dissection into muscle, fat and bone (Figure 2.8), as described by Einkamerer (2008). The composition of each tissue was used as an estimation of the carcass composition.

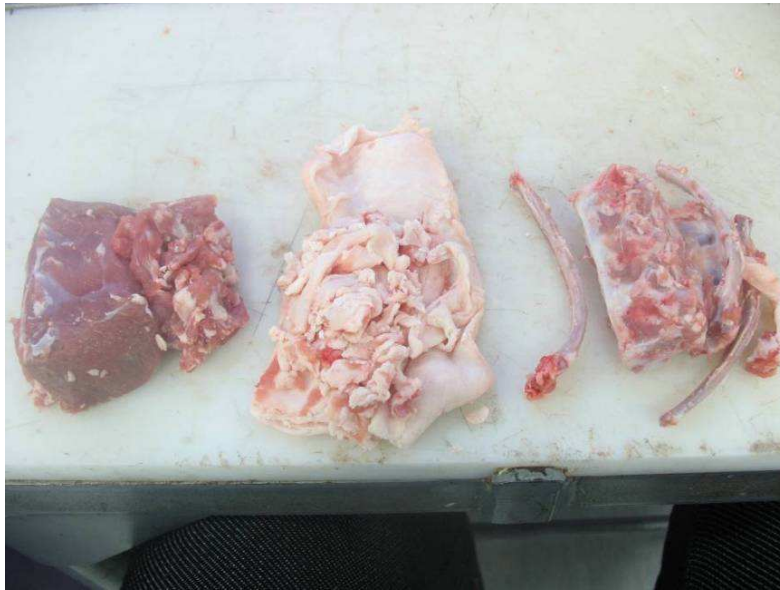


Figure 2.8 Muscle, fat and bone tissues dissected from the 3-rib cut.

2.8 Statistical analysis

Data were subjected to analysis of variances (ANOVA) using the General Linear Model (GLM) procedures of SAS (2006). The effects of the treatments on daily gain, feed intake, digestibility, water intake and carcass characteristics were assessed.

The following model was used:

$$Y_{ij} = \mu + t_i + e_{ij}$$

Where Y_{ij} = measured variable for the ij th treatment;

μ = overall mean;

t_i = effect of the i th dietary treatment (1-3)

e_{ij} = error term.

3. Feed intake by Dorper wether lambs in the feedlot and digestibility trials

Commercial lamb and mutton production is an important part of the livestock industry in South Africa and Namibia. Most commercial farmers use extensive production systems and sell weaned lambs as well as culled ewes and rams. Due to the extensive nature of the production systems as well as the seasonality of the rainfall and its effects on quantity and quality of veld, these sheep are often not ready or fat enough to be marketed. Therefore, it is common practice to use short intensive feeding periods to fatten or “round off” animals and improve carcass grading before slaughtering. This is done in feedlots both on farms or at specialised enterprises.

Feedlot diets invariably incorporate substantial quantities of good quality roughage such as lucerne hay. Lucerne has a high demand for water and, therefore, it is mostly produced commercially under irrigation. Since water resources are becoming increasingly scarce and expensive, an important feed such as lucerne is also becoming increasingly scarce and expensive, thus limiting the profitability of sheep feedlot operations. Therefore, there is a need to identify and develop affordable alternative feed sources for ruminant feedlot diets.

Over the past decade, sun-dried and coarsely ground *Opuntia* cladodes have been used experimentally as a feed source for ruminants. Previous studies by Zeeman (2005), Einkamerer (2008) and Menezes (2008) at the University of the Free State, Bloemfontein clearly demonstrated that sun-dried and coarsely ground *Opuntia* cladodes can replace a substantial part of lucerne hay (up to an inclusion level of 360 g/kg) in diets for young Dorper wether lambs. Additional nitrogen (N) was included as an NPN source, namely feed grade urea.

Therefore, this study focused on evaluating two feedlot diets for Dorper wether lambs, containing inclusion levels of about 1/3 sun-dried and coarsely ground *Opuntia* cladodes of the total diet and two different nitrogen sources (NPN and a natural protein).

Three treatment diets were used in this study (see section 2.4) and it was hypothesized that Dorper wether lambs fed *Opuntia*-based feedlot diets:

- 1) will have the same feed intake and apparent digestibility than those on a conventional feedlot diet.
- 2) with the inclusion of two different nitrogen sources, namely non-protein nitrogen (NPN) or natural protein, will not affect feed intake and digestibility of the diets.

To test these hypothesis, a conventional feedlot diet (T0) was used as control diet and compared with two *Opuntia*-based diets (T1 and T2) containing different nitrogen sources, namely feed grade urea (an NPN source) or sunflower oilcake meal (natural protein source).

In addition to the feedlot study, the feed intake and apparent digestibility of the three treatment diets were determined with some of the Dorper wether lambs in metabolism cages, as well as their water intake, urine excretion and faecal output.

3.1 Chemical composition of the three treatment diets

The chemical composition of the three treatment diets is presented in Table 3.1. Full detail of the methodology used in this study is presented in Chapter 2.

Table 3.1 Chemical composition of the three treatment diets (T0, T1 and T2)

Chemical constituents	Treatment diets*		
	T0	T1	T2
Dry matter (g DM/kg feed)	933.4	898.6	911.1
Crude protein (g CP/kg DM)	153.8	149.0	141.3
Acid-detergent fibre (g ADF/kg DM)	249.9	241.5	228.0
Neutral-detergent fibre (g NDF/kg DM)	465.4	410.5	418.9
Lipids (g lipids/kg DM)	23.8	24.9	25.3
Ash (g ash/kg DM)	72.4	112.0	104.6
Organic matter (g OM/kg DM)	889.8	850.8	860.9
Gross energy (MJ/kg DM)	16.8	15.4	15.9

* T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

The dry matter (DM) content of the three treatment diets varied slightly. Zeeman (2005) reported that the DM content of diets decreased with increasing inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes, while Einkamerer (2008) and Menezes (2009)

concluded that incremental levels of sun-dried and coarsely ground *Opuntia* cladodes up to an inclusion level of 360 g/kg do not have an effect on DM content of diets.

The differences in crude protein (CP) content of the diets were relatively small. Every effort was made to balance the diets with regard to CP content (see Table 2.1). However, inclusion of sun-dried and coarsely ground *Opuntia* cladodes in the diets inevitably reduces the CP content of the diets because of the relatively low CP content of *Opuntia* cladodes (Ben Salem *et al.*, 1996; Nefzaoui & Ben Salem, 2000; Ben Salem *et al.*, 2002; Batista *et al.*, 2003). The latter authors concluded that the CP content of *Opuntia* cladodes is much lower than the maintenance requirements of ruminants. Therefore, an NPN source (feed grade urea) and a natural plant protein source (sunflower oilcake meal) were used in this study to balance the N content of the two *Opuntia*-based diets namely (treatment diets T1 and T2) and maintain a final CP level required to promote growth as comparable as possible to that for treatment diet T0. It should be noted that treatment diet T0 also contained a small quantity of feed grade urea (see Table 2.1).

Acid-detergent fibre (ADF), neutral-detergent fibre (NDF), organic matter (OM) and gross energy (GE) have all decreased slightly with inclusion of sun-dried and coarsely ground *Opuntia* cladodes in the diets (Table 3.1). In agreement with the *Opuntia* inclusion levels by Zeeman (2005), Einkamerer (2008) and Menezes (2008), the observed results are explained by the lower ADF, NDF, OM and GE content of *Opuntia* cladodes.

The ash content (Table 3.1) increased with inclusion of sun-dried and coarsely ground *Opuntia* cladodes in the diets. This was expected because of the high ash content of *Opuntia* cladodes (Batista *et al.*, 2003). Despite the low lipid content of *Opuntia* cladodes (Zeeman, 2005), the lipid content of the *Opuntia*-based diets showed small increases (Table 3.1).

3.2 Feed and water intake of Dorper wether lambs in the feedlot

The experiment was conducted using a completely randomized design with fifteen (15) Dorper wether lambs per treatment diet, divided into three (3) replicates or subgroups. All 45 Dorper wether lambs were used for the growth trial in the feedlot to evaluate their growth performance and the feed and water intake while consuming treatment diets (T0, T1 and T2). For a more detailed description of the methodology used in this part of the study, refer to Chapter 2 Materials and Methods.

In the following two sections the feed intake (3.2.1) and water intake (3.2.2) of the Dorper wether lambs measured in the feedlot are presented and discussed.

3.2.1 Feed intake of Dorper wether lambs in the feedlot

The feed offered and feed refused at two-day intervals for all nine subgroups of five Dorper wether lambs each were recorded to determine the average daily feed intake (Table 3.2).

Table 3.2 The average (mean±s.e.) daily feed intake by Dorper wether lambs in the feedlot during the study period

	Treatment diets*			P	CV ¹ (%)
	T0	T1	T2		
Air dry feed intake (kg/day/head)	1.147±0.050 ^a	1.131±0.071 ^a	1.209±0.022 ^a	0.538	7.3
DM intake (kg/day/head)	1.071±0.045 ^a	1.016±0.064 ^a	1.102±0.020 ^a	0.454	7.2
Feeding period (days)	77	91	77		

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different (P < 0.05)

¹ Coefficient of variance

No significant differences (P>0.05) were observed between treatment diets (Table 3.2). However, numerically the feed intake by the Dorper wether lambs fed treatment diet T2 was the highest and those fed treatment diet T1 was the lowest.

3.2.2 Water intake of Dorper wether lambs in the feedlot

Although not significantly different (P>0.05), the daily water intake by Dorper wether lambs fed treatment diet T2 was numerically higher, followed by treatment diet T0 and for treatment diet T1 it was the lowest (Figure 3.1). Previous studies by Zeeman (2005), Einkamerer (2008) and Menezes (2008) reported higher daily water intake by Dorper wether lambs when fed *Opuntia*-based diets.

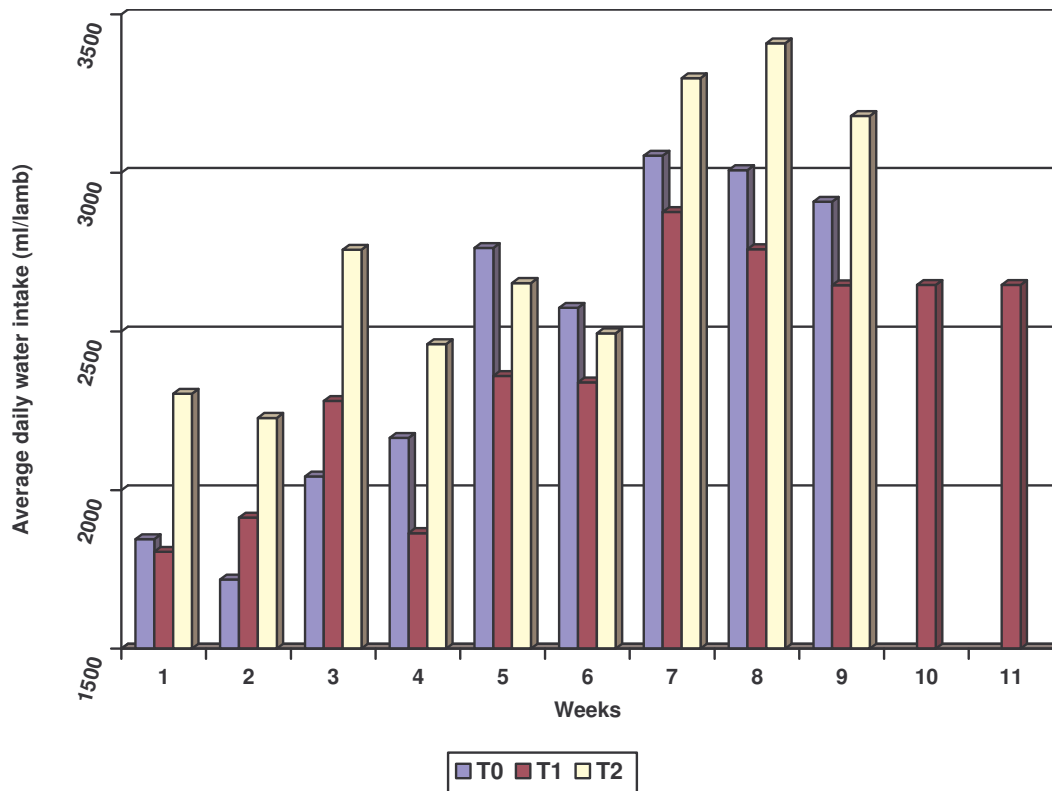


Figure 3.1 Average daily water intake (ml/lamb) of Dorper wether lambs in the feedlot during the study period.

The daily water intake by the Dorper wether lambs also increased as the feeding period progressed irrespective of the treatment diets. This observation is to some extent in agreement with the results by Einkamerer (2008). The higher water intake may in part be ascribed to the increase in live body weight of the Dorper wether lambs over the trial period (see later Table 4.1), but also the progressive long-term effect of adaptation to the treatment diets.

3.3 Intake during the digestibility trials

3.3.1 Dry matter and nutrient intake and apparent digestibility of treatment diets

One replicate group of five (5) Dorper wether lambs per treatment diet was moved from their feedlot pens to metabolism cages for a week, namely during weeks 1, 5 and 8 (as determined from being fed in the small subgroups of five lambs; see section 2.5.3). The DM and nutrient intake and apparent digestibility were determined during the three cage periods. The results for intake are shown in Tables 3.3, 3.5 and 3.7 and for the apparent digestibility of the diets in Tables 3.4, 3.6 and 3.8, respectively.

3.3.1.1 Cage Period 1

Except for ash and acid-detergent fibre (ADF), there were no significant differences ($P>0.05$) in intake of DM and other nutrients by Dorper wether lambs between the treatment diets (Table 3.3). The values of ash were higher for treatment diet T2 ($P<0.05$) compared to treatment diets T0 and T1. The values for ADF were similar for treatment diets T0 and T2 but significantly higher ($P<0.05$) than treatment diets T1 (Table 3.3). Similar DM, CP, NDF, Lipids, GE and OM intakes were recorded in the different treatment groups. No plausible explanation can be provided for the low but not significantly different ($P>0.05$) DM intake by Dorper wether lambs fed treatment diet T1.

Table 3.3 The daily intake (mean \pm s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 1

Intake of chemical constituents	Treatment diets*			P	CV ¹ (%)
	T0	T1	T2		
Dry matter (g DM/day)	1049.9 \pm 80.7 ^a	775.1 \pm 143.9 ^a	1120.8 \pm 126.7 ^a	0.142	27.4
Crude protein (g CP/day)	168.9 \pm 12.2 ^a	123.4 \pm 22.9 ^a	160.3 \pm 18.4 ^a	0.217	27.2
Acid-detergent fibre (g ADF/day)	282.2 \pm 21.3 ^a	180.2 \pm 29.7 ^b	271.7 \pm 26.7 ^a	0.033	23.9
Neutral-detergent fibre (g NDF/day)	560.4 \pm 36.2 ^a	390.3 \pm 61.9 ^a	559.6 \pm 54.7 ^a	0.062	23.1
Lipids (g lipid/day)	24.2 \pm 1.6 ^a	22.3 \pm 3.7 ^a	32.5 \pm 4.1 ^a	0.109	27.9
Gross energy (MJ GE/day)	18.9 \pm 1.5 ^a	12.7 \pm 2.3 ^a	18.4 \pm 2.1 ^a	0.086	26.6
Ash (g ash/day)	83.0 \pm 5.9 ^b	93.0 \pm 16.7 ^b	140.1 \pm 13.8 ^a	0.020	27.5
Organic matter (g OM/day)	966.8 \pm 74.8 ^a	682.0 \pm 127.2 ^a	980.7 \pm 112.9 ^a	0.127	27.4

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different ($P < 0.05$)

¹ Coefficient of variance

The apparent digestibility coefficients recorded for DM, CP, ADF, GE and OM (Table 3.4) were similar for the different treatment diets. Only NDF and lipids showed significantly higher ($P<0.05$) apparent digestibility for treatment diets T1 and T2 compared to treatment diet (T0) (Table 3.4).

Table 3.4 Apparent digestibility coefficients (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 1

Chemical constituents	Treatment diets *			P	CV ¹ (%)
	T0	T1	T2		
Dry matter (DM)	0.697±0.022 ^a	0.718±0.015 ^a	0.713±0.011 ^a	0.659	5.3
Crude protein (CP)	0.740±0.017 ^a	0.772±0.010 ^a	0.753±0.009 ^a	0.221	3.7
Acid-detergent fibre (ADF)	0.544±0.045 ^a	0.642±0.009 ^a	0.625±0.012 ^a	0.056	10.1
Neutral-detergent fibre (NDF)	0.698±0.024 ^b	0.774±0.005 ^a	0.757±0.012 ^a	0.013	4.8
Lipids	0.629±0.026 ^b	0.767±0.046 ^a	0.849±0.012 ^a	0.001	9.3
Gross energy (GE)	0.696±0.021 ^a	0.738±0.012 ^a	0.722±0.009 ^a	0.169	4.6
Ash	0.418±0.035 ^a	0.459±0.043 ^a	0.517±0.010 ^a	0.136	15.6
Organic matter (OM)	0.721±0.021 ^a	0.754±0.013 ^a	0.741±0.011 ^a	0.359	4.7

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different (P < 0.05)

¹ Coefficient of variance

These results could be explained by a number of factors. Firstly, the high levels of easily digestible carbohydrates present in *Opuntia* cladodes are positively correlated to increases in apparent DM digestibility of *Opuntia*-based diets (Ben Salem *et al.*, 1996; 2004; Misra *et al.*, 2006). Secondly, the low fibre content of *Opuntia* cladodes is positively linked to a higher digestibility of a feed, therefore it was to be expected that inclusion of *Opuntia* cladodes would result in a higher apparent digestibility (Nefzaoui & Ben Salem, 2000). Similar results were reported by Menezes (2008). Thirdly, the additional relatively high fibre content of the sunflower oilcake meal may have played a small but unknown role.

3.3.1.2 Cage Period 2

In general, results similar to those found during Cage Period 1 were also recorded during Cage Period 2 (Table 3.5). Similar intakes were observed between all groups. Except for lipids, GE and ash, there were no significant differences (P>0.05) for daily intake of the other chemical constituents of treatment diets by Dorper wether lambs (Table 3.5) during Cage Period 2. Similar results were observed for ash during the Cage Period 1. The same reasons given for the results of Cage Period 1 are also valid in this case.

Table 3.5 The daily intake (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 2

Intake of chemical constituents	Treatment diets*			P	CV ¹ (%)
	T0	T1	T2		
Dry matter (g DM/day)	1294.4±98.6 ^a	1140.6±164.8 ^a	1567.4±33.4 ^a	0.056	18.9
Crude protein (g CP/day)	220.6±16.2 ^a	187.3±27.0 ^a	216.9±4.9 ^a	0.402	19.8
Acid-detergent fibre (g ADF/day)	302.0±25.6 ^a	412.6±49.9 ^a	377.3±5.8 ^a	0.087	20.0
Neutral-detergent fibre (g NDF/day)	584.4±42.6 ^a	526.0±72.3 ^a	668.8±10.1 ^a	0.160	18.5
Lipids (g lipid/day)	36.1±2.7 ^{ab}	28.5±4.3 ^b	41.9±1.0 ^a	0.026	18.9
Gross energy (MJ GE/day)	21.9±1.8 ^{ab}	18.3±2.6 ^b	25.3±0.5 ^a	0.016	19.0
Ash (g ash/day)	99.7±7.3 ^b	122.8±18.4 ^b	165.7±4.3 ^a	0.006	20.2
Organic matter (g OM/day)	1194.8±91.3 ^a	1017.8±146.4 ^a	1401.6±29.1 ^a	0.059	18.8

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different (P < 0.05)

¹ Coefficient of variance

The apparent digestibility of the chemical constituents of the treatment diets (Table 3.6) did not differ significantly (P>0.05) during the Cage Period 2 among treatment diets, except for ADF and lipids. The apparent ADF digestibility was highest for treatment diet T1 and lowest for treatment diet T0. For lipids the lowest apparent digestibility was for treatment diet T0 and highest for treatment diet T2.

3.3.1.3 Cage Period 3

Apart from ash, ADF and NDF, the daily intake (Table 3.7) by Dorper wether lambs of chemical constituents did not differ significantly (P>0.05) among the treatment diets. The values for ADF and NDF were similar for treatment diets T0 and T2, but significantly higher (P<0.05) than for treatment diet T1. The values for ash were higher (P<0.05) for treatment diet T2 than treatment diet T0, but not significantly different (P>0.05) from treatment diet T1. This same trend was observed throughout the three digestibility trials (Cage Periods 1, 2 and 3). The main differences were observed in the ADF and NDF.

Table 3.6 Apparent digestibility coefficients (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 2

Chemical constituents	Treatment diets *			P	CV ¹ (%)
	T0	T1	T2		
Dry matter (DM)	0.731±0.024 ^a	0.708±0.073 ^a	0.780±0.013 ^a	0.527	13.6
Crude protein (CP)	0.787±0.019 ^a	0.788±0.052 ^a	0.812±0.010 ^a	0.832	9.2
Acid-detergent fibre (ADF)	0.572±0.040 ^b	0.756±0.062 ^a	0.696±0.017 ^{ab}	0.032	14.4
Neutral-detergent fibre (NDF)	0.700±0.027 ^a	0.732±0.072 ^a	0.759±0.015 ^a	0.666	13.9
Lipids	0.715±0.026 ^b	0.777±0.055 ^{ab}	0.858±0.007 ^a	0.045	10.1
Gross energy (GE)	0.718±0.023 ^a	0.728±0.074 ^a	0.797±0.011 ^a	0.425	13.5
Ash	0.371±0.052 ^a	0.356±0.146 ^a	0.539±0.033 ^a	0.324	48.5
Organic matter (OM)	0.761±0.021 ^a	0.750±0.065 ^a	0.809±0.011 ^a	0.561	11.6

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different (P < 0.05)

¹ Coefficient of variance

Table 3.7 The daily intake (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 3

Intake of chemical constituents	Treatment diets*			P	CV ¹ (%)
	T0	T1	T2		
Dry matter (g DM/day)	1356.3±74.5 ^a	1199.8±159.2 ^a	1533.9±69.6 ^a	0.138	17.9
Crude protein (g CP/day)	215.2±11.9 ^a	186.3±23.9 ^a	247.1±11.6 ^a	0.073	17.4
Acid-detergent fibre (g ADF/day)	309.9±18.7 ^a	240.2±29.8 ^b	344.8±13.8 ^a	0.016	16.4
Neutral-detergent fibre (g NDF/day)	630.4±33.5 ^a	443.6±58.7 ^b	598.4±26.0 ^a	0.018	16.8
Lipids (g lipid/day)	34.0±2.0 ^a	32.2±4.6 ^a	33.7±1.9 ^a	0.908	20.7
Gross energy (MJ GE/day)	23.3±2.8 ^a	19.6±2.6 ^a	26.2±1.2 ^a	0.068	17.4
Ash (g ash/day)	99.5±6.0 ^b	129.5±17.0 ^{ab}	144.7±7.2 ^a	0.041	20.1
Organic matter (g OM/day)	1256.8±68.6 ^a	1070.3±142.3 ^a	1389.3±62.6 ^a	0.110	17.7

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different (P < 0.05)

¹ Coefficient of variance

Table 3.8 Apparent digestibility coefficients (mean±s.e.) of DM and chemical constituents of the treatment diets by Dorper wether lambs during the Cage Period 3

Chemical constituents	Treatment diets *			P	CV ¹ (%)
	T0	T1	T2		
Dry matter (DM)	0.684±0.017 ^a	0.704±0.058 ^a	0.749±0.017 ^a	0.451	11.4
Crude protein (CP)	0.730±0.013 ^a	0.782±0.039 ^a	0.819±0.010 ^a	0.074	7.1
Acid-detergent fibre (ADF)	0.486±0.027 ^a	0.511±0.099 ^a	0.624±0.028 ^a	0.276	25.3
Neutral-detergent fibre (NDF)	0.620±0.018 ^a	0.612±0.079 ^a	0.688±0.022 ^a	0.493	17.0
Lipids	0.621±0.026 ^a	0.745±0.056 ^a	0.754±0.026 ^a	0.057	12.3
Gross energy (GE)	0.681±0.018 ^a	0.720±0.056 ^a	0.764±0.018 ^a	0.299	11.1
Ash	0.300±0.046 ^a	0.417±0.109 ^a	0.438±0.046 ^a	0.385	42.7
Organic matter (OM)	0.714±0.015 ^a	0.739±0.052 ^a	0.781±0.014 ^a	0.360	9.7

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different (P < 0.05)

¹ Coefficient of variance

Similar coefficients of apparent digestibility were observed for all chemical constituents of all treatment diets during Cage Period 3 (Table 3.8). It seems that after sufficient adaptation to the treatment diets containing sun-dried and coarsely ground *Opuntia* cladodes, no significant differences (P>0.05) in apparent digestibility of the diets were experienced.

Considering the results of all three cage periods, it can be summarised that the daily intake and apparent digestibility of DM and most of the other chemical constituents of the treatment diets by Dorper wether lambs increased or showed very small decreases as the trial progressed from Cage Period 1 to Cage Period 3, regardless of the treatment diets. Einkamerer (2008) also observed a similar trend, which may suggest that with time the Dorper wether lambs became better adapted to the treatment diets in the trial.

The lack of significant differences in most of the chemical constituents of treatment diets in terms of daily intake and apparent digestibility suggest that inclusion of sun-dried and coarsely ground *Opuntia* cladodes in the diets, as well as the different types of nitrogen, did not have a marked influence on those variables.

3.4 Water intake and urine excretion

In this study neither the inclusion of sun-dried and coarsely ground *Opuntia* cladodes in the treatment diets nor the quality of nitrogen in the diet had any significant influence ($P>0.05$) on the daily water intake by the Dorper wether lambs (Table 3.9).

Although not significantly different ($P>0.05$), Dorper wether lambs fed treatment diets T2 and T0 tended to have a higher daily water intake than those fed treatment diet T1. These results are in line with those reported by Zeeman (2005), Einkamerer (2008) and Menezes (2008). These authors reported that the daily water intake by Dorper wether lambs tended to increase with higher inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes in the diet. Part of the higher water intake was simply induced by the higher feed intake.

Table 3.9 The average (mean \pm s.e.) daily water intake during the three cage periods by Dorper wether lambs

	Treatment diets			P	CV ¹ (%)
	T0	T1	T2		
Cage Period 1 (ml/day)	1831.3 \pm 324.9 ^a	1840.0 \pm 233.5 ^a	2002.3 \pm 328.0 ^a	0.902	35.3
Cage Period 2 (ml/day)	2582.9 \pm 165.4 ^a	2032.3 \pm 273.6 ^a	2218.6 \pm 196.4 ^a	0.229	21.3
Cage Period 3 (ml/day)	2519.7 \pm 282.1 ^a	2110.9 \pm 306.9 ^a	2787.4 \pm 292.5 ^a	0.298	26.6

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 30-33% sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different ($P < 0.05$)

¹ Coefficient of variance

In this study, daily water intake by Dorper wether lambs increased as the trial progressed from Cage Period 1 to Cage Period 3 (Tables 3.9), regardless of the treatment diets.

Inclusion of sun-dried and coarsely ground *Opuntia* cladodes in the treatment diets or the type of nitrogen source used had no significant effect ($P>0.05$) on the urine excretion (Table 3.10) by Dorper wether lambs during the three cage periods.

Similar to the daily water intake, urine excreted by Dorper wether lambs increased as the trial progressed from Cage Period 1 to Cage Period 3, regardless of the treatment diets.

3.5 Faecal excretion

During the Cage Periods 1 and 2, no significant differences ($P>0.05$) were observed in the faecal DM excretion by Dorper wether lambs (Table 3.11) among treatment diets. However, faecal DM excretion differed significantly ($P<0.001$) among treatment diets during Cage Period 3. These results are also in line with the lower NDF intake of lambs fed treatment diet T1 during this last Cage Period 3 (Table 3.7).

Table 3.10 The average (mean \pm s.e.) daily urine excreted during the three cage periods by Dorper wether lambs

Chemical constituents	Treatment diets *			P	CV ¹ (%)
	T0	T1	T2		
Cage Period 1 (ml/day)	420.3 \pm 71.9 ^a	571.3 \pm 52.6 ^a	637.0 \pm 138.1 ^a	0.291	39.1
Cage Period 2 (ml/day)	573.1 \pm 77.3 ^a	666.0 \pm 106.9 ^a	692.3 \pm 109.7 ^a	0.679	34.4
Cage Period 3 (ml/day)	1102.5 \pm 183.7 ^a	804.9 \pm 135.5 ^a	1144.6 \pm 187.8 ^a	0.341	37.5

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different ($P < 0.05$)

¹ Coefficient of variance

Irrespective of the dietary treatments, faecal DM excreted by Dorper wether lambs increased as the trial progressed from Cage Period 1 to Cage Period 3. Overall, the Dorper wether lambs fed treatment diets T2 and T0 excreted similar quantities of faecal DM in all three cage periods, which were higher than for treatment diet T1.

Table 3.11 The average (mean \pm s.e.) faecal DM excreted during the three cage periods by Dorper wether lambs

Faeces excreted	Treatment diets*			P	CV ¹ (%)
	T0	T1	T2		
Cage Period 1 (g DM/day)	316.8 \pm 80.7 ^a	216.4 \pm 37.9 ^a	321.5 \pm 33.0 ^a	0.073	25.7
Cage Period 2 (g DM/day)	342.0 \pm 20.7 ^a	285.7 \pm 6.0 ^a	343.8 \pm 19.3 ^a	0.049	11.5
Cage Period 3 (g DM/day)	424.3 \pm 6.2 ^a	319.1 \pm 15.1 ^c	381.4 \pm 16.7 ^b	<0.001	8.0

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b,c} Means with different superscripts within a row are significantly different ($P < 0.05$)

¹ Coefficient of variance

3.6 Conclusions

In general, the inclusion of sun-dried and coarsely *Opuntia* cladodes at 300 or 330 g/kg of the feedlot diets had little or no effect on the feed intake and digestibility of the treatment diets of Dorper wether lambs. Exceptions were observed for the intake and apparent digestibility of ADF and NDF as a result of different fibre contents of the treatment diets. Similar water intake and urine excretion were observed for Dorper wether lambs fed any one of the treatment diets during the three cage feeding periods.

In line with the above conclusions, a similar faecal DM excretion was observed for all three the treatment groups during the first two cage feeding periods. However, during the third cage feeding period, the Dorper wether lambs fed treatment diet T1 excreted less faecal DM, probably as a result of the lower fibre (ADF and NDF) content of treatment diet T1.

Both hypotheses stated at the beginning of this part of the study were confirmed, namely that the feed intake and apparent digestibility of the feedlot diets for Dorper wether lambs would not be affected by: (1) the inclusion of sun-dried and coarsely ground *Opuntia* cladodes at 300 to 330 g/kg; and (2) the nitrogen source used (NPN or natural protein).

4. Growth performance and carcass characterisation

As discussed previously in Chapter 3, commercial lamb and mutton production is an important part of the livestock industry in South Africa and Namibia. Weaned lambs as well as culled ewes and rams are sold to feedlots where they are fattened to improve carcass grading quality before being slaughtered. The feedlot diets invariably include good quality roughage such as lucerne hay. Therefore, it is common to use short intensive feeding periods to fatten or “round off” animals before slaughtering. This is done at feedlots both on farm or at specialised enterprises.

Over the past decade, sun-dried and coarsely ground *Opuntia* cladodes have been used experimentally as a feed source for ruminants. Previous studies by Zeeman (2005), Einkamerer (2008) and Menezes (2008) at the University of the Free State, Bloemfontein clearly demonstrated that sun-dried and coarsely ground *Opuntia* cladodes can replace a substantial part of lucerne hay (up to an inclusion level of 360 g/kg) in diets for young Dorper wether lambs.

The growth performance and carcass characteristics are important when finishing lambs in a feedlot. These aspects have been reported for Dorper lambs under intensive conditions by Milne (2000), Cloete *et al.* (2000), Staab *et al.* (1999), Notter *et al.* (2004), Snowden and Duckett (2003) and Daniel and Held (2005). However, none of these studies have used *Opuntia* as part of the feedlot diets. Therefore, this study focused on evaluating two feedlot diets for Dorper wether lambs, containing inclusion levels of about 1/3 sun-dried and coarsely ground *Opuntia* cladodes of the total diet and two different nitrogen sources (NPN and a natural protein).

Three treatment diets were used in this study (see section 2.4) and it was hypothesized that Dorper wether lambs fed *Opuntia*-based diets:

- 1) will have the same growth performance and carcass characteristics in a feedlot than those fed a conventional feedlot diet.
- 2) with the inclusion of two different nitrogen sources, namely non-protein nitrogen (NPN) or natural protein, will not affect growth performance and carcass characteristics.

To test these hypothesis, a conventional feedlot diet (T0) was used as control diet and compared with two *Opuntia*-based diets (T1 and T2) containing two different nitrogen sources, namely feed grade urea (an NPN source) or sunflower oilcake meal (natural protein source). The composition of the treatment diets (T1, T2 and T3) is shown in Table 3.1. Full detail of the methodology used in this study is presented in Chapter 2.

4.1 Growth performance of Dorper wether lambs

The live body weight changes of Dorper wether lambs fed treatment diets T0 and T2 were slightly higher ($P>0.05$) than those fed treatment diet T1 (Figure 4.1), but their growth curves were very similar until the end of the feeding trial period.

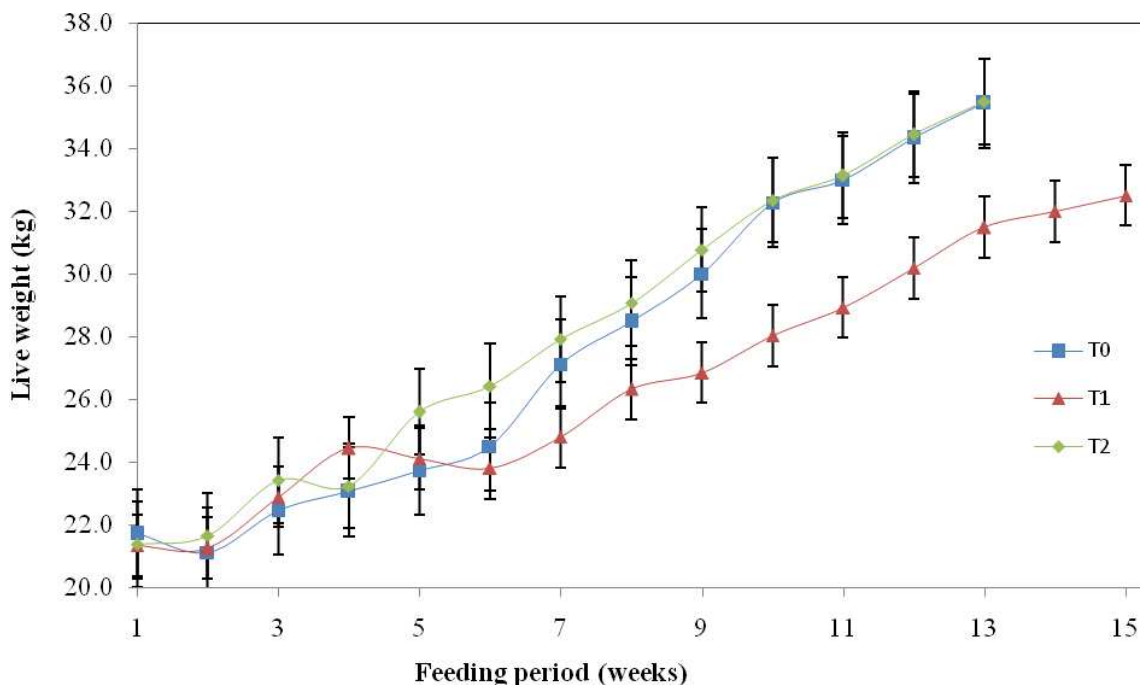


Figure 4.1 Average live body weight of Dorper wether lambs during the feeding period in the feedlot

Average initial body weight of the Dorper wether lambs was the same for all three treatment diets (Table 4.1), but the Dorper wether lambs fed treatment diets T0 and T2 reached the target weight of 35 kg for slaughtering after about 11 weeks. Two weeks later the Dorper wether lambs fed treatment diet T1 were still weighing on average only about 32.5 kg (Table

4.1) and it was decided to slaughter them. However, in terms of live body weight changes, there were no significant differences ($P>0.05$) among treatments.

Table 4.1 Performance of the Dorper wether lambs during the feeding period in the feedlot and the cost of diets

Variable	Treatment diets *			P	CV ¹ %
	T0	T1	T2		
Initial live body weight (kg)	21.23±0.55 ^a	21.13±0.46 ^a	21.67±0.50 ^a	0.730	9.13
Final live body weight (kg)	35.46±0.11 ^a	32.43±0.53 ^a	35.60±0.64 ^a	0.057	11.0
Total weight gain (kg)	13.90±0.41 ^a	11.30±0.09 ^a	13.93±0.32 ^a	0.064	25.6
Average daily weight gain (ADG) (g)	180.6±3.7 ^a	125.4±0.8 ^b	181.0±2.9 ^a	<0.001	24.6
Feed intake (kg DM/day/head)	1.147±0.050 ^a	1.131±0.071 ^a	1.209±0.022 ^a	0.538	7.3
FCR (kg DM intake/kg gain)	6.07±0.73 ^b	8.25±0.27 ^a	6.11±0.16 ^b	0.036	10.9
Cost of diet/kg (N\$)	3.14±0.01 ^a	2.42±0.02 ^b	2.70±0.01 ^b	0.001	0.9
Cost of diet/head/day (N\$)	3.71±0.18 ^a	2.73±0.19 ^b	3.26±0.01 ^b	0.007	5.7
Feeding period (days)	77	91	77		

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different ($P < 0.05$)

¹ Coefficient of variance

The observations in this study on the live body weight of Dorper wether lambs fed *Opuntia*-based diets were in agreement with the findings by Zeeman (2005), Einkamerer (2008) and Menezes (2008). Their studies showed that the inclusion of 360 g/kg sun-dried and coarsely ground *Opuntia* cladodes in diets did not have a significant effect on live body weight of Dorper wether lambs. However, it must be noted that the Dorper wether lambs used in the studies by Zeeman (2005), Einkamerer (2008) and Menezes (2008) were older and also heavier than those used in this study. Therefore, comparisons of animal performance must be viewed with caution.

In this study, the average daily gain (ADG) of the young Dorper wether lambs (Table 4.1) was significant ($P<0.05$) lower for Dorper wether lambs fed treatment diet T1 compared to those fed treatment diets T2 and T0.

When comparing the two *Opuntia*-based diets (T1 and T2), the ADG was significantly higher ($P < 0.05$) for lambs fed the diet containing natural protein (T2) (Table 4.1) than for those fed the diet with NPN (T1). Degu *et al.* (2008) reported similar results, namely that plant oilcake meals enhanced the growth performance of lambs on *Opuntia*-based diets.

The differences in ADG observed between treatment diets T1 and T2 could be partially attributed to the quality of N sources, specifically the amino acid profile, used to balance the *Opuntia*-based diets. Feed grade urea, an NPN source, was included in treatment diet T1 and sunflower oilcake meal (a source of natural plant protein) was included in treatment diet T2. Unlike the NPN source, the natural protein source provided amino acids and promoted better growth in animals. Newly weaned young lambs that have recently still been suckling, may still be lacking in development of the reticulo-rumen and is, therefore, still more dependent on dietary amino acids. As emphasised by Schilling (2005), protein is an essential dietary element that is necessary for proper soft tissue development in growing lambs and sufficient protein should therefore be provided to promote the desired growth rates.

It has been well documented (Sirohi *et al.*, 1997; Ben Salem *et al.*, 2002; 2004; Misra *et al.*, 2006; Tegegne *et al.*, 2005) that *Opuntia* cladodes have a low protein content and, therefore, additional N should be included in *Opuntia*-based diets to improve its nutritive value. Mendez-Llorente *et al.* (2008) observed improved growth by lambs fed an *Opuntia*-based diet containing fish meal. A similar observation was made by Misra *et al.* (2006) when groundnut meal was included in an *Opuntia*-based diet. Therefore, the results of the current study are in agreement regarding the positive effects of the inclusion of a natural protein source in *Opuntia*-based diets to promote growth of lambs.

Level of feed intake can have a great affect on the cost of livestock production (Schilling, 2005). This author stated that although a lower daily feed intake results in corresponding decreases in the cost of feeding, it also reduces average daily gain (ADG) and increases the number of days required to reach the target weight. As shown previously in Table 4.1, the Dorper wether lambs fed treatment diets T0 and T2 had higher ADG's and thus required fewer days to reach the target slaughter weight than Dorper wether lambs fed treatment diet T1. Furthermore, the Dorper wether lambs fed treatment diet T1 (containing NPN) failed to reach the target average body weight of 35 kg. It was therefore decided to slaughter these Dorper wether lambs after 91 days in the feedlot at an average body weight of 32.5 kg.

Efficiency of gain or feed conversion ratio (FCR) is another important determinant of feedlot efficiency. According to Schilling (2005), a decrease in the quantity of feed needed by an animal to reach a target weight may increase profitability. The results presented in Table 4.1 show that the Dorper wether lambs fed treatment diets T0 and T2 had a similar FCR, but these FCR's were significantly better ($P < 0.05$) than those fed treatment diet T1. Thus, the Dorper wether lambs fed treatment diet T1 required more feed than those fed treatment diets T0 and T2 to gain the same live body weight in the feedlot.

The basic information used for estimating the cost of the diets (Table 4.1) was derived mainly from the prices of different ingredients used to formulate the treatment diets and the quantity of feed eaten by the Dorper wether lambs during the feeding periods in the feedlot (see Chapter 3 for detail).

The information presented in Table 4.1 was used to estimate the cost of feeding one Dorper wether lamb a conventional feedlot diet (treatment diet T0) to reach a target slaughter weight of 35 kg after 77 days. This amounts to a total feed cost of N\$278.20 per head. However, it required N\$26.96 less in feed cost for a lamb fed treatment diet T2 to reach the target slaughter weight of 35 kg after the same feeding period of 77 days. Although, it took longer (91 days) for Dorper wether lambs fed treatment diet T1 to approach the target slaughter weight, the feed costs were however less than for treatment diets T0 and T2, namely N\$29.39 and N\$2.43 per head respectively. This can be partly explained by the lower unit cost of diets and cost of diet/head/day for treatment diet T1 compared to treatment diets T0 and T2.

4.2 Carcass evaluation

4.2.1 Carcass weight and dressing percentage

Carcass characteristics of the Dorper wether lambs in the three treatment groups (T0, T1 and T2) are presented in Table 4.2. The hot and cold carcass weights did not show significant differences ($P > 0.05$) among treatment diets. This was expected because the target live weight of 35 kg was predetermined. The dressing percentage was, however, slightly significantly ($P < 0.06$) higher for Dorper wether lambs fed the *Opuntia*-based treatment diets (T1 and T2) than those fed the conventional feedlot diet (T0).

Results of carcass weight for Dorper wether lambs fed *Opuntia*-based diets at an inclusion level of 300 to 330 g/kg were slightly lower than those (17.77 kg) reported by Einkamerer (2008) at a similar inclusion level of sun-dried and coarsely ground *Opuntia* cladodes. However, the Dorper wether lambs in the study by Einkamerer (2008) were older and heavier than those used in the present study.

4.2.2 Carcass value characteristics (grading)

Carcass value characteristics (grading) were assessed according to visible subcutaneous fat cover and leanness of the meat. According to Snowden and Duckett (2003), the fat cover over the *musculus longissimus dorsi* is a very important aspect of the carcass grading and value.

In addition, Lovandini *et al.* (2006) stated that a fattening score and conformation of carcasses are criteria that define carcass quality. Carcasses finished with good conformation tend to fetch a better price/kg at sale, especially in countries with a tradition of lamb and mutton production, as it is the case for Namibia and South Africa.

In the present study, fatness score and conformation did not differ significantly ($P>0.05$) among treatment diets (Table 4.2). After visual evaluation of the fatness score, all carcasses of the Dorper wether lambs in the three treatment diets fell between the second and the third quality grades, in the score range of 2.43 to 2.86. For conformation score, the carcasses varied from a score of 3.86 to 4.36. Moreover, the fatness score and the average fat thickness of Dorper wether lambs fed treatment diet T1 tended to be numerically slightly higher than for treatment diets T0 and T2 (Table 4.2).

The carcass quality grades and prices obtained by Dorper wether lambs are shown in Table 4.3. Most of the Dorper wether lambs fed treatment diets T2 and T0 obtained the highest possible grade (A2), with 66.7% of the lambs in treatment diet T2 and 53.8% in treatment diet T0. Fifty percent of the Dorper wether lambs fed treatment diet T1 obtained the second highest possible carcass quality grade (A3).

Table 4.2 Slaughter weight and carcass characteristics of the Dorper wether lambs fed three treatment diets in a feedlot

Variables	Treatment diets *			P	CV ¹ %
	T0	T1	T2		
Carcass weight and dressing percentage					
Slaughter weight (kg)	35.46±0.06 ^a	32.53±0.55 ^a	35.57±0.61 ^a	0.057	11
Hot carcass weight (kg)	16.77±0.36 ^a	16.33±0.54 ^a	17.69±0.51 ^a	0.133	10.5
Cold carcass weight (kg)	16.26±0.06 ^a	15.85±0.12 ^a	17.16±0.17 ^a	0.130	10.8
Hot carcass dressing (%)	47.30±0.17 ^b	50.62±0.67 ^a	49.62±0.44 ^a	0.006	5.3
Carcass value characteristics (grading)					
Fatness code (score 0 to 6)	2.57±0.23 ^a	2.86±0.23 ^a	2.43±0.17 ^a	0.357	30.3
Conformation (score 1 to 5)	4.36±0.20 ^a	3.86±0.27 ^a	3.86±0.14 ^a	0.171	19.7
Carcass measurements					
Carcass external length (cm)	55.59±0.75 ^a	51.65±1.07 ^b	57.13±0.52 ^a	<0.001	5.5
Shoulder circumference (cm)	29.16±0.61 ^a	26.11±0.39 ^a	23.54±1.64 ^b	0.002	14.7
Buttock circumference (cm)	41.71±0.42 ^a	41.59±0.60 ^a	41.36±0.77 ^a	0.920	5.5
<i>musculus longissimus dorsi</i> width (cm)	5.63±0.20 ^a	5.86±0.20 ^a	5.85±0.07 ^a	0.113	5.7
<i>musculus longissimus dorsi</i> depth (cm)	2.78±0.07 ^a	2.96±0.11 ^a	2.87±0.08 ^a	0.354	10.9
pH1	5.84±0.07 ^a	5.71±0.01 ^a	5.76±0.08 ^a	0.425	4.8
pH24	5.54±0.05 ^a	5.62±0.02 ^b	5.65±0.03 ^b	0.021	2.0
Fat thickness					
Fat thickness was measured at ¼ position on the 12th rib from the chine bone end	2.93±0.32 ^b	4.54±0.61 ^a	3.91±0.29 ^a	0.042	43.1
Fat thickness was measured at ½ position on the 12th rib from the chine bone end	6.32±0.99 ^a	4.17±0.51 ^b	4.00±0.45 ^b	0.041	53.6
Fat thickness was measured at ¾ position on the 12th rib from the chine bone end	6.76±0.83 ^a	8.35±0.91 ^a	7.31±0.59 ^a	0.362	39.3
Average fat thickness	5.34±0.06 ^a	5.69±0.07 ^a	5.08±0.13 ^a	0.746	40.6

* T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different (P < 0.05)

¹ Coefficient of variance

Based on the grading of carcasses, Dorper wether lambs fed treatment diet T2 obtained on average the highest price of N\$24.35/kg, while those fed treatment diets T0 and T1 on average obtained N\$ 23.50/kg and N\$23.67/kg, respectively (Table 4.3).

Table 4.3 Carcass grades and prices per kg obtained by the Dorper wether lambs fed the three treatment diets

Carcass grades obtained (%)	Treatment diets*		
	T0	T1	T2
	%	%	%
A2	53.8	36	66.7
A3	38.5	50	26.7
A4	7.7	7	6.7
A5		7	
Carcass price (N\$/kg)	23.80	23.67	24.35

* T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 to 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

4.2.3 Carcass measurements

Except for the external carcass length, shoulder circumference and pH24 (Table 4.2), there were no significant differences ($P>0.05$) in all other carcass measurements between the Dorper wether lambs on the different treatment diets. The external carcass length of the Dorper wether lambs was highly significantly different ($P<0.001$), with treatment diets T2 and T0 being the longest and treatment diet T1 recording the shortest carcasses. These values are in line with the differences in ADG (Table 4.1). The values for shoulder circumference were higher ($P<0.05$) for Dorper wether lambs fed treatment diet T0 than the two *Opuntia*-based diets, with Dorper wether lambs fed on treatment diet T2 being the lowest.

The results in Table 4.2 also indicate that pH measured in the left *musculus longissimus dorsi* of the carcasses 1 hour (pH1) after slaughtering were similar ($P>0.05$) for all treatment diets. However, pH measured 24 hours (pH24) post-mortem was significantly ($P<0.05$) lower for carcasses of Dorper wether lambs fed treatment diet T0 compared to those fed treatment diets T1 and T2. According to Lapenga *et al.* (2009), the pH usually indicates the preservation quality of the meat and that good quality meat usually has a pH of 5.4 to 5.7. Although there

were significant differences ($P < 0.05$) between treatments after 24 h, the pH₂₄ values were all within the normal range.

The ultimate pH, also referred to as the final pH of the meat, is usually reached 24 hours post-mortem. This pH is attained either by depletion of glycogen reserves in muscles or when the pH has reached a point at which enzymes become inactive (Sebsibe, 2009; Jeremiah *et al.*, 1991). Deviation from a normal pH range has the potential to produce carcasses that are more susceptible to microbial contamination.

4.2.4 Fat thickness

Average fat thickness over the *musculus longissimus dorsi* taken at three different positions on the 12th rib obtained in this study (Table 4.2) were not significantly ($P > 0.05$) different.

However, fat thickness varied across the three different positions over the *musculus longissimus dorsi* (or the eye muscle) on the 12th rib (Table 4.2), which could be suggesting a trend of uneven distribution of subcutaneous fat over the loin. Daniel and Held (2005) observed a fat thickness of 5.5 mm between the 12th and 13th rib in Dorper-sired lambs with an average carcass weight of 26.6 kg. However, irrespective of the nutritional influence, Cloete *et al.* (2000) reported that Dorper sheep are early maturing and capable of depositing fat at an early age and lighter weight than most other mutton breeds in South Africa.

4.2.5 Carcass composition

Daskiran *et al.* (2006) emphasised that tissue analysis for experimental purposes on whole or half carcasses requires much more time and labour beside the economical loss incurred when selling carcasses from this type of trial than when estimates are used. Therefore, only a 3-rib cut (9th to 11th ribs) was used for tissue analysis in this study in order to speed up analysis and cost-effective determination of tissue composition (Table 4.4).

Although slight variations were observed, the treatment effect was not significant when the proportions of muscle and bone were expressed as percentage of the 9th through 11th rib cut. However, with regard to tissues, the fat composition of carcasses of Dorper wether lambs fed treatment diet T2 was significantly ($P < 0.05$) higher than those fed treatment diets T0 and T1. Nevertheless, the carcasses were given a similar carcass grading, regardless of the treatment

diet used. This means that although there were differences in tissue composition, it had no effect on the carcass grading.

Table 4.4 Proportion of the muscle, bone and fat of the 3-rib cut from carcasses of the Dorper wether lambs

Tissue	Treatment diets *			P	CV ¹ %
	T0	T1	T2		
Muscle (%)	54.34±0.35 ^a	51.33±0.42 ^a	49.72±0.77 ^a	0.087	10.5
Fat (%)	25.00±0.80 ^b	25.20±0.00 ^b	31.30±0.80 ^a	0.026	24.6
Bone (%)	20.62±0.44 ^a	23.45±0.45 ^a	18.97±0.01 ^a	0.146	28.3

*T0 - conventional feedlot diet; *Opuntia*-based diets T1 & T2 – 330 and 300 g/kg sun-dried and coarsely ground *Opuntia* cladodes, with different nitrogen sources (T1 – NPN and T2 – Natural protein)

^{a,b} Means with different superscripts within a row are significantly different (P < 0.05)

¹ Coefficient of variance

4.3 Conclusions

The lack of significant differences in most of the carcass characteristics considered in this study suggest that carcass quality is not markedly affected by inclusion of sun-dried and coarsely ground *Opuntia* cladodes in feedlot diets (up to 300 or 330 g/kg) for Dorper wether lambs or by the type of nitrogen source used. Thus, the carcasses of the Dorper wether lambs fetched very similar prices per kg. The Dorper wether lambs fed treatment diet T1 were not able to reach the average target slaughter weight of 35 kg. Therefore, their carcasses with a lower weight and poorer grading fetched a lower price per carcass.

5. Conclusions and recommendations

Recent studies have established experimentally the potential of sun-dried and coarsely ground *Opuntia* cladodes as an alternative feed source for ruminants. Therefore, this study focused on the intake and digestibility, growth performance and carcass characteristics of young Dorper wether lambs fed sun-dried and coarsely ground *Opuntia*-based feedlot diets with two different nitrogen sources, namely an NPN (feed grade urea) or a natural protein source (sunflower oilcake meal).

Chemical analysis of the three treatment diets used in this study showed that acid-detergent fibre (ADF), neutral-detergent fibre (NDF), organic matter (OM) and gross energy (GE) have decreased with inclusion of sun-dried and coarsely ground *Opuntia* cladodes, which is ascribed to the lower ADF, NDF, OM and GE content of the *Opuntia* cladodes. On the other hand, ash and lipids increased with inclusion of sun-dried and coarsely ground *Opuntia* cladodes in the treatment diets.

The inclusion of sun-dried and coarsely ground *Opuntia* cladodes at 330 or 300 g/kg in the treatment diets in general had little or no effect on the feed intake and digestibility by Dorper wether lambs. Exceptions were observed for the intake and apparent digestibility of ADF and NDF as a result of the different fibre content of the treatment diets. Similar water intake and urine excretion were observed for Dorper wether lambs fed any one of the treatment diets during the three cage feeding periods.

Two hypotheses were formulated for the study and were confirmed by the results, namely that the feed intake and apparent digestibility of the feedlot diets for Dorper wether lambs would not be affected by: (1) the inclusion of sun-dried and coarsely ground *Opuntia* cladodes at 330 and 300 g/kg; or (2) two nitrogen sources used (NPN or natural protein) in the *Opuntia*-based diets.

Considering the results of the Cage Periods 1 to 3, it can be summarised that both the daily intake and apparent digestibility of DM and other chemical constituents of Dorper wether lambs increased or showed very little decreases as the trial progressed, regardless of the

treatment diets. It suggests that the reticulo-rumen of Dorper wether lambs were getting better adapted over time to the diets and consequently improved digestibility.

Feedlot performance in terms of average daily gain and feed conversion efficiency of Dorper wether lambs fed the *Opuntia*-based diet supplemented with natural protein were comparable to the conventional feedlot diet. The Dorper wether lambs fed the *Opuntia*-based diet supplemented with NPN had a lower growth rate than those fed the conventional feedlot diet and the *Opuntia*-based diet supplemented with natural protein. Feed conversion efficiency for treatment diet T1 (8.25) was significantly ($P>0.05$) different from treatment diets T0 (6.07) and T2 (6.11). Dorper wether lambs fed the conventional diet and the *Opuntia*-based diet supplemented with natural protein required less feed to gain weight than those fed an *Opuntia*-based diet supplemented with NPN. This suggests that, supplementing an *Opuntia*-based feedlot diet with a natural protein source will markedly improve feed efficiency and average daily gains of lambs compared to NPN. This may reduce the feeding period required to reach the target slaughter weight and increase the economic benefit associated with the use of sun-dried and coarsely ground *Opuntia* cladodes in feedlot diets.

There was a lack of significant differences in most of the carcass characteristics considered. This suggests that carcass quality is not markedly affected by inclusion of sun-dried and coarsely ground *Opuntia* cladodes in feedlot diets (up to 330 or 300 g/kg) for Dorper wether lambs or by the type of nitrogen source used to balance the feedlot diets. Furthermore, the carcasses of the Dorper wether lambs fed the three different treatment diets fetched very similar prices per kg. However, the Dorper wether lambs fed treatment diet T1 (*Opuntia*-based diet with the inclusion of additional nitrogen in the form of feed grade urea, an NPN source) were not able to reach the average target slaughter weight of 35 kg, even after 91 days in the feedlot. Therefore, their lighter carcasses at slaughter fetched a lower total price per carcass.

The natural protein source (sunflower oilcake meal) improved the nutritive value of an *Opuntia*-based diet and promoted better growth of Dorper wether lambs compared to those on an *Opuntia*-based diet balanced with an NPN source such as feed grade urea. The results of this study support the findings by other studies emphasising that dietary protein, specifically amino acids, is necessary for proper soft tissue development in growing lambs, and should therefore be provided in sufficient amounts to get the desired growth rates.

The results of this study, the fourth study under the auspices of the UFS, opened the prospect of formulating affordable *Opuntia*-based diets for specific application to ruminant species of different ages and production classes. However, more research is needed to evaluate the growth performance, carcass characteristics and profitability of other small stock breeds and ruminant species fed sun-dried and coarsely ground *Opuntia* cladodes in feedlot diets, balanced with different nitrogen sources.

6. References

- AOAC, 2000. Official Methods of Analysis of AOAC International. Vol.1. 17th Edn. Editor Horwitz, W. AOAC International®.
- Agri Laboratory Association of Southern Africa (AgriLASA), 2007. Plant and Feed Analysis Handbook. 2nd Edition.
- Anil, M.H., Yesildre, T., Aksu, H., Matur, E., McKinstry, J.L., Erdogan, O., Hughes, S. & Mason, C., 2004. Comparison of religious slaughter of sheep with methods that include pre-slaughter stunning, and the lack of differences in exsanguinations, packed cell volume and meat quality parameters. *Animal Welfare* 13, 387-392.
- Azocar, P., 2001. *Opuntia* as feed for ruminants in Chile. In: Cactus (*Opuntia* spp.) as forage. Eds. Mondragon-Jacobo, C. & Perez-Gonzalez, S. FAO Plant Production and Protection Paper 169. Food and Agricultural Organization of the United Nations, Rome. pp. 57-62.
- Batista, A.M.V., Mustafa, A.F., Santos, G.R.A., De Carvalho, F.F.R., Dubeux, J.C.B., Lira, M.A. & Barbosa, S.B.P., 2003. Chemical Composition and Ruminal Dry Matter and Crude Protein Degradability of Spineless Cactus. *Journal of Agronomy and Crop Science* 189, 123-126.
- Ben Salem, H., Nefzaoui, A. & Ben Salem, L., 2004. Spineless cactus (*Opuntia ficus-indica* f. *inermis*) and oldman saltbush (*Atriplex nummularia* L.) as alternative supplements for browsing Barbarine lambs given straw-based diets. *Small Ruminant Research* 51, 65-73.
- Ben Salem, H., Nefzaoui, A., & Ben Salem, L., 2002. Supplementing spineless cactus (*Opuntia ficus indica* var. *inermis*) based diets with urea-treated straw or oldman saltbush (*Atriplex nummularia*). Effect on intake, digestion and sheep growth. *Journal of Agricultural Science* 138, 85-92.
- Ben Salem, H., Nefzaoui, A., Abdouli, H. & Ørskov, E.R., 1996. Effect of increasing level of spineless cactus (*Opuntia ficus indica* var. *inermis*) on intake and digestion in sheep given straw based diets. *Journal of Animal Science* 62, 293–299.

- Brindle, B., Blue N., Bunnage, K., Chase, D., Jaipaul, R., Machielse, M., Melvill, L., Walkey, D., Woloshyn, P. & Wong, D., 2000. Breakeven analysis for feeder cattle: Economics and Marketing: Alberta feedlot management guide 2nd Edition. Available on line at <http://www1.agric.gov.ab.ca/Department/deptdocs.nsf/all/sis10772>.
- Broudiscou, L.P., Papon, Y. & Broudiscou, A., 1999. Effect of inorganic nitrogen and amino acids on the degradation of ammonia-treated barley straw and proteosynthesis in a continuous culture of rumen microbes. *Animal Feed Science Technology* 77, 149-162.
- Brutsch, M.O. & Zimmermann H.G., 1993, The Prickle Pear (*Opuntia ficus-indica* [Cactaceae]) In South Africa: Utilization of the Naturalized Weed, and of the Cultivated Plants. *Economic Botany* 47(2), 154-162.
- Brutsch, M.O. & Zimmermann, H.G., 1995. Control and utilization of wild opuntias. In: Agro-ecology, cultivation and uses of cactus pear. Eds. Barbera, G., Inglese, P. & Pimienta-Barrios, E.. FAO Plant Production and Protection Paper 132. Food and Agriculture Organization of the United Nations, Rome. pp. 155-166.
- Cloete, S.W.P., Snyman, M.A. & Herselman, M.J., 2000. Productive performance of Dorper sheep. *Small Ruminant Research* 36, 119-135.
- Daniel, J.A. & Held, J., 2005. Carcass and growth characteristics of wethers sired by White Dorper or Hampshire Rams. *Sheep and Goat Research Journal* 20, 47-50.
- Daskiran, M., Bingol A., Kor A., Demir A.O, Yilmaz, A. & Karaca S., 2006. Feedlot performance and carcass characteristics of Norduz male kids. *Journal of Animal Veterinary Advances* 5(5), 430-433.
- De Kock, G.C., 1980. Drought resistant fodder shrubs in South Africa. In: H.N. LeHouerou (ed.) Browse in Africa. The current state of knowledge. Papers presented at the International Symposium on Browse in Africa, Addis Ababa, International Livestock Center for Africa, pp. 399–408.
- De Kock, G.C., 2001. The use of *Opuntia* as a fodder source in arid areas of southern Africa. In: Cactus (*Opuntia* spp.) as forage. C. Mondragon-Jacobo and S. Perez-Gonzalez (ed.) FAO Plant Production and Protection Paper 169, FAO, Rome, Italy. pp. 101–105.

- De Waal, H.O., Zeeman, D.C. & Combrinck, W.J., 2006. Wet faeces produced by sheep fed dried spineless cactus pear cladodes in balanced diets. *South African Journal of Animal Science* 36, 10-13.
- Einkamerer, O.B., 2008. Animal performance and utilization of *Opuntia*-based diets by sheep. M.Sc. Agric. Thesis. University of the Free State, Bloemfontein, South Africa.
- Felker, P., 1995. Forage and fodder production and utilization. *In*: Barbera, G., Inglese, P., Pimienta-Barrios, E. (Eds.), *Agro-ecology, Cultivation and Uses of Cactus Pear*, vol. 132. FAO Plant Production and Protection Paper, Rome, pp. 144–154.
- Felker, P., Paterson, A. & Jenderek, M.M., 2006. Forage Potential of *Opuntia* Clone Maintained by the USDA, National Plant Germplasm System (NPGS) Collection. *Crop Science* 46, 2161–2168.
- Firew, T., 2001. *In vivo* assessment of the nutritional value of cactus pear (*Opuntia ficus-indica*) as a substitute to grass hay in sheep rations. Proceedings, 9th Annual Conference, Ethiopian Society of Animal Production, Addis Ababa, pp. 225–234.
- Fuentes-Rodriguez, J., 1997. Feeding prickly pear cactus to small ruminants in northern Mexico. I. Goats. *J. PACD* 2, 23-25.
- Gebremariam, T., Melaku S. & Yami A., 2006. Effect of wilting of cactus pear (*Opuntia ficus-indica*) on feed utilization in sheep. *Tropical Science* 46(1), 37-40.
- Goering, H.K. & Van Soest, P.J., 1970. Forage fibre analysis. U.S.D.A. Agricultural Handbook, No 379.
- Gokdal, O., Ulker, H., Karakus F., Cengiz F., Temur C., and Handil, H., 2004. Growth, feedlot performance and carcass characteristics of Karakas and crossbred lambs (F₁) (Ile de France x Akkaraman (G₁) x Karakas) under rural farm conditions in Turkey. *South African Journal of Animal Science* 34(4), 223-232.
- Government Notice No. R. 863, 1 September 2006. Regulation Gazette No. 4890, Government Gazette of South African No. 14046, vol. 3245: Meat Classification System for beef, lamb, mutton and goat meat.
- Gruber, S.L., Tatum, J.D., Engle, T.E., Mitchell, M.A., Laudert, S.B., Schroeder, A.L. & Platter, W.J., 2007. Effects of ractopamine supplementation on growth and carcass

- characteristics of feedlot steers differing in biological type. *Journal of Animal Science* 85, 1809-1815.
- Jeremiah, L.E., 1998. Development of a quality classification system for lamb carcasses. *Meat Science* 48, 11-223.
- Jeremiah, L.E., Tong, A.K. & Gibson, L.L., 1991. The usefulness of muscle color and pH for segregating beef carcasses into tenderness groups. *Meat Science* 30, 97-114.
- Jones, S.D.M., Richmond, R.J. & Robertson, W.M., 1995. Beef carcass grading or classification using video image analysis. *Reciprocal Meat Conference* 48, 81-85.
- Khalafalla, M.M., Abdellatef, E., Mohameed Ahmed, M.M. & Osman, M.G., 2007. Micropropagation of Cactus (*Opuntia ficus-indica*) as strategic tool to combat desertification in arid and semi arid regions. *International Journal of Sustainable Crop Production* 2(4), 1-8.
- Lapenga, K.O., Ebong, C. & Opuda-Asibo, J., 2009. The effect of feed supplements on weight and carcass characteristics of intact male Mubende goats fed elephant grass (*Pennisetum purpureum*) *ad libitum* in Uganda. *Journal of Animal Veterinary Advances* 8(10), 2004-2008.
- L´opez-Garcia, J.J., Fuentes, R.J.M. & Rodriguez, R.A., 2001. Production and use of *Opuntia* as forage in northern Mexico. In: Mondragon, C., Gonzalez, S. (Eds.), *Cactus (Opuntia spp.) as Forage*, vol. 169. FAO Plant Production and Protection Paper 163, pp. 29–36.
- Louvandini, H., McManus, C., Dallago, B., de Oliveira Machado, S. & Antunes, D.A., 2006. Evaluation of carcass traits, non-carcass components and 12th rib analysis of hair sheep supplemented with phosphorus. *Sociedade Brasileira de Zootecnia* 35(2), 550-555. Available online at www.sbz.org.br.
- Mareko, M.H.D., Aganga, A.A., Ompile, U.J. & Mokhudu, M., 2006. Carcass characteristics and Meat composition of yearling Tswana Goats Fed *Terminalia sericea*, *Boscia albitrunca* browses or lucerne as supplements. *Journal of Animal Veterinary Advances* 5(11), 964-969.

- Menezes, C.M.D.C., 2008. Effects of sun-dried *Opuntia ficus-indica* cladodes on digestive processes in sheep. M.Sc. Agric. Thesis. University of the Free State, Bloemfontein, South Africa.
- Milne, C., 2000. The history of the Dorper sheep. *Small Ruminant Research* 36, 99–102.
- Misra, A.K., Mishra, A.S., Tripathi, M.K., Chaturvedi, O.H., Vaithiyathan, S., Prasad, R. & Jakhmol, R.C., 2006. Intake, digestion and microbial protein synthesis in sheep on hay supplemented with prickly pear cactus [*Opuntia ficus-indica* (L.) Mill.] with or without groundnut meal. *Small Ruminant Research* 63, 125–134.
- Momani Shaker, M., Abdullah, A.Y., Kridli, R.T., Blaha, J. & Sada, I., 2003. Influence of the nutrition level on fattening and carcass characteristics of Awassi ram lambs. *Czech Journal of Animal Science* 48(11), 466-474.
- Nefzaoui, A. & Ben Salem, H., 1996. Nutritive values of diets based on spineless cactus (*Opuntia ficus-indica varintermis*) and Atriplex (*Atriplex nummularia*). Native and Exotic Fodder Shrubs in Arid and Semi-Arid Zones, Regional Training Workshop, Tunisia, 27 October–2 November, 1996.
- Nefzaoui, A. & Ben Salem, H., 2000. *Opuntia*: A strategic fodder and efficient tool to combat desertification in the WANA region. Ed. Inglese, P. *CACTUSNET Newsletter* 2000, 2-24.
- Nefzaoui, A. & Ben Salem, H., 2001. *Opuntia* spp.: A strategic fodder and efficient tool to combat desertification in the WANA region. In: Mondragon, C., Gonzalez, S. (Eds.), Cactus (*Opuntia* spp.) as Forage, vol. 169. FAO Plant Production and Protection Paper, pp. 73–90.
- Nefzaoui, A., Chermiti, A. & Ben Salem, H., 1993. Spineless cactus (*Opuntia ficus-indica var-intermis*) as a supplement for treated straw. In: Nikolaidis A and Papanastasis V (eds). Management of Mediterranean Shrublands and Related Forage Resources, FAO, Rome, pp. 130–133.
- Nefzaoui, A., Ben Salem, H. & Ben Salem, L., 1995. Ewe-lambs feeding with cactus-based diets. Effect of the type of nitrogen supplement. IVth International Symposium on the Nutrition of Herbivores - Satellite "Ruminant use of fodder resources in warm climate countries" Montpellier (France), 7-9 September 1995.

- Nefzaoui, A., 1995. Nutritive value of spineless cactus (*Opuntia ficus-indica* var. *inermis*) and *Atriplex nummalria* based-diets. IVth International Symposium on the Nutrition of Herbivores - Satellite "Ruminant use of fodder resources in warm climate countries" Montpellier (France), 7-9 September 1995.
- Notter, D.R., Grenier, S.P. & Wahlberg, M.L., 2004. Growth and carcass characteristics of lambs sired by Dorper and Dorset rams. *Journal Animal Science* 82, 1323-1328.
- Retamal, N., Duran, J.M. & Fernandez, J., 1987. Seasonal variations of chemical composition of prickly pear (*Opuntia ficus-indica*). *Journal of Science Food Agricultural* 38, 303-311.
- Robertson, J.B. & Van Soest, P.J., 1981. The detergent system of analysis and its application to human foods. In: The analysis of dietary fibre. Eds James, W.P.T. & Theander, O. Dekker, New York.
- Russell, C.E. & Felker, P., 1987. The prickly pear (*Opuntia* spp.) Cactaceae: a source of human and animal food in semi-arid regions. *Economy Botany* 41, 433-435.
- Santos, G.R.A., Batista, A.M.V., Mustafa, A.F, De Carvalho, F.F.R., Dubeux, J.C.B., Lira, M.A & Barbosa, S.B.P., 2003. Chemical composition and ruminal dry matter and crude protein degradability of spineless cactus. *Journal of Agronomy and Crop Science* 189, 123-126.
- SAS, 2006. SAS[®] User's Guide. Version 6.12. SAS Institute Inc., Cary, NC., USA.
- Schilling, B.S., 2005. Performance evaluation, carcass characterization and palatability assessment of hair sheep. M.Sc. Thesis. Texas Tech. University, USA.
- Schoeman, S.J., 2000. A comparative assessment of Dorper sheep in different production environments and systems. *Small Ruminant Research* 36, 137-146.
- Sebsibe, A., 2009. Chapter 5: Sheep and goat meat characteristics and quality, sheep and goats production handbook for Ethiopia. Available on line: [http://www.esgpip.info/HandBook/Handbook_PDF/Chapter 12_Sheep and Goat meat characteristics and quality.pdf](http://www.esgpip.info/HandBook/Handbook_PDF/Chapter_12_Sheep_and_Goat_meat_characteristics_and_quality.pdf). (downloaded on 26/10/2009).
- Sirohi, S.K., Karim, S.A. & Misra, A.K., 1997. Nutrient intake and utilization in sheep fed with prickly pear cactus. *Journal of Arid Environments* 36, 161-166.

- Snowder, G.D. & Duckett, S.K., 2003. Evaluation of the South African Dorper as a terminal sire breed for growth, carcass, and palatability characteristics. *Journal of Animal Science* 81, 368-375.
- Staab, K.A., Hess, B.W., Means, W.J., Nel, J.E. & Cecil, J.T., 1999. Feedlot performance and carcass differences among Dorper, Suffolk, and Western white-faced sired lambs. *Journal of Animal Science* 77, 105-106.
- Steenkamp, C.W.P. & Hayward, F.C., 1981. Voergewasse deur skape. Publ. Departement van Landbou en Visserye, Pretoria, South Africa (in Afrikaans).
- Strydom, P.E. & Smith, M.F., 2005. Predicting yields of high priced trimmed beef cuts by means of carcass weight and visual assessments of fat cover and conformation. *South African Journal of Animal Science* 35(3), 195-205.
- Tegegne, F., Nefzaoui, A. & Inglese, P., 2002. Fodder Potential of *Opuntia ficus-indica*, Proc. 4th IC on Cactus Pear and Cochineal Eds. *Acta Horticulturae* 581, ISHS.
- Tegegne, F., Kijora, C. & Peters, K.J., 2007. Study on the optimal level of cactus pear (*Opuntia ficus-indica*) supplementation to sheep and its contribution as source of water. *Small Ruminant Research* 72, 157-164.
- Tegegne, F., 2001. Nutritional value of *Opuntia ficus-indica* as a ruminant feed in Ethiopia. In: Mondragon, C., Gonzalez, S. (Eds.), *Cactus (Opuntia spp.) as Forage*, vol. 169. FAO Plant Production and Protection Paper, pp. 91-99.
- Tegegne, F., Peters, K.J. & Kijora, C., 2005. Cactus pear (*Opuntia ficus indica*): a strategic crop in combating food and feed insecurity and desertification in Tigray, Northern Ethiopia. *Proceedings Society of Nutrition Physiology* 14, 60.
- Tien, D.V. & Beynen, A.C., 2005. Growth Performance of Lambs in Phangrang, Vietnam: Effects of a Dietary Supplement Containing Prickly-Pear Cactus. *Tropical Animal Health and Production* 37, 237-244.
- Van der Westhuizen, E.J., Brand, T.S. & Hoffman, L.C., 2009. The effect of age on the fat distribution in Merino lambs, Available on line: <http://www.icomst.helsinki.fi/icomst2008/PaperCD/Generalspeakers+posters-3papers/Session7/7A/7A.25.vdWesthuizen.pdf>. (downloaded 26/10/2009).

Vieira, E.L., Batista, A.M.V., Mustafa, A.F., Araújo, R.F.S., Soares, P.C., Ortolane, E.L. & Mori, C.K., 2008. Effects of feeding high levels of cactus (*Opuntia ficus-indica* Mill) cladodes on urinary output and electrolyte excretion in goats. *Livestock Science* 114, 354-357.

Zeeman, D.Z., 2005. Evaluation of sun-dried *Opuntia ficus-indica* var. Algerian cladodes in sheep diets. M.Sc. Agric. Thesis. University of the Free State, Bloemfontein, South Africa.